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Enhanced Adaptive Call Admission Control Scheme with Bandwidth Reservation for LTE Networks

Maniru Malami Umar, Usmanu Danfodiyo University, Sokoto, Nigeria

Aminu Mohammed, Usmanu Danfodiyo University, Sokoto, Nigeria

Abubakar Roko, Usmanu Danfodiyo University, Sokoto, Nigeria

Ahmed Yusuf Tambuwal, Usmanu Danfodiyo University, Sokoto, Nigeria

Abdulhakeem Abdulazeez, Usmanu Danfodiyo University, Sokoto, Nigeria

ABSTRACT

Call admission control (CAC) is one of the radio resource management techniques that regulate resources for new or ongoing calls in a network. The existing CAC schemes waste bandwidth, due to their failure to check for the effect of degradation before degrading admitted RT calls and the schemes increases the call dropping probability (CDP) and calling blocking probability (CBP) of RT calls due to the delay incurred when bandwidth is degraded from the admitted RT calls. This paper proposed an enhanced adaptive call admission control (EA-CAC) scheme with bandwidth reservation. The scheme employs a prior-check mechanism that ensures bandwidth to be degraded will be enough to admit the new call request. It further incorporates an adaptive degradation mechanism that degrades NRT calls before degrading the RT calls. The performance of the EA-CAC scheme was evaluated against that of Adaptive Call Admission Control (ACAC) and QoS-Aware Call Admission Control (QA-CAC) schemes using the Vienna LTE system-level simulator. The EA-CAC scheme exhibits better performance compared to the two schemes in terms of throughput, CBP, and CDP of RT calls without sacrificing the performance of NRT calls.

KEYWORDS

Bandwidth, Degradation, Radio Resource Management (RRM), Call Admission Control (CAC), Real-Time, Non-real time, call blocking probability (CBP), call dropping probability (CDP), Long term evolution (LTE).

INTRODUCTION

Today, wireless broadband technologies (WiBB) are fast evolving to satisfy the present and future demand of users for efficient transmission of multimedia applications. Long Term Evolution (LTE) is one such WiBB technologies designed by the Third Generation Partnership Project (3GPP) for efficient transmission of multimedia applications by delivering high data rates, improving flexibility, and spectral efficiency. These features make LTE an attractive solution for both users and mobile operators (Angelos, Elli, Luis, and Christos, 2011).

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LTE employs different radio resource management (RRM) techniques to improve the utilization of available network resources and minimize network congestion for different types of users (Mamman, Zurina, Azizol, and Abdullah, 2018). An efficient RRM technique that will handle the network resources efficiently is required due to the fact that network resources are in most cases scarce (Daniel, Edem and Enoch, 2014). Specifically, an efficient call admission control (CAC) scheme which regulates resources for new call requests or ongoing calls is needed. Call admission control is the process of accepting a new call or a handoff call request into the network while maintaining the quality of service (QoS) of admitted or ongoing calls (Vaishali and Uttam, 2019). Call requests are classified into two: new call and handoff call request. A new call is a call request that is requesting for a new connection into the network while a handoff call is an ongoing or already connected call that needs to be transferred from one cell to another without compromising the quality of service (QoS) of existing calls (Solomon, Abdulhakeem, Aminu, Maniru and Zaharadeen, 2019).

Several CAC schemes have been proposed in LTE with the aim of reducing call blocking and call dropping probability, guaranteeing the QoS of calls and utilizing the available network resources. The schemes proposed in (Ali *et al*, 2010, Senkapa and Franklin, 2012, and Ramraj *et al*, 2014) focused on reducing call blocking and call dropping probabilities for both new and handoff calls. However, the schemes starve lower priority call requests thereby increasing their call blocking and dropping probabilities. The schemes also fail to utilize network resources efficiently in some situations where bandwidth are reserved in advance for handoff call requests. While the scheme in (Chadchan & Akki, 2011, Khabazian *et al* 2012, Belghith *et al*, 2016a; AlQahtani, 2017) were more concerned about guaranteeing QoS of different users. However, the schemes increase call blocking and call dropping probabilities of lower priority calls. On the other hand, the schemes proposed in (Lei *et al*, 2008 and Belghith *et al*, 2016b) focused on improving resource utilization for different traffic types. The schemes ensure that resources and bandwidth are utilized effectively among all traffic types.

An Adaptive Call Admission Control with Bandwidth Reservation scheme was proposed by Maharazu, Zurina, Azizol & Abdullah (2017) to provide efficient resource utilization and prevent BE traffic starvation. The scheme increases the throughput of BE traffic and reduces both Call Blocking Probability (CBP) and Call Dropping Probability (CDP) for BE traffic. However, the QoS of RT calls is not guaranteed as a result of the degradation mechanism that is applied to all admitted RT calls when there are insufficient resources to admit a new call. Recently, a QoS-aware call admission control (QA-CAC) was presented by Maniru, Aminu, Abubakar, Ahmed & Abdulhakeem (2019). The scheme guaranteed the QoS of RT calls thereby increasing the throughput RT calls and reduces their dropping rate. However, it wastes bandwidth in a situation whereby the degraded bandwidth is less than the requested bandwidth. It also reduces the throughput of NRT calls as a result of the degradation approach applied to NRT calls

In this paper, an enhanced adaptive call admission control (EA-CAC) scheme is proposed to address the shortcomings of the scheme proposed by Maharazu *et al.* (2017) and the QA-CAC scheme presented by Maniru *et al* (2019). For the purpose of this paper, the scheme presented by Maharazu *et al.* (2017) will be given the acronym of ACAC i.e. adaptive call admission control scheme. The EA-CAC scheme introduced a prior-check mechanism that will ensure bandwidth to be degraded will be enough to admit the requested call. It further employs an adaptive

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degradation mechanism that will degrade all admitted calls one (class) after the other, i.e. by degrading NRT first and then degrading RT calls.

The major contributions of this paper are: implementation of a prior-checking mechanism which leads to an improved CAC scheme that guaranteed QoS of calls, better network throughput, low blocking and dropping rates of RT calls without sacrificing the performance of NRT calls in terms of throughput, CBP and CDP. The rest of the paper is organized as follows. The next section presents the review of related works and then followed by the description of the proposed enhanced adaptive call admission control (EA-CAC) scheme with bandwidth reservation for LTE networks. The performance evaluation of the proposed EA-CAC scheme against the ACAC and QA-CAC is also presented. Lastly, the paper concludes by summarizing the results obtained after several simulation experiments.

BACKGROUND

In this section, some related call admission control schemes in LTE network are reviewed by highlighting the operation, strength(s) and weakness(s) of each scheme:

Lei *et al.* (2008) presented an adaptive CAC scheme to reduce the CBP of calls for LTE systems with heterogeneous services. The scheme adaptively determines the threshold for each service class based on the traffic condition. It employs a transmission guard interval strategy which gives higher priority to RT services that are close to their delay deadline. The scheme admits an RT calls by employing a QoS indicator but unconditionally admits an NRT call if there are sufficient resources in the system. It degrades admitted NRT traffics to accept handover traffics when the network is congested. The scheme reduces the CBP of higher priority calls when the traffic intensity is low but starves lower priority traffic and increases their CDP due to degradation strategy employed.

Ali *et al* (2010) proposed a CAC and Resource Block (RB) reservation scheme to reduce CDP of handoff calls. The scheme separates an incoming call request according to their priority and then it assigns a higher priority to handoff calls. It employs an RB's strategy which allocates the maximum number of RB's when resources are enough but allocates resources lower than the required resources when there are insufficient resources in the system. The scheme employs a degradation strategy that degrades lower priority calls when there are insufficient resources to admit a higher priority call. Furthermore, it employs a degradation strategy which degrades RB's of the lower priority calls to admit an NC that has not exceeded its latency. The scheme reduces CDP and maintains low blocking probability for handoff calls. However, it starves lower priority calls due to the degradation procedure and as such their QoS is not guaranteed.

Chadchan & Akki (2011) presented a Priority-Scaled (PS) preemption scheme to guarantee Quality of Service (QoS) for LTE networks. The PS scheme computes two parameters on the arrival of a request; R_{Total} and R_{Min} where R_{Total} is the amount of resources that can be obtained by total preemption of all Lower Priority Preemptable Active Bearers (LP PABs) while R_{Min} is the amount of resources that can be obtained by reconfiguring all LP PABs to their minimum QoS level. The scheme blocks a new request if R_{Total} is not sufficient to satisfy its QoS needs else if R_{Min} is sufficient to service the new request, then the Priority-Scaled Minimum QoS Preemption Algorithm (PS-MQPA) is used. The PS-MQPA preempts more resources from the lower priority bearers than from higher priority bearers to ensure better QoS for higher priority bearers. Furthermore, If R_{Min} is sufficient to service a new request but

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the new request requirements are less than R_{Total} then the Total Preemption Algorithm (TPA) is used. The TPA employs a total preemption strategy by dropping all LP PABs with the lowest priorities and highest resources. The scheme guarantees QoS for LP PABs, but in the presence of a large number of higher priority requests, LP PABs experiences a higher dropping rate due to the total preemption strategy employed by the scheme.

Senkapa & Franklin (2012) proposed an Extensive Dynamic Bandwidth Adaptation Call Admission Control (DB-CAC) procedure to reduce CDP and to guarantee the QoS of NC and HC. The DB-CAC scheme takes into account the separation between incoming traffic for each class of service and prioritizes HC over NC using a load balancing strategy. It also employs a prediction mechanism that helps to reserve resources in advance whenever a call is detected based on the user's experience. The scheme operates in two stages which are arrival and departure stages. At the first stage, the scheme gets as many resources as required to service HCs and NCs in the queue by degrading the active NRT calls. At the departure stage, more resources are assigned to the RT calls to increase overall system utilization. Furthermore, it arranges all the NRT calls in descending order and degrades them to service RT calls when resources are not sufficient. The scheme reduces the CBP of calls due to the prediction strategy employed by the scheme. However, the NRT calls are not treated fairly due to the degradation strategy employed by the scheme.

Khabazian *et al* (2012) presented a CAC scheme with resource reservations to avoid call QoS degradation. The scheme takes into consideration two categories of traffics which are the narrow-band and wideband services. The scheme admins a narrow band call when there are enough unused resources to provide the data rate of admission and during its call holding time, otherwise, the call is blocked. It admits a wideband service call if there are enough resources that can service the requested data rate at admission time and when a narrowband service call is terminated or leaves the cell, otherwise the call is blocked. In addition, the scheme reserves a fixed amount of extra resources to a particular service during the admission process to eliminate QoS degradation. The scheme reduces call's QoS degradation under heavy traffic intensity, but it increases CBP for the wideband service calls.

Ramraj *et al* (2014) proposed a CAC scheme for high-speed vehicular communications to reduce CB and CDP for RT and NRT traffic. The scheme employs a strategy that is based on Resource Blocks (RBs) reservation that reserves resources for ongoing calls and NCs. It estimates the Bit Error Rate (BER) based on the Rayleigh fading model in high vehicular speed. The scheme admits a call when the requested RBs are less than or equal to the available resources. Otherwise, if the RBs are not sufficient, then the remaining RBs will be reserved for future or expected incoming calls. It further admits a future or expected incoming call when the required resources are equal or less than the available resources. The scheme reduces CBP and CDP but inefficiently utilizes the network resources due to the reservation strategy used by the scheme which leads to a situation in which the reserved resources are not fully utilized by the future calls.

Belghith *et al* (2016a) presented a Flexible Call Admission (FCAC) scheme to increase resource utilization and support multimedia services with diverse traffics. The scheme classifies requests into RT and NRT and also estimates channel quality based on RSS to identify a new and handoff call request. The scheme accepts RT requests with bad channel if the Occupation Ratio of the Bandwidth (OR_BW) is lower than a set threshold for RT calls. It accepts NRT request if the OR_BW is lower than a threshold set for NRT requests, otherwise, the request is rejected if the total number of available PRBs is not sufficient to service the request. The scheme further employs a preemption

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strategy to preempt resources from admitted NRT calls that have been fully or partially served to service RT requests. The scheme reduces CDP for RT calls due to higher priority given to RT requests but increases CBP for NRT requests due to preemption strategy employed.

Belghith *et al* (2016b) proposed an Efficient Bandwidth Call Admission Control (EB_CAC) to reduce CBP and guarantee the QoS of RT and NRT calls. The scheme classifies service types as RT and NRT and also classifies call requests as NC and HC. The scheme also estimates channel quality based on RSS to determine good and bad channels. It then applies a congestion threshold and blocking probabilities for each call type. The scheme further classifies RT call type as either RT_HC or RT_NC and accepts an RT_HC call if there are enough PRBs neglecting the channel condition and Bandwidth occupational ratio (BOR). The scheme rejects NRT requests if there are insufficient PRBs in the system. The scheme guarantees QoS for different service classes and also increases the overall system throughput. It also admits more RT_HC calls but NRT request experience high dropping rate due to priority given to RT requests.

AlQahtani (2017) presented a Delay Aware and Users' categorizing based Call Admission Control with adaptive Resource Reservation scheme to guarantee QoS and increase resource utilization. The scheme categorizes users as Golden (G) and Silver (S) users and classifies service types of each user as RT and NRT. It virtually reserves a set of PRBs for each service type. The scheme admits a request when the requested PRBs are less than or equal to the available PRBs else the request is admitted into a waiting queue provided the queue is not filled up otherwise the request is rejected. It drops a queued request if it exceeds its predefined queuing time limit. The scheme further determines the Adaptive Priority (AP) of all non-empty queues using the total number of PRBs currently used by all users, number of virtual reserved PRBs, Maximum tolerable delay, and Current latency. It gives the highest priority to the queue with the minimum AP and the queue is served first. The scheme guarantees QoS and efficiently utilizes resources because of the virtual resources reservation strategy used. However, requests with the lowest priority which are the NRT and BE traffics experience a high blocking rate and sometimes even starved due to priority given to higher priority requests.

Maharazu *et al* (2017) proposed an Adaptive Call Admission Control with Bandwidth Reservation scheme to provide efficient resource utilization and prevent BE traffic starvation. It allocates maximum and minimum required bandwidth to RT and NRT respectively at the point of admission. The scheme degrades bandwidth from all the admitted RT calls when a new call arrives and there is insufficient bandwidth to admit a new call request. A call is admitted if the available and degraded bandwidth is less than or equal to the requested bandwidth, otherwise, the call is rejected. The scheme increases the throughput of BE traffic and reduces the CBP and CDP of the BE traffic. However, the QoS of RT calls is not guaranteed as a result of the degradation mechanism that is applied to all admitted RT calls when there are insufficient resources to admit a new call.

Maniru *et al* (2019) presented a QoS-aware call admission control (QA-CAC) to guarantee the QoS and increase the throughput of RT calls. The QA-CAC scheme admits a new call if the requested bandwidth is less than or equal to the available bandwidth, otherwise, a degradation approach is applied on all admitted NRT calls. It degrades all admitted NRT calls to their minimum bandwidth requirement and then adds up the degraded bandwidth to the available bandwidth in the system. If the available bandwidth is less than or equal to the requested bandwidth, the call

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is accepted otherwise the call is rejected. The QA-CAC guarantees the QoS of RT calls thereby increasing the throughput of RT calls and also reduces the dropping rate of RT calls. However, it wastes bandwidth in a situation whereby the degraded bandwidth is less than the requested bandwidth. It also reduces the throughput of NRT calls as a result of the degradation approach applied to NRT calls.

Table 1 shows the summary of the existing CAC schemes reviewed in this paper by showing the name of scheme, it strength(s) and weakness(s) of each of the scheme.

S/N	Scheme	Strength(s)	Weakness(s)
1	Adaptive call admission control (CAC) scheme. (2008)	Achieves low blocking probability under low traffic.	Starves lower priority traffic and increases their dropping probability due to degradation strategy used.
2	CAC and Resource Block (RB) reservation scheme (2010).	Reduces handoff dropping probability and maintain low blocking probability.	Starves lower priority class due to its degradation procedure and as such their QoS is not guaranteed.
3	CAC with Priority - Scaled (PS) preemption scheme (2011).	Guarantees QoS for LP PABs but in the presence of a large number of higher priority requests.	LP PABs experiences higher dropping rate due to total preemption strategy used by the scheme
4	Extensive Dynamic Bandwidth Adaptation Call Admission Control scheme (DB-CAC) (2012).	Reduces new call blocking probability due to the prediction strategy employed by the scheme. It also improves resource utilization because resources are restored when a call is over.	NRT calls are not treated fairly due to degradation strategy employed by the scheme
5	CAC scheme with resource reservation (2012)	Reduces call's QoS degradation under heavy traffic but it.	Increases call blocking probability for the wide-band service calls
6	CAC scheme for high-speed vehicular communications (2014).	Reduces CBP and CDP of calls.	Fails to utilize network resources efficiently because the reserved resources may not be fully utilized by the calls.
7	Flexible Call Admission (FCAC) scheme (2016).	Reduces CDP for RT calls due to higher priority given to RT requests.	Increases CBP for NRT requests due to the preemption strategy employed.
8	Efficient Bandwidth Call Admission Control (EB_CAC) scheme (2016).	Guarantees QoS for different service classes and increases the total system throughput. It also increases the number of accepted RT_HC calls.	NRT request experience high dropping rate due to priority given to RT requests.
9	Delay Aware and Users' categorizing based Call Admission Control scheme with adaptive Resource Reservation (DA-UC-ARR) (2017).	Guarantees QoS and efficiently utilizes resources because of the virtual resources reservation strategy used	Requests with the lowest priority which are the NRT and BE traffics experiences a high blocking rate and sometimes even starved due to priority given to higher priority requests
10	Adaptive Call Admission Control with Bandwidth Reservation scheme (2017).	Increases the throughput of BE traffic and reduces both CBP and CDP for BE traffic.	Causes bandwidth wastage and also increases the delay of already admitted RT calls

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			which leads to an increase in CBP and CDP of calls
11	QoS-aware Call Admission control (QA-CAC) scheme (2019).	It increases the throughput of RT calls thereby guaranteeing the QoS of RT calls and also reduces the dropping rate of RT calls.	It wastes bandwidth in a situation whereby the degraded bandwidth is less than the requested bandwidth. It also reduces the throughput of NRT calls as a result of the degradation approach applied to NRT calls.

It is therefore important to note that the previous schemes in the above literature focused on QoS provisioning, reducing CBP and CDP, and also improving the utilization of network resources. However, the schemes that focused on the utilization of network resources waste bandwidth due to the failure to check whether the bandwidth to be degraded will be enough to admit the new call request. In a situation where the degraded bandwidth was not enough to admit the new call request, the degraded bandwidth is thereby wasted and the delay of the admitted calls i.e. these from which the bandwidth was degraded is increased and may later lead to call drop. To address these aforementioned problems, this paper proposed an Enhanced Adaptive Call Admission Control (EA-CAC) with bandwidth reservation to mitigate these problems.

ENHANCED ADAPTIVE CALL ADMISSION CONTROL (EA-CAC) SCHEME WITH BANDWIDTH RESERVATION FOR LTE NETWORKS.

This section presents the description of the proposed EA-CAC scheme by describing the operations of the scheme. First, the description and shortcomings of the ACAC and QA-CAC schemes are presented. The ACAC scheme allocates maximum and minimum bandwidth requirements to RT and NRT calls respectively at the point of admission. It accepts an RT call when the requested bandwidth is less than or equal to the available bandwidth otherwise the call is rejected. The scheme admits an NRT call request if the requested bandwidth is less than or equal to the available bandwidth, otherwise, a degradation procedure is applied to all admitted RT calls since they were assigned their maximum at the point of admission. All admitted RT calls are degraded to their minimum and then if the degraded bandwidth is less than or equal to requested bandwidth, the call is admitted otherwise rejected. However, the scheme wastes bandwidth and also increases the CBP and CDP of RT calls. Figure 1 shows the diagrammatic description of the ACAC scheme.

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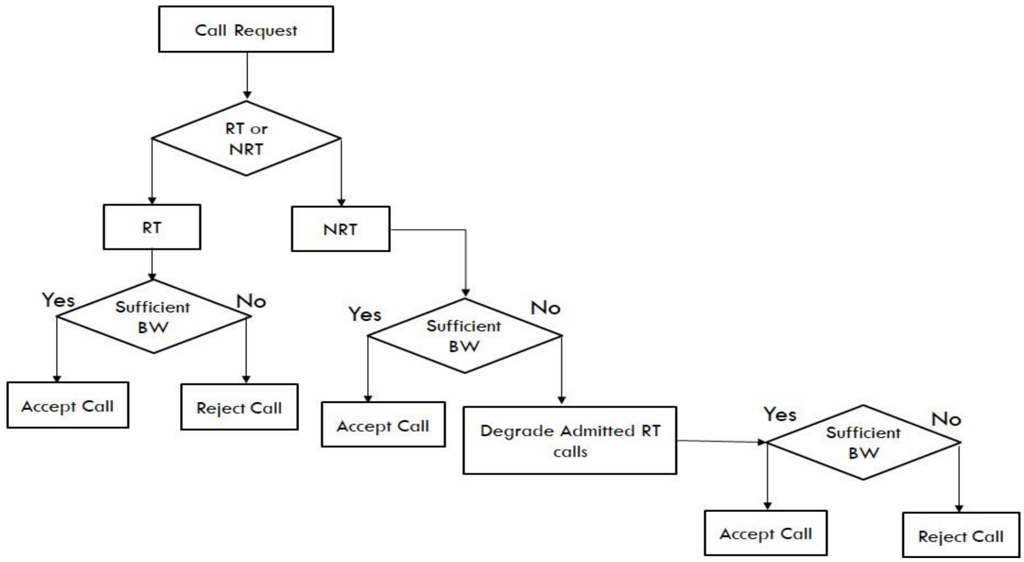
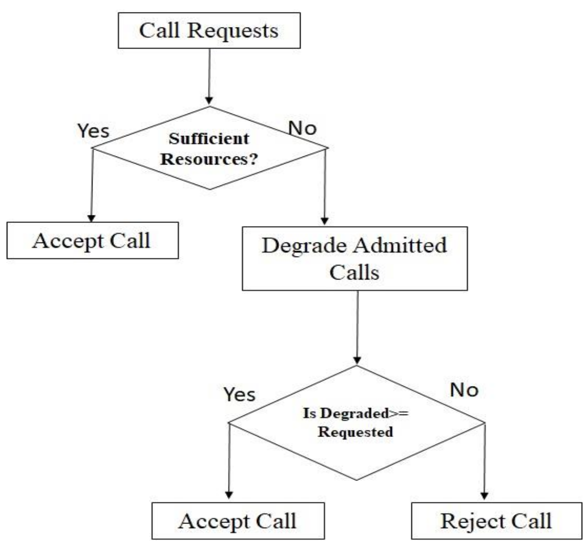
Figure 1. Diagrammatic description of ACAC scheme



The QA-CAC scheme allocates maximum bandwidth to both RT and NRT calls at the point of admission. The scheme accepts a call when the requested bandwidth is less than or equal to the available bandwidth else, bandwidth is degraded from all admitted NRT calls. If the degraded bandwidth and the available bandwidth are sufficient to admit the new call, then the call is admitted otherwise the call is rejected. All admitted NRT calls are degraded to their minimum bandwidth requirement to avoid call drop. The QA-CAC scheme increases the throughput and reduces the blocking rate of RT calls but waste bandwidth due to its failure to check if the degradable bandwidth will be enough to admit the new call before degrading the admitted NRT calls. Figure 2 shows the diagrammatic description of the QA-CAC scheme.

Figure 2. Diagrammatic description of QA-CAC scheme



The EA-CAC scheme tries to address the shortcomings of both ACAC and QA-CAC by introducing a prior-checking mechanism to ensure that the bandwidth to be degraded will be enough to admit the new call request, thereby

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reducing the wastage of bandwidth. It also incorporates an adaptive degradation which will degrade admitted NRT first before RT calls.

The proposed EA-CAC scheme allocates maximum bandwidth requirements to both RT and NRT at the point of admission. For RT call requests, the maximum bandwidth requirement is described as:

$$Call_{RT} = BW_{max} \tag{1}$$

Where $Call_{RT}$ denotes an RT call and BW_{max} represent the maximum bandwidth for an RT call.

Similarly, for NRT call requests, the maximum bandwidth requirement is denoted as:

$$Call_{NRT} = BW^{max} \tag{2}$$

Where $Call_{NRT}$ denotes an NRT call and BW^{max} represents the maximum bandwidth for an NRT call.

Furthermore, new call requests are admitted into the network, if there is sufficient bandwidth i.e. if the requested bandwidth is less than or equal to the total available bandwidth as described:

$$NC_{accept} = BW_{req} \leq BW_{avail} \tag{3}$$

Where NC_{accept} is a new call to be accepted, BW_{req} is the requested bandwidth and BW_{avail} is the total available bandwidth.

Similarly, a new handoff request is accepted into the network if there is sufficient bandwidth i.e. the requested bandwidth is less than or equal to the total available bandwidth and total reserved bandwidth as:

$$HC_{accept} = BW_{req} \leq BW_{avail} \tag{4}$$

Where HC_{accept} is the HC to be accepted, BW_{req} is the requested bandwidth, BW_{avail} is the total available bandwidth.

If there is insufficient bandwidth to admit a new call request, then a degradation mechanism is applied. The degradation is applied in two stages. At the first stage, degradation is applied to all admitted NRT traffics. The degradable bandwidth for a call can be computed as:

$$BWC_{deg} = BW_{max} - BW_{min} \tag{5}$$

Where BW_{deg} is the degradable bandwidth for an admitted call, BW_{max} is the maximum bandwidth requirement for a call and BWC_{min} is the minimum bandwidth requirement for a call.

After the first degradation stage, then the total degraded bandwidth is added up to the available bandwidth as shown in equation 6 and then the requested call is admitted if the bandwidth is enough. Calls admitted after degradation allocated their minimum bandwidth requirement to them at the point of admission.

$$\sum NRT\_BW_{deg} + BW_{avail} \tag{6}$$

Where $\sum NRT\_BW_{deg}$ is the sum of degraded bandwidth from admitted NRT calls and BW_{avail} is the total available bandwidth of the system.

If $\sum NRT\_BW_{deg}$ is not sufficient to admit the new call request, then the second stage of degradation is employed on all admitted RT calls. But before the degradation is done, a pre-check mechanism is first used to check whether the degradable bandwidth from admitted RT calls and the available bandwidth will be enough to admit the new call as described:

$$\sum RT\_BW_{deg} + BW_{avail} \geq BW_{req} \tag{7}$$

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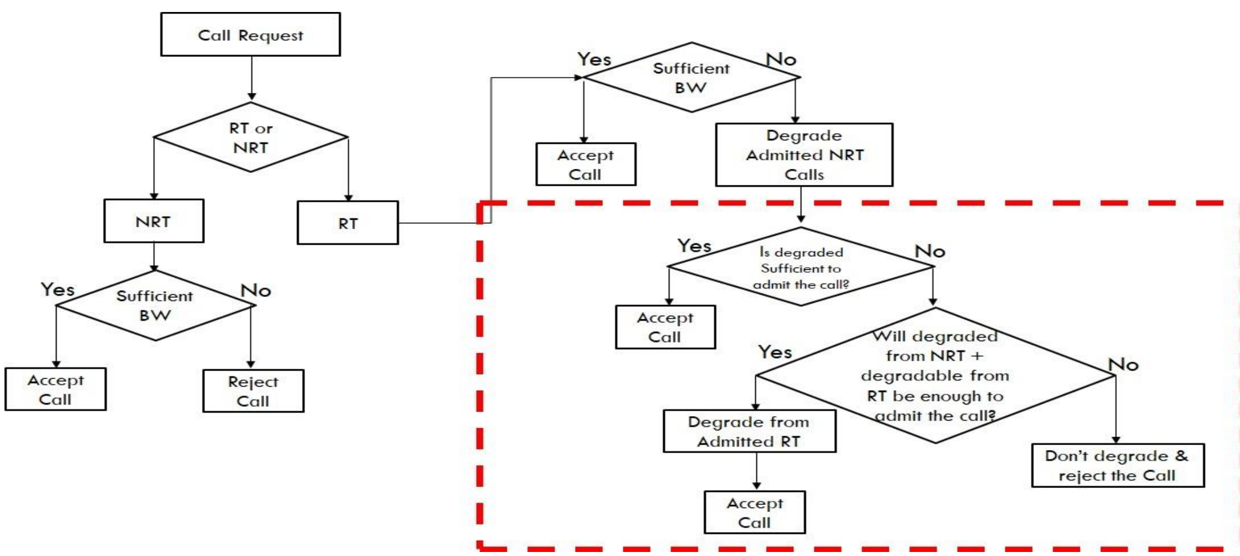
Where $\sum RT\_BW_{deg}$ is the sum of degradable bandwidth from admitted RT calls, BW_{avail} is the bandwidth and BW_{req} is the requested bandwidth.

If equation 7 is satisfied then the second stage degradation is performed otherwise the degradation is not performed and the call request is rejected. This will ensure that the bandwidth to be degraded will be utilized i.e. will be enough to admit the new call request. Thus, this will reduce the bandwidth wastage thereby improving the utilization of bandwidth.

Finally, the EA-CAC scheme adopts the adaptive reservation procedure that was used in the benchmark scheme. The adaptive reservation will prevent fixed reservation of bandwidth for handoff calls. It will ensure that a limited amount of bandwidth is reserved for handoff calls if there are few arrivals of the calls, a large amount is reserved if there is frequent arrival of handoff calls. This will prevent resource wastage compared to what happened in the previous schemes that reserved a fixed amount of bandwidth for handoff calls. The reserved bandwidth is then wasted when there is few or no handoff call.

Figure 3 shows the diagrammatic description of the proposed EA-CAC scheme and the pseudo-code of the scheme is shown in algorithms 1, 2, and 3.

Figure 3. Diagrammatic description of the proposed EA-CAC scheme



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Algorithm 1 represents the pseudo-code for the prior-check mechanism that is employed in the EA-CAC scheme.

Algorithm 1: EA-CAC Prior-check Mechanism Algorithm

Input:
AD_RT_{calls}: Admitted RT calls
$\sum RT\_BW_{deg}$: Sum of degradable bandwidth from admitted RT calls
BW_NRT_{deg}: Degraded bandwidth from admitted NRT calls
Initializations
while $BW\_NRT_{deg} \leq BW_{req}$ **then check**
    if $BW\_NRT_{deg} + \sum RT_{BW\,deg} \geq BW_{req}$
        degrade AD_RT_{calls} **then**
            accept call
    else
        don't degrade **then**
            reject call
    end if
end while

Algorithm 2 presents the pseudo-code of the adaptive degradation mechanism employed by the proposed EA-CAC scheme.

Algorithm 2: EA-CAC Adaptive degradation mechanism.

Input:
BW_{avail}: Available bandwidth
BW_{req}: Requested bandwidth
AD_NRT_{calls}: Admitted NRT calls
AD_RT_{calls}: Admitted RT calls
$\sum BW\_NRT_{deg}$: Sum degraded bandwidth from admitted NRT calls
Initialization
if $BW_{req} \leq BW_{avail}$ **then**
    degrade AD_NRT_{calls}
else if
    $\sum BW\_NRT_{deg} + BW_{avail} \geq BW_{req}$ **then**
        degrade AD_RT_{calls}
else
    don't degrade
        reject call
end if

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Algorithm 3 presents the pseudo-code for the Enhanced Adaptive Call Admission Control (EA-CAC) Scheme with bandwidth Reservation for LTE networks.

Algorithm 3: Enhanced Adaptive Call Admission Control (EA-CAC) Scheme with bandwidth Reservation for LTE networks algorithm

```
1.  Input:
2.  NC: New call
3.  HC: Handoff call
4.  RT: Real-Time traffic
5.  NRT: Non-real time traffic
6.  SMT: Simulation time
7.  Initializations
8.  while TTI is within SMT do
9.      for NC
10.         compute NC according to equation (3.3)
11.             if equation (3.3) holds then
12.                 accept NC
13.             else
14.                 degrade admitted NRT according to equation (3.6)
15.             end if
16.     end for
17.     if equation (3.6) holds then
18.         accept NC
19.     else if algorithm 3.1 holds
20.         else if algorithm 3.2 holds
21.             accept NC
22.     else
23.         reject NC
24.     end if
25.     for HC
26.         compute HC according to equation (3.4)
27.             if equation (3.7) holds then
28.                 accept HC
29.             else
30.                 execute step 17 to 24
31.             end if
32.     end for
33. end while
```

PERFORMANCE EVALUATION

The simulation topology used consists of one eNodeB, one application server, and several UEs connected to the eNodeB for different simulation experiments is depicted in figure 4. The server generates two traffics each from a different application. Each UE carries one traffic and each user uses only one type of traffic at a time. The two types of traffic are RT call and NRT call traffic. An example of an RT call can be live streaming while an NRT can be an email. A call request can either be an RT or NRT while a call type can either be NC or HC.

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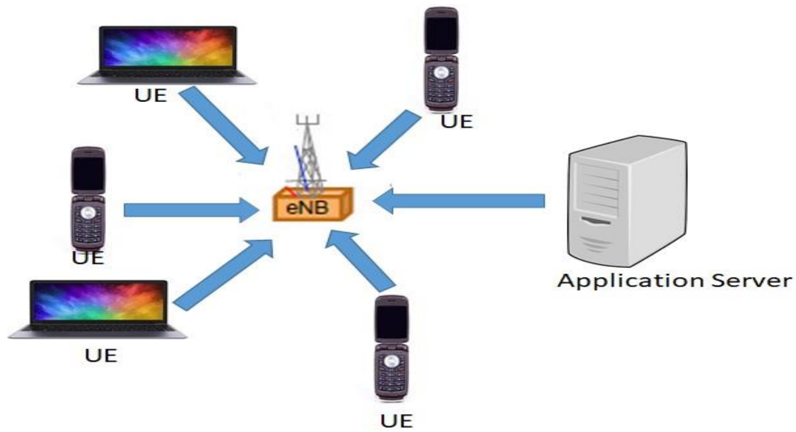
Figure 4. Simulation Experiment Topology



The total bandwidth used for the simulation is 5MHz with 25 resource blocks (RBs) per slot of 12 subcarrier spacing. The simulation time used is 1000s while the results were obtained by taking the average over 10 trials/runs of the simulation. The simulation parameters used were adopted from Maharazu *et al* (2017) as shown in table 1. Different simulation experiments were conducted for 20, 40, 60, 80, 100, and 120 UEs. In each experiment, RT and NRT traffic are generated randomly because we assume both RT and NRT should have the same priority as against the benchmark scheme that gave the NRT traffic higher priority. The simulation results were obtained with the aid of the Vienna LTE system-level simulator. The simulator is open-source and released free for academic and non-commercial purposes.

Table 2. Simulation Parameters

Parameter	Value
System Bandwidth	5MHz
Number of RBs	25
TTI	1ms
Call Arrival	Poisson Process
Simulation period	1000s
Transmission scheme	2x2 MIMO, OLSM
Cyclic prefix used	Normal cyclic prefix
UE distribution	Uniform

RESULTS AND DISCUSSIONS

The results obtained after performing several simulations experiments are presented in this section. The simulation experiments were performed based on the three performance metrics: throughput, call dropping probability (CDP) and call blocking probability (CBP) for both RT and NRT calls.

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Figure 5. Throughput achieved by the schemes for RT calls

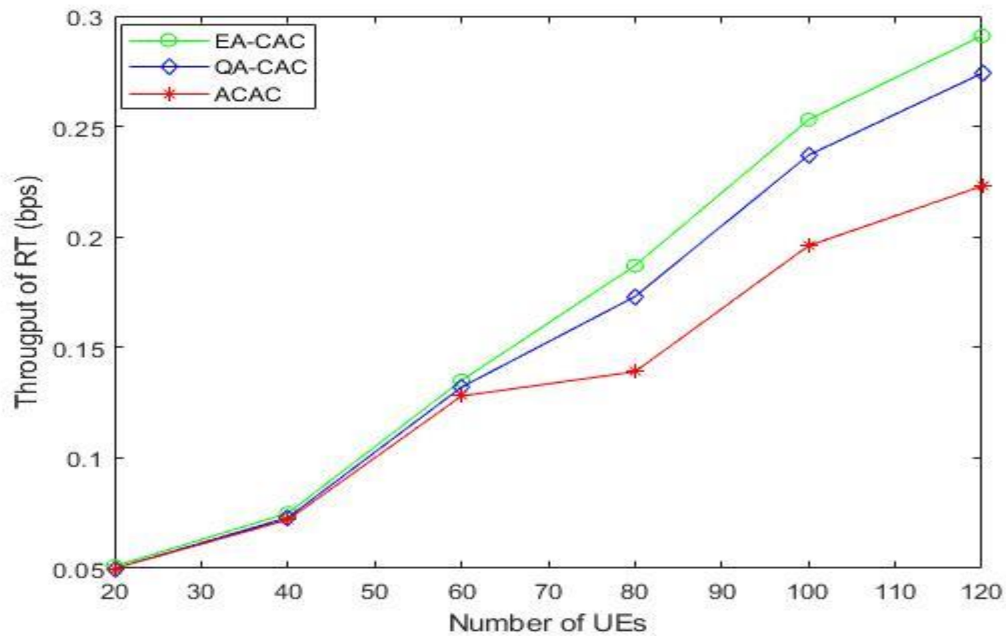

Figure 5 illustrates the throughput achieved by the three schemes for RT calls. The figure demonstrates that both the QA-CAC and the EA-CAC schemes increase the throughput of RT traffic. It can be observed that when the traffic intensity is low, all the schemes perform well by admitting a reasonable number of calls. But when the traffic intensity increases, QA-CAC and EA-CAC scheme admits more RT calls than the ACAC scheme. The improved performance can be traced to the maximum bandwidth requirements that are allocated to all calls at the point of admission by both the QA-CAC and EA-CAC against the ACAC scheme which allocates maximum bandwidth to only RT calls at the point of admission. Also, the QA-CAC degrades all admitted NRT calls when there are insufficient resources to admit a new call request without degrading the admitted RT calls. For the EA-CAC scheme, the increased in the performance can be traced to the adaptive degradation mechanism employed by the scheme which degrades admitted NRT calls first before degrading admitted RT calls. The throughput of RT calls is increased by 25.0% and 30.1% by the QA-CAC and EA-CAC schemes respectively compared to the ACAC scheme.

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Figure 6. Throughput achieved by the schemes for NRT calls

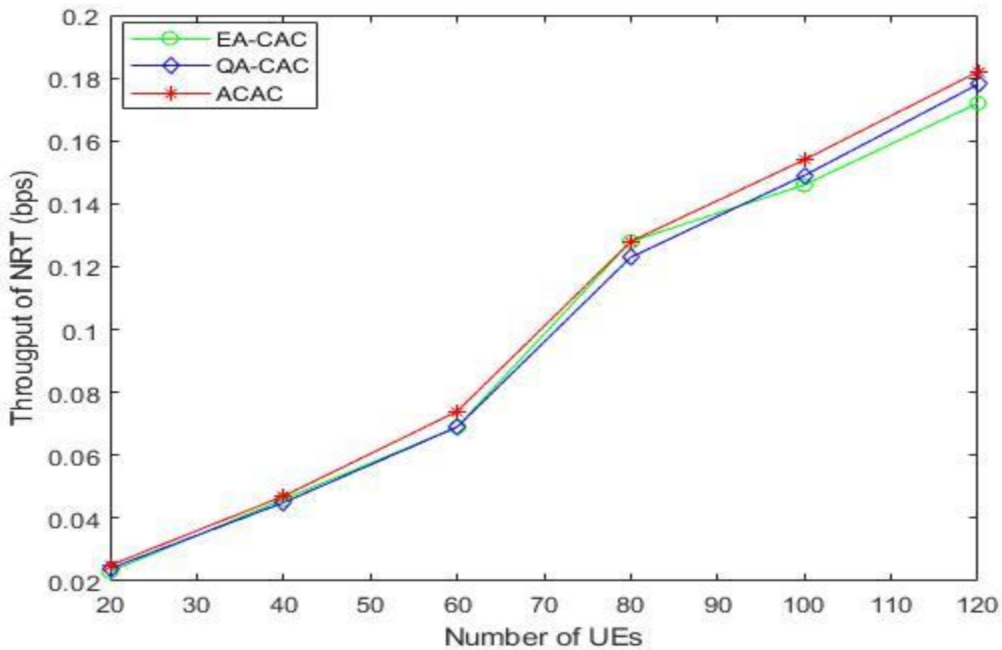

Figure 6 demonstrates the throughput achieved by the three schemes for NRT calls. It can be seen that when the traffic intensity is low, the three schemes have almost the same performance i.e. all the schemes admit almost the same number of calls. When the traffic intensity increased or is high, the performance of the ACAC scheme increased slightly by admitting more NRT calls compared to the QA-CAC and the EA-CAC schemes. It can be observed that all three schemes almost have the same performance when the traffic intensity is both low and high. This is as a result that the ACAC scheme gave higher priority to NRT calls and the ACAC scheme degrades only admitted RT calls when there is insufficient bandwidth in the system without degrading the admitted NRT calls. The QA-CAC admits lesser calls compared to the ACAC as a result of the degradation approach that is applied all admitted NRT calls when there is insufficient bandwidth to admit new calls. The EA-CAC scheme admits lesser calls than the ACAC and QA-CAC schemes because of the adaptive degradation mechanism employed by the scheme. The ACAC scheme increases the throughput of NRT calls by 2.3% and 2.8% compared to the QA-CAC and EA-CAC schemes respectively.

Figure 7 Shows the CBP achieved by the three schemes for RT calls. It can be seen that when the traffic intensity is low, none of the schemes blocks any call, this is because at that the stage, there are sufficient resources in the system and all requested calls are admitted. But when the traffic intensity is high, the EA-CAC and QA-CAC schemes block fewer RT calls. This improvement is a result of the degradation that is applied to all admitted NRT calls when there is insufficient bandwidth for the QA-CAC and the adaptive degradation mechanism employed by the EA-CAC scheme which degrades admitted NRT calls first before degrading admitted RT calls. After the degradation, subsequent calls are admitted with their minimum requirement, therefore, making it possible for the scheme to admit more calls and blocks fewer RT calls. The QA-CAC and EA-CAC schemes reduces the blocking rate of RT calls by 12.2% and 24.6% respectively against the ACAC scheme.

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Figure 7. Blocking ratio achieved by the schemes for RT calls.

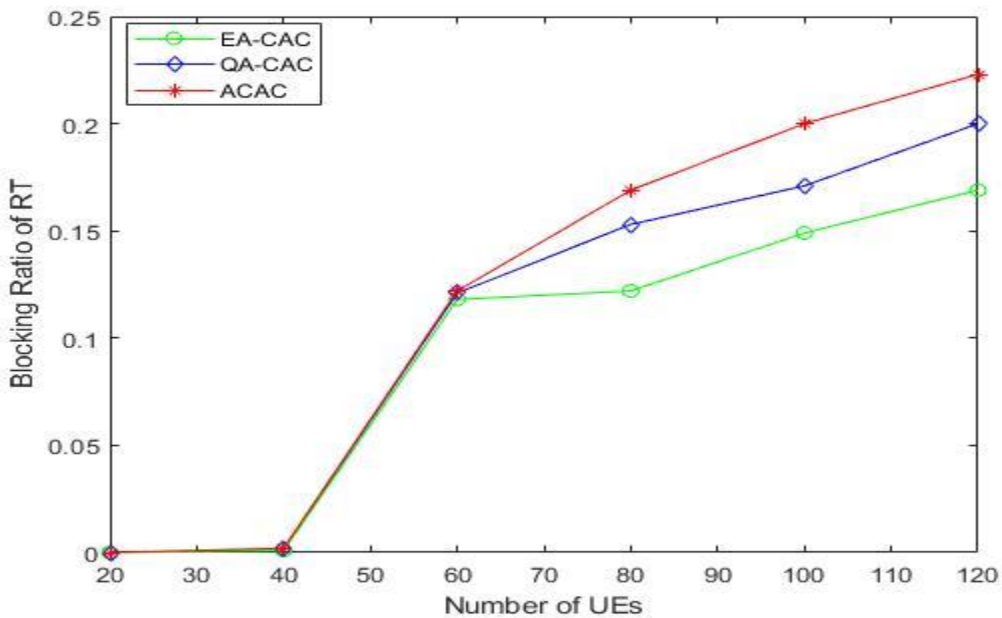

Figure 8 illustrates the CBP achieved by the three schemes for NRT calls. It can be seen that when the traffic intensity is low, the performance of the three schemes is the same i.e. no call is blocked. But when the traffic intensity is high or increases, the ACAC scheme blocks fewer calls than the QA-CAC and EA-CAC. This is as a result of the higher priority given to the NRT calls by the ACAC scheme. The QA-CAC scheme blocks a high number of calls than the ACAC scheme, this is because the QA-CAC scheme degrades bandwidth from admitted NRT calls when there is insufficient bandwidth to admit requested calls. The EA-CAC scheme also blocks more calls than the ACAC scheme as a result of the adaptive degradation mechanism used by the scheme. The QA-CAC scheme increases the blocking rate of NRT calls by 2.1% and also the EA-CAC increases the CBP of NRT calls by 2.2% compared to the ACAC scheme. Therefore, the QA-CAC and EA-CAC schemes try to maintain the same performance with the ACAC scheme for the NRT calls.

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Figure 8. Blocking rate achieved by the schemes for NRT calls

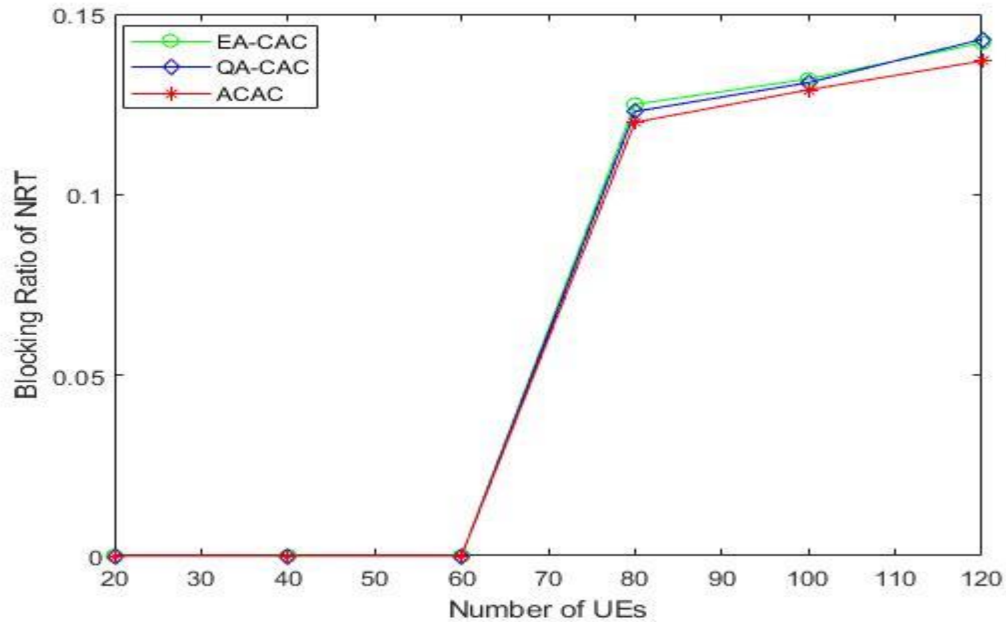

Figure 9 demonstrates the dropping ratio achieved by the three schemes for RT calls. The results reveal that when the traffic intensity is low, the performance of the three schemes is the same i.e. all the schemes drop almost the same number of RT calls. When the traffic intensity is low, the scheme drops no calls as a result of sufficient bandwidth to admit the calls. But when the traffic intensity increases or is high, the QA-CAC drops fewer calls as a result of the degradation that is applied on all admitted NRT calls when there is not sufficient bandwidth to admit calls. Similarly, the EA-CAC scheme drops lesser calls compared to the ACAC and QA-CAC. This improvement is a result of the prior-check mechanism and the adaptive degradation mechanism employed by the scheme. These ensure that the bandwidth to be degraded will be enough to admit the new requested calls after the adaptive degradation is applied on admitted NRT calls. The QA-CAC and EA-CAC schemes reduces the CDP of RT calls by 15.2% and 21.7% respectively against the ACAC scheme.

Figure 10 shows the CDP achieved by the three schemes for NRT calls. The results show that when the traffic intensity is low, the three schemes have the same performance i.e. none of the schemes drops any call. However, when the traffic intensity is high, the QA-CAC scheme drops more NRT calls than the ACAC scheme, this is because the ACAC scheme gave a higher priority to the NRT calls and degrades only admitted RT calls when there are not enough resources. The EA-CAC scheme drops a higher number of calls compared to the ACAC and QA-CAC, this is because of the prior checking mechanism which ensures bandwidth to be degraded will be enough to admit the new calls and the adaptive degradation mechanism employed by the scheme which degrades admitted NRT calls first before degrading admitted RT calls. The QA-CAC and EA-CAC schemes increase the dropping ration of the NRT calls by 1.9% and 2.0% respectively compared to the ACAC scheme.

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Figure 9. Dropping ratio achieved by the schemes for RT calls

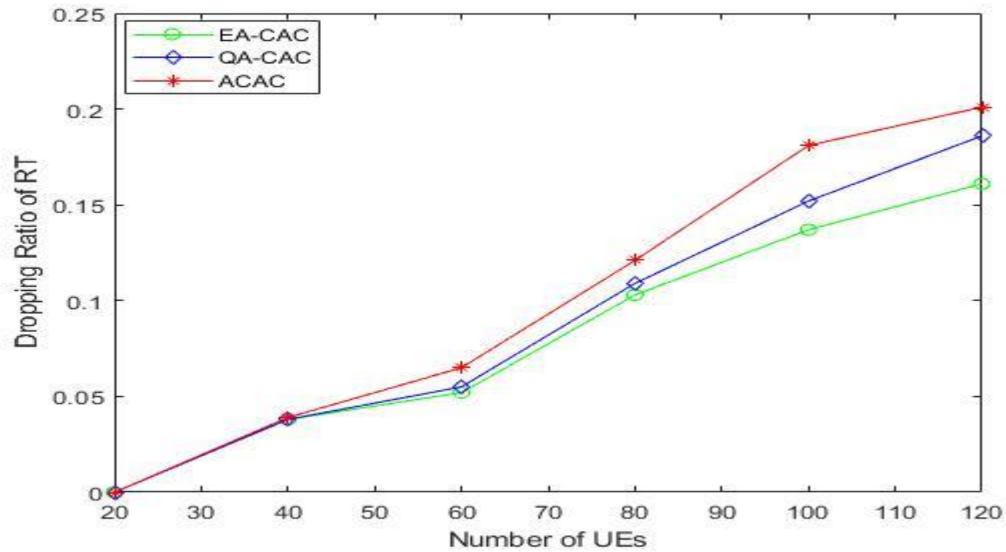
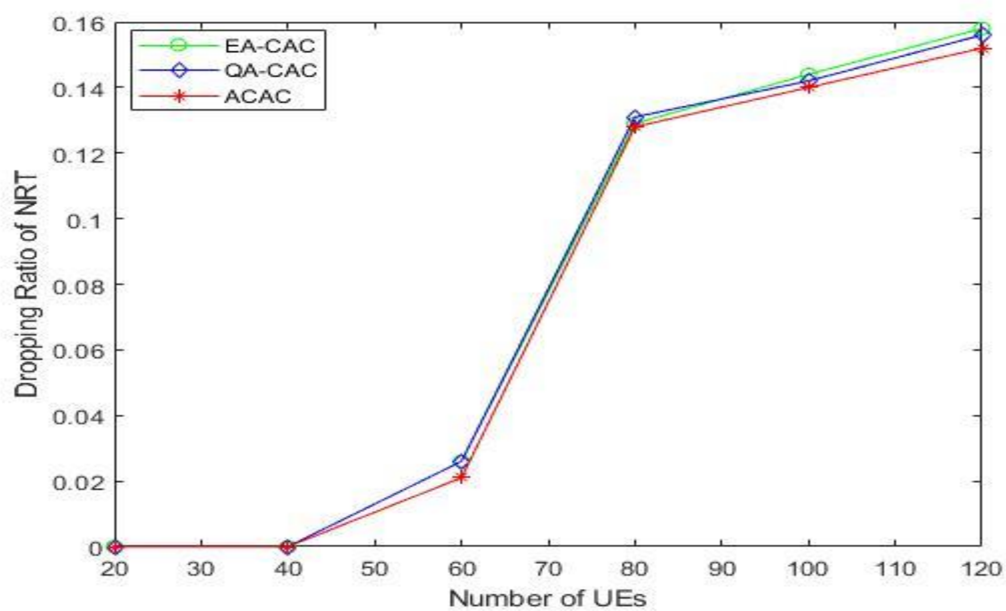


Figure 10. Dropping ratio achieved by the schemes for NRT calls



CONCLUSION AND FUTURE WORK

In this paper, an EA-CAC scheme was proposed to improve the utilization of network resources, reduces the delay incurred by RT calls, and also increase the CBP and CDP of both RT and NRT calls. The scheme is an improvement of the ACAC and QA-CAC schemes. The QA-CAC is an improvement of the ACAC while the EA-CAC is an improvement of both the ACAC and QA-CAC schemes. The EA-CAC scheme introduced a prior-checking

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mechanism which ensured that the bandwidth to be degraded from admitted calls is enough to admit the new requested calls. This reduces wastage of bandwidth and then improved the throughput of calls. The scheme further incorporates an adaptive degradation mechanism that degrades NRT calls first before degrading RT calls, this increased the throughput of RT and also reduces both CBD and CDP of the RT calls.

Simulation experiments were performed with the aid of the Vienna LTE system level simulator to evaluate the performance of the proposed EA-CAC scheme against the ACAC and QA-CAC schemes in terms of throughput, CBP and CDP. The results revealed that the proposed EA-CAC exhibited superior performance through increased throughput, reduced CBP, and CDP of RT calls. The scheme also maintains almost the same throughput for NRT calls with the ACAC and QA-CAC schemes as the difference in the performance is an insignificant one. Thus, the EA-CAC scheme performed better than the ACAC and QA-CAC scheme in terms of throughput, CBP, and CDP of RT calls without sacrificing the performance of NRT calls.

In the future, we intend to incorporate a bandwidth adaptation technique that will ensure bandwidth released by calls that have been serviced can be used to admit new incoming call requests.

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