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Re-CAC: A Re-Engineered Call Admission Control for LTE Downlink Networks Using Stepwise Bandwidth Degradation Concept

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Abstract

In Long Term Evolution (LTE) networks, bandwidth degradation is a concept that Call Admission Control (CAC) schemes employ to improve the Quality of Service (QoS) of admitted real-time (RT) calls. However, it has led to noticeable resource wastage due to the inappropriate degradation method employed. In this paper, a Re-engineered Call Admission Control (Re-CAC) scheme that uses stepwise bandwidth degradation is proposed. This contribution to improving resource management allows sequential bandwidth degradation in a stepwise manner. The Re-CAC scheme was tested in MATLAB using the Video and File Transfer Protocol (FTP), representing RT and non-real-time (NRT) classes of service standardized by 3GPP for LTE networks. The performance of Re-CAC was evaluated using throughput, call blocking probability (CBP), call dropping probability (CDP), and spectral efficiency metrics. The Re-CAC scheme was further compared with quality of service-aware CAC (QA-CAC), adaptive CAC (ACAC), and enhanced adaptive CAC (EA-CAC) schemes with reference to the ACAC scheme: Re-CAC, EA-CAC, and QA-CAC schemes achieved respective throughput increase of RT calls by 19.55%, 16.84%, and 12.30% while Re-CAC, QA-CAC, and EA-CAC schemes achieved throughput reduction of NRT calls by 3.25%, 5.38%, and 6.80%, respectively. The Re-CAC, EA-CAC, and QA-CAC schemes achieved corresponding CBP reduction of RT calls by 27.72%, 24.69%, and 12.78% while the Re-CAC, QA-CAC, and EA-CAC schemes achieved corresponding CBP increase of 1.23%, 3.02% and 3.75% for NRT calls. Furthermore, the Re-CAC, EA-CAC, and QA-CAC schemes achieved corresponding CDP reductions of 27.21%, 19.27%, and 12.41% for RT calls, whereas the Re-CAC, QA-CAC, and EA-CAC schemes achieved corresponding CDP increases of 3.01%, 5.13%, and 6.57% for NRT calls. At the same time, the Re-CAC, EA-CAC, and QA-CAC achieved increases in spectral efficiency of 19.34%, 16.84%, and 12.17%, respectively, for RT calls. In contrast, the Re-CAC, QA-CAC, and EA-CAC schemes achieved respective percentage reductions in spectral efficiency of 3.05%, 5.58%, and 6.60% for NRT calls. These results demonstrate the superiority of the Re-CAC scheme over the benchmark CAC schemes in handling RT services.

Keywords: Call Admission Control; Long Term Evolution; Bandwidth Degradation; QoS; RT and NRT Calls.

1- Introduction

Long Term Evolution (LTE) is a fourth generation network standard designed to support broadband connectivity. The Third Generation Partnership Project (3GPP), the group that developed this standard, has introduced enhanced methodologies in its specifications to improve Quality of Service (QoS) [1][2]. LTE network supports Multiple Input Multiple Output (MIMO) technology to achieve high peak data rates of up to 300 Mbps, improve spectral efficiency, and provide wide coverage [3].

The radio access of the LTE network employs Orthogonal Frequency Division Multiple Access (OFDMA) for downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink transmissions [1][4].

In LTE downlink transmissions, radio resources are partitioned across both the frequency and time domains

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using OFDMA [5][6][7]. This partitioning results in a structured radio resource grid, as depicted in Figure 1.

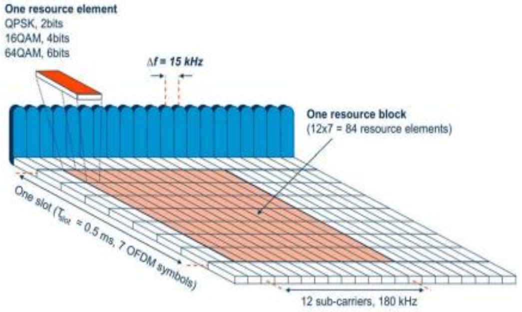

Fig. 1 LTE Downlink Resource Grid Based on OFDM [8]

The resource grid in Figure 1 comprises a matrix of subcarriers in the frequency domain and time slots in the time domain, allowing for efficient allocation and management of radio resources to meet the varying demands of users and applications. These resources are grouped into ten sub-frames. Each sub-frame consists of two slots. Each slot counts 6 or 7 OFDM symbols for a normal or extended cyclic prefix. Assuming an extended cyclic prefix, a resource block (RB) is made up of 7 OFDM symbols and 12 sub-carriers in the time-frequency domain. In the frequency domain, RB has a bandwidth of 180 kHz; thus, the spacing between the sub-carriers is 15 kHz. In the time domain, a slot is 0.5 ms. This shows that each RB contains 84 resource elements (REs) for a normal cyclic prefix. For the extended cyclic prefix, each RB contains 72 resource elements [8]. The LTE downlink physical parameters, including channel bandwidth, subcarrier spacing, the number of occupied subcarriers, and the number of resource blocks, are presented in Table 1.

Table 1: LTE Downlink Physical Parameters [5]

Channel Bandwidth (MHz)	1.4	3	5	10	15	20
Subcarrier Spacing (kHz)	15					
No of occupied Sub-carriers	72	180	300	600	900	1200
Number of Resource Blocks	6	15	25	50	75	100

The information presented in Table 1 was obtained using OFDM symbols with a normal cyclic prefix. As observed, there is a direct relationship among the system channel bandwidth, the number of resource blocks, and the number of occupied sub-carriers.

In the LTE network standard, one aspect that is not fully addressed is CAC strategies. It is one of the distinctive features in the Medium Access Control (MAC) sublayer of a network [9]. CAC is one of the radio resource management (RRM) techniques that can be implemented at the network's admission point. It is among the essential innovations for improving network QoS [10]. CAC is employed by a router or switch to accept or reject a flow according to a predefined flow specification. Before accepting any new flow for processing, the CAC checks the flow specifications to ensure that its total resource, which includes its previous commitments to other flows, is sufficient to accommodate the additional new flow.

In recent times, research interests have focused on CAC schemes, as they have shown significant potential for effectively addressing radio resource wastage in communication networks [1][11][12]. Consequently, relevant contributions to improving resource management using CAC have been proposed. This paper focuses on various CAC schemes proposed for LTE networks.

Mamman et al. suggested an adaptive CAC (ACAC) with bandwidth reservation for downlink transmission in an LTE network [1]. At the admission point into the network, the ACAC scheme allocates the maximum and minimum required bandwidths to the respective RT and NRT calls. When there is insufficient bandwidth to admit a call upon arrival, it degrades the bandwidth of the admitted RT calls to their minimum bandwidth requirements. The bandwidth recouped is added to the system's available bandwidth and used to admit NRT call if its bandwidth requirement is less than or equal to the available bandwidth; otherwise, the scheme rejects the call. On the other hand, RT call is accepted if the needed bandwidth is less than or equal to the available system bandwidth; otherwise, the scheme rejects the call. The ACAC scheme achieved increased throughput and reduced the NRT call blocking rate, though at the expense of RT calls. This approach wastes bandwidth because it lacks a mechanism to determine whether the available bandwidth can accommodate additional calls before degrading the bandwidth.

A Quality of Service aware call admission control (QA-CAC) scheme was used to guarantee QoS for RT calls [11]. The RT and NRT calls are initially assigned maximum bandwidth upon arrival in the network. Upon the subsequent arrival of RT call and there is insufficient resource to accommodate it, the scheme degrades the bandwidth of the admitted NRT calls to their minimum requirement bandwidth. The recouped bandwidth is added to the available system bandwidth. The RT call is accepted if the requested bandwidth is less than or equal to the new available bandwidth; otherwise, the call is denied access. On the other hand, NRT call is accepted if the requested bandwidth is less than or equal to the available system bandwidth; otherwise, the call is rejected. This scheme also wastes resources when the bandwidth recouped from the degradation action is insufficient to handle the newly arrived RT call. This is because the scheme lacks a

mechanism to determine whether the reduced bandwidth is sufficient to accept a new call before the reduction.
Meanwhile, the new call blocking probability is reduced using an adaptive Markov-based CAC scheme [13]. The scheme dynamically reserves physical resource blocks (PRBs) for new calls, and the remaining available PRBs are used to admit other call request types. Under heavy traffic, the scheme degrades the bandwidth of lower priority calls so long as the resources to admit new higher priority call requests are insufficient. This scheme reduced the probability that higher priority calls would be starved during an influx of call requests. This leads to starvation of low priority calls and is attributed to the bandwidth degradation strategy the scheme employs.

In another study, Ali et al. [14] presented a CAC scheme that increased resource usage and reduced the probability of different call requests being dropped. Calls were classified either as a handoff call (HC) or a new call (NC). Higher priority is given to HC and lower priority to (NC). This scheme first checks for the availability of PRB to admit NC or HC call. However, NC can only be accepted if the available PRB exceeds the PRB requested by the new call; otherwise, the call request is denied access. This scheme reduces the probability of dropping the HC call. However, the reserved resources are wasted when no frequent arrivals of HC. Also, the scheme wastes resources if the demand does not match the allocation.

The CAC algorithm for mobility management in the LTE network was suggested [15]. The aim was to reduce the handoff call drop rate, delay and network traffic congestion. The scheme was divided into two sections: to handle handoff calls in the queue, the first module was built using a limited-queue mechanism. The second module was designed specifically to prevent incoming calls from exceeding the base station's threshold. An intelligent fuzzy logic controller was employed to control the capacity of the base station queue. However, the scheme did not apply any form of bandwidth degradation to the admitted call with the maximum bandwidth requirement.

Maharazu et al. presented a CAC scheme for vehicular LTE networks [16]. The scheme prioritized the RT handoff call over the NRT new call. The scheme computed the threshold value and divided the traffic intensity into low and high categories. When the threshold value was less than or equal to the traffic intensity, a new or handoff call was accepted into the network. If the threshold value is higher than the traffic intensity, the suggested strategy rejects handoff calls or new ones. However, the scheme did not apply any form of bandwidth degradation to the admitted call with the maximum bandwidth requirement.

An Enhanced Adaptive CAC (EA-CAC) scheme with bandwidth reservation is suggested in [12]. Initially, maximum bandwidth is assigned to RT and NRT calls. The scheme implemented two mechanisms: adaptive degradation and pre-check mechanisms. The former mechanism first degrades NRT calls before RT calls, and the latter mechanism is used on the admitted RT calls to ascertain if the bandwidth recouped is sufficient to admit new calls. The RT call is accepted if the requested bandwidth is less than or equal to the available system bandwidth; otherwise, the admitted NRT calls are degraded to their minimum required bandwidth. The bandwidth recouped is added to the available bandwidth. Next, the RT call is admitted if the requested bandwidth is less than or equal to the available system bandwidth; otherwise, the admitted RT calls are degraded. Pre-check action is vital to ensure that the degradable bandwidth is enough to accept RT calls. The EA-CAC still wastes RT resources and increases the rate at which NRT calls are blocked or dropped due to the inappropriate degradation mechanism applied.

The reviewed CAC schemes that employ bandwidth degradation are unable to address the problem of resource wastage effectively. As observed, when there is insufficient bandwidth to admit a new call request, the schemes always degrade the admitted RT call bandwidths to their minimum straight away. Afterwards, the new calls are assigned their minimum required bandwidth, and any remaining degraded bandwidth is wasted. An inappropriate bandwidth degradation strategy causes this problem. This paper aims to address this issue by employing a stepwise bandwidth degradation mechanism. This proposal will not only minimize resource wastage but also improve other network QoS parameters.

The remaining parts of this paper are structured as follows: Section 2 presents the methods for achieving the proposed CAC scheme; Section 3 presents the results and discussion; and Section 4 provides the concluding remarks and future research directions.

2- Methodology

The CAC conceptual model is presented in Figure 2. The user equipment UEs are wirelessly connected to an eNodeB. The CAC scheme is implemented at the MAC layer domiciled at the eNodeB.

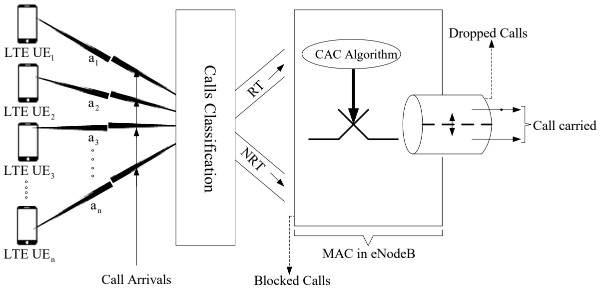

Fig. 2 Conceptual View of an LTE CAC Model

For the admissions process, the UEs transmit calls generated by the call generating module to the eNodeB. Each generated traffic has features such as call type, packet size, arrival time, among others. The traffic is routed to the call prioritizing and classification module, whose function is to categorize the generated calls into two QoS class types, namely RT and NRT calls. The higher priority calls are sent to the CAC module, which is responsible for admissions. Each time a call arrives, the modules verify the traffic specification, which includes the call type, QoS class, arrival time, required bandwidth, and available system bandwidth. It first verifies these parameters, then checks the requirements for admitting the class type and call type. If the requirements are met, the call is approved; otherwise, it is denied. When the bandwidth requested by a call is unavailable, the call is routed to the module responsible for bandwidth degradation. If the degradation requirements are met, the respective accepted calls are degraded.

2-1- Proposed Re-CAC Scheme Development

The Re-CAC concept is conceived because EA-CAC, QA-CAC, and ACAC schemes are unable to effectively address resource wastage in the LTE network. For a deeper understanding, readers of this work are encouraged to read the complete work on each scheme [1][11][12].

Stepwise Bandwidth Degradation Concept

This concept refers to the gradual reduction of the bandwidth assigned to the admitted call. The reduction is in a discrete manner. The assigned bandwidth is gradually degraded in response to a new call service request. The stepwise bandwidth degradation process is achieved following the listed steps:

1. **Initial Bandwidth Allocation:** The scheme allocates a defined amount of bandwidth to each service class.
2. **Monitoring for New Call Requests:** The new call request is monitored, and the call type is classified for resource allocation.
3. **Apply Stepwise Degradation Policy:** The scheme reduces the allocated bandwidth in a stepwise manner.
4. **Further Degradation:** The scheme continues gradual degradation of the allocated bandwidth if the minimum required bandwidth for the admitted calls has not been reached, and the minimum bandwidth needed for the new call request has not been recouped.

At the network admission point, the Re-CAC scheme assigns the maximum bandwidth requirement to RT and NRT calls. Eq. (2.1) and (2.2) are the mathematical operations of the maximum bandwidth allocated to the respective RT calls and NRT calls.

$$\mathrm{RT_{calls}} = \mathrm{Max_{BW\_RT}} \tag{2.1}$$

$$\mathrm{NRT_{calls}} = \mathrm{Max_{BW\_NRT}} \tag{2.2}$$

Where $\mathrm{RT_{calls}}$ and $\mathrm{NRT_{calls}}$ indicate respective real time and non-real time calls. Whereas, $\mathrm{Max_{BW\_RT}}$ and $\mathrm{Max_{BW\_NRT}}$ denote the respective maximum bandwidth requirement allocated to RT and NRT calls.

When bandwidth is not enough to admit a new call, the scheme checks whether bandwidth can be degraded to accept the call. The RT call, being delay sensitive, is prioritized over NRT calls. Thus, it checks the availability of the admitted NRT bandwidth first before checking the availability of the admitted RT bandwidth. This is expressed as in Eq. (2.3).

$$\mathrm{NRT\ Call_{BW_{avail}}} > 0 \tag{2.3}$$

Where $\mathrm{NRT\ Call_{BW_{avail}}}$ indicates the availability of the admitted NRT bandwidth.

After checking that the NRT call's bandwidth is available for degradation, the scheme further checks whether the maximum degradable bandwidth of NRT calls is greater than the bandwidth required to admit a new call. The mathematical operation to that effect is presented in Eq. (2.4).

$$\mathrm{NRT\ Call_{Max_{BW_{deg}}}} > \mathrm{BW_{req}} \tag{2.4}$$

Where $\mathrm{NRT\ Call_{Max_{BW_{deg}}}}$ indicates the maximum degradable NRT bandwidth and $\mathrm{BW_{req}}$ indicates the bandwidth request for a call.

If the maximum degradable NRT bandwidth is sufficient, the Re-CAC scheme uses a stepwise degradation on the admitted NRT calls. The stepwise degradation is achieved using a generalized mathematical operation described by Eq. (2.5).

$$\mathrm{Deg_{BW_n}} = \mathrm{Max_{NRT\_BW}} - \mathrm{Min_{BW}} \tag{2.5}$$

$\mathrm{Min_{BW}}$ is obtained using an expression in Eq. (2.6)

$$\mathrm{Min_{BW}} = \mathrm{Max_{NRT\_BW}} - \mathrm{h} \tag{2.6}$$

Where $\mathrm{Deg_{BW_n}}$ indicates the bandwidth obtained at n = {1, 2, ….. , i} degradation steps. $\mathrm{Max_{NRT\_BW}}$ indicates the maximum allowable admitted NRT bandwidth, $\mathrm{Min_{BW}}$ indicates the minimum degradable bandwidth at each step, and h is the step decrement size.

For clarity, given $\mathrm{Max_{NRT\_BW}}$ = 1450 and *h* = 50, the Re-CAC degrades the maximum allowable admitted NRT call bandwidth in a stepwise manner to recoup available degradable bandwidth using Eq. (2.7):

$$\mathrm{Deg_{BW_1}} = \mathrm{Max_{NRT\_BW}} - \mathrm{Min_{BW}} \tag{2.7}$$

While $\mathrm{Max_{NRT\_BW}}$ and $\mathrm{Min_{BW}}$ retain their original meanings, $\mathrm{Deg_{BW_1}}$ indicates the bandwidth obtained after the first phase of the stepwise degradation of the admitted NRT calls. The bandwidth recouped is added to the available system bandwidth, and a call request is given access if there are sufficient resources, as shown in Eq. (2.8). Minimum bandwidth requirement is allocated to calls admitted after degradation at the point of admission.

$$\mathrm{Avail_{BW}} + \mathrm{Deg_{BW_1}} \geq \mathrm{Req_{BW}} \tag{2.8}$$

Where $\mathrm{Avail_{BW}}$ indicates the available bandwidth, $\mathrm{Deg_{BW_1}}$ retains its original meaning, and $\mathrm{Req_{BW}}$ indicates the requested bandwidth for a call.

When the obtained bandwidth is insufficient, the second phase of stepwise degradation is performed using the mathematical operation in Eq. (2.9).

$$\mathrm{Deg_{BW_2}} = \mathrm{Max_{NRT\_BW}} - \mathrm{Min_{BW}} \tag{2.9}$$

Where $\mathrm{Deg_{BW_2}}$ indicates the bandwidth obtained after the second phase of stepwise degradation of the admitted calls. The bandwidth recouped after the second phase of the stepwise degradation is added to the available system bandwidth, and a call is accepted only if there is enough bandwidth, as shown in Eq. (2.10).

$$\mathrm{Avail_{BW}} + \mathrm{Deg_{BW_2}} \geq \mathrm{Req_{BW}} \tag{2.10}$$

Where $\mathrm{Avail_{BW}}$ and $\mathrm{Req_{BW}}$ retained their original meanings and $\mathrm{Deg_{BW_2}}$ indicates the bandwidth obtained after the second phase of the stepwise degradation of the admitted NRT calls.

The process of stepwise bandwidth degradation continues in an iterative and sequential manner up to the last allowable degradation step. At this point, the Re-CAC perform the final degradation on the admitted NRT calls. The mathematical operation employed is shown in Eq. (2.11).

$$\mathrm{Deg_{BW_n}} = \mathrm{Max_{NRT\_BW}} - \mathrm{Min_{BW}} \tag{2.11}$$

Where $\mathrm{Deg_{BW_n}}$ indicates the bandwidth obtained after the last phase of the stepwise degradation of the admitted NRT calls.$\mathrm{Max_{NRT\_BW}}$ and $\mathrm{Min_{BW}}$ retain their original meanings.

The recouped bandwidth after the final stepwise bandwidth degradation is added to the available system bandwidth. A call is accepted provided there is enough bandwidth, as shown in Eq. (2.12), and the minimum bandwidth requirement is allocated to calls admitted at the network admission point.

$$\mathrm{Avail_{BW}} + \mathrm{Deg_{BW_n}} \geq \mathrm{Req_{BW}} \tag{2.12}$$

Where $\mathrm{Avail_{BW}}$, $\mathrm{Deg_{BW_n}}$, and $\mathrm{Req_{BW}}$ retain their original meanings

If the available bandwidth and the one recouped after the final stepwise degradation of the NRT calls are added up, and the bandwidth is still insufficient to handle the RT calls, the Re-CAC scheme now checks the availability of the admitted RT bandwidth for degradation using the expression in Eq. (2.13).

$$\mathrm{RT\ Call_{BW_{avail}}} > 0 \tag{2.13}$$

Where $\mathrm{RT\ Call_{BW_{avail}}}$ indicates the availability of admitted RT bandwidth.

If the admitted RT bandwidth is available, the Re-CAC pre-checks the admitted RT calls. This is to ascertain if the recouped bandwidth after degradation would be enough to admit a call before performing degradation. In this case, Eq. (2.14) is used.

$$\mathrm{Avail_{BW}} + \sum \mathrm{BW_{RT_{deg}}} \geq \mathrm{Req_{BW}} \tag{2.14}$$

Where $\mathrm{Avail_{BW}}$ and $\mathrm{Req_{BW}}$ retain their former meanings and $\sum \mathrm{BW_{RT_{deg}}}$ indicates the total of the RT degradable bandwidth**.**

If the condition is met, then the RT call bandwidth is degraded using the proposed stepwise degradation and the call request is accepted; else, the call request is rejected. The aim of employing stepwise degradation on RT calls is to ensure that the bandwidth degraded from RT is used, thereby reducing network resource waste. The flow process for achieving the Re-CAC scheme is presented in Figure 3, while its pseudocode is shown in Algorithm 1

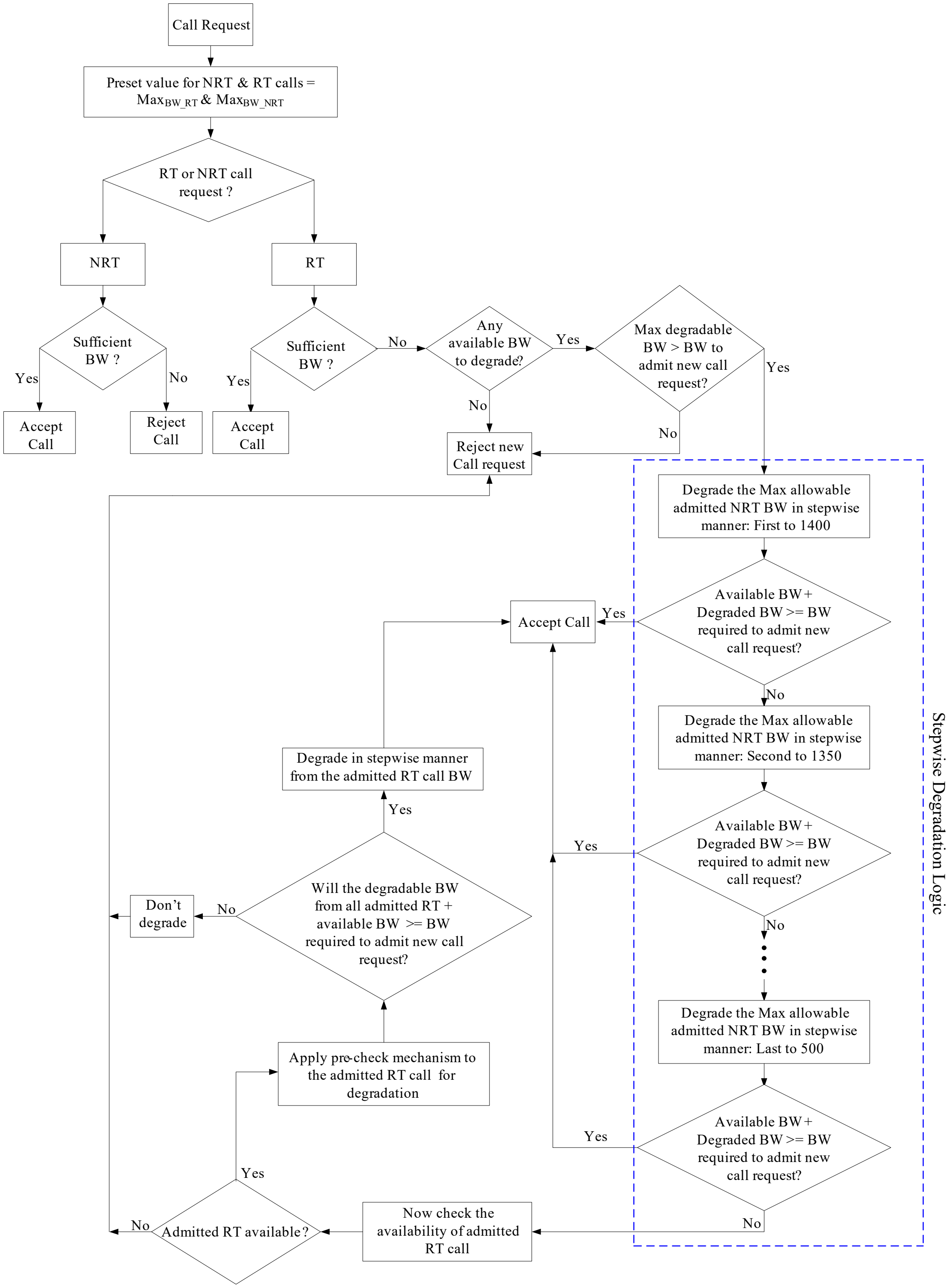

Fig. 3 Flowchart Illustrating the Suggested Re-CAC Scheme

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Algorithm 1: Re-CAC Scheme Pseudo Code

```
Input Parameters:
  • RT: Real time call
  • NRT: Non-real time call
  • $\text{Max}_{BW\_RT}$: Maximum allowable RT bandwidth
  • $\text{Max}_{BW\_NRT}$: Maximum allowable NRT bandwidth
  • $\text{RT}_{BW_{avail}}$: Available RT bandwidth
  • $\text{NRT}_{BW_{avail}}$: Available NRT bandwidth
  • $\text{Req}_{BW}$: Request bandwidth for a call
  • $\text{Avail}_{BW}$: Available bandwidth in the network
  • $\text{NRT Call}_{\text{Max}_{deg}}$: Maximum allowable degraded NRT bandwidth
  • SMT: Simulation time
  • TTI: Transmission Time Interval
  • h: Step decrement size
Initializations
While TTI is within SMT do
    Begin
        Input Call Request
    If Call Request is NRT Then
        Check $\text{NRT}_{BW_{avail}}$
            If Sufficient $\text{NRT}_{BW_{avail}} >= \text{Req}_{BW}$ Then
                Accept Call
            Else
                Reject Call
            End If
    Else If Call Request is RT, Then
        Check $\text{RT}_{BW_{avail}}$
            If Sufficient$\text{RT}_{BW_{avail}} >= \text{Req}_{BW}$ Then
                Accept Call
            Else
                Check if any bandwidth is available for degradation
            If No Available Bandwidth to degrade Then
                Reject Call Request
            Else
                    Check if Max Degradable Bandwidth > $\text{Req}_{BW}$
                        If Yes Then
                            Accept Call
                        Else
                            Reject Call Request
                        End If
                End If
            End If
        End If
        While $\text{Avail}_{BW}$ < Required BW & Steps Avail for Deg
            Degrade Bandwidth in stepwise manner
            If $(\text{Avail}_{BW} + \text{Degraded BW}) >= \text{Req}_{BW}$ Then
                Accept Call
            End If
        End While
        If $(\text{Avail}_{BW} + \text{Degraded BW}) < \text{Req}_{BW}$ Then
            Check Availability of Degradable RT bandwidth
                If $(\sum \text{RT}_{BW_{deg}} + \text{Avail}_{BW}) \geq \text{Req}_{BW}$ Then
                    Degrade Admitted RT
                        Accept Call
                Else
                    Don't Degrade Admitted Call
                        Reject Call
                End If
            End If
        End
End While
```

2-2- Implementation of the Re-CAC Scheme

The Re-CAC scheme is implemented in MATLAB. LTE supports nine (9) traffic classes, and each traffic class is categorized as either RT or NRT [17][18]. In this paper, the RT traffic class (Video Streaming) and the NRT traffic class (File Transfer Protocol, FTP) are the two traffic service classes considered.

Video traffic is generated using the networkTrafficVideoConference object. This object specifies the configuration to create a video application pattern. It was achieved using object-oriented programming in MATLAB. The video traffic generated follows Weibull distribution pattern. On the other hand, the FTP traffic was generated using the networkTrafficFTP object in MATLAB. The networkTrafficFTP object specifies the configuration to generate FTP application pattern. The FTP traffic generated follows a Lognormal distribution pattern. The generated traffic is transmitted to the network's Access Point, and call arrivals follow a Poisson process.

For LTE networks with a typical Maximum Transmission Unit (MTU) of 1500 bytes, the maximum video streaming packet size is around 1400–1450 bytes, and the minimum is around 200–500 bytes for medium-bitrate video. On the other hand, for networks with an MTU of 1500 bytes, the maximum FTP packet size is around 1400 – 1450 bytes, and the minimum FTP packet size is around 50 – 100. The packet size supported by an LTE network can vary depending on the specific network configuration, device capability, and QoS settings. In this paper, respective maximum and minimum packet sizes of 1450 and 500 bytes were used for video streaming, while respective maximum and minimum packet sizes of 1450 and 100 bytes were used for FTP. Table 2 presents all the non-default parameters used in this paper. These parameters are the same for both the Re-CAC and benchmark CAC schemes, thus giving a common ground for simulation and analysis.

Table 2**:** Simulation Parameters

Parameters	**Value**
System Bandwidth	5 MHz
Number of Resource Blocks	25
Sub-carrier Spacing	15 kHz
Number of eNB	1
Maximum UE in eNB	120
TTI Duration	1ms
Services Classes Tested	Video and FTP
Simulation Time	1000s
Packet Size [Video]	Maximum = 1450 Bytes; Minimum = 500 Bytes
Packet Size [FTP]	Maximum = 1450 Bytes; Minimum = 100 Bytes
Call Arrival	Poisson Process
Transmission Scheme	2×2 MIMO, OLSM Antennas
Considered Cyclic Prefix	4.7 µS Normal Cyclic Prefix
UE Distribution	Uniform

3- Result and Discussions

The results achieved by simulating the Re-CAC scheme and benchmark CAC schemes (QA-CAC, ACAC, and EA-CAC) are discussed. These schemes are evaluated based on Throughput, Call Blocking and Call Dropping Probabilities, and Spectral Efficiency metrics for both RT and NRT calls.

In the result analysis, the following are worth noting: the scheme that recorded the highest throughput is graded better than others in performance, the scheme that recorded the lowest CBP and CDP is graded better than others in performance, and the scheme that achieved the highest spectral efficiency value is rated to outperform others.

3-1- Throughput Results

Figure 4 presents the throughputs of RT calls with Re-CAC and benchmark CAC schemes. As observed, when the call request is low, Re-CAC, together with the benchmark CAC schemes, achieved equal throughputs. This is because the available bandwidth was enough to handle all call requests. As call requests increase, Re-CAC outperformed all benchmark schemes in admitting more RT calls. The Re-CAC achieved an average throughput of 0.1657 Mbps, whereas EA-CAC, QA-CAC and ACAC schemes achieved throughputs of 0.1603, 0.1520, and 0.1333 Mbps, respectively. With reference to the ACAC scheme, further analysis shows that Re-CAC, EA-CAC, and QA-CAC achieved throughput increases of 19.55%, 16.84%, and 12.30%, respectively. The results are as expected, since Re-CAC prioritized RT calls over NRT calls. Most importantly, unlike the benchmark schemes which when there is insufficient bandwidth to admit a new call upon arrival, degrades the bandwidth of the admitted RT calls to their minimum bandwidth requirements straight away, the Re-CAC scheme degrades in a stepwise manner (i.e., gradual degradation until it gets to the minimum bandwidth required by the admitted calls) on active NRT calls before using it on the RT calls. The Re-CAC scheme also adopted a pre-check mechanism and employed it at every degradation step. This ensures that when the active call's bandwidth is degraded and added to the unused bandwidth, the total bandwidth remains neither insufficient nor oversufficient for the new RT calls. EA-CAC, together with the QA-CAC scheme, increases RT call throughput compared to ACAC. The reason is that the EA-CAC scheme first degrades NRT calls before degrading RT calls.

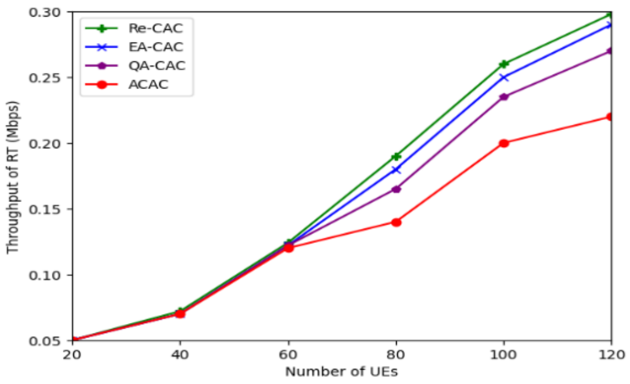

Fig. 4 Throughput of RT Calls with Re-CAC and Benchmark CAC Schemes

Figure 5 shows the throughputs achieved by NRT calls with the Re-CAC scheme, along with those of the benchmark CAC schemes. As observed, as the number of calls requesting admission increases, the ACAC scheme achieves a slightly higher throughput than the Re-CAC, QA-CAC, and EA-CAC schemes. Descriptively, the ACAC achieved an average throughput of 0.0985 Mbps, whereas the Re-CAC, QA-CAC, and EA-CAC schemes achieved individual throughputs of 0.0953, 0.0932, and 0.0918 Mbps, respectively. With reference to the ACAC scheme, further analysis shows that the Re-CAC, QA-CAC, and EA-CAC schemes achieved throughput reduction of 3.25%, 5.38%, and 6.80%, respectively. The reason is that the ACAC scheme degrades RT calls to their minimum bandwidth requirement instantly if there is insufficient bandwidth to admit a new call. The new call is admitted using the recouped bandwidth and the unused system bandwidth. The Re-CAC scheme admitted slightly more NRT calls than the QA-CAC and EA-CAC schemes due to the gradual degradation of NRT calls when the required bandwidth to admit a new call is insufficient. Calls admitted using the QA-CAC scheme are fewer than those admitted under both the ACAC and Re-CAC schemes. This is due to the degradation approach it uses for admitted NRT calls when the bandwidth to admit a new call is insufficient.

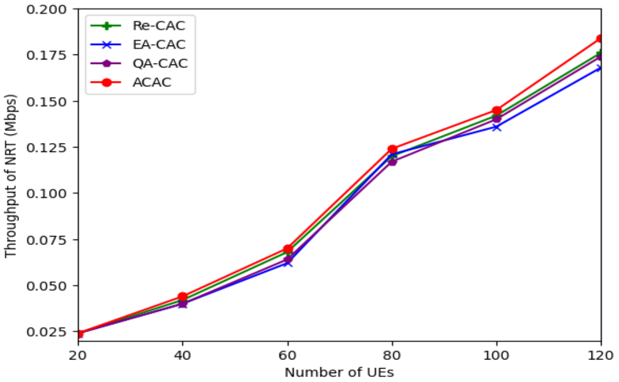

Fig. 5 Throughput of NRT Calls with Re-CAC and Benchmark CAC Schemes

3-2- Throughput Results

The CBP achieved by RT calls with Re-CAC and benchmark CAC schemes are presented in Figure 6. As the call request increases, the Re-CAC, QA-CAC, and EA-CAC schemes reject fewer calls than the ACAC scheme. The Re-CAC scheme has the lowest RT call blocking. The CBP for RT calls with Re-CAC, EA-CAC, QA-CAC, and ACAC schemes are 0.0837, 0.0872, 0.1010, and 0.1158, respectively. With reference to the ACAC scheme, further analysis shows that the Re-CAC, EA-CAC, and QA-CAC schemes achieved CBP reductions of 27.72%, 24.69%, and 12.78%, respectively. The Re-CAC scheme achieves the lowest CBP reduction because it allocates sufficient resources to RT calls at the network admission point. Also, due to the stepwise degradation applied to NRT calls when there is insufficient bandwidth to accept a new call, the recouped bandwidth is used to admit more RT calls. The Re-CAC scheme also employed a pre-check mechanism for RT calls to ascertain their availability before degradation. Furthermore, the EA-CAC scheme blocks fewer RT calls than the QA-CAC scheme, and the QA-CAC scheme rejects fewer calls than the ACAC scheme.

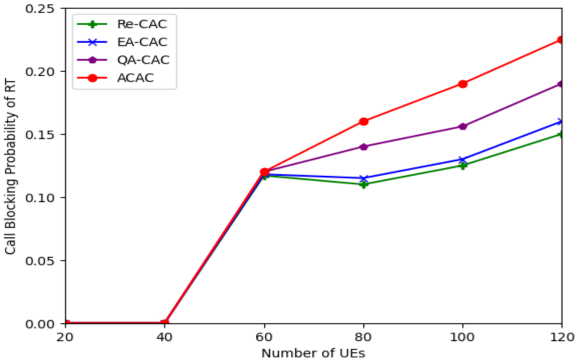

Fig. 6 CBP of RT Calls with Re-CAC and Benchmark CAC Schemes

Meanwhile, Figure 7 presents the CBP achieved by NRT calls with Re-CAC and benchmark CAC schemes. From the observation, when call arrivals into the network are low, both the Re-CAC and the benchmark schemes block no NRT calls. This is because at that moment, enough resources are available to accommodate all calls requesting admission to the network. As call requests keep increasing, the ACAC scheme has experienced the lowest NRT call blocking. The CBP values for NRT calls with the ACAC, Re-CAC, QA-CAC, and EA-CAC schemes are 0.0642, 0.0650, 0.0662, and 0.0667, respectively. With reference to the ACAC scheme, further analysis shows that the Re-CAC, QA-CAC, and EA-CAC schemes achieved corresponding CBP increases of 1.23%, 3.02%, and 3.75%, respectively. The ACAC scheme achieves the lowest CBP for NRT calls by prioritizing NRT calls over RT calls. Thus, the admitted RT calls were degraded so that the bandwidth obtained was used to admit NRT calls. On the other hand, the Re-CAC blocks fewer NRT calls than the QA-CAC and EA-CAC schemes.

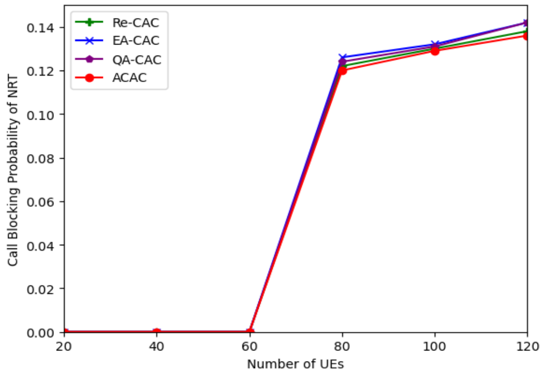

Fig. 7 CBP of NRT Calls with Re-CAC and Benchmark CAC Schemes

3-3- Call Dropping Probability Results

The CDP experienced by RT calls with Re-CAC and benchmark CAC schemes is shown in Figure 8. It is observed that all the schemes drop no RT calls when the call arrival is low. This is because, at that point, sufficient resources were available for call admissions. As the number of call requests increases, the Re-CAC scheme drops fewer RT calls than the EA-CAC, QA-CAC, and ACAC schemes. The CDP for RT calls with Re-CAC, EA-CAC, QA-CAC, and ACAC schemes are 0.0733, 0.0813, 0.0882, and 0.1007, respectively. With reference to the ACAC scheme, further analysis shows that Re-CAC, EA-CAC, and QA-CAC schemes achieved CBP reduction of 27.21%, 19.27%, and 12.41%, respectively. The Re-CAC scheme achieves the lowest CDP reduction because it assigns sufficient resources to RT calls at their point of admission. Additionally, the scheme applies stepwise bandwidth degradation to NRT calls when the bandwidth required to admit a new call is insufficient. Thereafter, the bandwidth obtained at each step decrement is used to admit RT calls. The Re-CAC scheme also employed a pre-check mechanism for RT calls. The EA-CAC scheme drops fewer RT calls than the QA-CAC and ACAC schemes, while the QA-CAC scheme rejects fewer RT calls than the ACAC scheme.

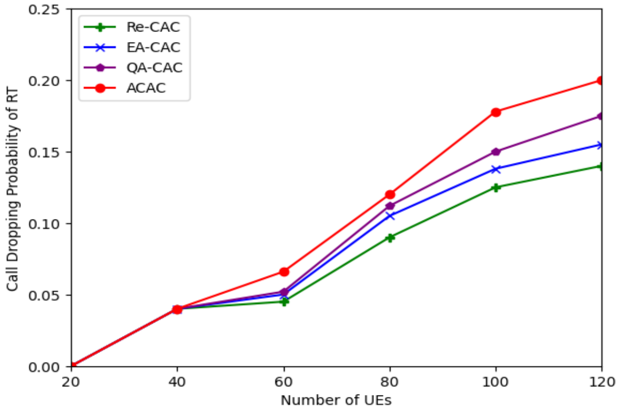

Fig. 8 CDP of RT Calls with Re-CAC and Benchmark CAC Schemes

Conversely, Figure 9 presents a plot of the CDP experienced by NRT calls under the Re-CAC and benchmark CAC schemes. It can be seen that when the number of call requests for access to network resources is low, no NRT calls are dropped by the Re-CAC or other benchmark schemes. This is because there are sufficient resources to handle all admission requests. As the number of call requests continues to increase, the ACAC scheme rejects slightly fewer NRT calls than the Re-CAC, EA-CAC, and QA-CAC schemes. The CDP of NRT calls with ACAC, Re-CAC, QA-CAC, and EA-CAC schemes are 0.0740, 0.0763, 0.0780, and 0.0792, respectively. With reference to the ACAC scheme, further analysis shows that the Re-CAC, QA-CAC, and EA-CAC schemes achieved corresponding CBP increases of 3.01%, 5.13% and 6.57% for NRT calls. The ACAC scheme achieves the lowest CDP for NRT calls by prioritizing NRT calls over RT calls. Thus, when bandwidth is insufficient, the scheme degrades RT calls, and the recouped bandwidth is used to admit more of NRT calls. Also, the CDP with the Re-CAC scheme is slightly lower than the EA-CAC and QA-CAC schemes. The reason is that the Re-CAC scheme gradually reduced the admitted NRT call bandwidth in steps. The QA-CAC scheme rejects slightly fewer NRT calls than the EA-CAC scheme, due to the degradation mechanism it applies to admitted NRT calls.

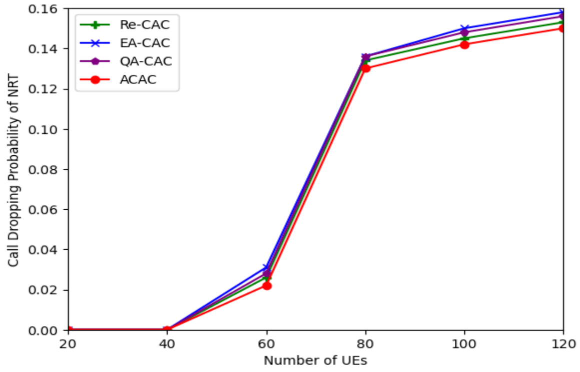

Fig. 9 CDP of NRT Calls with Re-CAC and Benchmark CAC Schemes

3-4- Spectral Efficiency Results

The efficacy of the Re-CAC scheme in reducing bandwidth wastage is further demonstrated through the spectral efficiency metric.

Figure 10 presents the spectral efficiency achieved by RT calls with the Re-CAC and benchmark schemes. It can be seen that when the number of calls requesting network access is low, the Re-CAC and benchmark schemes achieve equal spectral efficiency. As call requests keep increasing, the spectral efficiencies achieved with the schemes are increasing, and the Re-CAC scheme outperforms EA-CAC, QA-CAC, and ACAC in spectrum utilization for RT calls. The results of the Re-CAC scheme showed that a 0.0331 bps/Hz spectrum is used on average. On the other hand, the average of 0.0321, 0.0304, and 0.0267, all in bps/Hz, is used by the EA-CAC, QA-CAC, and ACAC schemes, respectively. With reference to the ACAC scheme, further analysis shows that Re-CAC, EA-CAC, and QA-CAC schemes achieved spectral efficiency increases of 19.34%, 16.84%, and 12.17%, respectively. The superiority of the Re-CAC scheme over EA-CAC, QA-CAC, and ACAC is attributed to the stepwise degradation mechanism it employs.

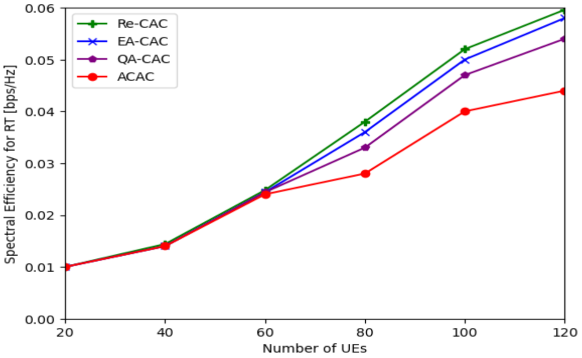

Fig. 10 Spectral Efficiency of RT Calls with Re-CAC and Benchmark CAC Schemes

Similarly, the spectral efficiency achieved by NRT calls with Re-CAC and benchmark CAC schemes is presented in Figure 11. As observed, when call requests are low, both the Re-CAC and benchmark schemes achieve equal spectral efficiency for NRT calls. As the number of calls requesting admission increases, the ACAC scheme achieves slightly better spectrum efficiency than the Re-CAC, QA-CAC, and EA-CAC schemes. The ACAC achieved an average spectral efficiency of 0.0197 bps/Hz, whereas the Re-CAC, QA-CAC, and EA-CAC schemes achieved spectral efficiencies of 0.0191, 0.0186, and 0.0184 bps/Hz, respectively. With reference to the ACAC scheme, further analysis shows that the Re-CAC, QA-CAC, and EA-CAC schemes achieved reductions in spectral efficiency of 3.05%, 5.58%, and 6.60%, respectively. The reason is that the ACAC scheme gave NRT calls higher priority. Thus, when there is a need to carry out degradation action, RT calls are degraded to their minimum bandwidth requirement, and the bandwidth obtained is added to the available system bandwidth to admit new NRT calls. This leads to increased spectrum utilization for NRT calls. The Re-CAC scheme slightly admitted more NRT calls than the QA-CAC and EA-CAC schemes. Calls requests admitted using the QA-CAC scheme are fewer than those admitted under both the ACAC and the Re-CAC schemes.

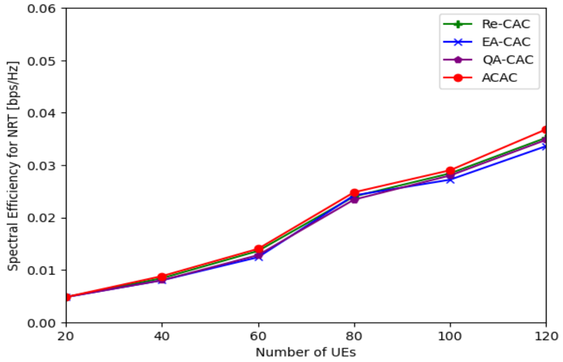

Fig. 11 Spectral Efficiency of NRT Calls with Re-CAC and Benchmark CAC Schemes

4- Conclusions

Stepwise bandwidth degradation is recommended when gradual bandwidth degradation is desired. In this paper, the stepwise bandwidth degradation concept is employed in the formulation of the Re-CAC scheme for the LTE downlink network. It was observed that resource wastage is associated with the bandwidth degradation approach considered by the bandwidth degradation-based CAC scheme. The Re-CAC significantly reduced bandwidth wastage. This is demonstrated by the obtained spectral efficiency value and other performance metrics, namely throughput, CBP, and CDP. The improvement is achieved by addressing the fundamental limitation of EC-CAC, QA-CAC, and ACAC schemes (i.e., the use of an inappropriate bandwidth degradation mechanism). The Re-CAC scheme introduced a stepwise bandwidth degradation instead. This ensures that the degradable bandwidth from the active calls is not surplus to admit new calls into a network. The reason is that calls admitted after degrading active calls should be allocated their minimum required bandwidth at the network admission point. The Re-CAC scheme can be beneficial to network and traffic managers whose target is on resource optimization.

The Re-CAC scheme was implemented and further compared with ACAC, QA-CAC, and EA-CAC schemes in

MATLAB. This comparison is based on throughput, CBP and CDP, and spectral efficiency metrics. The superiority of the Re-CAC over the ACAC, QA-CAC, and EA-CAC schemes is demonstrated by the results. The Re-CAC scheme achieved higher throughput, reduced CBP and CDP, and higher spectral efficiency for RT calls without sacrificing the expected performance of NRT calls.

Estimating an exact bandwidth to degrade without resorting to resource waste is a future research interest. We intend to explore machine learning capabilities for estimating the exact bandwidth degradable step to employ when a call requests admission. This concept will further reduce to the barest minimum the resource wastage with the existing CAC schemes.

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