A Connection Admission Control Algorithm for IEEE 802.16e Networks Based on Bandwidth Reservation and Dynamic Thresholds Adjustment

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Abstract — In this paper, we present a Connection Admission Control (CAC) algorithm for the IEEE 802.16e standard, based on dynamic bandwidth reservation. These reserves are obtained by segmenting the amount of the channel's bandwidth by thresholds, which are dynamically adjusted according to the admissions of handoff and new connections. Simulations were performed using the NS-2, demonstrating that the proposed algorithm can avoid the waste of network resources, increase its efficiency and provide QoS, in terms of bandwidth, for applications.

Index Terms: CAC, threshold, dynamic adjustment, Quality of Service, QoS, IEEE 802.16e, WiMAX

I. INTRODUCTION

The IEEE 802.16e standard [1] for wireless broadband, also known as mobile WiMAX (Worldwide Interoperability for Microwave Access) is an important solution to provide multimedia wireless mobility, including Quality of Services (QoS) warranties for real-time applications and for those that require high transmission rates. In IEEE 802.16e networks, the system resources are controlled by a Base Station (BS), which can effectively guarantee QoS for the Mobile Stations (MS) applying a Connection Admission Control (CAC) scheme, which determines whether or not a connection can be established according to the network resources availability [2], a traffic policing scheme and also a packet scheduling scheme that defines which service class should be served with the higher priority, based on predetermined criteria. The 802.16e standard does not specify how to implement such mechanisms, letting it open for each equipments manufacturer to create its own scheme and thereby encourage the competitiveness of each product.

In 802.16e networks, when a MS moves away from the original serving BS, the quality of the communication degrades, what makes the MS transfer the connection to a neighboring BS with a better signal quality. This process is called handoff. Generally, CAC schemes will prioritize an existing user in handoff process over a new user, in order to provide a better QoE (Quality of Experience) perceived by the user that is already connected. The design of a handoff mechanism should take into account the need of available bandwidth to meet the minimum QoS requirements of handoff connections. As a result, the BS must reserve a certain bandwidth amount exclusively for handoff connections and dedicate the remainder for new connections. However, if a fixed bandwidth amount is reserved for handoff users and this can never be used by new connections, there will probably be a waste of network resources. Therefore, a CAC scheme for 802.16e networks should take into account the need of bandwidth for handoff connections with the challenge of not wasting network resources [3] and accept the maximum possible number of new connections.

In this paper, we propose a CAC algorithm that performs a dynamic bandwidth reservation for the connections, based on the different service classes and taking into account the handoff connections. These reserves are dynamically adjusted in order to minimize the waste of network resources, improve its efficiency, provide justice in the admission of connections and ensure QoS in terms of bandwidth, for applications. To demonstrate these features of the proposed algorithm, simulations were conducted, returning satisfactory results in all evaluated parameters.

The remainder of this paper is organized as follows: Section II presents the IEEE 802.16e Service Classes. Section III identifies the related works, followed by Section IV that describes the proposed mechanism. Section V defines the network scenario and the simulation parameters, and Section VI contains the results analysis. Finally, Section VII presents the conclusions of this work.

II. IEEE 802.16E SERVICE CLASSES

The MAC layer specified in IEEE 802.16e standard provides different levels of QoS for each service flow, which is an unidirectional sequence of packets that is associated to a specific level of QoS, according to the service class that is was assigned. The standard specifies five types of service classes, which are described as follows:

1) Unsolicited Grant Service (UGS): UGS is designed to support real-time service flows that generate fixed-size data packets on periodic basis, such as VoIP (Voice-over-Internet-Protocol) applications without silence suppression. This service allocates grants with fixed amounts of bandwidth for CBR (Constant Bit Rate) applications, without any requests.

2) Real-time Polling Service (rtPS): rtPS is designed to support real-time service flows with variable packet size, generated at periodic intervals (i.e. VBR - Variable Bit Rate), such as MPEG (Motion Pictures Experts Group) videos. The MSs request bandwidth periodically through a mechanism known as unicast polling.

3) Extended Real-time Polling Service (ertPS): This service uses a grant mechanism similar to that used by UGS. However, the allocated grants can be used to periodically send
requests to inform the BS about the need for a new grant size. The BS does not change the grant size until it receives from the MS a bandwidth request \[4\]. ertPS is designed to support real-time traffic flows with variable data rate, such as VoIP with silence suppression.

4. Non-real-time Polling Service (nrtPS): This service is designed for non-real-time applications, which require regular grants of variable length, such as FTP application. The service offers unicast polling, but less frequently than rtPS service.

5. Best Effort (BE): BE is designed for applications which have no QoS requirements. The MS can use the unicast slots or contention slots to request bandwidth.

The QoS parameters and the application types supported by each service class are described in Table I.

<table>
<thead>
<tr>
<th>Classes</th>
<th>Applications</th>
<th>QoS parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGS</td>
<td>VoIP without silence suppression.</td>
<td>Max. Sustained Traffic Rate; Max. Latency; Jitter;</td>
</tr>
<tr>
<td>rtPS</td>
<td>Video Streaming.</td>
<td>Max. Sustained Traffic Rate; Min. Reserved Traffic Rate; Max. Latency;</td>
</tr>
<tr>
<td>ertPS</td>
<td>VoIP with silence suppression.</td>
<td>Max. Sustained Traffic Rate; Min. Reserved Traffic Rate; Max. Latency; Jitter;</td>
</tr>
<tr>
<td>nrtPS</td>
<td>FTP.</td>
<td>Max. Sustained Traffic Rate; Min. Reserved Traffic Rate;</td>
</tr>
<tr>
<td>BE</td>
<td>Web browsing, e-mail.</td>
<td>Max. Sustained Traffic Rate;</td>
</tr>
</tbody>
</table>

III. RELATED WORKS

In \[5\] the authors propose a CAC scheme that differentiates the connections by its service class. It has 03 modules: traffic classifier, dispatcher and the CAC Decision Maker. The Decision Maker module is based on the maximum rate for UGS and ertPS connections, the average rate for rtPS, the minimum rate for nrtPS and the average rate divided by 2 for BE connections. A connection will be accepted if: \([(\text{Total bandwidth}) - (\text{bandwidth allocated to the current connections}) - (\text{requested bandwidth})] > 0\). The proposed algorithm also differentiates the connections by its service classes and uses bandwidth reserves for attending the connections according to service class to which they belong.

The CAC scheme proposed in \[6\] is based on bandwidth reserves with fixed thresholds. These thresholds split the bandwidth into reserves for the connections belonging to the different service classes. In our proposal, the algorithm also uses bandwidth reserves with thresholds, but their values are not fixed, these are dynamically adjusted based on admissions of the connections.

It is proposed in \[7\] a CAC scheme with a dynamic bandwidth reserve for handoff connections. This reserve varies according to the admission of new handoff connections and the ending of handoffs already admitted. In our work, the variations of the thresholds are caused by admissions of handoffs as well as new connections.

In \[8\] the authors propose an adaptive CAC algorithm named AACA - Adaptive Admission Control Algorithm, which dynamically determines the reserved bandwidth for handoff connections according to the arrival distributions of both handoff and new connections. When a handoff connection is accepted, the reserve is extended and when a new connection is admitted, the reserve is reduced. In our proposal, besides the reservation for handoff connections, there are also reserves for new connections of real-time, non-real-time and BE traffic. These reserves allow the differentiation in the treatment of each traffic type, in terms of the amount of bandwidth that is destined for each one. Furthermore, these reserves will change only if their occupation reaches a predetermined threshold value. As a result, more connections can be admitted in the network.

IV. PROPOSED CONNECTION ADMISSION CONTROL (CAC) ALGORITHM

In this paper, we propose an algorithm for connection admission control (CAC) based on bandwidth reservations, with thresholds that are dynamically adjusted in order to avoid the waste of reserved bandwidth and maintain the QoS of already admitted connections. The bandwidth reserves are destined for handoff connections and the new connections of real-time, non-real-time and Best Effort traffic. Fig. 1 depicts the proposed bandwidth reservation scheme.

Denote the total bandwidth that the BS can allocate to the connections as \(B\), the boundary between the reserves of handoff and real-time connections (UGS and rtPS) as "\(t_{\text{Handoff}}\)" (handoff threshold), the boundary between the reserves of the real-time and non-real-time connections (nrtPS) as "\(th\)" (threshold) and the boundary between the reserves of non-real-time and Best Effort (BE) connections as "\(t_{\text{BE}}\)". Denote as \(b_{\text{h}_{\text{Max}}}, b_{\text{h}_{\text{Min}}}, b_{\text{r}_{\text{Max}}}, b_{\text{r}_{\text{Min}}}\) the portion of the bandwidth \(B\) already allocated to the existing handoff, UGS, rtPS and nrtPS connections, respectively and \(b_{\text{req}}\) as the amount of bandwidth that a new connection requires before being admitted.

The threshold "\(t_{\text{Handoff}}\)" varies within the range \([t_{\text{Max}}, th_{\text{Handoff}_{\text{Max}}}]\) and its initial value is \([t_{\text{Handoff}_{\text{Max}}} - t_{\text{Max}}] * 0.8\). The threshold "\(th\)" varies within the range \([t_{\text{Min}}, t_{\text{Max}}]\) and its initial value is \([t_{\text{Max}} - t_{\text{Min}}]/2\).

\(B\) is split into segments to provide bandwidth reserves to the different types of traffic. The bandwidth reserved for handoff connections corresponds to \((B - t_{\text{Handoff}})\), the reserve for the real-time connections is \((t_{\text{Handoff}} - th\) for the non-real-time is \((th - t_{\text{BE}})\) and finally for the BE connections is "\(t_{\text{BE}}\)". The admission of a connection by the BS obeys the following priority order: handoff connection > UGS connection > rtPS connection > nrtPS connection. All BE connections are allowed and a little portion of the bandwidth \((t_{\text{BE}})\) is reserved for them, in order to avoid the "bandwidth starvations" of the BE traffic in the scheduling process.
A handoff connection will be admitted if:

\[(b_{\text{req}} + b_{\text{req}}) \leq (B - \text{thHandoff})\]  \hspace{1cm} (1)

If the connection is admitted, \(b_{\text{req}}\) will be added to \(b_{\text{ho}}\), that is:

\[b_{\text{ho}} = b_{\text{ho}} + b_{\text{req}};\] \hspace{1cm} (2)

After the update of \(b_{\text{ho}}\) if the following condition is satisfied:

\[((b_{\text{req}} + b_{\text{req}}) \geq (B - \text{thHandoff})/2 \text{ and } (b_{\text{ugs}} + b_{\text{req}}) < (\text{thHandoff} - \text{th})\)  \hspace{1cm} (3)

\text{thHandoff} will be reduced by \(b_{\text{req}}\) (limited to the value of \(\text{thMax}\)), that is:

\[\text{thHandoff} = \text{thHandoff} - b_{\text{req}};\] \hspace{1cm} (4)

The purpose of this condition is to increase the size of the reserve for the handoff connections, if the bandwidth dedicated to the already admitted handoff connections approaches the defined limit for the change (first term in condition (3)), respecting the reserves for the UGS and rtPS connections (the second term of condition (3)). Unlike the exposed in [8], in which the threshold changes every time a connection is accepted, in this proposal the threshold \(\text{thHandoff}\) only changes if the occupation of the reserve for handoff connections reaches the value \([B - \text{thHandoff}] / 2\). This avoids the decrease of the reserve for real-time connections before the occupation of half of the reserve for handoff connections, giving more admission opportunities to real-time connections.

An UGS or rtPS connection will be admitted if:

\[(b_{\text{req}} + b_{\text{req}} + b_{\text{req}}) \leq (\text{thHandoff} - \text{th})\] \hspace{1cm} (5)

If the connection is admitted, \(b_{\text{req}}\) will be added to \(b_{\text{ugs}}\) or \(b_{\text{rtps}}\), that is:

\[b_{\text{ugs}} = b_{\text{ugs}} + b_{\text{req}}; \text{ (if UGS)}\] \hspace{1cm} (6)

\[b_{\text{rtps}} = b_{\text{rtps}} + b_{\text{req}}; \text{ (if rtPS)}\] \hspace{1cm} (7)

After the update of \(b_{\text{ugs}}\) or \(b_{\text{rtps}}\), if the following condition is satisfied:

\[((b_{\text{req}} + b_{\text{req}} + b_{\text{req}}) \geq (\text{thHandoff} - \text{th}) \text{ and } (b_{\text{req}} \leq B - \text{thHandoff} - b_{\text{req}}))\]  \hspace{1cm} (8)

\text{thHandoff} will be increased by \(b_{\text{req}}\) (limited to the value of \(\text{thHandoffMax}\)), that is:

\[\text{thHandoff} = \text{thHandoff} + b_{\text{req}};\] \hspace{1cm} (9)

and, if the following condition is satisfied:

\[((b_{\text{req}} + b_{\text{req}} + b_{\text{req}}) \geq (\text{thHandoff} - \text{th}) \text{ and } (b_{\text{req}} < (\text{th} - \text{thBE} - b_{\text{req}})))\]  \hspace{1cm} (10)

\(\text{th}\) will be decreased by \(b_{\text{req}}\) (limited to the value of \(\text{thMin}\)) that is:

\[\text{th} = \text{th} - b_{\text{req}};\] \hspace{1cm} (11)

The purpose of these conditions is to increase the size of the reserve for real-time connections.

A rtPS connection will be admitted if:

\[(b_{\text{req}} + b_{\text{req}}) \leq (\text{th} - \text{thBE})\] \hspace{1cm} (12)

If the connection is admitted, \(b_{\text{req}}\) will be added to \(b_{\text{rtPS}}\) that is:

\[b_{\text{rtPS}} = b_{\text{rtPS}} + b_{\text{req}};\] \hspace{1cm} (13)

After the update of \(b_{\text{rtPS}}\), if the following condition is satisfied:

\[((b_{\text{req}} + b_{\text{req}} + b_{\text{req}}) \geq (\text{th} - \text{thBE}) \text{ and } (b_{\text{req}} + b_{\text{req}}) < (\text{thHandoff} - (\text{th} + 4* b_{\text{req}})))\]  \hspace{1cm} (14)

\(\text{th}\) will be increased by \(b_{\text{req}}\) (limited to the value of \(\text{thMax}\)), that is:

\[\text{th} = \text{th} + b_{\text{req}};\] \hspace{1cm} (15)

The purpose of this condition is to increase the size of the reserve for rtPS connections. Finally, all BE connections will be admitted and a little portion of the bandwidth (\(\text{thBE}\)) will be reserved for them, in order to avoid the "bandwidth starvation" of the BE traffic in the scheduling process. The values of the fixed thresholds (\(\text{thHandoffMax}, \text{thMax}, \text{thMin}, \text{thBE}\)) may be assigned by the network administrator in accordance with the traffic profile of the users.

Fig. 2 depicts the proposed CAC algorithm.
To evaluate the proposed CAC algorithm, we used the simulation tool NS-2 [9] with the WIMAX module developed by NIST [10]. It was necessary to extend this module to include the proposed CAC model and the AACA described in [8]. The considered scenarios involve multiple MSs entering the network at regular intervals and random positions. Each MS was assigned to a type of traffic and the handoff connections were also considered. The main parameters of the simulation are shown in Table II:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink Transmission Rate</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>UGS traffic</td>
<td>CBR Traffic Rate = 96 Kbps</td>
</tr>
<tr>
<td>rtPS traffic</td>
<td>Video Streaming MPEG; Average rate = 480 Kbps</td>
</tr>
<tr>
<td>nrtPS traffic</td>
<td>FTP (Min. rate = 160 Kbps; Max. rate = 800 Kbps)</td>
</tr>
<tr>
<td>BE traffic</td>
<td>HTTP traffic (Average rate = 64 Kbps)</td>
</tr>
<tr>
<td>Handoff connections</td>
<td>CBR Traffic Rate = 96 Kbps</td>
</tr>
</tbody>
</table>

VI. RESULTS ANALYSIS

The results presented in this section refer to simulations performed with the use of the AACA algorithm described in [8] and the proposed algorithm, in order to compare the performance of each one. At the experiments in which the AACA algorithm was used, the considered thresholds were: \( \text{thMax} = 0.9 \times B; \text{thMin} = 0.1 \times B; \text{thad} = \left( \text{thMin} + \text{thMax} \right)/2 \).

When the proposed algorithm was used, the considered thresholds were: \( \text{thHandoffMax} = 0.9 \times B; \text{thHandoff} = \left( \text{thHandoffMax} - \text{thMax} \right)/0.8; \text{thMax} = 0.4 \times B; \text{thMin} = 0.1 \times B; \text{th} = \left( \text{thMax} - \text{thMin} \right)/2; \text{thBE} = 0.02 \times B \).

We considered the service classes UGS, rtPS, nrtPS and BE. For the handoff connections, the CBR traffic and UGS service class was considered. The minimum rate was adopted as the connection admission criteria. We adopted the ratio of one handoff connection attempt to eight new connections attempts. All were uniformly distributed over the simulation time. The performance of each CAC algorithm will be compared in terms of the number of admitted connections for each service class and the connections blocking rates.

The total simulation time was 50 seconds and the presented results are the average outcome of 10 simulations runs. The connection attempts started after 15 seconds of simulation. The results indicated that on average, the AACA algorithm admitted the total of 53 connections with 10 handoffs, 12 UGS, 9 rtPS, 12 nrtPS and 10 BE, whereas the proposed algorithm admitted the total of 68 connections with 10 handoffs, 14 UGS, 11 rtPS, 13 nrtPS and 20 BE, resulting in the admission of 15 more connections than the AACA algorithm, that is, an increase of network efficiency by 16.7%.

Fig. 3 depicts the blocking rates over time for handoff and the real-time connections. The blocking rate of non-real-time and BE connections are illustrated in Fig. 4. It is shown in these figures that the blocking rates remain equal to zero when the network load is low (the simulation time is less than 30 seconds), for both used algorithms. As the connections are
admitted, the network load increases and the blocking rates rise progressively due to the lack of available bandwidth to be reserved.

Table III shows the blocking rates at the end of the simulation. The new connections blocking rates obtained by the proposed algorithm were lower than those obtained by the AACA algorithm, which results in a smaller number of blocked connections and greater network efficiency.

Table III. Final Blocking Rates

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Blocking Rate - AACA (%)</th>
<th>Blocking Rate - Proposed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handoff</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>UGS</td>
<td>40%</td>
<td>30%</td>
</tr>
<tr>
<td>rtPS</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>nrtPS</td>
<td>40%</td>
<td>35%</td>
</tr>
<tr>
<td>BE</td>
<td>50%</td>
<td>0%</td>
</tr>
</tbody>
</table>

VII. CONCLUSIONS

In this paper, we presented a Connection Admission Control (CAC) algorithm for the IEEE 802.16e standard that performs bandwidth reservation for the connections, taking into account the different service classes and handoff connections. These reserves are dynamically adjusted in order to minimize the waste of network resources, improve its efficiency, provide justice in the admission of connections and ensure QoS in terms of bandwidth, for applications. The performance of this algorithm was evaluated in terms of the number of admitted connections and the blocking rates of new and handoff connections. The simulation results showed that the proposed CAC algorithm outperforms the CAC algorithm based on adaptive bandwidth reservation, with the admission of a larger number of new connections to the network and a decrease of the new and handoff connections blocking rates.

REFERENCES