

A Dual Preamble Random Access Protocol for Reducing Access Congestion in Disaster Situations

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Abstract—In long term evolution (LTE) systems, the random access (RA) protocol is used for initial access. Since the protocol is designed based on contention, the congestion on physical RA channel (PRACH) can get worse severely as the number of contending user equipments (UEs) increases. On the other hand, when a disaster occurs, we expect that a huge number of access attempts and traffic bursts rush to LTE systems, and these are likely to block each other, which can lead to excessive access delay and packet loss. In this paper, we propose a novel RA scheme for solving the congestion on the PRACH of LTE system. In the scheme, UEs attempt to access the LTE network by using not a single access preamble but two preambles simultaneously. As a result, we get the same effect as the number of preambles is logically increased. Although the congestion can be reduced with the proposed scheme, it can bring about unnecessary resource overhead. We formulate an optimal problem, by which we can maximize the system performance considering both the congestion control and the resource overhead. The simulation results show that the proposed scheme well resolves the congestion while reducing the overhead as much as possible.

I. INTRODUCTION

An urban-area disaster exceeding a certain scale is likely to be accompanied by the blackout in the area. In such a case, most private network access devices such as access point (AP) of WiFi and femto base station (BS) cannot operate. Even some macro BSs also may undergo power failure. The problem gets worse, because a huge number of access attempts and traffic bursts rush to a few operating BSs in such emergency situations. The resulting access congestion leads to large delay, high packet loss, and service unavailability in the extreme case.

On the other hand, most of commercial cellular networks including the long term evolution (LTE) system adopt a contention-based random access (RA) protocol, for initial network access. The RA procedure of LTE consists of the following four steps as shown in Fig. 1 [1].

- 1) **Random access preamble:** Each UE selects one of the available RA preambles and transmits the selected preamble on physical RA channel (PRACH).
- 2) **Random access response:** Random access response (RAR) message is sent by the eNB (i.e., BS of LTE) via downlink channels. The RAR message conveys the

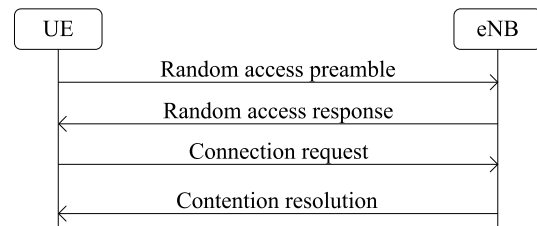


Fig. 1. Random access procedure in LTE system.

identity of the detected preamble and an initial uplink resource grant for connection request.

- 3) **Connection request:** Upon receiving RAR, UE sends the connection request message including a resource request. In the case of preamble collision in the first step (i.e., when two or more UEs select the same preamble), the colliding UEs receive the same RAR in step 2, and their connection requests will also collide with each other.
- 4) **Contention resolution:** If the connection request message is successfully received, the eNB sends contention resolution message and completes the RA procedure.

Since the number of available RA preambles depends on the physical features of the system, the RA preambles are a kind of finite resource and the congestion on PRACH can severely get worse as the number of UEs requiring access increases. Such congestion may commonly happen in disaster situations. Indeed, the congestion inevitably blocks most of the RA attempts from UEs, even if the network has a great deal of unused capacity, which can lead to an under-utilized network. This is called the RA overload problem and has been steadily attracting great attention from researchers as one of the bottlenecks in cellular networks.

Several methods for alleviating the RA overload problem have been researched. The LTE system applies access class barring (ACB) technique to handle the overload on PRACH [2]. An eNB broadcasts an ACB parameter b ($0 \leq b \leq 1$) to all UEs via system information block (SIB) [3]. When a UE wants to access the eNB, the UE first generates a random number uniformly between 0 and 1. It participates in

the access contention only when the generated random value is smaller than or equal to the ACB parameter b . That is to say, in case of RA overload, the network limits the number of UEs simultaneously accessing the network. The authors in [4] proposed a method to estimate the appropriate ACB parameter by predicting the number of UEs attempting RA. A scheme adaptively updating the ACB parameter based on the RA preamble collision ratio was proposed in [5]. The authors in [6] proposed a prioritized random access protocol, where several ACB parameters with different priority are used.

Another approach is based on backoff method where UEs attempt to access the network only when backoff count reaches to zero. Whenever a UE fails to access, a backoff counter is randomly selected and it decreases one by one every RA opportunity. Ref. [7] and [8] respectively proposed backoff algorithms for releasing the RA overload in LTE and IEEE 802.16 systems. However, the backoff-based schemes are less effective upon massive batch access attempts, as expected in disaster situations.

On the other hand, it is obvious that UEs succeed in accessing the network with higher probability as available preambles get more. That is, more preambles may be one of feasible approaches for resolving the RA overload problem. However, as we mentioned above, the number of available preambles is physically restricted by the system. In this paper, instead of increasing the number of physical preambles we take an approach which virtually increases the number of preambles by logically extending the domain of RA preambles. In the proposed scheme, the eNB and UEs regard a pair of physical preambles as a virtual preamble. Each UE selects two different physical preambles (i.e., dual preambles) and transmits them on PRACH simultaneously. Then, the eNB responds with RAR message corresponding not to a single detected preamble but to a pair of two detected physical preambles. For example, suppose that a UE transmits preamble 3 and 4 while another UE transmits preamble 6 and 2. In this case, the eNB detects preamble 2, 3, 4, and 6. Since the eNB cannot know which UEs and how many UEs have transmitted the preambles, it sends the RAR messages corresponding to all possible preamble combinations, i.e., (2, 3), (2, 4), (2, 6), (3, 4), (3, 6), and (4, 6), not only (2, 6) and (3, 4). As guessed from this example, the proposed scheme may incur unnecessary RARs. We define the unnecessary RAR as false RAR and a pair of dual preambles causing the false RAR as a false preamble pair. Since the false RARs waste downlink resources, it is obvious that they should be as few as possible.

In this paper, we propose a new RA protocol, which alleviates the RA overload by using dual preambles in initial access while avoiding the waste of downlink resource by reducing the false RARs. The proposed dual preamble RA (DPRA) scheme is expected to effectively serve the massive accesses in comparison with the conventional single preamble RA scheme, at the beginning of a disaster occurrence having a huge number of initial access requests.

The rest of this paper is organized as follows. Section II describes the system model. The proposed DPRA scheme is

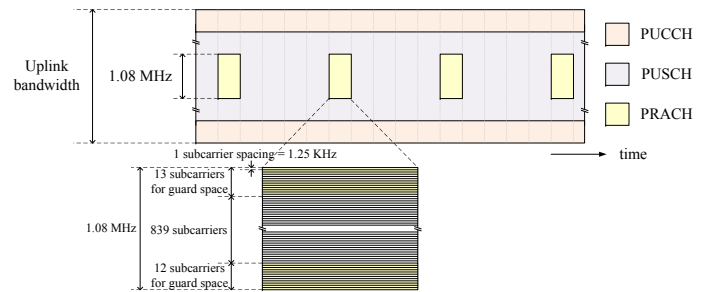


Fig. 2. PRACH structure of LTE system.

elaborated in section III. The performance of the proposed scheme is compared with those of other schemes in section IV. Finally, the paper is concluded with section V.

II. SYSTEM MODEL

A. Structure of PRACH

In LTE system, the PRACH is multiplexed with other uplink channels such as physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) in time and frequency as shown in Fig. 2. The PRACH is periodic in time and the eNB determines the period, which is broadcasted as PRACH configuration index via SIB.

A PRACH occupies 1.08 MHz frequency band which consists of 864 subcarriers. That is, the subcarrier space of a single subcarrier of the PRACH is 1.25 KHz. Note that, the subcarrier space of the PRACH is quite narrower than those of other channels, because the radio signal of RA preamble need not to be decoded but just to be detected at the eNB. Among the 864 subcarriers, 13 uppermost subcarriers and 12 lowermost subcarriers are used for guard space, and the rest of subcarriers (i.e., 839 center subcarriers) are dedicated for preamble transmission. Utilizing the 839 subcarriers, total 64 RA preambles are available in LTE system. To make it easier for further explanation, we refer to each PRACH as an RA slot.

B. Network and Resource Model

We consider an operating eNB with coverage radius R . Initially, it is assumed that N_0 activated (i.e., attempting access) UEs are uniformly distributed in the cell. In addition, we assume that new activated UEs are arrived at the system according to Poisson distribution with mean λ . Let N_r denote the number of activated UEs at the r th RA slot. Then, $N_{r+1} = N_r - S_r + A_r$ where S_r is the number of UEs that succeed in access and A_r is the number of newly activated UEs, at the r th RA slot.

The eNB calculates and notifies the ACB parameter at the beginning of every RA opportunity (RA slot). Then, N_r UEs attempt to access the eNB according to this ACB parameter. The value of ACB parameter can be recalculated every RA slot by the eNB considering the number of activated UEs, the number of available preambles, etc.

C. Domain of Dual Preamble

The number of originally available preambles (i.e., physical preambles) in the system is Ω . We define a set of the preambles as $\mathcal{P} = \{1, 2, \dots, \Omega\}$. If UEs can select two separate preambles from the set $\mathcal{P}$ without any rules, the maximum number of logically extended preambles is $\binom{\Omega}{2} = \Omega(\Omega - 1)/2$. Hereafter, we will denote the number of extended preambles by Ω' . Since more preambles bring about more potential RAR messages in the second step of the RA procedure and an RAR message consists of 7 octets in LTE system¹, the number of logically extended preambles should be appropriately determined in order to avoid the excessive occupation of downlink resource by RAR messages.

To this end, we suggest a composition method for the domain of dual preambles. Constituting the domain, we first assume that Ω is a square number (i.e., $\Omega = s^2$ where s is a natural number). Because Ω is 64 in LTE system, the assumption can be somewhat reasonable (i.e., $s = 8$). Next, the elements of set $\mathcal{P}$ are represented as square matrix form, $\mathbb{P}_s$, where s is the number of rows (or columns) of the matrix. That is,

$$\mathbb{P}_s = [p_{ij}]_{s \times s}, \quad (1)$$

where p_{ij} is the element for the i th row and j th column, and $p_{ij} = s(i - 1) + j$, while $1 \leq i \leq s$ and $1 \leq j \leq s$. For example, $\mathbb{P}_8$ is as follows.

$$\mathbb{P}_8 = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 \\ 17 & 18 & 19 & 20 & 21 & 22 & 23 & 24 \\ 25 & 26 & 27 & 28 & 29 & 30 & 31 & 32 \\ 33 & 34 & 35 & 36 & 37 & 38 & 39 & 40 \\ 41 & 42 & 43 & 44 & 45 & 46 & 47 & 48 \\ 49 & 50 & 51 & 52 & 53 & 54 & 55 & 56 \\ 57 & 58 & 59 & 60 & 61 & 62 & 63 & 64 \end{bmatrix}. \quad (2)$$

When a UE wants to access network, it first selects a preamble p_1 from set $\mathcal{P}$. If the column index of p_1 in the matrix $\mathbb{P}$ is j , the UE selects the second preamble p_2 from j th row in the matrix. When $s = 8$ and $\Omega = 64$, for example, if a UE selects 35 as p_1 (i.e., its column index is 3), the UE has to select p_2 between 17 and 24 (i.e., among the numbers in the third row). Note that, when $p_1 = p_2$, the UE again selects the second preamble. Consequently, the total number of possible combinations of dual preambles (Ω') is $s(s - 1)(2s + 1)/2$ (e.g., when $s = 8$, $\Omega' = 476$). It is noted that the composition can be altered in order to adjust Ω' . For instance, by getting rid of preambles (p_{ij}) such that $i = j$ (i.e., the diagonal elements in the matrix $\mathbb{P}$) in constituting the domain of dual preambles, Ω' is 364. Hereafter, we will call the RA scheme using the domain of RA preambles with $\Omega' = 476$ and $\Omega' = 364$ as “DP476” and “DP364”, respectively.

¹In fact, the RAR MAC protocol data unit (PDU) consists of MAC header and one or more MAC RARs. Sizes of MAC header and MAC RAR are 1 octet and 6 octets per detected preamble, respectively. Thus, total amount of resources is 7 octets per detected preamble. The RAR messages are sent via downlink channels.

D. RAR Overhead and Filtering Method

As the number of UEs that simultaneously attempt to access increases, the number of preambles detected by the eNB may increase. As a result, the amount of downlink resources for sending corresponding RAR messages also increases. Since the eNB has to send RARs corresponding to false preamble pairs as well as valid preamble pairs, resources may be dissipated. In this paper, we regard the total number of RARs which the eNB should send down as the RAR overhead. We use a filtering method based on timing information (TI) in order to eliminate some of false preamble pairs.

Since the propagation delay of radio signal mainly depends on the distance between the transmitter and the receiver, the preambles from UEs located in different position may be received with different timing delay at the eNB. In general, the eNB can distinguish the TI by the basic time unit (T), which is $1/(3.072 \times 10^7)$ seconds. We define a timing separation distance $d = T \times c$ where c is the signal propagation speed, and we assume that the radius of cell is an integer multiple of d (i.e., $R = ad$ where a is a positive integer). Then, the TI value of signal transmitted by a UE u with distance $d_u \in [\tau d, (\tau + 1)d)$ from the eNB is τ ($\tau \in \{0, 1, \dots, a - 1\}$). With the TI values, the eNB sends the RAR message only when the TI values of two detected physical preambles are same and they satisfy the rule of dual preamble composition (i.e., the column index of a preamble is equal to the row index of another preamble).

For example, a UE transmits preamble 3 and 17 with TI value of 1 while another UE transmits preamble 12 and 27 with TI value of 4. In this case, the eNB sends the RAR messages only for dual preambles (3, 17) and (12, 27). Even though the false preamble pair (27, 17) is included in the domain of dual preambles (i.e., the column index of 27 equals to the row index of 17 in the matrix $\mathbb{P}_8$), the TI values of preamble 27 and 17 are different. This prevents the eNB from sending the false RAR corresponding to the false preamble pair (27, 17).

III. PROPOSED DPRA PROTOCOL

In order to reduce the RA overload, we adopt not only the dual preamble approach but also the ACB scheme. The optimal ACB parameter which maximizes the number of UEs that succeed in RA is already known [9], but we formulate an optimal problem considering both the number of successful UEs and the RAR overhead because dual preambles can bring about false RARs which are the definite overhead of system. This ACB scheme will be called the RARACB scheme against the optimal ACB (OPTACB) scheme. At the beginning of every RA slot, the eNB calculates and notifies the ACB parameter, and the UEs transmit dual preambles according to the parameter.

A. Problem Formulation

We define two functions $f(b; N)$ and $g(b; N)$ as the expected number of successful UEs and the expected number of RAR messages which the eNB has to send (i.e., RAR overhead) in an RA slot, respectively, according to the ACB

parameter b when the number of activated UEs, N , is given. Undoubtedly, there is a trade-off between $f(b; N)$ and $g(b; N)$. Thus, we formulate an optimal problem as follows.

$$b^* = \underset{b}{\operatorname{argmax}} \left(w_1 \frac{f(b; N)}{f_{\max}} - w_2 \frac{g(b; N)}{g_{\max}} \right) \quad (3)$$

$$\text{subject to } w_1 + w_2 = 1, \quad (4)$$

$$0 \leq b \leq 1, \quad (5)$$

where w_1 and w_2 are weight factors and $f_{\max}$ and $g_{\max}$ are the maximum values for normalizing $f(b; N)$ and $g(b; N)$, respectively. The authors of [10] analyzed and approximated the expected number of successful UEs in an RA slot when the number of activated UEs N and the ACB parameter b are given. According to the approximated formula in [10],

$$f(b; N) = Nb \times \exp(-Nb/\Omega'). \quad (6)$$

B. Derivation of RAR Overhead

Now, we will derive $g(b; N)$. For large N , since $g(b; N)$ does not depend on the constitution of preamble domain but only on the number of logically extended preambles (Ω'), we do not consider any rules for the domain for easier derivation. That is, any two separate physical preambles can be a valid preamble pair. However, since the size of the simplified domain, $\binom{\Omega}{2}$, is much larger than that of “DP476” when $\Omega = 64$, we regard the number of physical preambles for the simplified domain as an integer minimizing $|\Omega(\Omega - 1)/2 - \Omega'|$ in this subsection. For example, $\Omega = 31$ when $\Omega' = 476$.

Let T_u be a random variable representing the TI value of radio signal from UE u . Since the UE u is located within the ring between τd and $(\tau + 1)d$ from eNB,

$$\Pr\{T_u = \tau\} = \frac{\pi((\tau + 1)d)^2 - \pi(\tau d)^2}{\pi R^2} = \frac{2\tau + 1}{a^2}. \quad (7)$$

For given N and b , when U_τ denotes a random variable representing the number of UEs transmitting dual preambles among the activated UEs with TI of τ ,

$$\begin{aligned} \Pr\{U_\tau = u\} &= \sum_{m=u}^N \binom{N}{m} \left(\frac{2\tau + 1}{a^2} \right)^m \left(1 - \frac{2\tau + 1}{a^2} \right)^{N-m} \\ &\quad \times \binom{m}{u} b^u (1 - b)^{m-u} \\ &= \binom{N}{u} \left\{ \frac{(2\tau + 1)b}{a^2} \right\}^u \left\{ 1 - \frac{(2\tau + 1)b}{a^2} \right\}^{N-u}. \end{aligned} \quad (8)$$

Let V_τ be a random variable representing the number of detected physical preambles with TI of τ at the eNB, for given N and b . According to the inclusion-exclusion principle of combinatorial theory,

$$\begin{aligned} \Pr\{V_\tau = v | U_\tau = u\} &= \\ \frac{\binom{\Omega}{v}}{\binom{\Omega}{2}^u} \sum_{i=0}^{v-2} \left\{ (-1)^i \times \binom{v}{i} \times \binom{v-i}{2}^u \right\}, \end{aligned} \quad (9)$$

for $2 \leq v \leq 2u$. $\Pr\{V_\tau = v | U_\tau = u\} = 0$ when $v < 2$ or $v > 2u$ or $u = 0$. In (9), since at least two physical preambles

should be detected at the eNB for $u > 0$, the upper bound of summation is $v - 2$. Then,

$$\Pr\{V_\tau = v, U_\tau = u\} = \Pr\{V_\tau = v | U_\tau = u\} \times \Pr\{U_\tau = u\}, \quad (10)$$

and

$$\Pr\{V_\tau = v\} = \sum_{u=1}^N \Pr\{V_\tau = v, U_\tau = u\}. \quad (11)$$

Let Ψ_τ be the number of RARs caused by UEs with TI of τ , for given N and b . Then,

$$\mathbb{E}[\Psi_\tau] = \sum_{v=2}^{\Omega} \Pr\{V_\tau = v\} \times \binom{v}{2}. \quad (12)$$

Note that a detected preamble pair with TI of τ can be also detected with any other TI values. So, for given N and b , let Q_τ be a binary random variable representing whether an arbitrary dual preamble with TI of τ is also detected with other TI values or not. $Q_\tau = 1$ if there are other TI values with the dual preamble; $Q_\tau = 0$ otherwise. Since the probability that a specific preamble pair is not included within v detected preambles at the eNB is $(1 - \binom{\Omega-2}{v-2} / \binom{\Omega}{v})$, the probability that a specific preamble pair with TI of τ is not detected at the eNB with TI of $t (\tau \neq t)$ is given by

$$\begin{aligned} \phi_t &:= \sum_{v=2}^{\Omega} \Pr\{V_t = v\} \times \left(1 - \frac{\binom{\Omega-2}{v-2}}{\binom{\Omega}{v}} \right) \\ &= 1 - \frac{\mathbb{E}[V_t^2] - \mathbb{E}[V_t]}{\Omega^2 - \Omega}. \end{aligned} \quad (13)$$

Then,

$$\Pr\{Q_\tau = 0\} = \prod_{t=0, t \neq \tau}^{a-1} \phi_t. \quad (14)$$

Finally, from (12) and (14), we have

$$g(b; N) = \sum_{\tau=0}^{a-1} \mathbb{E}[\Psi_\tau] \times \Pr\{Q_\tau = 0\}. \quad (15)$$

IV. PERFORMANCE EVALUATION

In this section, the performance of the proposed DPRA scheme is compared with those of the conventional RA scheme used in LTE systems and an RA scheme with extended RAR proposed in [11]. In contrast with the conventional RA scheme, in the extended RAR scheme of [11], eNB assigns multiple RARs to each detected preamble. Since multiple RARs are sent corresponding to a detected preamble, they all contain the same identity of RA preamble. However, the uplink grant in such RARs will be different. If two UEs select the same preamble (in step 1 of Fig. 1), both of them obtain multiple RARs, each of which has a different uplink grant. On receiving multiple RARs, the two UEs randomly select one of them. This additional randomness may increase the probability of successful transmission. By randomly choosing one RAR, the contending UEs obtain one more chance to avoid a potential collision. The number of multiple RARs per detected preamble is set to 2, 4, and 8 in the evaluation. Unless otherwise

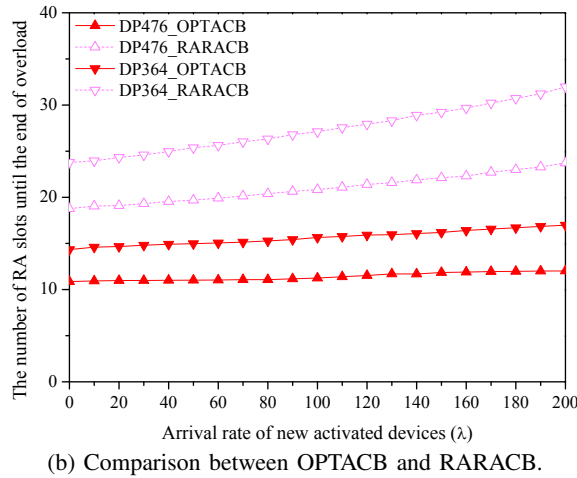
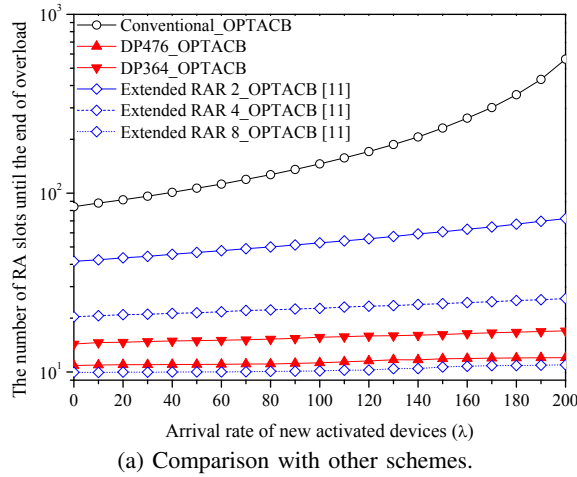


Fig. 3. The number of RA slots until the end of overload.

stated, ACB is applied to all compared schemes and the ACB parameter value is set so that the number of successful UEs is maximized, according to [9].

In the simulation, the cell radius $R = 1000$ m, the number of physical RA preambles $\Omega = 64$, the initial number of activated UEs at the beginning of a disaster $N_0 = 2000$, the arrival rate of new activated UEs $\lambda \in [0, 200]$, and the period of RA slots is 100 ms. We carried out two hundreds of simulation runs for a set of simulation parameters. Each run is finished if the number of remaining activated UEs is fewer than a half of the total number of preambles because the RA overload can be regarded as being almost released at that point.

When a disaster occurs the quickness of information delivery is critical and the access delay may be a crucial part for the end-to-end delay. So, we first examine the number of RA slots until the end of overload. Fig. 3(a) shows the performance for each of the compared schemes according to varying λ . We can observe from the figure that the proposed scheme with two different domain of dual preambles (i.e., DP476 and DP364) and the extended RA scheme with 8 RARs (i.e., Extended RAR 8) get over the overload problem more quickly than the others. However, as we can see in Table I,

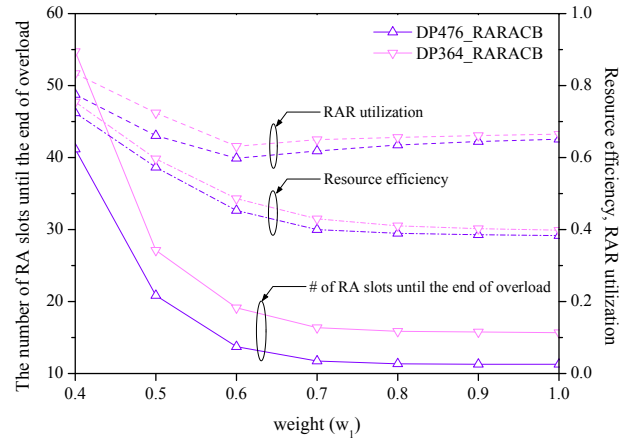
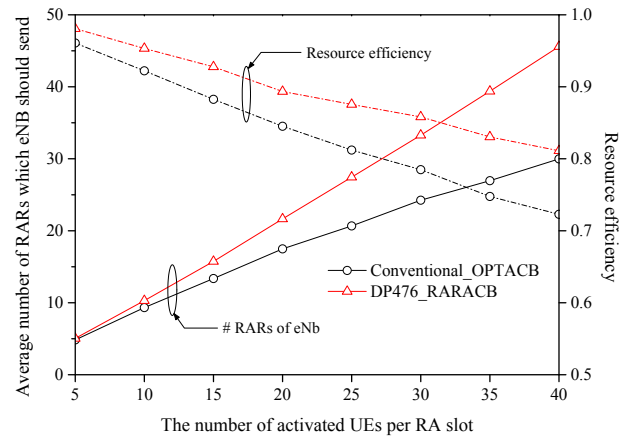
Fig. 4. Performance according to the weights of RARACB, $\lambda = 100$.

Fig. 5. Performance under low load environment.

these schemes solving the overload quickly incur excessive RAR messages which the eNB should send per RA slot. On the other hand, delay and packet loss may be serious with the conventional and extended RAR scheme with 2 RARs (i.e., Extended RAR 2) under a disaster situation.

To assess the effect of the RARACB, the proposed DPRA scheme is compared with both the OPTACB and the RARACB elaborated in section III. The OPTACB is corresponding to the RARACB with $w_1 = 1$ and $w_2 = 0$ in (3). In Fig. 3(b), we set the $w_1 = w_2 = 0.5$ for the RARACB. As shown in the figure and the Table I, the DPRA scheme with RARACB needs slightly more RA slots until finishing the overload, while incurring quite fewer RARs and improving the resource efficiency which is the number of UEs succeed in accessing network divided by the number of sent RARs. The tremendous amount of RAR messages caused by the DPRA scheme with the OPTACB, in practice, overburdens the system and even obstructs the normal operation of the system. Thus, the RARACB which reduces the excessive RARs and improves the resource efficiency is better than the OPTACB.

Next, to investigate the effect of the weights in (3), we plot in Fig. 4 the number of RA slots until the end of overload, the resource efficiency, and the RAR utilization. We define η

TABLE I
THE AVERAGE NUMBER OF RARS AND THE RESOURCE EFFICIENCY

Random access scheme	Average number of RARs which eNB should send	Resource efficiency
OPTACB	40.35	0.58
DP476_OPTACB	446.94	0.38
DP364_OPTACB	325.28	0.40
DP476_RARACB	167.62	0.57
DP364_RARACB	130.53	0.60
EXTENDED2_OPTACB	110.24	0.43
EXTENDED4_OPTACB	250.63	0.37
EXTENDED8_OPTACB	511.56	0.36

as the ratio of the number of false RARs to the total number of RARs. Then the RAR utilization is $1 - \eta$. The value of λ is fixed as 100. The RA overload situation cannot be resolved when w_1 is less than 0.4. As w_1 increases, the number of RA slots until the end of overload and the resource efficiency of the proposed scheme with RARACB unquestionably decrease. On the other hand, the RAR utilization of the proposed scheme decreases until w_1 of 0.6 and slightly increases after that because the scheme quickly get over the overload, while incurring relatively fewer false RARs in average. Moreover, we can see that the DPRA scheme with the size of dual preamble domain of 364 (i.e., DP364) is superior to the DP476 from the viewpoint of resource efficiency and RAR utilization.

Finally, we conduct the simulation under low load environments for normal (low load) condition, because a single RA protocol is better rather than alternating two different protocols from a viewpoint of operation. In the low load environments, we set the number of activated UEs per RA slot between 5 and 40. Fig. 5 shows that the proposed DP476 scheme with RARACB brings about slightly more RARs which the eNB has to send than the conventional RA scheme with the OPTACB. However, the difference of resource amounts needed for sending the RAR messages between the two schemes is not large. Also, the resource efficiency of the proposed scheme is higher than that of the conventional scheme.

V. CONCLUSION

We have proposed an RA scheme which utilizes a pair of two preambles simultaneously in order to reduce the RA congestion during initial access. Since the amount of the unnecessary resource overhead is increased in proportion to the number of possible dual preambles, a rule for constituting a restricted domain of dual preambles has been suggested. In addition, we have formulated an optimal problem maximizing the system performance by deriving an ACB parameter considering both the number of successful UEs and RAR overhead in an RA slot. The simulation results show that the proposed scheme can quickly resolve the access overload than the compared scheme as well as the conventional scheme. Furthermore, although the proposed scheme brings about the more RAR overhead in comparison with the conventional scheme, the resource efficiency of our scheme is almost same or slightly higher than that of the conventional scheme. On the other

hand, the proposed scheme with RARACB greatly reduces the RAR overhead while resolving the overload with the speed comparable to the scheme with OPTACB. In conclusion, the proposed scheme not only resolves the RA overload quickly while maintaining the resource efficiency at a high level but also achieves higher resource efficiency than the conventional scheme even under low load environments.

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