MSCR based bandwidth request mechanism for heterogeneous WiMAX networks

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Abstract

The next generation wireless networks aim to provide users with always-best connectivity through available different access networks. In this paper, we consider heterogeneous of worldwide interoperability for microwave access (WiMAX) and wireless local area network (WLAN). These heterogeneous networks suffer from low bandwidth utilization and access delay with contention based bandwidth request through single stage truncated binary exponential backoff (TBEB) algorithm. To resolve contention effectively, we propose exponential increase exponential decrease (EIED) backoff with multistage contention resolution (MSCR). The results show that the proposed backoff scheme outperforms the conventional TBEB scheme with an improvement of 35.29% in access delay, 26.67% in queuing delay and 67.65% in throughput.

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Keywords: Bandwidth request; contention resolution; IEEE 802.16; medium access control; TBEB; EIED

1. Introduction

The advent of ubiquitous computing and the growth of portable devices have raised the importance of mobile and wireless networking. Recently, WiMAX networks using the IEEE802.16 standard [1] received a great deal of attention because of the high data rate support, its intrinsic quality of service (QoS), mobility capabilities and wider area coverage enabling ubiquitous connectivity. During recent years, IEEE802.11 WLAN has been deployed widely and 802.11 access points (APs) are able to cover areas of a few hundred square meters, making them suitable for enterprise networks and public hot spot scenarios such as airports and hotels. An interworking between these two technologies has been considered as a doable option for the realization of the fourth generation (4G) network [2]. However, this convergence raises several challenges especially when seamless session continuity is required [3]. Since the WiMAX

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and WLAN networks have different protocol architectures and QoS support mechanisms [4], protocol adaptation would be required for their interworking. In addition, to ensure consistent user experience across heterogeneous wireless networks, the main challenge is to provide end-to-end QoS and to optimize transmission to and among end users [13]. In this paper, we propose a heuristic contention resolution mechanism in WiMAX/WLAN networks to improve the QoS.

Heterogeneous WiMAX network consists of various nodes namely WiMAX base station (BS), WiMAX/WLAN gateway (WWG) and subscriber stations (SS) with WLAN and/or WiMAX interface. The two main operations carried out by the SS and WWG are ranging and bandwidth request. The two types of bandwidth request mechanism specified in 802.16 standards are unicast polling (contention free access) and contention resolution [5]. Although access delay is very less in the case of polling mechanism compared to contention resolution, the former suffers from low bandwidth utilization and polling overhead [6]. In contention resolution, the SS contends for transmission opportunity (TxOP) to perform bandwidth request. If the SS is successful in obtaining the TxOP, then it proceeds in sending the bandwidth request. If unsuccessful, it undergoes single stage contention resolution (SSCR) with TBEB. In the case of heterogeneous networks, there is no guarantee that the WWG will acquire its TxOP over specified time as it contends for resource with WiMAX SS. This results in longer waiting time and increased collision. Hence, the challenging task is to design an efficient contention resolution mechanism, which reduces the access delay and improves the throughput of the system. Hence, the WWG in heterogeneous WiMAX networks suffer from fairness as since it serves many SS (WLAN and/or WiMAX). In addition, in the proposed system we consider WWG as an alternative to WiMAX relay stations to extend connectivity in terms of data rate and coverage.

In literature, many backoff mechanisms are proposed for wired and wireless systems. We briefly review some related works that are pertaining to wireless systems. Yang et al. [7] have proposed a wireless medium access control (MAC) protocol using implicit pipelining that derives the idea of dual stage contention resolution (DSCR) for WLAN systems and considered binary exponential backoff at both the stages. Fallah et al. [8] have made excellent discussions on the issues of TBEB and its performance analysis in WiMAX networks. Kwak et al. [9] have proposed EIED based contention resolution mechanism for initial ranging in WiMAX networks. Song et al. [10] introduced the concept of EIED for WLAN networks. Chunxuan Ye et al. [11] derived an analytical model to evaluate the performance of EIED. To the best of our knowledge, no work has been carried out with EIED backoff for bandwidth request in WiMAX. In this paper, we propose a heuristic contention resolution with multistage EIED backoff to increase the contention efficiency of WWG in heterogeneous WiMAX networks.

The rest of the paper is organized as follows: MSCR with EIED backoff for heterogeneous WiMAX network was presented in Section II. The simulation results are shown in Section III and concluding remarks is given in Section IV.

2. Proposed multistage contention resolution in heterogeneous WiMAX system

In heterogeneous WiMAX networks, during uplink transmission (form SS to BS or WWG to BS) the station has to acquire its transmission opportunity for data transmission. The main challenge in designing the backoff mechanism is to avoid overlapping between the stations backoff counters else, it results in collision. An efficient design of contention resolution, improves the probability of transmission but the probability of success in WiMAX depends only if the BS has enough bandwidth to accept the request. Collisions may occur during initial ranging and bandwidth request intervals in the uplink subframe. Since we considered the effect of bandwidth request alone we assume that initial ranging have been carried successfully. In the proposed system, the SS have only single active uplink service flow with equivalent single connection identifier. Hence, the request decision is made only for per connection identifier or per service basis.
In the proposed system, we exclude the impairments due to channel. The problem with the existing heterogeneous network is the SS that has direct connectivity with the BS undergoes single stage contention resolution. The SS that has WLAN connectivity and WiMAX MS that is out of coverage with BS transmits data through WWG. Thus the contention resolution by these stations is carried out in two stages namely from SS to WWG and WWG to BS. This reduces the QoS of the network as the end user through WWG suffers from high probability collision, waiting time and possible unavailability of bandwidth during the second stage (form WWG to BS). One may think of prioritizing the gateways or assigning residual bandwidth to WWG. However, both the techniques suffer from low bandwidth utilization. This motivated in designing multi stage EIED that reduces the possibility of collision between WWG and SS during contention resolution. The MSCR does not increase the waiting time of the SS since the initial value and final value of contention window remains the same. However, the TxOP can be allocated only when the SS successfully contends in both the stages.

![Fig. 1. Simulation scenario of proposed heterogeneous system with WiMAX as backhaul network](image)

The MSCR used in WLAN systems [7] uses binary exponential backoff (BEB) algorithm that differs from the proposed scheme that uses EIED backoff in WiMAX. In addition, the random access mechanism of WiMAX network is much different from that of WLAN system that the former uses backoff without carrier sense and latter uses carrier sense multiple access with collision avoidance (CSMA/CA). Since carrier sensing was not used by WiMAX stations, the SS does not freeze its backoff decrement if another station is transmitting. This motivates in using MSCR that introduces the concept of pipelining implicitly into the proposed system. The heterogeneous WiMAX network used for simulation is shown in Fig. 1.

The target applications considered in this paper for contention resolution are heavy loaded hypertext transfer protocol (HTTP) and file transfer protocol (FTP) [12]. SS_WiMAX_WLAN_AP in Fig. 1 correspond to the WWG in the proposed system. The introduction of MSCR in the proposed system makes the gateways (WWG) to undergo less collision than the conventional system. Since the gateway serves large number of SS (both WiMAX and WLAN), the throughput of the system is improved. Compared with the previous works, our method is more flexible and provides better performance over a wider range of contending stations.
The contention process in WiMAX network is not started until uplink channel descriptor (UCD) is received. The maximum time between the transmissions of two consecutive UCD messages is 10s. The BS must transmit UCD message at a periodic interval in order to define the characteristics of an uplink physical channel. The UCD message present in downlink subframe contains uplink transmit parameters and it is broadcasted by the BS. The choice of the request backoff start and the request backoff end by the BS, gives much flexibility in controlling the contention resolution. The MS in the proposed system has the flexibility to switch over from one contention mechanism to other by referring the value in channel quality information (CQI) channel. The WiMAX BS has the flexibility of accepting the SS CQI Period or it will assign a period of its own. With more WWG, the BS will assign the CQI period and if the period is set to one then the SS undergoes MSCR and conventional TBEB algorithm on receiving zero.

The contention resolution algorithm works as follows. When an SS has information to send and wants to start the contention resolution process, it sets its internal backoff window equal to the request initial backoff window defined in the UCD message. The SS randomly selects a number within this backoff window. The obtained random value indicates the number of contention transmission opportunities that the SS will defer before transmitting. An SS considers only the contention transmission opportunities for which this transmission would have been eligible. The SS transmits its bandwidth request when its backoff counter reduced to zero. If the SS does not receive any response from the BS after a specific duration of time, it assumes loss of request and starts it backoff with TBEB algorithm. The number of stages is two in the proposed system to limit channel waiting time and queuing delay.
The operation of contention resolution with EIED backoff is shown in Fig.2. The SS starts its backoff mechanism by entering into the first phase of contention resolution. The $CW_1_{\text{min}}$ and $CW_1_{\text{max}}$ denote the minimum and maximum contention window respectively at stage 1 and the values are mapped from the initial backoff start and end values broadcasted from the BS. The performance of EIED backoff algorithm depends on the value of $n$ and $M$. Hence, the SS is made to tune its values based on its current traffic load. The next major effort is the calculation of increment and decrement backoff factor based on the values of $n$, $M$, $CW_1_{\text{min}}$ and $CW_1_{\text{max}}$. The value of $n$, $M$ is chosen such that the SS undergoes stage 1 backoff with less waiting time.

The system starts its backoff by computing the value of backoff counter. The backoff counter at phase 1 in the proposed method is calculated with minimum value contention window and the number of gateways in the network. If the number of gateways in the network increases then the SS has to wait for a long time and vice versa. Hence, the system is made to adapt with the number of gateways in the heterogeneous network. On every successful transmission, the value of the contention window (CW) is incremented by $R_i$ and with unsuccessful transmission the SS decrements its value by $R_d$. The dynamic tuning of CW based on $R_i$ and $R_d$ makes EIED to perform better than the traditional TBEB algorithm. Since the SS undergoes dual stage contention resolution, the stations enter stage 2 only when the backoff counter at stage 1 reaches zero. At the end of stage 1 only few SS that won at stage 1 enters stage 2. This reduces the possibility of collision with the gateway.

The phase 2 begins with setting of $CW_2_{\text{min}}$ and $CW_2_{\text{max}}$, where $CW_2_{\text{min}}$ and $CW_2_{\text{max}}$ denote the minimum and maximum contention window respectively at stage 2. The value of $CW_2_{\text{min}}$ and $CW_2_{\text{max}}$ is set to half the $CW_1_{\text{min}}$ and $CW_1_{\text{max}}$. At stage 2 the backoff counter is calculated only with minimum value of contention window and not with number of gateways. The SS at stage 2 competes for BR along with the gateways. Hence, the WWG is affected with lesser number of stations in stage 2 that in turn increases the transmission opportunity. When the backoff counter reaches zero at stage 2, the SS successfully obtains the TxOP and transmits the BR. On successful BR, the SS transmits its data. On successful transmission at stage 2, if the current station load is greater than the predefined threshold value then it remains in stage 2 else it enters stage $1$. The maximum backoff value in both stages is set to 5 in the proposed system. In addition, the number of retries is set to 16 and the station drops its data when it reaches maximum number of retransmission.

3. Performance evaluation

To evaluate the performance of the WiMAX/WLAN based heterogeneous system, numerous end-to-end simulations were conducted. The OPNET 14.5 simulator is used for evaluation. The simulations are carried out by making suitable modification at the MAC layer. At the MAC layer, the modifications are made only to the contention resolution process and other operations are left as system default. The configuration parameters used for the simulation are listed in Table 1.

3.1 Simulation platform

The OPNET 14.5 model supports the IEEE 802.11 and IEEE 802.16 standards. It evaluates custom algorithms for WiMAX/WLAN base and subscriber stations for different MAC and PHY layer profiles. The nodes in the network are configured with FTP and heavily loaded HTTP model. The primary application being targeted is wireless web browsing. To support best effort traffic, the start time offset has been set to uniform distribution with minimum outcome 5 and maximum outcome of 10. The duration of web browsing has been set to end of profile. Also the inter repetition time has been set to exponential distribution with a mean outcome of 300. The number of repetitions has been set to unlimited and the repetition pattern is serial. HTTP traffic can increase the data rate up to channel capacity by transmission control protocol (TCP) congestion control mechanism.
Table 1. Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplexing</td>
<td>Time division duplex</td>
</tr>
<tr>
<td>Base frequency (GHz)</td>
<td>5.8</td>
</tr>
<tr>
<td>Bandwidth (MHz)</td>
<td>20</td>
</tr>
<tr>
<td>Number of stations</td>
<td>45</td>
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<tr>
<td>Frame duration (ms)</td>
<td>5</td>
</tr>
<tr>
<td>Symbol duration (us)</td>
<td>100.8</td>
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<tr>
<td>UL subframe size (symbols)</td>
<td>12</td>
</tr>
<tr>
<td>Number of subcarriers</td>
<td>2048</td>
</tr>
<tr>
<td>Number of data subcarriers</td>
<td>1120</td>
</tr>
<tr>
<td>Number of subchannels</td>
<td>70</td>
</tr>
<tr>
<td>Usage mode</td>
<td>Partial usage of subchannels</td>
</tr>
<tr>
<td>Platform</td>
<td>Opnet 14.5</td>
</tr>
</tbody>
</table>

3.2 Observations

From Fig. 3(a), we can notice that the access delay of the proposed (EIED with MSCR) system performs better than the conventional TBEB for bandwidth request. The average access delay is 0.034s for the conventional system and 0.023s for the proposed system. Although EIED with MSCR introduces waiting time at the WiMAX SS, it substantially reduces the overall access delay by 35.29%. Such reduction is critical for web browsing application and it result in faster loading of web pages at the SS. The improvement of the access delay can be seen in the enhancement of the throughput. This delay can further be reduced with aggregated bandwidth request.

![Fig. 3. (a) Uplink access delay with best effort traffic; (b) Queuing delay with best effort traffic](image)

The queuing delay between conventional and proposed method is appreciated in Fig. 3(b). The reduction in queuing delay is due to the result of reduced access delay and number of retransmission attempts. The average queuing delay with the conventional system is 0.015s and 0.011s for the proposed system. Although, there is no delay guarantee specified in WiMAX standard for BE traffic, if the queuing delay is not addressed, it would degrade the performance of the application. The proposed system shows
an improvement of 26.67% than conventional system. By reducing the waiting time of the stations with MSCR, the queuing delay can further be improved. Nevertheless, we have considered the trade off between the collision and waiting time. With reduced collision between WWG and WiMAX SS, the overall throughput in heterogeneous WiMAX network is improved. This provides fairness to SS that route packet through WWG. This in turn makes the system resilient to data dropping due to buffer overflow.

The Fig. 4(a) compares the throughput of heterogeneous WiMAX networks with contention based BW request methods. The performance of the network was evaluated under error-free channel conditions. Hence, the source of packet failure is due to unavailability of bandwidth or collision of packets during contention. From the graph, it is seen that, for the system with TBEB mechanism, the system throughput is 3.4 Mbps. However, with EIED based on MSCR the throughput of the system increases up to 5.7 Mbps, under same network conditions. This throughput reduction in conventional system is because the collisions occur more frequently between the WWG and WiMAX SS. However, the system with MSCR allows fewer stations to compete with each other that result in fewer collisions. Thus, the throughput performance is improved with large number of stations and the proposed system shows a performance improvement of 66.65 %.

![Graph showing throughput comparison](image)

Fig. 4. (a) Throughput with best effort traffic; (b) Retransmission attempts made by WWG

The proposed system benefits when the number of WWG in network is growing in numbers. The next generation wireless networks will have more wireless gateway nodes and hence the risk of collisions becomes high. Hence, under such circumstances the MSCR is recommended. On the other hand, with homogeneous WiMAX system (in the absence of WWG), MSCR is not recommended. Fig. 4(b) shows the performance of system in terms of its retransmission attempts. The proposed system with MSCR has fewer retransmission attempts because the system with MSCR reduces collision due to contention for TxOP. The proposed system shows an improvement of 37.93 % then the conventional system.
Table 2. Performance comparison of existing and proposed systems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional System (TBEB with SSCR)</th>
<th>Proposed System (EIED with MSCR)</th>
<th>Improvement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access delay (s)</td>
<td>0.034</td>
<td>0.023</td>
<td>35.29</td>
</tr>
<tr>
<td>Queuing delay (s)</td>
<td>0.015</td>
<td>0.011</td>
<td>26.67</td>
</tr>
<tr>
<td>Throughput (Mbps)</td>
<td>3.4</td>
<td>5.7</td>
<td>67.65</td>
</tr>
<tr>
<td>Retransmission attempt (packets)</td>
<td>0.058</td>
<td>0.036</td>
<td>37.93</td>
</tr>
</tbody>
</table>

The performance comparison of the proposed MSCR based EIED backoff with that of conventional TBEB is shown in Table 2. Thus, the proposed MSCR with EIED backoff is efficient with heterogeneous WiMAX networks. That is the network with many WWG’s. In near future the gateways were expected to be mobile and will grow in numbers per cell. In addition, the next generation stations can be updated with simple software upgrade. Hence, the proposed contention resolution can be upgraded and operates as an alternative to the convention TBEB algorithm.

4. Conclusion

This paper proposes a heuristic multistage contention with EIED backoff for bandwidth request in heterogeneous WiMAX networks. The proposed method allows WiMAX SS to perform contention in two stages and resolves possible collision with WWG due to contention. The EIED was chosen to control the backoff factor on collision and success so that it will reduce the waiting time introduced during multistage contention. The proposed method achieves better performance without prioritizing the gateway either by assigning residual bandwidth or with polling technique. The results of the proposed method was compared in accordance with the conventional TBEB algorithm with SSCR and the simulation results conclude that the proposed contention resolution shows an improvement in QoS of the system in terms of throughput and delay. The deployment of the proposed architecture allows users to switch seamlessly between WiMAX and WLAN networks and continue their network access for mobile Internet applications.

References


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