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Using Decision Lattice Analysis to Model IOT-based Companies' profit

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Abstract
Demand uncertainty and high initial investments for IOT-based projects lead to analyzing various types of options, especially real options in project execution to decrease these uncertainties. In this study, we investigate the firms' expected profits that resulted from appropriate chosen static and dynamic pricing strategies namely low-pricing, high-pricing, and contingent pricing combined with binomial decision lattices. Besides, the reciprocal influence between pricing strategies and IOT investment could provide useful insights for the firms that confront demand uncertainties in selling the firms' products. We propose a model which is the integration of binomial decision lattices, which have been calculated by Real Option Super Lattice Solver 2017 software, and pricing policies under uncertainty. The results provide insights into what pricing strategies to choose based on the project's real option value and the level of the firm uncertainty about the purchasing of the high-value consumer. Among the mentioned static and dynamic pricing strategies, high-pricing and contingent pricing strategies under different situations can be selected and expected profits of each of the strategies will be calculated and compared with each other. On the contrary, as the low-pricing strategy resulted in the lowest option value, it will not be scrutinized in this study. Experimental results show that if the IOT investment level and high-value consumer purchasing likelihood are high, the firm will implement the high-pricing strategy, otherwise choosing the contingent pricing due to the demand uncertainty would be appropriate.
Key words: IOT; Pricing Strategies; Demand Uncertainty; Binomial Decision Lattice; Real Options

1- Introduction

The Internet Of Things (IOT) implementation has been increased in previous years. Various kinds of companies and organizations are using IOT as an essential part of their business because of creating value, bringing new opportunities to the firm, and realizing customer behaviors [1].
IOT has been implemented in pervasive areas such as customer relationship management (CRM), transportation, healthcare, logistics, manufacturing, personal life, home appliances, financial and banking sector, and risk management [1, 2, 3, 4, 5]. As monitoring and forecasting customers' behaviors and customer satisfaction have become an issue in a competitive market [6, 7], IOT systems play an essential role in choosing pricing decisions and demand planning that leads to reducing demand uncertainty.

Making an appropriate decision is extremely necessary for project life. Binomial decision lattice analysis is an approach that is capable of implementing uncertainties in any period of the project and decides to continue or abandon that project and they could be applied in plenty of situations such as evaluating real and financial option prices [8, 9, 10]. Because of the complexity of applying real option in projects [11], it has rarely been used in technology-based projects, namely IT and IOT product projects. Moreover, obtaining higher expected profits of selling these products is a matter that the IOT-based companies have confronted; hence, how to obtain higher expected profits in different situations according to the IOT level investment, is the question that will be responded in this study. Based on what has been explained, the main contribution of this paper is to propose a model that how IOT-based firms could achieve an expected profit for the company according to the chosen pricing decisions.

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The remainder of this article is organized as follows. Section 2 reviews internet of things, pricing strategies, and real option analysis. Section 3 proposes the model of this contribution. Section 4 provides the decision lattices and expected profits of chosen pricing strategies. Section 5 concludes what had been explained and provides suggestions for further research.

2- Literature Review

Our research is intently based on three streams of literature: internet of things definitions and visions, pricing strategies under uncertainty, and real option valuation that is combined with binomial decision lattices.

2-1- Internet of Things (IOT)

Internet of things as a new phenomenon that is also well-known as the Web of Things (WOT), is still in incipient stages where everybody is attempting to explain this technology according to their visions and such as other emerging technologies, it has complex social and economic implications [2, 12, 13, 14, 15, 16]. The IOT importance in industries and even our personal lives could not be denied. The number of connected objects and global IOT market size have been increasing, so far; therefore, investing in IOT and inspecting the impact of IOT investment on various companies' selling pricing schemes for technology-based products and services due to high demand uncertainty to earn higher profits for companies, have become an issue in recent years.

2-2- Pricing Under Uncertainty

Demand uncertainty typically happens when the firms' sellers are not able to predict consumer behavior and demand for the different types of their products and services; hence, applying innovative dynamic pricing strategies that reflect customer behaviors and preferences are necessary for most of the firms regarding their business [1, 17, 18, 19, 20, 21, 22, 23, 24, 25]. For instance, the sellers could improve the firms' profits by implementing contingent pricing that is well-suited in e-commerce and IT services and products [26]. On the other hand, static pricing strategies namely low-price strategy and high-price strategy also play a noticeable role in the business process in which both of these types of strategies can be influenced by IOT investment [1].

2-3- Real Option Analysis

Project uncertainties that impact future cash flows can be managed by management flexibility tools such as various types of real options, play an important role in these uncertain situations due to the ability to enhance the expected returns or reduce its expected losses [11]. These options can be implemented to expand, wait, contract, or abandon the project during its execution and evaluated by different methods [8, 27, 28].

IT and IOT projects as emerging technologies in recent years are not common projects because of requiring high initial investments and confronting high uncertainties and risks during the execution time [29]; hence in this paper, we contribute to a model that decreases these uncertainties by implementing real options combined with decision lattices in the production process and IOT investment in selling strategies.

Therefore, this model lead to decide effectively on doing the project and following that, selling the products which were produced during that project.

3- Model Setup

Traditional valuation methods namely discounted cash flow method (DCF) and dividend valuation models because of not applying managerial flexibility, have brought some constraints for the investors. The existence of some managerial flexible tools in the projects are necessary because the investors are an aspirant for making decisions during the project life; hence, in this paper, we are going to focus on and analyze implementing real options in projects by creating a discrete binomial lattice and proposing expected profits for IOT-based companies according to their chosen pricing strategy.

3-1- Real Option Valuation

The Black and Sholes and Prasad Kodukula innovative models have been implemented to value both financial and real options [27, 28]. Among various techniques which were proposed by Kodukula, binomial lattice analysis is our chosen method to value real options in technology-based projects. This valuation will be implemented in three steps as follows:

3-1-1- Present Value

The project present value at time 0 is determined by the discounted cash flow (DCF) method. Three scenarios are going to be considered with the DCF method which leads to three present values at time 0, namely optimistic, average, and pessimistic. The present value of the project is measured as follows:

$$PV = \frac{FV}{(1+r)^n} \quad (1)$$

Where PV is the present value, FV is the future value, r is a discount rate per period, and n is the number of periods. Optimistic and pessimistic present values respectively PV_{opt} and PV_{pes} can also be calculated similar to Eq. (1), and it is clear that PV_{avg} is the average of optimistic and pessimistic present values in each of the periods.

3-1-2- Volatility Assumption

The management assumption approach which is based on three mentioned scenarios and appropriate in technology-based projects will be applied to estimate project volatility as follows [28]:

$$\sigma = \frac{ln\left(\frac{PV\ opt}{PV\ pes}\right)}{4\sqrt{T}} \quad (2)$$

3-1-3- Binomial Lattice Analysis

Binomial lattice method in comparison with the Black-Sholes model and Monte Carlo simulation provides more flexibility in the project because of the transparent concepts which can be easily explained to the upper managers.

The present value, risk-neutral probabilities, and up and down movement factors are the rudimentary factors to create a binomial lattice that are calculated as follows:

$$u = exp\ (\sigma\sqrt{\delta t}) \quad (3)$$

$$d = exp\ (-\sigma\sqrt{\delta t}) \quad (4)$$

In Eq. (4), T was the option life, where δt is the number of lattice steps during the project execution.

The risk-neutral probability can be measured by:

$$p = \frac{exp\ (r\delta t\ ) - d}{u - d} \quad (5)$$

Where r is a risk-free interest rate and other factors have been determined, so far.

After calculating option parameters and creating the binomial lattice, the option values at each node can be calculated by a backward approach while asset valuation is determined forward.

3-2- IOT-based Firms' Profits

Among the dynamic and static pricing strategies defined before, contingent pricing (CP), low-price strategy (LP) and high-price strategy (HP) will be the chosen pricing strategies and their expected profits will be derived in this research. In this study, low-value and high-value consumers are called LV and HV respectively.

Assume a firm has one unit of product to sell the consumers and in each period, one type of consumer will show up; the LV consumer who has full certainty will show up in the first determined period, while the HV consumer will come up with less certainty.

Investing in IOT at the level of $\rho \in (0, 1)$, leads to increasing the purchasing likelihood of an HV consumer which is measured as follows:

$$\tilde{q}(\rho) = (q - q_0)\rho + q_0 \quad (6)$$

Where q is the maximum likelihood that an HV consumer will purchase the product and q_0 is the HV consumer purchasing likelihood without considering IOT investment. The capital cost which is the convex function of ρ is calculated as follows:

$$c(\rho) = -\frac{1}{2}\ c\ \rho^2 \quad (7)$$

Where c is a capital cost coefficient in IOT investment.

Under LP, the firm exclusively targets LV consumers and HV consumers will be ignored completely. The firm's profit in this policy is [1]:

$$\pi_L = -\frac{1}{2}\ c\rho^2 + p_L \quad (8)$$

IOT implementation can be a factor that increases the value of the product or service in the consumer's opinion, so IOT can influence a consumer's product valuation significantly which can be measured by the following equation [1]:

$$v_i = v_{i0}(1 + a\rho), a \geq 0, i = H, L \quad (9)$$

Where a is the benefit capture coefficient and v_{i0} is the product value to HV and LV consumers when IOT has not been invested

Under HP, the firm only emphasizes on HV consumers and misses the chance of selling to an LV consumer; however if the HV consumer does not show up, the firm will receive a salvage price (p_S). Hence, The firm's expected profit is [1]:

$$\pi_H = -\frac{1}{2}\ c\rho^2 + (q - q_0)(p_H - p_S)\rho + q_0(p_H - p_S) + p_S \quad (10)$$

Under CP, Since the consumers do not arrive with each other at the same time, the firm can sell the product to an LV consumer but reserves a right to reassign the product to an HV consumer in the second period. The firm's expected profit in this situation is [1]:

$$\pi_{CP} = -\frac{1}{2} c\rho^2 + \big((q - q_0)\rho + q_0\big)\big(p_H - v_{L0}(1 + a\rho + p\mathcal{L} \quad (11)$$

3-3- IOT-based Firms' Pricing Strategies Combined with Binomial Lattices

Assume a technology-based project such as IOT device production, which has been valued by decision lattice analysis, and for decreasing the uncertainties during the project execution, we implemented real options. Dynamic and static pricing strategies will be chosen as selling policies in the firm; thus, the strategy which is resulted in a higher real option value will be selected. J. Zhang et al. (2008) proposed a decision lattice with different stages which was modeled with high-end and low-end service customers [30]. However, in this paper, our approach is summarized in three lattices which include high pricing, low pricing, and contingent pricing which are related to high-value and low-value consumers who are willing to purchase technology-based products, not services.

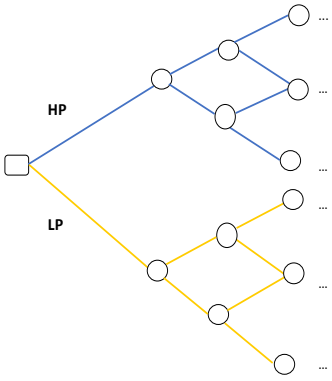

Fig. 1 HP and LP Approach

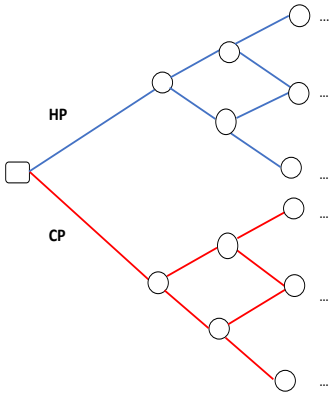

Fig. 2 HP and CP Approach

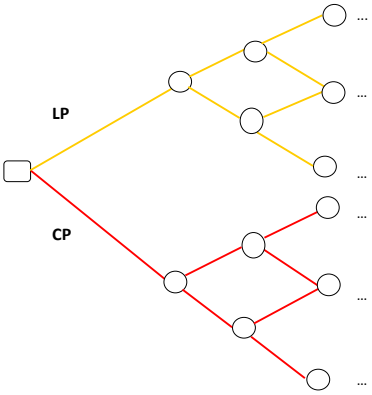

Fig. 3 LP and CP Approach

4- Model Analysis

We will illustrate our approach with a technology-based four-period project such as IOT device production, which is calculated by binomial decision lattices.

Project future cash flows have been predicted by applying three scenarios namely, optimistic, average, and pessimistic scenarios that are related to high pricing, contingent pricing, and low pricing strategies respectively. The spreadsheet is shown in Table 1.

Table 1: Project spreadsheet

Period	Year	Investments and Costs			Revenue			Cash Flows		
		Pessimistic	Average	Optimistic	Pessimistic	Average	Optimistic	Pessimistic	Average	Optimistic
0	2020	27,454	27,454	27,454	-	-	-	-27454	-27454	-27454
1	2021	32,945	28,899	24,853	75,080	105,44	135,728	42,135	76,505	110,875
2	2022	36,139	31,789	27,439	89,116	125,345	161,574	52,978	93,556	134,135
3	2023	47,206	39,736	32,266	112,133	156,681	201,230	64,927	116,945	168,964
4	2024	70,809	52,451	34,093	132,396	203,686	274,976	61,586	151,234	240,882

The appropriate discount rate is the risk-free rate which is considered 1.25%. Discounting cash flows to time 0 will result in PV_{pes} = \$ 186,991, PV_{avg} = \$ 395,937, PV_{opt} = \$ 604,884, and the project annual volatility is 15%.

4-1- Project Valuations' Binomial Lattices According to Pricing Strategies

In this subsection, a real option which results in threefold expansion of current operations at a cost of $ 900,000 will be applied in the project. Pricing strategies' approaches are as follows:

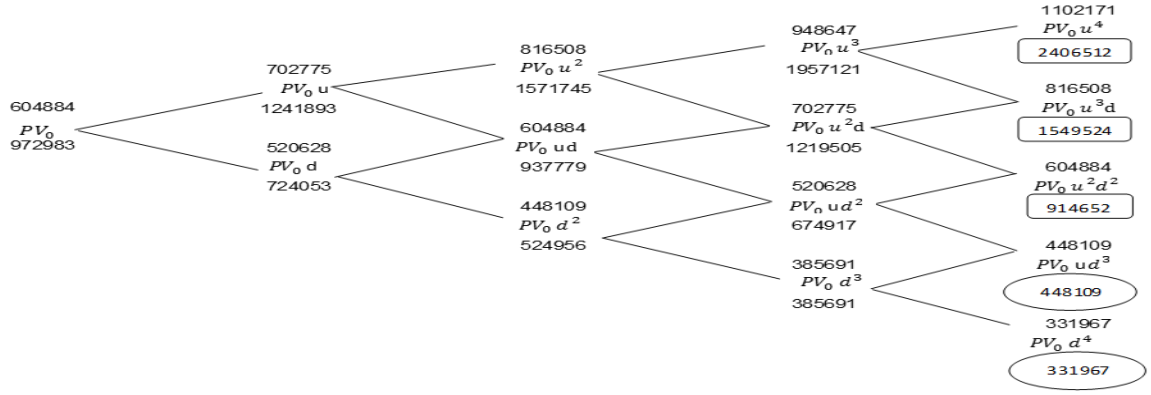

Fig. 4 HP Strategy

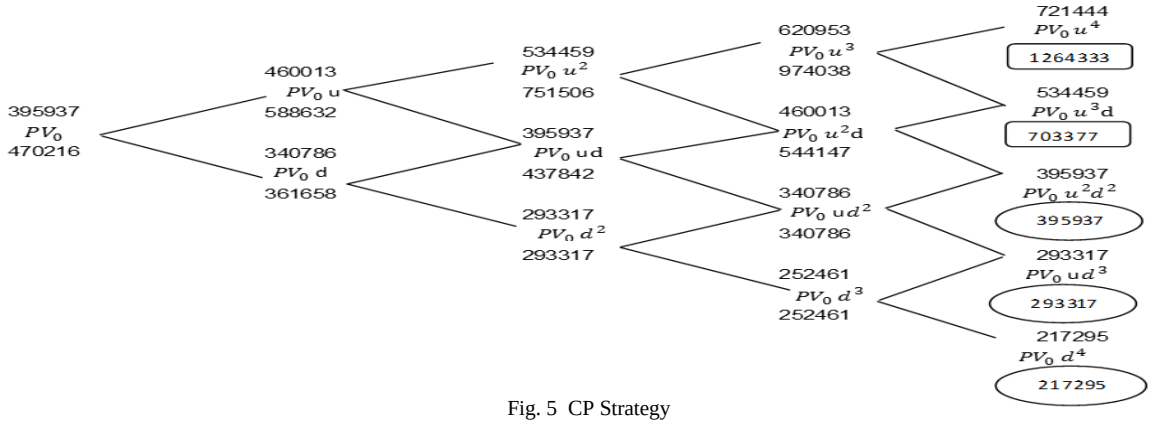

Fig. 5 CP Strategy

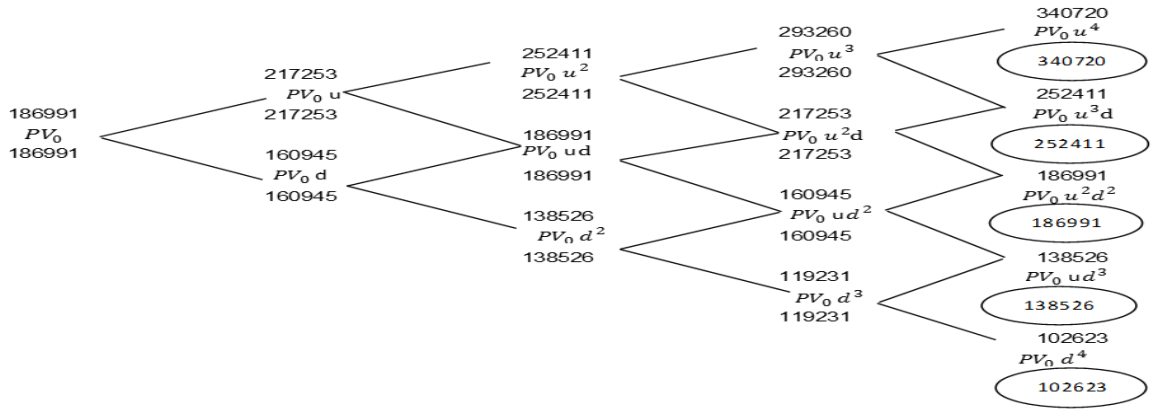

Fig. 6 LP Strategy

Based on the above approaches, HP and CP strategies are resulted in higher option values so LP could not be an appropriate strategy; therefore these two policies will be scrutinized and compared as follows:

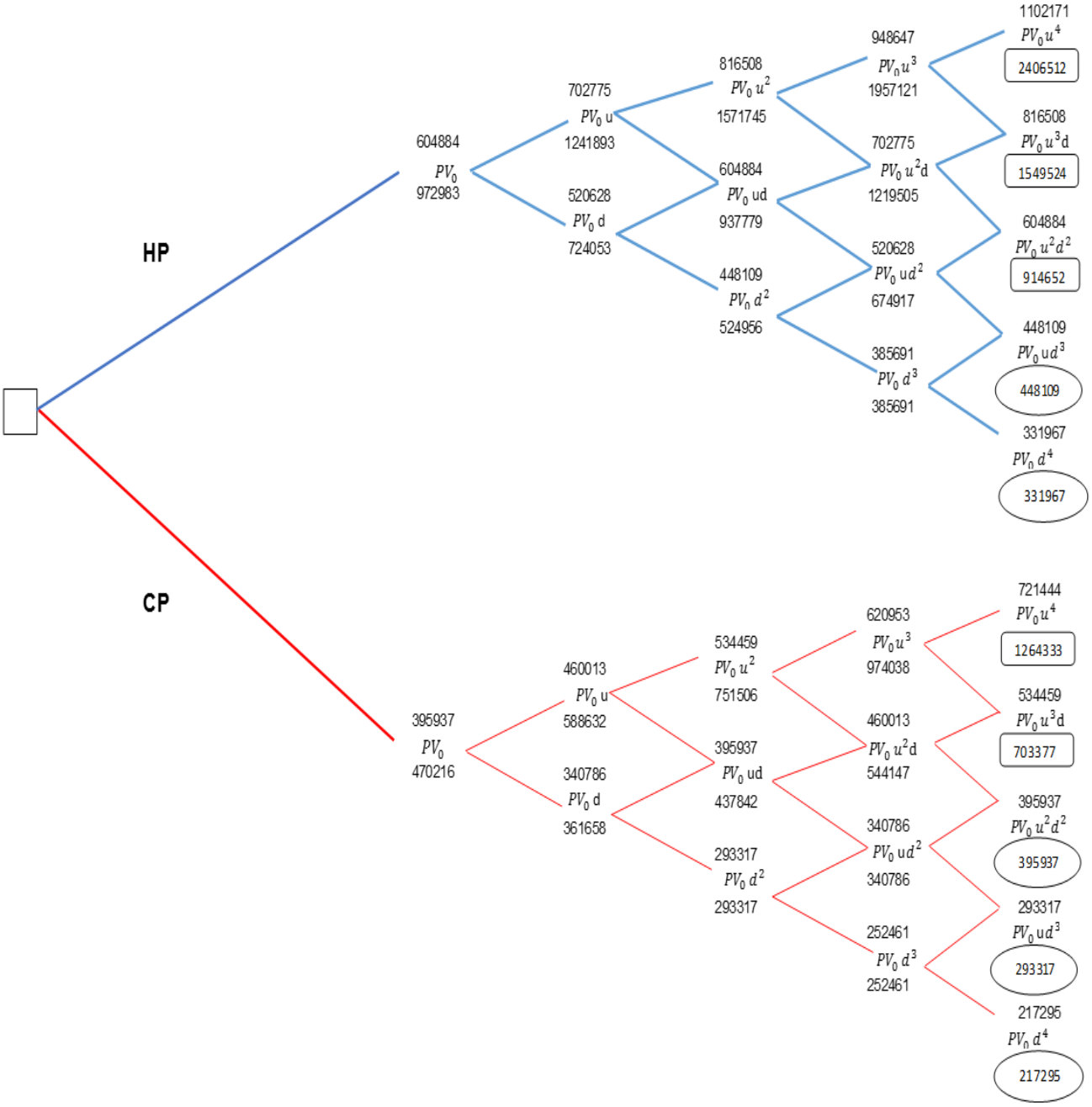

Fig. 7 HP and CP Project Valuation

In figures 4, 5, 6, and 7, all numbers are in dollars, top numbers are project values, bottom numbers are option values, rectangle option values indicate project expansion, and circled option values indicate the end of the project.

Figure 7 illustrates that the HP strategy has been resulted in a higher option value; therefore, in the next subsection the expected profits of these two strategies will be calculated and choosing the best strategy for selling the product, based on the different situations, will be discussed.

4-2- Expected Profits For Chosen Pricing Strategies

As it resulted above, high pricing or contingent pricing could be the appropriate selling strategies in this project; hence, these two policies under different conditions will be scrutinized.

Our benchmark case is analyzed by assuming two scenarios namely considering IOT investment or ignoring it. Besides, with the aid of market research, we consider P_H = 365, P_L = 206, P_S = 154, c = 1.25, and $v_{L0} = 300$ to calculate expected profits of these strategies. Figures 8 -12 imply these scenarios as follows:

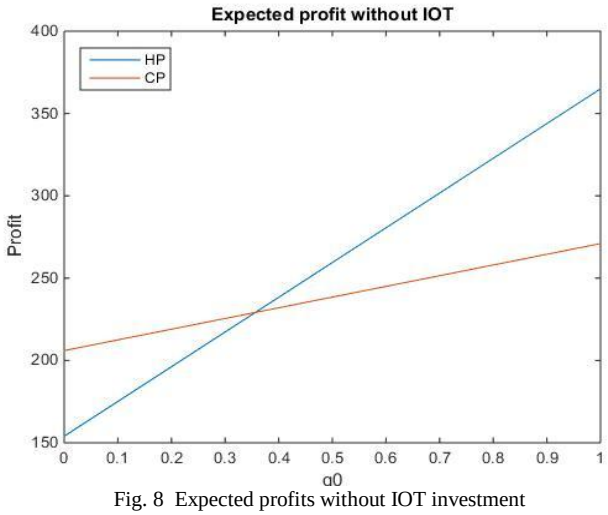

Fig. 8 Expected profits without IOT investment

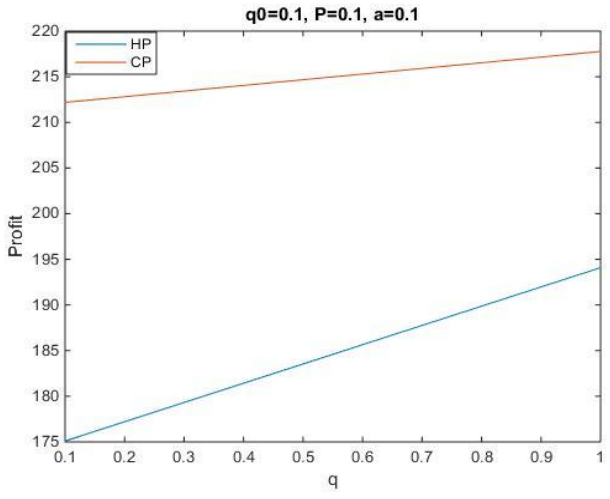

Fig. 9 Expected profits with IOT investment, q_0 = 0.1, $\rho = 0.1$, a=0.1

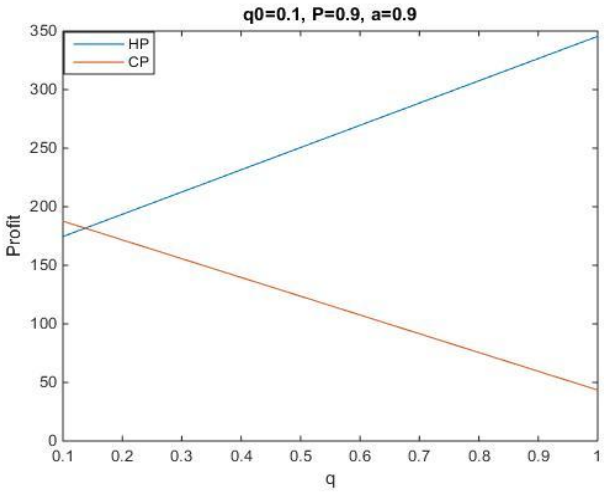

Fig. 10 Expected profits with IOT investment, q_0 = 0.1, $\rho = 0.9$, a=0.9

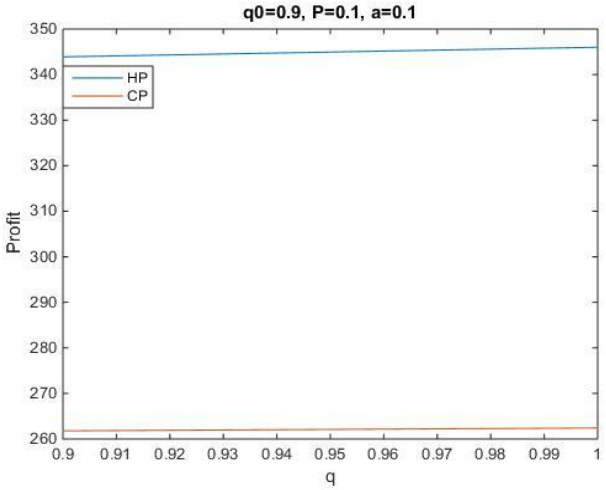

Fig. 11 Expected profits with IOT investment, $q_0 = 0.9$ $\rho = 0.1$, a=0.1

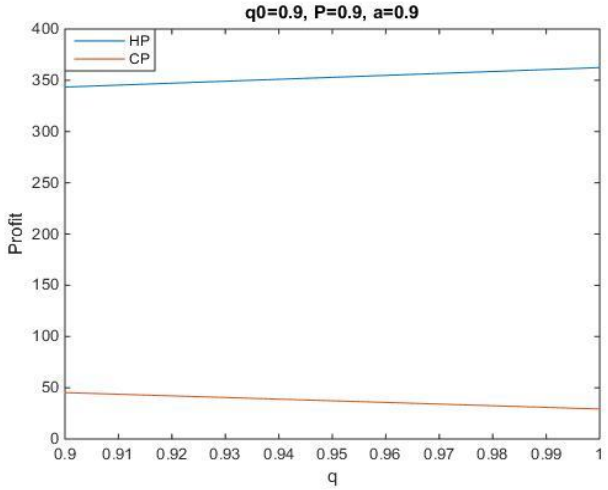

Fig. 12 Expected profits with IOT investment, $q_0 = 0.9$, $\rho = 0.9$, a=0.9

Table 2: choosing the appropriate pricing strategies with considering IOT investment

q_0	ρ	a	Chosen pricing strategy
0.1	0.1	0.1	CP
0.1	0.9	0.9	If q>0.14, HP will be chosen.
0.9	0.1	0.1	HP
0.9	0.9	0.9	HP

Figure 8 illustrates that without investing in IOT, if q0<0.36, CP will be chosen as the pricing strategy for the firm, otherwise, HP. On the other hand, when the IOT investment is applied, different cases could be analyzed. When the initial purchasing likelihood of the HV consumer is low and the firm does not invest in a high level on IOT, CP will be our selected policy because of the uncertainty that the firm has confronted. However, if the firm invests highly in IOT and the product value has been affected by this investment, for q>0.14 Hp will be the appropriate strategy. It means that if the HV consumer purchasing likelihood is 0.15, we can apply HP strategy, while in the case without IOT investment or low-level investment, CP strategy will be implemented.

In the other words, investing in IOT will lead to produce products which the consumers are willing to buy, target more HV consumers, decrease the firm's uncertainty and following that, implementing HP strategy to obtain higher profits. It is also shown that if the IOT investment level affects product value in the consumer's opinion, HP will be more appealing than CP. Comparing figures 9 and 10 reveals that, investing highly in IOT has targeted more HV consumers and resulted in a higher expected profit.

Moreover, when the initial purchasing likelihood of the HV consumer is high, investing in IOT is not necessary due to the privilege of the HP strategy for any amounts of q. However, even in this situation, the more investing in IOT, the higher profits will be obtained as it is shown in figures 11 and 12.

Based on what has been analyzed, we can conclude that the scenarios which were resulted in a higher option value, could be chosen as the IOT-based firms' pricing policies. In this study, among the mentioned scenarios which are related to pricing strategies, HP was selected as the best one. The results can also verify that HP strategy can be resulted in higher profits with the aid of the IOT investment.

5- Conclusions

Technology-based projects especially IT and IOT projects are not common because of high initial investments and demand uncertainties that they may face during the project execution. Applying real options in our investment can lead to mitigating the mentioned demand uncertainties and the risk of high initial investments. Various types of real options can be implemented during the project; since our case was an IOT-device expansion project, we comprehensively focused on option to expand in this study.

Because IOT is introduced as an emerging technology in recent years, selling strategies of these products must be chosen appropriately to obtain the highest profit for the firm. Investing in IOT as it leads to improving consumer targeting can decrease the demand uncertainty in this condition. Choosing appropriate static and dynamic selling strategies namely low-pricing, high-pricing, and contingent pricing strategies that are integrated with IOT investment can be a useful solution for this problem. Comparing these strategies resulted that HP and CP under special situations depend on the firm certainty can be our policy; however, LP strategy will never be chosen. In other words, if the IOT investment level and the purchasing likelihood of an HV consumer is high, the HP strategy will be selected because of obtaining a higher expected profit. On the other hand, if the firm is uncertain about HV consumer's arrival, contingent pricing combined with IOT investment will lead to obtaining higher profit for the firm.

Although this paper provides new insights, the model may not be implemented for service cases as it just focuses on product projects, so One direction for future research is to scrutinize IOT-based service firms. Moreover, including other pricing strategies such as probabilistic selling in trinomial decision lattices can be suggested for future research.

References

[1] X. Zhang and W. T. Yue, "Transformative value of the Internet of Things and pricing decisions," Electronic Commerce Research and Applications, vol. 34, No. November 2018, 2019, p. 100825.

[2] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," Computer Networks, vol. 54, No. 15, 2010, pp. 2787–2805.

[3] S. Kim and S. Kim, "A multi-criteria approach toward discovering killer IoT application in Korea," Technological Forecasting and Social Change, vol. 102, 2016, pp. 143–155.

[4] S. Cuomo, P. De Michele, F. Piccialli, A. Galletti, and J. E. Jung, "IoT-based collaborative reputation system for associating visitors and artworks in a cultural scenario," Expert Systems with Applications, vol. 79, 2017, pp. 101–111.

[5] Y. H. Tehrani, Z. Fazel, and S. M. Atarodi, "A survey of two dominant low power and long range communication technologies," Journal of Information Systems and Telecommunication, vol. 6, No. 2, 2018, pp. 60–66.

[6] M. Fasanghari and A. Keramati, "Customer Churn Prediction Using Local Linear Model Tree for Iranian Telecommunication Companies," Journal of Industrial Engineering, University of Tehran, 2011, pp. 25–37.

[7] M. Fasanghari, "E-Commerce Assessment in Fuzzy Situation,"in E-commerce, Shangha, China: InTech, 2010, ch. 2, pp. 21–31.

[8] J. C. Cox, S. A. Ross, and M. Rubinstein, "Option pricing: A simplified approach," Journal of Financial Economics, vol. 7, No. 3, 1979, pp. 229–263.

[9] P. Tufano and T. Copeland, "A Real-World Way to Manage Real Options," Harvard Business Review, Vol. 82, 2004, pp. 90-99.

[10] T. Copeland and V. Antikarov, Real options, New York: Texere LLC, 2001.

[11] L. E. Brandão, J. S. Dyer, and W. J. Hahn, "Using Binomial Decision Trees to Solve Real-Option Valuation Problems," Decision Analysis, vol. 2, No. 2, 2005, pp. 69–88.

[12] D. Singh, G. Tripathi, and A. J. Jara, "A survey of Internet-of-Things: Future vision, architecture, challenges and services," in 2014 IEEE World Forum on Internet of Things (WF-IoT), Mar. 2014, pp. 287–292.

[13] A. Čolaković and M. Hadžialić, "Internet of Things (IoT): A review of enabling technologies, challenges, and open research issues," Computer Networks, vol. 144, 2018, pp. 17–39.

[14] M. H. Miraz, M. Ali, P. S. Excell, and R. Picking, "A review on Internet of Things (IoT), Internet of Everything (IoE) and Internet of Nano Things (IoNT)," in 2015 Internet Technologies and Applications, ITA 2015 - Proceedings of the 6th International Conference, 2015, pp. 219–224.

[15] H. Lamaazi, N. Benamar, A. J. Jara, L. Ladid, and D. El Ouadghiri, "Challenges of the Internet of Things: IPv6 and Network Management," in 2014 Eighth International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing, Jul. 2014, pp. 328–333.

[16] H. Hamidi, "Safe use of the internet of things for privacy enhancing," Journal of Information Systems and Telecommunication, vol. 4, No. 3, 2016, pp. 145–151.

[17] S. Fay and J. Xie, "Probabilistic goods: A creative way of selling products and services," Marketing Science, vol. 27, No. 4, 2008, pp. 674–690.

[18] G. Gallego, S. G. Kou, and R. Phillips, "Revenue management of callable products," Management Science, vol. 54, No. 3, 2008, pp. 550–564.

[19] V. Mak, A. Rapoport, and E. J. Gisches, "Competitive dynamic pricing with alternating offers: Theory and experiment," Games and Economic Behavior, vol. 75, No. 1, 2012, pp. 250–264.

[20] I. P. L. Png and H. Wang, "Buyer uncertainty and two-part pricing: Theory and applications," Management Science, vol. 56, No. 2, 2010, pp. 334–342.
[21] M. Kremer, B. Mantin, and A. Ovchinnikov, " Dynamic Pricing in the Presence of Myopic and Strategic Consumers: Theory and Experiment," Production and Operations Management, vol. 26, No. 1. 2017, pp. 116-133.
[22] L. Cabral, "Dynamic pricing in customer markets with switching costs," Review of Economic Dynamics, vol. 20, 2016, pp. 43–62.
[23] J. J. Anton, G. Biglaiser, and N. Vettas, "Dynamic price competition with capacity constraints and a strategic buyer," International Economic Review, vol. 55, No. 3, 2014, pp. 943–958.
[24] E. Biyalogorsky and E. Gerstner, "Contingent Pricing to Reduce Price Risks," Marketing Science, vol. 23, No. 1, 2004, pp. 146-155.
[25] H. A. Najafabadi, A. Shekarchizadeh, A. Nabiollahi, N. Khani, and H. Rastegari, "The innovation roadmap and value creation for information goods pricing as an economic commodity," Journal of Information Systems and Telecommunication, vol. 7, No. 2, 2019, pp. 154–164.
[26] H. K. Bhargava and S. Sundaresan, "Contingency Pricing for Information Goods and Services under Industrywide Performance Standard," Journal of Management Information Systems, vol. 20, No. 2, 2003, pp. 113–136.
[27] F. Black and M. Scholes, "The pricing of options and corporate liabilities," Journal of Political Economy, vol. 81, No. 3, 1973, pp. 637–657.
[28] P. Kodukula and Ch. Papudesu , Project Valuation Using Real Options Analysis, A practitioner's Guide, J. Ross Publishing, 2006.
[29] X. Li and J. D. Johnson, "Opportunities Using Real Options Theory," Information Resources Management Journal, vol. 15, No. 3, 2002, pp. 32–47.
[30] J. Zhang, S. Bandyopadhyay, and S. Piramuthu,
"Real option valuation on grid computing," Decision Support Systems, vol. 46, No. 1, 2008, pp. 333-343.

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AI based Computational Trust Model for Intelligent Virtual Assistant

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Abstract
The Intelligent virtual assistant (IVA) also called AI assistant or digital assistant is software developed as a product by organizations like Google, Apple, Microsoft and Amazon. Virtual assistant based on Artificial Intelligence which works and processes on natural language commands given by humans. It helps the user to work more efficiently and also saves time. It is human friendly as it works on natural language commands given by humans. Voice-controlled Intelligent Virtual Assistants (IVAs) have seen gigantic development as of late on cell phones and as independent gadgets in individuals' homes. The intelligent virtual assistant is very useful for illiterate and visually impaired people around the world. While research has analyzed the expected advantages and downsides of these gadgets for IVA clients, barely any investigations have exactly assessed the need of security and trust as a singular choice to use IVAs. In this proposed work, different IPA users and non-users (N=1000) are surveyed to understand and analyze the barriers and motivations to adopting IPAs and how users are concerned about data privacy and trust with respect to organizational compliances and social contract related to IPA data and how these concerns have affected the acceptance and use of IPAs. We have used Naïve Byes Classifier to compute trust in IVA devices and further evaluate probability of using different trusted IVA devices.

Keywords: Artificial Intelligence; Virtual Assistant System; Product Quality; Trust, Privacy; Security; Voice Recognition; Naïve Byes Classifier.

1- Introduction

IVA is like an assistant for its users which completes the task when it gets the command. The best feature of these virtual assistant applications is that it gets active only when it hears a keyword like 'Alexa' or 'okay Google'. IVAs are AI based and able to learn from the commands and the human behavior so that next time it could easily understand what the user's command all is about. An IVA also reduces the human effort for example now no user has to search any contact to call to any person, they just have to speak the 'call' with the user contact and instead of going to a website and searching about the weather of your city you simply have to speak 'what is the weather today or in your language' and you will get quickly get the weather status of your city. The assistant application first records your voice and saves using speech recognition algorithm and it directly sends all the data to its respective servers to faster computation of data and the data gets split into words and those words are filtered to find the keywords and subjects and after the processing, the result or the output is sent back to respective assistant. Few of the most used IVAs are discussed in subsequent subsections.

1-1- Alexa

Alexa is virtual assistant software that has been developed by Amazon.com. It is based on Artificial Intelligence and it has been mainly written in Node.js and java, python, C has also been used. Its main purpose was to help the user to get commands in a natural language like humans and also to give output in the same languages which will lead to reducing the human effort. This assistant gets active when the user speaks 'Alexa' then it responds and now the assistant is ready to get commands from the user [1]. This was made to do all the works which other assistant does with a specialty feature that it can also control your smart home devices using your voice. According to the company, it is safe and secured to use and can also help to

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keep you organized. Alexa can be a good competition in the market to the other virtual assistant like google assistant, Siri, and Cortana assistant because of its features. Before the Alexa was only available in smart devices only but it has been offered in smartphones too to compete with other virtual assistants. When you say 'Alexa', "what's the weather today", your speech is recorded in the form of speech of text and which is sent to the main server of amazon's Alexa voice services and there these words are been broken or split into words and the main subject words or nouns are separated from it. After this the result is analyzed and sent back to the device and which has been responded to the user by the Alexa assistant application [2].

1-2- Google Assistant

Google Assistant is another virtual assistant software application which is developed by Google.com and this assistant is also fully based on Artificial Intelligence and natural language processing and was writ- ten in C++ programming language. This is also like Alexa as it also uses to way communication to get com mands from the user using the It is available on smartphones and other smart home devices [3]. It is available in approximately 31 languages and more are on the coming to way. This assistant gets active when the user speaks 'Okay Google' or in some devices 'Hey Google' then it responds and now the assistant is ready to get commands from the user in any language you want. Like the operating system, the google assistant also works as interface and helps us to interact with the hardware and the software of devices. Google's assistant [4] first records your speech and interpreting the sounds takes a lot of time and computational power so it is sent to Google's servers to be analyzed more efficiently. The important words or nouns or the main subjects words are split from the sentence to carry out the task and after which if the word found is like 'temperature' or 'weather' then it would open the weather app and also the resultant information or the result is sent back to the device is again spoken by the virtual assistant to the user in Figure 1.

1-3- Siri

Siri is another virtual assistant software application [5] that has been developed by Apple. This virtual assistant is written in Objective-C Programming Language. But Apple did not entirely develop Siri by themselves as It started from an AI initiative in 2003 funded by DARPA (Defense Advanced Research Projects Agency) and run by a Stanford University affiliate, SRI International and Their goal was to make a program that helps military personal with office work and making decisions, resulting in CALO (Cognitive Assistant that Learns and Organizes) that learns from its users and the vast amounts of available data. It was used for organizing and scheduling meetings as well as providing the necessary documents for the participants.

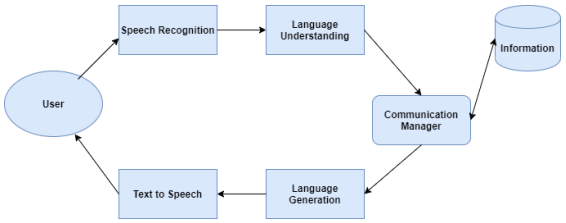

Figure 1. Structure of Virtual Assistants

This application also uses a two-way communication process to get the commands from the user and this is again fully based on Artificial Intelligence and according to the company it is the safest and securest application that manages the data of your device [6]. Siri assistant is available for almost all of the apple de- vices. This assistant uses voice queries and a natural- language user interface to answer questions, make recommendations, and perform actions by delegating re- quests to a set of internet services. Siri comes with both the two voices male and female too. This virtual assistant Siri gets active when the user will speak 'Hey Siri' and then now you are ready to give the command to the Siri or the virtual assistant in your language.

It has come after when iPhone 4S has launched [7]. After receiving the request, Siri records the frequencies and the sound waves from the user's voice and translates it into a code. Then it breaks or splits the sentence into words to identify the keyword and the patterns used and then the data gets input into a com- plex algorithm that gets matched and compared to the thousands of combinations of sentences the determine the meaning of the sentence. Once Siri determines what is the request all about or the task which needs to be carried out, then it determines whether the in- formation has to be accessed by the phone's bank or its online servers. After then it can complete its task given by the user and performs the task accordingly to the user with giving the appropriate output.

2- Related Work

A strategy for directing a call between a guest and an intelligent voice reaction (IVR) framework, the guest utilizing a gadget to lead the call, the gadget arranged to execute a menial helper, the technique involving utilizing the remote helper to lead the call at any rate to some degree by impacting the style of data given to the guest during the call as well as the substance of data went between the gadget and the IVR [8] framework during the call. In intelligent virtual assistant, Intelligent techniques

are not only used in day to day interaction like play music and open an application but also in business interaction [9]. IVAs advanced from chatbots, programming specialists customized to banter with people through either text or voice. The first chatbot, ELIZA, was created by Joseph Weizenbaum at MIT 16 years after Alan Turing previously proposed his test of man-made consciousness in 1950. ELIZA utilized common language handling to perceive catchphrases in composed info what's more, produce pre-scripted reactions that to certain clients took after human understanding [10]. Repel, presented in 1972 by a therapist named Kenneth Colby who persuaded various prepared specialists that it was a genuine individual with distrustful schizophrenia. A technique and framework for making a theme-based 3D virtual condition-The imaginative strategy and framework give a 3D virtual condition that incorporates pictures, landscapes, and substances that identify with the subject of conversation in the virtual condition [11]. On the off chance that the virtual "meeting" ought to be suspended or finished, the framework spares the information, conversations that happened during the gathering, and all the landscape and sub- stance identified with the virtual gathering so the gathering can proceed with the entirety of the substance and symbolism set up. A virtual situation format containing this data is stacked and utilized for resulting virtual gatherings talking about a similar theme.

Remote helper [12] is an aid for everybody in this new time of the 21st century. It has cleared a path for another innovation where we can pose inquiries to the machine and can collaborate with IVAs as individuals do with people. This innovation pulled in the practically entire world from numerous points of view like advanced mobile phones, workstations, PCs, and so forth.

The most well-known use of the iPhone is" Siri" [13] which makes a difference in the end client to convey end client portable with voice and it like- wise reacts to the voice orders of the client. The same kind of utilization is likewise evolved by Google that is "Google Voice Search" which is utilized for Android Phones. Be that as it may, this Application for the most part works with Internet Connections.

Amazon's Echo [14] and its conversational specialist Alexa open energizing open doors for seeing how individuals see and associate with virtual operators. Drawing from client audits of the Echo presented on Amazon.com, this contextual investigation investigates how much client surveys show exemplification of the gadget, friendliness level of associations, factors connected with representation, and effects on client fulfillment.

One of the objectives of Artificial knowledge (AI) [15] is the acknowledgment of common discourse among people and machines. Lately, the exchange frameworks, otherwise called intuitive conversational frameworks are the quickest developing territory in AI. Ongoing advances in programming incorporation and endeavors toward more personalization and set- ting mindfulness have brought nearer the long-standing vision of the omnipresent smart individual collaborator. This has gotten especially striking with regards to cell phones and electronic tablets [16], where com- mon language connections can significantly improve the portable experience. A long way past simply offering more choices as far as UI, this pattern may well attendant in an authentic change in perspective in man-machine correspondence.

Although these advancements appear to be widely received, individuals do not expect to utilize them sometimes. Innovation reception has been read for a long time, and there are many general models in the writing depicting it. Be that as it may, having more models for developing advances upon their high- lights appears to be essential.

In this investigation, we built up a theoretical a model including another framework [17] quality build, i.e., connection quality, which we accept can better depict appropriation of AI- based advances.

A technique for executing a believed application on a believed security zone empowered electronic gadget [18]. The strategy involves receptive to a confided in security subzone not being provisioned on the electronic gadget, creating, by a server, an impermanent trust token, transmitting the brief trust token to the electronic gadget, and contrasting the transitory trust token and a majority of trust tokens put away in the electronic gadget to decide the dependability of the brief trust token.

This paper [19] just highlights communication net- works established over several servers and how they turn to be efficient in their ways. Inbuilt security systems available with IVAs have a significant role in imparting safety and protecting the ethical and civic rights of the internet users. Several threats exist against a security system. The key to successfully entrench a communication network lies in recognizing, extracting, and eliminating such attacks with pre-designed applications that can predict or possibly identify such malware threats at the earliest, thus preventing any damage to the data, devices, or its users.

3- Comparison of different IVAs

Previously, we have seen how the trust gets build when we connect to computer machines in a network using the IP (Internet Protocol) and Port by socket programming. Now, we will see how the trust gets built when the computer system gets connected with the voice of Human and the command is been executed according to the user by his/her voice as a command. This is a much more efficient and effective way to execute the commands in comparison to the previous one. This reduces the typing error and avoids the chance of getting spelling mistakes while giving the

command to the user. Previously we used socket programming to build trust among the machine to machine but now will use the natural language processing tool to make it much more efficient and effective. Previously the work was done by encoding and decoding the information in machines at the time of sending and receiving the in- formation to build trust but now this will be reduced and now the voice will work as command and now will focus on the keywords said by the user or the developer to get executed in the machine [20].
All Google Assistant, Siri, and Amazon Alexa are getting smarter day by day with their regular training and their self-capability to learn by using Artificial Intelligence [21].

If we talk about the comparison then the entire voice assistant is almost the same as they have the almost same functionality and the same level of trust but if we go more in detail then we will find some points which make a difference among all these applications [22]. Human Trust is measured in Virtual assistant are based on virtual reality. to measure this Physiological Sensing has been used [23].

3-1-Alexa vs Google Assistant vs Apple's Siri s

We talk about waking up of these assistants then Amazon's Alexa is better than the Google Assistant as 'the waking word' (the word which will make the assistant active for listening to the user) for the Amazon's Alexa is just one simple word 'Alexa' and Google's Assistant is 'Okay, Google'.
If we talk about data or IQ then Google Assistant will be better than Amazon's Alexa as because Google sells the data to Amazon and its N number of copies are also sold to several companies by Google, hence we can say that Google will have will more data to serve to us than Amazon . Google has direct access to the indexed information from all searches whereas Alexa has direct access to the indexed information from all purchase's information. The main difference where Google's Assistant can be much better than Amazon's Alexa is that Google has more resources on their AI (Artificial Intelligence) side to serve its Assistant but Amazon is not that much advance but still Amazon has more Applications (skills) that makes it's Alexa currently richer. Google's Assistant is powered with Google Ma- chine learning library and algorithms which get better day by day and providing better voice recognition and better results. After when the human voice is recorded then Google Assistant sends it to the Google server's and Alexa Assistant sends it to its Amazon Alexa Ser- vices server to make computational decisions and its interpretation in Figure 2.
If we talk about platforms for working then Apple's Siri is limited to Apple's ecosystem but Google Assistant supports all Android and iOS devices too. Google uses a natural language user interface to respond to queries, and perform actions by delegating the request to a set of services and it is closely integrated with the Google search engine whereas Apple's Siri uses natural language processing to meet searching and operation and it uses it's phone's default search engine to get results. If we talk about data than some- where Google's Assistant can go better than Apple's Siri because Google is the hub of huge data and also sells it to so many other companies whereas Apple uses only it's default browser to search the results. Hence, somewhere Google has more data than Apple to serve its users.

Both the assistant works similar like both can play song, radio, answer your questions and provide information regarding the traffic of your area and weather but somewhere Google Assistant becomes better as it excels in terms of handling search-based web queries because searching is Google's main functionality sown in Table 1 and it becomes more natural to use whereas Siri is the oldest and one of the most used digital assistants out there as it was launched at the time when iPhone 4S was launched and it's most common uses web browsing and dictation. If we talk in terms of integration, then Google's Assistant becomes better as it works with more than 5,000 smart home devices from than 100s of brands whereas Siri is just limited to Apple's Ecosystem only with a very limited range of devices supported in an individual brand.

Table 1: Comparison of different application of IVA

Music	**A**lexa	**G**oogle	**S**iri
Amazon Music	Yes	No	No
Apple Music	Yes	No	Yes
Deezer	Yes	Yes	No
Google Play Music	No	Yes	No
iHeartRadio	Yes	No	No
Pandora	Yes	Yes	No
SiriusXM	Yes	No	No
Spotify	Yes	Yes	No
TuneIn	Yes	No	No
Tidal	Yes	No	No
YouTube Music	No	Yes	No

4- Trust issues in Intelligent Virtual Assistant

Before exploring cybersecurity issues [6], we need to list down all the applications of IoT. Corporations, Governments, and people are the three-broad class of IoT stakeholders. Corporations provide IoT devices, Governments are responsible for the regulation of IoT devices, and people are the end-users. Based on the IoT device usage point, these can be divided into A. Personal / Household IoT Devices A smart home is probably the first

thing that comes to anyone's mind when we talk about IoT devices. Home Lights, AC, TV, speakers, washing machine, refrigerator, oven, etc. are some examples of Household IoT devices. Smart- watch is an example of a personal IoT device.

Public IoT Devices After a smart home, a smart city is also getting popular. Smart cities, based on IoT devices, will be energy efficient, economical, environmentally friendly, more secure, and better administered.

Transportation, economy, health, environment, security, and administration are broad application classes for public IoT devices. Using GPS [10] and public transportation card, we can better monitor bus timing and peak in public headcount. We can give real-time bus timing to everyone using GPS tracking [7]. Extra buses can be arranged in peak hours after the analysis of transportation card data. Traffic can also be diverted between different routes using GPS tracking.

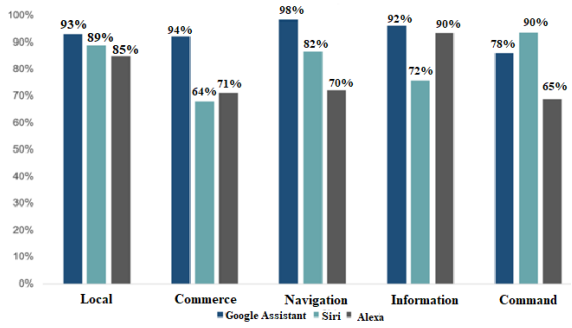

Figure 2. Comparison of Google Assistant, Siri and Alexa

Tourism can be benefitted by sending push- notifications of nearby attractions, restaurants, malls, etc. to tourists in the city. Better infrastructure to selective locations can be provided after an analysis of tourist's footfall data. The emergency button in our watch or smartphone can provide a timely response from the hospital [9], fire department, police, etc. Automate health devices can send an alert to your doctor directly if an abnormal health condition is observed like high sugar level, high blood pressure, etc. The environment can be benefited largely by using different sensors for water pipeline leakage detection and air population-level detection. Real-time responses can be activated to tackle these. Sensors in gas-pipeline and smoke detectors can send timely alerts even before any mishappening. Drones and traffic cameras can identify a report any security issues. Overall, we will live in a more secure city. Using biometric [8] and Aadhar like services, the administration can be more efficient and faster. Services can be delivered directly on smart- phones. Apart from these, innovations are happening daily in public IoT applications.

The recent convergence of multiple technologies and IoT or Internet of Things (A system of interrelated computer devices or M2M) has become the foundation for the concept of 'Smart Homes' which include home security systems, smart lighting, thermostats, etc. these can then be controlled using devices which are considered as user-friendly access points such as smartphones and speakers (Artificial Intelligence-based software).

Trust in such technologies enables users to make their everyday life more time-friendly, pragmatic, and sorted efficiently. Essentially that is the basis of the popularity of AI software like Google Home, Amazon's Alexa and Echo, Apple's- watch, home-pod, home-kit, etc. Such facilities are extremely beneficial during emergencies. In cases of medical emergencies, a person's medical record may be shared over multiple interfaces to make it accessible to the doctors treating the person. Trust and better communication across all devices sharing a network make situations like this possible. Of course, there is the fear that this trust may be misused to procure data by unauthorized personnel. As such threats do exist in the real world, every soft- ware developing company, by default, builds security firewalls to protect the user data and grant exclusive data-sharing privileges to devices that the user trusts. Trusted devices also assist people suffering from dis- abilities, injuries, and even elderly people. Cochlear implants, pacemakers, other specialized implants, voice control navigation, assistive touch, etc. all help in flexibly accommodating the needs of such individuals.

So now the question arises that how can we compute trust in a model where we have no intuition about how will it work internally? A reliable basis for trust could be testing. But to 'test' a model we need to list down our expectations from that model. Firstly, in that case a complete specification of the model itself would be generated. But to methodize our expectations is not an easy task because the concept of 'fairness', cannot be given or presented through any mathematical algorithm. Trust in a machine could also be entrusted through experience.

The experience a ma- chine already incorporates in any user could be a re- liable basis to generate the trust of that user in that machine or program. Another method to compute trust can be feature. The amount and level of features a machine or a program promises to a user is directly dependent on the number of users generating their trusts on that machine. But again, testing the machine first and then going for the features and blindfold trusting them would be more precautionary.

5- Computational Trust Model for IVA

The idea or plan behind "trust management" is to develop a relationship or bond based on trust worthiness among all the nodes or among users and nodes those are involved in computational trust model. Here we consider nodes as different IVAs. As it is essential to understand without the trust among all the participating nodes and users the communication cannot establish. While on the other hand, maintaining the trust relationship between the systems, objects etc. It is vital to make sure that the complete system is more structured in terms of security. Naive Bayes, more technically referred to as the Posterior Probability, updates the prior belief of an event given new information. The result is the probability of the class occurring given the new data. Naive Bayes theorem is one of the simplest probabilistic classifiers, based on the Bayes theorem with strong (naive) independence assumptions. Naive Bayes is used to predict class membership probabilities, i.e. the probability that a given sample belongs to a category.

$$f(x|\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\,\sigma^2}} e^{\frac{-(x-\mu)^2}{2\,\sigma^2}} \qquad (1)$$

where 'μ' and 'σ2 are the average and the variance respectively of the values in X.

As Naïve Bayes theorem has different characteristics including simplest probabilistic classifiers, able to handles both continuous and discrete data, scalability in term of number of predictions and data points and fast convergence to make real time predictions. These are reasons to choose Naïve Bayes theorem to compute trust and furthers evaluate probability of using trusted IVA devices.

Prior probability, in Bayesian statistical inference, is the probability of an event before new data is collected. This is the best rational assessment of the probability of an outcome based on the current knowledge before an experiment is performed. To calculate Bayes' probability following formula is used

P(A|B) = [P(B|A) * P(A)] / P(B) , where: A and B are certain events. P(A) is the prior probability of event A occurring. Three different classes of prior probability p<.025, p<.05, p<.001 are used.

6- Implementation, Result and Analysis

We have implemented Naïve Bayes classifier in Python language. To perform result analysis, different IVA users and non-users (N=1000) are surveyed. This survey is performed to understand and analyze the barriers and motivations to adopting IVAs and how users are concerned about data privacy and trust with respect to organizational compliances and social contract related to IVA data and how these concerns have affected the acceptance and use of IVAs.

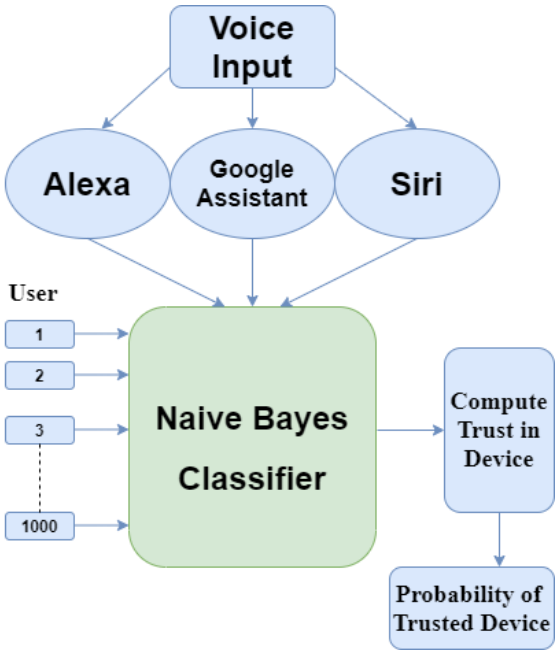

Figure 3. Computational Trust Model

We have used Naïve Byes Classifier to compute trust in IVA devices and further evaluate probability of using different trusted IVA devices.

6-1- Research Question 1: Find out key Reasons to Use or Non-use of IVAs

Key reasons to using IVAs-

Out of 1000 respondents 652 respondents who had/have ever utilized a Phone IVA—including the individuals who utilized it and the individuals who had utilized it before—we asked them to recognize for what valid reason they utilized it. The overview incorporated a rundown of 11 potential reasons, (in addition to an open-finished alternative), and respondents could choose various reactions. The most mainstream purposes behind utilizing a Phone IVA were: (1) posing genuine inquiries (82%); (2) getting bearings/area of a spot (67%); (3) asking senseless/clever inquiries only for chuckles (62%); (4) directing an instant message or email (58%); (5) set- ting a clock (49%). Extra reactions that gathered fewer votes included asking counsel, asking wellbeing explicit inquiries and home robotization. For the 380 respondents

who announced possessing a Google Home or Amazon Alexa, we approached them to list their inspirations for buying the gadget. Almost half (48%) said they had gotten the IVA as a blessing; others said they had bought the gadget essentially to control home gadgets (17%), to clear something up or for no particular reason (18%), to stream music (11%), and to have sans hands access to online data (15%).

Key barriers to not using IVAs- For the 457 respondents who said they didn't utilize a Phone IVA—including the individuals who had never utilized it and the individuals who had deactivated IVA highlights on their telephone—we requested that they rate factors that may have assumed a job in their choice. The variables regularly referred to by these respondents reflected worries about utility, privacy and protection.

Table 2. Probability of use the IVAs on behalf of trust and privacy

Probability of use the IVAs on behalf of trust and privacy		
Odds Ratio for different probabilities		
Classification	Case1 Phone IVA	Case2 Home IVA
Gender	-.24 (.80)	.00 (1.02)
Age Group (Young/Adult)	.03 (1.01)***	-.00 (.98)
Working/not working	-.00 (1.00)	.10 (1.14)**
Digital Native/Digital Migrant	.57 (1.76)***	.23 (1.22)*
Types (Siri, Alexa and Google Assistance)	.43 (1.54)***	-.03 (.94)
Trust based on privacy and security		
Issues related to general privacy	-.17 (.84)*	.02 (1.00)
Issues related to smart phone privacy	.03 (1.01)	.34 (1.44))**
Concerns/Issues related to IVA data	-.08 (.92)	-.44 (.60)***
Data confidence Concerns/Issues	.34 (1.34)***	.26 (1.32)*
Type of IVA used		
Home IVA	.52 (1.52)***	–
Phone IVA	–	.54 (1.72)***
Apply equation 1(Naïve Bayes Classifier)	2=140.0, =11***	2=114.98, =11***
Google Assistance	0.7	0.65
Siri	0.83	0.81
Alexa	0.76	0.79
*p<.025, **p<.05, ***p<.001		

6-2- Research Question 2: Predicting Adoption and Use of IVAs based on Trust and Privacy

Binary logistic regression models are used to classify user and non-users of IVAs. Three major IVAs Siri, Alexa and Google Assistant are evaluated by users. Table 1 summarizes the "Probability of use the IVAs on behalf of trust and privacy".

To find this probability different variables and parameters including background and demographic variables, privacy and security concerns, and experience with three types of IVAs (Siri, Alexa and Google Assistance). Results from Naïve Byes based Trust management model has indicated that general privacy concerns are major parameter. Three different classes of probability p<.025, p<.05, p<.001 are used. After applying Naïve Bayes Classifier, we have find out that Siri has higher probability of use as users and non-users have shown more confidence in iPhone based Siri due to high level of security and privacy which enhanced their trust.

7- Conclusions

Besides the IoT perspective, Trust management must provide uniform decisions. Despite all the hard work performed by various researchers and scientists on this aspect to provide a reliable uniform trust managing scheme, it will remain a broad and complex field that will always remain open for any further researches and proposals. There seem to be around 200 billion devices and sensors by 2020 which will be interconnected in a way to make things and life better for us. Thus, their importance is immense in the coming future. Due to their rising importance, it is also necessary to limit the security threats to which the people and the government could become vulnerable. The more connected the world becomes, the more the risks arise. To evaluate trust, we have surveyed 1000 respondents. While we found a way to arrive at a differing set of respondents through our inspecting technique, we were obliged to college representatives, prompting a profoundly taught test. Moreover, results depended on a onetime study and hence give a preview of a specific second in time. The outcomes from this investigation uncover a perplexing picture of IVA clients and non-clients.

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References

[1] J. Caminha, A. Perkusich, and M. Perkusich, "A smart trust management method to detect on-off attacks in the internet of things," Security Commun. Netw., vol. 2018, pp. 1–10, Apr. 2018.

[2] A.V. Singh, V. Juyal and R.Saggar, "Trust based Intelligent Routing Algorithm for Delay Tolerant Network using Artificial Neural Network" in Wireless Networks (WINE), US:Springer Publication, vol. 22, no. 135, pp. 1-10, Jan. 2016.

[3] G. D'Angelo, S. Rampone and F. Palmieri, "An Artificial Intelligence based Trust Model for Pervasive Computing", Proceedings on 10th International Conference on P2P Parallel Grid Cloud and Internet Computing 3PGCIC 2015 art. no. 7424653, pp. 701-706, 2015.

[4] K. Siau and W. Wang, Building Trust in Artificial Intelligence, Machine Learning, and Robotics, Cutter Business Technology Journal, Vol. 31, No. 2, pp. 47-53, 2018.

[5] I.-R. Chen, F. Bao and J. Guo, "Trust-based service management for social Internet of Things systems", IEEE Trans. Depend. Secure Comput., vol. 13, no. 6, pp. 684-696, Nov./Dec. 2016.

[6] S. M. Sony and S. B. Sasi, "On-Off attack management based on trust", In 2016 Online International Conference on Green Engineering and Technologies (IC-GET), pp. 1-4, November, 2016.

[7] F. Jiang et al., "Deep learning based multi-channel intelligent attack detection for data security", IEEE Trans. Sustain. Comput., [online] Available: https://ieeexplore.ieee.org/document/8259310/.

[8] J. Jiang, G. Han, C. Zhu, S. Chan and J. J. P. C. Rodrigues, "A trust cloud model for underwater wireless sensor networks", IEEE Commun. Mag., vol. 55, no. 3, pp. 110-116, Mar. 2017.

[9] Kot, Mateusz Tomasz, and Grzegorz Leszczyński. "The concept of intelligent agent in business interactions: is virtual assistant an actor or a boundary object?." Journal of Business & Industrial Marketing (2020).

[10] F. Fei, S. Li, H. Dai, C. Hu and W. Dou, "A K-anonymity based schema for location privacy preservation", IEEE Trans. Sustainable Comput.2017.

[11] S. Talari et al., "A review of smart cities based on the Internet of Things concept", Energies, vol. 10, no. 4, pp. 421, 2017.

[12] F. Boustanifar and Z. Movahedi, "A trust-based offloading for mobile M2M communications", Proc. Int. IEEE Conf. Ubiquitous Intell. Comput., pp. 1139-1143, 2016.

[13] Gartner Says Worldwide Spending on VPA-Enabled Wireless Speakers Will Top \$2 Billion by 2020, Gartner, Oct. 2016, [online] Available: www.gartner.com/newsroom/id/3464317.

[14] A. Liptak, Amazon's Alexa Started Ordering People Dollhouses after Hearing Its Name on TV, The Verge, Jan. 2017, [online] Available: www.theverge.com/2017/1/7/14200210/amazon-alexa-tech-news-anchor-order-dollhouse.

[15] K. York, Dyn Statement on 10/21/2016 DDoS Attack, [online] Available: dyn.com/blog/dyn-statement-on-10212016-ddos-attack, Oct. 2016.

[16] Yuting Liao, Jessica Vitak, Priya Kumar, Michael Zimmer, and Katherine Kritikos. Understanding the Role of Privacy and Trust in Intelligent Personal Assistant Adoption. In Information in Contemporary Society, Natalie Greene Taylor, Caitlin Christian-Lamb, Michelle H. Martin and Bonnie Nardi (eds.). Springer International Publishing, Cham, 102--113. https://doi.org/10.1007/978--3-030--15742--5_9, 2019.

[17] Chung, Hyunji, Michaela Iorga, Jeffrey Voas, and Sangjin Lee. Alexa, Can I Trust You? Computer 50: 100, 2017.

[18] A. S. Tulshan and S. N. Dhage, "Survey on virtual assistant: Google assistant Siri Cortana Alexa", Proc. Int. Symp. Signal Process. Intell. Recognit. Syst., pp. 190-201, 2018.

[19] Kshama V. Kulhalli, "Personal Assistant with Voice Recognition Intelligence", ISSN 0974-3154 Volume 10, Number 1, 2017.

[20] Amanda Purington, Jessie G. Taft, Shruti Sannon, Natalya N. Bazarova, and Samuel Hardman Taylor. 2017. "Alexa is my new BFF": Social Roles, User Satisfaction, and Personification of the Amazon Echo. In Proceedings of the CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17). ACM, New York, NY, USA, 2853—2859, 2017.

[21] V. Këpuska and G. Bohouta, "Next-Generation of Virtual Personal Assistants (Microsoft Cortana, Apple Siri, Amazon Alexa and Google Home)," in 2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC), pp. 99–103, 2018.

[22] J. R. Bellegarda, "Spoken language understanding for natural interaction: The Siri experience" in Natural Interaction with Robots Knowbots and Smartphones, New York:Springer-Verlag, pp. 3-14, 2014.

[23] Kunal Gupta, Ryo Hajika, Yun Suen Pai, Andreas Duenser, Martin Lochner, and Mark Billinghurst. "Measuring Human Trust in a Virtual Assistant using Physiological Sensing in Virtual Reality." In 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 756-765. IEEE, 2020.

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IT Capability Evaluation through the IT Capability Map

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Abstract
Organizations are increasingly in search of ways to derive more business values from IT investments and the need for IT capabilities (ITC) is surging. ITC is critical significant to build enterprise agility and promote organizational performance. However, IT capability is always treated as the causal factor already existing and there are few studies on how IT capability is created and evaluated. Appropriate evaluation is necessary for an organization to measure, manage and improve enterprise ITC. This research aims to identify and map the dimensions of an organization's ITC. Using a mixed research method, this paper comprises two sections. The qualitative section adopts a systematic literature review (SLR) approach to identify the dimensions of ITC. The quantitative section employs factor analysis to validate identified ITC dimensions and their indicators in an attempt to develop a more precise model for ITC evaluation. The proposed ITC model includes IT management, IT human resources, IT infrastructure, and implementation of IT solutions dimensions as well as the 25 related indicators. Drawing on the results of this paper, organizations can engage in evaluation and improve/create essential ITCs based on the evaluation results.

Keywords: Information technology capability; Information technology capability evaluation indicators; Information technology dimensions; Information technology map.

1- Introduction

Information System (IS) and Information Technology (IT) play a vital role in supporting business activities and technology that are intended to realize the vision, mission and goals that contribute to the growth of an organization [1] [2]. Lack of analysis and sound governance over the optimization of IT advantages, or the use of IT resources [1] [3] [4] [5], as well as the management of the risks associated with IT are the underlying factors that inhibit organization from IT investment such as Information system deployment [6] [7] [8]. IT capability (ITC) can compensate for this shortcoming [1] [9] [10]. ITC describes an organization's ability to create business value and to acquire, deploy, combine, and reconfigure IT resources in order to support and upgrade business strategies and business processes [11] [18] [19] [20]. The actual performance benefits of IS integration in an organization can only be accomplished if its IT capability is well controlled and governed [2] [21] [22] [23] [24]. As a result, recognizing all types of organization's ITC and its realistic evaluation is critical for building and cultivating IT resources. In addition, clarification of the relationship between ITC and organizational performance calls for ITC measurement and evaluation [25] [26], which must be examined quantitatively and qualitatively. The bulk of previous research have considered ITC as a platform and infrastructure for organizational activities and work flows. Despite the above, scant attention has been paid to the evaluation of overall organization's IT capability in the literature with some studies just mapping the types of IT capability and its drivers [27] [28] [29] [30]. On the other hand, the modelling and mapping of organizational capability has offered an approach to the creation of enterprise architecture. It seeks to develop a model for the complete set of capabilities required by an organization to fulfil its mission. Some frameworks are related to ITC in the realm of enterprise architecture. One of such frameworks is COBIT, which highlights the central role of IT in building business value and helping managers in connection with IT governance and the IT management by considering the business requirements, capabilities and IT resources, as well as different stakeholders of organizational needs. COBIT framework maintains a balance between benefits, risks and resources of organizations [31]. As noted in previous research, ITC covers a wide range of capabilities [27] [28] [29] [30], which must be controlled and evaluated, but COBIT framework only focuses on integrating enterprise governance and IT governance, and therefore a complete assessment of IT capability cannot be made under COBIT

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framework. IT capability must be enhanced based on an evaluation results using valid indicators.

It is worth noting, however, that IT capabilities are a competitive necessity, as their absence can pose a competitive disadvantage. Given the importance of ITC issue, the question raised in this research is "What are the dimensions of ITC and its indices?"

This research seeks to address this gap in the literature in two sections: a qualitative section that examines the foundation (ITC dimensions and its indicators) through a systematic literature review (SLR) and EA expert interviews, and a quantitative section that focuses on developing a model for evaluating ITC based on the SLR information, data analysis, and the standpoints of EA experts for the purpose of organizational ITC evaluation.

2- Background

Organizational capability suggests that an organization should be organized and managed to take the most out of its resources. Subsequently, ITC is defined as IT resources deployed concurrent with other resources and capabilities [27] [32]. According to the concept of IT capability (ITC) proposed by Ross et al. [1], "IT capability represents the ability of an organization to collect, integrate and deploy IT resources". Hence, may studies have investigated the role of IT capability as an organizational capability for enhancing and improving organizational performance [2] [3] [10] [11] [12] [13] [14] [15] [16]. In fact, for the first time, the concept of ITC has been developed from a resource-based approach, according to which superior organizational performance is attributed to an organization's resources and capabilities [11] [12]. IT capability is a rare, non-reproducible, and non-substitutable organizational ability that offers great benefits when deployed perfectly [25]. rapid and innovative response are crucial to foster organizational agility. According to this view, ITC manifests a fundamental ability to influence the rapidness of organization [19] [26]. ITC can create time lag before opponents forcefully devastate the competitive advantage of an organization [34] [26], serving as a strategic obstacle to other competitors. Some studies classify ITC into three dimensions: IT infrastructure capability, IT business spanning capability, and IT proactive stance [19] [21] [35] [36] [37]. The first dimension reinforces processing and management of data accurately, creation of network channels, access to updated information about customer preferences as well as the latest technology and new regulations [19] [36]. Infrastructure integration can create unlimited digital alternatives that improve and enrich organizational learning, upgrading an organization's ability to share and apply existing knowledge [35]. The second dimension of IT capability is concerned with integrated communications between the overall ITC of an organization and its main decision makers. The goal of these communications is business, planning and strategy analyses in the organization. The ongoing cooperation between business units and IT units establishes a real mutual trust between both of them, which facilitates information sharing and presentation of incredible services. In addition, it ensures the adaptability of organization workflows that require fundamental changes by information systems, procedures and operations of organization on a regular basis. Another dimension of IT capability is IT proactive stance, which describes how organizations are constantly in pursuit of innovative methods to realize and determine the optimal use of IT potentials on order to seize opportunities in the market. As a result, organizations will be well–equipped to define, choose and track IT developments [19] [35] [36].

IT capabilities control IT costs and provide the required business systems. Moreover, it affects organizational objectives through IT implementation. Some papers have examined IT capabilities from a resource- based view (RBV) [2] [22] [38] [39]. According to RBV, IT is a resource that creates competitive advantages, which leads to a superior performance [40]. According to Chen and Tsou (2012), based on RBV, IT Capability can be classified into four categories. IT infrastructure is the main foundation for delivering business applications and services, sharing information supplied by IT infrastructure in organizations. IT business experience enables an organization to merge IT strategy and business strategy. IT relationship resources represent an organization's ability to incorporate IT functions into business units and exploit IT resources. IT human resources are a major component of the IT asset base, serving as a strategic organizational resource and a major organizational capability.

As noted, various dimensions of ITC have been deliberated so far. Despite different terms used to describe these dimensions according to their features or type of ability, they overlap in many respects and should be categorized into a single group. In addition, most papers have focused on IT infrastructure capability as major ITC dimension.

3- Research Methodology

This study employs an exploratory mixed-methods approach to identify ITC dimensions and its evaluation indicators. To do so, the following steps were taken:

3-1- Qualitative Section

In the first step, previous research related to IT Capability was studied. for this purpose, an SLR approach was selected. Generally, the SLR process is performed in three

consecutive stages: planning, execution and analysis of results [41].

3-1-1- Review Design

The review design defines the foundation of this review by describing SLR questions and search keywords.
This research was designed to identify the dimensions of ITC and its indicators. The SLR research question is as follows:
RQ. What are the dimensions of ITC and its indicators in the organization?

3-1-1-1- Search Process

We searched major scientific databases rather than specific books or reports on the assumption that the major research results described in books and reports are also usually cited or explained in scientific papers. The selected sources are:

- IEEE Xplore;
- Jstor;
- Science Direct – Elsevier;
- Springer Link;
- Google Scholar;

The keywords searched in the title, keywords, and abstract of the papers included: ‘‘Information technology capability’’ or ‘‘Information technology capability dimensions’’ or ‘‘Information technology capability measures’’ or ‘‘Information technology capability evaluation’’ or ‘‘IT capability"

3-1-2- Review Conduction

The review protocols of the SLR, which describe the structure and rules of review, are defined in this section.

3-1-2-1- Inclusion and Exclusion Criteria

All relevant studies were identified according to the predefined criteria. We included full papers in English published in peer-reviewed journals, conferences and workshops. In the case of duplicated studies, only the most thorough versions were selected. Inclusion and exclusion criteria are as follows:

Inclusion criteria:

- English peer-reviewed studies that address research questions
- Studies that explore ITC dimensions.
- Studies that explore ITC measurement and evaluation
- Studies that explore ITC

Exclusion criteria:

- Studies published in languages other than English
- Studies not pertained to the research questions
- Duplicated studies

3-1-2-2- Study Selection

The studies were checked for their relevance in the following process:

- Identifying relevant studies by searching defined keywords in the databases.
- Excluding studies based on the exclusion criteria.
- Analyzing titles and abstracts of paper and excluding irrelevant studies.
- Reading and assessing full-text papers.
- Reassessing the results of random studies.
- Extracting primary studies.

3-1-2-3- Quality Assessment

To control the strength of inferences and clarify outcomes derived from the studies, the following criteria were used for the evaluation of the selected studies:

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- the thorough data analysis supported by evidence or theoretical arguments
- a study context similar to this research
- the support of study goals by the research design

3-1-2-4- Synthesis

The results obtained from searching keywords in databases are shown in Table 1. Table 2 shows the numbers of selected paper based on their type and Table 3 lists the citations of selected papers, which were obtained from Google Scholar.

Table 1: Results of study search

Source	Found	Candidate	Selected
Google Scholar	48	43	18
Jstor	22	9	7
IEEE Xplore	95	3	1
Science Direct – Elsevier	31	11	3
Springer Link	59	2	0
Total	230	66	29

Table 2: Type of selected study and their numbers

Study	No.	Percentage
Journal papers	27	93
Conference proceeding	1	3/3
Books	1	3/3

Table 3: Citation for selecting papers

#	Cited	Ref	#	Cited	Ref	#	Cited	Ref
S1	1	[42]	S11	136	[30]	S21	38	[36]
S2	2	[35]	S12	951	[48]	S22	2807	[21]
S3	1122	[27]	S13	489	[49]	S23	1540	[27]

#	Cited	Ref	#	Cited	Ref	#	Cited	Ref
S4	4977	[37]	S14	273	[50]	S24	670	[55]
S5	31	[43]	S15	3	[51]	S25	770	[56]
S6	20	[44]	S16	177	[23]	S26	33	[28]
S7	780	[45]	S17	17	[52]	S27	29	[57]
S8	919	[46]	S18	306	[53]	S28	131	[10]
S9	122	[47]	S19	1144	[54]	S29	5	[29]
S10	223	[32]	S20	593	[19]			

3-1-3- Results

In this section, RQs are answered.

RQ. What are ITC dimensions and indicators in the organization?

The question is answered based on the analysis of extracted data. As a result, ITC indicators were identified and aggregated for further classification. After re-examination and elimination of overlapping indicators and the grouping of indicators, three main dimensions of ITC were identified by IT experts including IT infrastructure, IT management, and human resource capabilities.

3-2- Quantitative Section

In this section, the identified ITC dimensions and indicators are validated by a statistical analysis to present a more detailed model for ITC evaluation.

3-2-1- Data Collection

Information was gathered using a questionnaire with a 5-point Likert scale (from strongly disagree (1) to strongly agree (5)). The factual and content validity of questionnaire were examined by IT experts and IT professors before distributing questionnaires among respondents.

Considering the definition and concept of an enterprise architecture, which plays an essential role in the information technology management [58], the statistical population of this research consisted of IT managers of organizations that were members of the Enterprise Architecture and Information Technology Association of Iran and IT constituted an integral part of their business. Accordingly, nearly 300 organizations were selected. We requested the IT Manager of these organizations to fill out questionnaire. Based on Morgan's table, a sample size of n=169 organizations was selected, but we distributed 189 questionnaires to account for dropout and incomplete questionnaires. Finally, 168 questionnaires were returned.

We also collected information about respondent's demographic variables, such as education, gender, and IT knowledge. According to the results, 13.7% of respondents were female and 86.3% were male. Regarding the level of education. 13.7% had a doctorate degree, 63.7% had a master's degree, 22% had a bachelor's degree and 0.6% had an associate degree. With respect to IT knowledge, 11.9 % of respondents had very high, 40.5% had high, 43.5% had medium and 4.2% had low knowledge of IT.

Prior to the factor analysis of ITC indicators, the reliability of questionnaire was evaluate using Cronbach's alpha coefficient (0.963), which was acceptable.

3-2-2- Exploratory Factor Analysis (EFA)

Exploratory factor analysis (EFA) can be used when the researcher has no theory about the research structure, or does not intend to incorporate the expected structure as a part of calculations. For the confirmatory factor analysis (CFA), researcher needs a theory of factor structure for the analysis in order to limit estimated parameters. There must be a certain degree of correlation between questionnaire's item and excessive correlation prevents the extraction of independent factors [59]. On the other hand, if such as correlation is below a certain degree, the unity matrix will be found. The significance of the Bartlett's test shows the correlation is adequate for factor analysis. The Kaiser-Meyer-Olkin (KMO) test surveys whether the items could be categorized into a smaller set of factors. A KMO value closer to one suggests the usefulness of the factor analysis for the data. However, the EFA cannot be performed properly if its values are below 0.5 [60].

In our study, KMO index value was 0.95, which manifests the suitability of sampling and data numbers for factor analysis. Also, the significance of Bartlett's test of sphericity was less than 0.05 ($p = 0.00$), indicating that the correlation matrix is suitable for data factor analysis.

After performing EFA for ITC indicators, four main dimensions were identified with eigenvalues greater than 1, which is consistent with the gravel graph obtained from the software (Figure 1). Besides, these four dimensions explained 62.912% of variance in the ITC factors, which is acceptable.

For each of these four dimensions, a quadrant is extracted with a special value above 1. Cronbach's alpha of all four dimensions is greater than 0.7, exhibiting that the internal consistency is acceptable. The results show that all bivariate relationships between variables were statistically significant (Table 4).

Items 9, 10, 11 and 12 loaded on IT resources capability and had a factor loading of over 0.4. However, according to expert`s opinions they were excluded due to the lack of conceptual meanings.

Table 4: Results of the ITC questionnaire EFA

Factors (Dimensions)	Cronbach alpha coefficient	Factor loading	Items	Eigenvalue	Percentage of variance
IT management capability	0.911	0.458	5	14.522	18.592
		0.622	6		
		0.559	19		
		0.554	20		
		0.658	21		
		0.691	22		
		0.732	23		
		0.494	24		
		0.506	25		
IT human resources capability	0.828	0.548	26	1.454	17.308
		0.558	27		
		0.677	28		
		0.503	29		
Implementation of IT solutions capability	0.911	0.518	7	1.205	16.502
		0.573	8		
		0.602	13		
		0.77	14		
		0.605	15		
		0.674	16		
		0.63	17		
		0.568	18		
IT infrastructure capability	0.793	0.758	1	1.063	10.51
		0.71	2		
		0.52	3		
		0.407	4		

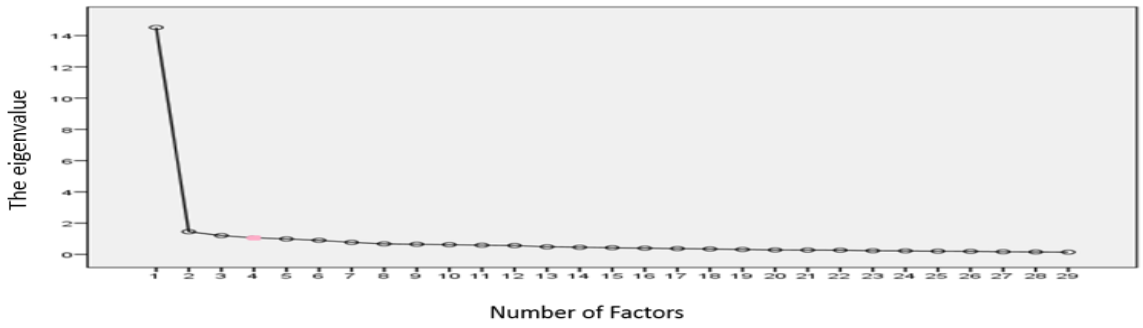

Figure 1: Scree Plot of the ITC Questionnaire

3-2-3- Research Hypotheses

IT human resources capability: It describes skills required for resources management, including four types of skills: technology management, business function, interpersonal and management, and technical skills [61].

H1: IT capability has an effect on IT human resources capabilities.

IT management capability: " refers to IT staff's ability to manage resources in order to create business value for the organization" [53].

H2: IT capability has an effect on IT management capability.

Implementation of IT solutions capability: Previous research has not addressed key issues of this dimension of IT capability; however, according to this study, it refers to

IT staff 's ability to manage IT project implementation and support all steps and activities that lead to IT solutions.

H3: IT capability has an effect on the implementation of IT solutions capability.

IT infrastructure capability: "An organization's capacity to organize a set of shareable platforms, which captures the extent to which an organization is dexterous at providing data management services and architectures, application portfolio, network communication services and services" [19].

H4: IT capability has an effect on the implementation of IT infrastructure capability.

3-2-4- Confirmatory Factor Analysis (CFA)

The confirmatory factor analysis (CFA) is usually conducted to minimize the difference between the estimated and observed matrices [62]. In the second-order confirmatory factor model, the factors obtained from the observed variables are influenced by other latent variables at a higher level. Accordingly, in addition to investigating the relationship between observable variables and factors, the association between latent variables and factors is also examined [63]. All four factors of the study (ITC dimensions) measure ITC (as a latent variable). In this section, the fitness of measurement and structural model is investigated by CFA using SmartPLS.

3-2-4-1- Evaluation of Measurement Model

This section evaluates reliability and validity of the model. Reliability is assessed in three ways: evaluation of factor loading, Cronbach's alpha and composite reliability. Factor loading values greater than 0.4 are suitable. Also, Cronbach`s alpha coefficients greater than 0.70 indicate that the measurement model is reliable [64]. The value of composite reliability can vary between 0 and 1 with values higher than 0.6 being considered as acceptable [65]. As shown in Table 5, the model reliability is acceptable.

Table 5: Results of Validity and Reliability

Variables	Item icon	Factor loading	T values	Cronbach alpha coefficient	The Composite reliability	AVE
IT infrastructure capability	ITC1	0.823	24.07	0.79	0.86	0.621
	ITC2	0.784	17.25			
	ITC3	0.788	21.01			
	ITC4	0.755	16.22			
Implementation of IT solutions capability	ITC13	0.837	33.9	0.91	0.93	0.625
	ITC14	0.86	37.17			
	ITC15	0.824	29.57			
	ITC16	0.776	23.47			
	ITC17	0.758	19.47			
	ITC18	0.68	15.06			
	ITC7	0.799	31.5			
	ITC8	0.78	22.96			
IT human resources capability	ITC19	0.709	12.4	0.91	0.92	0.586
	ITC20	0.721	16.8			
	ITC21	0.812	29.4			
	ITC22	0.762	20.7			
	ITC23	0.806	31.7			
	ITC24	0.778	22.8			
	ITC25	0.749	19.15			
	ITC5	0.791	17.1			
	ITC6	0.804	25.8			
IT management capability	ITC26	0.813	27.02	0.82	0.88	0.659
	ITC27	0.849	36.32			
	ITC28	0.829	27.07			
	ITC29	0.755	15.29			
IT capability	-	-	-	0.95	0.96	0.782

The convergent validity is assess based on the average variance extracted (AVE). According to [66], AVE ≥0.50 manifests a sufficient degree of convergent validity, meaning that the latent variable (constructs) explains more than half of variance in its indicators. The discriminant validity test shows the degree of variance in indicators that could be explained by variance in the construct [67]. As the results of Table 5 show, the convergent validity and discriminant validity test of the research model were acceptable.

The normality of research data was evaluated using Kolmogorov–Smirnov test. The results showed that the distribution of research variable did not follow the normal statistical distribution. Moreover, Spearman's rank correlation coefficient was conducted to assess the correlation between ITC variable and other variables (4

identified factors). The correlation significance between all variables were less than 0.05, which is acceptable.

3-2-4-2- Evaluation of Structural Model

The effect of an exogenous variable on an endogenous variable is evaluated using R^2 coefficient, which is related to the latent (dependent) variables of the model. The three values of R^2 coefficient, i.e. 0.19, 0.33 and 0.67, are the criterion for the weak, moderate and strong values [63]. The results of the structural model assessment are presented in Table 6. Based on the results, the overall model had an acceptable fit.

Table 6: Tests of hypotheses and results of R2 criteria

Variables	R^2	Related Hypotheses	T-value	Path Coefficient
IT human resources capability	0.71	H1	37.616	0.846
IT management capability	0.89	H2	102.68	0.893
Implementation of IT solutions capability	0.84	H3	72.807	0.848
IT infrastructure capability	0.67	H4	29.875	0.821

3-2-5- Model Validation

Tenenhaus et al. [68] have suggested a global criterion for the goodness of fit (i.e., GoF index), which accounts for the performance of the PLS model and validates both the measurement model and the structural model with a focus on overall prediction performance of the model. Accordingly, three values of 0.01, 0.25 and 0.36 were considered as weak, moderate and strong values for GOF. In this research, GOF was equivalent to 0.696, which shows the strong fitness of the overall research model.

4- Research Findings

According to the findings of the qualitative and quantitative sections, the ITC dimensions and its indicators were finally identified. In this paper, we proposed a model of ITC dimensions that comprises 4 dimensions and 25 indicators, as shown in Table 7. As mentioned earlier, 3 ITC dimensions and 29 indicators were identified in the qualitative section, but after performing CFA in the quantitative section, the number of identified dimensions increased to four and the number of indicators dropped to 25.

The presented model includes both tangible and intangible IT capabilities. Tangible capabilities include technical and infrastructure elements (appropriate communication network, formats of information, standards, well-integrated web applications), and intangible IT capabilities include the business group's knowledge and awareness of IT and their ability to interact with the business group.

According to the findings, the implementation of IT solutions capability dimension, despite its strong correlation with ITC, has received scant attention in the literature. However, IT infrastructure capabilities, despite its weak correlation with ITC, has received greatest attention in previous research (Table 6).

IT infrastructure capability includes 4 indicators IT management capability includes 9 indicators, Implementation of IT solutions capability includes 8 indicators and finally IT human resources capability includes 4 indicators.

5- Discussion

Many studies have identified different ITC dimensions and indicators. These studies contain limitations and deficiencies that can be mentioned:

In most of previous studies, IT capability is considered based on technology components, as a set of shared, tangible, and technological resources [16] [17] [48] [55] [69] [70]. However, IT capability covers a wide range of capabilities. For example, the knowledge and expertise of IT staff is one of major IT capabilities that play an important role in improving organizational performance and achieving competitive advantage [42] [50] [53] [61]. Identifying all ITC dimension in order to evaluate its status requires a comprehensive review that incorporates different perspectives. In addition, ITC is a dynamic rather than static organizational capability. In diverse organizations, the role and nature of ITC are different. However, in many organizations, ITC can support the business and provide a competitive advantage, which acts as a business driver [26] [34]. Therefore, identifying all types and dimensions of ITC requires examining a wide array of organizations where IT plays different roles.

In the literature, some papers have explicitly identified the ITC dimensions [27] [28] [29]. Chen and Tsou [30], while evaluating the impact of ITC on the organizational performance of Nigerian banks, identified different dimensions of ITC. Their results laid the foundation for many other studies. For the first time, Bhatt and Grover [27] presented a classification of ITC dimensions, which contained only 4 indicators introduced in this study. The two dimensions of IT management capabilities and IT solutions capabilities were not considered in their study. Thus, out of 19 indices related to these two dimensions, only one (business experience of IT group) was mentioned. Yoon [28] focused on IT management capabilities, covering 5 out of 9 indicators associated with this dimension. It is worth noting that Yoon [28] considers development, deployment and management of information systems including ERP, SCM, CRM, and KMS as an organization's IT capabilities. However, depending on the type and requirements of an organization, no information systems may be necessary. However, the present study

considers the enterprise architecture development as one of IT management capabilities that help develop information systems in the organization. Zhang et al. [29] presented a classification of ITC dimensions that consisted of only 5 indicators presented in this study, leaving out. Implementation of IT solutions capabilities wasn't considered by them. Chen and Tsou [30] presented a relatively complete set of ITC dimensions. Although their model addressed 4 dimensions of IT capability, they only considered 8 indicators introduced in the present research. Table 7 compares ITC identified in some of previous studies with the present article. As can be seen, the types of ITC identified in the present study exceed that of other studies. Risk management, data and database management, asset management and infrastructure management as well as IT services management system (planning, development and support of IT services) have been overlooked in the aforementioned studies.

To date, several enterprise architecture frameworks have used capability notation, considering the development of organizational capability as an important component of business architecture, including TOGAF, DODAF, MODAF, Service-Oriented Architecture (SOA), NAF, and Archimate frameworks [71]. The purpose of identifying ITCs in an enterprise architecture is modeling and creating an IT capability guide that offers several benefits, including planning key ITCs improvement and aligning ITC with business strategies. Up to now, various business capability frameworks and roadmaps have been developed to facilitate the identification and evaluation of business capabilities maturity. The IT capability maturity framework (ITCMF) evaluates the ITC maturity in organizations [72]. It consists of four primary categories, where each category covers several sub-capabilities known as IT capabilities, which are basically distinct from ITC definition in the present study. In fact, each category represents a role that could be assumed by an IT unit in an organization. ITCMF builds a bridge between organizational change and IT capability [73], but it falls short of a clear evaluation of ITC in organizations that are weak in this respect.

IT governance is another concept closely related to IT capability. IT governance represents the process of controlling and monitoring decisions related to an organization's IT capability [74]. A variety of frameworks, including COBIT, ITIL, Val IT have been developed for IT governance. In general, IT governance frameworks constitute a set of best practices and procedures that help organizations build their value through ITC and achieve their strategic goals. An important part of IT governance is evaluation and control. COBIT is a framework for monitoring and managing IT activities through which IT resources are managed in a way to obtain IT objectives [31]. COBIT also includes a maturity model that illustrates the status of IT management processes in organizations at six levels. The state of IT capabilities should also be noted. ITIL is an IT governance framework at the IT service level. Thus, it evaluates IT capability only at the level of IT service development and support. The evaluation of ITC through the ITC map presented in this research does not only lead to IT management and IT services evaluation. It assesses the status of an organization's IT capabilities at the levels of ITC management, IT services and solutions, IT infrastructure and staff expertise, and clarifies ITC weaknesses, which contribute to the management, control and also improvement of an organization's ITC. In light of the above, the main innovation and contribution of this research are as follows:

- ITC dimensions were identified in a systematic literature review (qualitative review); the quantitative statistical methods relied on resource-based and strategic-based approaches.
- The proposed ITC map identified more ITC indicators than previous research did. New ITC indicators have not been considered in previous classifications.
- The proposed ITC map detects ITC in accordance with four layers of enterprise architecture (business, application, data and infrastructure). It can be used as an enterprise architecture framework in the IT governance management that evaluates an organization's ITC status.

Table 7: ITC evaluation studies comparison

Dimensions	ITC Type	This research	[30]	[29]	[28]	[27]
IT infrastructure capabilities	Providing appropriate network communication services	*	*	*	*	*
	Adapting and sharing various formats of information and data	*				
	Complying with security standards and risk management	*				
	Using well-integrated web applications	*	*			
IT management capabilities	Developing and implementing an strategic plan of ICT	*		*	*	
	Applying enterprise architecture	*				
	Ensuring interaction between IT units and other business units	*	*		*	*
	Understanding how IT supports competitive advantages as well as IT investment value.	*		*	*	
	Evaluating IT performance	*			*	
	Planning for control security and complying with security standards	*			*	
	Scheduling for risk management and disaster recovery	*				
	Planning for IT resources and asset management	*	*			

Dimensions	ITC Type	This research	[30]	[29]	[28]	[27]
	Supporting modern IT usage methods and innovations	*	*			
Implementation of IT solutions capabilities	Managing ICT projects	*	*	*	*	
	Managing IT providers (software vendors, networks, data centers)	*				
	Testing and implementing IT services	*				
	Supporting IT services	*				
	Backing up	*				
	Delivering and exploiting IT solutions	*				
	Maintaining and backing up an organization's databases	*				
	Setting up service level agreements (SLAs)	*				
IT human resource capabilities	Encouraging IT employees to learn	*				
	Encouraging IT employees and inter-unit effort, dealing with business problems and promoting teamwork	*				*
	Raising IT employee's awareness of business	*	*	*		*
	Recruiting expert and skilled IT employees	*	*	*	*	

6- Limitations and Future Work

This paper offers some avenues of research that could be built upon in future research. This paper focused on different dimensions of ITC and its indicators in order to evaluate and improve such dimensions in organizations. The indicators presented for each IT capability in the research model could be merged in IT frameworks such as IT4IT and COBIT, to be further developed. The future research can analyze the weight and significance of each dimension and indicator. Furthermore, a maturity model of ITC dimension could be developed by ranking ITC indicators or identifying and defining a range of levels for them in the organization. This research can also benefit from a wider range of data from various industries. Also, the capability of IT in a particular industry can also be measured in future works based on this model.

7- Conclusion

Organizations are increasingly in search of ways to derive more business value from their IT investments. Developing an organization's IT capability is a common approach to achieve this goal. However, the absence of a comprehensive, structured and validated model for evaluating ITC and its dimension status is felt. The goal of this study was to explicate the nature of IT capability dimensions and identify the dimensions of ITC and their indicators. Through a meticulous review of ITC literature and related academic theory as well as statistical analysis, a model for evaluating ITC dimension was proposed, which could be used as a map, checklist or questionnaire that contains ITC dimensions and their indicators. According to this model, an organization's IT capability comes from underlying strengths in four main types of ITC including IT management, IT human resources, IT infrastructure, and implementation of IT solutions, which are evaluated by 25 indicators. Together, they serve as a guide for studying ITC status in an organization.

References

[1] N. A. A. Hamid, C. W. Liew, N. H. Abdullah, and S. S. Omar, "The role of information technology human capability in the implementation of information technology governance (ITG): a systematic literature review on malaysian organizations," *Technology and Engineering Systems Journal*, Vol. 4, No. 4, 314-322, 2019.

[2] A. S. Bharadwaj, "A resource-based perspective on information technology capability and firm performance: An empirical investigation," *MIS quarterly*, Vol. 24, No. 1, pp.169–196, 2000.

[3] S. Mithas, N. Ramasubbu, M. S. Krishnan and V. Sambamurthy, "Information technology infrastructure capability and firm performance: An empirical analysis. Working paper," Ross School of Business, University of Michigan, Ann Arbor, 2005.

[4] G. K. Chepkole, and J. Deya, "Effect of strategic capability on competitive advantage of information technology firms in Nairobi City County, Kenya," *International Academic Journal of Human Resource and Business Administration*, Vol. 3, No. 5, 104-127, 2019.

[5] C. H. Chen, and T. Cates, T. "The role of information technology capability and innovative capability: An empirical analysis of knowledge management in healthcare," *International Management Review*, Vol. 14 No. 1, 5–16, 2018.

[6] J. Luftman, K. Lyytinen, and T. B. Zvi, "Enhancing the measurement of information technology (IT) business alignment and its influence on company performance," *Journal of Information Technology*, Vol. 32, No. 1, 26-46, 2018.

[8] P. Mikalef, and A. Pateli, "Information technology-enabled dynamic capabilities and their indirect effect on competitive performance: Findings from PLS-SEM and fsQCA," *Journal of Business Research*, Vol. 70, No.1, 1-16, 2017.

[9] M. Queiroz, P. Tallon, R. Sharma, and T. Coltman, "The role of IT application orchestration capability in improving agility and performance, The Journal of Strategic Information Systems," Vol. 27, No. 1, 4-21, 2018.

[10] M. Zhang, S. Sarker and S. Sarker, "Unpacking the effect of IT capability on the performance of export-focused SMEs: A report from China," *Information Systems Journal*, Vol. 18, No. 4, pp.357-380, 2008.

[11] H. Liu, K. Ke, K. Wei and ZH. Hua, "The impact of IT capabilities on firm performance: The mediating roles of

absorptive capacity and supply chain agility," *Decision Support Systems*, Vol. 54, pp.1452–1462, 2013.

[12] K. J. Ringim, M. R. Razalli and N. Hasnan, N "The relationship between information technology capability and organizational performance in Nigerian banks," *International Journal of Business Research and Development*, Vol. 4, No. 2, pp.1- 10, 2015.

[13] H. C. Chae, C. E. Koh and K. O. Park, "Information technology capability and firm performance: Role of industry," *Information and Management*, Vol. 55, No. 5, pp.525-546, 2018.

[14] Z. Wang, D. Q. Yao, X. Yue and J. J. Liu, "Impact of IT Capability on the Performance of Port Operation," *Production and Operations Management*, Vol. 27, No. 11, pp.1996-2009, 2017.

[15] U. Hameed, M. Shabbir, A. Raza and A. Salman, "Remedies of low performance among Pakistani e-logistic companies: The role of firm's IT capability and information communication technology (ICT)," *Uncertain Supply Chain Management*, Vol. 7, No. 2, 2018.

[16] J. Braojos, J. Benitez and J. Llorenz, "How do social commerce-IT capabilities influence firm performance? Theory and empirical evidence," *Information & Management*, Vol. 56, No. 2, pp.155–171, 2019.

[17] J. B. Barney, "Firm resources and sustained competitive advantage," *Journal of Management*, Vol. 17, No. 1, pp.99–120, 1991.

[18] M. Wade and J. Hulland, "Review: the resource-based view and information systems research: review, extension, and suggestions for future research," *MIS Quarterly*, Vol. 28, No. 107, 2004.

[19] Y. Lu and K. Ramamurthy, "Understanding the link between information technology capability and organizational agility: an empirical examination," *MIS Quarterly*, Vol. 35, No. 4, pp.931–954, 2011.

[20] V. Sambamurthy and R. W. Zmud, "At the heart of success: organization-wide management competencies," in *Steps to the Future: Fresh Thinking on the management of IT-Based Organizational transformation*, Sauer, C. and P. Yetton, P. (Eds.), San Francisco, CA: Jossey-Bass Publishers, 1997, pp.143-164.

[21] F. J. Mata, W. L. Fuerst and J. B. Barney, "Information technology and sustained competitive advantage: a resource-based analysis," *MIS Quarterly*, Vol. 19, No. 4, pp.487-505, 1995.

[22] B. B. Tyler, "The complementarity of cooperative and technological competencies: a resource-based perspective," *Journal of Engineering and Technology Management*, Vol. 18, No. 1, pp.1–27, 2001.

[23] S. H. Huang, C. Ou, C. M. Chen and B. Lin, "An empirical study of relationship between IT investment and firm performance: a resource-based perspective," *European Journal of Operational Research*, Vol. 173, No. 3, pp.984-999, 2006.

[24] J. Benitez-Amado and R. M. Walczuch, "Information technology, the organizational capability of proactive corporate environmental strategy and firm performance: A resource-based analysis," *European Journal of Information Systems*, Vol. 21, pp.664–679, 2012.

[25] L. Kang, C. H. Tan and J. L. Zhao, "Organizational quest for competitive advantage through innovation: where should IT capability be focused?," in *Twenty-Second Pacific Asia Conference on Information Systems*, Yokohama, Japan, 2018.

[26] J. G. Kamau, T. A. Senaji and S. C. Nzioki, "Effect of information technology capability on competitive advantage of the Kenyan banking sector," *International Journal of Technology and Systems*, Vol. 4, No. 1, pp.1 – 20, 2019.

[27] D. G. Bhatt and V. Grover, "Types of information technology capabilities and their role in competitive advantage: an empirical study," *Journal of Management Information Systems*, Vol. 22, No. 2, pp.253-277, 2005.

[28] C.Y. Yoon, "Measuring enterprise IT capability: a total IT capability perspective," *Knowledge-Based Systems*, Vol. 29, No. 7, pp.1-6, 2011.

[29] M. Zhang, M. Brodke and J. McCullough, "Cross-cultural reliability and validity of a scale to measure information technology capability," *Journal of Technology Research*, Vol. 2, No. 1, pp.1–20, 2010.

[30] J. S. Chen and H. T. Tsou, "Performance effects of IT capability service process innovation and the mediating role of customer service," *Journal of Engineering and Technology Management*, Vol. 29, No. 1, pp.71-94, 2012.

[31] J. W. Lainhart, "COBIT: a methodology for managing and controlling information technology risks and vulnerabilities. *Journal of Information Systems*, Vol. 1, No. 14, pp. 21–25, 2000.

[32] Y. Chen, Y. Wang, S. Nevo, J. Jin, L. Wang, and W. S. Chow, "IT capability and organizational performance: the roles of business process agility and environmental factors," *European Journal of Information Systems*, Vol. 23, No. 3, pp.326–342, 2014.

[33] J. W. Ross, C. M. Beath, and D. L. Goodhue, "Develop long-term competitiveness through IT assets," *Sloan Management Review*, 38, No. 1, pp.31-45, 1996.

[34] Z. Aiqun, "An IT Capability Approach to Informatization Construction of Higer Education Institutions," *Procedia Computer Science*, Vol.131, pp.683-690, 2018.

[35] A. Q. Bataineh, M. G. Al-Abdallah and A. Y. Alhadid, "The role of information technology capabilities in capitalizing market agility in jordanian telecommunications sector," *International Journal of Academic Research in Business and Social Sciences*, Vol. 5, No. 8, pp.90-101, 2015.

[36] H. Mao, S. Liu and J. Zhang, "How the effects of IT and knowledge capability on organizational agility are contingent on environmental uncertainty and information intensity," *Information Development*, Vol. 31, No. 4, pp.358-382, 2014.

[37] A. S. Bharadwaj, S. G. Bharadwaj and B. R. Konsynski, "Information technology effects on firm performance as measured by Tobin's q," *Management Science*, Vol. 45, No. 7, pp.1008-1024, 1999.

[38] H. S. Han, J. N. Lee and Y. W. Seo, "Analyzing the impact of a firm's capability on outsourcing success: a process perspective," *Information and Management*, Vol. 45, No. 1, pp.31–42, 2008.

[39] F. Lai, D. Li, Q. Wang and X. Zhao, "The information technology capability of third-party logistics providers: a resource-based view and empirical evidence from China," *Journal of Supply Chain Management*, Vol. 44, No. 3, pp.22-38, 2008.

[40] M. Zhang, "Information systems strategic flexibility and firm performance: an empirical investigation," *Journal of*

Engineering and Technology Management, Vol. 22, No. 3, pp.163–184, 2005.

[41] B. Kitchenham and S. Charters, *Guidelines for performing systematic literature reviews in software engineering* (Report No. EBSE-2007-01"School of Computer Science and Mathematics, Keele University, 2007.

[42] I. Bakan and ZH. Sekkeli, "Types of information technology capability and their impacts on competitiveness," *Research Journal of Business and Management*, Vol. 4 No. 2, pp.212-220, 2017.

[43] R. Bi, R. M. Davison, B. Kam and K. X. Smyrnios, "Developing Organizational Agility through IT and Supply Chain Capability," *Journal of Global Information Management*, Vol. 21, No. 4, pp.38-55, 2013.

[44] B. Boar, "*Cost Effective Strategies for Client/ Server Systems*. New York, NY: Wiley and Sons, 1996.

[45] M. Broadbent, P. Weill and D. S. Clair, "The implications of information technology infrastructure for business process redesign," *MIS quarterly*, Vol. 23, No. 2, pp.159–182, 1999.

[46] T. A. Byrd and D. E. Turner, "Measuring the flexibility of information technology infrastructure: exploratory analysis of a construct," *Journal of Management Information Systems*, Vol.1, No.17, pp.167-208, 2000.

[47] Y. Chen, Y. Wang, S. Nevo, J. Benitez-Amado and G. Kou, "IT capabilities and product innovation performance: The roles of corporate entrepreneurship and competitive intensity," *Information & Management,* Vol. 52, No. 6, pp. 643-657, 2015.

[48] N. B. Duncan, "Capturing flexibility of information technology infrastructure: A study of resource characteristics and their measure," *Journal of Management Information Systems*, Vol. 12, No. 2, pp.37–57, 1995.

[49] R. G. Fichman, "Real options and IT platform adoption: Implications for theory and practice," *Information Systems Research*, Vol. 15, No. 2, pp.132–154, 2004.

[50] L. Fink and S Neumann, "Gaining agility through IT personnel capabilities: the mediating role of IT infrastructure capabilities," *Journal of the Association for Information Systems*, Vol. 8, No. 8, pp.440–462, 2007.

[51] N. H. Hassan, N. I. Arshad, E. E. Mustapha and J. Jaafar, "*A literature review: exploring organizational learning orientation as antecedent of information technology (IT) infrastructure capability to achieve organizational agility*. In Third International Conference on Research and Innovation in Information Systems (ICRIIS), Kuala Lumpur, Malaysia, 2013.

[52] M. A. Karimi, A. Amini and M. Latifi, "The impact of information technology capability on firm performance; a focus on employee customer profit chain," *Iranian Journal of Management Studies (IJMS)*, Vol. 7, No. 1, pp.95-120, 2014.

[53] G. Kim, B. Shin., K. K. Kim and H. G. Lee, "IT capabilities, process-oriented dynamic capabilities, and firm financial performance," *Information Systems*, Vol. 12, No. 7, pp.491–492, 2011.

[54] D. M. Lee, E. M. Trauth and D. Farwell, "Critical skills and knowledge requirement of IS professionals: a joint academic and industry investigation," *MIS Quarterly*, Vol. 19, No. 3, pp.313–340, 1995.

[55] P. Tallon, "Competing perspectives on the link between strategic information technology alignment and organizational agility: insights from a mediation model," *MIS Quarterly*, Vol. 35, No. 2, pp.463-486, 2011.

[56] P. Weill, M. Subramani and M. Broadbent, "Building IT infrastructure for strategic agility," *MIT Sloan Management Review*, Vol. 44, No. 1, pp.57–66, 2002.

[57] M. Zhang, "*Information Technology Capability, Organizational Culture, and Export Performance*. Washington State University, Washington, 2005.

[58] J. W. Ross, P. Weill and D. C. Robertson, "*Enterprise architecture as strategy: creating a foundation for business execution*. Boston, MA: Harvard Business School Press, 2006.

[59] B. Thompson, "*Exploratory and confirmatory factor analysis: Concepts and applications*. Washington, DC: American Psychological Association, 2004.

[60] B. Williams, T. Brown and O. Andrys, "Exploratory factor analysis: a five-step guide for novices," *Australasian Journal of Paramedicine*, Vol. 8, No. 3, pp.1-13, 2010.

[61] J. Y. Park, K. S. Im and J. S. Kim, "The role of IT human capability in the knowledge transfer process in IT outsourcing context," *Information and Management*, Vol. 48, No. 1, pp.53–61, 2011.

[62] J. B. Schreiber, A. Nora, F. K. Stage, EA. Barlow and J. King, "Reporting structural equation modeling and confirmatory factor analysis results: a review," *the Journal of Educational Research*, Vol. 99, No. 6, pp.323-337, 2006.

[63] W. W. Chin, B. L. Marcolin and P. R. Newsted, "A partial least squares latent variable modeling approach for measuring interaction effects: Results from a monte carlo simulation study and voice mail emotion/adoption study," in *Proceedings of the Seventeenth International Conference on Information System*, Cleveland, Ohio. 1996, pp.21-41.

[64] J. C. Nunnally, "*Psychometric theory*. 2nd (ed.) New York: McGraw-Hill Book Company, 1978.

[65] R. P. Bagozzi and Y. Yi, "On the evaluation of structural equation models," *Journal of the Academy of Marketing Science*, Vol. 16, No. 1, pp.74–94, 1988.

[66] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement errors," *Journal of Marketing Research*, Vol. 18, No. 1, pp.39–50. 1981,

[67] W. M. A. B. W. Afthanorhan, "A comparison of partial least square structural equation modeling (PLS-SEM) and covariance based structural equation modeling (CB-SEM) for confirmatory factor analysis," *International Journal Engineering and Science Innovative Technologies (IJESIT)*, Vol. 2, No. 5, pp.8, 2013.

[68] M. Tenenhaus, S. Amato and V. Esposito Vinzi, "A global goodness-of-fit index for PLS structural equation modelling," *Proceedings of the XLII SIS Scientific Meeting*, pp. 739-742"Padova: CLEUP, 2004.

[69] M. J. Earl, "*Management Strategies for Information Technology*. Upper Saddle River, NJ: Prentice Hall, 1989.

[70] Q. Xianfeng, L. Boxiong and G. Zhenwei, G. "Conceptual model of IT infrastructure capability and its empirical justification," *TSINGHUA SCIENCE AND TECHNOLOGY*, Vol. 13, No. 3, 2008.

[71] J. Zdravkovic, J. Stirna and J. Grabis, "Capability consideration in business and enterprise architecture frameworks," in *Capability Management in Digital Enterprises*,

K. Sandkuhl and J. Stirna, (Eds.), Springer International Publishing, Cham, 2018, pp.41–56.

[72] M. Carcary, "IT Risk Management: A Capability Maturity Model Perspective," *Electronic journal of information systems evaluation*, Vol. 16, No. 1, 2013.

[73] S. McLaughlin, "Using the IT-CMF as an Enabler for Transformational Change," IVI White Paper Series, 2013.

[74] P. Zhang, K. Zhao and R. L. Kumar, "Impact of IT Governance and IT Capability on Firm Performance," *Infromation Systems Management*, Vol. 33, pp.17, 2016.

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Using Static Information of Programs to Partition the Input Domain in Search-based Test Data Generation

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Abstract
The quality of test data has an important effect on the fault-revealing ability of software testing. Search-based test data generation reformulates testing goals as fitness functions, thus, test data generation can be automated by meta-heuristic algorithms. Meta-heuristic algorithms search the domain of input variables in order to find input data that cover the targets. The domain of input variables is very large, even for simple programs, while this size has a major influence on the efficiency and effectiveness of all search-based methods. Despite the large volume of works on search-based test data generation, the literature contains few approaches that concern the impact of search space reduction. In order to partition the input domain, this study defines a relationship between the structure of the program and the input domain. Based on this relationship, we propose a method for partitioning the input domain. Then, to search in the partitioned search space, we select ant colony optimization as one of the important and prosperous meta-heuristic algorithms. To evaluate the performance of the proposed approach in comparison with the previous work, we selected a number of different benchmark programs. The experimental results show that our approach has 14.40% better average coverage versus the competitive approach.

Keywords: search-based software testing; test data generation; ant colony optimization; input space partitioning.

1- Introduction

Software testing is a vital part of the software development life cycle with the aims of revealing failures in a program under test. Besides improving the quality of the testing activity, automation also reduces cost and time [3][4]. Test data generation as the main part of the software testing process is the activity of finding test data for testing programs, effectively.

Symbolic execution and dynamic methods are known as the two main approaches in automatic test data generation [5]. In symbolic execution [6] symbolic values are assigned to the input variables in order to formulate program paths in terms of logical constraints. These constraints must be solved in order to discover input values that trace specific paths in the program. Dependency on the capability of constraint solvers (that are unable to solve complex constraints) is the main issue of this method; pointer references, loop-dependent or array-dependent variables, and calls to functions whose implementations are unknown and external libraries also are the issues related to this approach. In dynamic methods by instrumenting the program and executing it with some input data, the state of the program is observed. Since functions are executed with real argument, pointer values and array subscripts are known at run-time, thus, many of the problems relevant to the symbolic execution are resolved.

The application of optimization algorithms as dynamic methods in test data generation is called Search-Based Software Testing (SBST). In this approach, the input domain of the program is the search space, and a fitness function is determined to evaluates and scores different inputs of the program (as solutions) with respect to the given test criterion. The fitness function aims to guide the search into promising, unevaluated areas of the search space.

The authors of [1] investigated the relationship between the search space size and search effectiveness and efficiency. They proposed a method to reduce the search space by removing irrelevant variables that are recognized based on the slicing approach. This approach has been applied to three categories of meta-heuristic algorithms, Hill Climbing as a local search, Genetic Algorithm as a global technique, and Memetic Algorithm as a hybrid optimization technique, which is based on the combination of global and local searches. The method has shown a

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positive effect on three meta-heuristic algorithms but has not outperformed random testing.

In order to not being limited to irrelevant variables, we introduce an approach to partition the input domain of relevant variables. Our approach focuses on the analysis of program predicates, i.e., places where logical expressions of variables are evaluated to select the next branch to continue. In fact, we are going to establish a relationship between the structure of the program and the input domain. We obtain some values per each input variable. Then, we partition the search space with respect to these values.

Furthermore, we customize the basic Ant Colony Optimization (ACO) algorithm, as a well-known optimization algorithm, according to the partitioned space. This way, we propose a new test data generation approach which is based on the static analysis of the code.

To evaluate our proposed approach, we consider average coverage as the evaluation metric. According to the results of the experiments, this approach has better results in comparison to the previous work. We will also show that the suggested static input space partitioning approach implicitly contains irrelevant variable removal capability [1], as well.

The rest of the paper is structured as follows. In the next section, a brief overview of related work is given. In Section 3, our approach to partition the search space with the modified ACO algorithm is presented. The experimental results and analysis are presented in Section 4, followed by the conclusion and an outline of future work in Section 5.

2- Related Work

In this section, we first review some of the important works for test data generation based on different optimization algorithms, such as Genetic Algorithm (GA), Simulated Annealing (SA), ACO, and Particle Swarm Optimization (PSO) with more emphasis on ACO because we customize ACO based on our input space partitioning. Then, the approaches related to input domain reduction in the search-based test data generation [1] are presented.

In the 1990s, GA was tuned to generate test data. Jones [7] and [8] examined the usage of GA in order to automate test data generation with respect to branch coverage. Their experiments on some small programs demonstrate that GA notably works better than the random testing method. An empirical study on GA-based test data generation for large-scale programs performed by Harman and McMinn [9][10]. Their experiments showed the superiority of GA over other optimization algorithms such as Hill Climbing. A tool named EvoSuite was implemented by Fraser et al. [11] to generate test suite for satisfying the determined coverage criterion. In EvoSuite, a list of coverage criteria can be set such as branch coverage, data flow, and mutation testing.

Tracey et al. introduced a framework for generating test data by using SA as one of the well-known optimization algorithms which works based on the idea of neighborhood search [12]. Their method applies SA to structural test data generation with the hope of overcoming some of the problems raised with the application of local search. In this work, test data can be generated for coverage criteria such as branch and statements coverage. Moreover, Cohen et al. used SA in order to generate test data in combinatorial testing [13].

Sine ACO has shown notable results in solving optimization problems [14][15][16], some scholars have utilized it to resolve software engineering problems in a wide range of sub-fields such as software project scheduling [17], release planning optimization [18], software quality prediction [19], and software testing [20]. Lam et al. [21] and Srivastava et al. [22] utilized ACO to generate test sequences for state-based software testing. In conformance testing of object-oriented software, the problem of state explosion was solved by Bouchachia et al. [23] via presenting Class Finite State Machines (CFSM).

Li et al. [24] also utilized the ACO algorithm for generating test data in respect of the branch coverage criterion. However, this study lacked detailed experimental and comparative analysis. Mao et al. [2] also applied ACO for generating test data and have compared their approach against GA, PSO, and SA for the same purpose. Their findings exhibited that ACO has better performance than GA and SA and is comparable to PSO.

The approach in [25] outperformed the work of Mao et al. [2] by incorporating (1+1)-evolution strategies to enhance search exploitation through improving the movement of ants in the local search. In [25]**,** pheromone values were defined in each branch, and also, were considered as a part of the fitness function to discourage every ant from traversing branches already covered by other ants. Since this viewpoint is only appropriate for branch coverage, authors in [26][27] introduced a method for using ACO to cover prime paths. They applied the idea of adaptive random testing in local search and used the information of program predicates in partitioning the search space [26]. The experimental results confirm the positive effects of the proposed approach, especially for programs with complex predicates.

Regarding the approaches related to the input domain reduction, the authors of [28] reduced the search space by the interval arithmetic method. Their approach is appropriate only for simple predicates such that each side of the clauses contains a single interval variable. Also, some important issues, such as converting local variables to input variables, have not been addressed in their

approach. Therefore, we do not consider this approach in the evaluation section.

An approach in order to reduce the dimension of the input domain introduced by Harman [1], [29] called "irrelevant input variable removal". Irrelevant input variables are input variables that do not affect executing the target structure. Therefore, they can be removed from the input domain without affecting the feasibility of the target. Their approach was empirically evaluated for search-based structural test data generation. The results showed that irrelevant input variable removal has no impact on the random search, but enhance the performance of optimization techniques. The authors of [1] encouraged concentrating on relevant variables to more reduce the search space via utilizing the static analysis stage; an idea which is followed in this study.

3- Proposed Approach

In this section, after describing the overall process of our approach, we explain our static analysis approach to input space partitioning. Then, we explain the customization of the ACO algorithm based on the partitioned space in section 3.3. The proposed algorithm produces test data to satisfy the desired coverage criterion.

3-1- Overall Process

Fig. 1 shows the overall process of our approach, which consists of two main phases: *Partitioning the input domain* and *Customizing the ACO algorithm*.

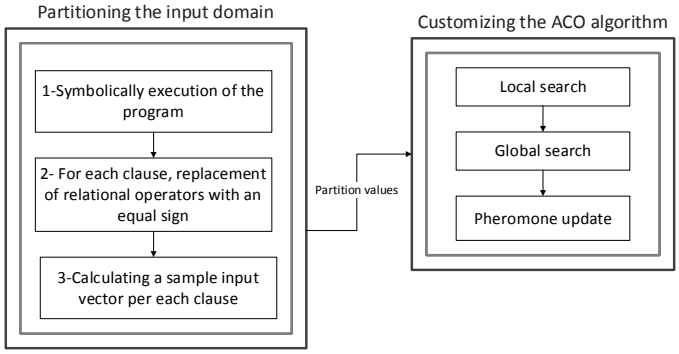

Fig. 1: The overall process of the proposed approach

Partitioning the input domain: Since the search space is constructed by the domain of input variables, we start with symbolic execution [30] to transform each clause of the program to a new clause that only includes input variables. Each resulting clause divides the search space into two partitions; the input vectors in one partition cause the clause to be evaluated to True, while the input vectors in the other partition lead to False value for the clause. Replacing the relational operator (i.e., $<, \leq, >, \geq, \neq$) by the equality operator in clauses, the borders of these partitions are determined. Each input vector on these borders can be considered as partition values.

Customizing the ACO algorithm: In this phase, the ACO algorithm is customized based on the partitioned search space obtained in the previous phase.

3-2- Partitioning the Input Domain

To perform static partitioning, the program clauses should be initially analyzed. A clause is a predicate that does not have any logical operator. For example, the predicate $((a + b > c)\,\&\&\,(b + c > a)\,\&\&\,(c + a > b))$ contains three clauses. The output of analysis is a set of values per each input variable. The partitioning of the input space is done based on these values. In the rest of the paper, these values are called partition values. For obtaining partition values, the following three steps must be done. Step 1 is done for predetermined test paths of the program (We assume that these test paths cover all the branches of the program); step 2 and step 3 are done for each clause.

1. By performing symbolic execution for predestinate test paths of the program, the clauses of the program are converted such that they only involve input variables. This is carried out because the space we are searching through is constructed by input variables.
2. Modifying each clause *C* by using the (=) operator instead of the $(\leq, \geq, \neq, <, >)$ operators. The resulting clause is called C'.
3. Finding a combination of input values that satisfy C'. For example, values that satisfy $a + b = c$ (e.g., a = 100; b = 100; c = 200) can be considered as partition values for clause a + b > c.

For clarifying the elimination of non-input variables in step 1, static partitioning is done on a sample program shown in *Fig. 2*.

```
Sample Function (a, b, d) {
1    int c, n;
2    int i = 0;
3    if (a < d){
4        c = a;
         }
5    else{
6        c = d;
         }
7    n = c;
8    while (n < 8){
9    if (b > c) {
10           c = 2;
         }
11   else {
12   n = n + c + 7;
     }
13   n = n + 1;
}
```

(a)

```
Sample Function (a, b, d) {
1    int c, n;
2    int i = 0;
3    if (a < d){
4        c = a;
         }
5    else{
6        c = d;
         }
7    n = c;
8    while (n < 8){
9    if (b > c) {
10           c = 2;
         }
11   else {
12   n = n + c + 7;
     }
13   n = n + 1;
}
```

(b)

```
Sample Function (a, b, d) {
1    int c, n;
2    int i = 0;
3    if (a < d){
4        c = a;
         }
5    else{
6        c = d;
         }
7    n = c;
8    while (n < 8){
9    if (b > c) {
10           c = 2;
         }
11   else {
12   n = n + c + 7;
     }
13   n = n + 1;
}
```

(c)

Fig. 2: Sample program (a) The first predicate (b) The second predicate with the related assignments (c) The third predicate with the related assignments

As it can be seen in Fig. 2, three conditions exist in the program, in lines 3, 8, 9; the first predicate does not have non-input variables (Fig. 2. (a)), while the second predicate in line 8 has variable n that is a non-input variable; assignments which could be used to calculate the relationship between n and input variables are distinguished by red in Fig. 2. (b) . At last, two functions $"n = a"$ and $"n = d"$ are achieved to show the relationship between n and input variables. The same thing is done for the predicate in line 9 (Fig. 2. (c)).

The predicates that are obtained by eliminating the non-input variables along with the obtained partition values are shown in Table 1.

Table 1: Partition values for each predicate of the sample program

Line number	predicate	Partition values		
		a	b	d
3	$a < d$	100		**100**
8	$a < 8$	8		
8	$d < 8$			**8**
9	$b > a$	100	100	
9	$b > d$		100	**100**

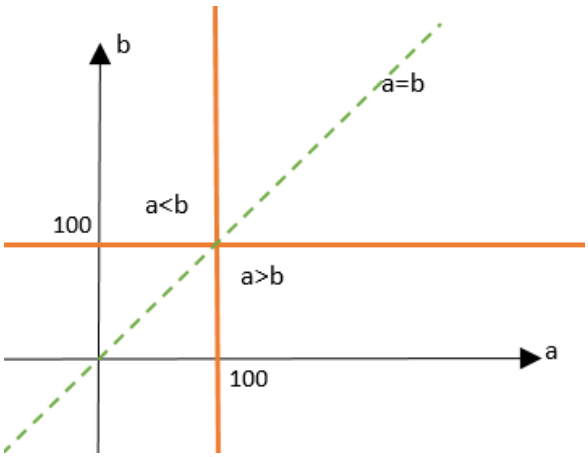

Fig. 3: Partition values for the predicate a<b in the two-dimensional search space

To illustrate why we use these partition values in partitioning the search space, we review some examples. The only input vector for partitioning the clause *a<8* is *a=8*, which causes the input domain of *a* to be divided into two parts; input vectors in one of these parts lead the True value for *a<8* while input vectors in the other part make *a<8* False. Regarding clause *a<b*, with *a=100* and *b=100* as selected partition values, there are (2*2=4) partitions in the whole input domain. As shown in *Fig. 3*, all input

vectors in the top left part force the program execution to traverse the True case, while all input vectors in the bottom right part cause it to traverse the False case of clause $a<b$. As additional example, input vectors that satisfy $a+b=c$ (e.g., $a= 100$, $b=100$ and $c=200$) are suitable to be selected as partition values for clause $a+b>c$. Due to partitioning the input domain of a, b and d into two parts, there are (2*2*2=8) partitions in the whole input domain. Values in at least one of these parts make $a+b>c$ True, and values in at least one of these parts cause $a+b>c$ to be False.

Although we illustrated the partitioned area in the search space only for one clause in the above example, in the next section, we use the partitioned space produced by all the clauses of the program.

3-3- Customizing the ACO Algorithm

ACO as an optimization algorithm is inspired from ants that release pheromone in the environment. ACO algorithms were originally utilized to solve the shortest route in traveling salesman problem [31]. To generate test data, we change the basic ACO with respect to the partitioned search space.

We first formally describe the test data generation for the program under test P. Suppose P has d input variables represented by vector $X = (x_1, x_2, \dots, x_d)$. Vector X is the position vector of an ant in ACO. If each input variable x_i $(1 \le i \le d)$ takes its values from the domain D_i, the corresponding input domain of the program is $D = D_1 \times D_2 \times \dots \times D_d$.

In the problem of generating test data, each ant's position actually is a test data which is shown by a vector in the input domain D. For any ant k $(1 \le k \le n)$, its position is marked as $X_k = (x_1, x_2, \dots, x_d)$.

For generating test data with the ACO algorithm, an important consideration is the form of pheromone. In this paper, pheromones are defined on the partitions established by static partitioning, explained in the previous section. This way, in each partition, there is a pheromone value that is initialized to one.

The pseudo-code of the customized ACO algorithm is presented in Algorithm 1[1]. Table 2 contains the notations and parameters used in this algorithm. The output of Algorithm 1 is a set of test data (or a test suite) that cover the given test targets. The test data generation process in Algorithm 1 is repeated until all the test targets are traversed by the test suite, or the predefined number of iterations is exceeded. The data generation process consists of two stages. In the first stage, all pheromone values are initialized by one (Lines 4-9) and an input vector in the input domain is randomly assigned to each ant as the position vector (Lines 10-12).

In the second stage (Lines 13-34), the local search and global search are performed for each ant. Then, the pheromone values are updated with respect to Eq. 1 (Section 3.2.3). The fitness values of the ants are calculated at the end of each iteration. The position of any ant k that covers an uncovered test target is added to the test suite, i.e., TS. The methods local search, global search, and pheromone update are explained in the following sub-sections.

Algorithm 1 The proposed ACO algorithm

```
1: Input:
       1. SUT and ACO input parameters.
2: Output: Test suite TS.
3: Flag = false;
4: Stage1: Initialization
5: for i = 1 : n do
6:   for j = 1 : b[i] do
7:     τ[i][j] = 1;
8:   end for
9: end for
10: for k = 1 : m do
11:   randomly initialize ant[k];
12: end for
13: Stage2: Optimum Solution Searching
14: while iteration ≤ maxIteration and Flag == false do
15:   for k = 1 : m do
16:     LocalSearch(k);
17:   end for
18:   calculate the average fitness f_avg of the ant colony;
19:   for k = 1 : m do
20:     if ant[k].fitness > f_avg then
21:       GlobalSearch(k);
22:     end if
23:   end for
24:   UpdatePheromone();
25:   for k = 1 : m do
26:     if ant[k] covers an uncovered path then
27:       Add ant[k].position to TS;
28:     end if
29:   end for
30:   if all path are covered then
31:     Add ant[k].position to TS;
32:     Flag = true;
33:   end if
34: end while
35: Return TS;
```

[1] This algorithm along with Table 2 is similar to Algorithm 1 and Table 3 in [26], respectively. This is because both are based on ACO. However, the way of development was different in both papers.

Table 2: The parameters and notations used in the proposed ACO algorithm

Parameter/Notation	Description
maxIteration	Maximum iteration
n	The number of input variables
m	The number of ants
ant[k]	The ant *k*
ant[k].position	The position of ant *k* that is a vector in the input domain (i.e., a test data)
ant[k].fitness	The fitness of ant *k*
b[i]	The number of parts for the ith input variable
TS	The output test suite

3-3-1- Local Search

In the local transfer of ants, for an ant k $(1 \leq k \leq n)$ in partition b, the aim is to investigate whether there is a partition in the neighborhood of b that has a better fitness function. If there is such a partition, the ant k will transfer to the partition with the best fitness function value. This transfer increases the value of pheromone in the destination partition.

The neighboring partitions of an ant k $(1 \leq k \leq n)$ in partition *b* are the partitions that have at least one common partition value. In our implementation, a random location per neighboring partition is selected, and these locations are the representatives of their partitions.

In the local search ant k transfer from Xk to Xk if the fitness of Xk is better than that of Xk and Xk is in the neighborhood's partition of Xk which has the best fitness value amongst neighborhoods of Xk; otherwise, the ant's location does not change in the local search and remains in the previous location. It must be noted that less fitness is considered better fitness, and the best fitness value is 0. This process is done for all ants in the partitioned space.

3-3-2- Global Search

The global search is used to solve two problems related to local search. First, there may be some partitions with acceptable fitness that are not visited by any ant in a reasonable time (or iteration limit) and second, there may be ants with the local optima trap [32][32] (that could not find a neighboring place with superior fitness value). To resolve these issues, when each ant's fitness value is worse than the average fitness value of all ants, a random value q is generated. If q is less than a predefined probability $q0$, the ant will randomly be moved to a new partition; otherwise, the partition with the highest pheromone value will be the destination of the ant.

3-3-3- Pheromone Update

Eq.1 is used to update the pheromone value in each partition of the input domain.

$$\tau(j) \leftarrow \alpha \times number\ of\ ants\ in\ partition\ j + (1-\alpha) \times \tau(j) \quad (1)$$

Where $\alpha \in (0, 1)$ represent pheromone evaporation rate, $\tau(j)$ is the amount of pheromone in the *jth* partition, and *j* stands for partition index.

4- Experiment

In this section, we compare our approach with the approach presented in [1]. Although the competitive approach has been applied to the genetic algorithm, hill climbing, and memetic algorithm, we select its implementation with the genetic algorithm because the experimental results in [1] showed that removing irrelevant input variables has the greatest effect on the genetic algorithm.

Evaluation Metrics

Average Coverage (AC), Average Time (AT), and Mutation Score (MS) are used as the evaluation metrics. Average coverage is the average percentage of the covered branches and is calculated while the two competitive approaches run with the same iterations.

Average time is the average of elapsed time that has been taken to run the algorithms and is calculated to compare the efficiency of the two competitive approaches.

Mutation score is a testing metric provided by the mutation analysis as a fault-based testing technique. To perform mutation analysis, PIT [33] is used as a state-of-the-art tool for this purpose.

Benchmark Programs

To conduct experiments, several benchmark programs have been selected (see Table 3): the first eleven programs from the Numerical Case Study (NCS) of EvoSuite[1]. Tcas and Totinfo from the Software-artifact Infrastructure Repository (SIR)[2], and the others from various related work. Table 3 displays the number of lines of code (LoC), and the description of each benchmark program.

[1] https://github.com/EvoSuite/evosuite/tree/master/removed/examples/ncs/src/ncs

[2] http://sir.unl.edu/php/showfiles.php

The Parameters of the Algorithms

The parameters of algorithms have been set to the values presented in Table 4 before performing the experiments. Parameter selection for our algorithm was done based on the sensitivity analysis which had been done in [2]. Although we can use any coverage criteria, in this paper, we consider branch coverage with the fitness function proposed in [1].

Table 3. Programs selected for the empirical studies

#p	Program name	LoC	Description
1	Bessj	245	Bessel *J*n function
2	BubbleSort	38	Bubble sort algorithm
3	Encoder	86	Encode the input
4	Expint	109	Exponential integral function
5	Fisher	157	Fisher statistical function
6	Gammq	112	Gamma function
7	Median	40	Calculate the median value of the input array
8	Remainder	30	Calculate the remainder of the first argument divided by the second argument
9	TT1	43	Find the type of triangle
10	TT2	50	Find the type of triangle
11	Variance	43	Calculate the variance of the input array
12	GCD	24	Find the greatest common divisor
13	MinMax	41	Find the minimum and maximum values in an array
14	BinarySearch	55	Binary search algorithm
15	ComputeTax	164	Compute tax amount
16	PrimeBetween	42	Calculate the prime number between two numbers
17	Synthesis-1	48	Synthesis of while, for and if
18	Synthesis-2	101	Synthesis of while, for and if
19	PrintCalender	187	Print calendar according to two inputs "year" and "month"
20	Number	265	Calculate the number of days between two dates
21	Tcas	173	Avoid air craft collision
22	Totinfo	416	Calculate some statistical information
23	Mcknap	1301	Solve the knapsack problem

Table 4. Parameter setup

	Parameter	Value
Genetic Algorithm	Selection method	Roulette wheel
	Crossover method	Single point
	Crossover probability	80%
	Mutation probability	0.05%
	Chromosome-type	Binary string
ACO	α	0.3
	q_0	0.5
Both Algorithms	Population size	30
	No of iteration	50

4-1- Experiment Results

Experiments were repeated 50 times with various initial population to consider the accidental nature of optimization algorithms. The average coverage resulted per each algorithm for all benchmarks are displayed in Fig. 4. The results demonstrate that the proposed approach has better average coverage for most benchmarks, except three, i.e., BubbleSort, Median, and Variance. The two approaches reached 100% average coverage for these three benchmark programs because satisfying the conditions of these programs is very easy.

The Wilcoxon test in R [34] are conducted to statistically evaluate our experimental results. Table 5 presents the average coverage and average time along with resulted P-values and effect size. The effect sizes of the comparisons are quantified with the Vargha-Delaney $\hat{A}$ statistics. In case of average coverage, $\hat{A}_{xy}$ is an estimation of the probability that, if we run the approach *x*, we will obtain better coverage than running it with the approach *y*. When two approaches are equivalent, then $\hat{A}_{xy} = 0.5$. A high-value $\hat{A}_{xy} = 1$ means that, in all of the runs of *x*, we obtained higher coverage than the coverage obtained in all of the runs with *y*.

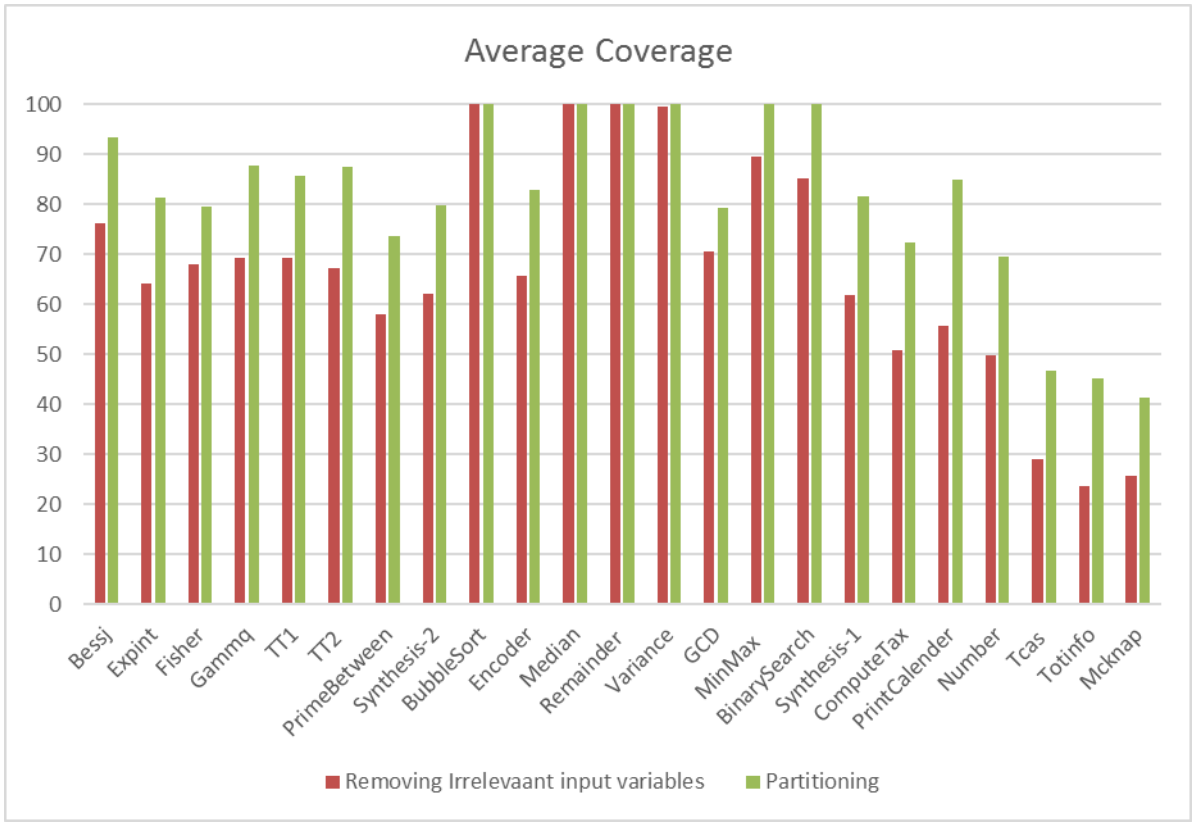

Fig. 4: The resulted average coverage by the proposed approach and the approach presented in [1]

Table 5. Statistical analysis of the results of experiments

Program name	The approach in [1]		Our approach		AC		AT	
	AC	AT	AC	AT	Effect size	P-value	Effect size	P-value
Bessj	76.11	135.34	93.44	138.98	0.73	**0.01**	0.43	0.05
BubbleSort	64.20	35.23	81.22	39.78	0.53	1.00	0.41	1.00
Encoder	67.89	65.39	79.44	57.67	0.59	1.00	0.58	1.00
Expint	69.22	76.23	87.66	70.36	0.71	**<0.001**	0.60	0.06
Fisher	69.20	110.67	85.83	67.89	0.64	**0.03**	0.61	0.09
Gammq	67.23	104.78	87.39	99.67	0.69	**<0.001**	0.53	**<0.001**
Median	57.89	3.65	73.55	6.30	0.52	1.00	0.42	1.00
Remainder	62.22	4.6	79.78	4.99	0.58	0.76	0.49	0.76
TT1	79.67	43.2	100	41.49	0.50	**<0.001**	0.5	**0.01**
TT2	65.74	36.2	82.79	30.5	0.71	**<0.001**	0.58	**<0.001**
Variance	100	23.7	100	31.89	0.5	0.15	0.34	0.95
GCD	100	25.4	100	20.5	0.5	0.94	0.59	0.74
MinMax	99.5	3.6	100	4.50	0.56	0.28	0.42	0.98
BinarySearch	70.6	6.5	79.33	7.78	0.58	0.90	0.49	0.40
ComputeTax	89.6	48.9	100	40.5	0.69	**<0.001**	0.52	**<0.001**
PrimeBetween	85.2	250.7	100	200.31	0.59	**0.01**	0.69	**0.03**
Synthesis-1	61.78	154.7	81.56	143.64	0.67	**0.02**	0.77	**0.04**
Synthesis-2	50.76	120.7	72.44	119.43	1	**<0.001**	0.51	**0.03**
PrintCalender	55.78	67.98	85	50.32	1	**<0.001**	0.69	**<0.001**
Number	49.67	301.67	69.55	278.43	0.98	**<0.001**	0.76	**<0.001**
Tcas	28.9	404.7	46.8	306.43	0.87	**<0.001**	0.80	**<0.001**
Totinfo	23.67	505.6	45.17	398.54	0.82	**<0.001**	0.76	**<0.001**
Mcknap	25.78	408.5	41.33	375.89	0.78	**<0.001**	0.61	**<0.001**

The results reveal significant improvements in the average coverage for 15 out of 23 benchmarks and significant improvement in the average time for 7 out of 23 benchmarks in comparison to the approach presented in [1]. The main cause for this outperformance is partitioning the input domain based on the information that exists in the conditional statement. In other words, we created a relationship between the input domain and the structure of the program. This causes performing searches more intelligently. Therefore, individuals converge to the test goal with higher speed. Utilizing the logic of the program to trace pheromone values results in having better exploitation. Furthermore, this causes having better exploration in the partition which has the highest pheromone value.

To explain more precisely, consider the following clauses and calculated partition values that are selected from program Synthesis-1[1]:

- $x > 200 : \{x = 200\}$,
- $x < y : \{x = 20; y = 20\}$,
- $x + y > z : \{x = 50; y = 50; z = 100\}$,
- $y \times y - 4 \times x \times z > 0 : \{x = 4; y = 4; z = 1\}$
- $y \neq x : \{y = 150; x = 150\}$.

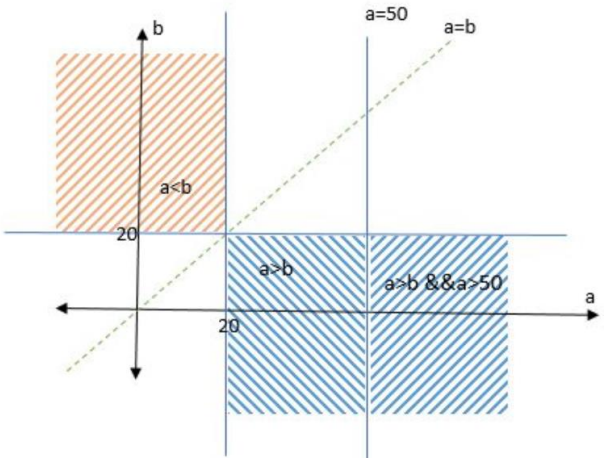

Fig. 5: The partitioned input domain based on the clauses a > 50 and a > b [26]

The obtained partition values for each input variable are: x={4, 20, 50, 150, 200}, y={4, 20, 50, 150}, and z={1, 100}. As the result, the input domain of x, y, and z respectively divided into 6, 5, and 3 parts. The composition of them creates $3 \times 5 \times 6 = 90$ partitions in the whole input domain. If we assume each predicate involves only one clause, choosing one input vector from each of these partitions will lead to one of the branches being traversed. Partitioning based on the program structure causes individuals to converge to the targets sooner than when we just consider irrelevant input variables.

Even though the search space is partitioned by considering only one clause (i.e., we do not consider a predicate), occasionally, the partitions that lead to True or False for a predicate are created spontaneously. This leads to more improvements in the efficiency of the proposed approach. To more explain, consider predicate (a > b && a > 50). As shown in Fig. 5, the partition that leads True for this predicate is made spontaneously just via dividing the input domain by "a > 50" and "a > b", separately.

Most importantly, our approach implicitly benefits from the strength point of the previous work [1]. In the case of having an irrelevant input variable, by definition, this variable is not used in any predicate of the target test paths. Since only the involved input variables are used for obtaining partition points in our approach, no partition value is found for irrelevant input variables. Consequently, only one part exists with respect to the domain of an irrelevant input variable; hence, it does not matter which value is selected for irrelevant input variables.

Table 6: Statistical analysis of the resulting mutation scores.

Program	The approach in [1]	Our approach	Effect size	P-value
Bessj	21.34	29.43	0.98	0.67
BubbleSort	71.4	80.98	0.97	0.06
Encoder	67.56	76.54	0.89	**< 0.001**
Expint	59.43	73.76	0.99	**< 0.001**
Fisher	45.43	56.33	0.86	**< 0.001**
Gammq	68.87	81.96	0.9	0.56
Median	87.22	91.89	0.84	0.34
Remainder	95.7	98.12	0.82	0.08
TT1	92.8	95.1	0.5	0.05
TT2	78.33	79.32	0.87	0.10
Variance	100	100	0.5	1
GCD	77.1	84.13	0.5	0.09
MinMax	75	75	0.51	1
BinarySearch	93.93	100	0.68	0.78
ComputeTax	80.8	83	0.69	**< 0.001**
PrimeBetween	64	81.9	0.1	**< 0.001**
Synthesis-1	78	80.67	0.95	**< 0.001**
Synthesis-2	100	96.17	0.99	0.25
Tcas	47.03	93	0.89	**< 0.001**

We performed mutation analysis to experimentally investigate the failure detection capability of test suites generated by the proposed approach against test suites produced by the previous approach [1]. In order to conduct this analysis, we used 19 of 23 benchmarks presented in Table 4. Four benchmarks PrintCalender, Number, Totinfo, and Mcknap, had been implemented in C, and therefore, could not be used in PIT, which is a java-based tool. The statistical analysis of the results is shown in Table 6. In this table, the significant level for the p-value is considered as p-value ≤ 0.05. The results show that, with

[1] This example is the same as the one presented in [26].

high statistical confidence, in 7 out of 19 programs, the generated test suites by our approach have a more mutation score, and thus, have a better ability to detect failures.

In some benchmarks, such as Remainder, there is no significant difference between mutation score achieved by the two approaches, while the improvement of mutation score on a program like Tcas is noticeable. Test data generation for more complicated programs such as Tcas with 12 input variables is likely more time-consuming. In these programs, fewer data from the input domain are desired, and therefore, using static information to generate test data enhance the mutation score of the generated test suites.

5- Threats to Validity

Threats to internal validity might come from the way the empirical study was carried out. To reduce the probability of having faults in our implementation, it has been carefully tested. But it is well known that testing alone cannot prove the absence of defects. Furthermore, optimization algorithms have random behavior, and thus, are affected by chance. To cope with this problem, we repeated experiments 50 times. Then, we followed statistical procedures to analyze the results. As a threat to the external validity of our results, it should be noted that a different selection of the benchmark programs might result in different conclusions.

6- Conclusions and Future Work

In this paper, we have presented an approach to input space partitioning based on the program's conditional statements. We also customized the ACO algorithm with respect to the partitioned space. In the evaluation section, we have compared our approach with the irrelevant input variable removal method. The results revealed that our approach leads to better results in respect of average coverage. The following research areas will be considered as future work:

- Customizing other meta-heuristic algorithms based on predicate's information
- Considering the combination of clauses to select better partition values
- Presenting a more comprehensive way to reduce the input domain so that it can be applied to all optimization algorithms
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References

[1] P. McMinn, M. Harman, K. Lakhotia, Y. Hassoun, and J. Wegener, "Input domain reduction through irrelevant variable removal and its effect on local, global, and hybrid search-based structural test data generation," IEEE Trans. Softw. Eng., vol. 38, no. 2, pp. 453–477, 2012, doi: 10.1109/TSE.2011.18.

[2] C. Mao, L. Xiao, X. Yu, and J. Chen, "Adapting ant colony optimization to generate test data for software structural testing $," Swarm Evol. Comput., vol. 20, pp. 23–36, 2014, doi: 10.1016/j.swevo.2014.10.003.

[3] S. Anand et al., "An Orchestrated Survey on Automated Software Test Case Generation," J. Syst. Softw., vol. 86, no. 8, pp. 1978–2001, 2013, doi: 10.1016/j.jss.2013.02.061.

[4] S. Ali, L. C. Briand, H. Hemmati, and R. K. Panesar-Walawege, "A Systematic Review of the Application and Empirical Investigation of Evolutionary Testing," IEEE Trans. Softw. Eng., vol. 36, no. 6, pp. 742–762, 2010, doi: http://doi.ieeecomputersociety.org/10.1109/TSE.2009.52.

[5] P. Ammann and J. Offutt, Introduction to software testing. Cambridge University Press, 2016.

[6] M. Weiser, "Program Slicing," IEEE Trans. Softw. Eng., vol. SE-10, no. 4, pp. 352–357, 1984, doi: 10.1109/TSE.1984.5010248.

[7] B. F. Jones, H. H. Sthamer, and D. E. Eyres, "Automatic structural testing using genetic algorithms," Softw. Eng. J., vol. 11, pp. 299–306, 1996.

[8] R. Pargas, M. J. Harrold, and R. Peck, "Test-Data Generation Using Genetic Algorithms," J. Softw. Testing, Verif. Reliab., vol. 9, pp. 263–282, 1999.

[9] P. Mcminn, "Search-Based Software Testing : Past , Present and Future," pp. 153–163, 2011, doi: 10.1109/ICSTW.2011.100.

[10] M. Harman and P. McMinn, "A theoretical and empirical study of search-based testing: Local, global, and hybrid search," IEEE Trans. Softw. Eng., vol. 36, no. 2, pp. 226–247, 2010, doi: 10.1109/TSE.2009.71.

[11] G. Fraser and A. Arcuri, "Whole test suite generation," IEEE Trans. Softw. Eng., vol. 39, no. 2, pp. 276–291, 2013, doi: 10.1109/TSE.2012.14.

[12] N. Tracey, "An Automated Framework for Structural Test-Data Generation 2 Optimisation-Based Struc- tural Test-Data Generation 1 Introduction," 1904.

[13] M. B. Cohen, C. J. Colbourn, and A. C. H. Ling, "Augmenting simulated annealing to build interaction test suites," Proc. - Int. Symp. Softw. Reliab. Eng. ISSRE, vol. 2003-Janua, pp. 394–405, 2003, doi: 10.1109/ISSRE.2003.1251061.

[14] E. Elbeltagi, T. Hegazy, and D. Grierson, "Comparison among five evolutionary-based optimization algorithms," Adv. Eng. Informatics, vol. 19, no. 1, pp. 43–53, 2005, doi: 10.1016/j.aei.2005.01.004.

[15] K. Socha and M. Dorigo, "Ant colony optimization for continuous domains," Eur. J. Oper. Res., vol. 185, no. 3, pp. 1155–1173, 2008, doi: 10.1016/j.ejor.2006.06.046.

[16] C. Simons and J. Smith, "A comparison of evolutionary algorithms and ant colony optimization for interactive software design," 2012.

[17] B. Suri and P. Jajoria, "Using ant colony optimization in software development project scheduling," in 2013 International Conference on Advances in Computing,

Communications and Informatics (ICACCI), 2013, pp. 2101–2106.
[18] J. T. de Souza, C. L. B. Maia, T. do Nascimento Ferreira, R. A. F. Do Carmo, and M. M. A. Brasil, "An ant colony optimization approach to the software release planning with dependent requirements," in International symposium on search based software engineering, 2011, pp. 142–157.
[19] D. Azar and J. Vybihal, "An ant colony optimization algorithm to improve software quality prediction models: Case of class stability," Inf. Softw. Technol., vol. 53, no. 4, pp. 388–393, 2011.
[20] B. Suri, "Literature Survey of Ant Colony Optimization in Software Testing," 2010.
[21] H. Li, "An Ant Colony Optimization Approach to Test Sequence Generation for State-Based Software Testing," no. 1, pp. 255–262, 2005.
[22] P. R. Srivastava and K. Baby, "Automated Software Testing Using Metahurestic Technique Based on an Ant Colony Optimization," Electron. Syst. Des. (ISED), 2010 Int. Symp., 2010, doi: 10.1109/ISED.2010.52.
[23] A. Bouchachia, R. Mittermeir, P. Sielecky, S. Stafiej, and M. Zieminski, "Nature-inspired techniques for conformance testing of object-oriented software," Appl. Soft Comput. J., vol. 10, no. 3, pp. 730–745, 2010, doi: 10.1016/j.asoc.2009.09.003.
[24] K. Li, Z. Zhang, and W. Liu, "Automatic Test Data Generation Based on Ant Colony Optimization," 2009 Fifth Int. Conf. Nat. Comput., vol. 6, pp. 216–220, 2009, doi: 10.1109/ICNC.2009.239.
[25] H. Sharifipour, M. Shakeri, and H. Haghighi, "Structural test data generation using a memetic ant colony optimization based on evolution strategies," Swarm Evol. Comput., vol. 40, pp. 76–91, 2018, doi: 10.1016/j.swevo.2017.12.009.
[26] A. M. Bidgoli and H. Haghighi, "Augmenting ant colony optimization with adaptive random testing to cover prime paths," J. Syst. Softw., vol. 161, p. 110495, 2020.
[27] A. Monemi Bidgoli, H. Haghighi, T. Zohdi Nasab, and H. Sabouri, Using Swarm Intelligence to Generate Test Data for Covering Prime Paths, vol. 10522 LNCS. 2017.
[28] X. Lv, S. Huang, and H. Ji, "Input Domain Reduction of Search-based Structural Test Data Generation using Interval Arithmetic.," Int. J. Performability Eng., vol. 14, no. 6, 2018.
[29] M. Harman, Y. Hassoun, K. Lakhotia, P. McMinn, and J. Wegener, "The impact of input domain reduction on search-based test data generation," Proc. 6th Jt. Meet. Eur. Softw. Eng. Conf. ACM SIGSOFT Symp. Found. Softw. Eng., pp. 155–164, 2007, doi: 10.1145/1287624.1287647.
[30] C. Cadar and M. Nowack, "KLEE symbolic execution engine in 2019."
[31] M. Dorigo and L. M. Gambardella, "Ant colonies for the travelling salesman problem," BioSystems, vol. 43, no. 2, pp. 73–81, 1997, doi: 10.1016/S0303-2647(97)01708-5.
[32] V. Maniezzo, "Ant System: Optimization by a Colony of Cooperating Agents," vol. 26, no. 1, pp. 1–13, 1996.
[33] H. Coles, T. Laurent, C. Henard, M. Papadakis, and A. Ventresque, "PIT: A practical mutation testing tool for Java (Demo)," ISSTA 2016 - Proc. 25th Int. Symp. Softw. Test. Anal., pp. 449–452, 2016, doi: 10.1145/2931037.2948707.
[34] R Developement Core Team, "R: A Language and Environment for Statistical Computing," R Found. Stat. Comput., vol. 1, p. 409, 2015, doi: 10.1007/978-3-540-74686-7.

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An Effective Method of Feature Selection in Persian Text for Improving the Accuracy of Detecting Request in Persian Messages on Telegram

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Abstract

In recent years, data received from social media has increased exponentially. They have become valuable sources of information for many analysts and businesses to expand their business. Automatic document classification is an essential step in extracting knowledge from these sources of information. In automatic text classification, words are assessed as a set of features. Selecting useful features from each text reduces the size of the feature vector and improves classification performance. Many algorithms have been applied for the automatic classification of text. Although all the methods proposed for other languages are applicable and comparable, studies on classification and feature selection in the Persian text have not been sufficiently carried out. The present research is conducted in Persian, and the introduction of a Persian dataset is a part of its innovation. In the present article, an innovative approach is presented to improve the performance of Persian text classification. The authors extracted 85,000 Persian messages from the Idekav-system, which is a Telegram search engine. The new idea presented in this paper to process and classify this textual data is on the basis of the feature vector expansion by adding some selective features using the most extensively used feature selection methods based on Local and Global filters. The new feature vector is then filtered by applying the secondary feature selection. The secondary feature selection phase selects more appropriate features among those added from the first step to enhance the effect of applying wrapper methods on classification performance. In the third step, the combined filter-based methods and the combination of the results of different learning algorithms have been used to achieve higher accuracy. At the end of the three selection stages, a method was proposed that increased accuracy up to 0.945 and reduced training time and calculations in the Persian dataset.

Keywords: Feature Selection*;* Text Mining*;* Classification Accuracy*;* Machine Learning*;* Ensemble Classifier*.*

1- Introduction

Nowadays, the rapid progress and easy access to Internet technologies, multimedia, and social networks have drastically changed and affected human life. In addition to facilitating individual communication, social networks also serve as channels of communication between companies and customers [1], [2]. Social networks have a considerable impact on the potential value of businesses [3]. They are widespread and highly regarded among users. Thus, virtual societies have become valuable sources of political, social, and commercial information. Social networks are utilized in many businesses to provide services and interact effectively with customers. Therefore, the knowledge extracted from social networks such as Facebook, Twitter, Telegram, and other social networks is valuable for marketing and data mining companies [4]-[6].

Telegram is a messaging service with many users from different countries [7]. The number of monthly active users of Telegram in October 2019 is 300 million worldwide [8]. Moreover, 60% of Iranians use Telegram [9], and it has become a popular and extensively used social network in various fields such as the development of certain Internet businesses and contains valuable information. Telegram data possesses hidden knowledge, the extraction of which is extremely useful. The request-type messages that are exchanged among Telegram users are among these data with hidden knowledge. In Telegram, a message can be sent containing a request for help to buy a house or a product, etc. If this request is identified and sent to the owners of related jobs, it will promote business development.

In this research, the authors are dealing with Telegram text data, and it is necessary to process and classify the text to

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identify the hidden requests in these text documents. The task of classifying text is to classify a document into a predefined category [2]. In the present study, each Telegram message is considered as a document. Each category or class is a Boolean value that indicates whether the message is a request or not. A major problem with text classification is the increase in the size of the data being processed or the feature space's high dimensions [10], [11]. One solution is to reduce features using feature selection methods [10]-[15].

Feature selection involves selecting a set of relevant and informative features to build a predictive model with maximum efficiency [2]. Future selection (FS) has played an important role in machine learning and data science [16]-[19]. Although there are many and comprehensive methods for FS, it is an open and NP-Complete problem due to its complexity. There is no definitive and single solution. Nowadays, there are many articles on new FS methods, each with its advantages and disadvantages. Some of them combined three main categories of FS methods, filter, wrapper, and embedded [10], [12], [16], [20], to increase performance and accuracy. Some FS methods are designed to be applied in various fields, and some are designed for a specific issue [18].

However, the feature selection for the Persian text has not been sufficiently investigated. In addition to traditional methods, addressing this type of data requires more advanced techniques. Because this data has certain words and features, previous methods did not consider which. Due to this dataset's nature, a feature selection method is required to select the appropriate features for the Persian dataset of Telegram. Due to the use of learning algorithms, the wrapper and embedded selection methods show better performance than filters. However, filters are faster because they are independent of learning algorithms [12], [18], [20], [21]. In this study, the most extensively used methods were applied based on local and global filters, and wrapper methods described in Section 2 were used to take advantage of filter speed and wrapper accuracy at the same time. Local and global filtering methods are applied as pre-processing in the wrapper method and reduce the feature. The combination of these methods with the proposed approach in the present study led to high accuracy. No such combination has been developed in Telegram's Persian data so far. When the number of main features is very significant, filter and wrapper methods are a powerful combination for selecting the optimal subsets of features. The combination of the two methods can overcome the disadvantages caused by each. Combining these methods reduces the calculation time and calculates the relationships between the features [22].

The authors have proposed a combination method for selecting the most relevant features and optimizing the classifier parameters to achieve higher classification accuracy in the Persian text on Telegram with high dimensions. Although the accuracy obtained by applying the most used employed filter and wrapper methods was acceptable, these proposed combination approaches were used with ensemble methods to increase the accuracy, and another method was suggested to provide higher accuracy. Ensemble data mining methods are frequently used to improve classification performance and are also known as classifier combination. This method is not suitable for high-dimensional datasets [23]. In the present investigation, an ensemble method was proposed for classifying high-dimensional data. In the proposed method, the authors use the combined output of the most broadly used methods based on local and global filters as input and pre-processing features and reduce the main features' space. Each generated feature subset is then trained by a learning algorithm, and the results of each classifier are combined with a majority vote.

The performance of our proposed approaches has been evaluated with a Persian dataset. This dataset has been extracted from the Idekav-system 1of Yazd University, which is a Telegram search engine. Millions of messages are monitored daily on Idekav-system. Many of these messages exchanged among Telegram users are request-type messages. Request-type messages create many opportunities for monetization and are attractive to many businesses. The authors identify these requests and send them to business owners who can respond to them. Responding to these requests solves many users' problems and helps them quickly access their requests that lead to business development, and marketing is done by saving time and money. Therefore, request identification is an important issue that should be addressed further concerning the expansion of social networks.

In this regard, the authors suggest a combined machine learning method for the feature selection process in Persian texts of Telegram messengers using three feature selection techniques. As previously mentioned, FS has not been sufficiently investigated for the Persian text and no such combinations have been made for the Persian data. Furthermore, the data in this study is different from other messengers, both in terms of language and gender. Therefore, the second innovation of this research is identifying the requests of the Persian messages of Telegram. The authors performed many experiments to prove the method's validity with a different number of samples and features and analyzed the results. Therefore, the main part of this article is summarized as follows:

- In feature selection, a combined approach was offered based on local and global filters, which is useful for evaluating selected features and improving the efficiency of the training and testing phases.
- Empowering the selection of features for request identification in Persian messages on Telegram by

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introducing an approach of selecting the combined feature of filter and wrapper. This method uses the advantage of filters' speed and wrapper accuracy to increase accuracy.

- The authors offered a new method that combines the benefits of selecting features and ensemble classifiers to improve performance and accuracy of the classification in Persian text.
- In order to increase the performance of the classification in the Persian text dataset, an ensemble approach was introduced by combining the results of multiple classifications (SVM, NB, DT, MLP) using a majority voting based on average probabilities.
- This proposal has been compared with 85,000 samples using the methods available in a test platform consisting of a Persian dataset. Experimental results show that the proposed solution maintains Micro−F1, Macro−F1, and RMSE criteria at acceptable levels.

2- A Review of Combined Research in the Field of Feature Selection

Some recent studies have shown that combining feature selection methods can improve classification performance. In these combined methods, it was concluded that one method's performance might be inadequate as an individual, but its combination with other methods provides high efficiency. In general, feature selection methods are divided into three main categories: wrapper, embedded, and filter [10], [12], [16], [20], and their combination can be used to increase performance.

Combined Filter and Wrapper-based Feature Selection

In some studies, some techniques have been proposed that combine a filter and a wrapper method. Feature selection and model learning are made simultaneously by embedded methods. Wrapper methods use a learning algorithm to evaluate the subset of features, which increases performance [12], [18], [20], [21]. However, these algorithms require a great deal of time to be fully processed, and their main problem is to create an additional calculation cost [21]. For this reason, they are not directly preferred for text classification [21]. Some studies, e.g., Wah et al. [24], have compared filter and wrapper feature selection methods to maximize the accuracy of the classifier; and in some other studies, the FS methods, which are a combination of filter-based local methods and wrapper-based methods, have been investigated by Uysal [25]. In one category, wrappers can be applied in two areas: forward and backward methods. Xie et al. [26] presented a combined FS method that utilizes the benefits of filter and wrapper methods to select the optimal feature subset from the set of main features. They combined improved F-score, a filter evaluation criterion, with a wrapper evaluation system named Sequential Forward Search (SFS) to find a subset of the optimal feature in the FS process. The results revealed that the features decreased, and the classification accuracy increased. In this study, the authors applied SFS and a combination of filtering methods as pre-processing was used to increase training speed.

Combined Filter-based Feature Selection

Filter methods select features based on a pre-processing step and independent of the learning algorithm [18], [20]; and for this reason, they are straightforward and fast in terms of computation [12], [21]; hence they work well for high-dimensional data; although wrapper methods are highly time-consuming for high-dimensional data and provide acceptable accuracy in practice [21]. Furthermore, despite filtering methods, wrapper and embedded methods require frequent classifier interaction, which increases execution time [12]; therefore, filtering methods are more efficient.

Filtering methods have two categories, local and global [12], [21]. In some studies, global methods have been named as corpus-based, and local methods have been called class-based [21]. In the study of Ogura et al. [27], filter-based feature selection methods are divided into two categories of one-sided and two-sided based on their characteristics. Popular feature selection methods [12], [14] include: document frequency [21], information gain [21], [27], [28], Gini index [27], and distinguishing feature selector [12]. Odds ratio [12], [28], [29] and Correlation coefficient [12], [27], [29] are commonly used local selection methods. In the present study, a comprehensive study was performed on the most widely used filter-based FS methods, and then a brief description of the mathematical contexts of these methods was presented in Section 3.

Filter-based methods have been applied in many studies. Sometimes these methods are used individually and sometimes in combination with non-filter methods. In [12], [14], [25], filter-based methods have been combined with wrapper methods; they have also been employed with Principal Component Analysis (PCA) and genetic algorithms. Uysal and Gunal [30] suggested a filter-based probabilistic feature selection method called Distinguishing Feature Selector for text classification. BİRİCİK et al. [15] showed that chi-squared feature selection methods and correlation coefficient produce a subset of better features.

Recently, Uysal [12] combined the power of a filter-based global feature selection method and a one-sided local selection method called IGFSS1 to improve FS by applying filtering methods. The results indicated that this combined method's performance was better than the individual performance of the methods. This proposed method was not

1. Improved Global Feature Selection Scheme (IGFSS)

suitable for unbalanced data with a large number of classes. In order to solve this problem, Agnihotri et al. [14] proposed the VGFSS1 method, which is a combination of a global and odds ratio method. The idea is to build a set of final features that show each class based on the distribution of terms in the classes. By comparing and experimentally evaluating both local and global methods, Melo et al. [31] showed that local feature selection performed better than global [31]; additionally, in some investigations, local methods produced better results for lower feature value and global methods for higher feature value [21]; therefore in this study, a combination of global and local filter-based methods are also used to get better results; in other words, the global and local scores are employed directly in the feature ranking [14]. The references [25], [32], [33] are among the studies that have independently used filtering methods in combination.

Combined Feature Selection and Ensemble Classifier

The ensemble method is a machine learning technique that combines the results of several basic classifiers and increases accuracy [34]. For example, Bolon-Canedo et al. [35] provided a combination of classifiers and filters. The results revealed that the proposed method performed better in most cases and reduced the number of features by more than 80%. In the present study, using ensemble methods and combined filtering methods instead of individual filtering methods, an approach was proposed that provided the most accuracy for the dataset applied in this study. In other studies, filter compounds (combined filter methods) were not utilized as input and pre-processing of learning algorithms.

Ensemble methods are popular in machine learning research and pattern recognition. The purpose of ensemble methods is to combine the decisions of a set of weak learning algorithms or base learners to increase the accuracy and strength of the developed classified model. The generalizability of ensemble methods is better than that of single base learners. Ensemble methods can be divided into two categories: dependent and independent [36]. Voting is the simplest and most extensively used form of combining basic learning algorithms. There are several methods to combine the output of basic classification algorithms. These combined methods include majority voting, weight majority voting, combination Law of Naïve Bayes, behavioral knowledge space method, and probabilistic approximation [36]. In the present study, the authors used majority voting in the third proposed method by applying the combined method of local and global filters.

In this article, the combined or two-step methods were used to achieve reduced dimensions. Also, the most widely used methods of local and global filters were combined; the combined methods reduced the feature and increased accuracy. The combination of combined filter and wrapper methods was applied, and better accuracy was obtained. Moreover, in order to increase accuracy, the first proposed combination methods were applied using ensemble methods, which significantly increased the accuracy. The following is a description of these proposed methods.

1. Variable Global Feature Selection Scheme (VGFSS)

3- Proposed Method

Filter-based feature selection methods provide us important features by scoring each feature in a dataset. These methods are independent of classification algorithms. Filter-based methods inherently use statistical tests on a dataset, and the ranking of features is the main criterion in selecting the features. The authors determine a threshold experimentally. All features are scored and removed if they are less than the threshold value. Due to the simplicity of these methods, they can be extensively used for practical applications involving large amounts of data [12], [21]. Combining the output of these filter-based methods can increase accuracy. This combined method is referred to as the first proposed method.

The wrapper selection methods have less simplicity and speed compared to filters. However, these methods have higher accuracy than filters due to the application of learning algorithms. These methods can be combined to take advantage of both speed and accuracy. In the combined method, the features obtained using filter-based methods as the pre-processing step for wrapper methods can be applied. Wrapper methods are not suitable for large amounts of data due to their low speed. However, the use of filters as pre-processing can be appropriate. This combined method is called the second proposed method.

In combined methods, different classifications or learning algorithms are used to evaluate the accuracy. In the present study, ensemble methods are applied as the third proposed method, which is a combination of these algorithms. However, in order to increase the accuracy, the output of the methods in the first proposed method is used as input for this method. SVM, NB, MLP, and DT are of the algorithms used in this method, which are broadly used in text classification studies and feature selection.

In this section, some of the most extensively applied methods for selecting features are described based on local and global filters. The authors use the outputs related to these filtering methods for FS. In some sections, the output of these methods is combined, which include IG, GI, DF, CC, OR, DFS. By combining these methods, appropriate results are obtained, which include an increase in accuracy. Some of these output features are common features with high scores and, therefore, can be considered as selected features.

Information Gain (IG): IG is one of the FS methods used in text classification, which utilizes a global filter-based approach [37]. IG is a method for evaluating entropy-based features [38] and is widely used in statistics and machine learning [21]. The higher the entropy is, the more information about the feature is obtained [37].

$$IG(t) = -\sum_{i=1}^{M} P(C_i)\log P(C_i) + P(t)\sum_{i=1}^{M} P(C_i|t)\log P(C_i|t) + P(\bar{t})\sum_{i=1}^{M} P(C_i|\bar{t})\log P(C_i|\bar{t}) \quad (1)$$

Gini Index (GI): GHI is a method to select global features for text classification. It was first used in DT algorithms, and then an improved form of this algorithm was proposed for FS in the text. It is a supervised method with a simpler calculation compared to IG [12], [39], [40].

$$GI(t) = \sum_{i=1}^{M} P(t|C_i)^2 P(C_i|t)^2 \quad (2)$$

Distinguishing Feature Selector (DFS): DFS is one of the most recent and appropriate FS methods for text classification, which has been proposed by Uysal and Gunal [41].

$$DFS(t) = \sum_{i=1}^{M} \frac{P(C_i|t)}{P(\bar{t}|C_i)+P(t|\bar{C}_i)+1} \quad (3)$$

Document Frequency (DF): This method scores the features according to the number of views in the document [40]. DF defines the document label based on the highest frequency term, and it is the simplest global feature selection [40], [42].

$$DF(a_j) = N.p(a_j) \quad (4)$$

Correlation Coefficient (CC): This method is a type of chi-square and can be seen as a one-side chi-square. This FS method selects terms with the highest value of cc as a feature. CC is an FS method based on the local filter [15], [29].

$$cc(t, c_i) = \frac{\sqrt{N}[P(t,c_i)P(\bar{t},\bar{c_i}) - P(t,\bar{c_i})P(\bar{t},c_i)]}{\sqrt{P(t)P(\bar{t})P(c_i)P(\bar{c_i})}} \approx \frac{\sqrt{N}(AD-CB)}{\sqrt{(A+C)\times(B+D)\times(A+B)\times(C+D)}} \quad (5)$$

Odds Ratio (OR): The OR criterion is a filter-based local method, which obtains the membership of a special class with nominator and obtains the non-membership with a denominator. Membership and non-membership scores are normalized by dividing them over each other; in order to obtain the highest score from the formula, the nominator and denominator values must be maximized and minimized, respectively [12], [39], [40].

$$OR(t|C_i) = log\frac{P(t|C_i)[1-P(t|\bar{C_i})]}{[1-P(t|C_i)]P(t|\bar{C_i})} \quad (6)$$

3-1- Process of Implementing the Proposed Method

In this section, the details, parameters, and steps of the proposed method are described in a step-by-step manner. In Fig. 1, the general steps of the proposed method are presented.

The proposed method in the present article uses the output of the methods described earlier. The authors use the output of these methods in three ways, the result of which is to provide three proposed methods. In all three methods, individual filter methods are applied for the initial FS process. Each of the above methods selects different features. These features are considered to be the most important features according to their computational formula. The output of each proposed method is used by applying learning algorithms and evaluation criteria to determine the final features. A threshold is determined experimentally to determine the number of final features and is specified at each step. After determining the output features of each proposed method, if it meets the threshold criterion, it is determined as the output feature and sent for the purpose of classifying the text. The rest of the features are removed from the features matrix. The following figures demonstrate the three proposed methods. The following algorithm is used in these proposed methods for FS.

Data production and labeling: The authors used real-time textual data extracted from the Idekav-system for test and evaluation. These data are Persian Telegram messages and a label is considered for each message. Then the first 80% and 20% of the dataset are considered as training and test, respectively.

Pre-processing: The output of the previous step is a set of text documents that need to be pre-processed. Pre-processing converts textual contents into numbers and includes the tokenization, stop words, stemming, and weighting phases. The text in this study is a number of messages and each message is a sentence. In pre-processing, each sentence is broken down into a number of words and each word is a feature. The number of obtained features is significant. In order to remove insignificant and redundant features, pre-processing steps, such as deleting stop words, must be applied. In this step, a bag of word (BOW) was created and a feature vector was formed for each sentence. If there is a feature in a sentence, the corresponding entry in the feature vector gets a value equal to one. In the absence of that feature, the corresponding entry is equal to zero. The final feature vector of a matrix consists of zeros and ones. After the pre-processing steps, the total number of features extracted from the original text is equal to 6754. The authors also perform the steps of constructing a feature vector or matrix for feature selection methods.

In this research, each of the filter-based feature selection methods is applied to select the optimal set from 6754 features extracted from the original text. The selected feature sets of each local and global method are created separately; hence, the results in this section are shown separately for each method per feature matrix. The feature vector is used for learning methods as input, and each feature indicates the presence or absence of a word. The feature vector is considered as a matrix. First, the term class matrixes are extracted from the main dataset. The term class is a matrix, the columns and rows of which represent terms and classes, respectively. Each cell of this matrix contains the number of documents that contain a term such as t in a class such as c. The calculation of this matrix is necessary for all other feature selection methods.

After selecting the optimal feature subset as shown in Fig. 1, from the original matrix, the columns should be selected for which the corresponding feature is selected and a new matrix should be created. This new matrix will actually be the input to the combined feature selection methods.
The following are the algorithms used for these proposed combined FS methods.

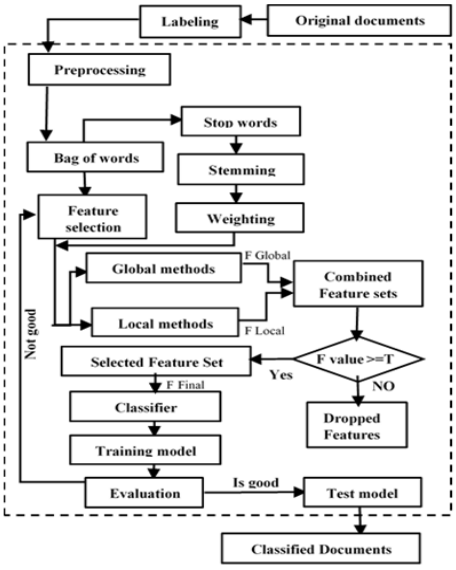

Fig. 1. General diagram of the research method
(In this diagram, a combination of local and global filtering methods is used as input to learning methods)

Algorithm 1. Scoring features with filter methods
Step 1- Set of main features: The set of features obtained from the preprocessing stage is shown with F = {F_1, F_2, …, F_N} and defined as a set of all the main features that in this set, N = 6754. The set C_i also denotes the positive and negative classes, which are equal to C_i = {C_1, C_2}.

Table 1. Explain the parameters used to select the feature vector in the proposed method

Parameter	Description	Collection
F	Set of main features without feature reduction	**F ={F_1, F_2, … , F_N }**
F Local	Selected features by local feature selection method	**F Local={F_1, F_2, … , F_L }, l < n**
F Global	Selected features by global feature selection method	**F Global={F_1, F_2, … , F_G }, g < n**
F Final	Final selected features by combining local and global features	**F Final={F_1, F_2, … , F_M }, m < l +g**
C_i	Selected feature class	**C_i = { C_1,C_2}**
T	Threshold value for selected features	**F value < T→ Dropped Features F value > T→ Feature Selection**
F value	The value of the selected feature	

Step 2- Feature selection: The number of features in set F are considerably large, that makes the implementation of learning methods time consuming. For this reason, the dimensions of the features must be reduced through some ways. The filter-based algorithms are examples of the most extensively used methods for reducing dimensions. For these feature vectors, both local and global feature selection methods are performed. In the feature selection steps, a series of parameters are applied, which are explained in Table 1. Also, in Fig. 2, the step of selecting a combined feature (combined FS) is shown in more detail. The steps of the feature selection method used in this article are as follows:
Step 3- Feature selection with local methods: In this step, using the local feature selection methods OR and CC, the features of each C_i class in set F are given a score. These methods are described in Section 3. These scores indicate the difference between terms or features in a dataset. In the next step, all the terms are arranged in descending order according to the score they gained in the feature selection stage. Then, *L* features with the highest score in the feature set are selected as the final features. The value of *L* is a definite number that is usually obtained experimentally. F Local ⊆ F is selected as a set of locally selected features. F Local = {F_1, F_2, …, F_L} contains *L* number of features.
Step 4- Feature selection with global methods: In this step, using the global feature selection methods GI, IG, DF and DFS, the features of each C_i class in the set F are given a score. These methods are described in Section 3. Then, as in the previous step, the features are arranged in descending order of scores. F Global ⊆ F is defined as a set of selected global features. F Global = {F_1, F_2, … , F_G} contains a number of *G* features.
Algorithm 2. Combining local and global output features
Step 1- Combining feature sets: From steps 3 and 4 in Algorithm 1, two feature sets were obtained, each of which has a specified value. In this step, the combination of the set of output features arranged from each of the local methods with the set of output features arranged from each of the global methods are performed. From these two sets, the features with higher scores are selected.
Step 2- If the F value feature is greater than the threshold T, that feature is selected, otherwise it is removed from the feature set. The value of T is determined experimentally.
Algorithm 3. Selecting the final set of the first proposed method
Step 1 - Selected Features: From Algorithm 2, a set of final features F Final = {F_1, F_2, …, F_M} is obtained, that F Final ⊆ (F Global ∪ F Local). The F Final feature set possesses a set value in which the best features with higher values are selected.
The combined algorithm in this research is shown in Fig. 2. The details of selecting the feature of the previous steps are shown in this figure with different colors. Local methods are shown in yellow and the output is the F Local features. Global methods are illustrated in blue and the output is the F Global features. After combining these two feature sets, the F Final set is obtained in green color, which selects the features with the F value > T feature. The value of T in this figure represents a threshold for the selected features that have been determined experimentally. This step is shown in more detail in Fig. 1.

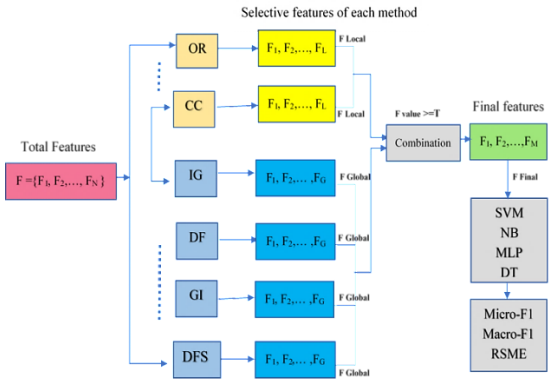

Fig. 2. Details of the steps to combine the feature set obtained from the feature selection methods

Step 2- Evaluation: Finally, the classification algorithms take the F Final set. After passing the training model, if the evaluation is acceptable, the documents will be classified.

The performance of classifications can be measured using learning methods. As shown in Fig. 2, four learning methods SVM, NB, MLP and DT were used in the present investigation. Micro-F1, Macro-F1 and RSME evaluation criteria were also applied. According to Fig. 1, if the evaluation results were not good enough, the feature selection step can be retrieved and the selection criteria be changed to reach the new set and the desired result.

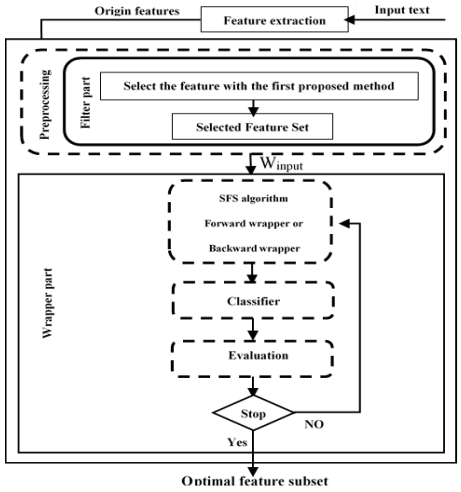

Fig. 3. General diagram of the second proposed method
(In this method, the output of a combination of local and global methods is used as input for learning-based methods)

Therefore, a new set of features have been obtained that includes the features with highest scores from the combination of local and global methods. Now, this new set can be tested using common learning methods in text classifications and feature selection and then the results can be compared. The experimental details of these steps are given in Section 4. This set of features (the feature set obtained in the first proposed method) is also used for the second proposed method (Fig. 3) and the third proposed method (Fig. 4).

Algorithm 4. Selecting the final set of the second proposed method

Step 1: The W_{input} dataset is equal to the output features of algorithm 3 or the F Final set of the step 4 of this algorithm.

Step 2: With T-threshold, determine the number of input features.

Step 3: Send the specified features as the input to the wrapper method.

Step 4: If the number of selected features is less than half of the T-threshold, continue to select the feature with the wrapper method.

Step 5: Repeat step 1 for all the features of the combined set, which are obtained from local and global methods.

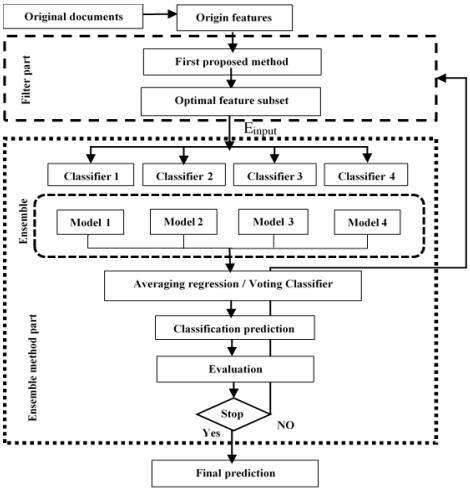

Fig. 4. General diagram of the third proposed method
(In this method, the output of a combination of local and global methods is used as input for ensemble learning methods)

Algorithm 5. Selecting the final set of the third proposed method

Step 1: The E_{input} dataset is equal to the output features of algorithm 3 or the F Final set of the step 4 of this algorithm.

Step 2: With T-threshold, determine the number of input features.

Step 3: Send the specified features to the classifiers as input.

Step 4: Train each classifier for each model.

Step 5: Get the output of step 4 with majority voting or average regression.

In this article, these algorithms were used to provide a model for classification and selecting features in the Persian text, using local and global filter feature selection methods, wrapper, and combining different classifiers. As shown in the figures, the pre-processing steps were performed before any action. Instead of using individual filter methods, a combination of local and global methods was applied as pre-processing for wrappers and combining of the classifiers. By following the suggested methods,

high accuracy was achieved. In the next section, the dataset used and the evaluation results will be presented.

4- Evaluation Results

In this section, the proposed FS models will be practically evaluated using two sets of real data (the Persian dataset of the Idekav-system and the famous Reuters dataset). The use of two datasets attempts to evaluate the performance of extensively used machine learning algorithms in FS fields. In the following, the dataset and the various widely used criteria will be presented, which are used in the text classification and FS studies.

4-1- Data and Evaluation Criteria

Persian Dataset of Telegram: In order to detect requests, it is required to check user messages. Therefore, the relevant documents with the highest and lowest scales are extracted; however, since numerical rankings cannot be applied equally to all phrases and sentences that are a part of the review, filter methods are used based on the characteristics of the studied language. The authors carry out the pre-processing steps, such as deleting the stop words of the Persian language, stemming, etc., on the phrases, and then use the matrix of the obtained features to calculate the score of that phrase. The Idekav dataset is applied.

The extracted dataset from the Idekav-system, which is a Telegram search engine, was applied to validate the proposed algorithm. This system includes many messages from the Telegram social network in Persian, which are regularly updated. The Telegram messenger is quite popular and beneficial among its users. These text messages have several different topics that can be used in different areas, such as data mining, opinion mining, and request identification. In the present investigation, the data used was extracted and processed by ourselves. The process of collecting and preparing this data was performed by seven senior and doctoral students of Yazd University. Training the work steps began with an explanatory session on labeling methods and rules. Each person received a username and password. People entered the Idekav-system and used interrogative keywords such as "how," "who," "I'm a buyer," and "I need" in the search field to find users' questions. They labeled sentences and messages according to the defined rules. For labeling, at first, it should be determined whether the message is a request type message or not. The authors label a message that contains a request with a positive label, and if there is no request, with it is labeled with a negative label. These explanations relate to the discussion of request identification or question identification. After the labeling process, the obtained file included 85748 records, each of which expressed a text message. The specifications of each message were shown in 14 columns. The columns indicate the characteristics of the text of the message, the message length, the positive and negative or neutral labels by the first and second person, the group ID, the group name, the number of group members, the user ID that sent the message, the message type and the sending time of the message, respectively. The dataset collection process started on February 7, 2017, and ended on March 29, 2017. Each message is labeled by two people to ensure that the labeling is correct. Labeling was performed in several different time stages. Before the last step, the statistics are reported as follows:

U1: 448, U2: 439, U3: 15185, U4: 14289, U5: 20462, U6: 9942, U7: 14569.

The obtained final statistic, which was recorded in an excel file, includes 85748 records. In the present investigation, because the data is inherently random, 80% of the primary data was used as a training data set, and the remaining 20% was applied as a test data set. Cross-validation was used for training and testing purposes.

Evaluation Criteria: Selecting the right criterion for evaluation is considerably important. Common evaluation criteria applied in text classification for evaluating the performance of learning algorithms are divided into two categories: internal and external. Internal criteria include similarity measurements. Accuracy [21], precision, recall, and F-measure [12], [14] have been identified as external criteria. The authors used Micro−F1, Macro−F1, and RMSE to evaluate the performance of the proposed methods. These criteria are regularly applied to measure the performance of classification methods. Depending on a classification model and a test dataset, the performance of the model in the test dataset can be measured based on these criteria.

Micro-averaged calculations give each document equal weight. However, macro-averaged provides equal weight to each category [43]. In the Micro−F1 calculation equation, p is the value of precision and r is the value of recall for all classification decisions in the whole dataset [12], [14], [25], [30], [39].

$$Micro - F1 = \frac{2 \times p \times r}{p + r} \tag{7}$$

The Macro−F1 calculation equation is the average calculation of each specific class. Where, p is the precision value and r is the recall value of class k [12],[14],[25],[30],[39]. The F1 score is the harmonic mean of precision and recall. Balancing precision and recall performance in optimizing the classifier is performed by its assistance [44].

$$Macro - F1 = \frac{\sum_{k=1}^{C} F_k}{C} . \quad F_k = \frac{2 \times p_k \times r_k}{p_k + r_k} \tag{8}$$

The RMSE (Root Mean Square Error) is the standard deviation of the remainder in the data. RMSE demonstrates the proximity of the predicted values to the

actual values; therefore, a lower value of RMSE indicates that the model performance is appropriate [45], [46].

$$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \quad (9)$$

All experiments were performed with the Python language using the machine configuration as follows: OS: 64-bit Windows 10, CPU Speed: 2.60 GHz, Processor: Intel Core i7-3720QM, RAM: 24GB .The authors also used the Scikit-Learn library for machine learning to train the text classification model.

4-2- First Proposed Method (Combined Local and Global Filters)

The performance of the first proposed method is presented in the following figures. SVM was the first type of machine learning algorithm used. Fig. 5 indicates the Micro−F1 criteria for individual filter methods using this algorithm. Among individual methods, CC had a higher accuracy value.

Fig.6 presents the Micro−F1 criterion for combined filter methods using this algorithm. The highest accuracy obtained for this algorithm was equal to 0.844, which was related to the CC&DF combined method. The accuracy of this algorithm without selecting the feature was equal to 0.696. The accuracy values obtained with these algorithms in the first proposed method had a higher percentage of increase compared to the accuracy values without FS. According to the obtained results, SVM and NB learning methods performed better than other methods in the Persian dataset.

In combined methods, an optimal feature subset was obtained, which included 300 features. The results of this algorithm have been compared with the average results of other machine learning algorithms in Fig. 7.

In the first proposed method, the SVM classifier showed a more considerate increase in accuracy; hence, different kernels were obtained from this Kernel-based learner. The kernel types are linear, polynomial, sigmoid, and Radial Base Functions (RBF). Different kernels select different features, which also changes the amount of accuracy. The different kernels' results are presented in Fig. 8. In the Linear SVM, the CC&DF combination method had an accuracy of 0.846 for 300 features, which was higher than other kernels.

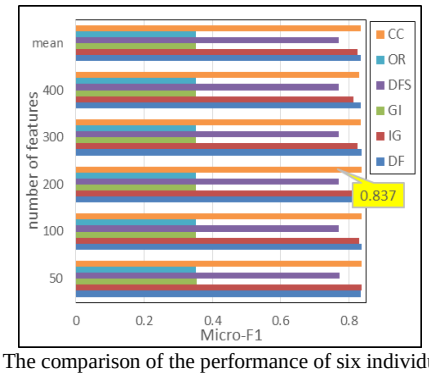

Fig. 5. The comparison of the performance of six individual filter methods for the different number of features and average of features using SVM classifier and Micro-F1 criterion.

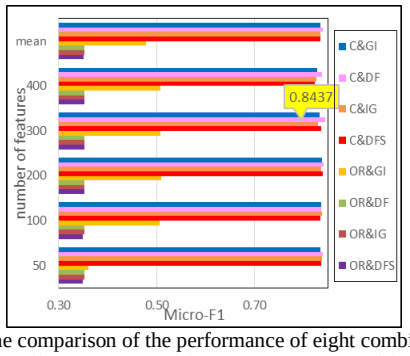

Fig. 6. The comparison of the performance of eight combined filter methods for different number of features and average of features using SVM classifier and Micro-F1 Criterion

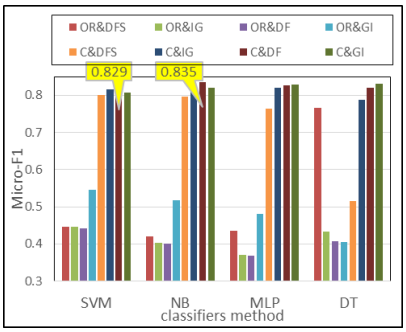

Fig. 7. The comparison of the average of SVM, AND, MLP, DT classifiers, and Micro-F1 criterion for eight combined methods of the filter.

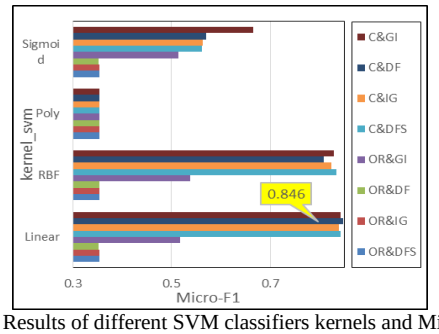

Fig. 8. Results of different SVM classifiers kernels and Micro-F1 criterion for eight combined filter methods

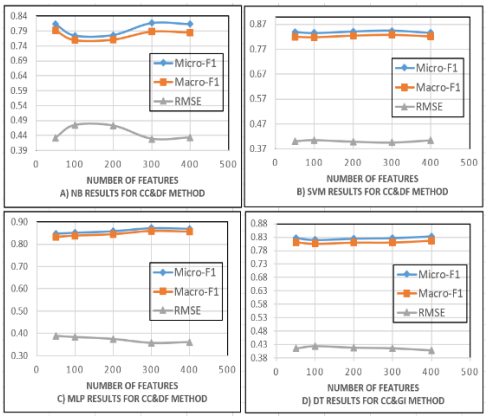

Fig. 9. Results of Micro−F1, Macro−F1, and RMSE criteria in the SVM, NB, MLP, and DT classifiers for the combined filter methods with the best results

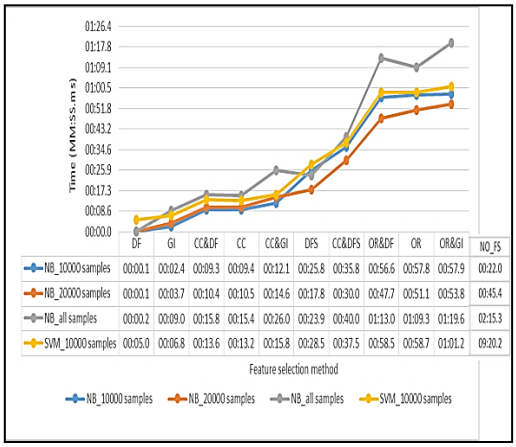

Fig. 10. Comparison of results of the times of the proposed methods when changing the processed dataset with NB and SVM classification algorithms with and without feature selection

Fig. 9 shows the values measured for different evaluation criteria. These diagrams are related to the combined methods with the highest accuracy in each learning algorithm. In NB and MLP, as in SVM, the CC+DF combination method presents a better result. In the following diagrams, the different criteria of this combined method are indicated. In the proposed method, a series of new features are obtained for each FS method, some of which may have selected common features. In Fig. 9, it is shown that the combination of CC and DF had a higher degree of accuracy.

The main focus of the present research was on increasing the accuracy, and it is shown in the results diagram that the reduction of feature using the proposed method led to an increase in the accuracy. However, some experiments have been performed to compare the timing of classification algorithms with and without feature selection. In some methods such as NB and SVM, the claim of time reduction as a result of feature reduction (its importance in the prediction stage by all means) was proved by performing the experiments.

The results of comparing the time of classification algorithms with and without feature selection is indicated in Fig. 10 for more accurate methods. In this figure, it is shown that using the proposed feature selection methods has reduced the training time. In particular, in SVM, it was shown that in most cases, the use of feature selection methods increased accuracy and reduced the training time. In some cases, an increase in time has been experienced. However, due to the percentage of increase in accuracy and the percentage of reduction of feature (as seen in Table 2), the increase in time is insignificant and negligible. In Fig. 10, SVM results with 10,000 samples of datasets and NB results with different numbers of samples (10,000 samples, 20,000 samples, and all samples) of datasets are shown. As demonstrated in the figure, as the amount of processed data increases, the time has increased accordingly in most methods. A column called NO_FS has been added to the diagram to indicate time for algorithms without feature reduction. As can be seen, there was a significant reduction in time in SVM by applying feature selection methods.

4-3- Comparison with Previous Studies

Because the database has been created by the authors, it is not possible to compare this database with the methods of other articles .In this section, the authors used another dataset, Reuters-21578, which has been applied in many studies related to text classification and FS, to evaluate and compare with previous works. This dataset has also been used in a study conducted by Uysal [12].

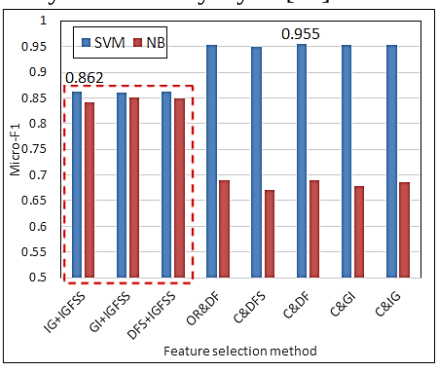

Fig. 11. Comparison of the proposed filter-based FS method of this article with the FS methods of previous articles with non-Persian data Reuters-21578 for SVM and NB classifiers and Micro-F1 criteria

The proposed methods in the present article were implemented on this dataset, and the results are shown Fig. 11; similar to Uysal's study, Micro-F1 and Macro-F1 criteria were used in the present research for evaluation. For individual methods using SVM, the highest accuracy is related to CC, which indicates the correlation coefficient and has a value of 0.954. Among the combined methods using SVM, the CC&DF method shows a better result compared to the other methods and has a value of 0.955. In Uysal's study, the highest result with SVM was equal to 0.862, which is lower than the highest accuracy (0.955) used in the first proposed method of this study. In Fig. 11, a comparison has been made between the combined

method, the first proposed method, and the proposed method of Usyal's study .In this diagram, it can be seen that in both studies, the use of SVM led to better results than NB. In Fig. 11, the first three pairs of bar graphs are related to the results of Usyal's method, and the next five bar graphs are related to the proposed method of the present research.

4-4- Second Proposed Method (Combined Filter and Wrapper Methods)

In this method, before assigning the main features to the wrapper methods, they must pass through the filter of the first proposed method, and then these more optimal features to be assigned to the wrapper methods as input features. The highest result is related to the combination of SFS and filter methods that include CC. Moreover, its combination with CC, which is a local method, shows a better result among individual methods. Among the combined methods, the combination of the SFS and FCC+DFS method provides a better result.

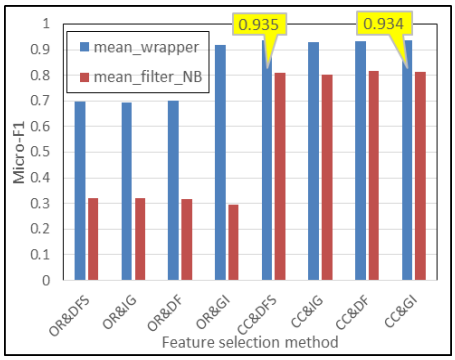

Fig. 12. Comparison of the average of combining the wrapper method and combined filter methods in 10,000 samples using NB classifier and Micro-F1 criteria

In the first proposed combined method, FCC+DFS gives an excellent result of 0.848. The combination of this method and the wrapper method has an accuracy equal to 0.937, which indicates the efficiency of the second proposed method and a higher degree of accuracy for the FS process. These results are obtained for 10,000 samples with 50 features. In Fig. 12, the comparison of the average number of different features in the combined wrapper and filter methods is presented.

4-5- Third Proposed Method (Use of Ensemble Learning Methods)

In this method, the output of the first proposed method was applied as input. In the third method, a combination of classifiers or learning algorithms was employed. In Fig. 13, the results of combining the output of the first proposed method and ensemble methods are shown. The results revealed that the combined filtering methods produced a higher result compared to the individual methods of filtering in this proposed method. Among the first proposed methods, the $E_{CC\&DF}$ combination method has a better result than the other combinations. The output of F_{CC+DF} is the input of ensemble methods, and the combined method of $E_{CC\&DF}$ was obtained. In this proposed method, other classifiers, such as random forest or KNN, can be used, and the results can be compared with the current results. The authors applied the same classifiers in the first proposed method.

In Fig. 14 the comparison of this proposed method is presented using different features and an average of features. On average, the combined method of $E_{CC\&IG}$, which is a combination of ensemble methods and CC&IG, provides better results than other methods. Moreover, the use of combined methods with CC as an input in ensemble methods leads to better results.

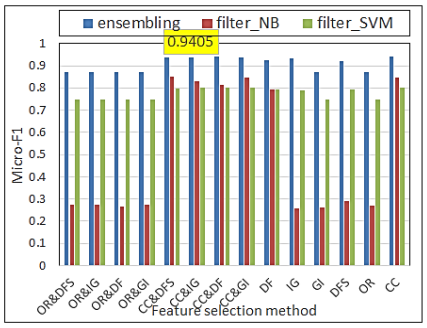

Fig. 13. Comparison of the combination of ensemble methods (combining the results of SVM, NB, MLP, and DT classifiers) and individual and combined filter methods in 50 features and 10,000 samples in SVM and NB classifiers with Micro-F1 criteria

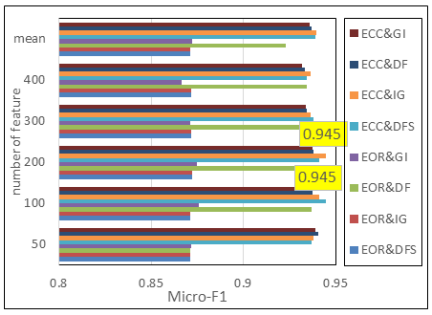

Fig. 14. Comparison of the average of combining the ensemble methods (combining the results of SVM, NB, MLP, and DT classifiers) and eight combined filter methods in 10,000 samples with Micro-F1 criteria

4-6- Comparison of the Three Proposed Methods

In the present study, three proposed methods were presented, which were described in the previous sections. In this section, all three proposed methods were compared. The results of performance evaluation and comparison are presented in Fig. 15. In this diagram, three methods are displayed all-in-one view, and it is observed that on average, the third proposed method, which is a combination of filter and ensemble

methods, outperforms the first and second proposed methods. Then the second proposed method, which is a combination of the wrapper and filter methods (the first proposed method), shows better results compared to the first proposed method. Moreover, combining the individual CC method with all the proposed methods possesses a higher value. Therefore, the combinations of this method, which has a high value, frequently show a favorable result. Now, by combining each of these combined methods with wrapper and ensemble methods, these combinations produced better results. The high degree of accuracy in CC-containing methods is because the correlation coefficient exactly selects the words that indicate membership in a classification. Therefore, the use of CC in FS leads to a significant improvement in classification performance. There is a relationship between the size of feature set, performance, and finding the size of the optimal feature set where there is the performance peak. Moreover, with the increase in the number of samples, this increase in performance has risen. The accuracy has been increased with an increase in the number of features until reaching the optimal subset. However, after the optimal set, the performance has decreased with an increasing number of features. Regularly, combining several FS methods may be better than a single method if each FS method shows unique scoring behavior and relatively high performance.

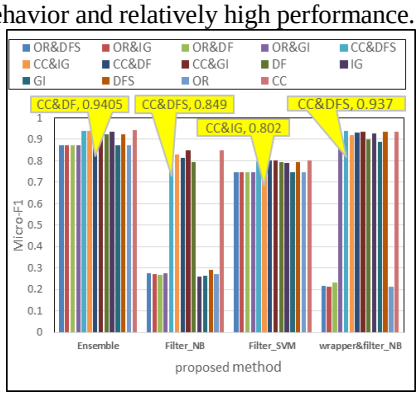

Fig. 15. Comparison of the combined ensemble methods (combining the results of SVM, NB, MLP, and DT classifiers), individual and combined filter methods (with SVM and NB classifiers), wrapper combinations in 10,000 samples, and 50 features with Micro-F1 criteria

In this figure, the results for 10,000 samples are presented. With this number of samples, the subset of the optimal feature possesses 50 features. With more samples, it is also true that the third proposed method shows a higher result than the second and first proposed methods but leads to an increase in the number of features in the optimal feature subset.

The results of the present research revealed that the combination of methods based on local and global filters showed a better classification performance than individual methods. These combinations reduced the dimensions of the feature space by producing the optimal subset of all the important and efficient features, leading to an increase in accuracy. On the other hand, the algorithms that select the best subset of the features are extremely optimal in terms of time and reduced the computational time. In other words, the learning model is obtained with higher generalizability, which shows the importance of FS in the classification. With these combined methods, the most optimal subset of the feature can be obtained. At each step, the FS operation is performed, and its related learning model is trained. The authors will continue these steps until reaching the best feature reduction rate and classification accuracy.

Table 2. The percentage of increase in accuracy and percentage of feature reduction of the proposed methods with Micro-F1 criterion and number of different training samples

Accuracy Without Feature Reduction	Accuracy with Feature Reduction	Percentage of Increase in Accuracy	Classifier	Better Method	Optimal Features	Percentage of Feature Reduction	Number of Samples
First Proposed Method							
0.69	0.84	21.74%	SVM	CC	200	-96.67%	all samples
0.69	0.843	**22.17%**	SVM	CC&DF	**300**	-95.00%	all samples
0.74	0.83	12.16%	NB	IG	50	-99.17%	all samples
0.74	0.82	10.81%	NB	CC&DF	300	-95.00%	all samples
0.856	0.864	1%	MLP	DF	300	-95.00%	all samples
0.856	0.872	1.87%	MLP	CC&DF	300	-95.00%	all samples
0.838	0.83	-1%	DT	IG	400	-93.33%	all samples
0.838	0.832	-0.72%	DT	CC&GI	400	-93.33%	all samples
0.602	0.848	40.86%	NB	CC	50	-99.17%	10000
0.602	0.849	**41.03%**	NB	CC&DFS	**50**	-99.17%	10000
0.345	0.777	125.22%	SVM	DFS	100	-98.33%	20000
0.345	0.776	124.93%	SVM	CC&DF	100	-98.33%	20000
Second Proposed Method							
0.602	0.937	55.65%	NB	CC&DFS	50	-99.17%	10000
Third Proposed Method							
0.746	0.94	26.01%	SVM	CC&DF	50	-99.17%	10000
0.602	0.94	**56.15%**	NB	CC&DF	**50**	-99.17%	10000
0.746	0.871	16.76%	SVM	CC&DF	200	-96.67%	all samples
0.602	0.871	**44.68%**	NB	CC&DF	**200**	-96.67%	all samples

The highest increase in accuracy was related to 50 features in 10,000 samples. In 20,000 samples, the maximum increase in accuracy was related to 100 features. In all samples, the maximum increase in accuracy was in 300 features, and this set was considered to be the optimal subset. Therefore, it can be concluded that as the volume of processed data increases, the optimal feature subset also rises. The percentage of increase in some cases is considerably small and also in some cases, is significant, and there is no incremental percentage in other cases; however, it is noteworthy that the reduction of training time has been significant due to the feature reduction.

Table 2 also indicates the percentage of increase in accuracy and the percentage of feature reduction of the proposed methods with the Micro-F1 criterion and the number of different training samples (increase in the amount of data processed). In this table, the results of the proposed algorithms are shown when changing the database.

5- Conclusions and Future Work

In the present article, three proposed methods were suggested to increase the accuracy of request identification in Persian messages on Telegram. In the first method, which was a combination of local and global filter-based methods, the CC&DF combination method increased the accuracy up to 0.844. This value

is related to the SVM classifier, which showed a better result than other classifiers. It is the reason that the authors have calculated the different kernels, among which the linear kernel showed a better result. The optimal feature subset in this method included 300 features. Based on the results obtained, the proposed combined methods considerably increased the accuracy, and the computation time was reduced. Accuracy and calculation time are effective criteria in machine learning methods. Wrapper algorithms have more accuracy than filter methods; however, their implementation of high-dimensional data takes much time to calculate. Therefore, the first proposed method of this research was applied as pre-processing for these methods, and the data dimensions were significantly reduced. Furthermore, this combined method was better than the first proposed method by providing an accuracy of 0.937. In the third proposed method, the output of the first proposed method was used as the input of ensemble methods. Then, the classifiers used in the first method were combined, and the result was better compared to the first and second proposed methods. The accuracy of the third proposed method was equal to 0.945. The authors applied Micro−F1, Macro−F1, and RMSE criteria to evaluate the performance of the proposed methods.

In the future, other ensemble classifiers, such as Random Forest, AdaBoost classifier, etc., will be evaluated. A combination of other filter and wrapper-based, as well as embedded methods will be used and the results will be compared with the results of the present study. Data on other social media can also be applied. It is also possible to use the proposed methods to select important features of bourse signals and improve business development by increasing the prediction accuracy.

References

[1] W. Y. Wang, D. J. Pauleen, and T. Zhang. "How social media applications affect B2B communication and improve business performance in SMEs". Industrial Marketing Management, vol. 54, pp. 4–14, 2016.

[2] E. Omer, "Using machine learning to identify jihadist messages on Twitter". M.S Theses, Dept. Information Technology, Uppsala Univ., Sweden, 2015.

[3] J. Surma and A. Furmanek. "Improving marketing response by data mining in social network ", in 2010 International Conference on Advances in Social Networks Analysis and Mining, 2010, pp. 446–451.

[4] W. He, S. Zha, and L. Li. "Social media competitive analysis and text mining: A case study in the pizza industry". International Journal of Information Management, vol. 33, no. 3, pp. 464–472, Jun. 2013.

[5] H. A. Vamerzani and M. Khademi. "Exploring the Uses and Challenges of Big Data in Opinion Analysis," in Proceedings of the 7th Iranian Conference on Electrical and Electronics Engineering, Gonabad, Islamic Azad University of Gonabad, 2016.

[6] M. Kiani nejad, T. hashemi, and M. rashidi. " Text mining social networks for consumer brand feelings and desires," in Proceedings of the 6th International Conference on Economics, Management and Engineering Sciences, Belgium, International Center for Academic Communication, 2016.

[7] Iran Analytical News Agency, "In which countries do telegram messengers favor?", khabaronline.ir, July. 2, 2019. [Online]. Available: khabaronline.ir/news/1275665. [Accessed:4 Jan 2020].

[8] Wikipedia contributors, "Telegram (software)," Wikipedia, The Free Encyclopedia, 27 Dec 2019, 15:24 UTC. [Online].Available: https://b2n.ir/907494.[Accessed:4 Jan 2020].

[9] Economics News, "Latest statistics from the mostpopular social networks in Iran", eghtesadnews.com, April. 9, 2019. [Online]. Available: https://b2n.ir/661242. [Accessed:4 Jan 2020].

[10] M. Nekkaa and D. Boughaci. "Hybrid harmony search combined with stochastic local search for feature selection". Neural Processing Letters, vol. 44, no. 1, pp. 199–220, 2016.

[11] X. Deng, Y. Li, J. Weng, and J. Zhang. "Feature selection for text classification: A review". Multimedia Tools and Applications, vol. 78, no. 3, pp. 3797–3816, 2019.

[12] A. K. Uysal. "An improved global feature selection scheme for text classification". Expert systems with Applications, vol. 43, pp. 82–92, 2016.

[13] L. M. Abualigah, A. T. Khader, M. A. Al-Betar, and O. A. Alomari. "Text feature selection with a robust weight scheme and dynamic dimension reduction to text document clustering". Expert Systems with Applications, vol. 84, pp. 24–36, 2017.

[14] D. Agnihotri, K. Verma, and P. Tripathi. "Variable global feature selection scheme for automatic classification of text documents". Expert Systems with Applications, vol. 81, pp. 268–281, 2017.

[15] G. BİRİCİK, B. Diri, and A. C. SÖNMEZ. "Abstract feature extraction for text classification". Turkish Journal of Electrical Engineering & Computer Sciences, vol. 20, no. Sup. 1, pp. 1137–1159, 2012.

[16] P. Lachheta and S. Bawa ."Combining synthetic minority oversampling technique and subset feature selection technique for class imbalance problem", in Proceedings of the International Conference on Advances in Information Communication Technology & Computing, 2016, p. 25.

[17] A. F. Sheta and A. Alamleh. "A professional comparison of c4. 5, mlp, svm for network intrusion detection based feature analysis", in The International Congress for global Science and Technology, 2015, vol. 47, p. 15.

[18] F. Aragón-Royón, A. Jiménez-Vílchez, A. Arauzo-Azofra, and J. M. Benítez. "FSinR: an exhaustive package for feature selection". arXiv preprint arXiv:2002.10330, 2020.

[19] A.-Z. Ala'M, A. A. Heidari, M. Habib, H. Faris, I. Aljarah, and M. A. Hassonah. "Salp Chain-Based Optimization of Support Vector Machines and Feature Weighting for Medical Diagnostic Information Systems", in Evolutionary Machine Learning Techniques, Springer, 2020, pp. 11–34.

[20] O. Stromann, A. Nascetti, O. Yousif, and Y. Ban. "Dimensionality Reduction and Feature Selection for Object-Based Land Cover Classification based on Sentinel-1 and

Sentinel-2 Time Series Using Google Earth Engine". Remote Sensing, vol. 12, no. 1, p. 76, 2020.
[21] D. Ö. Şahin and E. Kılıç. "Two new feature selection metrics for text classification". Automatika, vol. 60, no. 2, pp. 162–171, 2019.
[22] M. A. Hassonah, R. Al-Sayyed, A. Rodan, A.-Z. Ala'M, I. Aljarah, and H. Faris, "An efficient hybrid filter and evolutionary wrapper approach for sentiment analysis of various topics on Twitter". Knowledge-Based Systems, vol. 192, p. 105353, 2020.
[23] Y. Piao et al., "A new ensemble method with feature space partitioning for high-dimensional data classification". Mathematical Problems in Engineering, vol. 2015, 2015.
[24] Y. B. Wah, N. Ibrahim, H. A. Hamid, S. Abdul-Rahman, and S. Fong. "Feature Selection Methods: Case of Filter and Wrapper Approaches for Maximising Classification Accuracy. ". Pertanika Journal of Science & Technology, vol. 26, no. 1, 2018.
[25] A. K. Uysal. "On two-stage feature selection methods for text classification". IEEE Access, vol. 6, pp. 43233–43251, 2018.
[26] J. Xie and C. Wang. "Using support vector machines with a novel hybrid feature selection method for diagnosis of erythemato-squamous diseases". Expert Systems with Applications, vol. 38, no. 5, pp. 5809–5815, 2011.
[27] H. Ogura, H. Amano, and M. Kondo. "Distinctive characteristics of a metric using deviations from Poisson for feature selection". Expert Systems with Applications, vol. 37, no. 3, pp. 2273–2281, 2010.
[28] C. Huang, J. Zhu, Y. Liang, M. Yang, G. P. C. Fung, and J. Luo. "An efficient automatic multiple objectives optimization feature selection strategy for internet text classification". International Journal of Machine Learning and Cybernetics, vol. 10, no. 5, pp. 1151–1163, 2019.
[29] Z. Zheng and R. Srihari. "Optimally combining positive and negative features for text categorization", in ICML 2003 Workshop, 2003.
[30] A. K. Uysal and S. Gunal. "A novel probabilistic feature selection method for text classification". Knowledge-Based Systems, vol. 36, pp. 226–235, 2012.
[31] A. Melo and H. Paulheim. "Local and global feature selection for multilabel classification with binary relevance". Artificial intelligence review, vol. 51, no. 1, pp. 33–60, 2019.
[32] M. mojaveriyan, H. Ebrahimpour-Komleh, and S. jalaleddin Mousavirad. "Text Feature Selection using Document Frequency and Colonial Competitive Algorithm", in 8th National Conference on Data Mining, At Amirkabir University of Technology, Tehran, Iran, 2014.
[33] Ö. Uncu and I. B. Türkşen. "A novel feature selection approach: combining feature wrappers and filters". Information Sciences, vol. 177, no. 2, pp. 449–466, 2007.
[34] Y. Zhou, G. Cheng, S. Jiang, and M. Dai, "Building an Efficient Intrusion Detection System Based on Feature Selection and Ensemble Classifier". Computer Networks, p. 107247, 2020.
[35] V. Bolon-Canedo, N. Sanchez-Marono, and A. Alonso-Betanzos. "Feature selection and classification in multiple class datasets: An application to KDD Cup 99 dataset". Expert Systems with Applications, vol. 38, no. 5, pp. 5947–5957, 2011.
[36] A. Onan, S. Korukoğlu, and H. Bulut. "Ensemble of keyword extraction methods and classifiers in text classification". Expert Systems with Applications, vol. 57, pp. 232–247, 2016.
[37] K. Kurniabudi, A. Harris, and A. Rahim. "Seleksi Fitur Dengan Information Gain Untuk Meningkatkan Deteksi Serangan DDoS menggunakan Random Forest". Techno. Com, vol. 19, no. 1, pp. 56–66, 2020.
[38] T. Z. Win and N. S. M. Kham. "Information Gain Measured Feature Selection to Reduce High Dimensional Data", in Seventeenth International Conference on Computer Applications (ICCA 2019), 2019.
[39] B. Z. Abbasi, S. Hussain, S. Bibi, and M. A. Shah. "Impact of Membership and Non-membership Features on Classification Decision: An Empirical Study for Appraisal of Feature Selection Methods", in 2018 24th International Conference on Automation and Computing (ICAC), 2018, pp. 1–6.
[40] G. Kou, P. Yang, Y. Peng, F. Xiao, Y. Chen, and F. E. Alsaadi. "Evaluation of feature selection methods for text classification with small datasets using multiple criteria decision-making methods". Applied Soft Computing, vol. 86, p. 105836, 2020.
[41] A. K. Uysal and S. Gunal. "A novel probabilistic feature selection method for text classification". Knowledge-Based Systems, vol. 36, pp. 226–235, 2012.
[42] B. Tang, S. Kay, and H. He. "Toward optimal feature selection in naive Bayes for text categorization". IEEE transactions on knowledge and data engineering, vol. 28, no. 9, pp. 2508–2521, 2016.
[43] K. D. Rosa and J. Ellen. "Text classification methodologies applied to micro-text in military chat", in 2009 International Conference on Machine Learning and Applications, 2009, pp. 710–714.
[44] D. Sarkar. "Text Classification", in Text Analytics with Python, Springer, 2019, pp. 275–342.
[45] S. A. Verma, G. T. Thampi, and M. Rao. "Efficacy of a Classical and a Few Modified Machine Learning Algorithms in Forecasting Financial Time Series", in Internet of Things, Smart Computing and Technology: A Roadmap Ahead, Springer, 2020, pp. 3–30.
[46] M. Swamynathan. Mastering machine learning with python in six steps: A practical implementation guide to predictive data analytics using python. Apress, 2019.

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An Approach to Improve the Quality of Service in DTN and Non-DTN based VANET

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Abstract
Nowadays, with attention to soar in the number of network users, it is necessary to find new approaches to revolutionize network operation. Vehicular ad-hoc networks are bound to play a pivotal role in communication, therefore raising the traffic in the network, using only WiFi is unlikely to address this problem. Vehicles could use SDN and other networks such as 4G as well as 5G to distribute traffic to different networks. Moreover, many approaches for handling different data types are inappropriate due to the lack of attention to the data separation idea. In this paper, we proposed a control scheme called Improve Quality of Service in DTN and Non-DTN (IQDN) which works based on vehicle communication infrastructure using SDN idea. IQDN separates data to Delay-Tolerant Data (DTD), and Delay-Intolerant Data (DID) where the former buffers in a vehicle till the vehicle enters an RSU range and sends DTD using IEEE 802.11p. DID packets are sent by cellular networks and LTE. To transmit DTD via IEEE 802.11p, the network capacity is evaluated by SDN. If that network has room to transmit the data, SDN sends a control message to inform the vehicle. Simulations show that sending data over RSU and LTE increases the throughput and decreases the congestion, so the quality of service improves.

Keywords: DTN; Vehicular communications; LTE; IEEE 802.11p; SDN.

1- Introduction

Dedicated Short Range Communication (DSRC) based on IEEE 802.11p is used by vehicle communication [1]. Vehicular Ad-hoc Network is a subset of Mobile Ad-hoc Network, which is attractive for researchers due to challenges, features as well as different applications [2]. With rising in the number of network users, we need new approaches for managing network traffic and satisfy QoS's requirements. Using networks like 4G beside IEEE 802.11p could increase the available bandwidth in the network. Using SDN also could decrease the needed processing power; consequently, it helps to decrease overhead in the network. Communications in VANET are divided into Vehicle-to-Vehicle (V2V) as well as Vehicle-to-Infrastructure (V2I). Vehicles of V2I communication could send/receive data both via the IEEE 802.11p protocol as well as the 3G/3.5G/4G cellular network [3]. Vehicles could communicate with the internet via WiFi as well as LTE and due to demand for fast internet it can be possible to propose the ways that enable vehicles to gain benefit from both infrastructures, so both WiFi and LTE offloading could be an appropriate response for improving circumstances in VANET [5]. In [6] Huang and his colleagues used Handover Decision based on Software-Defined Network (OHD–SDN) for offloading from the cellular network to WiFi 802.11p. In this scheme, the main issue is IEEE 802.11p offloading and there are some defects and challenges: 1) The simulation in this scheme is different from the real scenario (urban or highway scenario). 2) There is no attention to the other aspects of quality of services such as Delay and Jitter. 3) With rising in the number of traffic by nodes, packet loss increases significantly. In our scheme, vehicles use LTE and IEEE 802.11p. Moreover, to make handoff decisions, we use the Software-Defined Network (SDN) [7]. We consider both Delay-Tolerant Data (DTD) and Delay-Intolerant Data (DID) in the network. Vehicles send and receive DID via 3G/3.5G/4G cellular network, while DTD is sent via RSUs and Wi-Fi 802.11p. Vehicles send control messages to SDN and give their information to it; therefore, the SDN controller is constantly being aware of the vehicles. A vehicle sends a connection request to the SDN controller before it reaches the RSU. The SDN controller calculates arriving time and distance to the RSU and sends them to the vehicle before entering the RSU range. So the vehicle knows its distance and its arrival time to the RSU. Afterward, the SDN controller decides whether that

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vehicle is allowed to send data through IEEE 802.11p or not. This decision depends on the IEEE 802.11p bandwidth. If there is no available bandwidth, the SDN controller does not grant permission to the vehicle to connect to the RSU, so the vehicle should wait for the next RSU. The simulation of our proposed scheme shows improvement in the quality of service in the network.

The paper is organized as follows: In the second section, we have a review of the related works. In the third section, we introduce the architecture of the network. In the fourth section, the pattern of sending delay tolerant data is introduced and in the fifth section, the simulation and evaluation of our proposed scheme in comparison to other schemes are stated.

2- Related Work

In [8], a routing plan to prevent congestion is presented. In this scheme, a part of vehicle routing is calculated and it makes a balance between user privacy and re-routing procedure. In [9], the authors present cellular networks as well as WiFi roaming decisions and AP selection based on IEEE 802.11u as well as the 3GPP network. It helps mobile nodes to decide roaming in the network at the right time. Also, authors in [10] provided a way to improve mobile data offloading. Authors in [11], [12] presented an offloading decision considering the availability of V2I capacity as well as QoS of V2V, the data volume, and the connection time between vehicles and RSUs. To manage the time and resources in heterogeneous vehicles, the authors in [13] used SDN, and they reduced the communication cost. In [14], authors with an opportunistic network approach, offer a way for stream offloading from the cellular network to WiFi. Park et al. [15] used SDN to present a centralized routing architecture to network traffic and also reduce packet loss. In [16], a resource allocation process has been introduced, including link scheduling and link bandwidth for short-term communication in VANET. In [17], the authors proposed a protocol that collects and distributes the data generated by the heterogeneous LTE and DSRC as well as the LTE offloading on the network. In [18], an approach has been introduced, in which, vehicles try to have the best connection choice in an urban environment and heterogeneous network, which aims to provide continuous access to services and reduce connection costs. Bravo et al. [19] provided an approach to offloading mobile data based on a virtualization layer in the communication protocol stack, as well as a routing protocol that combines topology and geography. This approach decreased overhead and delay in an urban environment and it increased data rate in the network. Authors in [20] presented an approach to guarantee the quality of service for mobile data and to balance between mobile data and QoS for vehicular cyber-physical systems (VCPSs). In [21], a cheap approach has been proposed for offloading data from the cellular network to WiFi. In [22], the authors presented a plan for WiFi offloading as well as switching in cellular networks and WiFi. They aim to raise capacity, improve transmission rate, and decrease cost and energy consumption in the network. In [23], the authors implemented the VANET network predicting the WiFi offloading. Authors in [24], [25] presented an approach, where SDN is used for mobile data offloading and routing respectively in VANET. In [26], the authors presented a smart network, which evaluates massive data and helps vehicles to make appropriate decisions to access the network. In [27], the authors proposed an algorithm that helps vehicles to use 4G LTE and WiFi and make communication among vehicles and infrastructure. Bazzi et al. [28], used virtual RSUs to decrease exchange data in the network, consequently, the packet transmission rate to RSU is improved. In [29], the authors presented data offloading in a cellular network to stream data in VANET.

3- Network Architecture and Overview to the Scheme

In this section network configuration as well as the general idea of our scheme is proposed. As known LTE covers a wider area than RSUs, so it is possible to employ them for communication in VANET. As can be seen in Fig.1, vehicles are connected to cellular networks and RSU for transmitting their packets. Considering the quality of service, the vehicles transmit DID via LTE, while they buffer DTD until they can transmit them through RSU. Offloading from LTE to IEEE 802.11p raises these questions:

1) When and how we should make a decision?
2) How to inform vehicles about RSUs information?

To do this, we employed the SDN controller for calculations, and it is assumed that vehicles are equipped with GPS so they are always informed

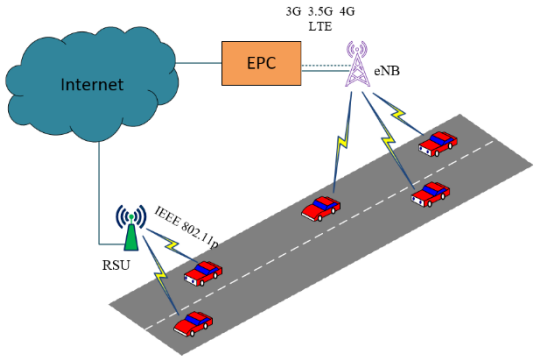

Fig. 1 Network Architecture

about their location. Furthermore, the vehicles send their location, direction, and speed to the SDN controller periodically. As a result, SDN has adequate information about vehicles and RSUs, and it evaluates the bandwidth of IEEE 802.11p network.

The vehicles usually transmit DID through LTE, however, for transmitting DTD, they initially send a request to the SDN for connecting to RSU. Consequently, the SDN sends a response to the vehicle, determining that the vehicle has permission to connect to RSU or not.

The request message includes vehicle demand to connect to IEEE 802.11p, its location, direction, and speed. Afterward, the vehicle waits for the response from SDN. Receiving a request from a vehicle, SDN calculates its arriving time to the nearest RSU and available IEEE 802.11p bandwidth. Consequently SDN makes two decisions:

1) If IEEE 802.11p has available bandwidths, the vehicle has permission to connect, so the vehicle could transmit its buffered packets via the RSU. Leaving the RSU covered area; the vehicle disconnects its link and sends a message containing RSU ID, the volume of transmitting data, and the RSU connection time to SDN.
2) If IEEE 802.11p has no available bandwidth, the SDN controller does not grant permission to the vehicle to connect to RSU. Therefore, the vehicle should buffer its DTD and waits for the next RSU.

A significant proportion of the data are DTD, where buffering them decreases traffic on the 3G/3.5G/4G LTE network.

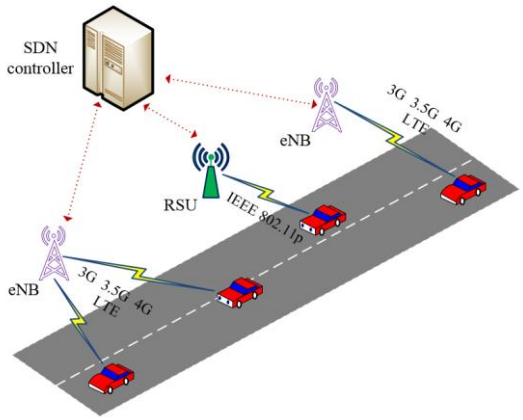

Fig. 2 Vehicles are connected to the SDN controller to exchange control messages

4- Process of Transmitting DTD

In this section, we introduce the SDN controller computations.

4-1- Arriving Time and Distance to the RSU Relation

Having periodic messages, the SDN controller could calculate the average speed of a vehicle:

$$V_{ave} = \frac{v_1+v_2\cdots+v_n}{n} \quad (1)$$

V_{ave} is the average vehicle speed. To calculate vehicle-RSU distance we consider the range of RSU's signal as a globe with the center of its antenna and the radius of its coverage range.

Vehicles move in two directions, so they are on a plate intersecting with the globe. If $O(x_0, y_0, z_0)$ is considered as the globe center, (2) shows the globe equation with a radius of r [30]:

$$(X - x_0)^2 + (Y - y_0)^2 + (Z - z_0)^2 = r^2 \quad (2)$$

Furthermore, if L-plate passes through point $A(x_2, y_2, z_2)$ and the vector n(a, b, c) be perpendicular on that and consider the optional point $Q(x, y, z)$ on this plate, so Q is on the L-plate if and only if dimensions n and $\overrightarrow{AQ}$ be perpendicular [30]. Therefore:

$$\overrightarrow{AQ} = (x - x_2,\ y - y_2,\ z - z_2), n(a,\ b,\ c)$$
$$\rightarrow\ n \perp \overrightarrow{AQ} \rightarrow n.\overrightarrow{AQ} = 0 \quad (3)$$

As a result equation L-plate which passes through a certain point such as $A(x_2, y_2, z_2)$ and is perpendicular to the inverse vector $n(a, b, c)$ has shown in (4) [30]:

$$a(x - x_2) + b(y - y_2) + c(z - z_2) = 0 \quad (4)$$

By expanding the plate equation as follows:

$$ax + bx + cx = ax_2 + by_2 + cx_2$$

$$\xrightarrow{ax_2+by_2+cx_2 = w} ax + bx + cx = w \quad (5)$$

We consider the road surface in xoy-plate and d as the height of RSU in the direction of the Z-axis, the intersection between the globe equation and plate equation is a circle [30].

Consider $O(x_0, y_0, z_0)$ as the center of the globe, and then a globe with the center of the RSU and its range is as follows:

$$(X - x_0)^2 + (Y - y_0)^2 + (Z - z_0)^2 = R^2 \quad (6)$$

Also, the plate equation is obtained as follows:

$$Z = d \quad (7)$$

With the intersection of (6) and (7) we have:

$$(X - x_0)^2 + (Y - y_0)^2 + (d - z_0)^2 = R^2 \quad (8)$$

In table-1 we can see the parameters that are used in equations.

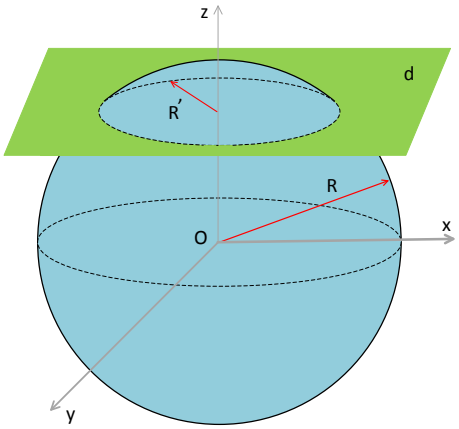

Fig. 3 A circle is obtained from the intersection of the plate and the globe

Table 1: parameters which are used

V_{ave}	Average vehicle speed
d'	Distance between center of the circle and vehicle crossing route
d	Height of RSU from road surface
R'	RSU range radius
|M|	Distance to RSU range
T_v	Arriving time to RSU
C	Half of distance which RSU signal covers
T_m	Covering time by RSU

By expanding the equation (8) we have:

$$(X - x_0) + (Y - y_0) = R'^2 \quad (9)$$

Equation (9) is the circle of RSU coverage on the road, if $V(x_v, y_v)$ be the vehicle's location, we can calculate the distance between the vehicle and the center of the circle as follows:

$$|\overrightarrow{VO}| = \sqrt{(x_0 - x_v)^2 + (y_0 - y_v)^2} \quad (10)$$

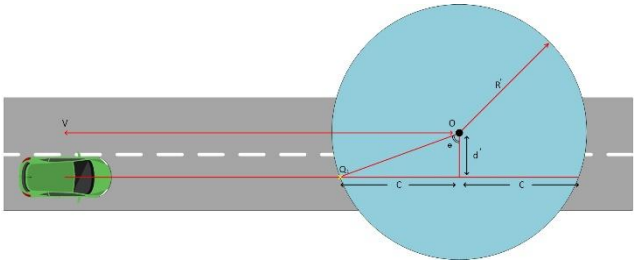

Fig. 4 Distance between the vehicle and RSU range

By subtracting R' (radius of RSU range) from $|\overrightarrow{VO}|$, the distance to RSU range is achieved and it is named as *M*.

$$|M| = \left| |\overrightarrow{VO}| - |R'| \right| \quad (11)$$

As it can be seen in Fig.4, and supposing that the vehicle moves in the X-axis direction, to calculate its arriving time to RSU range, *M* should be considered as well. We assume $Q_1(x_1, y_1)$ as the point of entering the vehicle to RSU range and T_v as its arriving time:

$$Q_1(x_1, y_1) = (x_v + |M|, y_v),\ T_v = \frac{|M|}{V_{ave}} \quad (12)$$

To calculate covering time by RSU signal, initially, d' should be considered:

$$|d'| = |y_0 - y_1| \quad (13)$$

With attention to $R \sin\theta = d'$ as well as $\tan\theta = \frac{C}{d'}$, we calculate θ and C. Therefore, $2C$ is the approximate distance in which the RSU signal covers the vehicle. T_m as

the covering time by RSU is the maximum time for the vehicle which can transmit packets via RSU.

$$T_m = \frac{2C}{V_{ave}} \quad (14)$$

4-2- IEEE 802.11p Capacity

IEEE 802.11p bandwidth is limited; therefore, all vehicles that need to transmit data should seek permission from the SDN controller. Suppose its bandwidth is 4Mbps, and four vehicles are connected to the RSU and they all are sending packets with the rate of 1Mbps. The SDN controller does not grant permission to the fifth vehicle due to the lack of available bandwidth. To do this, the SDN controller should constantly be aware of the network capacity to calculate the number of connected vehicles, as well as the number of their transmission rates. When a vehicle sends a request, the SDN controller at a duration time between request and arriving at RSU range calculates the volume of data that is transmitted. In the following equation, h_k is the volume of data that is sent by *k*th vehicle via RSU, and F(i) is the sum of data that is sent by *n* vehicles.

$$F(i) = \sum_{k=1}^{n} h_k \quad (15)$$

Consider t_k as the connection time between *k*th vehicle and the RSU, therefore, $F(t)$ is the average of RSU connection time for *n* vehicle.

$$F(t) = \frac{1}{n}\sum_{k=1}^{n} t_k \quad (16)$$

IEEE 802.11p bandwidth capacity, which is called FG is determined by:

$$FG(i,t) = n\sum_{k=1}^{n} \frac{h_k}{t_k} \quad (17)$$

4-3- Communication Among Vehicles and SDN Controller

In this section, we express handoff decisions in the network. As we can see in the flowchart, initially the vehicle should send a request to the SDN controller. Afterward, the controller sends a message to the vehicle containing distance to RSU range, covering the time by RSU, and arriving time to RSU. Before entering the vehicle into RSU range, if IEEE 802.11p has available bandwidth, the SDN controller informs the vehicle and the handoff procedure from the cellular network to RSU will be done. Consequently, the vehicle transmits its packets via RSU and after exiting from RSU coverage, it switches back to the cellular network. The vehicle should send its RSU connection time as well as its packet quantity to the SDN controller.

SDN controller considers a threshold value for allocating bandwidth for the vehicles. If FG_{TH} be that threshold:

$$FG_{TH} = FG + 1 \quad (18)$$

Based on FG_{TH}, the SDN controller decides if the vehicle is allowed to connect to RSU or not. If FG_{TH} is less than the IEEE 802.11p bandwidth, the SDN controller grants connection permit for the vehicle.

Receiving a request from a vehicle, the SDN controller makes many calculations which can be seen in Algorithm 1. Algorithm 2 shows how the SDN controller decides for a handoff between the cellular network and RSU.

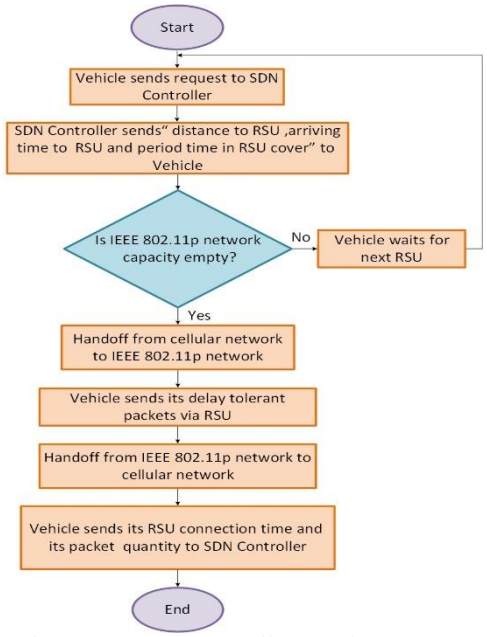

Fig. 5 The flowchart shows the handoff process from cellular network to RSU

Algorithm 1: Calculations before making handoff decisions

1. Send REQ to SDN for connection to RSU
2. Calculate RSU coverage: $(X - x_0) + (Y - y_0) = R^2$
3. Vehicle to RSU distance:
$|\overrightarrow{VO}| = \sqrt{(x_0 - x_v)^2 + (y_0 - y_v)^2}$
4. Distance from vehicle to RSU signal: $|M| = \left||\overrightarrow{VO}| - |R^{'}|\right|$
5. Time which vehicle reaches to RSU signal: $T_v = \frac{|M|}{V_{ave}}$
6. Maximum vehicle remaining time in RSU coverage: $T_m = \frac{2C}{V_{ave}}$
7. SDN sends T_v, T_m *and* $|M|$ to vehicle
8. Return

Algorithm 2: Making decision for handoff from cellular network to RSU

1. SDN controller receives data from vehicles
2. Calculates $V(i), V(t)$ *and* $VC(i,t)$
3. Calculates FG_{TH}: $FG_{TH} = FG + 1$
4. **if** $FG_{TH} < IEEE802.11p\ Bandwidth$
5. | Vehicle connect to RSU
6. **else** End

5- Simulation

As [31] and [32], we employed the NS-3 software and C++ program for simulation, and we investigate a VANET in a highway as our scenario using both LTE and IEEE 802.11p. The size of the area is considered 30*10000 square meters using 80 nodes with a speed of 20 m/s, also there were 20 nodes per kilometer, and followed them throughout the highway. We use two RSUs connected via a wired network. Each vehicle has a corresponding node to send and receive packets. LTE network has two EnodeB and is connected to the Internet. RSU range is 250 meters and all areas are covered by LTE. Vehicles generate two types of data: 1) DID which is transmitted with the rate of 64Kbps with 160 Byte packet sizes, 2) DTD which is transmitted with the rate of 1Mbps, and 1000Byte packet sizes, as a result, we considered a scenario with high congestion. Table.2 shows the simulation parameters. Furthermore, we executed the scenario 4 times and we consider the time of simulation 450 seconds, in which the last vehicle passes 10Km of the road.

Table 2: Simulation parameters

Parameter	Value
Road Size (m)	30*10000
Vehicle Speed (m/s)	20
Number of Vehicles (vehicle/Km)	20
RSU Range (m)	250
Number of RSUs	2
Packet Size (byte)	160/1000
Data Sending Rate	64 Kbps/ 1 Mbps
Cellular Network	LTE
RSU Bandwidth (Mbps)	6
Cellular Bandwidth (Mbps)	18
Simulation Time (s)	450
Number of Simulation	4

5-1- Simulation Result and Evaluation

For evaluating our scheme, we tried to evaluate all significant QoS parameters, IQDN is compared with OHD-SDN as well as Naive which are presented in [6]. Fig. 6 to Fig. 9 illustrate delay, jitter, packet loss, and throughput in three schemes respectively. It can be seen that our scheme has a significant decline in delay, jitter, and packet loss due to a decrease in traffic on LTE. Furthermore, our scheme has a higher throughput than the other two schemes. Fig.10 also shows the total data received at the destination which illustrates our scheme has more capacity rather than other schemes. After that, we compared DTD in the network. Fig. 12 shows packet loss in the network, which decreased significantly, while Fig. 11 shows a significant improvement in throughput on the network. That is because both OHD-SDN and Naive transmit their packets via LTE at any time, and when a vehicle arrives in RSU range either transmit packets via RSU (Naive) or if the situation in IEEE 802.11p is not appropriate stay in LTE and transmit packets via the cellular network (OHD-SDN), so, many packets are lost in the network. In contrast, in IQDN vehicles buffer their packets to transmit those using high reliability and QoS guaranteed network.

Fig. 13 shows the volume of data received by nodes in the network. In our scheme destination nodes receives less data rather than other schemes, because the vehicles in the network have limited time for connecting to RSU so it is clear that lower data will be transmitted.

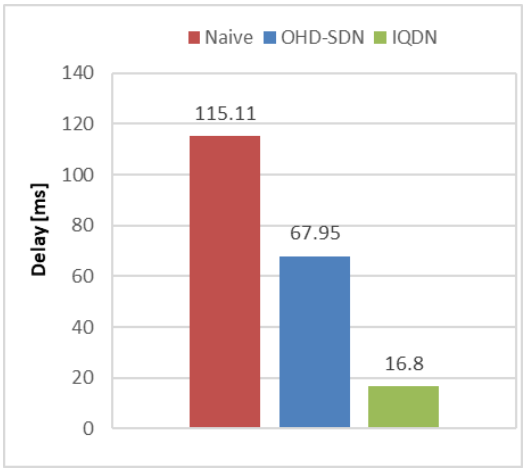

Fig. 6 Delay comparison in network

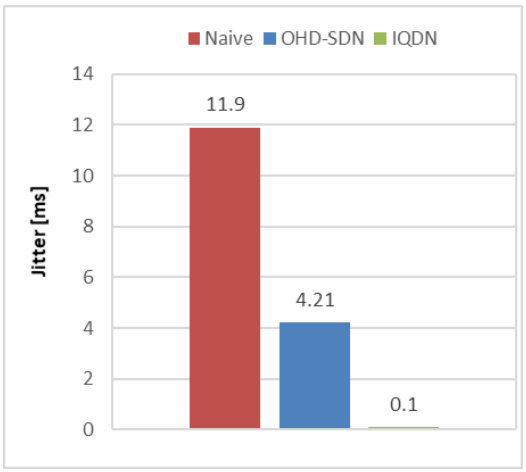

Fig. 7 Comparison of Jitter in network

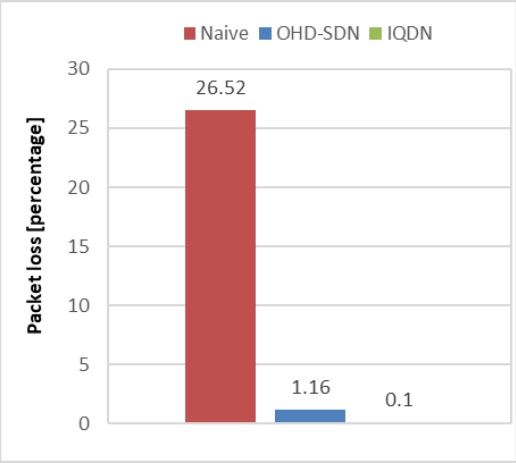

Fig. 8 Packet loss in network

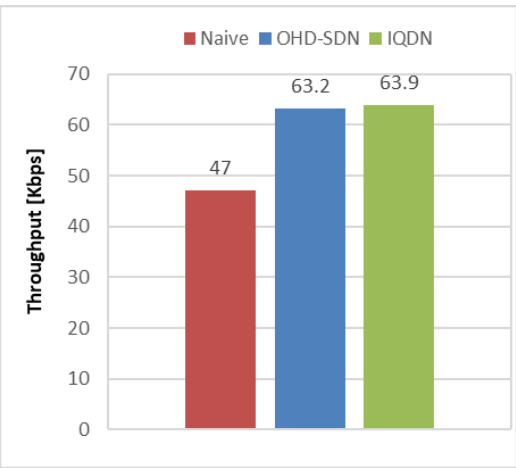

Fig. 9 Throughput in network

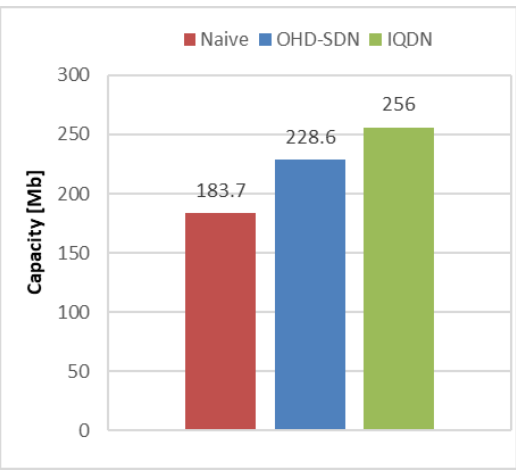

Fig. 10 Capacity in network

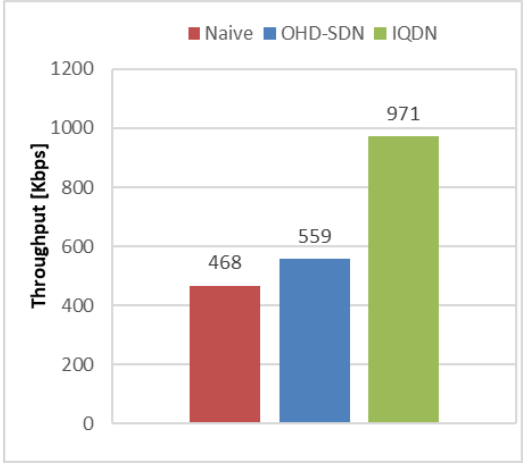

Fig. 11 Throughput in network

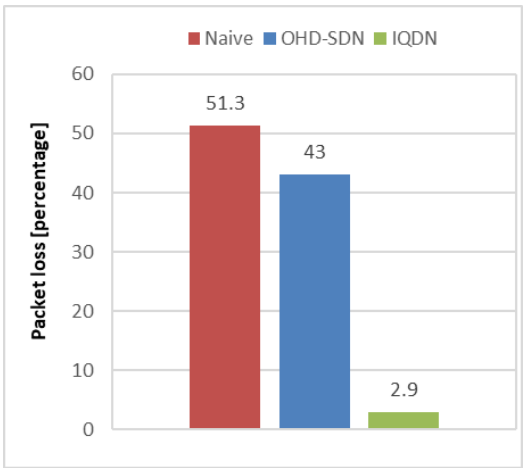

Fig. 12 Packet loss in network

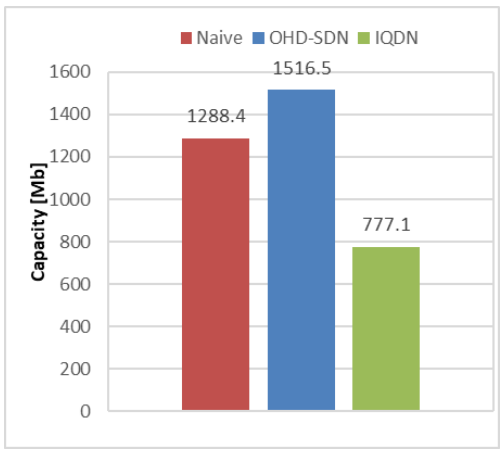

Fig. 13 Capacity in network

6- Conclusion

IQDN considered data into two categories, Delay-Intolerant Data (DID) as well as Delay-Tolerant Data (DTD) and treat them differently. It uses the SDN controller, LTE, and IEEE 802.11p to distribute traffic on the network. In this scheme, the vehicle sends DID just via LTE while DTD is sent through RSUs. For sending DTD via RSU, SDN evaluates capacity in IEEE 802.11p, then SDN decides to permit the vehicle to connect to RSU or not. IQDN with separate data in the network and using SDN for evaluating traffic in IEEE 802.11p can distribute traffic in the network efficiently. It also, decreases the traffic and improves the quality of service in the network. IQDN revolutionizes Jitter, Delay, Packet Loss, and Throughput in comparison with similar schemes. Using simple equations, IQDN grants permission for a vehicle to transmit its data to RSU or LTE. It showed higher protocol performance compared with two other schemes via simulation. For future work, the Epidemic protocol can be used for DTN so each vehicle sends its packet to another vehicle via V2V communication. It is expected to have high network capacity, with higher overhead in the network.

References

[1] X. Wu, S. Subramanian, R. Guha, R. G. White, J. Li, K. W. Lu, A. Bucceri, and T. Zhang, "Vehicular Communications Using DSRC: Challenges, Enhancements, and Evolution," IEEE Journal on Selected Areas in Communications, VOL.31, pp. 399–408, 09 2013.

[2] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, "A Comprehensive Survey on Vehicular Ad Hoc Network," Journal of Network and Computer Applications, VOL. 37, pp. 380–392, 01 2014.

[3] P. Matzakos, J. Hrri, B. Villeforceix, and C. Bonnet, "An IPv6 Architecture for Cloud-to-Vehicle Smart Mobility Services over Heterogeneous Vehicular Networks," Proceedings of 2014 International Conference on Connected Vehicles and Expo (ICCVE), pp. 767–772, Nov 2014.

[4] N. Cheng, N. Lu, N. Zhang, X. S. Shen, and J. W. Mark, "Opportunistic WiFi Offloading in Vehicular Environment: A Queueing Analysis," Proceedings of 2014 IEEE Global Communications Conference, pp. 211–216, Dec 2014.

[5] K. Lee, J. Lee, Y. Yi, I. Rhee, and S. Chong, "Mobile Data Offloading: How Much Can WiFi Deliver?" IEEE/ACM Transactions on Networking, VOL. 21, pp. 536–550, 04 2013.

[6] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, H. Zedan, "Vehicle-to-Infrastructure (V2I) Offloading from Cellular Network to 802.11p Wi-Fi Network based on the Software-Defined Network (SDN) Architecture," Vehicular communications, VOL. 9, pp. 288–300, 07 2017.

[7] D. Kreutz, F. M. V. Ramos, P. E. Verssimo, C. E. Rothenberg, S. Azodolmolky, and S. Uhlig, "Software-Defined Networking: A Comprehensive Survey," Proceedings of the IEEE, VOL. 103, NO. 1, pp. 14–76, Jan 2015.

[8] J. Pan, I. S. Popa, and C. Borcea, "DIVERT: A Distributed Vehicular Traffic Re-Routing System for Congestion Avoidance," IEEE Transactions on Mobile Computing, VOL. 60, NO. 1, pp. 58-72, Jan. 1 2017.

[9] N. Nguyen, M. Arifuzzaman, and T. Sato, "A Novel WLAN Roaming Decision and Selection Scheme for Mobile Data Offloading," Journal of Electrical and Computer Engineering, VOL. 2015, Article ID 324936, pp. 1–15, 2015.

[10] A. Aijaz, H. Aghvami, and M. Amani, "A Survey on Mobile Data Offloading: Technical and Business Perspectives," IEEE Wireless Communications, VOL. 20, NO. 2, pp. 104–112, April 2013.

[11] G. e. m. Zhioua, H. Labiod, N. Tabbane, and S. Tabbane, "A Traffic QoS Aware Approach for Cellular Infrastructure Offloading using VANETs," Proceedings of the 22nd IEEE International Symposium of Quality of Service (IWQoS), pp. 278–283, May 2014.

[12] G. E. M. Zhioua, H. Labiod, N. Tabbane, and S. Tabbane, "Cellular Content Download through A Vehicular Network: I2V Link Estimation," Proceedings of the 81st IEEE Vehicular Technology Conference (VTC Spring), pp. 1–6, May 2015.

[13] Z. He, D. Zhang, and J. Liang, "Cost-Efficient Sensory Data Transmission in Heterogeneous Software-Defined Vehicular Networks," IEEE Sensors Journal, VOL. 16, NO. 20, pp. 7342–7354, 10 2016.

[14] D. Suh, H. Ko, and S. Pack, "Efficiency Analysis of WiFi Offloading Techniques," IEEE Transactions on Vehicular Technology, VOL. 65, NO. 5, pp. 3813–3817, 05 2016.

[15] S. M. Park, S. Ju, and J. Lee, "Efficient Routing for Traffic Offloading in Software-Defined Network," Procedia Computer Science, VOL. 34, pp. 674–679, 2014.

[16] J. Chen, B. Liu, L. Gui, F. Sun, and H. Zhou, "Engineering Link Utilization in Cellular Offloading Oriented VANETs," Proceedings of 2015 IEEE Global Communications Conference (GLOBECOM), pp. 1–6, Dec 2015.

[17] P. Salvo, I. Turcanu, F. Cuomo, A. Baiocchi, and I. Rubin, "Heterogeneous Cellular and DSRC Networking for Floating Car Data Collection in Urban Areas," Vehicular Communications, 2016.

[18] A. Mabrouk, A. Kobbane, E. Sabir, J. Ben-Othman, and M. El Koutbi, "Meeting Always-Best-Connected Paradigm in Heterogeneous Vehicular Networks: A Graph Theory and A Signaling Game Analysis," Vehicular Communications, VOL. 5, pp. 1–8, 2016.

[19] J. F. Bravo-Torres, J. V. Sains-Vzquez, M. Lpez-Nores, Y. Blanco-Fernndez, and J. J. Pazos-Arias, "Mobile Data Offloading in Urban VANETs on Top of A Virtualization Layer," Proceedings of 2015 International Wireless Communications and Mobile Computing Conference (IWCMC), pp. 291–296, Aug 2015.

[20] S. Wang, T. Lei, L. Zhang, C.-H. Hsu, and F. Yang, "Offloading Mobile Data Traffic for QoS-Aware Service Provision in Vehicular Cyber-Physical Systems," Future Generation Computer Systems, VOL. 61, pp. 118–127, 08 2016.

[21] H. Park, Y. Jin, J. Yoon, and Y. Yi, "On The Economic Effects of User-Oriented Delayed Wi-Fi Offloading," IEEE Transactions on Wireless Communications, VOL. 15, NO. 4, pp. 2684–2697, 04 2016.

[22] Y. He, M. Chen, B. Ge, and M. Guizani, "On WiFi Offloading in Heterogeneous Networks: Various Incentives and Trade-Off Strategies," IEEE Communications Surveys Tutorials, VOL. 18, NO. 4, pp. 2345–2385, Fourthquarter 2016.

[23] N. Cheng, N. Lu, N. Zhang, X. Zhang, X. S. Shen, and J. W. Mark, "Opportunistic WiFi Offloading in Vehicular Environment: A Game-Theory Approach," IEEE Transactions on Intelligent Transportation Systems, VOL. 17, NO. 7, pp. 1944–1955, 07 2016.

[24] J. Cho, B. Nguyen, A. Banerjee, R. Ricci, J. Van der Merwe, and K. Webb, "SMORE: Software-Defined Networking Mobile Offloading Architecture," Proceedings of the 4th Workshop on All Things Cellular: Operations, Applications, and Challenges, AllThingsCellular '14, (New York, NY, USA), pp. 21–26, ACM, 2014.

[25] A. U. Khan and B. K. Ratha, "Time Series Prediction QoS Routing in Software-Defined Vehicular Ad-Hoc Network," Proceedings of 2015 International Conference on Man and Machine Interfacing (MAMI), pp. 1–6, Dec 2015.

[26] Y. Liu, X. Chen, C. Chen, and X. Guan, "Traffic Big Data Analysis Supporting Vehicular Network Access Recommendation," Proceedings of 2016 IEEE International Conference on Communications (ICC), pp. 1–6, May 2016.

[27] G. e. m. Zhioua, H. Labiod, N. Tabbane, and S. Tabbane, "VANET Inherent Capacity for Offloading Wireless Cellular Infrastructure: An Analytical Study," Proceedings of the 6th International Conference on New Technologies, Mobility and Security (NTMS), pp. 1–5, March 2014.

[28] A. Bazzi, B. M. Masini, A. Zanella, and G. Pasolini, "Virtual Road Side Units for Geo-Routing in VANETs," Proceedings of 2014 International Conference on Connected Vehicles and Expo (ICCVE), pp. 234–239, Nov 2014.

[29] G. el Mouna Zhioua, J. Zhang, H. Labiod, N. Tabbane, and S. Tabbane, "VOPP: A VANET Offloading Potential Prediction Model," Proceedings of 2014 IEEE Wireless Communications and Networking Conference (WCNC), pp. 2408– 2413, April 2014.

[30] G. Thomas, R. Finney. Calculus and Analytic Geometric: Addison-Wesley, 1988.

[31] R. Fernandes and M. Ferreira, "Scalable VANET Simulations with NS-3," Proceedings of the 75th IEEE Vehicular Technology Conference (VTC Spring), pp. 1–5, May 2012.

[32] H. Arbabi and M.C. Weigle, "HIGHWAY MOBILITY AND VEHICULAR AD-HOC NETWORKS IN NS-3," Proceedings of the 2010 Winter Simulation Conference, pp. 5-8 Dec. 2010.

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Low Complex Standard Conformable Transceiver based on Doppler Spread for DVB-T2 Systems

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Abstract
This paper addresses a novel Alamouti space-frequency block decoding scheme with discontinuous Doppler diversity (DDoD) and cyclic delay diversity (CDD). We investigate different antenna diversity concepts, which can be applied to orthogonal frequency division multiplexing (OFDM) systems over highly frequency selective channels. The main object of this research is standard compatibility and the effect of simple diversity techniques on the channel fading properties. Therefore, we analyze a receiver in terms of the effective channel transfer function, which leads to the possibility of optimizing diversity. Besides, a novel transceiver using DDoD is proposed, which increases the Doppler spread of the multipath fading channel without causing additional Intercarrier Interference (ICI). Moreover, an efficient Alamouti encoder and decoder based on CDD is proposed, which allows a high reliability and capacity enhancement. In order to evaluate the capability of that, we have implemented this scheme for the second-generation terrestrial video broadcasting (DVB-T2) system over different channels. Furthermore, mathematical analysis and simulation results show the bit error performance of the modified encoding method with these diversity techniques, performs mostly better than the other forms of encoding Alamouti over highly frequency-selective channels such as single frequency networks (SFN). The other advantages of the proposed method are simplicity, flexibility, and standard compatibility.

Keywords: SFBC; Transceivers; Diversity; MIMO; OFDM.

1- Introduction

The orthogonal frequency division multiplexing (OFDM) is known as an attractive modulation scheme for high-rate for transforming a frequency selective channel into multiple flat-fading channels [1], [2]. Moreover, multiple-input multiple-output (MIMO) is a very popular technology to increase communication reliability. Combining OFDM modulation with MIMO technology can be used to overcome the multipath distortion and increasing robustness over wireless fading channels [3]–[7] For this propose, the authors in [8] and [9] surveyed Space-time block codes (STBC) as a suitable multiple antenna technology. However, it needs processing at both transmitter and receiver.

To provide reliable transmission, some technologies like space-time coding are constrained with various designs such as the STBC transmission [10], [11]. Also, the Alamouti method with transmit antenna selection in flat Rayleigh fading channels is investigated in [5], [12], [13]. In [14], an improvement in the Alamouti method has been proposed by the combination of the Alamouti scheme and Bell Laboratories layered space-time (BLAST) methods based on using minimum mean square error (MMSE) detection. However, the results in [14] are valid only when the channel frequency response does not change over the entire Alamouti block code. It has also been shown in [15] that an SFBC-OFDM scheme and a finite-impulse response minimum-mean-square-error (FIR-MMSE) ICI cancellation algorithm can be used together for doubly-selective channels. It must be noted that the proposed solutions are not fully satisfactory due to incompatibility and inflexibility with standard systems such as digital system broadcasting. Also, the complexity of the equalizer will be increased to provide the satisfactory performance of the system for highly selective fading channels. In [16], the authors concentrated on turbo equalization receivers for frequency preceded collaborative spatial multiplexing (CSM) MIMO in the uplink of long term evolution advanced (LTE-A) system.

1-1- Motivation and Related Works

In recent years, different comparisons between theoretical and practical planning methods for DVB-T2 are presented

* Corresponding Author

in [17]–[20]. For instance, the authors in [17] proposed a new timing detection metric for frequency-selective fading. The symbol timing synchronization scheme was investigated to improve the estimation accuracy. Also, a rotated and cyclic Q-delayed (RCQD) quadrature amplitude modulation was proposed for DVB-T2 systems. Therefore, this system needs a sphere damping algorithm for fading channels, and the sphere-decoder is used for multiple input multiple output detection. As a result, the performance over fading channels can be improved. However, these methods improve the performance of the system with the considerable cost of complexity and time of the process, which makes critical problems for online broadcasting [21], [22]. Generally, the simple Alamouti decoding suffers from the time-variation of the channel, which is not necessarily flat over the entire Alamouti block code [19]. As a result, using the simple Alamouti decoding will cause performance degradation in such channels [23], [24]. Moreover, many multiple antenna technologies require processing at both transmitter and receiver [25], [26]. In practice, the delay diversity (DD) method, which is known as a simple method for increasing diversity, has been attracted as a simple and efficient method in the past few years [27], [28]. Other diversity techniques are cyclic delay diversity (CDD) and Discontinuous Doppler diversity (DDoD) [29], [30]. In fact, the idea of increasing diversity by using multiple transmit (Tx) antennas is not new. However, there is a lack of exploiting temporal diversity for DVB systems [31]. Therefore, the application of DDoD for DVB-T2 becomes attractive. Hence, there is still room for a much better decoding algorithm, increasing diversity, and exploiting standard compatibility methods.

1-2- Contributions and Organization

In a recent publication [32], we have used the conventional Alamouti scheme with CDD. To combat the performance degradation of the conventional Alamouti scheme, in this paper some methods of Alamouti encoding and decoding using CDD and DDoD are proposed. The other objective of this work is to analyze the performance of the CDD in different forms of Alamouti encoding scheme with two transmit antennas on the DVB-T2 systems [33] in highly frequency-selective channels. Also, in DDoD method, partially shifts each spectrum of an OFDM symbol at the transmitter using different phase shifts in the time domain at different antennas after the OFDM modulation. In this research, we modify the form of Alamouti encoding to obtain a significant performance enhancement in a bit error rate (BER) without increasing the number of antennas. The other advantages of the proposed scheme are its simplicity, flexibility, compatibility, high reliability, and tolerability with respect to the standard Alamouti scheme. This means that a receiver does not need to be aware of their implementations at the transmitter. The experimental results show that the proposed scheme in this paper can obtain a significant performance enhancement in the BER criterion without increasing the number of antennas.

This paper is organized as follows: in Section 2, the model system is presented which are included CDD, DDoD, and standard Alamouti code, channel properties, and determination of cyclic delay value. In Section 3, we present our proposed scheme which is an efficient coding-decoding Alamouti with CDD and DDoD. Section 4 provides simulation results including different delays with respect to two types of delay diversity techniques and presenting the property compatibility of the MIMO-OFDM with the CDD and DDoD schemes. In addition, the proposed scheme is compared with other well-known methods. Finally, the conclusion results of this research are presented in Section 5.

2- Model System

In DVB-T2 systems, in order to enhance bandwidth efficiency, multiple antenna technologies are used [33]–[36]. In other words, the DVB-T2 system output is typically a single signal to be transmitted. There is assumed that all DVB-T2 receivers shall be able to process the encoding Alamouti signals [37], [38]. Also, we do not require the transmitter to use a different frequency when distributing the same program since the guard interval features [27]. Therefore, we develop a single frequency network (SFN), where all transmitters use identical signals. We will have substantial improvements in the frequency economy and improve coverage for mobile reception due to diversity gain [1]. Figure 1 shows the front end of the DVB-T2 transmitter which is introduced in [33]. The system input may be one or more MPEG-2 transport streams that are built as a frame after, processing, interleaving and modulation. In the next step, after error protection, mapping, and interleaving, the MIMO coding is performed [33]. Then each independent data stream together pilots and transmission parameter signaling (TPS) data are arranged in an OFDM frame. After IFFT transformation, peak to average power ratio (PAPR) reduction, and guard interval (GI) addition, P1 symbol insertion is performed which can be used for signaling and detection purposes.

2-1- Diversity Techniques

Transmit antenna diversity plays an important role to increase the robustness and reliability of wireless fading channels. The DD scheme is a simple diversity scheme that was proposed by Witteneben in 1993 [28]. The DD scheme

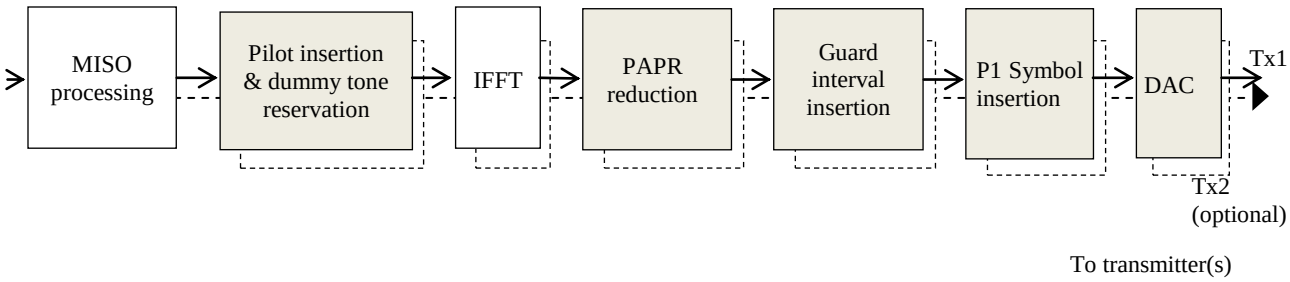

Fig. 1 The front end of the DVB-T2 transmitter [33]

has regained attraction recently as a transmit antenna diversity method for establishing a reliable link in fading channels. In principle, in the DD scheme, delay diversity of a signal over further TX-antenna is transmitted. To avoid ISI, the guard interval length NG should be longer than $L_{max}+d_i$ (maximum channel delay and delay diversity). The linearity features allow us to implement the DD scheme at the receiver side. However, the channel delay spread increment is imposed on the system. In order to solve this problem, the CDD method is applied in which the TX-antenna specific delays are replaced by cyclic shifts [33]. The frequency selectivity of the channel transfer function can be improved without increasing the observable time-domain channel delay spread at the receiver with the CDD scheme (Table. 1).

In the DDoD method, partially shift each spectrum of an OFDM symbol at the transmitter is applied by using different phase shifts in the time domain at different antennas after the OFDM modulation. In order to perform this operation, signals $\gamma_i(m)$ (i= 0,.., N_T-1, m=-N_G, …, N_{FFT}-1) are determined as sampled exponential function to perform a specific spectral shift of the signal $s(m)$ for specific frequency shift (f_i) and subcarrier spacing (Δf_{sc}). In fact, the main role of Doppler diversity (DoD) is to broaden the Doppler spectrum which results in a decreased channel coherence time such as CDD [39]. According to the results of [39], a specific frequency shift choose based on the value of Doppler width (f_D).

2-2- Standard SFBC Using Alamouti Code

The Alamouti STBC, which was primarily proposed for the MIMO system contained 2 transmit and 2 receive antennas. Since individual subcarriers can be considered as independent flat fading channels; applying the STBC for OFDM is a straightforward procedure [37], [40], [41].

Two adjacent data-carriers S_k and S^*_{k+1} for subcarriers k and k + 1, are considered, that the Alamouti coder outputs two pairs,[S_k $-S^*_{k+1}$] for the first antenna, and [S_{k+1} S^*_k] for the second antenna.

3- The Proposed Scheme for Transceivers

In the latest wireless broadcast systems, such as DVB-T2, in order to increase bandwidth efficiency, multiple antenna technologies are used [21]. The proposed scheme is implemented at both the transmitter and receiver sides, which will be explained in the following.

3-1- Transmitter

Our proposed scheme, as shown in figure 2, is a genetic MIMO-OFDM based on using the CDD scheme in the DVB-T2 system. The new proposed system provides additional propagation paths and is inserted into the system. Figure 2 shows the Front end of the proposed transmitter side, which has 2 data streams. In the first data stream, after the N_{FFT} point IFFT, a cyclic prefix (CP) is added to each symbol by repeating the end of the same symbol. In this case, the obtained signal $s_0(m)$, which is a sequence of N_{FFT} data symbols of S_l , for l=0,…,N_{FFT}-1, is transformed into time-domain and transmitted via the first TX-antenna without delay. In the other data stream, for providing additional diversity and as a result, improvement of system performance, the CDD scheme is implemented.

The average transmission power is kept normalized and independent of the number of related TX-antennas (N_T) by $(N_T - 1)^{0.5}$factor. Based on the block diagram, before inserting the CP with the length of N_G, the symbol is shifted cyclically and then the CP is inserted. Therefore, results in the antenna specific TX-signal can be express as bellow:

$$s_i(m) = \frac{1}{(N_T - 1)^{0.5}} \tilde{s}(m - d_i^{cyc} \bmod N_{FFT}) \quad (1)$$
$$for \qquad i = 0,..., N_T - 1, m = -N_G,..., N_{FFT} - 1$$

where k and i denote the numbers of data symbol and TX-antenna, respectively.

Table 1: Simple diversity techniques

Diversity Technique	Key technology	Condition (to avoid ISI)	More information	Ref.
Delay Diversity (DD)	The simple method to increase diversity. (delay diversity schemes are based on signal shifts in the time domain,)	$N_G \geq L_{max}\ d_{i\,max}$	causes the channel delay spread increment	[8], [9]
Cyclic Delay Diversity (CDD)	CDD scheme enhances the frequency selectivity of the channel transfer function	$N_G \geq L_{\max}$	Involved channel estimation	[19], [22]
Doppler Diversity (DoD)	Shift the antenna specific signals in the frequency domain.	$\gamma_i(m)= e^{j2\pi \cdot fi \cdot T \cdot m}$ $T=1/(N_{FFT}.\ \Delta fsc)$	Increasing the Doppler with DoD in OFDM systems in principle enlarges ICI	[23]
Discontinuous Doppler Diversity (DDoD)	The DoD Signal is constant for the duration of an OFDM symbol.	$\gamma_i(m)= e^{j2\pi \cdot fi \cdot T \cdot (N_{\text{OFDM}} \cdot (m \div N_{\text{OFDM}}))}$	Needs further investigation	[24], [30]

Also, $\hat{s}(k)$ is considered as a sample of k_{th} Alamouti symbol, which is modulated in the time domain and then the signal is shifted cyclically by d_i^{cyc} before the CP is added.

After removing the CP at the receiver side, as long as TX-antenna certain delays, d_i, is equal to cyclic shifts, d_i^{cyc}, both CDD and DD schemes yield the same signal. The OFDM symbols of the DD signal partly overlap with the CP of the subsequent OFDM symbol at about delay which is a restriction in the choice of d_i. Therefore, the ISI part of the received signal at k^{th} subcarrier can also be expressed as:

$$R_{ISI}(k) = \frac{1}{\sqrt{N_{FFT}}} \sum_{l=N_G+1}^{L_{\max}+d_{\max}} h(l) \sum_{k=0}^{l-N_G} s(m-l).e^{j2\pi km/N_{FFT}} \quad (2)$$

where $h_i(l)$ is the channel impulse response from TX-antenna i to the RX-antenna with delays of $l > N_G$ samples and the signal part $s(k)$, $k < -N_G$, since these terms cause ISI [30]. Also, the minimum length of CP should be $N_G \geq L_{\max}$ in the system based on the CDD and this length does not depend on the cyclic delays, d_i^{cyc}. Therefore, a shorter CP can be chosen and there is an advantage of CDD with respect to the DD that the CDD scheme does not depend on the number of TX-antenna and there is no overlapping of OFDM symbols in it. However, in the case of free-ISI, the DD scheme performs the same as CDD.

To avoid ISI interference, the guard interval length N_G must be $N_G > L_{max} + \max D_i$ for $i = 0,\ldots, N_{T-1}$, where L_{max} is the maximum channel delay samples. Also, we can choose the maximum possible cyclic delays according to:

$$d_i^{cyc} = \frac{N_{FFT}(i-1)}{N_T} = \frac{N_{FFT}}{N_T} + d_{i-1}^{cyc} \quad (3)$$

and

$$d_i^{cyc} = N_G + 1 + d_{i-1}^{cyc} \quad (4)$$

where N_T and N_{FFT} denote the number of TX-antenna and data symbol respectively [30].

3-2- Receiver

In the DVB-T2 system, standard Alamouti code is used in the transmitter for enhancing spectral efficiency and link reliability. This is done for maximizing the diversity in the receiver while using low complexity equalization based on the maximal ratio combining (MRC) method [10].

In this paper, we have utilized the Alamouti code, which was primarily introduced for MIMO systems with two transmit and two receive antennas. Assume S_k, S_{k+1} are the two successive subcarriers, $[S_k, -S_{k+1}^*]$ and $[S_{k+1}, S_k^*]$ are two pairs of MIMO encoder outputs for the first and the second data streams, respectively. On the receiver side, we use a decoding method [1], which is called "Δh-Alamouti decoding" in this paper. In this method, the first MIMO-OFDM symbol in (2) is the $S_0(k)$, which is transmitted as an un-shifted signal ($d_0^{cyc} = 0$) over the first TX-antenna. The other TX-antenna signal is shifted cyclically by d_i^{cyc} before adding the CP as shown in Figure 2. On the receiver side, after removing the CP, the remaining OFDM time domain symbol is transformed into the frequency domain by an FFT in the receiver side, as shown in Figure 3. The received data can be written in a compact form as follow:

$$\mathbf{Y} = \mathbf{S}\tilde{\mathbf{H}} + \mathbf{N} \quad (5)$$

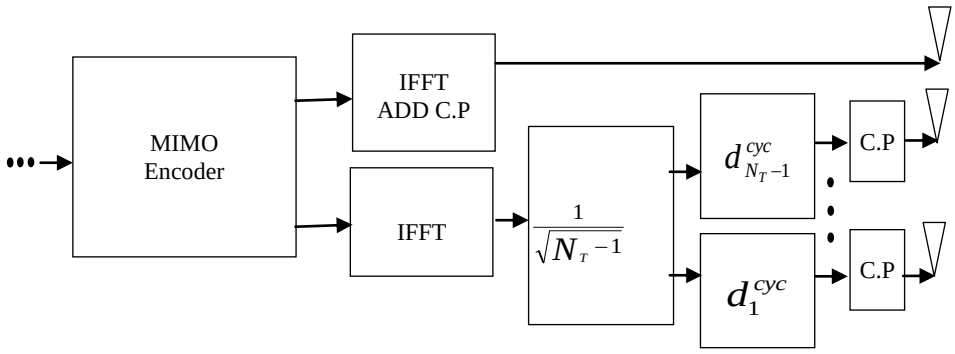

Fig. 2 The front end of the proposed scheme using CDD at the transmitter side

where $\tilde{\mathbf{H}}$ denotes an equivalent channel transfer function and is defined as bellow:

$$\tilde{\mathbf{H}} = \frac{1}{\sqrt{N_T}} \sum_{i=0}^{N_T-1}\sum_{m=0}^{N_{FFT}-1} h_i(\mathrm{m})\mathrm{e}^{\frac{\mathrm{j}2\pi.\mathrm{mk}}{N_{FFT}}}\mathrm{e}^{\frac{-\mathrm{j}2\pi.\mathrm{d}_i^{cyc}.k}{N_{FFT}}} + \mathbf{N} \quad (6)$$

where **N** is a complex Gaussian noise, which is mutually uncorrelated between different subcarriers, h_i is the i^{th} tap of the channel impulse response [30].

Equation (6) means that a receiver cannot distinguish whether a propagation path results from the CDD scheme or the channel itself [4]. After FFT transformation and pilot extraction at the receiver side, we have the following equations:

$$\begin{cases} Y_1^K = S_k H_{1,1}^k - S_{k+1}^* H_{1,2}^k + N_1^k \\ Y_2^K = S_k H_{2,1}^k - S_{k+1}^* H_{2,2}^k + N_2^k \\ Y_1^{K+1} = S_{k+1} H_{1,1}^{k+1} - S_k^* H_{1,2}^{k+1} + N_1^{k+1} \\ Y_2^{K+1} = S_{k+1} H_{2,1}^{k+1} - S_k^* H_{2,2}^{k+1} + N_2^{k+1} \end{cases} \quad (7)$$

where $\tilde{H}^k_{i,j}$ is the channel frequency response at carrier k^{th}, between i^{th} receive antenna and j^{th} transmit antenna, N_i^k is AWGN noise at the k^{th} carrier of i^{th} receive antenna, and * denotes conjugate operator.

In the standard Alamouti decoding should be assumed that the channel frequency response is constant over two consecutive carriers, i.e. $\tilde{H}^k_{i,j} = \tilde{H}^{k+1}_{i,j}$. However, the performance of the standard Alamouti decoding will be degraded over highly frequency-selective channels.

Since there should be quasi-static fading for adjacent subcarriers. In order to overcome this problem, an efficient Alamouti decoding scheme using the CDD scheme is proposed. By considering the changes in the channel matrix over adjacent OFDM carriers, we can write:

$$\Delta\mathbf{H}^{\mathrm{T}} = \begin{bmatrix} 0 & 0 & (H_{1,2}^{k+1} - H_{1,2}^k)^* & (H_{2,2}^{k+1} - H_{2,2}^k)^* \\ 0 & 0 & -(H_{1,1}^{k+1} - H_{1,1}^k)^* & -(H_{2,1}^{k+1} - H_{2,1}^k)^* \end{bmatrix} \quad (8)$$

where T refers to conjugate transpose operation. Equation (8) confirms that the variation of two consecutive carriers is considered. In other words, if the difference between two consecutive carriers is 0, the channel frequency response is flat over the Alamouti block. Therefore, there is not any necessity to consider the channel constant over

two consecutive subcarriers. In multiuser detection, optimal error-rate performance is achieved by the joint Maximum Likelihood (ML) detector, which its computational complexity increases exponentially. However, for the last part of detection, we use the results of [42] and [1], which have lower complexity than ordinary methods. For recovering the signal at the receiver side, ΔH is applied in a detection scheme by the MMSE criterion. Therefore, the estimated transmitted symbol can be expressed as [1]:

$$\tilde{\mathbf{S}} = \frac{1}{\det(\mathbf{I}_2 + \mathbf{B}\Delta\mathbf{H})} adj(\mathbf{I}_2 + \mathbf{B}\Delta\mathbf{H}).\mathbf{B}.\mathbf{Y} \quad (9)$$

where,

$$\mathbf{B} = (\mathbf{H}^T\mathbf{H})^{-1}\mathbf{H}^T \quad (10)$$

where det and adj denote determinant and adjoint operations, respectively and $\mathbf{I}_2$ is the identity matrix of order two.

The transmitted data can be recovered at the receiver side using Eq. (9). It is noticeable that the new scheme has a lower complexity since Eq. (9) does not consist of the

direct inverse of the matrix ($\mathbf{I}_2$+$\mathbf{B}\Delta\mathbf{H}$)

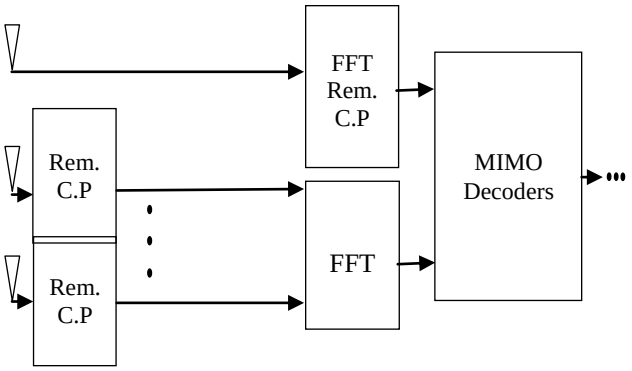

Fig. 3 The proposed scheme using CDD at the receiver side

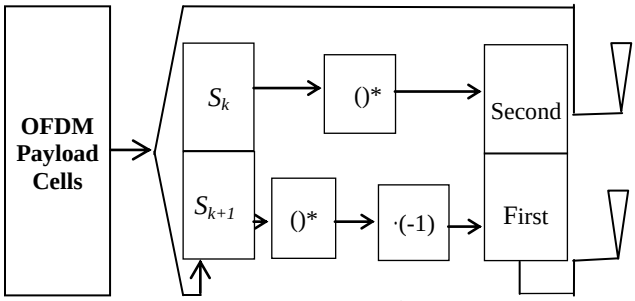

Fig. 4 Multiple Input, Encoder processing of OFDM payload cells [33]

3-3- An Efficient Alamouti coding and decoding using CDD

An optional initial stage, known as MISO processing in the DVB-T2 standard, provides the initial frequency domain coefficient, which is processed by a modified Alamouti [33]. Then, the DVB-T2 signal to be split between two groups of transmitters on the same frequency without the interference of signals [17].

Figure 4 shows that the MISO processing for transmitters in the MISO group1 copies the unmodified input cells to the output. Also, *N* data will be an even number, even in the frame closing symbol, even though value CFC (number of active cells in one frame closing symbol) might not be even. Hence we can use it in the proposed strategies.

In this section, we investigated Δh-Alamouti decoding using CDD. In other words, we have proposed an efficient scheme, which exploits the modified Alamouti using CDD. On the other hand, the core idea concerns the improvement of the transmitter and receiver sides. On the transmitter side, we use the CDD as an antenna diversity technique and improved Alamouti encoding (Fig. 3). The DVB-T2 standard using a modified form of Alamouti encoding, which is the respective payload cells are processed in the frequency direction.

In the MIMO encoder module, [S_k , S_{k+1}] is transmitted as the first data stream; without any modification regarding frequency order. In the second data stream, we have pairwise modification [S_{k+1}^*, S_k^*]. At the receiver side, the MIMO decoder module consists of MMSE criterion and a channel matrix equation as bellow:

$$\Delta\mathbf{H}^{\mathrm{T}}{}_{Effiicent} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ (H_{1,2}^{k+1} - H_{1,2}^{k})^* & (H_{2,2}^{k+1} - H_{2,2}^{k})^* & -(H_{1,1}^{k+1} - H_{1,1}^{k})^* & -(H_{2,1}^{k+1} - H_{2,1}^{k})^* \end{bmatrix} \quad (11)$$

Then, by applying equations (9) and (10), when the MIMO channel is estimated using the known pilot, the receiver can recover the transmitted data.

3-4- An Efficient Alamouti coding using DDoD

In this section, we investigate the use of Doppler diversity (DoD), which schemes shift the antenna-specific signals in the frequency domain [43], [44]. This type of scheme is used in studies such as [31]. Figure 5 shows the front end of the proposed scheme using

Doppler diversity at the transmitter side. After OFDM modulation using an IFFT and guard interval insertion as a cyclic prefix, the signal $s(m)$ is split (copied) into N_T TX-branches. After normalization by the factor, the time domain signal in each TX-branch is multiplied by a TX-antenna specific signal

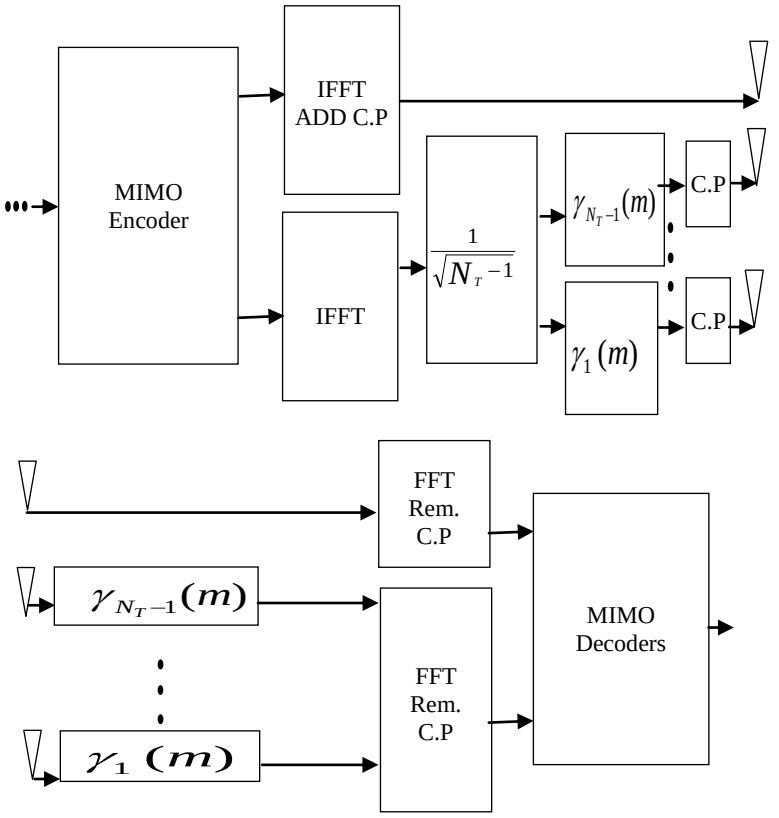

Fig. 5. The proposed scheme using DDoD (transmitter and receiver)

$\gamma_i(m)$. Therefore, results in the TX-antenna specific transmission signals can be expressed as [44] :

$$s_i(m) = \frac{1}{\sqrt{N_T}} s(m).-\gamma_i(m)$$
$$\text{for} \quad i = 0,\ldots,N_T - 1 \qquad (12)$$
$$m = -N_G,\ldots,N_{FFT} - 1$$

According to Fig. 5 (receiver side), the time domain signal for n^{th} OFDM symbol after removal guard interval can be written as follows [31]:

$$r_n(m) = \frac{1}{\sqrt{N_T}}$$
$$\sum_{i=0}^{N_T-1}\sum_{l=0}^{N_{\max}} s_n(m-l)h_i(m+n\cdot N_{OFDM},l)\cdot\gamma_i(m+n\cdot N_{OFDM}) \qquad (13)$$

where $h_i(m+n.N_{FFT}, l)$ denotes the time-variant Rayleigh fading process with a delay of l samples observed from Tx antenna i. After that, the received time-domain signal is transformed into the frequency domain and this processing can be described by the following equation [31]:

$$R_n(k) = \frac{1}{\sqrt{N}}\sum_{m=0}^{N-1} r_n(m)\cdot e^{-j\frac{2\pi}{N}\cdot k\cdot m} =$$
$$\frac{1}{\sqrt{N\cdot N_T}}\sum_{q=0}^{N} S_n(q)\cdot\sum_{i=0}^{N_T}\sum_{l=0}^{N_{\max}}\bar{\gamma}_{i\cdot n}\cdot H_{i,l,n}(q)\cdot e^{-j\frac{2\pi}{N}\cdot l.q} \qquad (14)$$

Where $S(q)$ denotes the DFT of $s(m)$ and,

$$H_{i,l,n}(q) = \frac{1}{\sqrt{N}}.\sum_{m=0}^{N-1} h_{i,n}(m,l)\cdot e^{-j\frac{2\pi}{N}k\cdot q} \qquad (15)$$

Equation (14) confirms that the effects of DDoD can be assigned to the channel. Also, this simplifies the parallel transmission (ICI-free) over subcarriers if there are constants channel fading $h_i(m,l)$ for the duration of an OFDM symbol. Otherwise, we mitigate the system performance degradation by using the proposed method

i.e. Δh-Alamouti in the third strategy. Therefore, we witness a considerable performance improvement. at the receiver side, and as a result, the transmitted data can be recovered at the receiver side using Eq. (9).

In table 1, the signals $\gamma i(m)$for DDoD is mentioned. In or der to achieve a TX-antenna specific spectral, these signa ls are chosen as exponential functions shift of the signal $s(m)$, before adding the cyclic prefix.

However, the effects of DDoD can be assigned to the channel. These effects are shown in Fig. 6. We applied DDoD with different f_D/f_{SC} to the MISO systems (2×1). We used the 2k mode (2048 points IFFT) with 4-QAM modulation. The guard interval length is N_G =1/4. For our investigations, we used 9-path multipath Rayleigh channel models which is similar to indoor commercial-channel B models in large open centers, such as shopping malls and airports. Its power-delay profile is [0 -8 -17 -19 -21 -23 -25] dB. The fading processes for the several propagation paths are statistically independent. This result of simulation and mathematical analyses in [23] could be considered to provide design criteria for the choice of TX-antenna parameters for DDoD.

4- Simulation Results

In this Section, three strategies have been performed to demonstrate the advantages of our proposed scheme. A Δh-Alamouti decoding scheme introduced in [1] is used in this simulation. According to [25], the performance of the DD and CDD schemes is equal if the transmission is ISI free. However, by increasing the CP length using the MISO-DD method, noticeable performance degradation will occur at the receiver side. There is a fact to take into account that if the CP length is increased for the DD scheme, the amount of interference will be huge. It should be mentioned that the channel estimation is assumed to be perfect. Also, for better comparison, Table 2 list the parameters and reason for its selection.

4-1- The Δh-Alamouti Decoding using CDD (strategy 1)

We have set up the first strategy to verify the better performance of the proposed Δh-Alamouti decoder using the CDD scheme with respect to Δh-Alamouti. In the first strategy, the MIMO-OFDM system has been applied to the DVB-T2 standard, in which 8k modes, i.e. 8192 sub-carriers with 4-QAM modulation, are used. We have applied 10000 OFDM symbols with a CP length of ¼ to a 2×2 MIMO DVB-T2 system. We have used the P1 multipath Rayleigh fading channel model [6], which has 20 taps without any Doppler effects. In this simulation, d_i^{cyc} = 2, this is because the SNR does not increase further when d_i^{cyc}>1.5μs, as shown in [4]. The performance of the un-coded strategy is also evaluated; thus the coding and interleaving blocks are bypassed in our system simulation. Four different profiles are used as MIMO channels with identity power and different phases. In order to make the uncorrelated channel, which is applied in [1], phases are randomly chosen between 0 and 2π.

In order to simulate highly frequency selective channels, random phase with different values for a and b parameters are used, where a and b are the power of the delayed channel and the delayed spread, respectively [26]. In principle, increment in the delay spread and the power of the delay channel convert the channel to a highly frequency-selective channel [1]. Figure 7 shows the results of different methods consisting of the efficient Alamouti decoding scheme using the CDD scheme, Δh-Alamouti, and the standard one, when, channel estimation is assumed to be perfect.

From the simulation result, it can be observed that for a=0.5, the proposed scheme performs approximately the same as the Δh-Alamouti scheme. However, the performance of the standard decoder degrades. Also, for a = 0.9, the performance of our proposed scheme is better than the Δh-Alamouti scheme.

Table 2:Parameters for simulations

Fig	Parameter	describe	References
6,10	Indoor commercial-channel B models	N_{tap}=20 Channel tap number length	[6]
10	2k mode (2048 points IFFT) with 4-QAM modulation. The guard interval length is NG =1/4	Mode selection	DVBT-2 standards model [33]
6-9, 11-13	8k modes, i.e. 8192 sub-carriers with 4-QAM modulation Nfft=8192	FFT size	[33],[6]

6-13	nRX=2; nTX=2;	Number of antennas	DVBT-2 standards model [33]
6-9,11-13	$d_i^{cyc} = 2$	Delay (CDD)	[4]
7-9, 11-13	DVBT-2 channel model a, b	the power of the delayed channel and the delayed spread	DVBT-2 standards model [33] and [1]

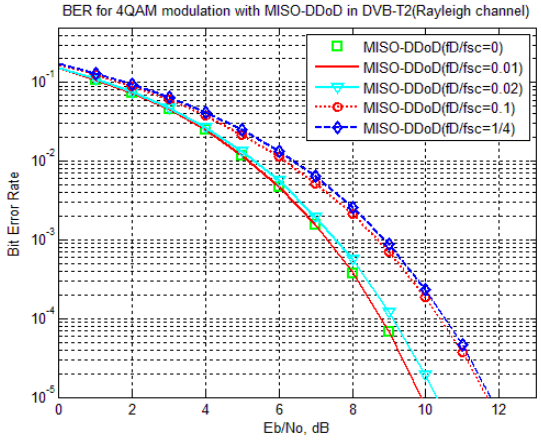

Fig. 6 The effect of discontinues Doppler diversity delay

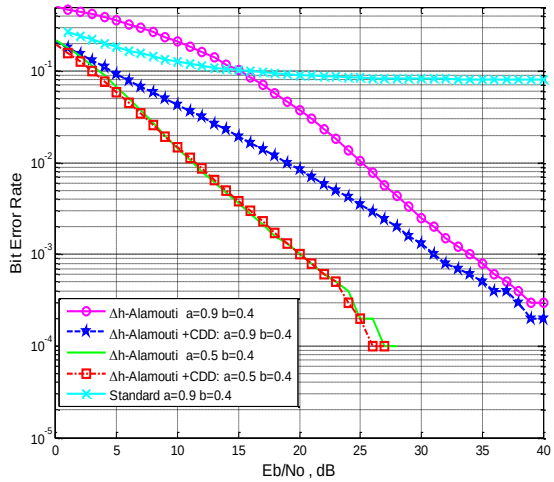

Fig.7 The performance of Δh-Alamouti using CDD schemes in BER vs. SNR.

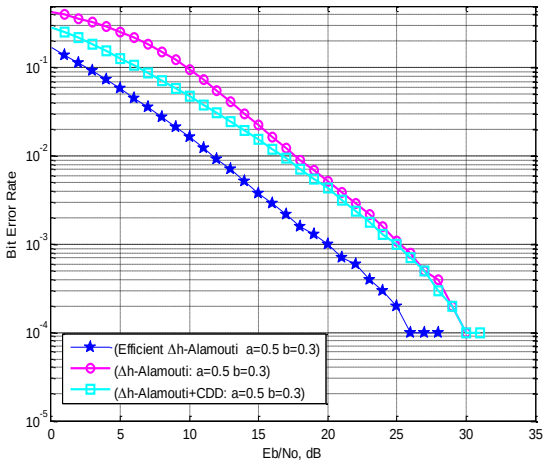

Fig. 8 A comparison of different schemes (a=0.5, b=0.3) in BER vs. SNR.

This improvement is due to the increased degree of diversity of the proposed method, which allows a significant performance enhancement that can be achieved without increasing the number of antennas. Besides, BER is also decreased by using this scheme and the performance of the proposed scheme is still much better than the other schemes. This is because the CDD scheme is capable of offering a larger degree of diversity to improve the performance, which is achieved through the reception of data signals from more than one path. For instance, Figure 7 shows that this scheme outperforms the scheme in [1] by 3.2 dB at an average BER of 10e-3.

4-2- The Efficient Δh-Alamouti Coding and Decoding Using CDD (strategy 2)

In this section, we investigate the efficient Δh-Alamouti coding and decoding using CDD, which is introduced in section 3. We consider the MIMO-OFDM system based on the DVB-T2 standard with 8k mode (8192 sub-carriers with 4-QAM modulation) and similar conditions of the previous strategy. The three schemes are compared in different channels.

In Figure 8, we observe that when *a*=0.5, two strategies of Δh-Alamouti with and without CDD perform a little convergence in the high SNR. However, the efficient Δh-Alamouti coding and decoding using CDD are much better than the other schemes. For instance, at BER= 10e-3, the efficient Δh-Alamouti coding and decoding using CDD get about 5dB gain than the other schemes.

For relatively high values of *a*=0.9 and *b*=0.4, the performance of the efficient Δh-Alamouti coding and decoding using CDD outperforms the previous schemes (Fig. 9). For example, at BER 10e-3, the modified encoding form with CDD gets about 9.8dB gain than the

standard encoding form with CDD. Due to the fact that, when channels are highly frequency-selective (with decreasing *a* and *b*), the efficient Δh-Alamouti coding and decoding using CDD can conserve its performance. But, the method of Δh-Alamouti with CDD has a minor performance improvement. In the proposed scheme, allows the high tolerability of the system to highly selective channels. Therefore, we gain better performance by using a new modified version of Alamouti encoding with CDD. Because, the efficient Δh-Alamouti coding using CDD provides additional diversity in channels and therefore, improves the system performance.

4-3- The Efficient Δh-Alamouti Decoding Using DDoD (strategy 3)

For an investigation of DDoD, we applied Alamouti

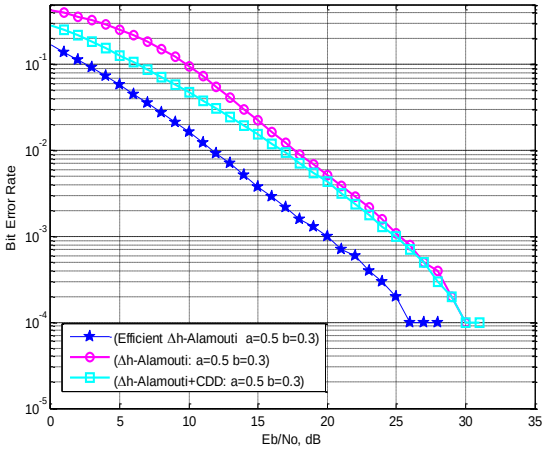

Fig. 8 A comparison of different schemes (a=0.5, b=0.3) in BER vs. SNR.

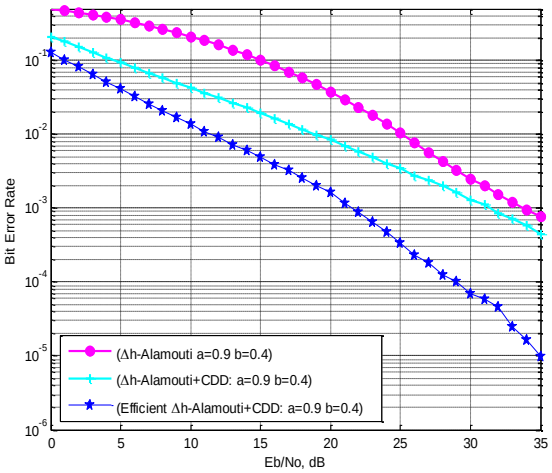

Fig. 9 A comparison of different schemes (a=0.9, b=0.4) in BER vs. SNR.

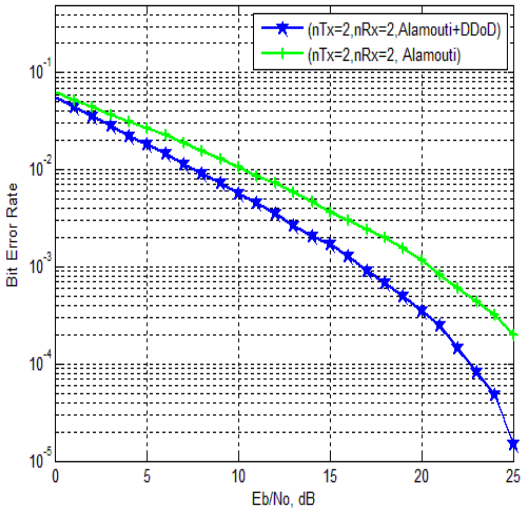

Fig. 10 The effect of discontinues DDoD

enhanced with DDoD and Alamouti standard. We used the 2k mode (2048 points IFFT) with 4-QAM modulation. The guard interval length is N_G =1/4. At the receiver sides, we assumed that the channel estimation was perfect. For our investigations, we used indoor commercial-channel B models (used in Fig.6). Compared to the Alamouti standard which required an SNR of 21 dB at BER=10e-3, an Alamouti enhanced using DDoD requires 16.5 dB, which provides a gain of 4.5 dB for the considered DVB-T2 parameter set (Fig. 10).

In the next experiment, we compared different systems based on multiple antenna techniques; Alamouti, DD, CDD with different *di* to the MISO systems (2×1), and DDoD in Rayleigh fading channel. The previous channel, which was constant over two adjacent OFDM carriers (non-highly selective fading), was applied for this experiment (Fig. 11).

All MISO methods are based on standard Alamouti and the combination of that with other simple diversity techniques was compared. After removing the CP at the receiver side, as long as TX-antenna certain delays, d_i, is equal to cyclic shifts, d_i^{cyc}, both CDD and DD schemes yield the same signal. In this simulation condition, the DD scheme performs the same as CDD. However, there is a fact to take into account that if the CP length is increased for the DD scheme, the amount of interference will be huge. [32]. The OFDM symbols of the DD signal partly overlap with the CP of the subsequent OFDM symbol at about delay which is a restriction in the choice of d_i. As a result, Figure 11 shows that the DDoD combination is better than the other methods.

We have set up the third strategy to verify the better performance of the proposed Δh-Alamouti decoder using

the CDD scheme and DDoD with respect to Δh-Alamouti, which was introduced in [1]. we observe a comprehensive comparison between Δh-Alamouti, efficient Δh-Alamouti using CDD, and Δh-Alamouti using DDoD in Fig. 12 and 13. The performance is evaluated using simulations in different channels that include the presence of high selective fading. The last experiment is applied in two different channels, which are introduced in [1] (also, is based on [26]).

In the first type of channel, we witness that efficient Δh-Alamouti using CDD and Δh-Alamouti using DDoD have a better performance than Δh-Alamouti. Because, in two methods based on DDoD and CDD, diversity is exploited without the need for additional complexity at the receiver. This a considerable advantage of these types of methods. Also, these two proposed methods are driven great benefit from efficient encoding and decoding, which is explained in previous sections. However, in Fig.13, the Δh-Alamouti

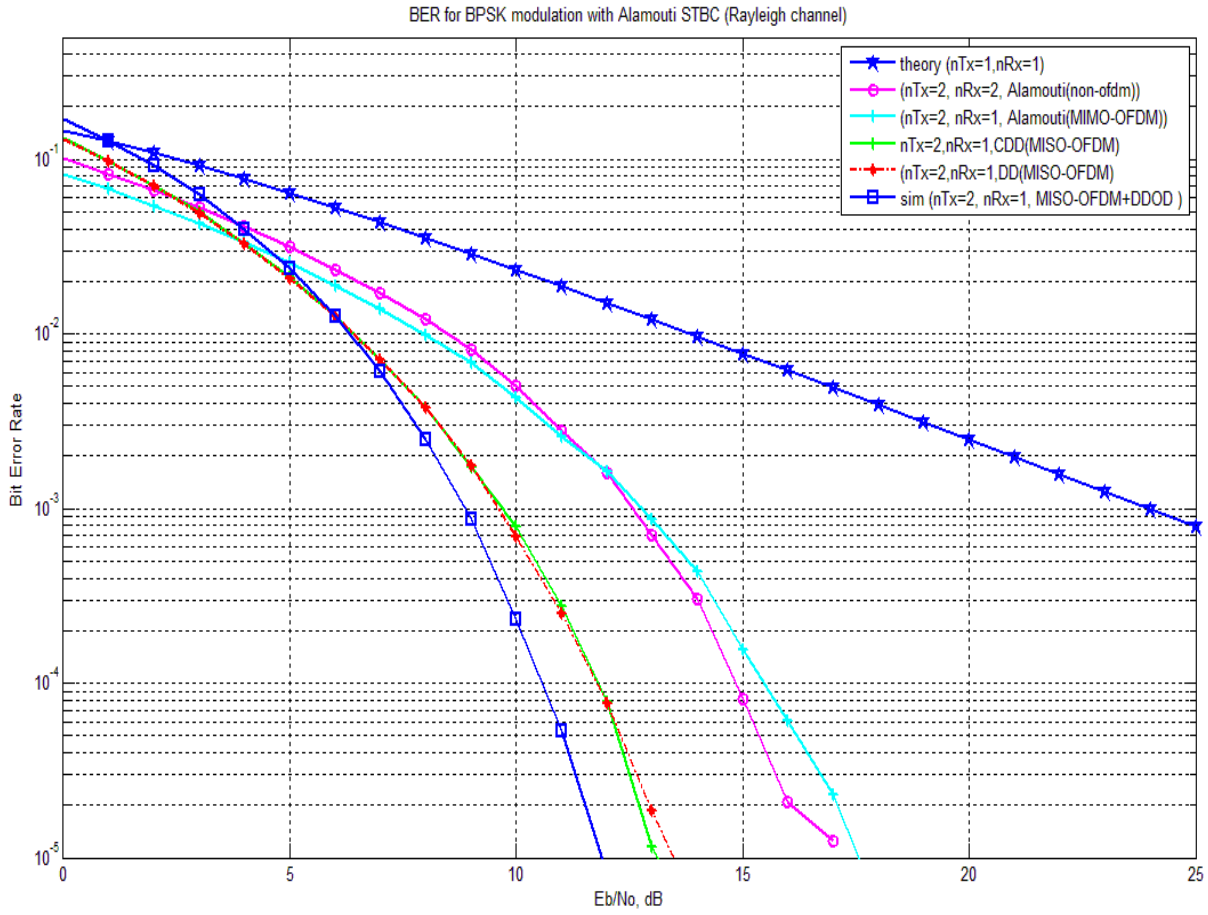

Fig. 11 A comparison of different schemes (theory, Alamouti, DD, CDD, and DDoD)

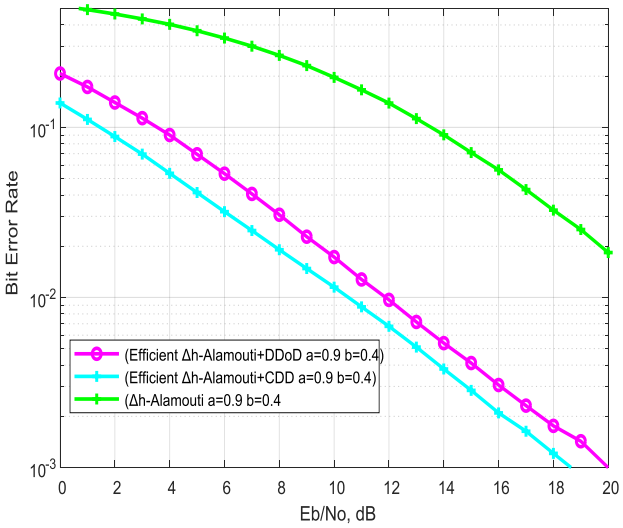

Fig. 12 A comparison of different schemes (Efficient Δh-Alamouti,CDD, and DDoD for a=0.9, b=0.4)

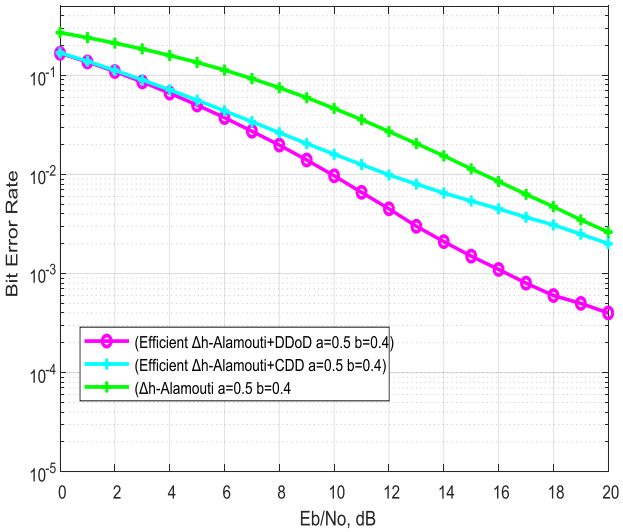

Fig. 13 A comparison of different schemes(Efficient Δh-Alamouti,CDD, and DDoD for a=0.5, b=0.4)

5- Conclusion

In this paper, it was shown that the performance of well-known Alamouti decoding degrades in the highly frequency selective channels. To tackle this problem, we proposed an efficient decoder using the CDD and DDoD scheme, which enhanced the standard Alamouti decoding and allowed high tolerability of the system in the frequency-selective channels by increasing the diversity.

Due to standard compatibility, a receiver does not need to be aware of their CDD and DDoD implementation. Also, the effect of the DDoD scheme is well noticeable on the receiver side. Analysis and simulation results demonstrated that the proposed scheme has significant performance improvement. Therefore, the new scheme is useful in MIMO-OFDM systems such as the DVB-T2 standard, which allows a high reliability and capacity enhancement. Due to all these features and as a future work, many wireless systems could take advantage of these schemes, explored with a low complexity implementation.

References

[1] A. Omri, R. Hamila, A. Hazmi, R. Bouallegue, and A. Al-Dweik, "Enhanced Alamouti decoding scheme for DVB-T2 systems in SFN channels," in 2011 IEEE 22nd International Symposium on Personal, Indoor and Mobile Radio Communications, 2011, pp. 1626–1630, DOI: 10.1109/PIMRC.6139779.

[2] E. P. Simon, L. Ros, H. Hijazi, and M. Ghogho, "Joint Carrier Frequency Offset and Channel Estimation for OFDM Systems via the EM Algorithm in the Presence of Very High Mobility," IEEE Trans. Signal Process, vol. 60, no. 2, pp. 754–765, Feb. 2012, DOI: 10.1109/tsp.2011.2174053.

[3] L. E. Nazarov, "Signal constructions based on OFDM signals resistant to the influence of spectrum-concentrated interference," J. Commun. Technol. Electron., vol. 64, no. 8, pp. 774–782, 2019.

[4] J. Yao et al., "Comprehensive study on MIMO-related interference management in WLANs," IEEE Commun. Surv. Tutor., vol. 21, no. 3, pp. 2087–2110, 2019. DOI: 10.1109/COMST.2019.2894160.

[5] K. Yang, N. Yang, C. Xing, J. Wu, and Z. Zhang, "Space-time network coding with transmit antenna selection and maximal-ratio combining," IEEE Trans. Wirel. Commun., vol. 14, no. 4, pp. 2106–2117, 2015. DOI: 10.1109/TWC.2014.2381217.

[6] E. Biglieri, R. Calderbank, A. Constantinides, A. Goldsmith, A. Paulraj, and H. V. Poor, "Capacity limits of MIMO system," in MIMO Wireless Communications. Cambridge, England: Cambridge University Press, 2009.

[7] N. Fernando, Y. Hong, and E. Viterbo, "MIMO Self-Heterodyne OFDM," IEEE Trans. Veh. Technol., vol. 65, no. 3, pp. 1271–1280, 2016

[8] S. H. Ahmed, S. M. U. Talha, and A. Khan, "Performance evaluation of DVB-T based OFDM over wireless communication channels," Lect. Notes Eng. Comput. Sci., Vol. 2195, 2012.

[9] M. Tormos, C. Tanougast, A. Dandache, D. Masse, and P. Kasser, "Modeling and performance evaluations of Alamouti technique in a single frequency network for DVB-T2," EURASIP J. Wirel. Commun. Netw., vol. 2013, no. 1, 2013.

[10] T. H. Liu, "Analysis of the Alamouti STBC MIMO System With Spatial Division Multiplexing Over the Rayleigh Fading Channel," IEEE Trans. Wirel. Commun., Vol. 14, no. 9, 2015, pp. 5156–5170, DOI: 10.1109/TWC.2015.2433924.

[11] A. Dammann and S. Kaiser, "Low Complex Standard Conformable Antenna Diversity Techniques for OFDM

Systems and its Application to the DVB-T System,", ITG FACHBERICHT. 2002, pp. 253-60.

[12] N. Cornillet, M. Crussiere, and J. F. Helard, "Performance of the DVB-T2 system in a single frequency network: Analysis of the distributed alamouti scheme," in 2011 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), 2011, DOI: 10.1109/BMSB.2011.5954961.

[13] K. Yang, N. Yang, C. Xing, J. Wu, and J. An, "Space-Time Network Coding With Antenna Selection," IEEE Trans. Veh. Technol., Vol. 65, no. 7, 2016, pp. 5264–5274, DOI: 10.1109/TVT.2015.2455233.

[14] R. Zakaria and D. Le Ruyet, "A novel filter-bank multicarrier scheme to mitigate the intrinsic interference: Application to MIMO systems," IEEE Trans. Wirel. Commun., vol. 11, no. 3, pp. 1112–1123, 2012. DOI: 10.1109/TWC.2012.012412.110607.

[15] S. Lu, S. Member, B. Narasimhan, and S. Member, "A Novel SFBC-OFDM Scheme for Doubly-Selective Channels," IEEE Trans. Veh. Technol.,Vol. 58(5), pp. 2573-2578, 2008.

[16] K. A. Banawan and E. Sourour, "Turbo equalization of precoded collaborative MIMO for the uplink of LTE-advanced," presented at the 2013 International Conf. on Computing, Networking and Communications (ICNC 2013), Jan. 2013, DOI: 10.1109/ICCNC.2013.6504225.

[17] Y. Jung and H. Song, "Low-Complexity and Robust Symbol Timing Synchronization Scheme for MIMO DVB-T2 Systems," IEEE Access, Vol. 6, 2018, pp. 43384–43391, DOI: 10.1109/ACCESS.2018.2863255.

[18] T. Arbi, B. Geller, J. Yang, C. A. Nour, and O. Rioul, "Uniformly Projected RCQD QAM□ : A Low-Complexity Signal Space Diversity Solution Over Fading Channels With or Without Erasures," IEEE Trans. Broadcast., Vol. 64, no. 4, 2018, pp. 803–815, DOI: 10.1109/TBC.2018.2811618.

[19] T. Sato, B. Roland, P. Ivan, and A. Pablo, "A comparison between theoretical and practical planning approaches for DVB-T2 single frequency networks," in 2015 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting, 2015., pp. 1-6.

[20] L. Fay, L. Michael, D. Gomez-Barquero, N. Ammar, and M. W. Caldwell, "An overview of the ATSC 3.0 physical layer specification," IEEE Trans. On Broadcast., vol. 62, no. 1, pp. 159–171, 2016. pp. 159–171, DOI: 10.1109/TBC.2015.2505417.

[21] A. A. A. Solyman et al., "A low-complexity equalizer for video broadcasting in cyber-physical social systems through handheld mobile devices," IEEE Access, vol. 8, pp. 67591–67602, 2020. DOI: 10.1109/ACCESS.2020.2982001.

[22] Y. H. You and J. H. Paik, "Suboptimal Maximum Likelihood Detection of Integer Carrier Frequency Offset for Digital Terrestrial Television Broadcasting System," IEEE Trans. Broadcast., Vol. 66, no. 1, 2020, pp. 195–202, DOI: 10.1109/TBC.2019.2921663.

[23] S. M. Alamouti, "A simple transmit diversity technique for wireless communication," IEEE J. Sel. Areas Commun., Vol. 16, no. 8, pp. 1451–1458, 1998.

[24] D. Gozálvez, D. Gómez-Barquero, D. Vargas, and N. Cardona, "Time diversity in mobile DVB-T2 systems," IEEE Trans. Broadcast., Vol. 57, no. 3, pp. 617–628, 2011, DOI: 10.1109/TBC.2011.2161189.

[25] S. Kaiser, "Spatial transmit diversity techniques for broadband OFDM systems," IEEE. Global Telecommunications Conf. (Cat. No. 00CH37137), 2000, Vol. 3, pp. 1824-1828).

[26] Y. Zhang, J. Cosmas, K. K. Loo, M. Bard, and R. D. Bari, "Analysis of cyclic delay diversity on DVB-H systems over spatially correlated channel," IEEE Trans. Broadcast., Vol. 53, no. 1, pp. 247–254, 2007, DOI: 10.1109/TBC.2007.891702.

[27] S. Plass, A. Dammann, G. Richter, and M. Bossert, "Channel correlation properties in OFDM by using time-varying cyclic delay diversity," J. Commun., Vol. 3, no. 3, pp. 19–26, 2008.

[28] M. Liu, M. Crussi, and A. M. T. Model, "Enhanced Mobile Digital Video Broadcasting with Distributed Space-Time Coding," in 2012 IEEE International Conf. on Communications (ICC), 2012, pp. 6971–6976.

[29] S. Plass, A. Dammann, and S. Sand, "An overview of cyclic delay diversity and its applications," IEEE Veh. Technol. Conf., 2008, DOI: 10.1109/VETECF.2008.133.

[30] A. Dammann, "On the influence of cyclic delay diversity and doppler diversity on the channel characteristics in OFDM systems," IEEE Int. Conf. Commun., 2007, pp. 4179–4184, DOI: 10.1109/ICC.2007.689.

[31] R. Raulefs, A. Dammann, S. Kaiser, and G. Auer, "The Doppler Spread – Gaining Diversity for Future Mobile Radio Systems," IEEE Glob. Telecommun. Conf. (IEEE Cat. No.03CH37489), 2003, pp. 1301–1305.

[32] B. Akbarian, S. Ghazi.M, "Better Performance of New Generation of Digital Video Broadcasting-terrestrial (DVB-T2) using Alamouti scheme with Cyclic Delay Diversity," JIST,vol. 10, 108-114, 2015.

[33] ITSI, Implementation guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2), ETSI, no. February 2012.

[34] Y. Fang et al., "Improved passive SAR imaging with DVB-T transmissions," IEEE Trans. Geosci. Remote Sens., Vol. 58, no. 7, 2020, pp. 5066–5076, DOI: 10.1109/TGRS.2020.2972156.

[35] A. Dammann, R. Raulefs, and S. Plass, "Soft cyclic delay diversity and its performance for DVB-T in ricean channels," GLOBECOM - IEEE Glob. Telecommun. Conf., 2007, pp. 4210–4214, DOI: 10.1109/GLOCOM.2007.801.C

[36] Q. Hamarsheh and O. Daoud, "Enhancing DVB-H BER based OFDM systems," J. Commun. Technol. Electron., Vol. 60, no. 8, pp. 880–889, DOI: 10.1134/S1064226915080069, 2015.

[37] A. Dammann, S. Plass, and S. Sand, "Cyclic delay diversity - A simple, flexible and effective multi-antenna technology for OFDM," IEEE Int. Symp. Spread Spectr. Tech. Appl., 2008, pp. 550–554, DOI: 10.1109/ISSSTA.2008.108.

[38] C. Gómez-Calero, L. Cuéllar, L. De Haro, and R. Martínez, "A 2 x 2 novel MIMO testbed for DVB-T2 systems," 2009 IEEE Int. Symp. Broadband Multimed. Syst. Broadcast. BMSB 2009, 2009, DOI: 10.1109/ISBMSB.2009.5133823.

[39] W. Zhou, J. Wu, and P. Fan, "High Mobility Wireless Communications with Doppler Diversity: Fundamental Performance Limits," IEEE Trans. Wirel. Commun., Vol. 14, no. 12, pp. 6981–6992 , 2015, DOI: 10.1109/TWC.2015.2463276.J

[40] L. De Haro, "A 2 x 2 MIMO DVB-T2 System : Design, New Channel Estimation Scheme and Measurements With Polarization Diversity," IEEE Trans. On Broadcast, 56(2), Vol. 56, no. 2, pp. 184–192,2010.

[41] K. Chanthirasekaran, M. A. Bhagyaveni, and L. R. Parvathy, "Multi-Parameter Based Scheduling for Multi-user MIMO Systems," J. Electr. Eng. Technol Vol. 10, no. 6, pp. 2406–2412, 2015.

[42] C. W. Tan and A. R. Calderbank, "Multiuser detection of alamouti signals," IEEE trans. commun., vol. 57, no. 7, pp. 2080–2089, 2009, DOI: 10.1109/TCOMM.2009.07.070592.

[43] R. Chai, A.L. Savvaris, and A. Tsourdos, "Violation learning differential evolution-based hp-adaptive pseudospectral method for trajectory optimization of space maneuver vehicle," IEEE Trans. Aerosp. Electron. Syst., vol. 53, no. 4, pp. 2031–2044, 2017

[44] F. Qu, Z. Wang and L. Yang, "Differential orthogonal space-time block coding modulation for time-variant underwater acoustic channels," IEEE j. ocean. eng., pp. 1–11, 2016.

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