2003년도 대한전자공학회 하계종합학술대회 논문집 제26권 제1호

Performance Analysis of an Enhanced DQRUMA/MC-CDMA Protocol with an LPRA Scheme for Voice Traffic

Jae Yoon Park
Korea Telecom R&D Group,
Woomyun-dong 17,
Seoul, 137-792, Korea

Seung Yeob Nam
Dept. of EECS, KAIST,
Daejon, 305-701, Korea

Dan Keun Sung
Dept. of EECS, KAIST,
Daejon, 305-701, Korea

Jemin Chung
Korea Telecom R&D Group,
Woomyun-dong 17,
Seoul, 137-792, Korea

Abstract— **This paper presents a comparative evaluation of a modified version (A-Protocol) of the Distributed-Queueing Request Update Multiple Access (DQRUMA)/Multi-Code Code Division Multiple Access (MC-CDMA) protocol and an enhanced version (P-Protocol) of the DQRUMA/MC-CDMA protocol with a lattice pool for request accesses (LPRA) scheme in a packet-based voice traffic environment. Analytical results agree with the simulation ones and show that the P-Protocol outperforms the A-Protocol in terms of the packet loss rate for voice traffic.**

I. INTRODUCTION

In the future generation wireless packet networks it is important to develop appropriate multiple access techniques in order to provide various types of services [1]. Liu et al.[2] proposed a DQRUMA protocol based on multi-code (MC) CDMA for wireless packet networks which features a piggybacking (PGBK) mechanism to reduce the number of access requests and a bandwidth-on-demand fair-sharing round-robin (BoD-FSRR) transmission scheduling policy with a maximum capacity power allocation (MCPA) approach in a slot-by-slot basis to fully utilize radio resources. Due to these good features this protocol can be applied to real-time traffic as well as non-realtime traffic. The modified version of the DQRUMA/MC-CDMA protocol (A-Protocol) is the same as the the original DQRUMA/MC-CDMA protocol (called the original protocol hereafter) except that real-time traffic has higher priority than the non-real-time traffic in the A-Protocol. Thus if the A-Protocol is applied to data traffic only, it is the same as the original protocol.

We previously derived the analytical result for the A-Protocol only [3] and introduced simulation results for an enhanced version of the DQRUMA/MC-CDMA protocol with an LPRA (Lattice Pool for Request Accesses) scheme (P-Protocol) in [4] in order to reduce request collisions. However, the mathematical analysis of the P-Protocol has not been available thus far. Herein, focusing on voice traffic only, we mathematically analyze the system performance in terms of the packet loss rate for voice traffic.

The rest of this paper is organized as follows: Section II introduces the enhanced DQRUMA/MC-CDMA protocol with an LPRA scheme. Notations used in analyzing the system performance are described and analytical results are obtained in Section III. In Section IV, analytical and simulation results are compared for both A-Protocol and P-Protocol. Finally, concluding remarks are given in Section V.

II. THE ENHANCED DQRUMA/MC-CDMA PROTOCOL WITH AN LPRA SCHEME (P-PROTOCOL)

The original protocol was proposed for data traffic only, especially for high data rate traffic using its multi-code, BoD-FSRR, MCPA, and piggybacking schemes [2].

The concept of an LPRA was introduced [4]. The P-Protocol has a new slot structure based on an LPRA scheme proposed for uplink where each time slot is divided into a number of small minislots and several codes are assigned for requests and request packets are transmitted concurrently with data(voice) packets of other calls during a time slot. It is necessary to reserve an additional capacity margin for concurrent request accesses besides background noise. Thus, in the P-Protocol, capacity for data transmission is smaller than for the original protocol (or A-Protocol) by a capacity margin for concurrent request accesses. Since request attempts are dispersed on the LPRA, actual interference on data transmission due to request attempts is small in the P-Protocol.

Fig. 1 shows a slot structure of the proposed P-Protocol where propagation delay is neglected and a time slot can be divided into $(M+2)$ minislots for request accesses considering guard time [5]. First M minislots are available for requests and the last two minislots are used for reception of a request acknowledgment and a transmission permission from the BS. There are two access schemes, i.e., Schemes I and II, in the P-Protocol. A random scheme (Scheme I) and a designated scheme (Scheme II) are distinguished depending on the methods which select a request code and a request minislot based on an LPRA scheme. Both schemes yield low request access delays due to few or no collisions during request accesses.

In Scheme I request packets can be sent in one of many minislots with a randomly chosen code concurrently with data packets of other calls during a time slot. Request packets are assumed to collide only when both the same code and the same minislot are selected. Hence, the number of code collisions of request packets can be greatly reduced due to an LPRA scheme. Scheme II is the same as Scheme I except that access requests are attempted in the pre-allocated minislot position with a request access code assigned during the call admission control (CAC) procedure. The LPRA size is defined as the product of

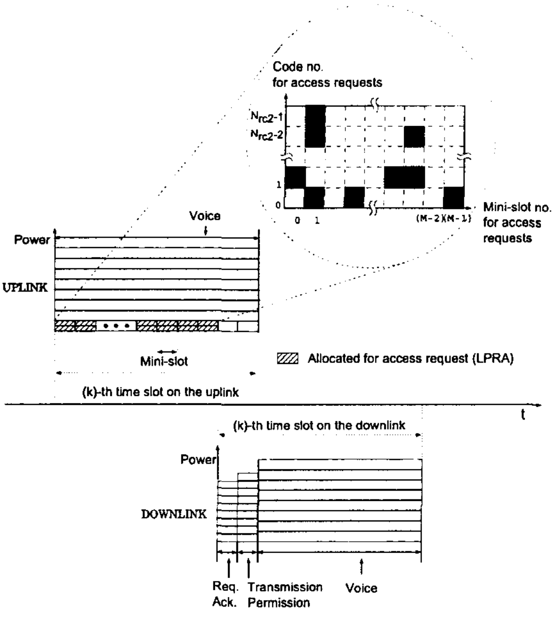

Fig. 1. The k-th time slot structure of the P-Protocol.

the number of request minislots per time slot and the number of codes assigned for request accesses. Thus, this scheme is available when the LPRA size is equal to or larger than the number of admitted calls.

If the LPRA size is large enough to allocate unique request access positions on the LPRA to all admitted calls, Scheme II is better than Scheme I because there is no request collision in Scheme II.

III. MATHEMATICAL ANALYSIS FOR VOICE TRAFFIC

In order to derive the voice packet loss probability for the P-Protocol, system model and assumptions in [3] are used in this paper.

A. Notations

$E1$	event that a source is in the S_p state in time slot i under the condition that the source is in the ON state
$E2$	event that a source is in the ON and S_p states in time slot i
$E3$	event that a request packet experiences a collision
$E4$	event that a source cannot receive transmission permission
$E5$	event that a request packet experiences neither collisions nor corruption
$E6$	event that a voice packet bit experiences corruption in S_1 in Fig.2 (b)
L_r	length of a request packet
L_v	length of a voice packet
M	number of request minislots per time slot
$N1$	number of sources which were in the ON and S_p states in the previous time slot
$N2$	number of sources which were in the OFF state in the previous time slot
$N3$	number of sources which were in the ON and S_{np} states in the previous time slot
N_{br}	number of requests in the minislot to which a bit belongs
N_{cb}	number of corrupted bits on a voice packet in a time slot
N_{cb2}	number of corrupted bits on voice packet transmission in the unoccupied parts of request packets during the span of a voice packet (that is, in the S_2 in Fig.2(b)
N_{mr}	number of requests in a minislot
N_{off}	number of sources in the OFF state in the previous time slot
N_{on}	number of sources in the ON state in the previous time slot
N_{or}	number of requests from the other sources except the target source
N_p	number of sources in the S_p state
N_{rc}	number of codes for access requests in a time slot in the A-Protocol
N_{rc2}	number of codes for access requests in a time slot in the P-Protocol
N_{rp}	minimum number of receiver-code pairs accommodating channel capacity, except for the capacity margin for background noise in a BS
N_s	number of sources in the system
N_w	number of sources waiting for transmission permission
P_{off-on}	transition probability of a voice source from the OFF to ON state
P_{on-off}	transition probability of a voice source from the ON to OFF state
$P_b(r)$	bit error probabilities of voice packets in one actual access request part with r other requests of M minislots
P_{b1}	bit error probability of voice packets in the S_1 in Fig.2(b)
P_{b2}	bit error probability of voice packets in the S_2 in Fig.2(b)
P_c	probability that a request packet experiences collisions in the A-Protocol
P_{cc}	probability that a request packet experiences collisions or corruption in the P-Protocol
P_l	voice packet loss probability
P_m	voice packet corruption probability due to MAI at the air interface in the A-Protocol
P_{mm}	voice packet corruption probability due to MAI at the air interface in the P-Protocol
$P_p(i)$	probability that a source is in the S_p state under the condition that the source is in the ON state in a time slot i
P_p	steady-state probability of $P_p(i)$
P_{pg}	probability of a voice packet discarded due to PGBK information loss

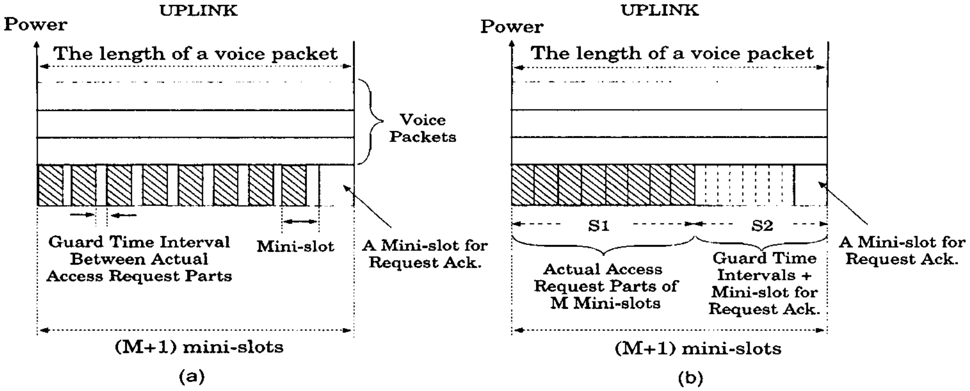

Fig. 2. Detailed time slot structure for the P-Protocol: (a) The proposed time slot structure (b) The modified structure for performance analysis.

$P_r(r)$	probability that a request packet is corrupted in the case that there are r other requests during a minislot
P_s	successful packet transmission probability
P_u	probability for non-receipt of transmission permission due to capacity limit
S_{np}	a source is in the state which has received no request acknowledgment or transmission permission
S_p	a source is in the state which has received both request acknowledgment and transmission permission
T	number of correctable bits in an encoded voice packet
δ	an additional capacity margin for access requests in the P-Protocol

B. Analytical derivation of the voice packet loss probability (P_l) for the P-Protocol

Some parts of the equations derived in [3] for the A-Protocol are modified in order to obtain P_l for the P-Protocol because of concurrent transmission of request packets and voice packets. In other words, request packet corruption may occur in the P-Protocol because the power level of request packets is reduced to lessen the MAI amount from other request and/or voice packets. Hence, calculation of P_{cc} and P_{mm} for the P-Protocol is different from that of P_c and P_m for the A-Protocol.

Now we calculate P_{cc}.

$$\begin{aligned} P_{cc} &\equiv 1 - P\{E5\} \\ &= 1 - \sum_{j=0}^{N_s-1}\sum_{i=0}^{j} P\{E5|N_{on}=j, N_p=i\} \\ &\quad \times P\{N_p=i|N_{on}=j\}P\{N_{on}=j\}, \end{aligned}$$

where

$$\begin{aligned} &P\{E5|N_{on}=j, N_p=i\} \\ &= \sum_{n=0}^{(N_s-1-i)} [P\{E5|N_{on}=j, N_p=i, N_{or}=n\} \\ &\quad \times P\{N_{or}=n|N_{on}=j, N_p=i\}]. \end{aligned} \tag{1}$$

The detailed slot structure of the P-Protocol is depicted in Fig.2(a). Herein, however, the slot structure shown in Fig.2 (b) is used for the performance analysis because the request packet error probabilities and the bit error probabilities of voice packets in the P-Protocol may vary depending on the number of requested packets for each minislot due to concurrent transmission of voice packets and request packets. In Fig.2 (b), the length of a voice packet can be divided into two parts. The first part is for actual access requests (S_1 in the figure). The second part is S_2, in which there are no access requests.

In Eqn.(1) we can derive

$$\begin{aligned} &P\{E5|N_{on}=j, N_p=i, N_{or}=n\} \\ &= \sum_{r=0}^{n} P\{N_{mr}=r|N_{on}=j, N_p=i, N_{or}=n\} \\ &\quad \times P\{E5|N_{on}=j, N_p=i, N_{or}=n, N_{mr}=r\} \\ &= \sum_{r=0}^{n}\binom{n}{r}\left(\frac{1}{M}\right)^r\left(1-\frac{1}{M}\right)^{n-r}\left(1-\frac{1}{L}\right)^r\left(1-P_r(r+1)\right) \\ &= \begin{cases} \sum_{r=0}^{n}\binom{n}{r}\left(\frac{1}{M}-\frac{1}{LM}\right)^r\left(1-\frac{1}{M}\right)^{n-r}\left(1-P_r(r+1)\right) & \text{(Scheme I)}, \\ \sum_{r=0}^{n}\binom{n}{r}\left(\frac{1}{M}\right)^r\left(1-\frac{1}{M}\right)^{n-r}\left(1-P_r(r+1)\right) & \text{(Scheme II)}. \end{cases} \end{aligned}$$

Since the performance results of Schemes I and II of the P-Protocol are very similar (as will be shown in Fig.4 in Section IV later), we calculate the voice packet loss rate for Scheme II only.

Assuming that packets of length L are transmitted over a memoryless binary symmetric communication channel with a bit error probability of P_b using a BCH FEC coding scheme that can correct up to T errors, the packet error probability P_E can be expressed as

$$P_E = \sum_{i=T+1}^{L}\binom{L}{i}P_b^i(1-P_b)^{L-i}. \tag{2}$$

Since the bit error probability of request packets is assumed to be constant during a mini-slot, the packet error probability

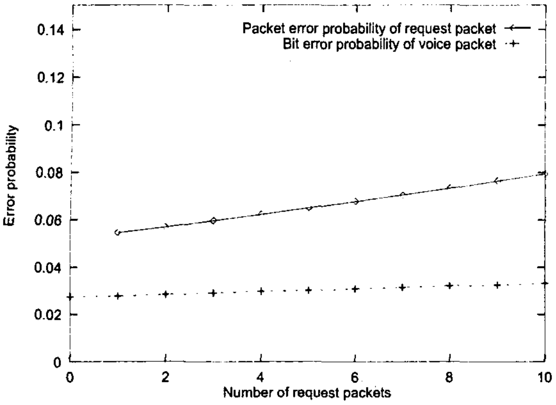

Fig. 3. Bit error probabilities of voice packets and request packet error probabilities according to the number of request packets per minislot in the P-Protocol.

of request packets can be obtained from Eqn. (2) in the A-Protocol. However, Eqn. (2) cannot be used for voice packets of the P-Protocol because the bit error probability differs from mini-slot to mini-slot depending on the number of request packets attempted in each mini-slot. A voice packet is said to be incorrectly received if the number of bits in error during a time slot is greater than the number of correctable bit errors T. In the A-Protocol, the bit error probabilities of voice packets are independent of the number of voice packets because power levels of voice packet transmissions are assumed to be optimally controlled [2]. However, in the P-Protocol the bit error probabilities may vary depending on the number of request packets from mini-slot to mini-slot because of concurrent transmission of voice packets and request packets.

Fig. 3 shows that bit error probabilities of voice packets and request packet error probabilities according to the number of request packets per mini-slot in the P-Protocol. Thus, if exactly two requests are attempted in every mini-slot, the same interference level as voice packet (at a basic rate) transmission is achieved except for guard time intervals between mini-slots. However, if the number of request packets is less than two in a mini-slot, voice packets during the span of the mini-slot in the P-Protocol experience less interference than in the A-Protocol.

From Fig.3 we can approximate $P_r(r+1)$ as a linear function such that: $P_r(r+1) \approx Ar + B$ where A and B are constants.

$$
\begin{aligned}
&P\{E5|N_{on}=j, N_p=i, N_{or}=n\} \\
&\approx \sum_{r=0}^{n} \binom{n}{r} \left(\frac{1}{M}\right)^r \left(1-\frac{1}{M}\right)^{n-r} (1-A-B-Ar) \\
&= (1-A-B) - \frac{A}{M} n. \qquad (3)
\end{aligned}
$$

$$
\begin{aligned}
&P\{N_{or}=n|N_{on}=j, N_p=i\} \\
&= \sum_{l=0}^{n} \binom{j-i}{l} (1-P_{on-off})^l (P_{on-off})^{j-i-l} \\
&\quad \times \binom{N_s-1-j}{n-l} (P_{off-on})^{(n-l)} (1-P_{off-on})^{N_s-1-j-(n-l)}. \qquad (4)
\end{aligned}
$$

Hence, substituting Eqn.(4) obtained in [3] and Eqn.(3) into Eqn.(1) yields

$$
\begin{aligned}
&P\{E5 \mid N_{on}=j, N_p=i\} \\
&\approx \sum_{n=0}^{(N_s-1-i)} \sum_{l=0}^{n} \binom{j-i}{l} (1-P_{on-off})^l (P_{on-off})^{j-i-l} \\
&\quad \times \binom{N_s-1-j}{n-l} (P_{off-on})^{n-l} (1-P_{off-on})^{N_s-1-j-(n-l)} \\
&\quad \times \left(1-A-B-\frac{A}{M}n\right) \\
&= \sum_{l=0}^{(N_s-1-i)} \sum_{n=l}^{(N_s-1-i)} \binom{j-i}{l} (1-P_{on-off})^l (P_{on-off})^{j-i-l} \\
&\quad \times \binom{N_s-1-j}{n-l} (P_{off-on})^{n-l} (1-P_{off-on})^{N_s-1-j-(n-l)} \\
&\quad \times \left(1-A-B-\frac{A}{M}n\right). \qquad (5)
\end{aligned}
$$

Letting $(n-l) = m$ simplifies

$$
\begin{aligned}
&P\{E5 \mid N_{on}=j, N_p=i\} \\
&\approx 1-A-B-\frac{A}{M} \sum_{l=0}^{(N_s-1-i)} l \binom{j-i}{l} (1-P_{on-off})^l (P_{on-off})^{j-i-l} \\
&\quad \times \sum_{m=0}^{(N_s-1-i-l)} \binom{N_s-1-j}{m} (P_{off-on})^m (1-P_{off-on})^{(N_s-1-j-m)} \\
&\quad -\frac{A}{M} \sum_{l=0}^{(N_s-1-i)} \binom{j-i}{l} (1-P_{on-off})^l (P_{on-off})^{j-i-l} \\
&\quad \times \sum_{m=0}^{(N_s-1-i-l)} m \binom{N_s-1-j}{m} (P_{off-on})^m (1-P_{off-on})^{(N_s-1-j-m)} \\
&= 1-A-B-\frac{A}{M}(j-i)(1-P_{on-off}) - \frac{A}{M}(N_s-1-j)P_{on-off}. \qquad (6)
\end{aligned}
$$

Therefore, P_{cc} is obtained as

$$
\begin{aligned}
P_{cc} \approx 1-\sum_{j=0}^{N_s-1} \sum_{i=0}^{j} \Big\{ &\left(1-A-B-\frac{A}{M}(j-i)(1-P_{on-off}) \right. \\
&\left. -\frac{A}{M}(N_s-1-j)P_{on-off}\right) \binom{j}{i} P_p^i (1-P_p)^{j-i} \\
&\times \binom{N_s-1}{j} \pi_{on}^j (1-\pi_{on})^{N_s-1-j} \Big\}
\end{aligned}
\qquad (7)
$$

$$= A + B + \frac{A}{M} \sum_{j=0}^{N_s-1} \sum_{i=0}^{j} \Bigg\{ (j-i)(1-P_{on-off}) \times \binom{j}{i} P_p^i (1-P_p)^{j-i} \binom{N_s-1}{j} \pi_{on}^j (1-\pi_{on})^{N_s-1-j} \Bigg\}$$
$$+ \frac{A}{M} \sum_{j=0}^{N_s-1} \sum_{i=0}^{j} \Bigg\{ (N_s - 1 - j) P_{off-on} \times \binom{j}{i} P_p^i (1-P_p)^{j-i} \binom{N_s-1}{j} \pi_{on}^j (1-\pi_{on})^{N_s-1-j} \Bigg\}. \quad (8)$$

And from Eqn.(12) in [3], we have

$$\sum_{j=0}^{N_s-1} \sum_{i=0}^{j} \Bigg\{ \alpha^{j-i} \beta^{N_s-1-j} \binom{j}{i} {P_p}^i (1-P_p)^{j-i} \times \binom{N_s-1}{j} {\pi_{on}}^j (1-\pi_{on})^{(N_s-1-j)} \Bigg\}$$
$$= [(1-\pi_{on})\beta + \pi_{on}[P_p + \alpha(1-P_p)]]^{N_s-1}. \quad (9)$$

Differentiating both sides of Eqn.(9) with respect to α and β and assigning $\alpha = 1$ and $\beta = 1$, we can obtain the following equations.

$$\sum_{j=0}^{N_s-1} \sum_{i=0}^{j} (j-i) \binom{j}{i} P_p^i (1-P_p)^{(j-i)} \binom{N_s-1}{j} \pi_{on}^j (1-\pi_{on})^{(N_s-1-j)} = (N_s - 1)(1 - P_p)\pi_{on}. \quad (10)$$

$$\sum_{j=0}^{N_s-1} \sum_{i=0}^{j} (N_s-1-j) \binom{j}{i} P_p^i (1-P_p)^{(j-i)} \binom{N_s-1}{j} \pi_{on}^j (1-\pi_{on})^{(N_s-1-j)} = (N_s - 1)(1 - \pi_{on}). \quad (11)$$

Substituting Eqns.(10) and (11) into Eqn.(8), we obtain a simplified form of P_{cc} as follows:

$$P_{cc} \approx A + B + \frac{A}{M}(1-P_{on-off})(N_s-1)(1-P_p)\pi_{on} + \frac{A}{M} P_{off-on}(N_s-1)(1-\pi_{on}).$$

And we now calculate P_{mm}.

$$\begin{aligned} P_{mm} &\equiv P\{N_{cb} > T\} \\ &= 1 - \sum_{l=0}^{T} P\{N_{cb} \le T, N_{cb2} = l\} \\ &= 1 - \sum_{l=0}^{T} \binom{L_v - L_r \times M}{l} {P_{b2}}^l (1-P_{b2})^{(L_v - L_r \times M)} \\ &\quad \times \sum_{k=0}^{T-l} \binom{L_r \times M}{k} {P_{b1}}^k (1-P_{b1})^{(L_r \times M - k)}, \end{aligned} \quad (12)$$

where

$$\begin{aligned} P_{b1} &\equiv P\{E6\} \\ &= \sum_{j=0}^{N_s-1} \sum_{i=0}^{j} \sum_{n=0}^{(N_s-1-i)} [P\{E6 | N_{on}=j, N_p=i, N_{or}=n\} \\ &\quad \times P\{N_{or}=n | N_{on}=j, N_p=i\}] P\{N_p=i | N_{on}=j\} \\ &\quad \times P\{N_{on}=j\}, \end{aligned}$$

and

$$\begin{aligned} & P\{E6 \mid N_{on} = j, N_p = i, N_{or} = n\} \\ &= \sum_{r=0}^{n} P\{N_{br} = r | N_{on} = j, N_p = i, N_{or} = n\} \\ &\quad \times P\{E6 | N_{on} = j, N_p = i, N_{or} = n, N_{br} = r\} \\ &= \sum_{r=0}^{n} \binom{n}{r} (\frac{1}{M})^r (1 - \frac{1}{M})^{n-r} P_b(r). \end{aligned}$$

We can approximate $P_b(r)$ from Fig.3 as follows: $P_b(r) \approx Xr + Y$ where X and Y are constants.
Hence,

$$\begin{aligned} & P\{E6 \mid N_{on} = j,\ N_p = i,\ N_{or} = n\} \\ &\approx \sum_{r=0}^{n} \binom{n}{r} (\frac{1}{M})^r (1 - \frac{1}{M})^{n-r} (Xr + Y) \\ &= Y + \frac{X}{M} n. \end{aligned}$$

In a similar manner described in Eqn.(5), $P\{E6 \mid N_{on} = j, N_p = i\}$ can be obtained as

$$\begin{aligned} & P\{E6 | N_{on} = j, N_p = i\} \\ &\approx \sum_{l=0}^{(N_s-1-i)} \sum_{n=l}^{(N_s-1-i)} \binom{j-i}{l} (1-P_{on-off})^l (P_{on-off})^{(j-i-l)} \\ &\quad \times \binom{N_s-1-j}{n-l} (P_{off-on})^{n-l} (1-P_{off-on})^{N_s-1-j-(n-l)} (Y + \frac{X}{M} n) \\ &= Y + \frac{X}{M}(j-i)(1-P_{on-off}) + \frac{X}{M}(N_s-1-j) P_{off-on}. \end{aligned}$$

Therefore, P_{b1} is approximated as

$$\begin{aligned} P_{b1} &\approx \sum_{j=0}^{N_s-1} \sum_{i=0}^{j} (Y + \frac{X}{M}(j-i)(1-P_{on-off}) + \frac{X}{M}(N_s-1-j) P_{off-on}) \\ &\quad \times \binom{j}{i} {P_p}^i (1-P_p)^{j-i} \binom{N_s-1}{j} \pi_{on}^j (1-\pi_{on})^{(N_s-1-j)} \\ &= Y + \frac{X}{M}(1 - P_{on-off})(N_s - 1)(1 - P_p)\pi_{on} \\ &\quad + \frac{X}{M} P_{off-on}(N_s - 1)(1 - \pi_{on}). \end{aligned} \quad (13)$$

Therefore, we can calculate P_{mm} from Eqns.(12) and (13). We can obtain P_l for the P-Protocol after replacing P_c and P_m by P_{cc} and P_{mm}, respectively, in Eqn.(4) in [3].

TABLE I

SIMULATION PARAMETERS (VOICE TRAFFIC)

Parameters	Value
Max. number of calls in the system	128
Required E_b/I_o of voice packets	2.6 dB
Processing gain	64
Request packet size, L_r	31 bits
Voice packet size, L_v	1023 bits
Voice packet corruption probability, P_m of A-Protocol	0.0116
Time slot duration	11.75 ms
Voice source rate	32 kbps
Voice activity	0.35
P_{on-off}	1/30
P_{off-on}	1/55
FEC for request packets	BCH(31,11,5)
FEC for voice transmission packets	BCH(1023,648,41)
Voice packet delay limit, D_{max}	1 time slot
Number of codes for LPRA, N_{rc2}	13
Number of minislots for LPRA, M	10
System capacity reservation factors of A-Protocol and P-Protocol	1, 2

IV. PERFORMANCE EVALUATION FOR VOICE TRAFFIC

All simulation environments and terminologies of the P-Protocol, except some parameters listed in Table I, are identical to those in the original DQRUMA/MC-CDMA protocol and the A-Protocol [2, 3].

Fig. 4 illustrates the voice packet loss rate for a varying number of voice calls. It shows that the analytical and simulation results are in good agreement. In the P-Protocol voice packet losses occur because of collisions or corruption of request packets (related to P_{cc}), dropping due to the channel capacity limit (P_u), corruption due to MAI on voice packet transmissions (P_{mm}), and discarding due to PGBK information loss (P_{pg}). When the number of mobile calls is less than approximately 110, dominant factors affecting voice packet losses are P_{cc}, P_{mm}, and P_{pg}. The request collision probability gradually increases as the number of mobiles increases. However, the request collision or corruption probability increases only slightly because of a decrease in request collisions by using the LPRA scheme in the P-Protocol. As the increasing number of mobiles limits the available channel capacity, the packet loss rate starts to rapidly increase because P_u increases. The number of voice packets discarded due to PGBK information loss is proportional to the number of corrupted voice packets because voice packet corruption on the air interface due to MAI affects the piggybacking information loss directly, from the relation $P_{pg} = \frac{1/P_{on-off}-1}{1/P_{on-off}} \cdot P_{mm}$.

The packet loss rates for the P-Protocol are better than for the A-Protocol, not only because the actual interference level caused by access requests is less than the reserved interference margin for access requests, but also because it yields less packet corruption due to MAI than the A-Protocol.

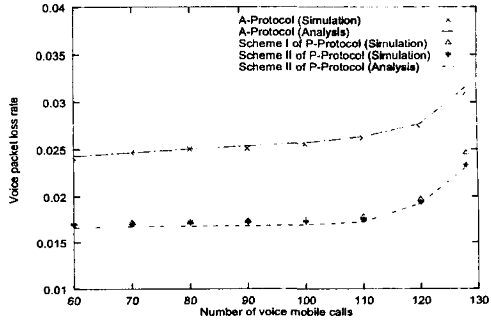

Fig. 4. Comparison of analysis and simulation results for voice traffic.

V. CONCLUDING REMARKS

We derived analytical results of an enhanced DQRUMA/MC-CDMA protocol with an LPRA scheme (P-Protocol) for voice traffic. Mathematical analysis focused on the performance measure of voice packet loss probability for the P-Protocol. The accuracy of this formula was verified by simulation. These results show that the P-Protocol yields better performance than the A-Protocol in terms of the voice packet loss rate because the LPRA scheme contributes to fewer request collisions and less interfered packet transmission.

REFERENCES

[1] S. Ohmori, Y. Yamao, and N. Nakajima, "The future generations of mobile communications ased on broadband access technologies," *IEEE Commun. Mag.*, pp. 134-142, Dec. 2000.

[2] Z. Liu, M. J. Karol, M. E. Zarki, and K. Y. Eng, "Channel access and interference issues in multi-code DS-CDMA wireless packet (ATM) networks," *Wireless Networks*, pp. 173-193, 1996, J.C. Baltzer AG, Science Publishers.

[3] J. Y. Park, S. Y. Nam, D. K. Sung, and S. H. Kim, "Performance Analysis of a Modified DQRUMA/MC-CDMA Protocol for Voice Traffic," *in Proc. APCC*, pp. 744-748, Oct. 2000.

[4] J. Y. Park, D. K. Kim, and D. K. Sung, "An enhanced DQRUMA/MC-CDMA protocol for wireless packet networks," *IEICE Trans. Commun.*, vol. E83-B, no.7, pp. 1567- 1571, Jul. 2000.

[5] M. J. Karol, Z. Liu, and K. Y. Eng, "An efficient demand-assignment multiple access protocol for wireless (ATM) networks," *Wireless Networks*, pp. 269-279, 1995, J.C. Baltzer AG, Science Publishers.