An Enhanced Election-Based Transmission Timing Mechanism in IEEE 802.16 Mesh Networks

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Abstract- IEEE 802.16, also known as the worldwide interoperability for microwave access (WiMAX), defines point-to-multipoint (PMP) and mesh modes to support wireless medium access. The mesh mode provides an easy and cheap way to construct the last-mile connection. The multi-hop environment with spatial reuse can use the radio resource more efficiently. IEEE 802.16 defines three kinds of scheduling algorithms without specifying the detail. In this paper, we propose a new enhanced election-based transmission timing mechanism to solve the problem currently on the coordinated distributed scheduling algorithm. According to the simulation results by using the network simulator ns2, the new mechanism can prevent the unexpected collisions of MSH-DSCH messages to gain better performance on time-sensitive traffic.
Keywords: IEEE 802.16, WiMAX, wireless medium access, scheduling algorithms

1. Introduction

The demand of broadband access is highly increased by the rapid growth of new services, such as voice over IP (VoIP), video on demand (VoD), online gaming, and peer-to-peer. It is a challenge to provide broadband access everywhere, hence wireless access technologies have become attractive solutions. Compared with the wired technologies such as HFC (hybrid fiber/coaxial) and DSL (digital subscriber line), the broadband wireless access (BWA) can be deployed easily with low cost regardless of the terrain layouts, and it is simple to add users by providing additional radio interface and capable link conditions[1][2]. IEEE 802.16, also known as the worldwide interoperability for microwave access (WiMAX), defines point-to-multipoint (PMP) and mesh modes to support wireless medium access [3]. In the PMP mode, the wireless link operates with a central base station (BS) to serve a group of subscriber stations (SSs) within the same antenna sector by broadcasting. All SSs receive the same transmission signal from BS within a given frequency channel, while BS coordinates all the transmissions from SSs to BS. On the other hand, SSs can communicate with each other directly without BS involved in the mesh mode.

To compete the transmission opportunities in the control subframe, the IEEE 802.16 standard proposes a pseudo-random election algorithm based on the scheduling information in the two-hop neighborhood. The coordinated distributed scheduling transmits its signaling packet by this election algorithm. However, IEEE 802.16 standard does not specify the detail of the competing method. [3][4] focus on adapting the holdoff time to improve performance of the election algorithm, but the scheduling information could still be inaccurate in the two-hop neighborhood. Ref. [7] proposes a new CF-CDS algorithm for both control and data subframe which can work under non-quasi-interference network environment, but it has to change the protocol format and wastes more overhead compared with the standard. [5] also proposes an extension of original election algorithm to solve the inaccurate information problem, but the extension does not really fix the situation. This paper proposed a modification on the extension to overcome the problem and examined its performance on ns2.

2. Enhanced Election-Based Transmission Timing (EEBTT) Mechanism

IEEE 802.16 EBTT mechanism is used to schedule the coordinated MSH-DSCH and MSH-NCFG messages in control subframe without explicit schedule negotiations [6]. This mechanism is supposed to be collision-free within each node's extended neighborhood. Moreover, it is completely distributed and needs no central control from BS.

Both original IEEE 802.16 EBTT and EEBTT can not completely avoid the possible collision on the MSH-DSCH messages from a node and its neighbors which are 2 hops far. We propose two modifications on the original IEEE 802.16 EBTT mechanism to solve the problem. First, *NextXmtMx* has to be modified to compensate the difference between Node K and Node J as Eq.(2). We can easily figure out that EEBTT's modified *NextXmtTimerInterval* can be earlier or later than the original one from Eq.(1), but with our new modification, the new *NextXmtTimeInterval* will always be earlier than or equal to the original one. Therefore, the length of *NextXmtTimeInterval* is not enough to contain all the *NextXmtTime* possibilities. To eliminate this limitation, we simply extend the length of *NextXmtTimeInterval* twice as Eq.(3). Since we can get the hop distance information in the MSH-NCFG messages to realize whether the neighbor is 2 hops far or not, the modifications should only apply to the neighbors that are 2 hops far, and the rest nodes remain unchanged.

$$2^{EXP_K} \cdot (MX_K - 1) < NXMT_k^{new} < 2^{EXP_K} \cdot (MX_K + 2) \tag{1}$$

$$MX_K^{\text{modified}} = floor\left(\frac{NXMT_K - XmtTime_J - 1}{2^{EXP_K}}\right) \tag{2}$$

$$2^{EXP} \cdot MX_K^{\text{modified}} < NXMT \le 2^{EXP} \cdot \left(MX_K^{\text{modified}} + 2\right) \tag{3}$$

[7] proposes Eq.(4) to calculate the number of slots S_K in which a node lost the election against the competing neighbors, where considers the neighbors which are 2 hops far as unknown. N_K^{known} represents the number of competing neighbors whose scheduling information is known to Node K and $N_K^{unknown}$ represents the number of competing neighbors whose scheduling information is unknown. In order to get S_K of the enhanced EBTT mechanism, let Δ denote the difference between the original beginning of *NextXmtTimeInterval* of Node K and the modified one that Node I estimates. Following the similar procedure as [7], assumed equal *XmtHoldoffExponent* in the network, we can get the probability that another Node I, which are two haps far from Node K, will compete with Node K in the given slot S_K=s and Δ_K=δ shown as Eq.(5), where μ = H + E[S_K] and p denotes the probability that a node wins a slot in enhanced EBTT mechanism. Since the difference Δ_K is uniform distributed in [0, L-1]. As in [7], we can approximates the number of compete node in the slot s M(s) shown as Eq.(6). Using Eqs.(5) and (6), after some manipulations, we get Eq.(7). Typically the last term in the second bracket of RHS is small enough to neglect, we can simplify Eq.(7) and get Eq.(8). Finally, the E[S_K] of the enhanced EBTT in this scenario can be expressed by Eq.(9).

$$E[S_K] = \sum_{J=1, J\neq K, EXP_J \ge EXP_K}^{N_K^{known}} \frac{2^{EXP_J} E[S_K]}{2^{EXP_J+4} + E[S_J]} + \sum_{J=1, J\neq K, EXP_J < EXP_K}^{N_K^{known}} 1 + N_K^{unknown} + 1 \tag{4}$$

$$P(\text{Node I competes with Node K} \mid S_K = s \,\&\, \Delta_K = \delta) \equiv P(Compete \mid S = s \,\&\, \Delta = \delta)$$
$$= \begin{cases} \dfrac{2L-\delta}{\mu} + \dfrac{1-(1-p)^{s+\delta}}{\mu p} & s \le 2L-\delta \\ \dfrac{s}{\mu} + \dfrac{(1-p)^{s-2L+\delta} - (1-p)^{s+\delta}}{\mu p} & 2L-\delta < s \le H-\delta \\ \dfrac{H-\delta}{\mu} + \dfrac{1-(1-p)^{s+\delta-H-1} + (1-p)^{s-2L+\delta} - (1-p)^{s+\delta}}{\mu p} & H-\delta < s \end{cases} \tag{5}$$

$$\frac{1}{p} \approx E_s[M(s)] = E_s[(N-1)P(Compete \mid S = s \,\&\, \Delta = \delta) + 1] \tag{6}$$

$$\frac{1}{p} = (N-1)\left(\frac{3L+1}{2\mu} + \frac{1}{\mu p} + \frac{-(1-p) + (1-p)^{L+1} + (1-p)^{L+2} - (1-p)^{2L+2} - (1-p)^{H-L+1} + (1-p)^{H+1}}{\mu L p^2 (2-p)}\right) \tag{7}$$

$$\frac{1}{p} \approx (N-1)\left(\frac{3L+1}{2\mu} + \frac{1}{\mu p}\right) + 1 \tag{8}$$

$$E[S_K] = \sum_{J=1, J\neq K, EXP_J \ge EXP_K}^{N_K^{1-Hop\_known}} \frac{2^{EXP_J} E[S_K]}{2^{EXP_J+4} + E[S_J]} + \sum_{J=1, J\neq K, EXP_J \ge EXP_K}^{N_K^{2-Hop\_known}} \left((N-1)\frac{3 \cdot 2^{EXP_J} + 2E[S_K] + 1}{2^{EXP_J+5} + 2E[S_J]}\right) + \sum_{J=1, J\neq K, EXP_J < EXP_K}^{N_K^{known}} 1 + N_K^{unknown} + 1 \tag{9}$$

3. Simulation Results

The network simulator ns2 [8] is used to realize the performance of our enhancements on EBTT. Thus we have developed a WiMAX mesh module for ns2 based on the IEEE 802.16 standard. The module is modified from the open source code of [9]. Four different EBTT mechanisms are compared in our simulation. The first one, termed as unaware, is the original IEEE 802.16 EBTT mechanism, and it treats all neighbors which are 2 hops far as unknown nodes. In opposite to the first one, all exact *NextXmtTime* of the neighbors in the two-hop neighborhood are known in the second mechanism, termed as aware. It should be the best mechanism compared with the others since it has the least competition probability. The third one is EEBTT; and the last one is our proposed enhanced EBTT. All scenarios are based on an equilateral grid network consists of 36 nodes. The distance between neighboring nodes is 275 meters, and the transmission range is 280 meters. The other simulation parameters are the frame length of 4ms, bandwidth of 10MHz, and simulation duration 100 seconds.

Fig. 1 shows the average competing nodes of four mechanisms with different *XmtHoldoffExponent*. Aware mechanism performs the best, and unaware mechanism performs the worst. Because the enhanced EBTT extends regular *NextXmtTimeInterval* twice, the enhanced EBTT performs a little worse than EEBTT while *XmtHoldoffExponent* is greater than three, but it still performs almost the same as EEBTT if *XmtHoldoffExponent* remains small. The interval between each DSCH message is the key factor to determine the access time of the control message. Fig. 2 is the results of the average DSCH messages interval with different *XmtHoldoffExponent*. In this figure, all four mechanisms perform almost the same. Since the DSCH messages interval is combined of *XmtHoldoffTime* and the number of the slots lost in the competition, the fact that *XmtHoldoffTime* increases exponentially by *XmtHoldoffExponet* makes the value of *XmtHoldoffTime* dominate the average DSCH messages interval. Fig. 3 is the error ratio of the DSCH messages caused by unexpected collisions. All mechanisms except EEBTT experience zero error ratio during the simulation. Although the error ratio of EEBTT is less than 0.5%, it still could have a significant impact on the time-sensitive traffic.

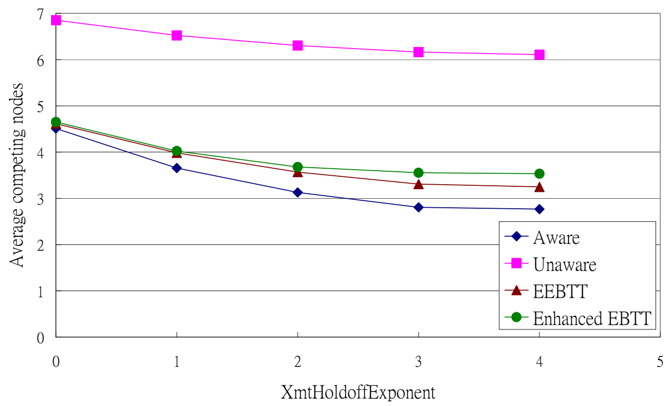

Fig. 1 Average competing nodes VS XmtHoldoffExponent.

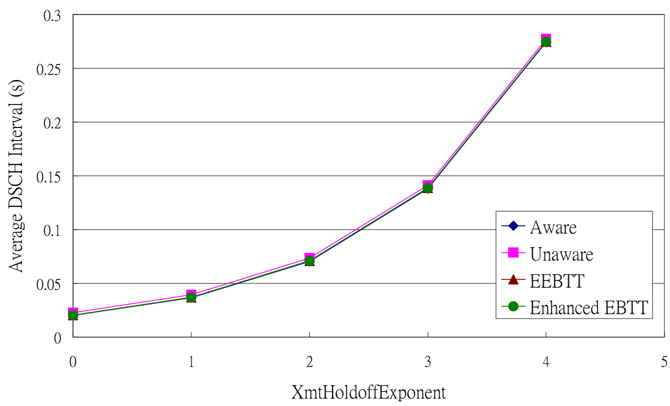

Fig. 2 Average DSCH Interval VS XmtHoldoffExponent.

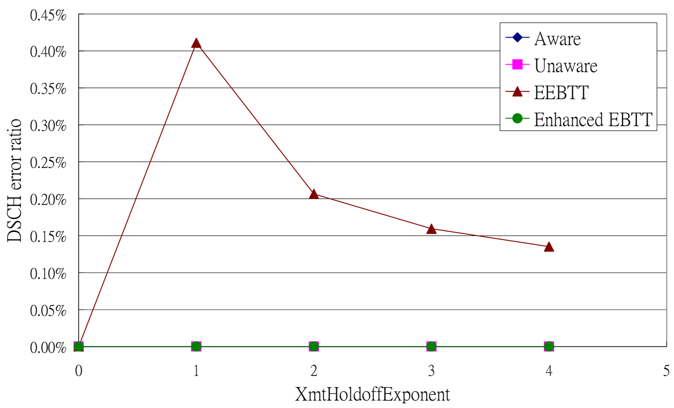

Fig. 3 DSCH error ratio VS XmtHoldoffExponent.

4. Conclusions

We describe the coordinated distributed scheduling algorithm of IEEE 802.16 and the control message transmission timing mechanism in this paper. We also state the problem that causes unexpected collision on the current mechanism. The enhanced EBTT mechanism is proposed to eliminate these collisions. The simulation results show that even the enhanced EBTT mechanism performs a little worse compared to EEBTT, it completely avoids colliding on the MSH-DSCH messages.

The future work will consider QoS by giving the higher priority nodes a better chance to transmit their MSH-DSCH. There are a few ways to achieve it. The topic about how to combine the centralized and distributed schedulings is also useful to guarantee QoS since it is not efficient to make a multi-hop connection via distributed scheduling, but it is also not suitable to do a neighboring node data switching via the centralized scheduling. The adaption of switching between the centralized and distributed schedulings is an interesting issue and remains unknown recently.

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