A Fast Bandwidth Request and Grant Method for IEEE 802.16 OFDMA/TDD Systems

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***Abstract*—In the design of a contention-based bandwidth request scheme, decrease in data transmission delay is the most important factor. This paper proposes a new CDMA-based bandwidth request method in which the bandwidth request code contains the channel quality information and amount of bandwidth required by a mobile station. A mobile station composes the bandwidth code according to the needed bandwidth and current channel situation. The base station allocates uplink bandwidth depending on the received code. Also, the proposed method adopts a negative acknowledgement method that determines whether a transmitted code has been successfully detected by the base station. The results of the performance analysis show that the proposed method can reduce delay in data transmissions.**

Keywords-ranging; bandwidth request; uplink scheduling.

I. Introduction

In IEEE 802.16[1], a Base Station (BS) performs an uplink Bandwidth Request (BR) and grants scheduling with the intent of providing each Mobile Station (MS) with bandwidth for uplink transmissions or opportunities to request bandwidth. The MS should reserve the required bandwidth before transmitting data to the BS according to its scheduling type [2] [3]. The request is used to indicate to the BS that the MS needs an uplink bandwidth allocation. By specifying the scheduling type and its associated QoS parameters, a BS can anticipate the throughput and latency needs of the uplink traffic and provide polls or grants at the appropriate times. IEEE 802.16 supports five scheduling types: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), extended rtPS, non-real-time Polling Service (nrtPS), and best effort (BE) service. UGS, rtPS, and extended rtPS are designed to support real-time uplink services that transport fixed-sized or variable-sized data [4]. The BS provides periodic uplink allocations or transmission opportunity for them. For nrtPS and BE, MSs competitively request uplink bandwidth allocations by using a contention-based method [5]-[7]. The BS allocates an uplink bandwidth to successful requests.

In the design of a contention-based BR, three factors must be considered. First, it must have a short signaling procedure. If the signaling procedure for a BR is lengthy, the delay in data transmission is increased. Second, it has to accept many requests with fewer contention resources. Third, it has to provide an acknowledgment method for an MS to decide whether its request was successfully transmitted to the BS.

In this paper, we propose a new CDMA-based BR method to meet these factors. The rest of the paper is organized as follows. In Section II, we describe the contention-based BR methods in IEEE 802.16 Orthogonal Frequency Division Multiple Access (OFDMA). We propose a new CDMA-based BR method and an acknowledgement method in Section III. A mathematical performance evaluation is presented in Section IV. Finally, conclusions are drawn in Section V.

II. BR Method in IEEE 802.16 OFDMA

The IEEE 802.16 OFDMA system supports two contention-based BR methods: a BR message-based contention method and CDMA-based contention method [1].

In the BR message-based method shown in Fig. 1, when MSs need to ask for an uplink bandwidth allocation, they send BR messages on randomly selected contention channels. The BR message includes the number of bytes of bandwidth requested by the MS. The contention channels are composed of two slots and are dynamically allocated by the BS. Upon receipt of the BR message, the BS broadcasts an UL_MAP containing the information regarding the bandwidth allocation. The MS transmits data by using the allocated bandwidth. This BR method has a short signaling procedure, and can reduce the delay for the BR. However, to avoid performance degradation due to collisions, the BS has to allocate many contention channels.

In the CDMA-based method, a BS allocates ranging channels and a set of BR codes for the BRs. Upon needing to request a bandwidth, as shown in Fig. 2, the MS selects a BR code from the code set with equal probability and generates a CDMA code corresponding to the BR code. The CDMA code is modulated and transmitted on a randomly selected ranging channel composed of six slots. After

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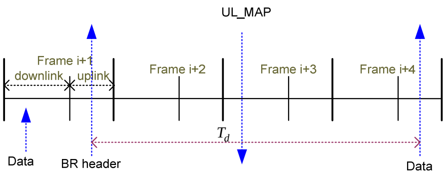

Fig. 1. BR message based BR method in IEEE 802.16

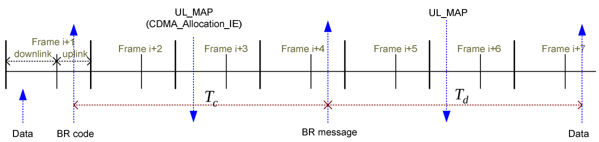

Fig. 2. CDMA-based BR method in IEEE 802.16

detection of the code, the BS provides an uplink bandwidth with CDMA_Allocation_IE, which specifies the identification parameters, namely, the BR code, frame number, symbol number, and subchannel number used by the MS for transmission of the CDMA code. This allows an MS to determine whether it has been given an allocation by matching these parameters with the parameters it used. The MS uses the allocation to transmit a BR message. The BS allocates an uplink bandwidth requested with the BR message. In this method, the BR code is used only to request a bandwidth allocation for a BR message, and thus the delay in the signaling procedure is increased.

In the contention-based BR method, The BS transmits CDMA_Allocaton_IE or uplink_allocation_IE as a positive acknowledgment of successfully received requests. However, IEEE 802.16 OFDMA does not provide a method enabling the MS to determine whether its request is unsuccessfully transmitted to the BS. In the CDMA-based BR method, the MS sets a predefined timer T3 upon transmitting a BR code, and waits for CDMA_Allocation_IE. The default value of T3 in the IEEE 802.16 OFDMA is 60ms, which is 12 frames in a unit frame of 5ms. After the expiration of T3, the MS regards the transmitted code as failed and retransmits a new ranging code. It increases the processing time of the BR signaling procedure, and the system performance is deteriorated by increasing the delay for data transmission.

III. The Proposed BR Method and Negative Acknowledgment Method

We propose a new CDMA-based BR method to improve the BR method of the IEEE 802.16 OFDMA. The proposed method is designed for Time Division Duplex (TDD) systems of IEEE 802.16 OFDMA. We also propose a method to enable an MS to determine whether its BR code was successfully transmitted to the BS.

A. The Proposed BR method

In the proposed BR method, the BR code indicates the amount of uplink bandwidth, and Modulation and Coding Scheme (MCS), required by the MS. Fig. 3 shows the procedure of the proposed BR method. When

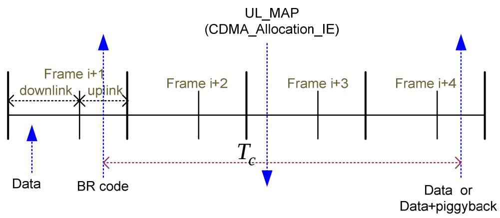

Fig. 3. The signaling procedure of the proposed method.

Table 1. UIUC number to MCS level.

MCS code	UIUC #	MCS	M (bytes)
0	1	QPSK1/2	6
1	2	QPSK3/4	9
2	3	16QAM1/2	12
3	4	16QAM2/3	16
4	5	16QAM3/4	18
5	6	64QAM2/3	24
6	7	64QAM3/4	27
7	8	64QAM5/6	30

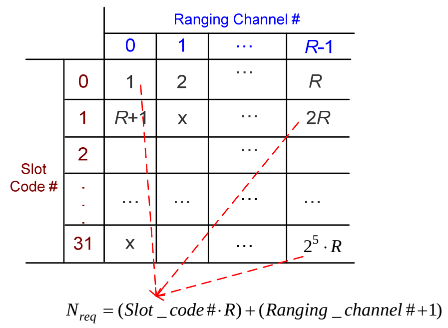

Fig. 4. Delivery method of N_{req}

uplink data is generated, the MS composes a BR code that depends on the MCS level and number of slots required for the data transmission. The CDMA code corresponding to the BR code is transmitted to the BS. Upon detecting the BR code, the BS calculates and allocates the amount of bandwidth requested by the code. In IEEE 802.16 OFDMA, the uplink allocation that is provided using CDMA_Allocation_IE can be used to transmit a BR message or data [1]. The MS transmits data with the allocated bandwidth. In this signaling procedure, the transmission of a BR message is omitted because the BR code presents the information regarding the necessary amount of bandwidth and Channel Quality Information (CQI).

The composition method of the BR code is as follows. The length of a BR code is 8 bits in IEEE 802.16 OFDMA. The proposed BR method classifies the 8-bit BR code into a 3-bit MCS code region and a 5-bit slot code. The MCS code region is used to indicate a MCS code value corresponding to an Uplink Interval Usage Code (UIUC). The slot code region is used to calculate the number of requested slots.

In IEEE 802.16 OFDMA, UIUC 1-10 is used to present the MCS level of an allocated bandwidth for data and the configuration is broadcast via an Uplink Channel Descriptor

(UCD) message. The 3-bit MCS code corresponds to an UIUC, an example of which is shown in Table 1. Generally, in TDD systems, the uplink CQI can be estimated by the downlink CQI because of channel reciprocity [8]. The MS determines the UIUC number based on the measured downlink CQI and chooses an MCS code corresponding to the UIUC number. If the UIUC number is larger than 8, the MCS code is set as 7. This may limit the efficient use of bandwidth.

After choosing the MCS code, the MS calculates the number of slots N_{req} required to transmit the uplink data, which is given by

$$N_{req} = \left\lceil \frac{Data\_Size(bytes)}{M_i} \right\rceil, \quad (1)$$

where M_i is the number of bytes that one slot can transmit when the MCS code is i. As shown in Fig. 4, N_{req} is presented with the slot code number and the ranging channel number where the BR code will be transmitted. By using the 5-bit slot code and the total number of ranging channels, R, the MS can request uplink slots up to the maximum N_{req}, which is $2^5 \cdot R$.

The slot code number is given by

$$\begin{aligned} & Slot\_code\# = \frac{N_{req}-1}{R}, \\ & where\ \ if\,(N_{req} > N_{\max}) \\ & \qquad N_{req} = \frac{N_{req}}{\frac{N_{req}}{N_{\max}}+1}. \end{aligned} \quad (2)$$

If N_{req} is greater than $N_{\max}$, the MS requests additional bandwidth by piggybacking a BR message with data when the CDMA_Allocation_IE has been received. In this case, the data transmission delay is equal to that of the legacy IEEE 802.16.

The MS composes a BR code with the calculated MCS code and slot code. In this paper, we assume that all of the codes are used for the BR scheme. The MS produces a CDMA code corresponding to the BR code and chooses a ranging channel number to transmit it.

$$Ranging\_Channel\# = (N_{req}-1)\%R \quad (3)$$

The BS chooses the BR code from the successfully detected CDMA code and retrieves the MCS code number and slot code number from it. The number of slots requested by the BR code is calculated with the slot code and the ranging channel where the BR code was received.

$$N_{req} = (Slot\_code\# \cdot R) + Ranging\_Channel\# + 1 \quad (4)$$

The BS allocates uplink bandwidth up to N_{req} with an MCS level corresponding to the MCS code number.

For collision resolution, the proposed method uses the same truncated binary exponential algorithm as IEEE 802.16, in which the initial window, W_0, is $R \cdot l$, where l

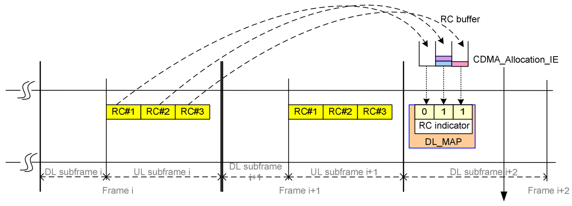

Fig. 5. CDMA-based BR method in IEEE 802.16.

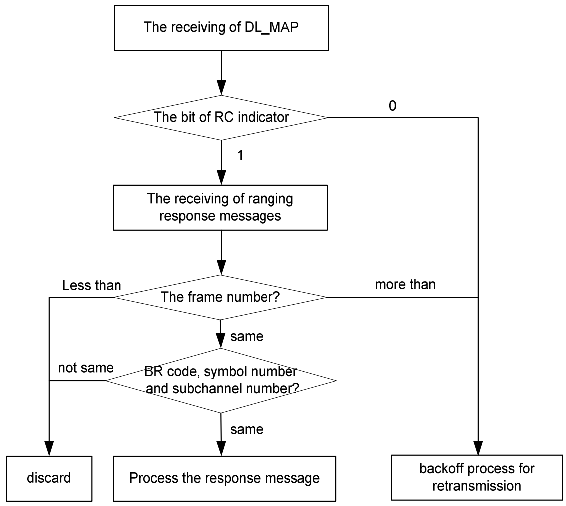

Fig. 6. The BR code structure

is a natural number.

B. *The Proposed Acknowledgment Method*

This paper proposes an acknowledgment method that enables an MS to determine whether its BR code is successfully transmitted. The proposed method uses the Ranging Channel (RC) indicator and frame number for the negative acknowledgment.

We propose adding an RC indicator field to DL_MAP. As shown in Fig. 5, the RC indicator reveals that an RC in the previous frames has the successfully received BR codes. After detecting the BR codes transmitted on each RC, the BS stores them in an RC buffer in the order in which they are received. Each RC buffer corresponds to one RC and one bit of the RC indicator. The length of the RC indicator is equal to the number of RCs. If there is a BR code stored in an RC buffer, the BS sets the corresponding bit of an RC indicator as 1. Otherwise, this value is set as 0.

The frame number is used for the negative acknowledgement in the conjunction with an RC indicator. In the IEEE 802.16, BR codes have no service priority. In this paper, the BS serves the BR codes stored in the RC buffer on a first-in-first-out basis. The CDMA_Allocation_IE contains the frame number for when the BR code was received. Thus, the BS transmits the CDMA_Allocation_IEs in an ascending sequence of frame numbers

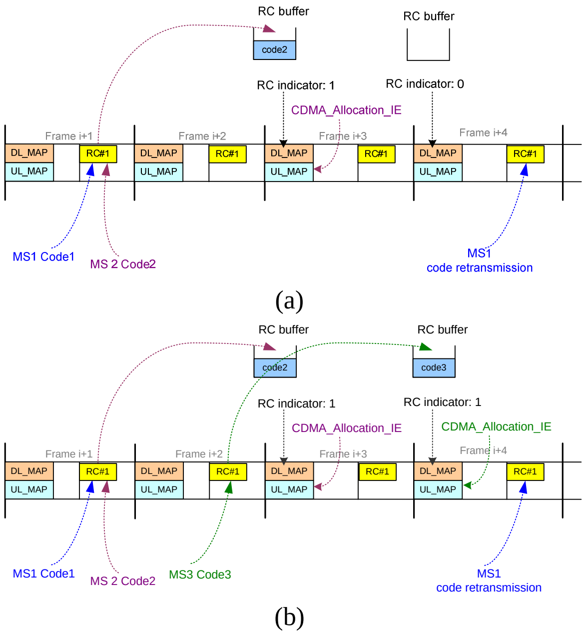

Fig. 7. The signaling procedure of the proposed method.

Fig. 6 shows the process in which an MS determines whether its BR code is successfully transmitted. First, the MS checks the bit of the RC indicator that corresponds to the RC number used to send its BR code. The MS considers a zero value as a negative acknowledgment of the transmitted code, and uses a truncated binary exponential binary backoff algorithm to perform the same retransmission procedure as that of IEEE 802.16. Otherwise, the MS receives CDMA_Allocation_IEs and compares their frame numbers with the frame number for when the BR code was sent. If the frame number of a CDMA_Allocation_IE is larger, the MS regards it as a negative acknowledgment and starts the retransmission procedure. If the frame number, BR code, symbol number, and subchannel number of the MS are the same as those of a CDMA_Allocation_IE, the MS processes the CDMA_Allocation_IE as a positive acknowledgment.

Examples of a CDMA-based BR with the proposed negative acknowledgement method are shown in Fig. 7. In these examples, we assume that only one RC is allocated for the BR method. As shown in Fig. 7(a), MS1 and MS2 transmit BR code 1 and code 2, respectively, in the $(i+1)^{th}$ frame. Code 2 is successfully detected at the BS, but Code 1 is not. The BS sets an RC indicator as 1 because the RC buffer has the received code 2 and sends the RC indicator and CDMA_Allocation_IE. Because the RC indicator is 1, MS1 and MS2 receive and check CDMA_Allocation_IE. MS2 acknowledges the successful code transmission by CDMA_Allocation_IE. MS1 does not receive any acknowledgment and continues the receiving process in the subsequent frames. The BS sets the RC indicator as 0 in the $(i+4)^{th}$ frame because the RC buffer is empty. MS1 perceives the failure of the code transmission by checking the RC indicator and retransmits a new BR code. In the same situation as in Fig. 7(a), Fig. 7(b) shows the case where MS3 transmits BR code 3 in the $(i+2)^{th}$ frame. The BS sends the RC indicator set as 1 and CDMA_Allocation_IE to the BR code 3 in the $(i+4)^{th}$ frame. MS1 compares the frame number of CDMA_Allocation_IE with the frame number used to transmit its BR code. Because the frame number of CDMA_Allocation_IE is larger, MS1 regards it as a negative acknowledgment and performs the retransmission process.

IV. NUMERICAL ANALISIS AND RESULTS

We assume a perfect channel and equal receiver power and consider that the data size is generated with exponential distribution. The CDMA code corresponding to the BR code is modulated using binary phase-shift keying and transmitted on 144 subcarriers [8]. When K_r different BR codes are transmitted on the r^{th} ranging channel, the received CDMA code sequence $s_1, s_2, \cdots, s_{144}$ is equal to the sum of the transmitted CDMA code sequence $c_{k,1}, c_{k,2}, \cdots, c_{k,144}$, which is given by

$$s_i = \sum_{k=1}^{K_r} c_{k,i}\,, \qquad c_{k,i} \in \{-1, +1\}. \tag{4}$$

The detection of a CDMA code is performed by exploiting its cross-correlation property [9]. If the scalar product of the received code sequence and CDMA code exceeds a certain threshold, T, the BR code that corresponds to the CDMA code is detected as transmitted [10].

The scalar product of the received CDMA codes and the CDMA code that is transmitted by an MS is given by

$$s \cdot c_j = \sum_{k=1}^{K_i} \sum_{i=1}^{144} c_{k,i} \cdot c_{j,i} = 144 + \sum_{k=1, k \neq j}^{K_i} \sum_{i=1}^{144} c_{k,i} \cdot c_{j,i}\,. \tag{5}$$

The product $c_{k,i} \cdot c_{j,i}$ is equal to the random variable $2 \cdot R_b - 1$ where R_b is a Bernoulli random variable with the probability, P_b, of 0.5. Equation (5) is replaced with

$$s \cdot c_j = 2 \sum_{b=1}^{144(K_r-1)} R_b - 144(K_r - 2)\,. \tag{6}$$

If the scalar product is less than the threshold, T, the CDMA code is not detected. The probability, P_f, of the BS failing to detect the transmitted CDMA code is given by

$$P_f = \sum_{x=0}^{Q-1} \binom{144(K_r-1)}{x} p_b^x (1-p_b)^{144(K_r-1)-x}, \qquad Q = \frac{T + 144(K_r-2)}{2}. \tag{7}$$

In the legacy CDMA-based method, the transmission of two or more of the same BR codes in the same RC causes a collision. When BW codes of K users that is equal to

$K_1 + K_2 \cdots + K_R$ are transmitted, the collision probability is given by

$$P_c = 1 - \sum_{k=0}^{K-1} \binom{K-1}{k} (1/Bs)^k (1-1/Bs)^{K-1-k} (1-1/R)^k, \quad (8\text{-}1)$$

where Bs is the total number of codes allocated for the bandwidth request procedure.

In the proposed method, if two or more identical BR codes composed of the same MCS and slot code are transmitted in the same RC, a collision occurs and the probability is given by

$$P_c = 1 - \sum_{k=0}^{K-1} \binom{K-1}{k} (1/U)^k (1-1/U)^{K-1-k} (1-1/N_{\max})^k, \quad (8\text{-}2)$$

where U is the number of MCS code types.

The probability, P_s, of a BR code being delivered to the BS without a collision and being successfully detected is given by

$$P_s = (1-P_c)(1-P_f). \quad (9\text{-}1)$$

In the BR message based method, when only one BR message is transmitted in one contention channel, successful transmission is achieved and the P_s is obtained by

$$P_s = (1-1/C)^{K-1}, \quad (9\text{-}2)$$

where C is the total number of contention channels and is equal to $3 \cdot R$.

Before transmitting a BR code, the MS performs a backoff process with the initial window, W_0, the maximum window, W_M, and the maximum permissible retries, N_R. Let $W(n)$ denote the average contention window after a n^{th} collision. We have

$$W(n) = \frac{\min(W_0 \cdot 2^{n-1}, W_M) - 1}{2}, \quad 1 < n < N_R. \quad (10)$$

Data transmission delay in the legacy CDMA-based BR method is presented with T_c and T_d, as shown in Fig. 2. The parameters T_c and T_d are the times for the BR code and BR message procedure, respectively. The mean delay until an MS successfully transmits the data is given by

$$D_{legacy} = \sum_{n=0}^{N_R} \left\{ (1-P_s)^n \cdot P_s \cdot (T_c + T_d + \sum_{j=1}^{n} (T_3 + W(j))) \right\}, \quad (11\text{-}1)$$

where T_3 is a predefined timer to wait for CDMA_Allocation_IE.

In the proposed CDMA-based BR method, when the size of N_{req} is less than $N_{\max}$, the MS requests all the bandwidth for data transmission by the BR code procedure, and the mean delay is given by

$$D_{fast} = \sum_{n=0}^{N_R} \left\{ (1-P_s)^n \cdot P_s \cdot (T_c + \sum_{j=1}^{n} (T_w + W(j))) \right\}. \quad (11\text{-}2)$$

When UIUC type is i, the maximum amount of data that the MS can request through the BR code procedure is given by

$$L_i = M_i \cdot N_{\max}. \quad (12)$$

If the data size is greater than L_i, piggybacking is used to request additional bandwidth. The mean delay is given by

$$D_{slow} = \sum_{n=0}^{N_R} \left\{ (1-P_s)^n \cdot P_s \cdot (T_c + T_d + \sum_{j=1}^{n} (T_w + W(j))) \right\}. \quad (11\text{-}3)$$

In (11-2) and (11-3), the parameter T_w is a waiting timer of CDMA_Allocation_IE. If the proposed negative acknowledgement method is adopted, T_w is at maximum three frames as shown in Fig. 5. Otherwise, it is equal to T_3.

The mean delay of the proposed BR method according to the data size is obtained by

$$D_{pro} = \sum_{i=1}^{U} \frac{1}{U} \left(F_\mu(L_i) \cdot D_{fast} + (1 - F_\mu(L_i)) \cdot D_{normal} \right), \quad (13)$$

where $F_\mu(\cdot)$ is the exponential cumulative distribution function with a mean of μ.

We analyze the performance of the proposed method using Table 2. Fig. 8 shows the probability that an MS successfully transmits a BR message or BR code to the BS in the contention-based BR method. The CDMA-based method has higher probability than that of the BR message-based method when the same number of slots is used. This is because a ranging channel in the CDMA-based method is able to transmit different multiple BR codes using the property of a CDMA code.

Fig. 9 shows the mean delay of the legacy CDMA-based BR method and the proposed CDMA-based BR method without adopting the proposed negative acknowledgement. The proposed BR method can omit the BR message transmission procedure because the BR code contains the information about a MCS level and amount of slots required by the MS. Thus, the proposed BR method can shorten the signaling procedure and reduce the mean delay for data transmission.

In the proposed BR method, when the size of N_{req} is less than $N_{\max}$, the MS can request all the bandwidth for data transmission by the BR code procedure. Thus, if the mean size of data is smaller or the ranging channels are further allocated, the data transmission delay can be reduced as shown in Fig. 10.

Fig. 11 shows the mean delay of the proposed BR method with or without the negative acknowledgement method. If adopting the negative acknowledgement method, the MS can quickly determine whether the BR code was successfully transmitted and start the retransmission procedure faster. Thus, the mean delay is decreased.

V. Conclusion

In this paper, we propose a new CDMA-based BR method and negative acknowledgment method for nrtPS and BE. The proposed BR method matches the BR code to the channel quality and the necessary number of slots. After the receipt of a BR code, the BS allocates the uplink bandwidth requested by the BR code. Also, the proposed negative acknowledgment method uses an RC indicator field in DL_MAP and the frame number of a ranging response message. The RC indicator indicates whether there are any successfully received codes in an RC. The BS sends the response messages to the received codes on a first-in-first-out basis. The MS checks the RC indicator and frame number of the response messages to determine whether the ranging code is unsuccessfully transmitted to the BS. Therefore, the proposed method will be able to support a faster data transmission.

ACKNOWLEDGMENT

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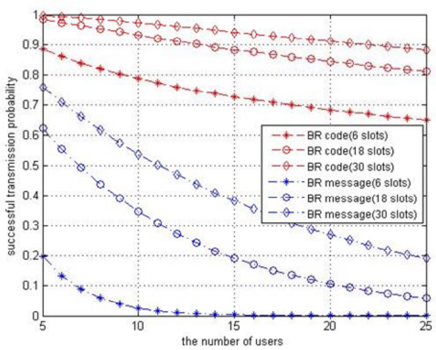

Fig. 8. The Successful transmission probability of BR message and BR code.

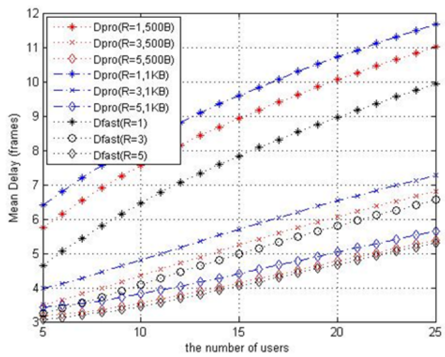

Fig. 10. The mean delay according to the data size (no negative acknowledgement).

Table 2. Parameters for analysis

parameter	value
T_c	3 frames
T_d	3 frames
T_3	12 frames
N_R	5
W_M	$2^4 \cdot R$
W_i	R
Threshold T	110

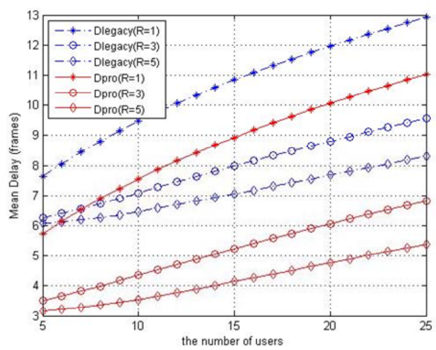

Fig. 9. The mean delay of the legacy BR method and the proposed BR method
(No negative acknowledgement, μ =500 bytes)

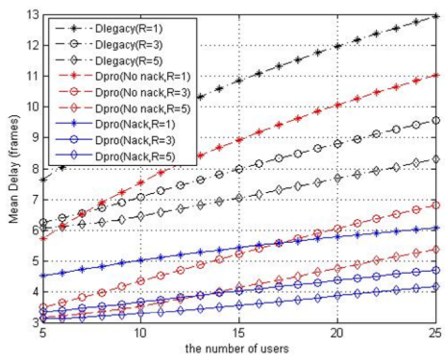

Fig. 11. The mean delay with the proposed negative acknowledgment method (μ =500 bytes).