Communication Protocol Engineering and Optimization of Network Entry Process in IEEE 802.16 Based Systems

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Abstract

The improvement of the communication systems is conducted through communication protocol engineering and optimization process. This paper presents an effort to upgrade the IEEE 802.16 and IEEE 802.16e protocol performance regarding the delay during subscriber network entry or base station handover. Our communication protocol engineering process of WiMax protocol and its optimization resulted in a new UCD-aware initial ranging transmission opportunity slots distribution. Using an analytical and numerical performance evaluation, we prove the relevance of the new algorithm and the increase of the IEEE 802.16-based network performance.

1. Introduction

The IEEE 802.16 [1] based communication systems play a dominant role in the area of wireless broadband communications. The Amendment from 2005 (IEEE 802.16e [2]) has expanded the WiMax broadband access for the mobile users of wireless services. Such users desire communication systems with high fidelity, short response times, and guaranteed quality of the communication services. On the other hand, WiMax is always encountered as an unavoidable technology for emergency and hazard situation communications [3]-[5]. This is due its inherent flexibility and its provision of high data rates, enabling the support of a wide range of real-time mobile multimedia services needed for emergency teams and planners. These extreme situation services further emphasize the need for high promptness of the communication network. Optimization of the network entry process is a major issue for rapid deployment of wireless networks, directly influencing the initial delays that users are experiencing. So far this problem has been insignificantly exploited [6], and even less optimized. The optimization of the network entry process requires the same communication protocol engineering concerns as it does the handover process between network base stations. In that matter, the conclusions stated in this paper are applicable for the optimization of the WiMax station handover procedures.

The paper is organized as follows. Section 2 presents the complete process of the WiMax station network entry, giving an appropriate protocol insight and the parameters nominal values. In Section 3 the network entry delay is calculated using suitable mathematical model. The proposed improvement of the IEEE 802.16 network entry process is elaborated in Section 4, and numerical results are presented in Section 5. The paper is concluded at the end, in Section 6.

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2. Network Entry and Initialization According to the Standard

The IEEE 802.16 based systems supports applicable procedures for entering and registering new subscribers to the network. This process is mandatory and is divided into the following compulsory phases:

- Scan for downlink channel and establish synchronization with the BS
- Obtain transmit parameters (from UCD message)
- Perform ranging
- Negotiate basic capabilities
- Authorize SS and perform key exchange
- Perform registration
- Set up connections

The first phase includes stations PHY synchronization using DL channel signal and the DCD management message by which the base station (BS) is advertising itself in a periodic manner. An additional MAC-layer synchronization is performed, using the DL-MAP management message, also emitted periodically by the BS. Downlink synchronization is a necessity for proper functioning of the user station (SS), and therefore is maintained by periodical exchange of DCD and DL-MAP messages.

The UCD MAC management message contains a set of transmission parameters for the usage of the uplink channel. The UCD message is also broadcasted in a periodical manner. The exchange of the UCD message between BS and SS is the only condition for maintaining the station's uplink synchronization.

The SS performs an initial ranging for acquiring the correct timing and power adjustments. The process of ranging is performed by the SSs in a contention manner. The contention is conducted in the Initial Ranging Interval (first slot of the UL-subframe), and is based on a truncated binary exponential backoff, with an initial backoff window controlled by the BS and specified in the UCD message. When a station needs to perform a ranging, it sets its internal backoff window and then randomly selects the number of the contention transmission opportunities that the SS shall defer before transmitting. The random number is selected within the backoff window, and the transmission opportunities are defined by the Initial Ranging Information Elements (IR-IEs) in the UL-MAP message. After the deferring period, the SS transmits a RNG-REQ MAC management message and activates a timer (T3) which defines the time that SS shall wait for the reception of the RNG-RSP MAC management message. If no response message is received, the backoff algorithm is performed using increased backoff window size by factor two.

Immediately after ranging, the SS and the BS exchange information and find the intersection of the SS's and BS's capabilities.

After the authentication and authorization process, the SS performs registration on the network and then it is allowed to establish provisioned connections.

3. Calculating the Network Entry Delay

In the previous section we have extracted the key points of the SS's network entry process in a WiMax based system. In the following, our interest will be the delay that SS encounters as a result of the network entry procedure, as defined in the IEEE 802.16 and .16e standards. This delay directly influences the SS's QoS which is especially needed in an emergency and hazard situations, where the reduction of the delay can save lives and material goods.

Hereafter, we will calculate the delay of the SS caused only by the MAC layer, abstracting the delay caused by the PHY and physical propagation. Our interest will be focused on the first three mandatory steps of the network entry procedure, and the delay they introduce, (1).

$$\tau_{TOTAL} = \tau_{DL\_SYNC} + \tau_{UL\_SYNC} + \tau_{RNG\_CONTENTION} \quad (1)$$

The DCD and DL-MAP messages are broadcasted periodically with a period less than 10 seconds and 600 milliseconds respectively, so the mean delay τ_{DL_SYNC} is around 5 seconds, considering uniform distribution of the SS's power-on sequence moments in respect of the DCD/DL-MAP period.

A similar assumption can be derived for the mean delay caused by the UL synchronization procedure. The UCD message is transmitted by the BS within a 10 seconds period, causing the value of the τ_{UL_SYNC} of 5 seconds.

Contrary to the mean DL and UL synchronization delays, the mean value of the contention based ranging process is a more complex variable. After the SS has received the UCD MAC management message, it obtains the Ranging Request Opportunity size, initial and maximum backoff window size for the collision avoidance procedure, and the uplink burst profile formats that can be used. Then it generates a random number within the initial window, in the following denoted as *rnd.* The *rnd* defines the number of the deferred contention transmission opportunities for which the SS is eligible. For example, if the initial contention window size is 4, *rnd* can be in range of 0 to 15 (2^4-1). If *rnd* = 8, and the number of transmission opportunities per Initial Ranging slot is 3, then the SS will defer 8 transmission opportunities, which means it will transmit its RNG-REQ message in the last transmission opportunity slot of the third consecutive UL sub-frame after the moment of the reception of UCD message.

The number of transmission opportunities per an Initial ranging allocation, is defined by a division between the total size of the Initial ranging allocation (defined by the UL-MAP message) and the Ranging request opportunity slot size (defied by the UCD message). This number is usually slowly changing variable, dependent of the expected number of new users per BS. Practically, it varies by BS's location (center of the town or suburb) and by the hour of the day (peak hour or relaxing hour). We should emphasize that an initial ranging do not perform only the new-activated SSs, but also the mobile users which carry out handover.

If we denote transmission opportunity duration with T_{TRROPP}, and the UL-MAP period with T_{ULMAP}, then we can calculate the mean delay of the contention based ranging process as (2), where N_{TRROPP} represents the number of transmission opportunities per initial ranging allocation, and *mod* is the modulo operator.

The Equation (2) calculates the delay until the moment of SS's transmission of RNG-REQ message. If a collision occurs during the transmission, or a lost of the RNG-REQ message sent by the BS, then the delay calculated by (2) is modified as in (3) where N_{COLL} is the number of the consecutive occurred collisions, or lost of responses, and T_3 is the ranging response reception timeout following the transmission of a ranging request. The default value for the T_3 timer is 200 milliseconds. We should emphasize here that a new value *rnd* is generated after each collision, using a doubled contention window.

$$\tau_{RNG\_CONTENTION} = \left\lfloor \frac{rnd}{N_{TRROPP}} \right\rfloor \cdot T_{ULMAP} + \mathrm{mod}(rnd, N_{TRROPP}) \cdot T_{TRROPP} \quad (2)$$

$$\tau_{RNG\_CONTENTION} = N_{COLL} \cdot T_3 + (N_{COLL} + 1)\left\{ \left\lfloor \frac{rnd}{N_{TRROPP}} \right\rfloor \cdot T_{ULMAP} + \mathrm{mod}(rnd, N_{TRROPP}) \cdot T_{TRROPP} \right\} \quad (3)$$

4. Optimization of the Network Entry Process

The optimization proposal stated here treats the algorithm for the transmission opportunity slot distribution in the initial ranging process. The IEEE 802.16 and .16e standards do not explicitly specify the number of transmission opportunities per an Initial ranging allocation. It is left for vendor implementation. As explained in the previous section, the classical manner of the slot distribution does not take into consideration the period and the phase of the periodic transmission of the UCD message, one of the crucial MAC management messages in network entry process. As a result, the transmission slots are distributed with a relatively low variance only caused by the change of the number of network entry queries during the day. The main and only relevant characteristic of this kind of transmission opportunity provision is the mean value of transmission slots per an initial ranging allocation.

We are proposing a more intelligent distribution of the initial ranging transmission opportunity slots created in accordance with the nature of the specified network entry process, and considering the two most relevant MAC management messages: UL-MAP and UCD. The UL-MAP message contains information for the time position of the initial ranging allocations and information for the number of transmission slots (implicitly, by the IR allocation duration). The UCD message contains information for the allowed transmitting modulation and coding, and information for the number of transmitting slots per allocation (defined implicitly, by declaring the transition slots duration). If one closely analyzes the network entry procedure in IEEE 802.16 based system (explained in the previous section), it can be realized that after the transmission of the UCD message by the BS, the probability for a transmission of RNG-REQ message by the SSs significantly increases. The reason lays in the fact that all the user stations that have been activated or performed an handover after the last transmitted UCD message (period with a maximum value of 10 seconds), are waiting the next transmission of this message to obtain the information needed for contention (minimum and maximum value of the contention window size), after which they generate the *rnd* value – the number of deferred slots before transmission of the RNG-REQ message.

Considering this, we propose a distribution of the transmission opportunity slots where ranging allocations following the UCD message are fully exploited, a propos the allocations just before the transmission of the next UCD message. The BS can change the initial ranging allocation duration, which information is broadcast by the UL-MAP message. The idea is to enlarge the duration of the allocations just after the UCD transmission and in that way to provide more transmission opportunity slots for which the SSs are eligible to send, and in such a way to reduce the delay that SSs are encountering because of the backoff ranging process. We call these boosted UL subframes. The maximal value of the allocation duration in a boosted subframe is determined by the current load of the BS represented by the number of already established connections, which require an UL allocation for their transmissions. To maintain the same mean value of the IR transmission slots, we recommend the existence of UL subframes without IR allocations which will follow the boosted UL subframes, dedicated only for the ongoing connections.

If N_{TRROPP} denotes the number of transmission opportunity slots per UL allocation in a classical way of distribution and N_{TRROPP_MAX} the maximal number of slots per allocation, then the total number of slots between two consecutive UCD messages can be calculated by (4), and the delay that a SS is encountering when IEEE 802.16 system uses the new proposed transmission slots distribution can be calculated using (5).

$$N_{RNG\_SLOTS} = \left\lfloor \frac{T_{UCD}}{T_{ULMAP}} \right\rfloor N_{TRROPP} \tag{4}$$

$$\tau_{NEW\_RNG\_CONTENTION} = \left\lfloor \frac{rnd}{N_{RNG\_SLOTS}} \right\rfloor \cdot T_{UCD} + \left\lfloor \frac{\mathrm{mod}(rnd, N_{RNG\_SLOTS})}{N_{TRROPP\_MAX}} \right\rfloor \cdot T_{ULMAP} + \mathrm{mod}(\mathrm{mod}(rnd, N_{RNG\_SLOTS}), N_{TRROPP\_MAX}) \cdot T_{TRROPP} \tag{5}$$

5. Numerical Results

Figure 1 represents the delay of the RNG-REQ message in the MAC queue caused by the appropriate protocol procedure. The horizontal axis represents the randomly selected values for the deferring number of slots. The stair-like shape of the curves is produced because of the very same time-slotting manner used in the protocol. A less steepness of the curve represents better protocol performance, meaning more uniform packet delay regarding the *rnd*-value. Another protocol performance indicator is the mean value of the packet delay, presented with dotted lines. In Figure 1 we have compared the protocol performance when using the classic packet transmission manner (red line) and our UCD-aware initial ranging transmission opportunity slots distribution (blue line). Our propose shortens the packet delay and improves the overall protocol performance. The figure is produced using T_{ULMAP} interval of 300 ms and T_{UCD} of 9 sec. N_{TRROPP_MAX} is 6, the mean number of transmission opportunities per frame is 3 and CWmin = 16.

In Figure 2 we compare the mean packet delay due to the collision avoidance algorithm. Pairs of red (original protocol) and blue (improved protocol) lines denote the delay dependence for different values of the Ntrropp. The CWmin is used as a curve parameter. Obviously, the new algorithm introduces a performance gain: all blue lines are lower than the appropriate red lines. On the other hand, increasing the CWmin introduces larger delays in both cases. Fig.3 emphasizes the UCD interval influence over the collision-avoidance delay. While the Tucd does not impact the classical protocol delay (red lines), it has a strong influence over the proposed method. A direct comparison of the performance improvement (delay gain defined as delay difference that two methods introduce) with the introduction of our proposed method is depicted in Figure 4.

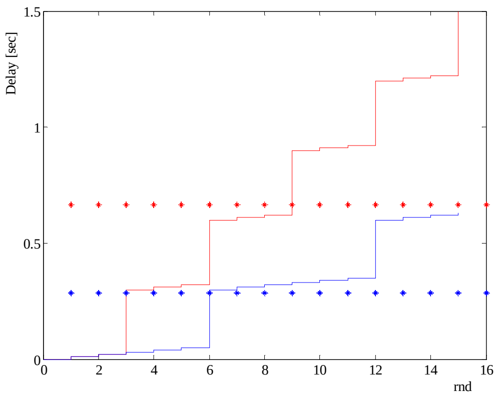

Figure 1. Delay vs. *rnd*

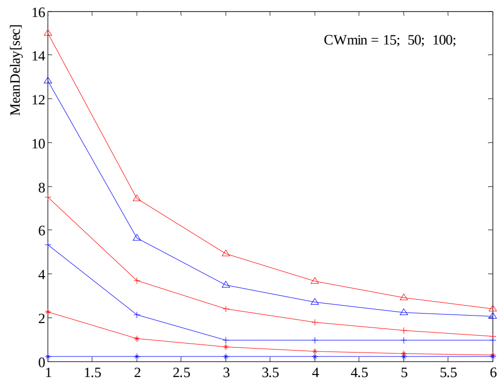

Figure 2. Mean Delay vs. N_{TRROPP} (parameter CWmin)

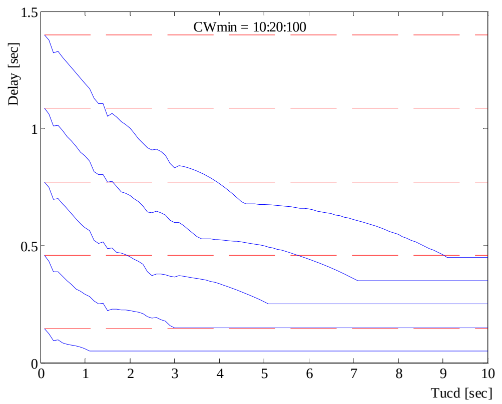

Figure 3. Delay vs. Tucd (parameter CWmin)

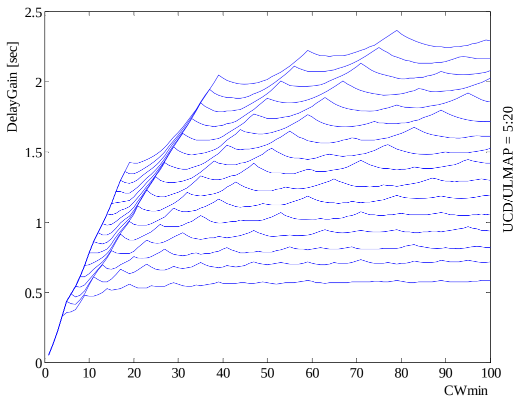

Figure 4. Delay Gain vs. CWmin

6. Conclusions

The communication protocol engineering and protocol optimization is not an easy task. Although many protocol parameters can be altered targeting an improvement, not all the ideas are applicable and relevant. Here we have put an effort to define a new protocol algorithm utilizable in the network entry process of the IEEE 802.16 communication system. The main idea was to improve the network entry delay, meaning its shortening. In such a way WiMax user will wait less during its entering the network which implicates better communication system's QoS. In this paper we have proposed a new WiMax network entry procedure using UCD-aware initial ranging transmission opportunity slots distribution. The testing results show a reduction of the network entry delay and an improvement of the system performance. There are many parameters that influence over the network performance and need to be optimized: DCD and UCD time period, DCD and UCD relative phase, initial ranging slot duration, initial ranging slot number, backoff window parameters, Tucd/Tulmap ratio, etc. The proposed algorithm is a result of the optimization of all these parameters.

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