QoS Guarantee-based Fast Handoff in IEEE 802.16j WiMAX MMR Networks

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Abstract

The IEEE 802.16 standard, namely Wireless Metropolitan Access Network (WiMAX), adopts the Truncated Binary Exponential Backoff (TBEB) algorithm as the Contention Resolution Process (CRP) to solve the collision problem arisen from the Initial Ranging (IR) or Bandwidth Request (BR). But, it may bring two critical problems. First, WiMAX does not differentiate the contention backoff window ranges corresponding to different priorities of subordinate stations (SSs), and thus increases collisions in IR and BR. Second, although WiMAX uses different CW ranges for different types of service flow, the service flows with the same type uses the same minimum CW and thus increases collisions. This paper thus proposes a high efficient algorithm to minimize collisions in contention-based IR and BR; especially, it can be applied to IR, and thus reduce the handoff procedure delay in the IEEE 802.16j Mobile Multihop Relay (MMR) Network. The approach consists of two schemes: (1) offering distributed different CW ranges for different SS types (i.e., new and handoff types) and (2) supporting different penalty waiting regions for new and handoff types. Numerical results of analysis and simulation indicate that the proposed approach significantly outperforms other approaches. Furthermore, the analysis and simulation yield almost the same results justify the correctness of the proposed approach, where the analysis is modeled as a discrete-time Markov chain model.

Keywords —— IEEE 802.16j MMR network, contention backoff window, ranging region, Markov chain model, fast handoff

1. Introduction

Based on IEEE 802.16e, WiMAX proposes IEEE 802.16j MMR networks [3] for increasing service coverage and network throughput, and improving transmission quality affected by Line-of-Sight (LoS) propagation. Various types of relay station (RS), namely Fixed RS (FRS), Nomadic RS (NRS) and Mobile RS (MRS), with two forwarding modes, namely transparent (T) and non-transparent (NT) modes, are included for achieving the above-mentioned features in IEEE 802.16j.

In the transparent mode, MS and T-RS use an individual ranging region, respectively, so these two-type stations will not collide with each type while performing contention ranging in IR and BR. Conversely, in the non-transparent mode MS and NT-RS use the same ranging region for IR and BR, and then increases ranging collision probability. For the reason of the trend of using distributed mechanism, we focus on minimizing the contention collision issue in NT-RS mode, especially for the case that various-type stations simultaneously perform IR and BR requests to a super-ordinate station.

The TBEB Algorithm used in IEEE 802.16 includes three main factors: (1) Contention Period Size (i.e., the number of slots used for ranging within a frame), (2) total number of contention slots and (3) number of SSs, which significantly affect collision probabilities of IR and BR, and network throughput. Previous studies [4][5] proposed the two and three dimensional Markov chain models to analyze collision probability for IEEE 802.16. Zheng *et al.* [9] proposed an analysis model but did not consider the important impact factor of the number of mobile stations. Clearly, the collision probability increases as the number of MSs increasing.

In [12], the Contention Period Size is decided according to the numbers of MSs, and thus controls the collision probability even though the total number of MSs increases. Due to the fixed frame size, the increasing of contention period size will reduce the number of data slots, and thus degrades the utilization. Sayenko *et al.* [19] proposed an analysis model to reduce collision probability but did not consider the access delay for the real-time service class. Perera *et al.* [20] proposed an algorithm different from the IEEE 802.16 standard, in which the same backoff window size is used for different classes of SS and yields high collision probability. Although the analysis in [21] has pointed out that the optimal value could be obtained when the ratio of contention Slots and node numbers is twice the node numbers plus one contention slot. However, it has not considered that the increasing of contention slots will reduce the number of data slots. As a result, [21] has the same problem of [12].

The remainder of this paper is organized as follows. The network model and evaluated performance metrics are defined in Section 2. Section 3 details the proposed fast-handoff WiMAX_FH approach. Section 4 depicts the mathematical analysis based on the Markov chain model. Numerical results of analysis and simulation are provided in Section 5. Conclusions and future works are given in Section 6.

2. Network Model

This section first defines the network model and then defines some useful notations for analysis. Finally, we define some important performance metrics for evaluating the proposed approach and other compared approaches.

An IEEE 802.16j MMR network is modeled as a graph $G=(V,E)$, where V represents the node set and E represents the wireless link set. In this model, a node v could be an MR-BS, an RS or an MS, as denoted as v_i^{BS}, v_j^{RS}, or v_k^{MS}, respectively, where i, j and k represent the node indexes. Moreover, this work considers two types of node: new and handoff types, in which, for example, a handoff RS, j, is denoted as $v_j^{RS_H}$.

3. Efficient IR/BR for Fast Handoff

This section details the proposed efficient IR/BR approach for guaranteeing rtPS service while performing handoff. Since IEEE 802.16 uses the contention-based IR/BR for the registration and bandwidth request processes, such a random access mechanism cannot guarantee access delay. As a result, handoff SSs are easily to be dropped and rtPS service flows may not be carried. This motivates us to propose an efficient IR/BR approach that consists of two adaptive CW control mechanisms: (1) the distributed differentiated contention window algorithm (namely *D^2CW*) and (2) the adaptive waiting-penalty algorithm (namely *AWP*). The main **contributions** include: to satisfy different access delays between new and handoff SSs, and to adaptively adjust the waiting-penalty CW for different-priority nodes according to network traffic density. The descriptions of these two algorithms are depicted in detail as follows.

A. The Distributed Differentiated Contention Window Algorithm (D^2CW)

In TBEB, after occurring collision in IR or BR, the backoff stage is changed from stage i to stage $i+1$ if i is less than the maximum stage m. Since different priorities of nodes use the same state transition after collision, their new CW ranges are not significantly differentiated and then leads to high collision probability especially under the case of high saturation traffic load. This work thus first proposes a distributed differentiated CW algorithm to differentiate the CW state transitions among various priorities of nodes after occurring collision. The backoff stage of a priority r node will be transited from stage i to stage $i+r$, where $r=0$ means the highest priority, as demonstrated in Fig. 1.

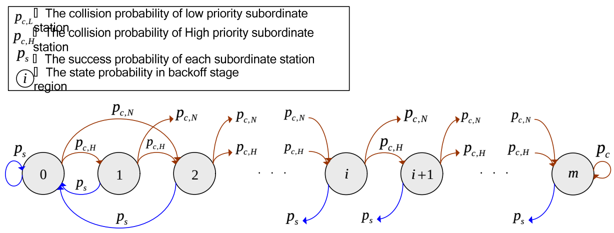

Fig. 1. State transition of collision

B. The Adaptive Waiting-Penalty Algorithm (*AWP*)

In WiMAX, a layer 2 MAC frame is sent via several layer 1 PHY frames. When the traffic load is high and WiMAX adopts group polling rather than unicast polling, the MAC frame will be sent after successful contention in BR.

For guaranteeing MAC frames of a real-time connection sent within the specified delay, we then propose the adaptive waiting-penalty algorithm to assure that the higher-priority node can enter into next contention request more quickly than the lower-priority node.

In addition, the waiting-penalty algorithm considers the impact factor of traffic density because high traffic load leads to high collision probability, and vice versa. The adaptive waiting-penalty algorithm thus adopts a long waiting-penalty CW when the traffic load is high. Conversely, it uses a short waiting-penalty CW when the traffic load is low. The adaptive feature achieving the proposed algorithm has the capability to adaptively adjust waiting-penalty CW according to traffic load, in which the traffic load, d, is defined as.

$$d = 1 - \frac{W_F^{Collision}}{W_F}, \tag{1}$$

where W_F means the number of slots used for IR or BR (i.e., the ranging region size), and $W_F^{Collision}$ represents the number of collided slots in IR or BR. Thus, the state transition of a successful transmission at stage i becomes

$$Z_i = Z_i - \lfloor Z_i \cdot (1-d) \rfloor, \tag{2}$$

where Z_i and Z_j are the waiting-penalty sizes of states $(i,0,-)$ before and after the computation, respectively, as demonstrated in Fig. 2. Specifically, the first time state transition of the waiting-penalty state $(i,0,-)$ is from state $(i,0,-)$ to state $(i,0,Z_j)$. After that, the waiting-penalty state is changed from state $(i,0,Z_j)$ to state $(i,0,Z_j-1)$ at each frame, where $0 \le Z_j \le Z_i$, till arriving at state $(i,0,0)$ the node can issue a new transmission request. Clearly, this transition depends on the traffic load, and then differentiates the CW transitions of the new and handoff SSs.

4. Markov Chain Analysis

This section first models a three-dimensional Markov chain model for the proposed approach, as demonstrated in Fig. 2. Based on the model, we then analyze the collision probability and network throughput. The model considers R number of node priorities; however, for the reason of simplicity we adopt the general two node-priorities, i.e., the new node (namely $r=2$) and the handoff node (namely $r=1$). The useful notations defined for the Markov chain model are shown as follows.

1) $p_{c,H}$: the collision probability of the handoff SS.

2) $p_{c,N}$: the collision probability of the new SS.

3) r: the ratio of the success probability to the collision probability, i.e., $r = p_{c,H} + \frac{p_{c,N}}{p_{c,H}}$.

4) $L_{r,retry}$: the maximum retransmit times of priority r SS.

5) $b_{i,k,z}$: the state probability of state (i,k,z), where i is the backoff stage, k is the backoff window and z is the waiting-penalty size

6) $P\{i,k,-|i,k+1,-\}$: the transition probability of from state $(i,k+1,-)$ to state $(i,k,-)$.

We then model the non-null transition probabilities of several derived cases in Markov chain process as shown below and in Eq. (5).

a) $P\{i,k,-|i,k+1,-\}$ is the transition probability of the backoff window from state $k+1$ to state k.

b) $P\{0,k,-|0,0,-\}$ is the transition probability from state $(0,0,-)$ to state $(0,k,-)$ when the SS wins the competition at the first contention request.

c) $P\{i+r,k,-|i,0,-\}$ is the transition probability of the backoff window of priority r SS from state $(i,0,-)$ to state $(i+r,k,-)$ if the SS occurs collision at the backoff stage i.

d) $P\{m,k,-|m,0,-\}$ is the transition probability from state $(m,0,-)$ to state $(m,k,-)$ when a collision happens at the m-th retransmission.

e) $P\{i,0,Z_i-z|i,0,-\}$ is the transition probability from state $(i,0,-)$ to state $(i,0,Z_i-z)$ of the waiting-penalty state after the SS succeeds the transmission.

f) $P\{i,0,z-1|i,0,z\}$ is the transition probability from state $(i,0,z)$ to state $(i,0,z-1)$ of the waiting-penalty.

g) $P\{0,k,-|i,0,0\}$ is the transition probability from state $(i,0,0)$ to state $(0,k,-)$ when the waiting-penalty size equals to zero.

$$\begin{cases} P\{i,k,-|i,k+1,-\}=1, & k\in[0,W_{r,i}-2], i\in[0,m] \\ P\{0,k,-|0,0,-\}=(1-p_{c,r})/W_{r,0}, & k\in[0,W_{r,i}-1] \\ P\{m,k,-|m,0,-\}=p_{c,r}/W_{r,m}, & k\in[0,W_{r,m}-1] \\ P\{i+1,k,-|i,0,-\}=p_{c,H}/W_{r,i}, & k\in[0,W_{r,i+1}-1], i\in[0,m-1] \\ P\{i+2,k,-|i,0,-\}=p_{c,N}/W_{r,i}, & k\in[0,W_{r,i+2}-1], i\in[0,m-2] \\ P\{i,0,z|i,0,-\}=p_j, & z\in[0,Z_i], j\subseteq z, i\in[1,m] \\ P\{i,0,z-1|i,0,z\}=1, & z\in[1,Z_i], i\in[1,m] \\ P\{0,k,-|i,0,0\}=1, & k\in[0,W_{r,i}-1], i\in[1,m] \end{cases} \tag{3}$$

To simplify the complexity of the analysis, we divide the Markov chain model into two regions: the waiting-penalty region and the backoff window region. First, the state of the waiting-penalty region is shown in Eq. (4),

$$\begin{cases} b_{i,0,z_i} = b_{i,0,-} \cdot \dfrac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \\ b_{i,0,z_i-1} = b_{i,0,-} \cdot \dfrac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot p_1 \\ \vdots \\ b_{i,0,0} = b_{i,0,-} \cdot \dfrac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \sum_{n=1}^{z_i} p_n \end{cases} . \quad (4)$$

From (4), we can obtain the general representation of the waiting-penalty region as shown in Eq. (5).

$$b_{i,0,z_i} + b_{i,0,z_i-1} + \cdots + b_{i,0,0} = b_{i,0,-} \cdot \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right). \quad (5)$$

To determine the probability of state $(0,0,-)$, it is necessary to derive the related equation from state $(i,0,-)$ and state $(0,0,-)$ as follows.

$$b_{i,0,-} \cdot \left(p_{c,H} + p_{c,N} + 1 - p_{c,H} - p_{c,N}\right) = b_{i-1,0,-} \cdot p_{c,H} + b_{i-2,0,-} \cdot p_{c,N}$$

$$\therefore b_{i,0,-} \cdot (1) = b_{i-1,0,-} \cdot p_{c,H} + b_{i-2,0,-} \cdot p_{c,N}$$

or

$$b_{i,0,-} = b_{i-1,0,-} \cdot p_{c,H} + b_{i-1,0,-} \cdot \frac{p_{c,N}}{p_{c,H}}$$

$$\therefore b_{i,0,-} = b_{i-1,0,-} \cdot \left(p_{c,H} + \frac{p_{c,N}}{p_{c,H}}\right)$$

Let $r = p_{c,H} + \dfrac{p_{c,N}}{p_{c,H}}$, we have

$$b_{i,0,-} = b_{i-1,0,-} \cdot r$$
$$\therefore b_{i,0,-} = b_{0,0,-} \cdot r^i, \qquad 0 \le i \le m. \quad (6)$$

After obtaining r, we partition the Markov chain of the backoff window region into three cases: 1) $i=0$, 2) $0<i<m$ and 3) $m=0$. Then, we derive the general equation of the backoff window region to deduce the steady-state probability of state $(i,k,-)$. The derivations of these three cases are depicted below.

1. **The cases of $i=0$**
   The probability of state $(0,0,-)$ is the sum of the probabilities of successful transmissions at state $(0,0,-)$, and the successful transmissions of all R types at state $(i,0,0)$.
2. **The cases of $0<i<m$**
   The probability of state ($i,0,-$), where $0<i<m$, is the sum of the probabilities of collision from state $(i-1,0,-)$ of handoff SS and the collision from state $(i-2,0,-)$ of new SS.
3. **The cases of $m=0$**
   The probability of state $(m,0,-)$ is the sum of the probabilities of collision at state $(m-1,0,-)$ and state $(m,0,-)$.

Therefore, the probability of state $(i,k,-)$ can be rewritten in Eq. (7) according to the three different kinds of backoff stage ranges.

$$b_{i,k,-} = \frac{W_{r,i}-k}{W_{r,i}} \cdot \begin{cases} b_{i,0,-} \cdot \left(1-p_{c,H}-p_{c,N}\right) + b_{i+1,0,0} + b_{i+2,0,0} + \cdots + b_{m,0,0}, & i=0, \\ b_{i-1,0,-} \cdot p_{c,H} + b_{i-2,0,-} \cdot p_{c,L}, & 0<i<m, \\ b_{i,0,-} \cdot \left(p_{c,H}+p_{c,N}\right) + b_{i-1,0,-} \cdot p_{c,H} + b_{i-2,0,-} \cdot p_{c,N}, & i=m. \end{cases} \quad (7)$$

From Eqs. (6)-(7) and r, the probability of state $(i,k,-)$ can be expressed as

$$b_{i,k,-} = \frac{W_{r,i}-k}{W_{r,i}} b_{i,0,-} C_i, \qquad 0 \le i \le m,$$

where

$$C_i = \begin{cases} \left(1-p_{c,H}-p_{c,N}\right) + \sum_{a=1}^{m-i} r^a \cdot \dfrac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_{i+a}} p_j} \cdot \sum_{n=1}^{z_{i+a}} p_n, & i=0, \\ 2, & 0<i<m, \\ 2+\left(p_{c,H}+p_{c,N}\right), & i=m. \end{cases}$$

Based on the closed-form characteristic of the Markov chain model, the sum of all states' probabilities should be one, as indicated in Eq. (8).

$$\sum_{i=0}^{m}\sum_{k=0}^{W_{r,i}-1} b_{i,k,-} + \sum_{i=0}^{m}\sum_{z=0}^{Z_i} b_{i,0,-} = 1 \quad (8)$$

or

$$\sum_{i=0}^{m} \frac{2^i W+1}{2} \cdot b_{i,0,-} \cdot C_i + \sum_{i=0}^{m} b_{i,0,-} \cdot \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right) = 1$$

In TBEB, a frame will be dropped when its total number of retransmission times exceeds the specified threshold. However, IEEE 802.16 has not differentiated different numbers of retransmission times to different SS priorities. Thus, the proposed approach improves above-mentioned issue by differentiating different numbers of retransmission times, $L_{r,retry}$, for different SS priorities to achieve low dropping for the handoff SS during handoff. The frame dropping probability is analyzed based on three cases: 1) $i \le L_{r,retry} \le m$, 2)

$i < m \le L_{r,retry}$ and 3) $m \le i \le L_{r,retry}$. The backoff window ranges of these 3 cases are $[0, 2^i W]$, $[0, 2^i W]$ and $[0, W_{r,i}^{\max} + 1]$, respectively. As a result, $W_{r,i}$ can be expressed as Eq. (9),

$$W_{r,i} = \begin{cases} 2^i W, & L_{r,retry} \le m, i = 0,1,\ldots,L_{r,retry}, \\ 2^i W, & L_{r,retry} > m, i = 0,1,\ldots,m-1, \\ 2^m W = \left(W_{r,i}^{\max} + 1\right), & L_{r,retry} > m, i = m,\ldots,L_{r,retry}. \end{cases} \quad (9)$$

Finally, the probability of state $(0,0,-)$ is affected by the retransmission times and the backoff window range. Thus, $b_{i,0,-}$ can be determined by Eqs. (6), (8) and (9), as indicated in Eq. (10) or (11).

$$\frac{1}{b_{0,0,-}} = \begin{cases} \sum_{i=0}^{L_{r,retry}} \frac{2^i W+1}{2} r^i C_i + \sum_{i=0}^{L_{r,retry}} r^i \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right) & L_{r,retry} \le m, i = 0,1,\ldots,L_{r,retry}, \\ \sum_{i=0}^{m-1} \frac{2^i W+1}{2} r^i C_i + \sum_{i=0}^{m-1} r^i \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right) & L_{r,retry} > m, i = 0,1,\ldots,m-1, \\ \sum_{i=m}^{L_{r,retry}} \frac{2^m W+1}{2} r^i C_i + \sum_{i=m}^{L_{r,retry}} r^i \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right) & L_{r,retry} > m, i = m,\ldots,L_{r,retry}. \end{cases} \quad (10)$$

$$b_{0,0,-} = \begin{cases} \frac{1}{\sum_{i=0}^{L_{r,retry}} \frac{2^i W+1}{2} r^i C_i + \sum_{i=0}^{L_{r,retry}} r^i \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right)}, & L_{r,retry} \le m, i = 0,1,\ldots,L_{r,retry}, \\ \frac{1}{\sum_{i=0}^{m-1} \frac{2^i W+1}{2} r^i C_i + \sum_{i=0}^{m-1} r^i \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right)}, & L_{r,retry} > m, i = 0,1,\ldots,m-1, \\ \frac{1}{\sum_{i=m}^{L_{r,retry}} \frac{2^m W+1}{2} r^i C_i + \sum_{i=m}^{L_{r,retry}} r^i \frac{\left(1-p_{c,H}-p_{c,N}\right)}{\sum_{j=1}^{z_i} p_j} \cdot \left(1+\sum_{n=1}^{z_i}\sum_{Z=1}^{n} p_Z\right)}, & L_{r,retry} > m, i = m,\ldots,L_{r,retry}. \end{cases} \quad (11)$$

In CRP, one subordinate station could at most have $L_{r,retry} + 1$ retransmission times. In the case of $0 \le i \le m$, the competition chance of an SS can be expressed as Eq. (12),

$$t_r = \sum_{i=0}^{L_{r,retry}} b_{i,0,-} = \frac{1-r^{L_{r,retry}+1}}{1-r} b_{0,0,-}. \quad (12)$$

Thus, the probability that N SSs randomly selects the same channel slot of the same L1 frame becomes

$$P_t = 1 - \prod_{r=1}^{R} \left(1-t_r\right)^N. \quad (13)$$

After that, the collision probability can be determined as shown in Eq. (14).

$$\begin{aligned} P_c &= \sum_{r=1}^{R} \left(1 - \left(1-t_r\right)^{N-1} \cdot \prod_{j=1, j\ne r}^{R} \left(1-t_j\right)^N \right) \\ &= \sum_{r=1}^{R} \frac{P_t - t_r}{1-t_r}. \end{aligned} \quad (14)$$

5. Numerical Results

This section evaluates the proposed efficient IR/BR for fast handoff approach by examining the metrics of collision probability, GoS and average goodput, and then we compare the results with that of IEEE 802.16 and important related studies. The impact factors include different number of wireless nodes (NDS) and various minimum contention windows. The 95% confidence intervals of the simulation results in the following figures originate from 25 independent runs. For each run, the simulated time is 100 time units.

The evaluated network model is demonstrated in Fig. 1, in which we consider one MR-BS and two types of SSs: the new and handoff SSs. The values of parameters used for analyses and simulations are listed in Table I, which are summarized from [19].

Table I. Parameters for analyses and simulations

Simulation parameter	*Value*
Simulation time (frame)	50000
Number of nodes (NDS)	10~100
Arrival rate of registration	0.1~1
Number of contention slots for IR or BR per frame	8
Retransmission limit ($L_{r,retry}$)	15
Maximum backoff window ($W_{r,i}^{\max}$)	1024
Maximum backoff stage	10
Minimum backoff stage	4

Fig. 3 demonstrates the collision probabilities of analysis and simulation of the evaluated approaches under different NDS ranging from 10 to 100. In each approach, the simulation result is close to the analysis result. The collision probabilities increase as NDS increases. Note that the collision probability of the proposed approach is significant lower than that of IEEE 802.16. The primary reason is that the proposed approach differentiates the CW state transitions among various priorities of nodes after collisions contributed by the distributed differentiated contention window algorithm (D^2CW).

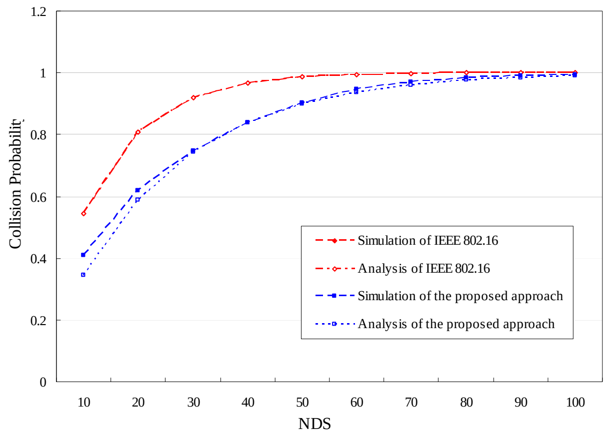

Fig. 3 Collision Probability under various NDS

Fig. 4 examines the GoS under different NDS ranging from 10 to 100. The GoS results of the proposed approach and IEEE 802.16 increase as NDS increasing.

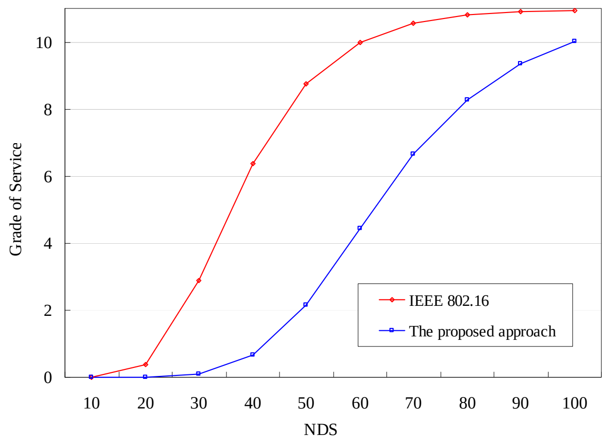

Fig. 4. GoS under various NDS

6. Conclusions

WiMAX adopts the TBEB algorithm in IR and BR for SSs as the Contention Resolution Process (CRP). Although TBEB works well during light and moderate traffic load, it suffers from heavy traffic load because of leading significantly high collision probability. Thus, this work proposed an efficient IR/BR for achieving fast handoff, low dropping, and low collision probability. The proposed approach consists of two contributions: 1) the distributed differentiated CW (D^2CW) algorithm and 2) the adaptive waiting-penalty (AWP) algorithm. Numerical results of analysis and simulation demonstrate that the proposed approach outperforms IEEE 802.16 in collision probability, GoS, and the average goodput.

7. References

[1] "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," *IEEE Std 802.16*, pp.1–857, Oct. 2004.

[2] "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," *IEEE 802.16e Standard*, pp. 1-864, Feb. 2006.

[3] IEEE 802.16j, "Baseline Document for Draft Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems," pp. 1-314, Jun. 2007.

[4] L. Lin, B. Han and W. Jia, "Modeling and Performance Analysis of Initial Connection in IEEE 802.16 PMP Networks," *IEEE 63rd International Conference on Multimedia and Expo*, pp. 609 - 612, Jul. 2006.

[5] W. Jia, W. Lu and L. Lin, "Performance Analysis of IEEE 802.16 Multicast and Broadcast Polling based Bandwidth Request," *IEEE Wireless Communications and Networking Conference*, pp. 1854-1859, Mar. 2007.

[6] L. Lin, W. Jia, B.o Han and L. Zhang, "Performance Improvement using Dynamic Contention Window Adjustment for Initial Ranging in IEEE 802.16 P2MP Networks," *IEEE Wireless Communications and Networking Conference*, pp. 1877-1882, Mar. 2007.

[7] B.-J. Chang, Y.-L. Chen and C.-M. Chou, "Adaptive Hierarchical Polling and Cost-based Call Admission Control in IEEE 802.16 WiMAX Networks," *IEEE Wireless Communications and Networking Conference*, pp. 1954-1958, Mar. 2007.

[8] B.-J. Chang and C.-M. Chou, "Adaptive Polling Algorithm for Reducing Polling Delay and Increasing Utilization for High Density Subscribers in WiMAX Wireless Networks," *IEEE International Conference on Communication Systems*, pp.1-5, Oct. 2006.

[9] P.-X. Zheng, Y-.J. Zhang and L.-S. Chang, "Analysis of Exponential Backoff with Multipacket Reception in Wireless Networks," *Proceedings 31st IEEE Conference on Local Computer Networks*, pp. 855–862, Nov. 2006.

[10] D.-H. Lee, K. Kyamakya and J.-P. Umondi, "Fast Handover Algorithm for IEEE 802.16e Broadband Wireless Access System," *Wireless Pervasive Computing, 2006 1st International Symposium on*, pp. 1-6, Jan. 2006.

[11] L. Wang, F. Liu, Y. Ji and R. Nararat, "Admission Control for Non-preprovisioned Service Flow in Wireless Metropolitan Area Networks," *Fourth European Conference on Universal Multiservice Networks*, pp. 243 – 249, Feb. 2007.

[12] S.-M. Oh and J.-H. Kim, "The Optimization of the Collision Resolution Algorithm for Broadband Wireless Access Network," *The 8th International*

Conference Advanced Communication Technology, pp. 1944–1948, Vol. 3, Feb. 2006.

[13] S.-M. Oh and J.-H. Kim, "The Analysis of the Optimal Contention Period for Broadband Wireless Access Network," *IEEE 3rd Conference on Pervasive Computing and Communications Workshops*, pp. 215-219, Mar. 2005.

[14] B.-J. Chang and J.-W. Chu, "H-EDCA: QoS-based High Performance Media Access Control for IEEE 802.11e WLANs," *IEEE Global Telecommunications Conference*, pp. 1 – 5, Nov. 2006.

[15] C. Cicconetti, L. Lenzini, E. Mingozzi and C. Eklund, "Quality of service support in IEEE 802.16 networks," *IEEE Network*, Vol. 20, pp. 50 – 55, Mar. 2006.

[16] S. Boumerdassi and A.-L. Beylot, "Adaptive Channel Allocation for Wireless PCN," *Mobile Networks and Applications*, Vol. 4, No. 2, pp. 111–116, Jun. 1999.

[17] B.N. Bhandari, Ratnam V. Raja Kumar and S.L. Maskara, "Performance of the IEEE 802.16 MAC Protocol with Varying Request Backoff Start," *IEEE Region 10 Conference TENCON*, pp. 14-17, Nov. 2006.

[18] A. Sayenko, O. Alanen and T. Hamalainen, "On Contention Resolution Parameters for the IEEE 802.16 Base Station," IEEE *Global Telecommunications Conference*, pp. 26-30, Nov. 2007.

[19] A. Sayenko, O. Alanen and T. Hamalainen, "Adaptive Contention Resolution for VoIP Services in the IEEE 802.16 Networks," *IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks*, pp. 1-7, June 2007.

[20] Perera S. and Sirisena H., "Contention Based Negative Feedback ARQ for VoIP Services in IEEE 802.16 Networks," *14th IEEE International Conference on Networks*, Vol. 2, pp. 1-6, Set. 2006.

[21] H.-C. Yang, H.-J. Lee and M.-J. Lee, "A Mobility Management Protocol for Multi-hop Relay Networks," *10th International Conference on Advanced Communication Technology*, Vol. 1, pp. 37-42, Feb. 2008.

[22] Genc V., Murphy S., Yu Y. and Murphy J., "IEEE 802.16J relay-based wireless access networks: an overview [recent advances and evolution of WLAN and WMAN standards]," IEEE Wireless Communications, Vol. 15, Issue 5, pp. 56 – 63, Oct. 2008.

[23] B.-J. Kwak, N.-O. Song and D.-S. Kwon, "Enhancement of IEEE 802.16 WirelessMAN Ranging Performance with EIED Backoff Algorithm," *IEEE 66th Vehicular Technology Conference*, pp. 1902 – 1906, Step. 2007.

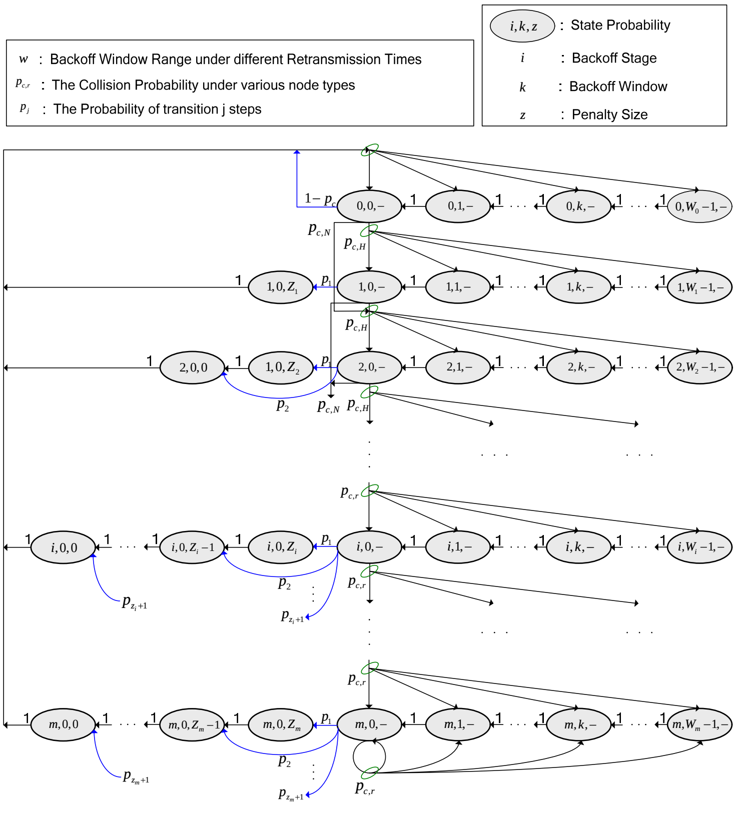

Fig. 2. Markov chain model for the proposed approach