Mathematical Derivation of Ranging Collision Probability and Period in WiBro System

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ABSTRACT

In this paper, ranging code collision probability and ranging period which are two important performance measures for code division multiple access (CDMA)-type ranging in wireless broadband (WiBro) system are mathematically derived. Based on the analysis, the appropriate ranging management solution for maintaining the ranging collision probability below a certain threshold level and correctly recognizing the transmitted ranging code against propagation delay is obtained in terms of the number of ranging codes, the number of ranging regions, and ranging period. In this analysis, user mobility features such as speed and moving direction are also considered.

Key Words : Ranging, OFDMA, WiBro, IEEE 802.16

Ⅰ. Introduction

The ranging schemes have been used for timing synchronization and power control between an access point (AP) and a subscriber station (SS) in wireless local area network (WLAN)- and wireless metropolitan area network (WMAN)-family systems. In addition, the ranging is also employed for bandwidth request and handoffs in WiBro which is a new portable internet services in Korea based on the standardization of IEEE 802.16 for WMAN[1]-[3]. From the primary roles of ranging, the ranging optimization problem has been considered as one of the important topics.

Especially, because ranging collisions may induce severe errors in demodulation/decoding at the receiver, collision avoidance solutions have been intensively studied[4]-[6]. H. Minn et al.[7] used orthogonality principle and best channel identification conditions in order to mitigate the ranging collision and then improve ranging signal detection. X. Fu et al.[8] proposed a TDMA-type preamble scheme for synchronization in orthogonal frequency division multiple access (OFDMA) uplink. It allocates K time-slots to K users, so the collision never occurs. On the other hand, WiBro adopts a CDMA-type ranging in which each user is identified by a ranging code he selects among a Pseudo Noise (PN) code set. Thus, when a ranging code is selected by two or more than two users, then AP cannot recognize the ranging user which is called a ranging collision. As a simple approach, increasing the number of ranging codes can reduce the likelihood of ranging collision. This approach, however, induces high implementation cost and hardware complexity.

Ranging period is also an important system parameter. Shorter ranging period yields more accurate timing synchronization and power control, but requires larger ranging overhead. Thus, efficient management of periodic ranging is also one of the much focused research areas. However, studies on periodic ranging have mostly concentrated on power

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management[5]-[6]. The appropriate value for the ranging period as the function of radio propagation delay and user mobility has not been extensively addressed in the literature.

In this paper, ranging code collision probability and ranging period which are two important performance measures for CDMA-type ranging in WiBro system are mathematically derived. Based on the analysis, the appropriate ranging management solution for maintaining the ranging collision probability below a certain threshold level and correctly recognizing the transmitted ranging code against propagation delay is obtained in terms of the number of ranging codes, the number of ranging regions, and ranging period. In this analysis, user mobility features such as speed and moving direction are considered.

The remainder of this paper is organized as follows. Section 2 briefly describes the channel architecture and ranging scheme of WiBro. A mathematical model to derive the ranging collision probability is given in Section 3. The optimum ranging period considering user mobility is derived in Section 4. Finally, Section 5 presents some conclusions.

Ⅱ. WiBro System and Ranging Description

Fig. 1 shows the WiBro channel architecture. The basic transfer unit is a frame with a length of 5 ms, which is divided into uplink and downlink sub-frames. WiBro adopts OFDMA with 1024 orthogonal subcarriers, among which 864 subcarriers are used as available user tones. And one time-slot corresponds to an orthogonal frequency division multiplexing (OFDM) symbol with a length of 115.2μs[1]-[3].

In WiBro, ranging processes are categorized into 4 types according to the purpose: initial, periodic, bandwidth request, and handoff. The initial and the periodic ranging processes are used to finely adjust the timing synchronization and transmission power at the initial network entry and periodically during normal operation, respectively. The signaling procedures related to bandwidth request and handoff are also undertaken by ranging processes[1]-[2].

In the ranging process, a SS selects a ranging code

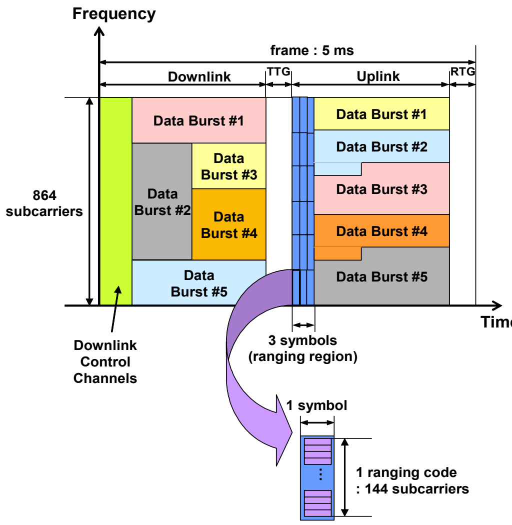

Fig. 1. WiBro Channel Architecture.

randomly among a code-set, which consists of orthogonal 144-bits length PN codes. The code-set is subdivided into 4 subsets according to the ranging type. The SS then transmits the selected ranging code through the ranging region, which is also randomly selected among the control field of 3-OFDM symbols at the beginning of the uplink sub-frame, as shown in Fig.1. Because binary phase shift keying (BPSK) modulation is used, 144 subcarriers are used to transmit a 144-bits ranging code[1]-[3]. Accordingly, 6 ranging codes can be transmitted via 864 subcarriers during one OFDM symbol, which means there are totally 18 ranging regions within 3-OFDM-symbol duration. The AP then refers to the received PN code in order to obtain synchronization and power control information. If the synchronization disagreement and the power level are within an acceptable region, the AP notifies the ranging success by sending a control message. Otherwise, the AP sends the corrected values of synchronization and power via a control message, and the SS then corrects the errors in timing synchronization and power level. The SS repeats the ranging process until it receives a ranging success message from the AP.

Due to the limited number of ranging codes and ranging regions, users compete with each other for ranging. In the ranging competition, the AP identifies the user which is trying a ranging using both the ranging code and the ranging region. Thus, AP first should recognize which ranging code is transmitted in each ranging region. To do this, the AP operates a parallel auto-correlation upon the received ranging code with candidate PN codes and then selects the code having the highest correlation value. If more than two SSs select the same ranging code and moreover transmit it through the same ranging region, then a ranging collision occurs. However, the AP can not recognize the collision and just takes the highest power-level one among the competitors. The competing SSs either can not recognize the collision. Hence, only the SS having the highest power can be successful in the ranging competition and the other stations inaccurately adjust their timing synchronization and power strength according to the winner's ones. This collision may induce severe errors in demodulation and decoding.

Ⅲ. Ranging Collision Probability

In this section, the ranging collision probability is mathematically derived from two different points of view: AP's and SS's view. First, the ranging collision probability from the AP's point of view, which is called the AP-view collision probability, is defined by the probability that a AP finds a ranging collision within a frame.

Let m, r, and n be the number of ranging codes, ranging regions, and ranging users, respectively. Because a SS has two selection items, the ranging code and ranging region, the number of raging code-region pairs among which SS selects one is $N_c = m \times r$. Then the number of cases that n users select ranging code-region pairs is N_c^n . To avoid the collision, all n users select different ranging code-region pairs and the number of cases is ${}_{N_c}P_n$. Therefore, the AP-view ranging collision probability is

$$P_{c\_AP} = \begin{cases} 1 - \dfrac{{}_{N_c}P_n}{N_c^n} & , m \times r \geq n \\ 1 & , m \times r < n \end{cases} \qquad (1)$$

where P represents the permutation as ${}_aP_b = \dfrac{a!}{(a-b)!}$.

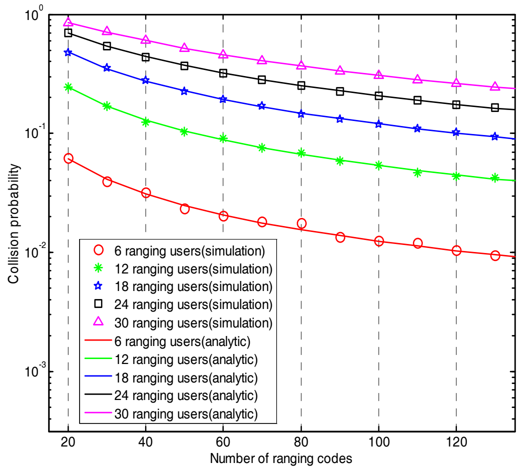

Fig. 2. AP-view Collision Probability (The number of ranging regions is 12).

Fig. 2 shows the AP-view collision probability versus the number of ranging codes for various numbers of ranging users. We don't specify a ranging type because the results are independent of the ranging type. As we seen in Fig. 2, the analytic and simulation results are agreed well each other. As expected, the collision probability decreases as the number of ranging codes increases and as the number of ranging users decreases. The slope of probability are gradually decreased as the number of ranging codes increases. It means that the gain obtained from collision probability reduction at the cost of hardware complexity become smaller as the number of ranging codes increases. Therefore, the hardware implementation cost required for parallel operations of autocorrelation at AP should be jointly considered in deciding the number of ranging codes.

Meanwhile, the ranging collision probability from the SS's point of view, which is called the SS-view collision probability, is defined by the probability that a SS's ranging attempt experiences a collision. For simplicity of explanation, the users are numbered by starting from $user_1$ and ending with $user_n$, i.e., $user_1$, $user_2, \cdots$ $user_n$. Let $user_1$ select one ranging code-region pair among N_c cases. A collision occurs when at least one user among the remaining users, $user_2, \cdots$ $user_n$ selects the same ranging code-region as $user_1$. First, let us consider the case that $user_2$

selects the same ranging code-region pair as $user_1$ which is the sufficient condition for ranging collision.

Thus whatever the remaining users, $user_3, \cdots user_n$, select the collision occurs and the number of cases that the remaining users, $user_3, \cdots user_n$, select ranging code-region pairs is N_c^{n-2}. Second, let us consider the case that $user_2$ selects different one and $user_3$ selects the same one as $user_1$. Then the number of cases for such kind of situation is $(N_c-1)N_c^{n-3}$, where N_c-1 is the number of cases $user_2$ selects a ranging code-region pair except for $user_1$'s one and N_c^{n-3} represents the number of cases the users, $user_4, \cdots user_n$ select ranging code-region pairs. We can repeat above mentioned procedure until the case that all the remaining users, $user_2, \cdots, user_{n-1}$, select the different one from $user_1$ and only the last $user_n$ selects the same one as $user_1$. Then the SS-view collision probability is finally derived by

$$P_{c\_SS} = \frac{N_c[N_c^{n-2}+(N_c-1)N_c^{n-3}+(N_c-1)^2N_c^{n-4}+\cdots+(N_c-1)^{n-2}]}{N_c^n} = \frac{\sum_{i=0}^{n-2}(N_c-1)^i \times N_c^{n-2-i}}{N_c^{n-1}}. \qquad (2)$$

In Eq. (2), the N_c at the front of the bracket represents the number of cases for the reference user's ($user_1$ in this example) selection.

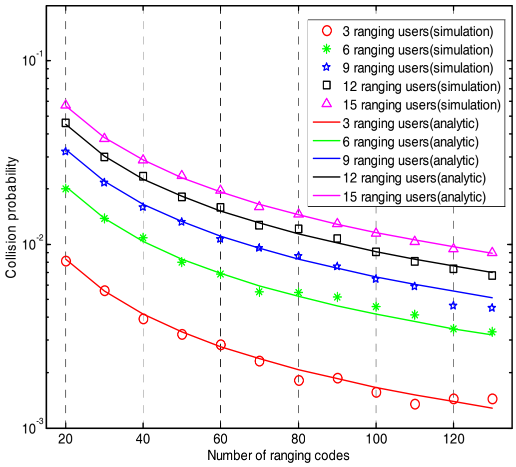

Fig. 3 SS-view Collision Probability (The number of ranging regions is 12).

Fig. 3 shows the SS-view collision probability versus the number of ranging codes for various numbers of ranging users. From this figure we can find the appropriate number of ranging codes to maintain the collision probability below a certain level. For example, when 9 users compete for ranging, at least 70 ranging codes are needed in order to maintain the SS-view collision probability below 1%. Undoubtedly, hardware implementation cost should be jointly considered.

Ⅳ. Ranging Period

Fig. 4 shows the correlation values between ranging code 1 delayed by 0.1T, 0.5T, and 0.9T, and other ranging codes (from ranging code 1 to 50), where T is 1-bit duration. The cases of 0.1T and 0.5T delay do not yield any incorrect recognition of the ranging code because the correlation value with ranging code 1 remains higher than that with any other ranging code. However, when the delay is 0.9T, the correlation value with ranging code 9 is higher rather than that with original one, ranging code 1.

Let the delay, 0.9T be the threshold for incorrect ranging code recognition. Then, in order to avoid incorrect ranging code recognition, the synchronization disagreement by delay should be corrected by a ranging process before it becomes larger than 0.9T. Since the disagreement is mainly caused by propagation de

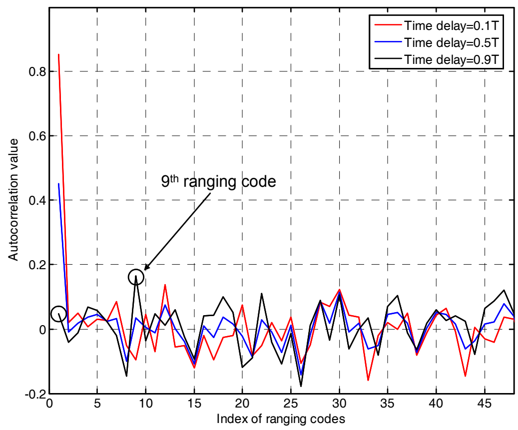

Fig. 4. Autocorrelation value between ranging code 1 and other ranging codes for various time delays.

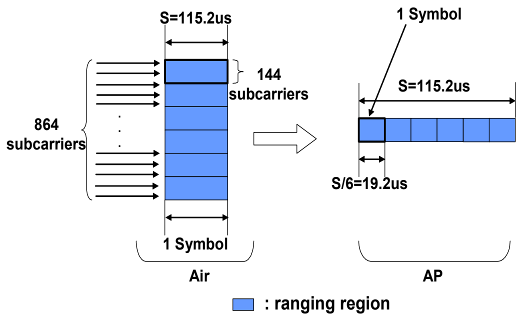

Fig. 5. Ranging code arrangement in transmission through an air interface and after FFT at AP.

lay, the ranging period should be smaller than the time taken by the user to run the radio propagation distance for 0.9T. The boundary value, 0.9, is called the ranging delay threshold, and is denoted by T_{r_th}. The ranging period depends on the user's mobility features such as moving direction and speed. Thus, the relationship should be analyzed in order to determine the appropriate ranging period.

As illustrated in Fig 5, 6 ranging codes are transmitted in parallel by 864 subcarriers during one OFDM symbol-duration of 115.2μs. After passing through the FFT operation at AP, the OFDM symbol is translated to 864-bits sequential data. Thus, a 144-bits ranging code occupies 19.2(=115.2/6)μs. Accordingly, 1 bit duration of ranging code, T, is 0.13333μs(=19.2μs/144). Therefore, the propagation delay threshold is derived as follows:

$$T_{d\_th} = T_{r\_th} \times 0.1333\mu s. \tag{3}$$

The radio propagation distance for T_{d_th} is thus:

$$D_{d\_th} = c \times T_{d\_th} \tag{4}$$

where c is the light velocity of $3 \times 10^8 m/s$.

Now the time taken by users to travel D_{d_th} should be determined. The worst scenario is that a user moves in a straight direction. Therefore, the ranging period threshold to guarantee the correct ranging-code recognition is

$$T_p = \frac{c \times T_{d\_th}}{v} \tag{5}$$

where v is the user speed. The ranging period should be shorter than T_p and the longer the ranging period, the smaller the ranging overhead. Thus, it can be stated that T_p is optimum.

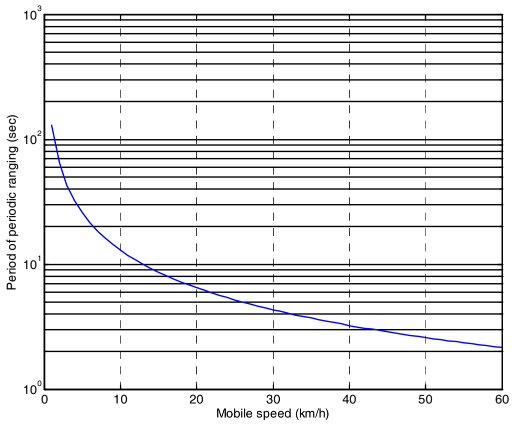

Fig. 6. The optimum ranging period versus the user velocity.

Fig.6 shows the optimum ranging period according to the user speed when T_{r_th} is 0.9T. If we assume WiBro supports user speed up to 60 Km/h. At this maximum speed, the ranging period for this case is about 2 sec, which corresponds to 400 frames.

Ⅴ. Conclusions

We mathematically derived the ranging collision probability of WiBro and analyzed it from two points of view; AP's and SS's view. The AP-view collision probability roughly represents the ratio of the number of collision frames to the total number of frames.

However, the effect of multiple collisions within a frame that may occur was not directly modeled, because the AP-view collision probability considers only whether a frame has a collision or not. On the other hand, the SS-view collision probability represents the ratio of the number of ranging collisions to the total number of ranging trials, and hence closely reflects how many collisions occur. Therefore, when designing the WiBro system in terms of the number of ranging codes and ranging regions, both the AP-view and SS-view should be considered. In addition, the hardware implementation cost for parallel operation of auto-correlation should be jointly analyzed when the optimum number of ranging code is chosen.

We have also found the optimum ranging period. Specifically, the next ranging is required to start before the delay offset of the ranging code becomes larger than the threshold and otherwise it, causes incorrect ranging code recognition. In real systems, the ranging period should be determined considering user mobility such as speed and moving pattern. The analytical and simulation results of this paper can be utilized in designing and evaluating the ranging performances of IEEE 802.16-based system.

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