An Efficient Random Access Scheme for OFDMA Systems with Implicit Message Transmission

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***Abstract*—Random access channel (RACH) is usually used for initial channel access, bandwidth request, etc. In this paper, we analyze the throughput and access delay performance of the RACH in an orthogonal frequency division multiple access (OFDMA) system. A closed-form expression of the RACH throughput is presented and its mean access delays under both binary exponential and uniform backoff policies have also been derived. Moreover, to further improve the utilization of RACH in an OFDMA system, we propose a novel message transmission scheme in a shared RACH. The message in the proposed scheme can be sent implicitly in the cyclic-shifted preambles which make the transmission much more reliable in a contention based RACH. Meanwhile, performance of the preamble detection has also been improved by the redundant information conveyed in messages. Finally, simulation results will demonstrate performance gains of the proposed scheme.**

***Index Terms*—Multiple access, random access channel, resource management, OFDMA, throughput, access delay.**

I. Introduction

ORTHOGONAL frequency division multiplexing (OFDM) has been proposed as one of the prime schemes for multi-user communications. In such OFDM-based systems, the total bandwidth is divided into multiple sub-channels so that multiple access can be accommodated in an orthogonal frequency division multiple access (OFDMA), such as in IEEE802.16d/e [1], [2] and 3GPP long term evolution (LTE) [3]. The main advantage of the OFDMA is that it can provide multiple sub-channels for users to achieve the multi-user diversity by selecting good channels for each user. Moreover, when the OFDMA is applied to the uplink transmission, the divided sub-channels can also alleviate the constraints on power consumption of user terminals when concerning their link budget. Therefore, in the last few years, the OFDMA has attracted more and more attention for its application in uplink wireless communications [4]- [7].

In a practical OFDMA uplink, random access is one of the most popular means for medium access control and random access channel (RACH) is usually used for initial radio access, bandwidth request, location update, etc. Benefited from the flexible sub-channel division within the transmission bandwidth of an OFDMA system, the RACH can also extend randomness from the time and code domains to the frequency domain as well. Thus, the freedom in randomness extension can be exploited to further improve the performance of the RACH in terms of throughput, access delay and signal detection efficiency, etc.

The throughput is an important metric parameter to govern utilization of the RACH. Various contributions have comprehensively studied the throughput of the RACH based on single-channel or multi-channel slotted ALOHA [8]- [10]. However, so far no closed-from expressions of the RACH throughput for the OFDMA systems have been derived in the literature. In this paper, we will analyze the RACH throughput for an OFDMA system concerning access randomness in the time, code and frequency domains.

In addition, the access delay is commonly regarded as another important characteristic parameter to evaluate the stability of random access procedures. Numerical results of access delay have been discussed in several articles, such as [11], [12], but few of them concerned the OFDMA systems. Although average access delay has been studied based on the IEEE802.16d [13], the periodic property of the access was not considered in its analysis models. It is noted that in an OFDMA system the access time can be allocated in periodic mode, which significantly affects the access delay. In this paper, considering this periodic access characteristics, we will derive two delay expectations under both binary exponential and uniform backoff policies.

The information conveyed in the RACH normally consists of preamble and other user specific message. The preamble is used for user identification, while the message contains the basic information about the user's transactions, such as link establishment cause, user priority, and resource request, etc. The design of the random access schemes is always targeted for effective usage of the RACH, i.e., the successful transmissions of the preamble and message from the attempting users.

In this paper, we propose a new implicit message transmission scheme on the RACH in an OFDMA system. The proposed scheme can provide a robust and flexible way to transmit the message along with the preamble. In IEEE802.16d/e, the preambles are classified with different access causes, so a user should first select the preamble group based on the specific cause and then randomly select one within the group. Unlike such a conventional scheme, the preambles of our proposed scheme are uniformly distributed in the pool and the user can randomly select one as the user signature. After that, the message like access causes can be implicitly transmitted in the unique structure of the shifted preamble. Meanwhile, the

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detection of the implicit message in our proposed scheme can be combined with the signature identification. Therefore, the additional detection complexity can be almost neglected.

The rest of this paper can be outlined as follows. Section II gives the system model and Section III analyzes the throughput of the RACH as well as the access delay in an OFDMA system. Then, Section IV presents our proposed scheme for the preamble and message transmissions in the RACH. The simulation results of the proposed scheme are given in Section V. Finally, the paper is concluded in Section VI.

II. System Description

In an OFDMA system, the sub-carriers are grouped into sub-channels and assigned to multiple users for simultaneous transmissions. There are two typical sub-carrier assignment schemes in OFDMA uplink, i.e., localized and distributed schemes. The localized signal is transmitted using contiguous sub-carriers, mainly for supporting frequency scheduled transmissions. On the other hand, the distributed signal is transmitted using scattered sub-carriers, aiming to achieve frequency diversity. The localized scheme is more attractive in practice for its robustness against multiple access interference (MAI) [3]. Thus, in this paper, our study focuses mainly on the localized scheme.

The RACH in the OFDMA system can be multiplexed with data transmission channel by TDM/FDM scheme periodically. Since the OFDMA system can provide small granularity in the frequency domain, the RACH can be shared in the time and frequency domains. For example, as illustrated in Figure 1, the RACH is predetermined in the time-frequency unit, and broadcasted to all users by Node-B. The random access durations (RAD) are staggered in the data slots, and each RAD consists of a number of random access slots (RAS). If there are multiple RACHs, random hopping can be used in the frequency domain. When a user launches the access request in the shared RACH, it should randomly pick up one signature from all available signature sequences which have equal probability to be selected and then send the preamble. If possible, additional corresponding messages can also be attached to the preamble. Otherwise, the message will be transmitted only after successful transmission of the preamble.

Basically, slotted ALOHA scheme has been commonly used for the random access in the OFDMA system and some retransmission policies are employed in case of user collisions. As for the backlogged users, due to the fact that the random access time is periodical, the backoff time counter for the retransmissions is decremented only during the random access time but frozen during the data transmission time. When the backoff timer reaches zero, the user can start the random access trial again.

III. Throughput and Access Delay of RACH

In this section, we should analyze the throughput and access delay of the RACH in an OFDMA system, as described in Section II.

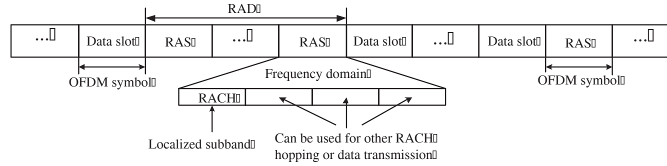


Fig. 1. Time and frequency resource structure of random access.

A. Throughput of RACH in OFDMA System

Assume that the arrivals of new and backlogged users in a RAS follow a Poisson distribution with a mean G. Here, G is also known as the traffic load. Let k be the number of the arrival users in the same access slot. Then, the distribution of k can be written as

$$P(K=k)=\frac{G^k e^{-G}}{k!} \tag{1}$$

Assume also that there are $W=N_sN_fN_c$ resource units for the random access in each access period, where N_s, N_f, N_c are the numbers of the RASs, the sub-channels in each RAS, and the signature codes in each sub-channel, respectively. If all resource units are of equal probability of utilization, then the probability that W resource units are selected by k users can be modeled by a multinomial distribution, i.e.,

$$p_w\left(k\right)=\frac{W^{-k}k!}{\prod\limits_{i=1}^{W}\left(\gamma_i!\right)}, \tag{2}$$

where we have $\sum_{i=1}^{W}\gamma_i=k$ and γ_i $(i=1,2,\cdots,W)$ is the number of users who select the ith resource unit from the W resource units.

The probability of n successfully accessed users out of the k competing users can be modeled by a classical occupancy problem [14], i.e.,

$$\begin{aligned} P_W(n/K=k) &= W^{-k}\sum_{\substack{sum\{\gamma_i\}=k\\ |\{\gamma_i|\gamma_i=1\}|=n}}\frac{k!}{\prod\limits_{i=1}^{W}\left(\gamma_i!\right)} \\ &= \sum_{n\le j\le \min(k,W)}\frac{(-1)^j(W-j)^{k-j}}{(j-n)!(W-j)!(k-j)!} \\ &\quad\cdot\frac{(-1)^n W!k!}{n!W^k} \end{aligned} \tag{3}$$

If we assume perfect detection of the user at Node-B, then throughput S, defined as the average number of the successfully accessed users, can be expressed as

$$S=\sum_{k=1}^{\infty}\sum_{\substack{n=1\\ n\neq k-1}}^{k} nP_W\left\{n|K=k\right\}\frac{G^k e^{-G}}{k!} \tag{4}$$

Figure 2 illustrates the throughput of RACH versus the traffic load G for different W, i.e., resource units per RAS. It can be seen that when $W=1$, the system becomes a single-channel slotted ALOHA system and the maximum throughput is reduced to $1/e=0.368$. On the other hand, if $W=n$, the maximum throughput is increased to n/e.

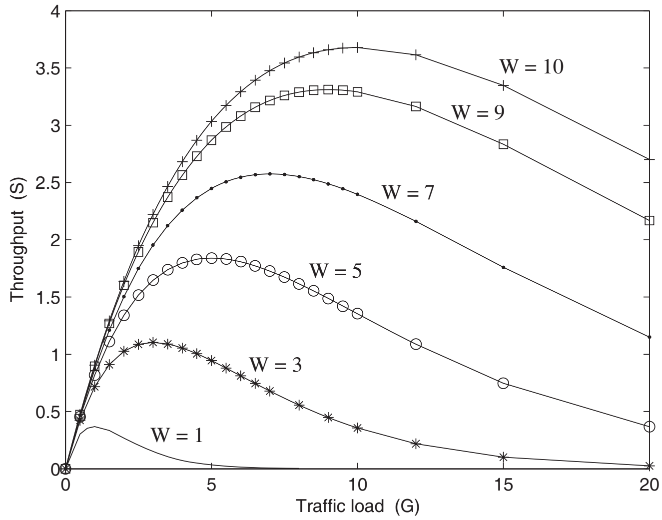


Fig. 2. Throughput of RACH in each RAS.

B. Access Delay in OFDMA System

Let D_i be the time delay before the *i*th retransmission. Here, D_0 is the access delay when the random access is successful at the first attempt. For description simplicity, we neglect the waiting time for acknowledgement feedback from the Node-B. Hence, the total access delay *D* can be given by

$$D = \sum_{i=0}^{R} D_i, \tag{5}$$

where *R* is the number of retransmissions during the random access. When the arrivals of the new and backlogged users are Poisson distributed, *R* can be accurately approximated by a geometric distribution given by [4]

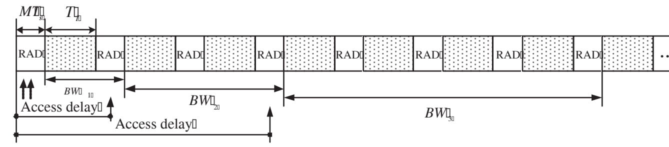
$$P\{R = r\} = p_s(1 - p_s)^r, \tag{6}$$

where *r* is the retransmission times and $p_s = e^{-G/L}$ is the successfully transmission probability.

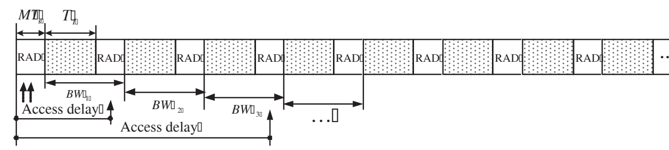
In a real OFDMA system, the RAD may be periodically allocated, such that the periodicity of the RAD should be considered in the analysis of the access delay. Moreover, the retransmission strategy determines the access delay. There are various backoff policies for retransmissions, such as the typical binary exponential and the uniform backoff policies [11], [12], as shown in Figure 3.

In Figure 3, we denote the duration of each RAS as T_s, and the number of the RASs in every RAD as *M*. Assume that the interval of two adjacent RADs is T_I. Then, the periodicity of the RAD is $T_I + M \cdot T_s$. Note that when $T_I = 0$, our analyzed model is the same as the conventional slotted ALOHA scheme.

As illustrated in Figure 3(a), the backoff window size BW in the binary exponential backoff policy increases exponentially. From Figure 3(a) we can see that the backoff window BW_i contains two parts: the access time $2^{i-1}MT_s$ and the frozen time $2^{i-1}T_I$. When a retransmitted user initiates random access in the backoff window, the ω_i-th RAD within the BW_i is randomly picked up, and then the U_i-th RAS in the selected RAD is randomly chosen. Here we know that ω_i and U_i are uniformly distributed in $[1, 2^{i-1}]$ and $[1, M]$, respectively. Suppose that the initial successful transmission delay D_0 is uniformly distributed in $[T_s, MT_s]$. The conditional expected total delay D_B under the binary exponential backoff policy is given by



(a) Binary exponential backoff policy.



(b) Uniform backoff policy.

Fig. 3. Two backoff policies in OFDMA system.

$$E[D_B|R = 0] = E[D_0] = \frac{1 + M}{2} T_s, \tag{7}$$

and

$$\begin{aligned} E[D_B|R = r > 0] &= \sum_{i=1}^{r} E[W_{i,B}] \\ &= \sum_{i=1}^{r} \{\omega_i(T_I + MT_s) + E[U_i]T_s\} \\ &= \frac{(2^r + r - 1)}{2}(T_I + MT_s) \\ &\quad + rE[U_i]T_s \end{aligned} \tag{8}$$

where $W_{i,B}$ is the backoff delay in the *i*th retransmission for the binary exponential backoff policy. Removing the condition on *R*, we obtain the average total delay $\overline{D_B}$ for the binary exponential backoff policy as

$$\begin{aligned} \overline{D_B} &= E[D_B] \\ &= \sum_{r=0}^{\infty} E[D_B|R = r] P\{R = r\} \\ &= \frac{1 + M}{2} T_s \frac{p_s^2 - p_s + 1}{p_s} \\ &\quad + \frac{(T_I + MT_s)}{2} \frac{4p_s - 3p_s^2 - 1}{p_s(2p_s - 1)} \end{aligned} \tag{9}$$

It is noted that in (9) the condition $p_s > 0.5$ must be satisfied to guarantee a finite $\overline{D_B}$.

Comparably, the backoff window size BW_i in the uniform backoff policy is always kept the same. As shown in Figure 3(b), the backoff delay in the *i*th retransmission now becomes $W_{i,U} = i(T_I + MT_s) + U_iT_s$. Therefore, the conditional expected delay D_U for the uniform backoff policy is given by

$$E[D_U|R = 0] = E[D_0] = \frac{1 + M}{2} T_s, \tag{10}$$

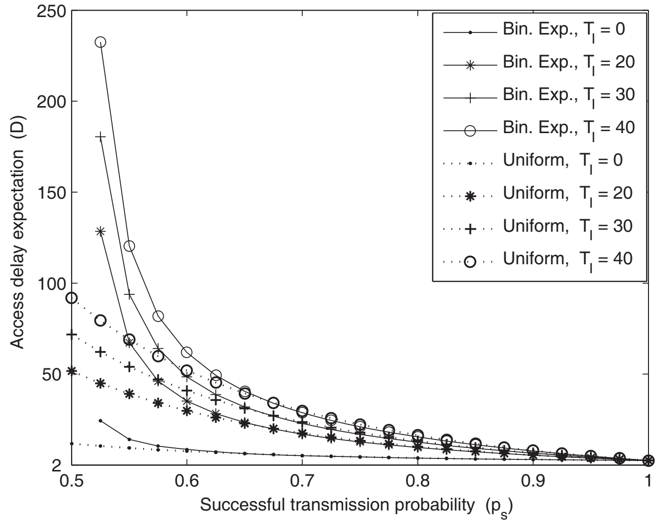


Fig. 4. Delay expectation of binary exponential and uniform backoff policies when $0.5 < p_s < 1$.

and

$$\begin{aligned} E[D_U|R=r>0] &= \sum_{i=1}^{r} E[W_{i,U}] \\ &= \sum_{i=1}^{r} (i(T_I+MT_s)+E[U_i]T_s) \\ &= \frac{(1+r)r}{2}(T_I+MT_s)+rT_sE[U_i] \end{aligned} \tag{11}$$

Similarly, after removing the condition on R, then we can get the average access delay $\overline{D_U}$ for the uniform backoff policy as

$$\begin{aligned} \overline{D_U} &= E[D_U] \\ &= \sum_{r=0}^{\infty} E[D_U|R=r]P\{R=r\} \\ &= \frac{1+M}{2}T_s\frac{p_s^2-p_s+1}{p_s} \\ &\quad +\frac{(1-p_s)}{p_s^2}(T_I+MT_s) \end{aligned} \tag{12}$$

Figure 4 compares the access delays of the above two polices versus successful transmission probability p_s with various T_I. For simplicity, we assume that $T_s = 1$ and $M = 1$. As shown in Figure 4, the difference in the average access delay between the two polices depends largely on p_s. When p_s is small, such as $0.5 < p_s < 0.65$, the average access delay of the binary exponential backoff policy is much larger. However, when p_s is larger, such as $0.7 < p_s < 1$, the difference between the two polices is diminished. Note that when $p_s = 1$, i.e., no retransmission is needed, the access delays for the two policies are the same, as also being observed from the equations (7) and (10).

In general, the number of retransmissions is always limited to $r_{\max}$ in practice and the choice of the variable $r_{\max}$ should consider the balance between the blocking probability and latency. Therefore, we can re-define a practical number of the retransmissions R' and obtain its distribution as [11]

$$\begin{aligned} P\{R'=r\} &= P\{R=r|R\le r_{\max}\} \\ &= \frac{p_s(1-p_s)^r}{1-(1-p_s)^{r_{\max}+1}}, \quad r=0,1,2,...,r_{\max} \end{aligned} \tag{13}$$

Replacing R by R' in the previous results and substitute (13) into (9), (12), we can also obtain the practical and finite expected access delay.

IV. Proposed Random Access Scheme

During the initial access, an attempting user must transmit both the preamble and the message. The message can be either separated [15], [16] from or combined [17], [18] with the preamble. The main disadvantage for the separated transmission mode is its relatively long access delay. Comparably, in the combined transmission mode, the access delay can be reduced but the detection on the message becomes much more vulnerable to the MAI. Although some robust channel coding and long scrambling code schemes can be employed to protect the message, the resource reservation for the message will be greatly increased. Moreover, it is still a considerable challenge to transmit the entire message on the contention-based channel. Therefore, an alternative way of implicit message transmission is proposed, such as used in the IEEE802.16d/e [1], [2]. As described in [1] and [2], the preambles are classified by different access causes which may be initial ranging or bandwidth request, etc. Different from that used in IEEE802.16d/e, all the preambles uniformly distributed in our proposed scheme are randomly selected with equal probability, and then the message is mapped to concatenatedly shifted preambles where the shift size indicates the message bits. In the text followed, we will explain the main procedure of our proposed scheme.

A. Preamble transmission

Signature sequence should provide good correlation property and low peak-to-average power ratio (PAPR). Therefore, in this paper, we use one kind of constant amplitude zero autocorrelation (CAZAC) sequence, namely Zadoff-Chu sequence, as the user signature sequences. The Zadoff-Chu sequence is expressed as [19]

$$C(l) = \begin{cases} \exp(-j\pi l^2\varepsilon/N), & N \text{ is even} \\ \exp(-j\pi l(l+1)\varepsilon/N), & N \text{ is odd} \end{cases} \tag{14}$$

where N is the length of the CAZAC sequence and $l = 0, 1, 2, ..., N-1$ is the sequence index. Moreover, ε must be co-prime with N and ε can be used for signature identity. The signature should be modulated as the preamble on one OFDM symbol and then repeated in the time domain to combat the channel fading and delay.

B. Message transmission

The transmission of the message can be severely affected by the MAI in the shared RACH. Besides, the performance of message demodulation process is also impacted by the accuracy in achieving uplink synchronization, power control and channel estimation in Node-B. Therefore, in order to guarantee correct message demodulation in the RACH with limited resource, we propose to transmit only the small portion of the message along with preamble. While, the remaining message will be transmitted in the scheduled channel.

The message symbols transmitted along with the preamble are cyclic-shifted in the time domain. The shift size of the message symbols can indicate the message information, such as link establishment cause, priority level, resource request, etc. We assume that the length of the message symbol is N', and the unit shift size is q. Hence, the total number of the usable shifted preambles is $L = N'/q$ and the maximum information conveyed in one message symbol is $B = \log_2 L$ bits. For instance, when $N' = 512$ and $q = 16$, the maximum bit transmitted implicitly in the message can be five bits. If the shift size of the message symbol are 0, 16, 32, ..., 496, then the message can be mapped to 00000, 00001, 00010, ..., 11111.

Assume that the length of OFDM symbol is fixed to N'. To increase the message information size *B*, the unit shift size q should be as small as possible. However, in a multipath fading environment, the minimum q is constrained by the delay spread of the channel. Therefore, we should strike for a good trade-off between q and the detection performance of the message. The basic method on setting q is to find the first integer number of sample durations in the preamble that is greater than the maximum delay spread of the channel, and then add some additional guard samples on q to guarantee a good detection performance. Here, practically, the number of guard samples for redundancy can be determined by simulation.

C. User detection in Node-B

In Node-B, the receiver should first identify the preamble of the user, and then detect the corresponding message. Since the message symbol is only a time shifted version of the preamble, the detection of the message and the preamble can be efficiently combined. As a result, there is only a slight complexity increase necessary for the message detection.

The preamble detection is often performed by comparing a pre-determined threshold [20]- [22]. Usually, the threshold can be either a fixed value [20], or adaptive to the instantaneous received energy measured by the preamble [21], [22]. Considering that the adaptive threshold is more robust in the random access detection, in our paper, we chose to use an adaptive threshold which is based on the estimated signal to interference plus noise ratio (SINR). The value of the threshold is determined through the simulation evaluations on both the detection and the false alarm probabilities. Detailed simulation method can be found in [21].

In user detection, the preamble and message are extracted from the dedicated sub-carriers within an appropriate detection window. Let the frequency domain signals from the preamble and message detection widow be $P_p(g)$ and $P_m(g)$, respectively, where $g = 0, 1, 2, ..., N-1$. Note that $P_p(g)$ and $P_m(g)$ may consist of random access signals from multiple users. Therefore, the received signals should be correlated with all possible signature sequences, i.e., multiply with the conjugate of each candidate signature sequence $S_u(g)$ which can be shown as

$$\tilde{H}_{p,u}(g) = P_p(g) \cdot S_u^*(g), \tag{15}$$

and

$$\tilde{H}_{m,u}(g) = P_m(g) \cdot S_u^*(g), \tag{16}$$

where the subscripts *p*, *m*, and *u* indicate the preamble, the message, and the user, respectively.

Next, the estimated channel transfer functions should be transformed to the time domain through an *F*-point IFFT as

$$\tilde{h}_{p,u}(d) = \frac{1}{F} \sum_{g=0}^{N-1} \tilde{H}_{p,u}(g) \cdot e^{j2\pi dg/F}, \tag{17}$$

and

$$\tilde{h}_{m,u}(d) = \frac{1}{F} \sum_{g=0}^{N-1} \tilde{H}_{m,u}(g) \cdot e^{j2\pi dg/F}, \tag{18}$$

where $d = 0, 1, 2, ..., F-1$ and the IFFT size *F* can be chosen as the smallest power-of-2 integer that is larger than *N*. The estimation of the noise plus MAI can be obtained by averaging $|\tilde{h}_{p,u}(d)|^2$ and $|\tilde{h}_{m,u}(d)|^2$, i.e.,

$$\sigma_u^2 = \frac{1}{2F} \sum_{d=0}^{F-1} \left(|\tilde{h}_{p,u}(d)|^2 + |\tilde{h}_{m,u}(d)|^2 \right) \tag{19}$$

Finally, we get the detection variable for the *u*th user calculated as

$$Z_u = \frac{\max\left[|\tilde{h}_{p,u}(d)|^2, |\tilde{h}_{m,u}(d)|^2 \right]}{\sigma_u^2} \tag{20}$$

As shown in Figure 5, the message can be detected by the distance between the main peaks of the preamble and message. The pulses scattered near to the main peak are due to the multipath fading channel and the virtual carriers in the OFDM symbols. The detection variable Z_u should be compared with a pre-determined threshold. If Z_u is larger than the threshold, then the preamble is detected and acquired. In addition, the message of the user can be decoded from the distance between the two peaks of $|\tilde{h}_{p,u}(d)|^2$ and $|\tilde{h}_{m,u}(d)|^2$, as shown in Figure 5. It is noted that the user timing offset and channel estimation can also be estimated from $\tilde{h}_{p,u}(d)$ and $\tilde{h}_{m,u}(d)$. To further improve the detection performance in a multipath fading environment, channel equalization can also be performed on the cyclic-shifted preamble before the message detection.

V. Simulation Results

In the simulations carried out in our study, performance of the proposed scheme is evaluated and compared with the conventional combined transmission scheme. For comparison fairness, both schemes are allocated four OFDM symbols in the same RACH. As illustrated in Figure 6, two of four symbols are assigned for the preamble transmission and the other two are for the message transmission. In the conventional scheme, the message bits are directly modulated and then spread by the CAZAC sequence in the frequency domain at the last two symbols. Comparably, in our proposed scheme,

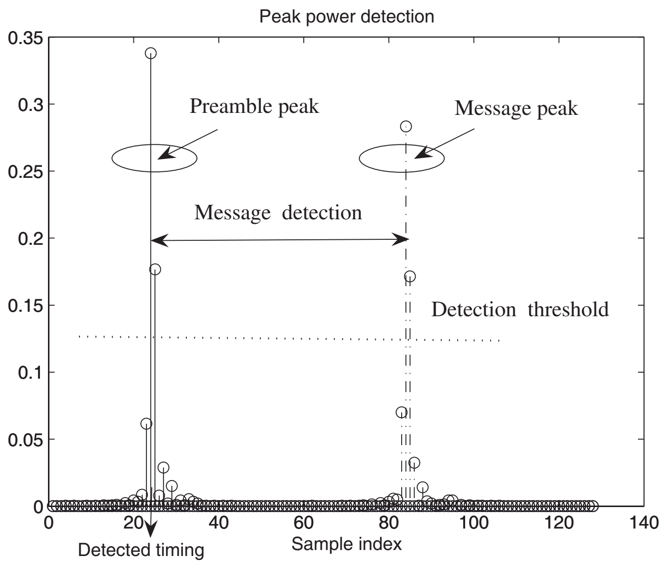
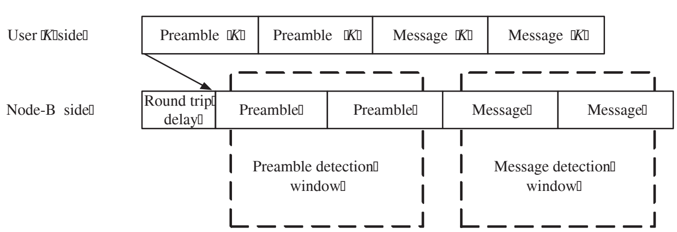
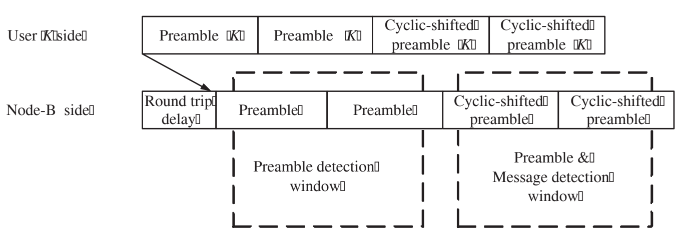


Fig. 5. Peak detection of preamble and message.



(a) Conventional combined transmission scheme.



(b) Proposed implicit message transmission scheme.

Fig. 6. Structures of random access symbols.

the massage is implicitly transmitted on the two symbols of cyclic-shifted preamble.

We assume that the round trip delay will not exceed one symbol duration and received power in Node-B from all the users are kept same. In the simulations, retransmission mechanism and user collisions are not considered, since we assume that the CAZAC sequences selected by the users are all orthogonal. In addition, considering that the ITU channel models are more commonly used in the OFDMA systems like IEEE802.16, in this paper, we concern one typical M.1225 channel model, i.e., the ITU vehicular channel A (ITU-VA) model [23] with ideal and real channel estimations for the message detection. The detailed simulation parameters are specified in Table I. Thus, the preamble detection probability and message detection block error rate (BLER) of the proposed scheme are shown in Figure 7 and Figure 8.

Figure 7 illustrates the preamble detection probability when the false alarm probability is maintained to be 10^{-3}. Here, we assume one or two users competing for the random access.

TABLE I
SIMULATION PARAMETERS

RACH bandwidth	1.25M
FFT size	128
Signature sequence (CAZAC)	Zadoff-Chu
Signature length	73
The number of signatures	16
Simultaneous users	1, 2
Message	5 bits
The minimum shift step (for proposed scheme)	16 samples
Message spreading (for conventional scheme)	Zadoff-Chu, Spreading factor is 13
Message modulation (for conventional scheme)	BPSK
Round trip delay	Random in one OFDM symbol
Tx/Rx	1/1
Channel model	TU6 30 km/hr
Channel equalization	MMSE

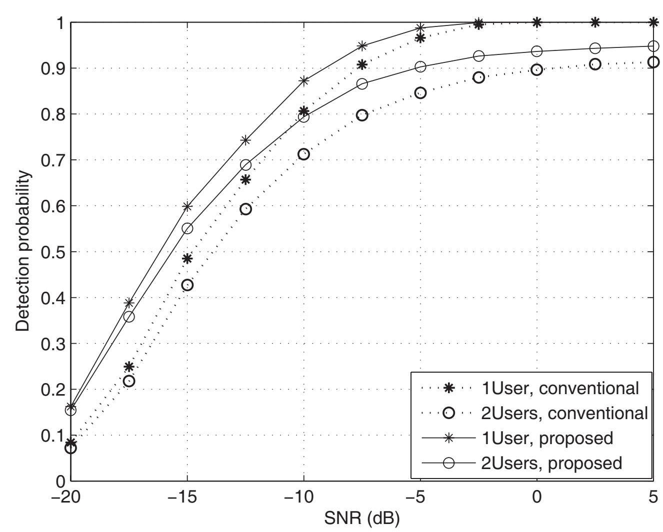
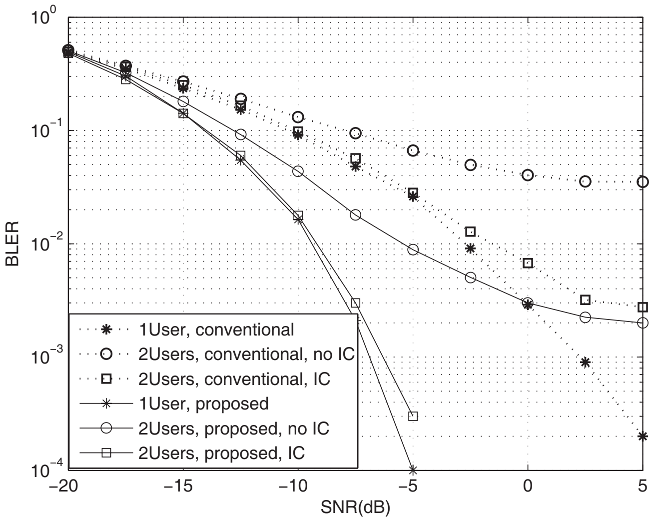


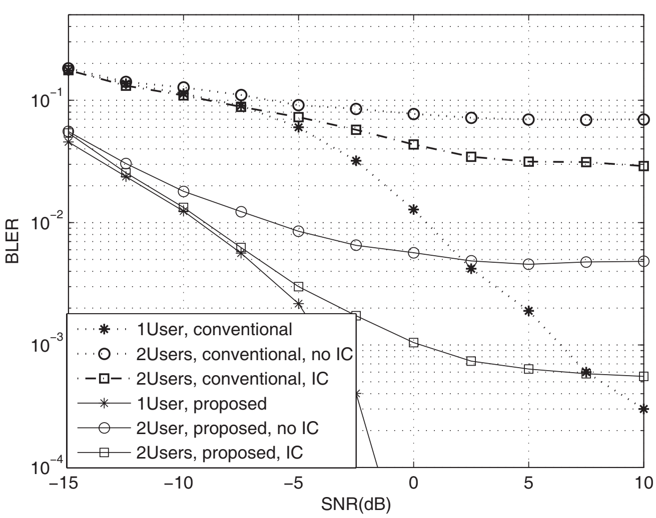
Fig. 7. Preamble detection probability comparisons.

We can observe from Figure 7 that the preamble detection probability for one user is much higher than that for two users because of the MAI between the users. Furthermore, it can be seen that the proposed scheme achieves at least 1.5 dB SNR gain in the preamble detection, because the message symbols are generated by the preamble shifting. It is noted that the message symbols, i.e., the cyclic-shifted preambles, can be used for the preamble detection if Node-B fails to detect the preamble in the preamble detection window.

Figure 8 presents the BLER performance comparisons on the message detection with ideal and real channel estimations. We can see From Figure 8(a) that error floors exist in the conventional scheme, even if the channel estimation is perfect and the interference cancelation (IC) is employed to mitigate the MAI. Moreover, it is also shown from Figure 8(a) that the proposed scheme provides much more robust transmissions in the presence of the MAI when the IC is employed. In our simulation scenarios, the achieved SNR gain of the proposed scheme is at least 5 dB when there is no MAI. On the other hand, if there is MAI the SNR gain will be further increased by using the IC.



(a) Under ideal channel estimation.



(b) Under real channel estimation.

Fig. 8. BLER performance comparisons.

Figure 8(b) compares the BLER performance of the message detection with the real channel estimation. In our simulations, when the preamble is acquired, the channel estimation is performed based on the detected preamble, as shown in the equations (17) and (18). From Figure 8(b) we can see that the performance of the conventional scheme is severely degraded by the MAI and channel estimation error. However, the performance of the proposed scheme is still very robust. Figure 8(b) also shows that under the real channel estimation, error floors exist on both schemes, even the IC is employed. Nevertheless, the IC can contribute at least 5 dB SNR gain in the proposed scheme and the BLER can achieve 10e-3.

VI. Conclusion

In this paper, we first study the RACH throughput in an OFDMA system and derive a closed-form expression by taking into account the time, code and frequency randomness in the random access. Second, we consider the access periodicity in the analytical model and derive access delay expectations under both binary exponential and uniform backoff policies. Finally, we propose an efficient random access scheme to transmit redundant cyclic-shifted preambles containing implicit short message. Simulation results show that the proposed scheme increases the successful user detection probability and offers reliable transmissions of the message in a contention based RACH.

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