

Novel, graded, priority-oriented admission control in mobile networks

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Abstract: Call admission control plays a crucial role in providing quality of service to the different services in mobile broadband networks (WiMAX, LTE). A new connection is admitted only when the network can support the QoS needs of the connection without degrading the QoS for existing connections. An efficient call admission control algorithm ensures higher throughput and fewer delays for the admitted connections. In this paper a graded priority-based call admission control algorithm is proposed for LTE and WiMAX networks. The number of permissible connections shall be segregated into two classes. The new connection shall be graded, prioritized, and admitted based on the device requesting the connection. Simulation results show that graded priority-based admission control algorithm improves the connection admission rate from 3% to as high as 30% for select users. This results in higher throughput for priority users.

Key words: Call admission control, LTE, WiMAX, quality of service

1. Introduction

In any wireless network, users generate different types of data, including voice, video, email, ftp, and browsing content. Each type of data comes with its own requirements for quality of service (QoS). Mobile broadband networks have to ensure that the data receive appropriate QoS.

1.1. QoS support in LTE

In LTE QoS is enforced at the granularity level of the bearer. A bearer (data resource bearer, DRB) is a packet flow between the user equipment (UE)/mobile station (MS) and the packet data network gateway. Each bearer is associated with a QoS class identifier (QCI). There are two types of bearers supported in the LTE network, namely the default bearer and dedicated bearer. LTE supports nine types of QCI values that can be associated with the bearers. QCI 1 is for conversational voice. QCI 2 is associated with conversational video. QCI 3 is for real-time gaming. QCI 4 is for nonconversational video. QCI 5 is for IMS signaling. QCI 6, 8, and 9 are for video and TCP traffic, and QCI 7 is for voice, video, and interactive gaming.

When a user generates data, a bearer is required to transmit the data. Hence, the UE sends a bearer establishment request to eNodeB. eNodeB then executes an admission control algorithm to decide whether to admit the bearer into the network or not.

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1.2. QoS support in WiMAX

WiMAX has a provision to handle different types of data based on the QoS parameters of the data [1–4]. WiMAX supports five different types of service classes that cater to diverse QoS needs. The first service class called unsolicited grant services (UGS) is designed to support real-time data streams that generate fixed-size packets at periodic intervals. Voice over IP without silence suppression is an example of traffic that is categorized as UGS.

The second service class called real-time polling services (RTPS) supports real-time data streams that generate variable-sized packets on a periodic basis. For example, an MPEG video consists of P frame, B frame, and I frame. Each of these frames is of different sizes and is generated periodically. An MPEG video needs variable bandwidth at periodic intervals of time to avoid jitter while viewing the video. Such packets are categorized as RTPS traffic.

The third service class, also called extended real-time polling services (eRTPS), supports real-time service flows that generate variable-sized data packets at periodic intervals. An example of eRTPS is VoIP with silence suppression. eRTPS is introduced in IEEE 802.16e as a new service class.

The fourth service class is called non-real-time polling services (nRTPS). nRTPS supports delay-tolerant data streams that generate variable-sized data packets. An example of one such type of traffic is the file transfer protocol data (FTP). FTP does not have stringent jitter requirements. However, it does have certain throughput requirements. Hence, such packets are classified as nRTPS.

The last service class, also called best effort (BE), supports data streams that do not require any service level such as Web browsing or email.

When a user generates packets, they are placed in the queue designated for the type of packets. If a connection does not exist for the service class, the mobile station (MS) sends a request to establish a connection for the data. The connection request contains the quality of service parameters that the connection expects. When the base station (BS) receives the connection request, it checks if it can service the QoS requirement of the connection. If the connection is accepted, the BS should be capable of servicing the connection as per its QoS needs.

1.3. Related work in admission control

Authors from academia and industry have proposed various call admission control algorithms. A bandwidth-based call admission control (CAC) algorithm was proposed in [5]. If there is sufficient bandwidth available to admit a connection, the connection gets admitted. A quality of service-aware call admission control algorithm was proposed in [6]. There shall be five queues, one for each service class. When the BS receives the admission control request, it shall queue it in its queue depending on the QoS parameters of the connection. The BS shall then scan through the queues to decide whether to admit the connection or not. The paper also listed the criteria to admit the connection. A partition-based CAC was proposed in [7,8]. The bandwidth is first divided into different parts (constant bit rate partition (CBR), variable bit rate partition (VBR), handover partition (HO), etc.) and the admission control algorithm is applied to each of these partitions. In [9] an admission control algorithm was proposed for a multihop network, which estimates the bandwidth requirements of a connection based on the probability of arrival of a user under a relay station and a system-specified size of the range for bandwidth allocation. In [10,11] the authors proposed an admission control mechanism that takes handover calls into consideration while admitting the connection. Since the ongoing calls are of a higher priority, handovers of ongoing calls are admitted first compared to new connection requests. A modulation

scheme-based admission control algorithm was proposed in [12]. In [13] the authors used handoffs, modulation schemes, and new connection requests together to decide whether to admit a connection or not. The number of available slots and the minimum reserve traffic rate is used to decide whether to admit a connection or not. In [14,15] the authors proposed admission control algorithms catering to a specific type of traffic. The periodicity of real-time video traffic is exploited by the admission control process. In [16] a service degradation-based admission control algorithm was proposed, wherein a handover connection request is accepted by degrading the existing connection's QoS, provided that the priority of the existing connections is less than that of the handover connection and sufficient bandwidth is not available to accept the handover connection. In [17] a bandwidth stealing-based call admission control algorithm was proposed. In this method, each connection is assigned a threshold value, and if a connection request arrives and other connections are using excess bandwidth, then the bandwidth is snatched from such connections and the new connection is admitted. A token bucket-based call admission control algorithm was proposed in [18]. In [19] an admission control algorithm for video streaming traffic was proposed that predicts the future traffic in order to admit connections. In [20] a medium bandwidth value was calculated and new connections are accepted only if the probability of them crossing the medium bandwidth is low.

In LTE, admission control based on data rates was proposed in [21,22]. Based on the proposed data rate of the new bearer, eNodeB decides whether to admit the connection or not. A bearer admission control algorithm for LTE that takes multiple factors into consideration was proposed in [23].

In [24] an admission control algorithm was proposed, which admits RTPS connections by degrading existing admitted connections without impacting the QoS. A multicriteria-based admission control algorithm was proposed in [25]. A new connection is admitted based on the delay, SNR, and bandwidth needs of new connection. Admission control based only on delay and bandwidth was proposed in [26]. In [26], handover connections are prioritized over new connections. Multiple criteria comprising class-based slot reservation, connection degradation, and modulation and coding scheme (MCS)-based admission control were proposed in [27].

An MS-based admission control algorithm was proposed in [28]. The MS rejects a new connection if the number of admitted connections reaches a specified threshold. In [29] the authors proposed an admission control algorithm for multiple connection admission requests. Connections are admitted based on average data rate and available bandwidth. Another multicriteria-based algorithm was proposed in [30] for a WiMAX mesh network. The criteria used for admission control are blocking factor, reliability of link, number of free slots, and hop count. Threshold-based admission control was proposed in [31]. BE service class has the lowest threshold and UGS has the highest threshold. A new connection from service class X is admitted if the current connection count for class X is less than the threshold specified for the class.

A multistage admission control algorithm was proposed in [32] that takes bandwidth and delay into consideration while admitting a new connection. In [33] an admission control algorithm based on data rate, SNR and delay requirement of a new connection was proposed for LTE networks. Degradation-based admission control in LTE networks was proposed in [34], wherein a new connection is admitted by degrading existing connections without compromising the QoS of existing connections. In [35] an admission control algorithm in LTE was proposed that prioritizes existing connections. If the QoS of the existing connection is less than a threshold then all new connection admission requests are rejected. New connections are admitted when the QoS of the existing connection crosses the specified QoS threshold.

All the CAC algorithms proposed above are either service class-based or modulation scheme-based

algorithms. In this paper, a novel call admission control algorithm is proposed. The algorithm aims to admit connections depending on the priority of the user. Users shall be segregated into different classes and connections shall be admitted based on the class of the user requesting the connection request.

The paper is divided into following sections. Section 2 describes the proposed graded priority-based admission control mechanism. Section 3 describes the system model. Section 4 describes the simulation results.

2. Proposed graded admission control mechanism

There shall be two different types of users in the network. The first set of users shall be called priority MS/users and the other set shall be called regular MS/users. There could be various criteria to decide a user as a priority user, as listed below:

- Subscription charges could be one criterion. There could be users who wish to enjoy higher priority for the same service class compared to a regular MS and are ready to pay more for the service.
- Another criterion could be the usage pattern of the users. Active users on the network generate more revenue because of high network utilization. Hence, such users could be categorized as priority users.
- A third criterion could be the type of device requesting the connection. For example, in a research and development establishment, there could be devices that are critical and need higher priority compared to devices used by the employees. Even on a university campus, there could be a device running critical software that needs higher priority compared to a student device that can be treated with lower priority.

The entire bandwidth shall be divided into two parts, namely the regular quota and the priority quota. A new bearer (for LTE network) or a new connection (for WiMAX network) is admitted from one of the quota as per Algorithm 3 or Algorithm 4.

The priority of the user can be stored and managed dynamically using the authentication, authorization, and accounting (AAA) server located with the network. The AAA server shall maintain a table of the MAC addresses of the devices and the priority associated with the users. When a device (say device “A”) registers with the service provider with a specific priority, it is updated in this table. When a connection request is received from device “A”, the BS checks the table to determine the priority of device “A”. Subsequently, the BS shall admit the connection based on Algorithm 3 or Algorithm 4. The user is free to change the priority level for their device. If a user decides to switch their priority level, the table is updated to reflect the change in priority. Subsequent connection admission requests from the device shall be evaluated based on the new priority levels. This ensures seamless movement of users between the two priority levels.

2.1. Call admission control at MS in WiMAX

There are two scenarios where an MS could request connection admission. The first case is when a new connection is being admitted, and the second is when an existing connection/bearer is being modified.

When an MS receives data from higher layers, it initiates a dynamic service addition (DSA) request procedure. The DSA message contains the requirement of the new connection, for example bandwidth, delay and jitter requirement. On receiving the DSA request, the BS shall check if it can admit the connection. A new connection ID is returned to the MS after the connection is accepted.

Similarly, when a service needs to move from one quality of service value to another, it sends a dynamic service change (DSC) message with the new QoS requirements for bandwidth, delay, and jitter. On receiving

the service change request, the BS shall check if it can upgrade/downgrade this connection. A new connection ID for this connection is sent to the MS after the service change request is accepted by the BS.

2.2. Radio (bearer) admission control at UE (i.e. MS) in LTE

When a user generates packets of certain QCI value (for example, conversational video with QCI value 2) and a dedicated bearer has not been established for the packets then the RRM module in LTE requests bearer admission. Then the QCI value for the bearer is passed to the radio admission control at the eNodeB.

2.3. Admission control at the BS in WiMAX

The MS interacts with the network via the BS. The BS is part of the access service network (ASN). The ASN in turn interacts with the network service provider (NSP). If the MS is in the home network, the BS in the ASN communicates with the home NSP. However, if the MS is roaming and is in a visitor NSP, the BS in the ASN shall communicate with the visitor NSP over R3 interface. The NSP has an AAA server that maintains the details of all the users in the network including their billing details, data plans, etc.

This paper proposes to add a new mapping structure at the AAA server. The AAA server shall map the MAC address of the user and the priority value associated with the user as shown in Table 1.

Table 1. MAC address to priority value mapping.

MAC address	Priority value
01:23:45:67:89:AB	0 (low priority user)
00:00:00:00:AA:BB	1 (high priority user)
98:76:54:32:10:00	0 (low priority user)

When the DSA request arrives at the BS in WiMAX network, the BS shall execute the admission control algorithm, as shown in Algorithm 1, Algorithm 2, and Algorithm 3.

Algorithm 1: Receive Request

```

1. ReceiveConnectionAdmissionRequest(req) {
2.   if(sizeof(AdmissionQueue) < maxQueueSize)
3.     AdmissionQueue.insert(req);
4. }
```

Algorithm 2: Process Request

```

onTimerExpiry() {
  1. if(sizeof(AdmissionQueue) > 0)
  2.   while (sizeof(AdmissionQueue) != 0)
  3.     req = AdmissionQueue.dequeue( );
  4.     ConnectionAdmissionAlgorithm (req);
  5.   end while
  6. endif
}
```

Algorithm 3: Admit Connection in WiMAX

```

1. ConnectionAdmissionAlgorithm(req)
2. Begin
3. if ( $req_{MinimumReserveTrafficRate} > RTPS_{MinimumReserveTrafficRate}$ )
4.     //Connection requirements are more than its minimum reserve traffic rate. Reject the
        connection admission request.
5.     return FAILURE
6. end if
7. //Calculate the cumulative QoS requirement of admitted connections from regular bandwidth.
8. TotalConFromRegBW :=  $\sum_{i=1}^n admitted_{regConn}^{connType} [i]$ ;
9. for i := 0; i < TotalConFromRegBW; i++
10.     RegBWUtilized := RegBWUtilized +  $QoSRequirement_{Conn_i}^{connType}$ ;
11. end for
12.     if(TotalRegBWPerFrame – RegBWUtilized) >  $req_{MinimumReserveTrafficRate}$ 
13.         //Connection can be admitted from regular quota. Hence, admit the
            connection from regular quota.
14.          $admitted_{regConn}[p] := req_{connectionID}$ ;
15.          $QoSRequirement_{Conn_p}^{RTPS} := req_{MinimumReserveTrafficRate}$ ;
16.     else
17.         if  $req_{UserType} == PRIORITY\_USER$ 
18.             //Insufficient BWin regular quota. If connection from a priority user, check if it
                can be admitted from the reserve quota.
19.             TotalConFromPriBW :=  $\sum_{i=1}^n admitted_{priConn}^{connType} [i]$ ;
20.             for i := 0; i < TotalConFromPriBW; i++
21.                 PriBWUtilized := PriBWUtilized +  $QoSRequirement_{Conn_i}^{connType}$ ;
22.             end for
23.             if(TotalPriBWPerFrame – PriBWUtilized) >  $req_{MinimumReserveTrafficRate}$ 
24.                 //Connection can be admitted from priority quota.
25.                  $admitted_{priConn}[p] := req_{connectionID}$ 
26.                  $QoSRequirement_{Conn_p}^{RTPS} := req_{MinimumReserveTrafficRate}$ ;
27.             else
28.                 //Not enough bandwidth even in priority quota. Hence, reject the
                    connection request.
29.                 return FAILURE;

```

```

30.         end if (TotalPriBWPerFrame - ....
31.     else
32.         //Either the user is NOT a priority user, or there is not sufficient bandwidth
           available. Hence, reject the connection.
33.         return FAILURE
34.     end if (reqUserType.....
35.     end //Algorithm
    
```

When a new connection request arrives, it is placed in the admission queue. The AdmissionQueue is checked at regular intervals of time for new connection admission requests. If there are pending requests, they are processed by the connection admission algorithm.

Figure 1 shows the pictorial representation of the proposed algorithms.

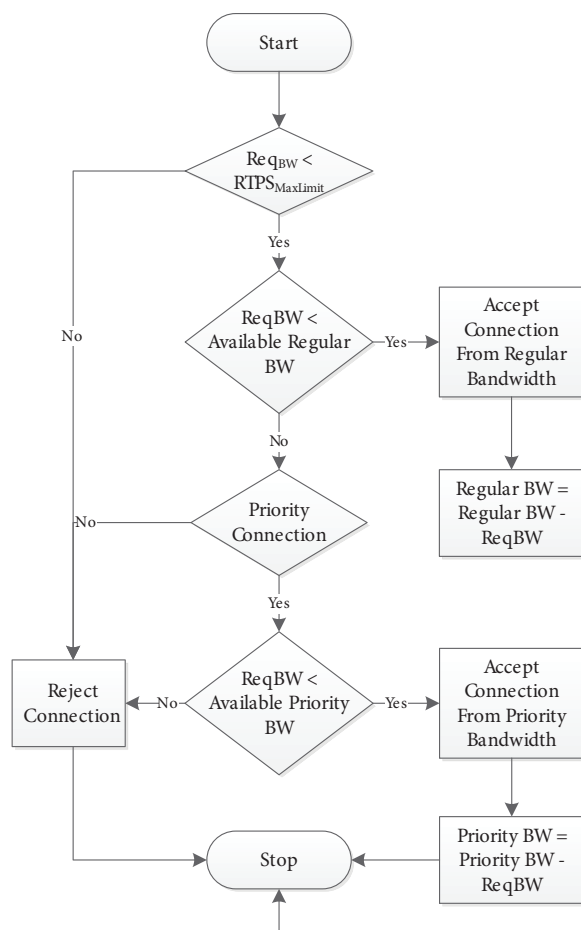


Figure 1. Flowchart representation of the proposed algorithm.

2.4. Bearer admission control at eNodeB in LTE network

Similar to the WiMAX network, the home subscriber server (HSS) shall maintain a mapping of the user to its priority value. When the bearer admission request reaches the eNodeB, the bearer admission control module retrieves the priority value associated with the user. The bearer admission algorithm executes as below:

Algorithm 4: Admit Connection in LTE

```

1. BearerAdmissionAlgorithm
2. Begin
3.   if  $Req_{DataRate_p} > QCI_{MBR}$  //MBR is the maximum guaranteed bit rate for guaranteed bit
      rate connections like onversational video.
4.       //reject connection as its data rates are beyond the supported rates for the bearer class.
5.       return
6. End
7.   if  $NoOfConnections_{QCI_{CLASS[i]}} > MaxNoOfConnection_{QCI_{CLASS[i]}}$ 
8.       //Network has reached connection limit for the QCI class of the requesting connection.
9.       //Reject the bearer admission request.
10.      return
11. end
12. //The available process resource blocks (PRB) are split into regular PRB and priority PRB.
13. if  $Req_{DataRate} < Available_{Regular\_PRB}$ 
14.     //The bearer can be serviced using the regular PRBs; hence, admit the connection.
15.     Admit_Bearer(i);
16.     //Reduce available regular PRB by the admitted bearer requirement.
17. Else
18.     //There is not sufficient BW to admit the bearer from the Regular PRB.
19.     if  $Req_i == PRIORITY\_USER$ 
20.         if  $Req_{DataRate} < Available_{Priority\_PRB}$ 
21.             //The bearer is from a priority user and its requirements can be satisfied from
                the Priority PRB, admit the connection.
22.             Admit_Bearer(i);
23.             //Reduce available regular PRB by admitted bearer requirement.
24.         Else

```



```

25.           //The bearer cannot be admitted. Reject the request.
26.         end
27.       Else
28.           //The user is not a priority user. Reject the bearer admission request.
29.         end
30.     End
31. End

```

Step 1: If the data rate of the new bearer is more than the rate supported by eNodeB for the QCI class associated with the bearer, the connection is rejected.

Step 2: The network operators can set a maximum limit on the per-QCI class limit. If the new connection belongs to, say, QCI class 2 and the network has reached an upper limit on the number of connections or PRB limits for QCI class 2, then the connection is rejected. This is a configurable value. If the network wishes not to have this check, then $MaxNoOfConnection_{QCI_{CLASS[i]}}$ can be set to a very high value.

Step 3: The PRB is split into priority PRB and regular PRB. If $Req_{DataRate}$ is the expected data rate on the new dedicated bearer then the number of PRBs required to support the data rates is calculated as below.

Let CQI be the channel quality of the channel. The MCS based on the CQI is calculated (let it be 16 QAM). The PRB requirement for the selected MCS shall be as per Eq. (1).

$$Req_{PRB} = \frac{Req_{DataRate}}{MCS * Noofsubcarrier_{PRB} * NoOfSymbolsPerSubcarrer(i.e. 6 or 7)} \quad (1)$$

If the request PRB can be satisfied from the regular PRB then the connection is admitted from the regular quota. Otherwise, eNodeB checks if the connection is from a priority user. If yes, and $Req_{PRB} < Priority_{PRB}$, then the bearer is admitted from the priority quota. Or else, the bearer is rejected as the bearer does not belong to the priority user.

Theorem 1 *The proposed connection admission algorithm (Algorithm 3) gives equal opportunity for connection admission to both priority and regular connections.*

Proof Let δ be the arrival time of the regular connection and let $\delta + \Delta$ be the arrival time of the priority request. Let $\theta = \delta - \rho$ be the time at which the previous timer has expired for connection admission. Let $\tau : \tau > \delta + \Delta$ be the time at which the next timer shall expire. Hence, $\theta < \delta < \delta + \Delta < \tau$. As per Algorithm 1, the connection requests are placed in the queue. Since $\delta < \delta + \Delta$, the regular connection request is placed in the queue followed by the priority connection request. As per Algorithm 2, at time τ , the requests are dequeued and the regular connection is tried for connection admission, followed by the priority connection. Since the time of arrival determines the connection admission procedure and not just the priority of the connection, the proposed algorithm gives all connection admission requests an equal opportunity for connection admission. \square

Theorem 2 *Algorithm 3 ensures that at the time of connection admission, priority connections enjoy higher probability of connection admission compared to regular connections.*

Proof At time τ when a regular connection is tried for connection admission, if $req_{MinimumReserveTrafficRate}^{regularConnection_i} < \alpha$, where α represents the available bandwidth for regular connections to admit a new connection, the connection admission request is rejected for the regular connection. However, in the case of priority connection, at time $\tau + \beta$ when the priority connection is tried for admission, initially the admission is tried against bandwidth for regular connections, α . If $req_{MinimumReserveTrafficRate}^{priorityConnection_i} < \alpha$ then the connection gets another chance at connection admission using the available reserve bandwidth for priority connection i.e. γ . The connection is rejected if $req_{MinimumReserveTrafficRate}^{priorityConnection_i} < \gamma$. Thus, the probability of connection admission for priority connection is higher compared to regular connections. □

3. System modeling

A network containing RTPS connections is modeled here. This model can be extended to the other service classes. The connection admission algorithm is executed when a new connection request arrives. Hence, the system is modeled as a discrete event system where the trigger for event processing is the arrival of a connection admission request. The interarrival time between two connection admission requests is random in nature. Hence, the system shall be a stochastic system. Moreover, the state of the system keeps changing based on the type of connection being admitted. Hence, the system shall be modeled as a dynamic system.

Since new connection requests arrive at the BS at random intervals of time, a Poisson arrival pattern for the new connections is assumed as given in Eq. (2). Moreover, since the arrival of connection admission requests is independent of the time (time of day), the system is modeled as a nonstationary Poisson process.

$$P_n(t) = \frac{(\varphi t)^n}{n!} e^{-\varphi t} \tag{2}$$

To model it, a random number generator has been used that generates uniformly distributed random number between (0,1) with the probability density function as in Eq. (3).

$$f(t) = \begin{cases} 1, & 0 \leq x < 1 \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

A natural logarithm of the uniformly distributed random numbers multiplied by mean interarrival time gives the exponential random variate, which is the interarrival time for connection arrivals. The arrival of connection admission requests is Poisson in nature. However, the decision to admit or reject a connection is done in constant time (deterministic in nature, similar to a degenerate distribution). Also, there is a single base station admitting the connection, and hence the queue at the BS that stores the connection admission request is modeled as M/D/1queue. Therefore, if λ represents the mean arrival rate of the connection admission requests at the BS and μ represents the constant service rate, if $\rho = \lambda/\mu$ then the mean delay faced by the admission requests is as per Eq. (4).

$$\text{Mean Delay} = \frac{1}{\mu} * \frac{2 - \rho}{2 - 2\rho} \tag{4}$$

An RTPS connection is accepted if it satisfies the criteria as given in Eq. (5). For the sake of simplicity, the minimum reserve traffic rate has been considered as the criterion to accept new connections.

$$reqBW \leq MinimumReserveTrafficRate_{RTPS} \tag{5}$$

Let reqBW be the bandwidth requirement of the connection being admitted. If the connection satisfies Eq. (5) and is being admitted, then the available uplink capacity, after admitting the connection, is calculated as per Eq. (6):

$$NormalBW = NormalBW - \sum_{i=1}^m acceptedPriCon [i] - \sum_{j=1}^n acceptedNonPriCon [j] - reqBW \quad (6)$$

Here, m is the number of priority connections accepted from normal bandwidth and n is the number if nonpriority connections are accepted from normal bandwidth.

When there is sufficient bandwidth, the connection can be admitted based on the regular bandwidth. Both regular and privileged users can be allotted bandwidth from the normal capacity. If sufficient bandwidth is not available and if the connection is from a priority user, it needs to be checked if the bandwidth request can be satisfied from the reserved bandwidth. If this is the case, then the connection is accepted based on the reserve uplink capacity (privileged bandwidth). Once the connection is accepted, the available privileged bandwidth is updated as per Eq. (7).

$$PrivilegedBW = PrivilegedBW - \sum_{i=1}^m acceptedPriCon [i] - reqBW \quad (7)$$

Here, m is the number of priority connections accepted from the reserve bandwidth. When the user has completed their task, they may stop using the service. This would entail a connection release and freeing up of the resources. Therefore, when the connection is freed, the BS reclaims the bandwidth. If the bandwidth was allotted as per Eq. (6) then it is reclaimed as per Eq. (8).

$$NormalBW = NormalBW + reqBW \quad (8)$$

However, if the connection was for a privileged user and the connection was accepted as per Eq. (7), then on releasing the connection, the resources are reclaimed as per Eq. (9).

$$PrivilegedBW = PrivilegedBW + reqBW \quad (9)$$

The above analysis describes a network condition when only an RTPS connection is present. It applies to a network that contains nRTPS and eRTPS connections as well.

The system can be described using a 3-state Markov chain. The admission control module can be in one of the 3 states as shown in Table 2.

Table 2. Three states of admission control algorithm.

State	Description
A	Admission control module has bandwidth to accept any connection.
B	Admission control module has only reserve bandwidth, and hence can accept only priority connections.
C	Admission control module cannot accept any connection since there is no bandwidth available.

The Markov chain transition diagram for the above states is shown in Figure 2. A transition from C → A could occur when a nonpriority connection is released or when a priority connection was initially accepted. C → B transition occurs when a connection accepted using Eq. (6) is released as in Eq. (8). A transition from

B→C means that the admission control algorithm has admitted a priority connection and it does not have any more bandwidth to admit even a priority connection. The transition probability matrix for the Markov chain is as shown in Eq. (10). The term P_{ij} indicates the probability that the call admission control algorithm transitions from state “i” to “j”.

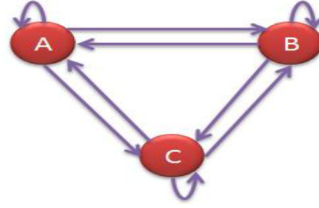


Figure 2. Markov chain transition diagram.

$$\begin{matrix} & A & B & C \\ \begin{matrix} A \\ B \\ C \end{matrix} & \begin{bmatrix} P_{AA} & P_{AB} & P_{AC} \\ P_{BA} & P_{BB} & P_{BC} \\ P_{CA} & P_{CB} & P_{CC} \end{bmatrix} \end{matrix} \tag{10}$$

The transition probability matrix is a stochastic matrix; hence, $P_{AA} + P_{AB} + P_{AC} = 1$. Similarly, $P_{BA} + P_{BB} + P_{BC} = 1$ and $P_{CA} + P_{CB} + P_{CC} = 1$. If the probability values P_{AA} , P_{BA} , or P_{CA} are higher, then it means that the network can support the connection requests that are being received by the admission control module. In this case the conventional CAC algorithm and the proposed user priority based CAC algorithm will perform equally well.

If the probability values P_{AB} , P_{BB} , or P_{CB} are high, then it means sufficient bandwidth is not available in the network to support nonpriority users. In such a scenario, the admission control algorithm can admit connections only from the priority users. In these cases, a user-based admission control algorithm provides higher QoS to the priority users.

Let S_0 represent the initial state distribution matrix as shown in Eq. (11).

$$S_0 = [P_{0A} \quad P_{0B} \quad P_{0C}] \tag{11}$$

State S_1 is calculated as shown in Eq. (12)

$$S_1 [P_{1A} \quad P_{1B} \quad P_{1C}] = [P_{0A} \quad P_{0B} \quad P_{0C}] \begin{bmatrix} P_{AA} & P_{AB} & P_{AC} \\ P_{BA} & P_{BB} & P_{BC} \\ P_{CA} & P_{CB} & P_{CC} \end{bmatrix} \tag{12}$$

Hence,

$$\begin{aligned} P_{1A} &= P_{0A} * P_{AA} + P_{0B} * P_{BA} + P_{0C} * P_{CA} \\ P_{1B} &= P_{0A} * P_{AB} + P_{0B} * P_{BB} + P_{0C} * P_{CB} \\ P_{1C} &= P_{0A} * P_{AC} + P_{0B} * P_{BC} + P_{0C} * P_{CC} \end{aligned} \tag{13}$$

State S_2 is calculated using S_1 as shown in Eq. (14).

$$S_2 [P_{2A} \quad P_{2B} \quad P_{2C}] = [P_{1A} \quad P_{1B} \quad P_{1C}] \begin{bmatrix} P_{AA} & P_{AB} & P_{AC} \\ P_{BA} & P_{BB} & P_{BC} \\ P_{CA} & P_{CB} & P_{CC} \end{bmatrix} \tag{14}$$

Subsequent states follow a similar pattern.

4. Results and discussion

Simulations were carried out in MATLAB to analyze the improvements brought by the priority-based admission control algorithm. Each reading is an average of three trials. Table 3 lists the parameters used for simulation. It is assumed that priority and nonpriority connection admission requests arrive at the BS with equal probability. Connection acceptance ratio is calculated as per Eq. (15).

$$ConnectionAcceptanceRatio = \frac{Connections\ Accepted}{Total\ Connections} \quad (15)$$

Figure 3a shows the simulation results when the uplink bandwidth is set at 20 Mbps and 5% of the uplink bandwidth is reserved for priority users. Figure 3b shows the results when 10% of bandwidth is reserved for priority users. Priority users enjoy anywhere between 5% and 9% more connection admissions compared to nonpriority users. Figures 3c, 3d, and 3e show the connection acceptance values when 15%, 20%, and 25% bandwidth is reserved for priority users.

Table 3. Simulation parameters.

Parameter	Value
Uplink capacity	20 Mbps
Arrival pattern for the connections at BS	Poisson arrival
Connection lifetime	1 to 60 s
RTPS data rate	100 kbps
Lifetime of each simulation iteration	3600 s

When the connection admission requests arrive at the BS, the BS by default accepts the connections based on nonreserve bandwidth. The lifespan of the connections could be of any duration between 1 and 60 s. If at any point in time, the network contains connections that are active for a longer duration and the new connection arrives at a higher connection rate, the BS will not be able to accept the new connections based on nonreserve bandwidth. In such a scenario, the connection requests from the priority users might get accepted if the BS admits them by utilizing the reserve bandwidth. This can be concluded from Figures 3a–3e. As the reserve bandwidth increases, the connection acceptance ratio for priority users goes up. The difference between the acceptance ratio between the priority user and nonpriority users ranges from 3% to 30%.

μ → number of active connections utilizing nonreserve bandwidth.

β_i → QoS needs for each of the active connections utilizing nonreserve bandwidth.

α → Available nonreserve bandwidth.

δ → number of active connections utilizing reserve bandwidth.

γ_i → QoS needs for each of the active connection utilizing reserve bandwidth.

ε → Available reserve bandwidth.

$$\alpha = TotalBW - ReserveBw - \sum_{i=1}^{\mu} \beta_i \quad (16)$$

$$\varepsilon = TotalBW - NonReserveBw - \sum_{i=1}^{\delta} \gamma_i \quad (17)$$

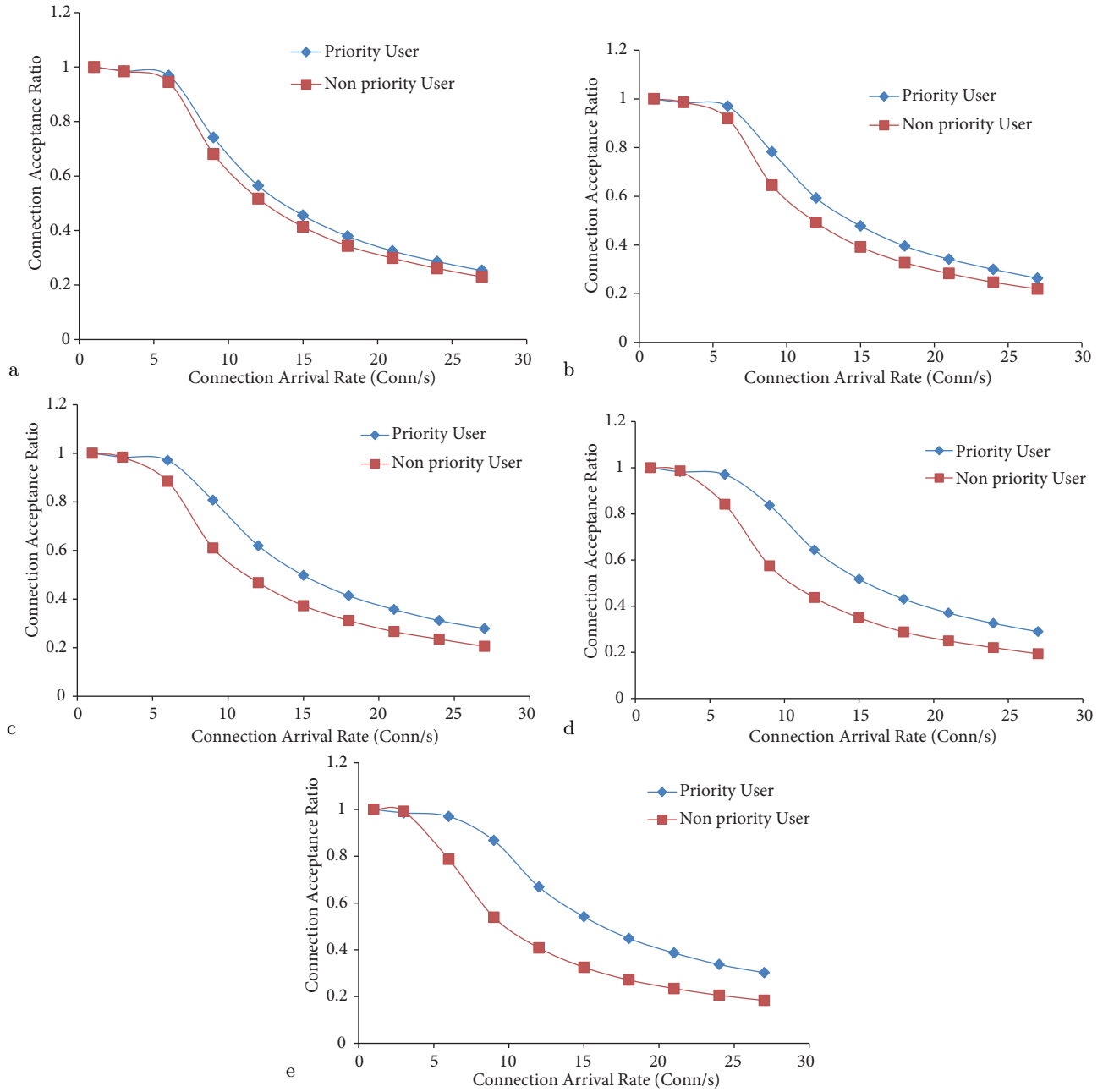


Figure 3 a) Reserve bandwidth = 5%. b) Reserve bandwidth = 10%. c) Reserve BW = 15%. d) Reserve bandwidth = 20%. e) Reserve bandwidth = 25%.

$$PriConnAccepted = \begin{cases} 1 & \text{if } QoS_{Connection} < \alpha \text{ or} \\ & QoS_{Connection} < \varepsilon \\ 0 & \text{otherwise} \end{cases} \quad (18)$$

$$NonPriConnAccepted = \begin{cases} 1 & \text{if } QoS_{Connection} < \alpha \\ 0 & \text{otherwise} \end{cases} \quad (19)$$

Since priority connections have the advantage of both α and ε , the connection admission probability of a priority connection is higher. However, the nonpriority connections are satisfied using ε , which results in relatively lower connection acceptance. This is even more pronounced when the reserve bandwidth keeps increasing, as is seen in Figures 3a–3e. The proposed graded, priority-based admission control algorithm was compared with the first-come-first-serve (FCFS)-based admission control algorithm. The reserve bandwidth was set to 15% for different connection arrival rates. Figure 4 shows the simulation results. It can be seen that the priority algorithm results in a higher connection acceptance ratio compared to the FCFS algorithm.

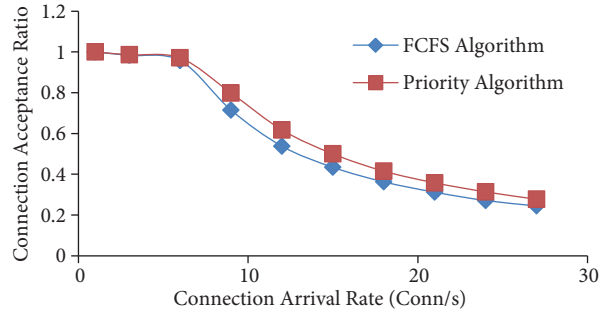


Figure 4. Comparison between FCFS and priority-based admission control.

Simulation was carried out to ascertain the behavior of the system at different simulation lifetimes (3500 s, 4500 s, and 5500 s) for different interarrival rates. Figure 5 shows the simulation results. The graph for “3500 s PU” illustrates the connection acceptance ratio for the priority user with the simulation lifetime set to 3500 s.

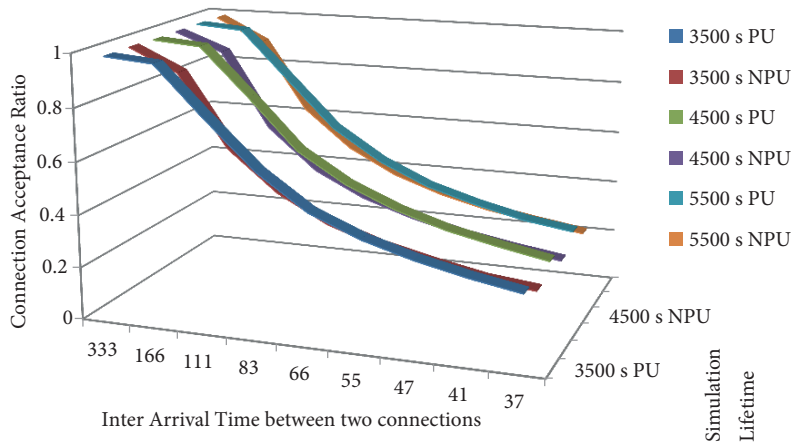


Figure 5. CAR for priority and nonpriority users under different simulation lifetimes.

Figure 5 attempts to show that for each of the simulation timespans (i.e. 3500 s, 4500 s, or even 5500 s), even when the interarrival time for connections decreases from 333 ms to 37 ms (i.e. connection arrival rate increases), the connection admission ratio for a priority user is higher compared to a regular user.

With the reserve bandwidth set at 12%, simulations were carried out with different uplink capacities. Figures 6a, 6b, and 6c show the simulation results for uplink capacities of 16 Mbps, 18 Mbps, and 20 Mbps. It can be seen that as the link capacity increases, the connection acceptance ratio (CAR) for a new connection increases proportionately. Hence, at higher uplink capacities, both priority users and regular users enjoy higher admission rates for their connections.

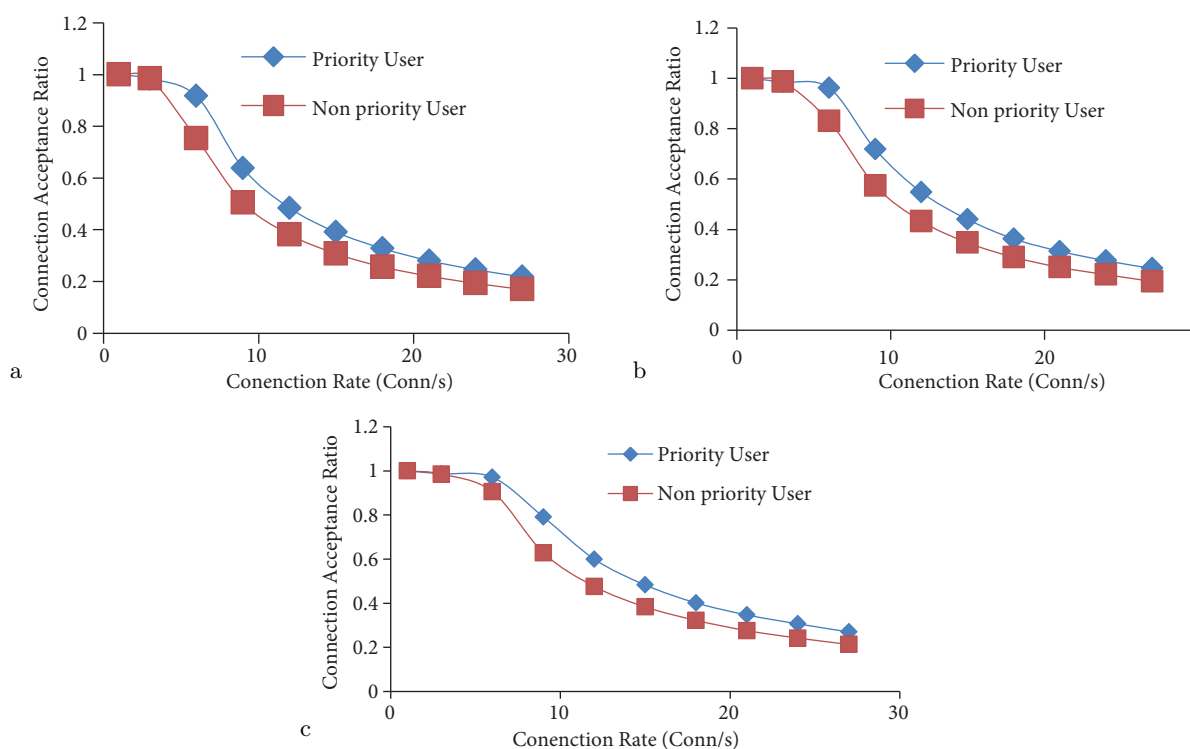


Figure 6. a) CAR for priority and nonpriority user for 16 Mbps uplink capacity. b) CAR for priority and nonpriority user for 18 Mbps uplink capacity. c) CAR for priority and nonpriority user for 20 Mbps uplink capacity.

Since a percentage of connections are reserved for priority users, there might be situations where the network might receive more connection admission requests from nonpriority users compared to the priority users. In such a scenario, the network might reject the connection requests even though bandwidth is available under the reserve category. With uplink capacity set to 20 Mbps, for connection lifetimes between 1 and 100 s, simulations were done to find out the connection admission ratio when 5% and 12% of the connections were reserved. The BS received twice the number of connection requests from nonpriority users compared to priority users. Figures 7a and 7b show the simulation results when 5% and 12% of the connections were reserved, respectively. From the results it is clear that when 5% of the bandwidth is reserved, about 0%–3% of the bandwidth gets wasted if the network contains twice the number of nonpriority users compared to priority users. The bandwidth wasted ranges from 0% to 7% when 12% of the bandwidth is reserved for priority users.

A simulation was carried out to experimentally determine the different values for the transition probability matrix for the Markov chain (Figure 1). Figure 8 shows the simulation results when the initial state distribution matrix was set to $S_0 = [1 \ 0 \ 0]$, the uplink bandwidth set to 20 Mbps, and the privileged bandwidth set to 12% of the total bandwidth. The average interarrival time for the new connection request was set at 111 ms. Figure 7 shows that the system transitions from State A back to State A for 55% of the simulation lifetime. From Figure 8 we can conclude that for more than 50% of simulation lifetime, the system is able to cater to the needs of both the priority and nonpriority connections. However, for about 8% of the time, the system was in a state where it could serve connection requests only from priority users. The percentage depended on the amount of reserve bandwidth allocated for priority connections.

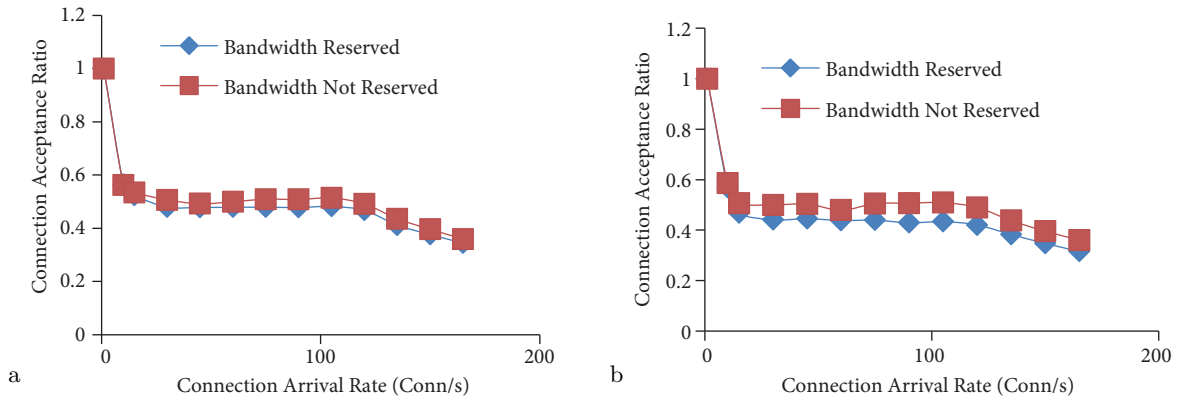


Figure 7. a) CAR for nonpriority connections when 5% connections are reserved. b) CAR for nonpriority connections when 12% connections are reserved.

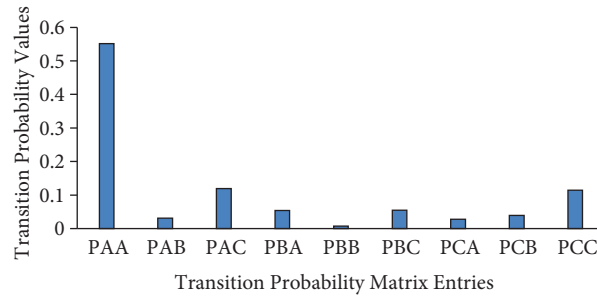


Figure 8. Transition probability matrix values.

Figures 9a, 9b, and 9c show the amount of time the system stays in the three different states of the Markov chain (Table 2). The uplink capacity was set to 20 Mbps. The average interarrival time used was 111 ms, and the privileged bandwidth was set to 5%, 12%, and 25% respectively. It is clear that as the reserve bandwidth increases, the system spends more time catering to priority connections. Hence, the priority connections have a higher connection admission ratio.

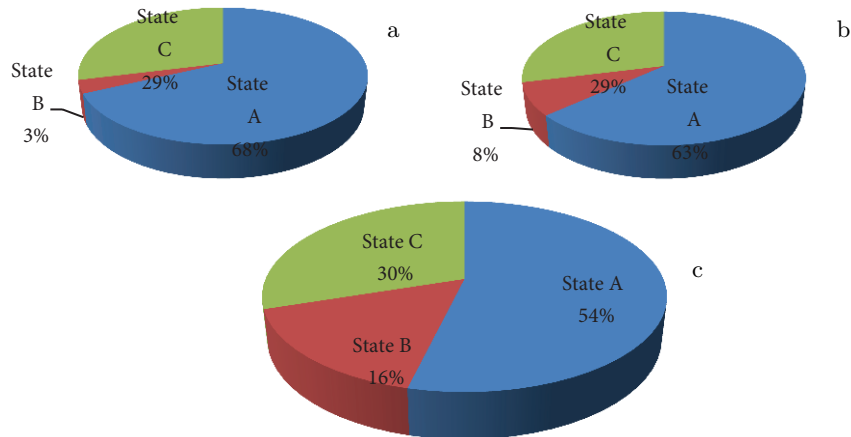


Figure 9. a) The time spent in different Markov states with privileged bandwidth set to 5% of total bandwidth. b) The time spent in different Markov states with privileged bandwidth set to 12% of total bandwidth. c) Time spent in different Markov states with privileged bandwidth set to 25% of total bandwidth.

As observed in [25,26,29], the criterion to admit the connection is biased towards the bandwidth requirements of the incoming connection request. Hence, such algorithms were classified as priority bandwidth algorithms. Simulations were done to compare the existing priority bandwidth-based algorithm with the proposed priority user-based algorithm. The uplink capacity is considered to be 10 Mbps with each RTPS connection generating data at an average rate of 500 kbps with a variance of $\pm 5\%$. Figure 10a reveals that the existing priority bandwidth algorithm and the proposed priority user algorithm perform equally well. Figure 10b shows the system throughput for the existing priority bandwidth allocation algorithm and proposed priority user algorithm. From Figure 10b it is clear that the overall system throughput is similar for both the algorithms. However, in the case of the priority-user algorithm, the numbers of priority users accepted are higher. Hence, the proportion of bandwidth utilized by priority users is higher, as seen in 10c. Hence, the proposed algorithm ensures that the system utilization is optimal, with a slight bias towards select users, leading to improved throughput for select users.

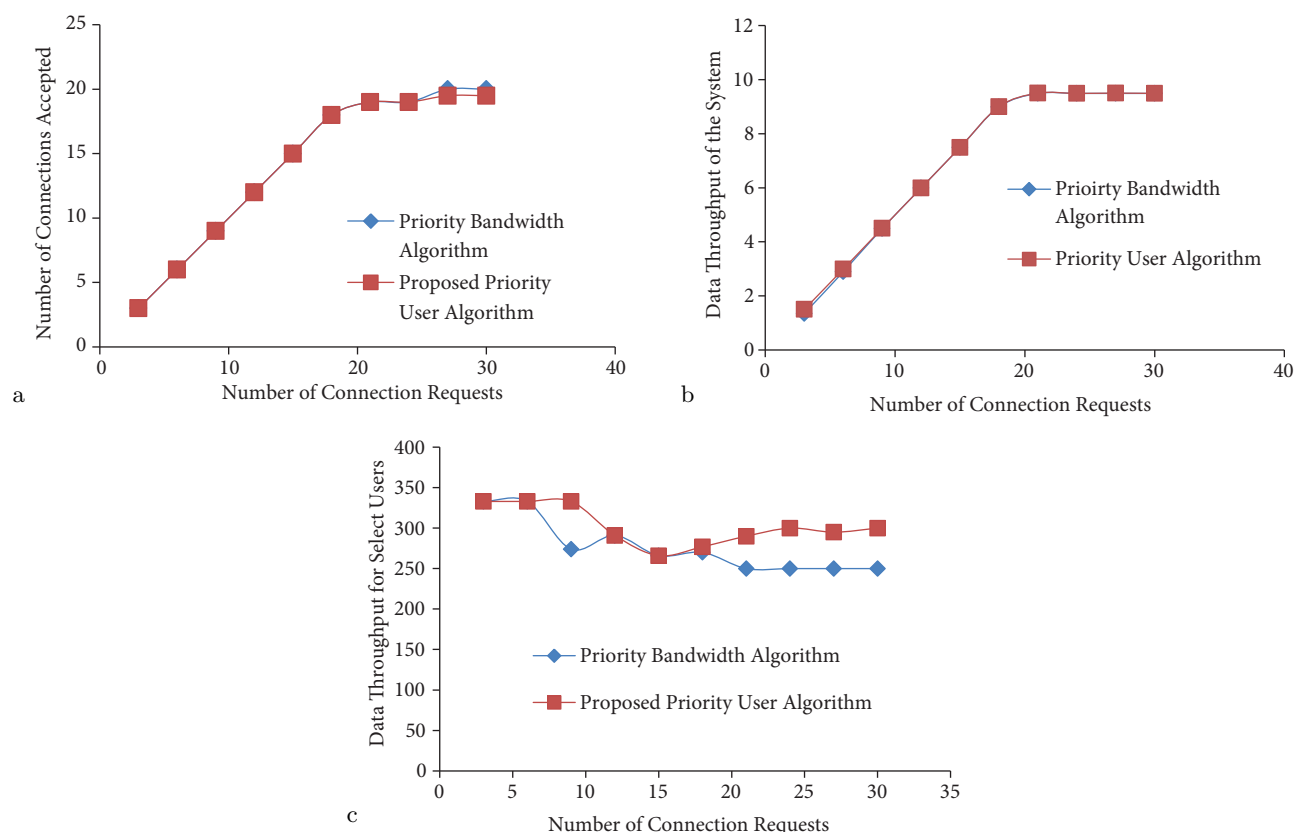


Figure 10. a) Connection acceptance for priority bandwidth algorithm vs. priority user algorithm. b) Data throughput for the system for priority bandwidth algorithm vs. priority user algorithm. c) Data throughput for select users for priority bandwidth algorithm vs. priority user algorithm.

5. Conclusion

Admission control algorithms generally take into consideration the QoS factors like delay, bandwidth, and jitter during the admission control process. Some admission control algorithms also consider the SNR values at the time of connection admission. However, sufficient research has not been carried out on user priority-based

admission control mechanisms. Priority of a user is an important factor that can be leveraged to provide graded quality of service among the users in the network. By admitting connections based on the priority of the user, such users stand to gain in a congested network as their connection admission requests are prioritized by the network. At the same time, the network operators stand to gain since the priority users pay more for the accelerated connection admission. Additionally, Theorem 1 proves that the nonpriority users do not suffer from starvation because of prioritization of connection admission requests for high-priority users. Hence, the proposed user priority-based admission control mechanism is a win-win proposal for both users and network operators.

Simulation results reveal a higher connection admission rate for priority users compared to nonpriority users. Simulation results also show that the proposed user-based admission control mechanism provides a higher connection admission rate compared to known mechanisms like FCFS and priority bandwidth algorithms.

When the proposed algorithm is implemented in a live network, it shall bring about a meaningful change in the connection admission process and thereby result in efficient utilization of network resources. It shall also result in satisfied users, thereby generating better revenue for network operators.

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