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의사 베이지안 접근법을 이용한 Joint CDMA/PRMA의 성능 향상에 관한 연구

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Performance Enhancement of the Joint CDMA/PRMA Protocol Using Pseudo Bayesian Approach

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Abstract

A new channel access function is proposed to enhance the performance of the joint CDMA/PRMA. It is obtained in consideration of the number of terminals in reservation mode and the number of terminals in contention mode whose probability distribution is estimated by applying pseudo Bayesian approach. Simulation results show that the performance of the joint CDMA/PRMA can be improved by applying new channel access function under voice-only traffic and mixed voice/random-data traffic.

1. Introduction

A wide range of services like voice, video, and data services, have to be provided in FPLMTS (Future Public Land Mobile Telecommunication Systems). In FPLMTS, a packet-switched network architecture will be preferred to the circuit-switched architecture. For packet-switched network architecture, research has been carried out on both time-division multiple access (TDMA)([3], [4], [5]) and direct-sequence code-division multiple access(DS-CDMA)([2], [7]).

In packet CDMA, rather large variance of multiple access interference(MAI) results from

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random access to the channel. Brand et al.([1]) have proposed a Joint CDMA/PRMA(code division multiple access/packet reservation multiple access) to reduce variance of the interference and to increase throughput. In Joint CDMA/PRMA, the time axis is divided into slots which are grouped into frames as in PRMA([4]) and resources are allocated on the basis of packet spurts. To reduce variance of the interference, Brand et al. propose a channel access function which relates the number of terminals in reservation mode in a slot to the permission probability for terminals in contention mode in the same slot of the subsequent frame. They have derived channel access function through a heuristic approach and shown that the capacity of a cell in a cellular environment can be increased up to 55-84% by Joint CDMA/PRMA, compared to that of the random access CDMA.

Since the performance of a Joint CDMA/PRMA depends on effectiveness of the channel access function, we focus on the derivation of more efficient channel access function. If we know the number of terminals in contention mode as well as the number of terminals in reservation mode in a slot, we can compute expected packet corruption probability for a given permission probability. Thus we can select permission probability as large as possible to increase channel efficiency, guaranteeing the QoS(Quality of Service) requirement on the packet corruption probability. But the number of terminals in contention mode is unknown at the beginning of a slot. So we adopted pseudo Bayesian approach suggested by Rivest([6]), who derived a pseudo Bayesian broadcast algorithm to enhance the performance of the slotted Aloha type broadcast channels, to obtain the probability distribution of number of terminals in contention mode in a slot approximately.

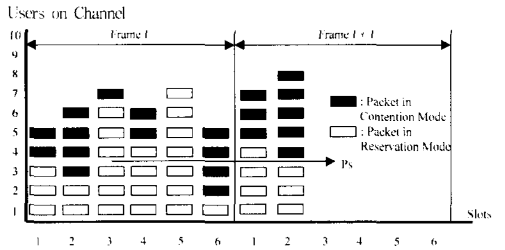
The rest of this paper is divided as follows. Section 2 describes the Joint CDMA/PRMA protocol. In section 3, the new channel access function is derived for voice only traffic and mixed voice/random-data traffic. Simulation results of the performance of the new channel access function are provided in section 4 and conclusions are presented in section 5.

2. Joint CDMA/PRMA Protocol

In Joint CDMA/PRMA, the time axis is organized in frames each containing a fixed number of time slots. A terminal that generates periodic data spurt switches from idle to contention mode and attempts to transmit the initial packet of a spurt by performing a Bernoulli experiment with a given permission probability. A terminal attempts to transmit the initial packet of a spurt in each consecutive slot until the base station acknowledges successful reception of the packet, or until the packet is discarded by the terminal because it has been delayed beyond a certain time limit, $D_{\max}$. If a terminal drops the first packet of a spurt, it continues to contend for a reservation to send subsequent packets. A terminal switches from contention to reservation mode as soon as a successful packet reception is acknowledged by the base station. If a terminal switches to reservation mode in i^{th} slot of a frame, it will stay in reservation mode and the subsequent packets are transmitted without contention in the i^{th} slots of the subsequent frames until the last packet of the current spurt is transmitted.

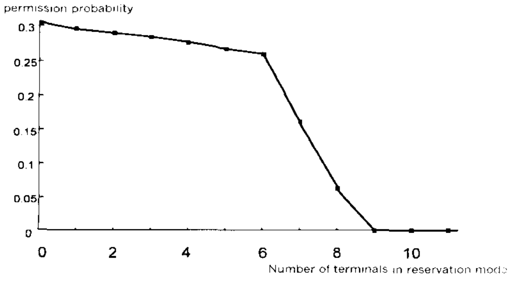
A terminal switches from reservation to contention mode and begins contending to send next packet if a packet sent in reservation mode is corrupted due to excessive MAI.

To reduce the packet corruption probability by excessive MAI, the number of terminals transmitting packets in a slot should be properly controlled. For this, Brand et al. proposed that the permission probabilities for speech, p_s, and data, p_d, for a given slot in a subsequent frame be set according to the number of terminals in reservation mode in the same slot of the current frame(see Fig. 1).



[Figure 1] The permission probability of slot 3 in frame ***I+1*** is set according to the number of terminals in reservation mode in the same slot of the previous frame ***I***

Fig. 2 depicts the channel access function, which relates the permission probability to the number of terminals in reservation mode, suggested by them heuristically through simulations. They have shown that the capacity of a cell in a cellular environment can be increased up to 55-84% by Joint CDMA/PRMA, compared to that of the random access CDMA.



[Figure 2] Channel Access Function

3. New Channel Access Function

In this section, we derive new permission probabilities for speech, $p_{s,i}$, and data, $p_{d,i}$, to be used in i^{th} slot of a frame which can enhance the channel efficiency guaranteeing the packet loss requirements of speech and data packets. Suppose that there exists only voice traffic in the system for the time being. Let Y_i, R_i, Z_i be random variables denoting the number of terminals in contention mode, the number of terminals in reservation mode, and the number of terminals that transmit packets by passing Bernoulli experiments among terminals that are in contention mode in i^{th} slot, respectively. If we know the probability distribution of Y_i, $p(y)$, the conditional probability distribution of Z_i for given $p_{s,i}$, $p(z|p_{s,i})$, can be obtained by

$$p(z|p_{s,i}) = \sum_{y=z}^{\infty}\binom{y}{z}p_{s,i}^{z}(1-p_{s,i})^{y-z}p(y) \qquad (1)$$

To increase the channel efficiency, it is desirable to make $p_{s,i}$ as large as possible while guaranteeing the packet loss requirement of voice packet. In Joint CDMA/PRMA, packet loss probability p_{loss} is the sum of packet corruption probability p_{cpted} due to excessive MAI and packet dropping probability due to delay beyond a certain time limit $D_{\max}$. Let $(p_{cpted})_{tar}$ be the target packet corruption probability and $E[p_{cpted}|r_i, p_{s,i}]$ be the expected packet corruption probability when the number of voice terminals in reservation mode, $R_i = r_i$, and permission probability for speech, $p_{s,i}$, are given. Here, we can approximate R_i as the sum of the number of terminals that were in reservation mode and the number of terminals that succeeded in contention in i^{th} slot of the previous frame because the number of terminals changing status from talk spurt to silence period during one frame are very few(we assume that R_i is known when $p_{s,i}$ is determined). That is, we can choose $p_{s,i}$ by

$$\begin{aligned} &\max \quad p_{s,i} \\ &s.t. \quad E[p_{cpted}|r_i, p_{s,i}] \leq (p_{cpted})_{tar} \end{aligned} \tag{2}$$

where

$$\begin{aligned} E[p_{cpted}|r_i, p_{s,i}] &= \sum_{z=0}^{\infty}[1 - Q_E(r_i + z)]p(z|p_{s,i}) \\ &= \sum_{z=0}^{\infty}[1 - Q_E(r_i + z)] \\ &\quad \sum_{y=z}^{\infty}\binom{y}{z}p_{s,i}^{z}(1 - p_{s,i})^{y-z}p(y). \end{aligned} \tag{3}$$

In (3), $Q_E[r_i + z]$ represents the packet success probability when $r_i + z$ packets are transmitted simultaneously(cf. Table 1).

Therefore, we need to obtain $p(y)$ to get $p_{s,i}$ by (2). For this, first observe that Y_i can be represented by

$$\begin{aligned} Y_i &= Y_{i-1} - Z_{i-1} + N_{st} - N_{ts} + n_{cpted}(i) \\ &\approx Y_{i-1} - Z_{i-1} + N_{st} + n_{cpted}(i) \end{aligned} \tag{4}$$

where $N_{st}(N_{ts})$ is a random variable denoting the number of terminals changing status from silence period(talk spurt) to talk spurt(silence period) in i^{th} slot and $n_{cpted}(i)$ is the number of terminals whose packets were corrupted in i^{th} slot of the previous frame(We assume that a terminal switches from reservation to contention mode when a packet transmitted in a slot is corrupted and that it begins to contend to transmit subsequent packet from the same slot of the next frame. We also assume that N_{ts} is very small.). If we consider 3^{rd} and 4^{th} terms of (4) later, we have following relationship

$$\widehat{Y}_i = Y_{i-1} - Z_{i-1}. \tag{5}$$

where $\widehat{Y}_i$ represents the number of terminals in contention mode in i^{th} slot which were in contention mode in $i-1^{th}$ slot but could not transmit initial packets in $i-1^{th}$ slot. As in [6], if we assume that Y_{i-1} can be approximated by a Poisson distribution with mean λ_{i-1}, that is,

$$\Pr\{Y_{i-1} = y\} = \frac{e^{-\lambda_{i-1}}\lambda_{i-1}^{y}}{y!}, \tag{6}$$

we have by Bayesian rule

$$\begin{aligned} &\Pr\ \{Y_{i-1} = y\ |Z_{i-1} = z\} \\ &= \frac{\Pr\{Y_{i-1} = y,\ Z_{i-1} = z\}}{\Pr\{Z_{i-1} = z\}} \\ &= \frac{\Pr\{Z_{i-1} = z \mid Y_{i-1} = y\} \cdot \Pr\{Y_{i-1} = y\}}{\sum_{y=z}^{\infty}\Pr\{Y_{i-1} = y,\ Z_{i-1} = z\}} \\ &= \frac{\{\lambda_{i-1}(1 - p_{s,i-1})\}^{y-z}e^{-\lambda_{i-1}(1-p_{s,i-1})}}{(y-z)!} \end{aligned} \tag{7}$$

since

$$\Pr\{Z_{i-1}=z \mid Y_{i-1}=y\} = \binom{y}{z} p_{s,i-1}^{z}(1-p_{s,i-1})^{y-z} \tag{8}$$

Therefore, from (5), we get

$$\begin{aligned}\Pr\{\widetilde{Y}_i=y \mid Z_{i-1}=z\} &= \Pr\{Y_{i-1}=y+z \mid Z_{i-1}=z\} \\ &= \frac{\{\lambda_{i-1}(1-p_{s,i-1})\}^{y} e^{-\lambda_{i-1}(1-p_{s,i-1})}}{y!}\end{aligned} \tag{9}$$

Since $\Pr\{\widetilde{Y}_i=y \mid Z_{i-1}=z\}$ is independent of z, we can see that $\widetilde{Y}_i$ also follows a Poisson distribution with mean $\lambda_{i-1}(1-p_{s,i-1})$.

Let's assume that the length of a time slot is 1 ms and the silence period and talk spurt follow exponential distributions with mean 1.35 and 1.0 second, respectively. Then the number of terminals due to 3^{rd} term of (4) follows binomial distribution with mean

$$n_s \times \int_0^{0.001} \frac{1}{1.35} e^{-1/1.35t} dt = 0.000740466 n_s \tag{10}$$

when the number of voice terminals in a silence period at the beginning of a i^{th} slot, N_s, is given as n_s. Since a binomial distribution, $B(n, p)$, can be approximated by a Poisson distribution when n is large and p is small, the 3^{rd} term of (4) can be approximated by a Poisson distribution. Therefore if we consider only the first three terms of (4), Y_i can be approximated by Poisson distribution with mean $\lambda_{i-1}(1-p_{s,i-1})+0.000740466 n_s$.

Suppose that a terminal switches from reservation to contention mode when a transmitted packet is corrupted and it begins to contend to transmit subsequent packet from the same slot of the next frame. Then the number of terminals due to 4^{th} term of (4) becomes $n_{cpted}(i)$ (we assume that $n_{cpted}(i)$ is known when $p_{s,i}$ is determined). Since Poisson random variable plus constant follows shifted Poisson distribution, Y_i of (4) does not follow Poisson distribution. But the packet corruption probability is very low and $n_{cpted}(i)$ accounts for only a small fraction of the number of voice terminals in contention mode in i^{th} slot. Since the major part of (4) follows a Poisson distribution, we can assume that Y_i follows approximately a Poisson distribution with mean

$$\lambda_i = \lambda_{i-1}(1-p_{s,i-1}) + 0.000740466 n_s + n_{cpted}(i) \, . \tag{11}$$

When there exist mixed voice and random-data traffic in the system, Y_i can be approximated by a Poisson distribution with mean

$$\lambda_i = \lambda_{i,v} + \lambda_{i,d} \tag{12}$$

where $\lambda_{i,v}$ and $\lambda_{i,d}$ are the mean number of voice and data terminals in contention mode in i^{th} slot. Let's assume that a random data terminal creates a new packet in every slot according to a Bernoulli experiment with parameter δ_d. Then by the similar logic as above, we can approximate $\lambda_{i,v}$ and $\lambda_{i,d}$ by

$$\begin{aligned}\lambda_{i,v} &= \lambda_{i-1,v}(1-p_{s,i-1}) + 0.000740466 n_s + n_{cpted}(i) \\ \lambda_{i,d} &= \lambda_{i-1,d}(1-p_{s,i-1}) + \delta_d n_d\end{aligned} \tag{13}$$

where n_d represents the number of data terminals at the beginning of i^{th} slot.

When we try to solve $p_{s,i}$ by (2), we adopted a simple heuristic method since the constraint function is a very complex function. That is, we increased $p_{s,i}$ by 0.01 from 0 until the constraint is violated. On the other hand, it takes much time to compute $p_{s,i}$ even by a simple heuristic method. So it is necessary to prepare $p_{s,i}$ for each combination of r_i and λ_i in an off-line way if we take into consideration of the implementation issues. But it is impossible to obtain $p_{s,i}$ for all combinations of r_i ($r_i = 0, 1, \cdots$) and $\lambda_i (0 < \lambda_i)$. So we assumed that λ_i takes value 0.2 between $[0, 0.2]$, 0.4 between $[0.2, 0.4]$, $\cdots$, 19.8 between $[19.6, 19.8]$, and 20 between $[20, \infty)$ to decide $p_{s,i}$ conservatively. And we made a table for $p_{s,i}$ for each combinations of r_i ($r_i = 0, 1, \cdots$) and λ_i ($\lambda_i = 0.2, 0.4, \cdots, 20$) and used them during simulation. This table can be looked up to obtain $p_{s,i}$ in real situations, too.

4. Simulation Results

The performance of the Joint CDMA/PRMA using new channel access function was evaluated by simulations. The main performance measure is the maximum number of simultaneous conversations that can be supported with an average voice packet loss probability(over all active terminals) less than or equal to required voice packet loss probability, $p_{loss} \le (p_{loss})_{req}$. The packet loss probability is the sum of packet drop probability due to excessive delay in contention mode, p_{drop}, and packet corruption probability due to excessive MAI, p_{cpted}. Let $M_{0.02}$ ($M_{0.001}$) denote the maximum number of simultaneous conversations that can be supported with $p_{loss} \le 0.02$ ($p_{loss} \le 0.001$).

The simulation environment is almost the same as that in [1] as follows. The slot length is 1 ms, a frame consists of 20 slots, and the maximum voice packet holding time $D_{\max}$ is 20 ms. Two types of source traffic are considered. A voice terminal is either in silence period or in talk spurt whose durations are assumed to follow exponential distributions. Voice packets are created only during talk spurts. The mean duration of the talk spurts and silence periods are 1 s and 1.35 s, respectively. Random data terminal creates a new packet in every slot according to a Bernoulli experiment with parameter $\delta_d (= 1/47)$.

A standard Gaussian approximation was used to determine bit-error ratio(BER). Probability of bit error P_e in a target cell 0 can be obtained by

$$P_e \approx Q(\overline{SNR}) \tag{14}$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-u^2/2} du$$

$$\overline{SNR} = \sqrt{\frac{3P_0 N}{(K-1)P_0 + \sum_{k=1}^{K} \sum_{i=1}^{R} P_{(k,i)_0}}}$$

In (14), N is a spreading factor, R is the number of cells outside of cell 0, K is the number of transmitters in each cell, P_0 is the received power level at the base station of cell 0 from transmitters within cell 0, and $P_{(k,i)_0}$ is the received power level at the base station of cell 0 from transmitters outside cell 0. Assuming that packets of length L bits are transmitted and employing a block code, which can correct up to t errors, the packet success probability Q_E can be derived from

$$Q_E=\sum_{i=0}^{t}\binom{L}{i}P_e^i(1-P_e)^{L-i}. \qquad (15)$$

For example, in a single cell environment, assuming a spreading factor $N=7$, packets of length $L=511(bit)$, and a code that can correct up to $t=38$ errors, Table 1 shows the packet success probability when K packets are transmitted simultaneously, $Q_E[K]$.

〈Table 1〉 Packet Success Probability

K	$Q_E[K]$	K	$Q_E[K]$
1	1.	11	0.572623
2	1.	12	0.248786
3	1.	13	0.0770013
4	1.	14	0.0198179
5	1.	15	0.003468018
6	1.	16	0.000634512
7	0.999834	17	0.0000899494
8	0.999719	18	0.0000169026
9	0.985993	19	0.0000026883
10	0.873207	20	0.00000036947

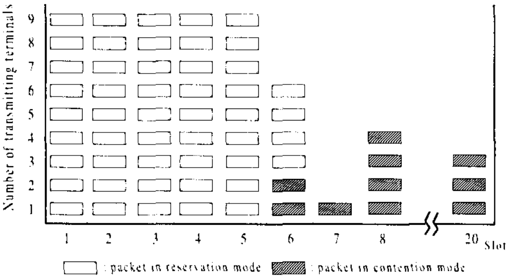
4.1 Results for Voice-Only Traffic

Following three cases were simulated to evaluate the performance of the new channel access function.

JCP_o : Old channel access function of Fig. 2 is applied to the Joint CDMA/PRMA.

JCP_n : New permission probability obtained by (2) is applied to the Joint CDMA/PRMA. When $(p_{loss})_{req}=0.02$, $(p_{crtcd})_{tar}=0.01$ is used to balance p_{drop} and p_{crtcd}. Similarly, when $(p_{loss})_{req}=0.001$, $(p_{crtcd})_{tar}=0.0004$ is used.

$JCP_{n,re}$: New permission probability obtained by (2) is applied to the Joint CDMA/PRMA and time slot rearrangement is applied to reduce the variance of the interference. Since we know that $Q_E[9]=0.985993$ ($Q_E[8]=0.999719$) from Table 1, we try to maintain the number of simultaneous transmissions as 9(8) as much as possible when $(p_{loss})_{req}=0.02$ ($(p_{loss})_{req}=0.001$) like Figure 3. That is, if the number of terminals in reservation mode in slot i is less than 9(when $(p_{loss})_{req}=0.02$) or a terminal switches from a talk spurt to silence period in i^{th} slot, the terminal in reservation mode in $j^{th}(j>i)$ slot is rearranged to i^{th} slot from the next frame.



[Figure 3] Frame Structure of $JCP_{n,re}$

For the above three cases, $M_{0.02}$ and $M_{0.001}$ obtained by simulations are summarized in

Table 2. All simulation results are the mean of 10 replications with 500 second simulated time discarding first 250 second as a warm-up period. From Table 2 we can see that when $(p_{loss})_{req}=0.02$, the performance of JCP_o and JCP_n are almost the same and $JCP_{n,re}$ increases the capacity about 2.3% compared to that of JCP_o. When $(p_{loss})_{req}=0.001$, JCP_n and $JCP_{n,re}$ increase the capacity about 6.6% and 12.8% respectively compared to that of JCP_o.

<Table 2> Simulation Results for Voice-Only Traffic

	JCP_o	JCP_n	$JCP_{n,re}$
$M_{0.02}$	386	384	395
$M_{0.001}$	288	307	327

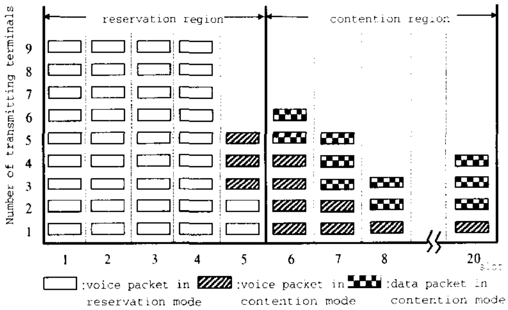
4.2 Results for Mixed Voice/Random-Data Traffic

Following three cases were simulated to evaluate the performance of the new channel access function when $(p_{loss})_{req}$ is given as 0.02.

JCP_o : Old channel access function of Fig. 2 is applied to the Joint CDMA/PRMA.

JCP_n : New permission probability obtained by (2) with $(p_{crted})_{tar}=0.01$ is applied to the Joint CDMA/PRMA.

$JCP_{n,ded}$: New permission probability obtained by (2) with $(p_{crted})_{tar}=0.01$ is applied to the Joint CDMA/PRMA and some slots are dedicated to packets in reservation mode, that is, a frame is divided into two region : reservation region and contention region like Fig. 4. Packets transmitted from the terminals in reservation (contention) mode are transmitted only through reservation (contention) region. The size of the reservation region is determined by the number of voice terminals in the system. For example, if 250 voice terminals are in the system, the average number of terminals in the reservation mode is 106.38(=250/2.35). So 11.82 (=106.38/9) slots are required and 12 slots are assigned to reservation region.



[Figure 4] Frame Structure of $JCP_{n,ded}$

For the above three cases, the maximum number of data terminals that can be supported with the voice packet loss probability less than or equal to 2% were obtained by simulations for a given number of voice terminals. All simulation results are the mean of 5 replications with 100 second simulated time discarding first 50 second as a warm-up period. Table 3 shows the maximum number of data terminals that can be supported for the varying number of voice terminals. From Table 3 we can see that the performance of JCP_n is always superior to that of JCP_o. JCP_n increases the capacity up

〈Table 3〉 Simulation Results for Mixed Voice / Random-Data Traffic

no of voice terminal	data terminal		
	JCP_o	JCP_n	gain(%)
150	117	148	26.5
175	102	132	29.4
200	90	113	25.6
225	77	95	23.4
250	67	79	17.9
275	57	61	7.0
300	46	46	0.0

to 29.4% compared to that of JCP_o. Table 4 compares the voice packet loss probability (packet drop probability plus packet corruption probability) of JCP_n and $JCP_{n,ded}$ under the same traffic load. From Table 4, we can see that the performance of $JCP_{n,ded}$ is slightly better than that of JCP_n.

〈Table 4〉 Voice Packet Loss Probability of the JCP_n and $JCP_{n,ded}$

no of voice terminal	data terminal	P_{loss}	
		JCP_n	$JCP_{n,ded}$
150	148	0.019443	0.017362
175	132	0.019847	0.017905
200	114	0.020231	0.016805
225	96	0.020238	0.016537
250	80	0.020177	0.015852
275	61	0.019624	0.014901
300	46	0.019188	0.014855

5. Conclusion

We have proposed a new channel access function to enhance the performance of the joint CDMA/PRMA. Under voice-only traffic, new channel access function has almost the same capacity as that by Brand et al. when the QoS requirement of the cell loss probability is 2%. When the QoS requirement of the cell loss probability is 0.1%, new channel access function increases capacity of a cell about 6.6%. Under mixed voice/random data traffic, new channel access function increases capacity of a cell up to 29.4%.

Under mixed voice/random-data traffic, $JCP_{n,ded}$, which reserves some slots for packets in reservation mode, has slightly higher capacity than that of JCP_n. Suppose that there are several types of source traffic which have different QoS requirements on the cell loss probability and are required to be sent in a reservation mode, like file transfer, etc. In this case, it would be preferable to reserve some slots for each types of packets in reservation mode respectively. The performance of this method needs to be further investigated.

We assumed that N_s in (10) is known ($N_s = n_s$) when $p_{s,i}$ is determined. But in real situations N_s is unknown and needs to be estimated. We will devise a method to estimate N_s and we will evaluate the performance of the new channel access function with estimated N_s in the future.

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