Investigation on IEEE 802.16m Networks under Developed Error Model

Rajesh Anbazhagan
Department of Electronics Engineering,
Pondicherry University,
Puducherry, 605 014, India

Nakkeeran Rangaswamy
Department of Electronics Engineering,
Pondicherry University,
Puducherry, 605 014, India

ABSTRACT
Contention based bandwidth request mechanism is suggested for best effort services in WiMAX networks. The design of contention mechanism depends on the error model that reflects the transmission failure. In this paper, we have developed an error model by integrating the collisions due to contention, unavailability of bandwidth and channel error. The conventional exponential increase and exponential decrease (EIED) backoff witnessed low contention efficiency and high access delay with the proposed error model. Hence, we modify the EIED scheme by computing the backoff factors with average contention window and estimating the response time to reduce the waiting time of stations. The performance of WiMAX network is studied with varying number of stations, error rates and the number of slots allocated for bandwidth request. The effectiveness of the developed model is validated by means of simulation results.

Keywords
Contention resolution, medium access control, WiMAX, EIED backoff, bandwidth request.

1. INTRODUCTION
Rapid growth of wireless multimedia services for residential and business customers has created an increasing demand for last mile broadband access. Worldwide interoperability for microwave access networks (WiMAX) has recently emerged to provide last mile broadband wireless Internet connectivity and/or backhaul support. In WiMAX network, the two nodes of interest are base station (BS) and mobile stations (MS's). The network topology follows mandatory point to multipoint (PMP) architecture. The two main operations carried out by the MS are ranging and bandwidth request. The MS executes bandwidth request during uplink channel access (from MS to BS).

The types of bandwidth request mechanism specified in 802.16m standards are polling (contention free access) and contention resolution. Although multiple physical layers are specified in WiMAX standard [1], orthogonal frequency division multiplexing (OFDM) air interface with time division duplexing (TDD) based system design is considered with time division multiple access (TDMA) in uplink subframe and time division multiplexing (TDM) in downlink subframe. The ranging and bandwidth request slots used for contention resolution is found in the uplink subframe.

The contention resolution with truncated binary exponential backoff (TBEB) suffers from low contention efficiency and high access delay. In contention access, the MS contends for transmission opportunity (TxOP) to execute bandwidth request. If the MS is successful in obtaining the TxOP, then it proceeds in transmitting the bandwidth request. If unsuccessful, it undergoes TBEB mechanism. In TBEB, the MS doubles the contention window up to maximum contention window on collision and the backoff window is set to minimum contention window on success. Thus, the backoff process in TBEB is linear with constant backoff factor.

In WiMAX networks with TBEB based contention resolution, the MS's transmit bandwidth requests in random slots to reduce the probability of collision. However, the constant backoff factor increases the probability of collision if two or more stations select the same backoff slot. If the MS reaches the maximum retransmission limit, then it drops the packet. Hence, an effective contention mechanism is required to improve the contention efficiency and access delay of the WiMAX network. To overcome these limitations, exponential increase and exponential decrease (EIED) based backoff is considered for bandwidth request.

The advantage of choosing EIED over TBEB is varying backoff factor that introduces non-linearity in contention resolution. Further, in this paper, the backoff factor in EIED is made as a function of average contention window. Another main challenge in contention resolution mechanism is that, there is no guarantee for the MS to acquire its TxOP with fixed response time (T_r) and hence prone to increase the access delay. The response time is the time over which the MS waits for response from BS after bandwidth request. The response time in conventional systems is constant and it depends on the frame duration. This motivated us in computing the response time and in this paper, we estimate the response time based on the developed error model.

The rest of the paper is organized as follows: Related works on bandwidth request mechanism in WiMAX network is presented in Section 2. The developed analytical model is explained in Section 3. Simulation results are shown in Section 4 and concluding remarks is given in Section 5.

2. RELATED WORKS
In literature, there are excellent discussions on the issues on contention resolution mechanism and its performance for wireless systems. In this section, we review the work related to WiMAX systems. Qiang et al [2] made detailed discussions on the issues of TBEB and its performance. Yaser et al [3] calculated the number of slots with TBEB until the end of current contention period. Byung et al [4] suggested EIED contention resolution mechanism in WiMAX networks for initial ranging (IR). Amir et al [5] proposed bandwidth allocation to support heterogeneous traffic with different QoS requirements in WiMAX networks. Young et al [6] analyzed an adaptive polling scheme for real-time gamming traffic in IEEE 802.16 (WiMAX) networks.

Several researches [7-10] carried out contention resolution with TBEB. To the best of our knowledge in WiMAX network, no work has been carried out with EIED backoff for bandwidth request. In addition, the literatures available on this topic do not explain any mechanisms to force the MS's to implement a backoff factor with adaptive contention window size and response time based on current channel status. Further, in this paper, we developed a unified error model for WiMAX network. The error models in [2] and [3] account for collision with either unavailability of bandwidth or channel error. Hence, we proposed an error model by including the three events that cause the transmission failure.

3. CONTENTION RESOLUTION WITH DEVELOPED ERROR MODEL

This section explains the design of contention resolution mechanism with EIED based backoff for WiMAX systems. The main challenge in designing the backoff mechanism is to avoid overlapping among the backoff counters with reduced channel idle time. In the proposed scheme, the overlapping of backoff counter is reduced by setting the backoff factor adaptive with average contention window. The channel waiting time is reduced by estimating the response time. Thus, the proposed design of contention resolution improves the probability of transmission of bandwidth request but the probability of success in WiMAX depends on the availability of enough bandwidth with BS to accept the request.

3.1 Proposed Integrated Error Model

The probability of failure of the WiMAX system can be characterized by three possible events namely: collisions due to contention, unavailability of bandwidth and channel error. Let, P_f denotes the probability of failure; P_e denotes the probability of error due to channel, P_c denotes the probability of collision due to contention, q denotes the probability of BS to accept a bandwidth request and T_r denotes response time or waiting time. Qiang et al [2] modeled the probability of failure with collision and channel error. According to them, it is given by:

$$P_f = P_c + P_e - P_c\,P_e \quad (1)$$

Yaser et al [3] modeled the probability of failure with collision and unavailability of bandwidth and hence it is given by:

$$P_f = P_c + \left(1 - P_c\right)\left(1 - q\right)^{T_r} \quad (2)$$

In WiMAX systems, the BS will not send any negative acknowledgement to the MS about their transmission failure. Hence, if the MS does not receive the bandwidth grant within their fixed response time then it assumes transmission is failed. The change in contention window size will not result in successful transmission when packet loss is due to unavailability of bandwidth and/or noisy channel condition. However, the authors [2] and [3] have not modeled their system with all possible events of transmission failure. Hence, in the proposed system the contention window is set by accounting above said three events while modeling contention resolution at medium access control (MAC) layer. Hence, the probability of failure (P_f) in the proposed system is given by:

$$P_f = P_c + \left(1 - P_e\right)\left(1 - P_c\right)\left(1 - q\right)^{T_r} + P_e \quad (3)$$

Equation (3) is developed by assuming that the three events are mutually exclusive. An illustration of P_f in emerging WiMAX networks is shown in Fig. 1. The contention resolution with conventional EIED reduces the contention efficiency and increase the access delay of the system. This motivated us to consider a more efficient backoff by computing the average contention window with EIED backoff and vary the backoff factors with the calculated contention window. In addition, with fixed response time, the system has to wait for a long time before it starts its retransmission. Hence, in the proposed system, we compute the response time dynamically.

3.2 Estimation of Backoff Factor and Response Time

In the proposed system, with EIED backoff algorithm, the contention window size is exponentially decreased by a backoff factor δ_D for every successful transmission (collision), and is exponentially increased by a backoff factor δ_I for each unsuccessful transmission. The value of δ_I and δ_D assumed to be constant in conventional EIED and it depends on the CW_{min}, CW_{max}, M, and n. The CW_{min} and CW_{max} correspond to minimum and maximum contention window size and, M and n are integers. The δ_I, δ_D, CW_{min}, and CW_{max} are related as $CW_{\max} = \left(\delta_I\right)^M\ CW_{\min}$ and $\delta_I = \left(\delta_D\right)^n$. In the proposed model, δ_I and δ_D are calculated based on average contention window$\left(\overline{W}\right)$.

The resultant backoff factors follow $\delta_I = \left(\overline{W}\right)^{\wedge\frac{1}{M}}$ and $\delta_D = \left(\overline{W}\right)^{\wedge\frac{1}{(M\times n)}}$. Hence, the MS compute the value of δ_I and δ_D and reset their contention window size. It should be noted that the MS calculate the average contention window by referring the maximum backoff stage 'm'. The average value of contention window is calculated as follows:

$$\overline{W} = \sum_{i=0}^{m-1} W_i\, P\left(W_i\right) \quad (4)$$

The W_i with EIED is given by,

$$W_i = W\ \delta^i \quad (5)$$

where δ corresponds to initial backoff factor and W is the size of current contention window. Further, the probability of events can be stated as probability of the corresponding values of contention window. Hence, $P\left(W_i\right)$ is formulated as follows,

$$P\left(W_i\right) = P\,P_f^i \quad (6)$$

where P is the probability of transmission. Substituting (5) and (6) in (4), the $\overline{W}$ is given by,

$$\overline{W} = \sum_{i=o}^{m-1}\left(W\,2^i\right)\left(P\,P_f^i\right) \quad (7)$$

$$\overline{W} = W\,P\sum_{i=o}^{m-1}\left(2^i\right)\left(\ P_f^i\right) \quad (8)$$

Representing the probability of transmission (P) in terms of probability of failure (P_f) and solving further, the average contention window with EIED is derived as follows,

$$\overline{W} = W\ \frac{\left(1 - P_f\right)}{\left(1 - P_f^m\right)}\ \frac{\left(1 - \left(\delta P_f\right)^m\right)}{\left(1 - \delta P_f\right)} \quad (9)$$

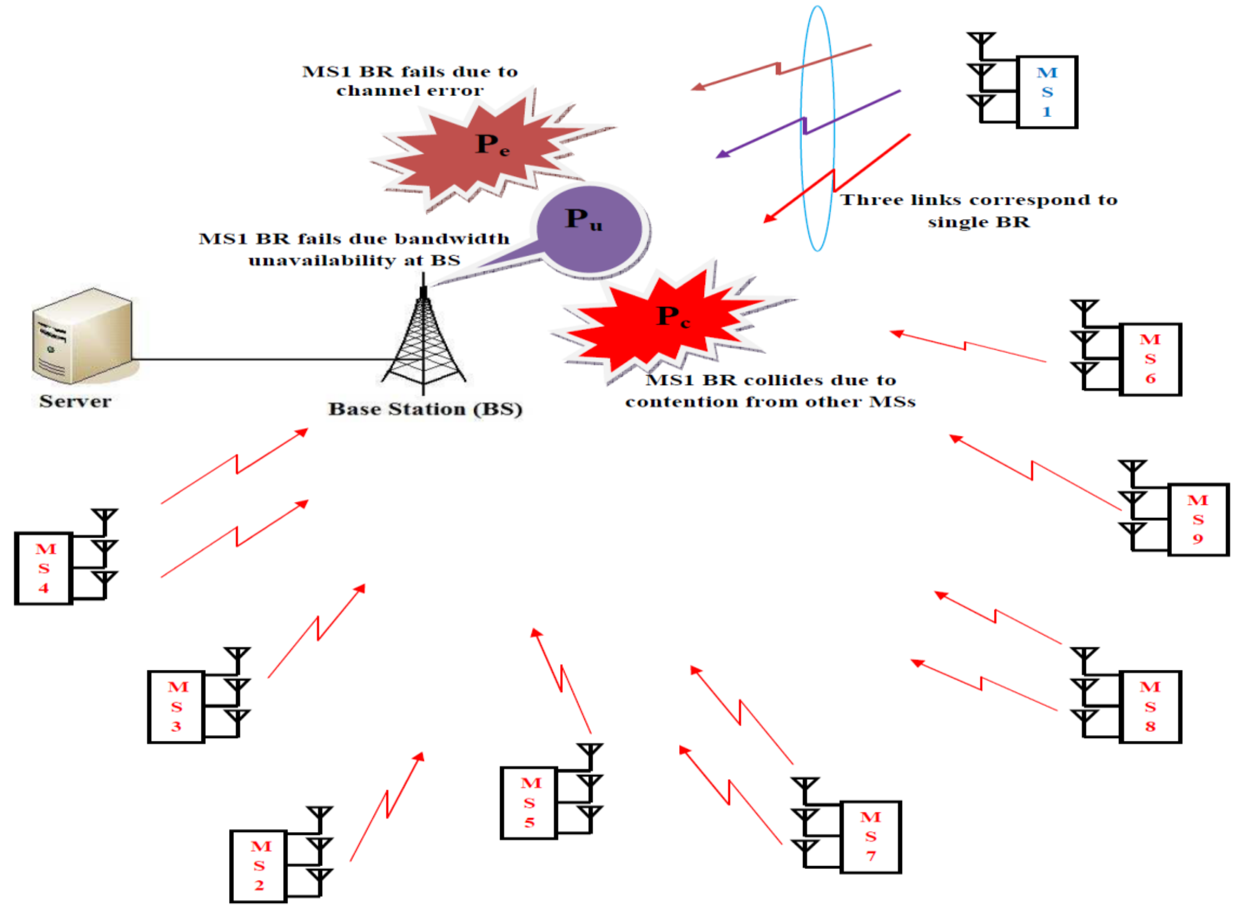

Fig 1: An illustration of probability of failure of three events during contention bandwidth request (BR)

The increment and decrement backoff factors are updated with the average contention window derived in (9). The system with varying backoff factors alone is not sufficient in improving the network performance. Therefore, we proceed in estimating the response time dynamically as it is kept constant in conventional systems. With best effort services as the prime target considered in this paper, the probability of transmission is modeled with geometric distribution [11]. The geometric distribution is modeled with average value of contention window and is given by the expected value of random process. Hence, the probability of transmission (P) with the average contention window becomes, P $=2/\overline{W}$ and is given by,

$$P=\frac{2\left(1-P_f^m\right)\left(1-\delta P_f\right)}{W\left(1-P_f\right)\left(1-\left(\delta P_f\right)^m\right)} \tag{10}$$

The probability of collision (P_c) is the conditional probability that collision occurs when any of the 'N-1' station transmits when the station 'N' is transmitting and it is expressed as follows,

$$P_c=1-\left(1-\frac{2\left(1-P_f^m\right)\left(1-\delta P_f\right)}{W\left(1-P_f\right)\left(1-\left(\delta P_f\right)^m\right)}\right)^{N_c-1} \tag{11}$$

The response time can be expressed in terms of P_e, Pc, q and number of contending stations (N_c). Since the events causing the transmission failure are assumed as independent, the T_r from (3) can be expressed as follows,

$$\left(P_f-P_c-P_e\right)=\left(1-P_e\right)\left(1-P_c\right)\left(1-q\right)^{T_r} \tag{12}$$

$$T_r\log\left(1-q\right) = \log\left(P_f-P_c-P_e\right)/\left(1-P_e\right)\left(1-P_c\right)$$

(13)

$$T_r=\frac{\log\left[\frac{P_f-P_c-P_e}{\left(1-P_c\right)\left(1-P_e\right)}\right]}{\log\left(1-q\right)} \tag{14}$$

Expressing P_c in terms of $\overline{W}$ and substituting (11) in (14), the T_r is given by,

$$T_r=\frac{\log\left[\frac{P_f-\left(1-\left(1-\frac{2}{\overline{W}}\right)^{N_c-1}\right)-P_e}{\left(\left(\frac{2}{\overline{W}}-1\right)^{N_c-1}\right)\left(1-P_e\right)}\right]}{\log\left(1-q\right)} \tag{15}$$

The contention efficiency (P_s) is the probability that a transmission opportunity containing a successful bandwidth request. The P_s in the proposed system is computed by accounting the channel error and hence it can be expressed as follows,

$$P_s = N_c\, P(1-P)^{N_c-1}(1-P_e)\left(1-(1-q)^{T_r}\right) \quad (16)$$

The access delay is defined as the ratio of the total number of contending stations to the product of available transmission opportunity and contention efficiency. It means that the average number of frames the MS will receive the response from BS. Hence, the access delay (D) is given as follows,

$$D = N_c / (TxOP\ x P_s) \quad (17)$$

The contention efficiency reflects how efficient a MS in acquiring the channel. Increase in throughput of the system and reduction in access delay are observed with increase in contention efficiency. Further, the access delay reduces the end-to-end delay of the system. Hence, we have calculated the parameters (contention window and response time) dynamically in the proposed contention resolution process.

4. SIMULATION RESULTS

To evaluate the performance of the WiMAX system with proposed bandwidth request scheme, simulations are conducted using Matlab 2010a simulator. The simulation results are obtained by averaging over 15 runs and each run has 10^5 iterations. The simulations are carried out by modeling the contention resolution process with EIED for WiMAX. The MAC parameters are configured in accordance with the standard discussed in [1]. In this section, the contention efficiency and access delay of the system are studied using the developed analytical model.

In our analysis, frame duration is chosen to be 2 ms, the number of contention slots within a physical frame for bandwidth request is chosen as 16, initial contention window is set to 8, maximum number of backoff stage is 10 and the total number of stations is 75. The efficiency of contention access is computed by varying the contending stations for different values of q, namely 0.25, and 0.60. The performance of the system is evaluated under error prone channel conditions. The error rates chosen for simulation are 25% and 50%. Fig. 2 illustrates the contention efficiency of WiMAX networks with contention based bandwidth request methods. The performance of the network is evaluated under 25% channel error conditions.

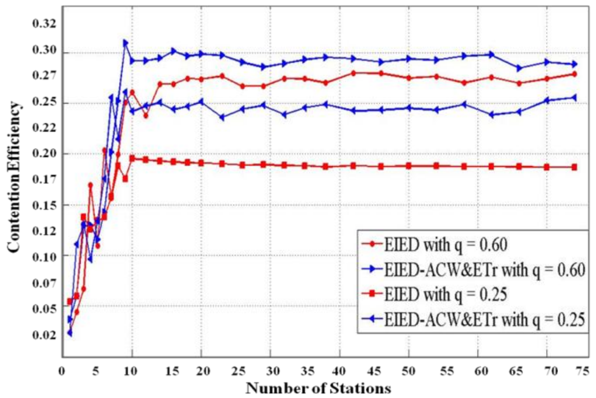

Fig 2: Contention efficiency under varying number of contending stations with 25% channel error.

Fig. 2 reveals the EIED based bandwidth request mechanism with and without average contention window and response time. From the simulation, it is understood that the system with EIED mechanism and q equal to 0.60 and 0.25, the contention efficiency is 0.2648 and 0.1879 respectively. However, with EIED based on average contention window and estimated response time the contention efficiency of the system increases to 0.2935 and 0.2352, under same network conditions (25% channel error). This efficiency reduction in conventional system is because of fixed values of response time and backoff factors.

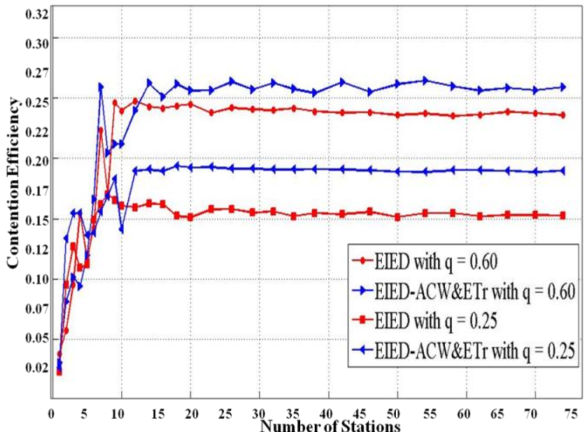

Fig 3: Contention efficiency under varying number of contending stations with 50% channel error.

The system with adaptive EIED allows stations to improve the contention efficiency by reducing the channel waiting time. The system shows an improvement of 11.51 % and 25.17% for 0.60 and 0.25 respectively when number of stations equals to 50. Fig. 3 shows the performance of WiMAX system with 50% channel error. The system with EIED backoff and varying q, the contention efficiency is 0.2357 and 0.1583. The contention efficiency of the system increases to 0.2612 and 0.1890 with adaptive EIED. The proposed system performs better than the conventional system with an improvement of 10.81% and 19.39% when q equal to 0.60 and 0.25 respectively.

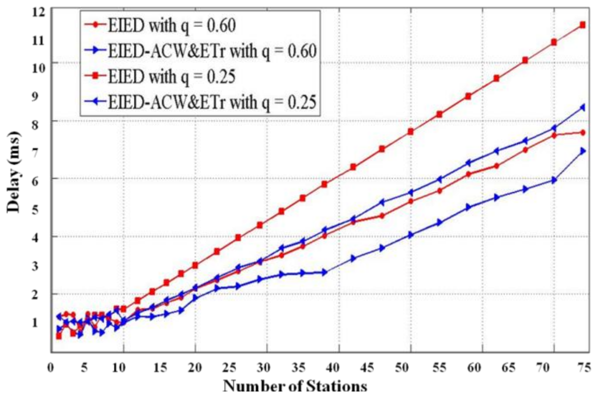

Fig 4: Access delay under varying number of contending stations with 25% channel error.

The access delay of the WiMAX system is simulated in Fig. 4 with 25% channel error. The access delay denote the duration over which the MS waits to receive the response from the BS after sending the bandwidth request. The reduction in access delay is due to the result of reduced number of retransmission attempts that comes from the estimation of response time. The access delay of the system with EIED is 5.1283 ms and 7.6043 ms for 0.60 and 0.25 respectively. The delay is reduced to 4.2386 ms and 5.5053 ms with adaptive EIED. The proposed system shows an improvement of 17.34% and 27.60% than conventional system.

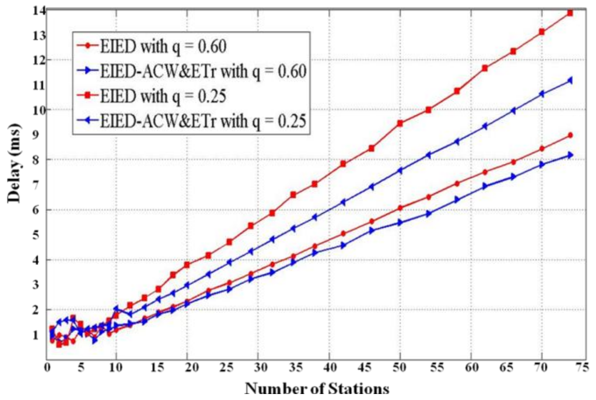

Fig 5: Access delay under varying number of contending stations with 50% channel error

Although, there is no delay guarantee specified in WiMAX standard for BE traffic, if the access delay is not addressed, it would degrade the performance of the system. With reduced access delay between MS and BS, the overall contention efficiency in WiMAX network is improved which in turn improves the throughput of the system. The simulation is repeated with 50% channel error and the access delay is computed as shown in Fig. 5. It is seen that, the system with EIED backoff and varying q, the delay is 6.0601 ms and 9.6402 ms. The delay reduces to 5.2693 ms and 7.3599 ms in the case of adaptive EIED.

The proposed system performs better than the conventional system with an improvement of 13.04% and 23.65% when q equal to 0.60 and 0.25. In the above discussions, the system with q=0.25 shows an improvement in performance than with q=0.60. This reveals that the proposed mechanism effectively computes the response time when the bandwidth availability is low. However, with increase in value of q, the failure due to bandwidth unavailability and the resultant collision due to contention are less significant. The major contribution of transmission failure in this case is channel error. The channel error can be reduced with proper modulation and coding techniques at physical layer which in turn improve the overall performance of the system.

5. CONCLUSION

In this paper, we have proposed a contention resolution mechanism using dynamic EIED backoff for IEEE 802.16m network, and developed an analytical model to evaluate its performance. The performance of the proposed EIED backoff has been evaluated under integrated error model with varying error rates. The results are compared with the existing EIED algorithm and the simulation results conclude that the proposed contention resolution shows an improvement in performance of the system in terms of contention efficiency and access delay.

6. ACKNOWLEDGMENTS

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