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Comparative analysis of call admission control techniques for efficient resource utilization and QoS in IEEE 802.16e network

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ABSTRACT

In order to provide solution to limited network resources in heterogeneous wireless networks supporting different applications with distinct quality of service (QoS) requirements, call admission control (CAC) schemes are implemented. This work is aimed at investigating three mostpopular CAC schemes employedin mobile worldwide interoperability for microwave access (WiMAX), namely dynamic CAC with bandwidth reservation (DCACBR), QoS-aware CAC (QoSACAC), and QoS guaranteed CAC (QoSGCAC) to identify their shortfalls which will form the focus of future research. A general platform is developed and simulated. The simulation was based on the following KPIs: blocking rate, dropping rate, and throughput for new and handoff connections. Simulation results for new connection shows that QoSGCAC outperforms scheme DCACBR and QoSACAC, having 26.9% and 8.56% improvements in throughput and 63.11% and 24.17% in blocking rate respectively. For handoff connection, QoSACAC showed the best performance having 13.25% and 47.84% improvements in throughput and 6.8% and 49.3% in blocking rate as compared to the DCACBR and QoSGCAC, respectively. Result analysis shows that QoSACAC has the best performance however, it admits new connections and degrade existing connections but failed to consider the delay-intolerant service classes. It is recommended that the QoSACAC be further improved.

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1. INTRODUCTION

Wireless technology is one of the most significantevolutions in human history. The growth of wireless network technologies has complementarily witnessed increased users demand [1], [2]. Over the last two decades, the global economy has been greatly influenced by wireless technologies. The International Telecommunication Union (ITU) proposed broadband accessin response to thechallengingcontinuous growth in the demand forwireless communication. The IEEE 802 project working group 16 developed broadband wireless access (BWA) and proposed the worldwide interoperability for microwave access (WiMAX), which is commercially designated as IEEE 802.16 [3], [4]. The latest variant, mobile WiMAX (IEEE 802.16e), is a versatile solutionto wireless access havingwide coverage, high mobility, and high data rates offering different quality of service (QoS) for different services classes via the media access control (MAC) layer [5].

Efficient management of wireless network resources is a priority to obtain better QoS for high fidelity communication [6]–[9]. Apart from the obstruction caused by simultaneous user's communication, there is also competition among users for limited resources. To avoid this, new connection requests might have to be declined by wireless networks to maintain good QoS for existing connections. Connection admission control (CAC) is one such solutions for the management of wireless resources to maintain better quality of service [10]–[12]. CAC algorithms are responsible for determining the admission or otherwise of a new or handoff connection as a function of network resources availability without compromising QoS requirements of existing connections [13], [14]. The most important concerns of CAC in WiMAX is ensuring QoS of different connections [15].

WiMAX evolution started recently [16], [17] when engineersdecided of developing a wireless internet access and other broadband services that functions efficientlyeven in remote communities where wired facilities are not economical. The pioneer 802.16 standard was released in December 2001 [18]. Finally, in 2005, mobile WiMAX (IEEE 802.16e) got certification providing mobile and nomadic features. The IEEE 802.16e employs orthogonal frequency division multiple access (OFDMA) and has capability to achieve better non-line-of-sight environments performance [19]. Access techniques, capacities, and different types of services supported by WiMAX as it evolved are shown in [20]. WiMAX uses scheduling services and MAC scheduler as data handling mechanisms and for data transmission respectively. The five service classes defined in WiMAX with their QoS requirements are discussed in [21].

This paper is aimed at comparing three popular CAC schemes with the view to identify their shortfalls which will form the focus of future research. The remaining sections are arranged as thus: section 2 discussed the evolution of mobile WiMAX and 802.16e QoS service classification. Section 3 discussed call admission control (CAC) in 802.16e. Furthermore, section 4 presents comparison of popular CAC schemes while section 5 presented performance evaluation and results analysis. Finally, section 5 is devoted for conclusion and recommendations.

2. CONNECTION ADMISSION CONTROL IN 802.16e

Limitations in network resources make CAC and the scheduling algorithms necessary to support all service classes imperative. Basic architecture of admission control with the QoS framework for uplink scheduling in 802.16e is shown in Figure 1 [22]. The radio resources for different scheduling service classes are controlled centrally by the base station. The MAC layer is a connection-oriented protocol that has the advantage of controlling the network resource sharing among individual connections. The protocol maps both connected and connectionless traffic to a unique connection identifier (CID). If traffic coming from upper layer (PHY) arrives at the MAC layer, the MSS attempts to establish a connection with the base station (BS). The BS employs CAC schemes to check if the available network resources can guarantee the QoS requirements of the new connection while simultaneously maintaining the QoS requirements for the existing connections. If the new or handoff connection is accepted, the BS responds to the MSS with a connection ID.

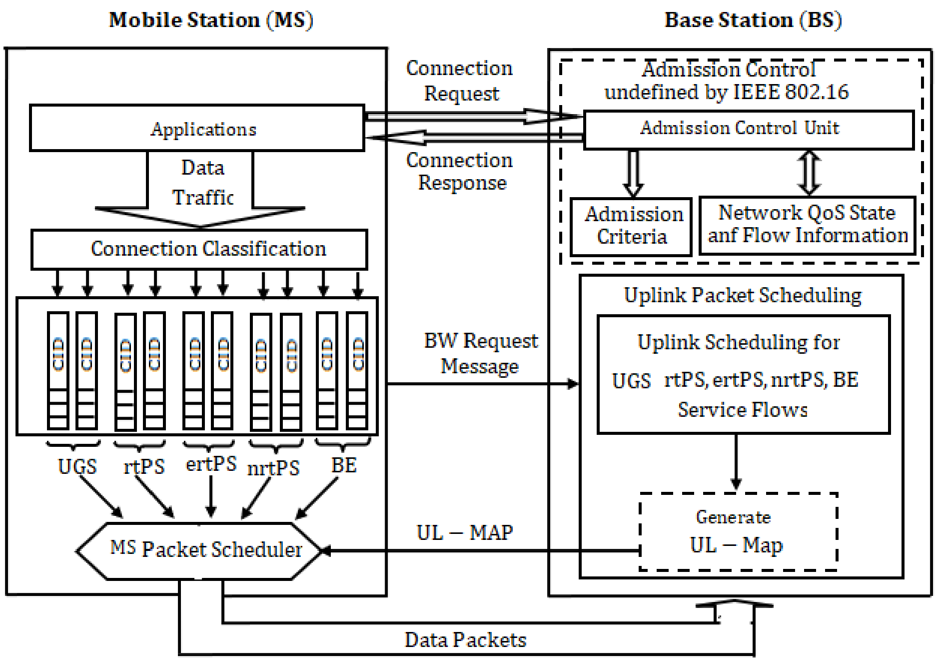

Figure 1. Basic architecture of admission control

Once a connection is set, the MSS request bandwidth from the BS, the BS grants bandwidth using the grant per subscriber (GPSS) station approach. Once the BS grants bandwidth to the MSS, the MSS packet scheduler allocates the bandwidth among all active connections. The MAC protocal of IEEE 802.16e is sub-divided into convergence sublayer, common part layer, and security sub-layer. Convergence sub layer receive the packet protocal data units (PDUs) from the higher layer, performs classification to the appropriate connection and process the higher layer PDUs based on the classification. Common part layer is the middle of MAC layer where MAC protocol data unit are constructed, bandwidth is managed, and connection established and maintained between the two side while the security sub-layer (SS) is aimed at security control across the broaddband wireless access (BWA) system. The physical laer received MAC PDU as a physical service data unit (PSDU). The general format of MAC PDU is composed of the MAC header, payload, cyclic, and redumcancy check (CRC). The physical layer which is the layer 2 in the OSI reference model is divided into downlink sub-frame and uplink sub-frame as discussed in [23].

3. COMPARISON OFTHREE POPULAR CAC SCHEMES

This section describes three most popular CAC schemes compared in this work. The schemes are (i) dynamic CAC with bandwidth reservation; (ii) QoS-aware CAC; and (iii) QoS guaranteed CAC. The algorithm for the three schemes will be simulated in MATLAB software 2021 version. The comparative analysis is to identify their merits and shortfalls which will form the focus for future research.

3.1. Dynamic CAC with bandwidth reservation

Criteria for admission are according to network loads [23]. Based on the QoS requirements of different scheduling services, this algorithm, alternatively, adopts the maximum or minimum bandwidth requirementsas a function of network load (nl). This results in adjustable admission criteria. The admission criteria are [23]:

$$b_i = \alpha b_{i,max} + (1-\alpha) b_{i,min}, \tag{1}$$

where i represent different service classes. i = 1, 2, 3, 4, 5 is for unsolicited grant service (UGS), extended real time polling service (ertPS), real time polling service (rtPS), non real time polling service (nrtPS), and best effort service (BE) connections respectively.

$$\alpha = \begin{cases} 1, nl < nl_{th}^{min} \\ \frac{nl_{th}^{max} - nl}{nl_{th}^{max} - nl_{th}^{min}} \; , nl_{th}^{min} \le nl < nl_{th}^{max} \\ 0, nl \ge nl_{th}^{max} \end{cases} \tag{2}$$

where $b_{i,min}$ and $b_{i,max}$ are the minimum and maximum bandwidth requirements respectively while nl_{th}^{min} and nl_{th}^{max} denotes the minimum and maximum threshold of network loads respectively.

A linear adaptation function regulates the admission criteria b_i with respect to network loadchangesnl. Where nl_{th}^{min} and $nl_{th}^{max}$are, respectively, the minimum and maximum thresholds of network load. If nl<nl_{th}^{min}, the weighted factorα will be 1 and $b_{i,max}$would be adopted as the admission criterion. Conversely, if $nl => nl_{th}^{max}$, α will be 0 and $b_{i,min}$would be used. For handoff connection to be accepted:

$$(b_{i,ho} + b_n + b_h) \le B \tag{3}$$

where b_n and b_h denotes bandwidth allocated to new and handoff connection respectively. For a new connection to be accepted:

$$\left((b_{i,new} + b_n) \le th_{ad}\right) AND \; ((b_{i,new} + b_n + b_h) \le th_{max}) \tag{4}$$

where $b_{i,ho}$ and $b_{i,new}$, respectively, are the admission criterion of handoff and new connections while th_{max} and th_{ad} denote the maximum threshold of reserved bandwidth and adaptive threshold of reserved bandwidth respectively.

3.2. QoS-aware CAC

The admission criterion in [24] uses services classes for admission of new and handoff connections scheduling service classes to admit new or handoff connections by classifying services as real-time and non-real time services. Here, UGS, rtPS, or ertPS being the real-time services as assigned maximum sustainable traffic rate (MSTR) while nrtPS is assigned minimum reserved traffic rate (MRTR) but with BE not having MRTR by standard. When new or handoff connection of the real-time services arrives, the required bandwidth is:

$$b_i = b_i^{max} \quad (5)$$

If the arrival is for the nrtPS and BE, the required bandwidth is:

$$b_i = b_i^{min} \quad (6)$$

where $b_i = b_i^{max}$ and b_i^{min} are the maximum bandwidth for the highest QoS and minimum bandwidth requirements corresponding to the lowest QoS respectively. Bandwidth degradation is used if there is no more available bandwidth for new connections. This applies only to rtPS and ertPS by decreasing their admission criteria to MRTR. The degradation $j(j = 1 \; or \; 2))$ is calculated as (7):

$$b_j^d = b_j^{max} - l_j^n \delta_j \quad (7)$$

where: b_j^d is the available bandwidth after degradation of class j; b_j^{max}=maximum bandwidth available on the existing connection in class j, l_j^n= current degradation level, δ_j=the quantity of degraded bandwidth. In (7) needs to satisfy (8):

$$b_j^{max} - l_j^n \delta_j \geq b_j^{min} \quad (8)$$

With the maximum degradation step level calculated as (9):

$$l_j^{max} = \frac{b_j^{max} - b_j^{min}}{\delta_j} \quad (9)$$

For handoff or a new connection to be accepted based on the admission procedure in (7) and (8):

$$\left(b_i^{hof} + \sum_{t=0}^{n}\left(b_i^h(t) + b_i^{nw}(t)\right) \leq B\right) \quad (10)$$

where $b_i^h(t)$, $b_i^{nw}(t)$ are bandwidth allocated to an admitted handoff and new connection over time respectively. This scheme also adopts the same data transmission rate as in [23] following the formula which depends on various modulation and coding schemes (MCSs) as defined in the (11):

$$R_{MCSi} = \left(n_{\frac{Data\_SC}{T_S}}\right) * b_{MCS_i} \quad (11)$$

where n_{Data_SC} is the number data sub-carriers; T_s is symbol period, and b_{MCS} is the amount of information bits per symbol with respect to the ith MCS (i.e. MCS_i). Also, an adaptive threshold is adopted from [25] that dynamically changes the bandwidth reservation threshold for handoff connections based on traffic intensity of the handoff connection as give in (12):

$$th_{adap} = \left[\rho_{hof} \times \beta\right] \times b_i^{hof} \quad (12)$$

The traffic intensity is given as (13):

$$\rho_{hof} = \frac{\lambda_{hof}}{\mu_{hof}} \quad (13)$$

where λ_{hof} and μ_{hof} are the arrival rates for handoff connections and mean service rate respectively. The required bandwidth for each handoff connection is b_i^{hof} with $\beta \epsilon [0,1]$ as the bandwidth reservation factor. A new connection $n_{con-accepted}(t)$ is accepted based on the admission criterion defined by (7) and (8) when the condition in (12) holds.

$$(b_i^{new} + \sum_{t=0}^{n}(b_i^h\,(t) + b_i^{nw}(t)) \leq B - th_{adap}) \; OR \; (b_i^{new} \leq b_j^d) \quad (14)$$

where b_i^{new} is the new bandwidth admission criteria.

3.3. QoS guaranteed CAC

Admission criteria is adopted in [26] just as in [24]. However, delay check mechanism is adopted alongside a pre-check at the points of admission and degradation on arrival of a new connection. Delay check is performed to confirm if or not admitting a new connection request will jeopardize the delay requirement of the existing as well as the requesting connections. Once the two checks are positive, new connection is admitted else, it is declined. The following condition must be fulfilled before admitting a new ertPS and rtPS connection:

$$b_r + r_k f \leq d_i * w_k(B_a - B_{UGS}) \quad (15)$$

where the maximum delay of the i^{th}connection is $d_i = m_i * T$ with T as the frame duration, m_i as any positive integer greater 1. The weight of the real time is:

$$w_k = \frac{r_k}{B_{ertPS}+B_{rtps}} = \frac{r_k}{B_{RT}} \quad (16)$$

where r is the token arrival rate.

The maximum number of transmitted packets to avoid delay violation is given as $b_r + r_k f$ where b_r is the token bucket size. The total assigned bandwidth to the ongoing five classes is represented as B_a while the bandwidth assigned to ongoing UGS class is referred to as B_{UGS}. Where B_{NRT} and B_{RT}, respectively, represent the bandwidth of all ongoing non-real time (nrt) and real time (rt) services where applicable. Thus, the delay check mechanism is:

$$b_r \leq \left|(m_i - 1)\left(1 + \frac{B_{NRT}}{B_{RT}}\right) - 1\right| r_k f \quad (17)$$

The pre-degradation check technique was introduced to determine if the degradation procedure result in enough bandwidth for the admission or otherwise of a connection request as (18):

$$r_B = \begin{cases} UGS_B^{MSTR}, a_B + b_{est}^j \geq UGS_B^{MSTR} \\ k_B^{MRTR}, a_B + b_{est}^j \geq k_B^{MRTR} \end{cases} \quad (18)$$

where b_{est}^j is the estimated bandwidth that can be obtained by degrading ongoing ertPS and rtPS connections. UGS_B^{MSTR} denotes the bandwidth that can be assigned to UGS connections since they can only support MSTR. k_B^{MRTR} is the MRTR requirement for non-UGS connections that will be assigned to non-UGS connections after degradation, a_B denotes the available bandwidth. A dynamic degradation mechanismwas introduced that is a function of a bandwidth intelligent function $I(B)$:

$$I(B) = 1 - \frac{B_t - B_U}{B_t - B_n^d} \quad (19)$$

Where the post degradation bandwidth utilization before assignment is:

$$B_u^d = B_u - B_n^d \quad (20)$$

The current bandwidth utilization is given as (21):

$$B_U = \sum_{i=1}^{n}(B_{UGS} + B_{ertPS} + B_{rtPS} + B_{nrtPS} + B_{BE}) \quad (21)$$

While the quantity of amount of bandwidth required for degradation is:

$$B_n^d = r_B - a_B \quad (22)$$

The variable step size defined as the quantity of resources to be degraded from each service class is:

$$l = I(B) * B_{d.i} \quad (23)$$

Where $B_{d,i}$is the allowed bandwidth to be assigned after degradation.

4. PERFORMANCE COMPARISON

Comparative analysis of the three schemes is to identify their shortfalls which will form the focus of future research. Table 1 shows the MCS parameters while the IEEE 802.16e PHY data rates parameters for a channel bandwidth of 10 MHz are shown in Table 2. A 2×2 multiple-input multiple-output (MIMO) was used in the simulation of the mechanism. Simulation period was 100 s and realization are 1000. The results are average values for 20 simulations. Simulation parameters are shown in Table 3 while point to multipoint mode (PMP) was the simulation topology.

The three popular CAC schemes designated as: DCACBR, QoSACAC, and QoSGCAC were evaluated to identify their shortfalls which will form the focus of future research. Simulations of IEEE 802.16e transmission scenarios was conducted for each of the schemes in MATLAB software 2021 version. The comparison was based on their respective algorithms using the same simulation parameters to ensure a realistic comparison.

Randomly generated traffics were classified into five service classes based on their QoS requirements. For each scenario, the arrival rates of new and handoff connections ($\lambda_n and\ \lambda_h$) are randomly. The mean arrival rate is assumed to $\frac{1}{10th}$ of the arrival rate. The handoff arrival and the new connection arrival rates are assumed as equal.

The BS estimates the bandwidth need of each connection considering its MSS. DCACBR, QoSACAC, and QoSGCAC were compared for new and handoff connection in terms of three key performance metrics namely: blocking rate, dropping rate, and throughput. In Table 3, only the real time service classes (UGS, rtPS, and ertPS) are involved in the handoff connection while new connection involves both the real and the non-real time service classes. To study scheduling classes, each scheme is considered for handoff and new connection.

Figure 2 shows the system throughput performance for the five service classes for new connection. It is seen that the compared schemes have a similar performance at the arrival rate of 0.01. As the arrival rate increases, QoSACAC and QoSGCAC have the same performance up to arrival rate of 0.21 obtaining nearly the same throughput performance. After arrival rate of 0.21, the schemes start to exhibit verifyingperformance. All three schemes show increase in throughput with the QoSGCAC showing the best performance. The QoSGCAC clearly outperforms the DCACBR and QoSACAC. The QoSGCAC has 26.9% and 8.56% improvements as compared to the DCACBR and QoSACAC respectively. This is as a result of the delay check mechanism in QoSGCAC enabling admission of new connections.

In Figure 3 shows the blocking rates for new connections. At arrival rate between 0.01 and 0.11, DCACBR has a low knee point while QoSACAC and QoSGCAC have the same high knee point, thus resulting to decrease and increase in blocking rate respectively. As the arrival rates increases up to 0.21, the DCACBR has high knee point which resulting in increase of the blocking rate. At the arrival rate of 0.11, QoSACAC and QoSGCAC start to have different increases in blocking rate and this continued with increase in arrival rate.

At 0.91 arrival rate, it is observed that QoSGCAC outperformed DCACBR and QoSACAC by 63.11% and 24.17% respectively. This correlates with the improved throughput performance of QoSGCAC. Therefore, QoSGCAC has the least blocking rate meaning that more connections are admitted.

Table 1. Modulation and coding parameters for 10 MHz [27]

Modulation	Coding Rate	Uplink
QPSK	$\frac{1}{2}$ CTC, 6x	0.78
	$\frac{1}{2}$ CTC, 4x	1.18
	$\frac{1}{2}$ CTC, 2x	2.35
	$\frac{1}{2}$ CTC, 1x	4.70
	$\frac{3}{4}$ CTC	7.06
16 QAM	$\frac{1}{2}$ CTC	9.41
	$\frac{3}{4}$ CTC	14.11
64 QAM	$\frac{1}{2}$ CTC	14.11
	$\frac{2}{3}$ CTC	18.82
	$\frac{3}{4}$ CTC	21.17
	$\frac{5}{6}$ CTC	23.52

Table 2. IEEE 802.16e PHY data rates parameters [27]

Parameter	Uplink
System bandwidth	10 MHz
FFT size	1024
Null subcarriers	184
Pilot subcarriers	280
Data subcarriers	560
Symbol period	102.9 μs
Frame duration	5 ms
OFDM symbols/frame	48
Data OFDM sysbols	44

Table 3. The maximum and minimum rates for different services classes

Service class	Maximum rate (kbps)	Minimum rate (kbps)
UGS	100	100
rtPS	75	25
ertPS	75	25
nrtPS	60	20
BE	20	0

Figure 4 shows the system throughput performance for the handoff connection. The schemes have the same throughput at arrival rate of 0.01. With further increase in arrival rate beyond 0.11, the schemes begin to experience different rates of increase in throughput performance. However, after 0.11 arrival rates, the performance of DCACBR and QoSACAC performance starts to differ significantly with QoSACAC exhibiting the best performance. QoSACAC, clearly, outperforms both the DCACBR and QoSGCAC. The QoSACAC has a 13.25% and 47.84% improvement on throughput as compared to the DCACBR and QoSGCAC respectively at arrival rate of 0.91. This is largely due to its ability to consider the handoff connection while degrading the rtPS and ertPS classes to enable the admission of more connections. The QoSACAC also ensures that threshold limit is not exceeded to avoid over degradation which can lead to starvation, thus increasing the handoff throughput performance. The system handoff connection dropping rates is presented in Figure 5.

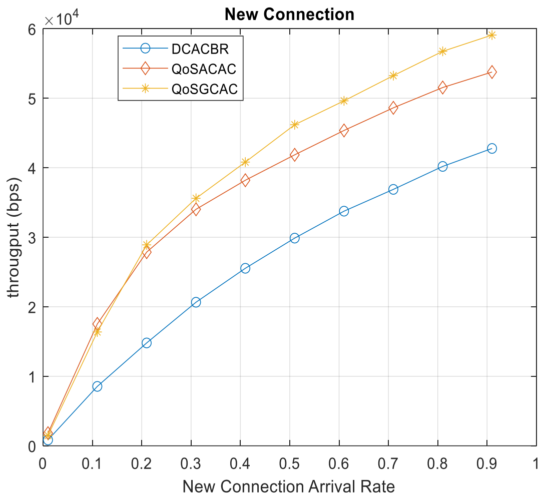

Figure 2. Throughput for new connection

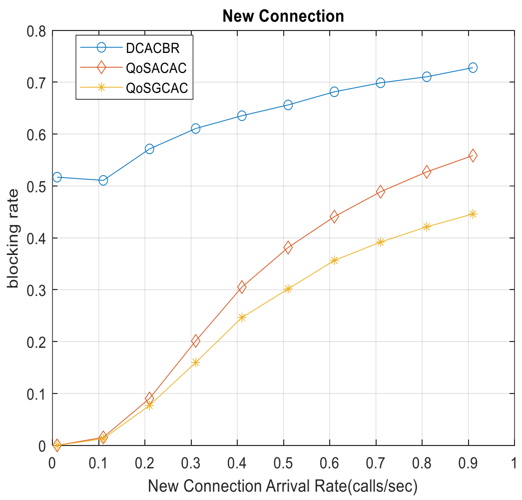

Figure 3. Blocking rate for new connection

The three schemes have different dropping rate at arrival rate of 0.01 with QoSACAC having the most reduced connection dropping rate. Analysis shows that QoSACAC outperformed DCACBR and QoSGCAC in terms of connection dropping rate of 6.8% and 49.3% respectively. This is because as handoff connections arrive, an adaptive reserved bandwidth threshold is adjusted by QoSACAC for handoffs connection. So, QoSACAC performs better than the DCACBR and QoSGCAC in terms of reduced dropping rate.

In order to aid the comparison and evaluation, the data collected from the simulation results are averaged and rated to observe the behavior of the scheme with best performance. The percentage values obtained from the figures are assigned to a particular scheme depicting the performance ratings of the scheme. Index 3 depicts scheme with the highest performance, followed by 2 and 1. Table 4 presents the performance rating of the new connection arrival rate. The index assigned at the total indicates scheme with the best KPI. The overall performance shows that QoSGCAC performed best having 26.9% and 8.56% improvements in throughput and 63.11% and 24.17% in blocking rate as compared to the DCACBR and QoSACAC respectively. This correlates with the improved throughput performance of QoSGCAC.

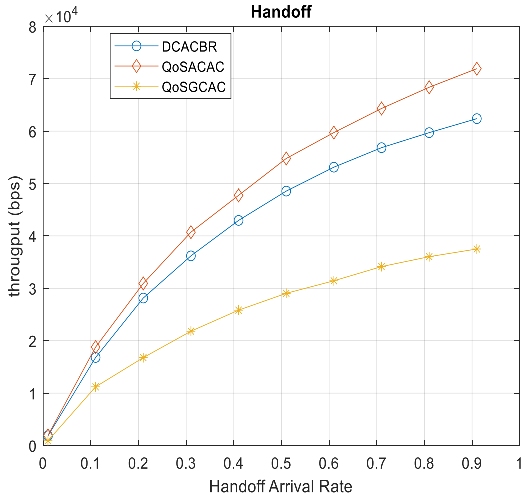

Figure 4. Throughput for handoff connection

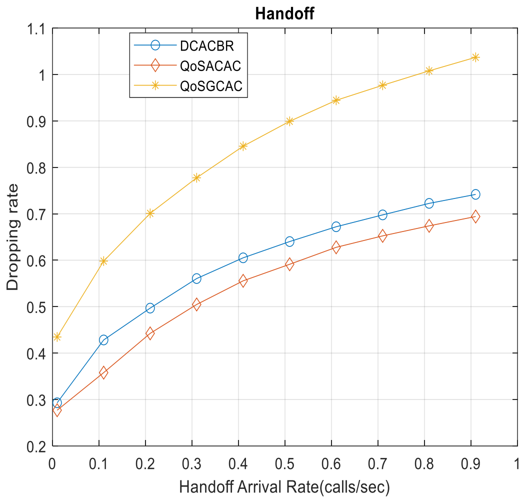

Figure 5. Dropping rate for handoff connection

Table 5 presents the performance rating of handoff connection arrival rate. The index assigned at the total indicates scheme with the best KPI as 1st, 2nd and 3rd. The overall performance shows that QoSACAC performed best having 13.25% and 47.84% improvements in throughput and 6.8% and 49.3% in blocking rate as compared to the DCACBR and QoSGCAC, respectively This is as a result of the new admission criteria that employ bandwidth degradation. Thus, allowing more new user connections into the network. For handoff, it also introduced adaptive threshold for dynamic adjustment of the amount of reserved bandwidth needed. The excess resources due to the fixed maximum bandwidth threshold are utilizedin admittingmore new connections thereby improving throughput and efficiency of the network.

Table 4. New connection performance

KPI\schemes	DCACBR	QoSACAC	QoSGCAC
Blocking rate	63.11%	24.17%	0%
Throughput	26.9%	8.56%	100%
Index	3rd	2nd	1st

Table 5. Handoff connection performance

KPI\schemes	DCACBR	QoSACAC	QoSGCAC
Blocking rate	6.8 %	0 %	49.3 %
Throughput	13.25 %	100 %	47.84 %
Index	2nd	1st	3rd

5. CONCLUSION

A detailed comparison of three most popular call admission control schemes for mobile WiMAX network has been carried out. Based on the performance matrices, the QoSACAC showed a competitive edge over DCACBR and QoSGCAC. This is attributable to its use of bandwidth degradation, thus increasing the number of new connections, introducing adaptive threshold for dynamic adjustment of reserved bandwidth necessary for handoff connections, support for real time, and non-real traffic classes, while considering both new and handoff connections. DCACBR uses linear adaptation approach as the admission criteria to achieve starvation of both the high and low service classes. Since QoSGCAC adopted same admission criteria as DCACBR, it faces the same challenge of starvation of the low priority service class, failure to consider non-real time services and handoff connection in addition to inefficient network resource utilization.

The findings from simulation performance for new connection shows that QoSGCAC outperforms DCACBR and QoSACAC having 26.9% and 8.56% improvements in throughput and 63.11% and 24.17% in blocking rate respectively. While for handoff connection, QoSACAC showed the best performance having 13.25% and 47.84% improvements in throughput and 6.8% and 49.3% in blocking rate as compared to the DCACBR and QoSGCAC, respectively. QoSACAC recorded considerable bandwidth degradation for both new and handoff connections thus analyzing the result using performance index shows that QoSACAC has the best performance index however, , it admits new connections and degrade existing connections without considering the delay-intolerant (rtPS) and (ertPS) connections which may increase the overall system delay. It is, therefore, recommended that the QoSACAC as used in CAC, considering its aforementioned merits be further improved by incorporation delay check to better service the needs of the delay-intolerant service classes.

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