An SS_RRA Protocol for Integrated Voice/Data Services in Packet Radio Networks

Intaek Lim, *Member, KIMICS*

Abstract—In this paper, an SS-RRA protocol that is based on Code Division Multiple Access is proposed and analyzed under the integrated voice and data traffic load. The backward logical channels consist of slotted time division frames with multiple spreading codes per slot. The protocol uses a reservation mechanism for the voice traffic, and a random access scheme for the data traffic. A discrete-time, discrete-state Markov chain is used to evaluate the performance. The numerical results show that the performance can be significantly improved by a few distinct spreading codes.

Index Terms—CDMA, Integrated service, Medium access control protocol, Slotted ALOHA.

I. INTRODUCTION

The future success of the wireless communication networks depends on the ability to accommodate a various types of services with different quality of service requirements. For doing so, efficient mechanisms are needed to support integrated services in the personal and mobile communication environment. It is also important to design a MAC protocol that meets the QoS requirements of the different traffic types and allocates the shared radio resources efficiently [1][5].

CDMA has been attracted more and more attentions due to its anti-jamming capability, multiple access capability, and low probability of intercept. In addition to this, CDMA has advantages of the simple cell planning and the increased system capacity [2].

There are several types of MAC protocols such as RRA (Reservation and Random Access) and PRMA (Packet Reservation Multiple Access), in which voice traffic is carried with the reservation scheme and data traffic is with slotted ALOHA random access scheme [3][4]. Those protocols do not take advantages of CDMA scheme.

In this paper, an SS-RRA (Spread Spectrum Reservation and Random Access) protocol that supports the integrated voice and data traffic is proposed and analyzed. The backward logical channels are composed of the frame-based time slots and the spreading codes per each slot. In this protocol, the voice terminal reserves an available logical channel by transmitting a reservation request packet, and uses the reserved channel exclusively until the talkspurt terminates. On the other hand, the data terminal transmits the packet through a random access mechanism whenever it generates a packet. This protocol has the characteristics of allocating channels on-demand.

This paper is organized as follows. Section II describes the backward logical channel structures and the proposed protocol. Section III contains the analytical model to evaluate the performance of the protocol. The numerical results are also given in Section III. Finally, Section IV concludes this work.

II. SYSTEM DESCRIPTIONS

A. Channel Structure

The proposed protocol, called SS-RRA, is designed to operate in the cellular packet radio networks. In the cellular packet radio networks, the mobile stations (MS) transmit their packets to a base station (BS) for communicating with a fixed or mobile station. It is assumed that the system consists of a base station and mobile stations that are uniformly distributed within a cell. All mobile stations share a channel to transmit their packet to the base station. Backward traffic (from MS to BS) and forward traffic (from BS to MS) can be transmitted simultaneously by FDD. The BS can schedule forward traffic without contention; therefore this paper will focus only on the backward channel. Fig.1 shows the structure of the backward logical channel and packet.

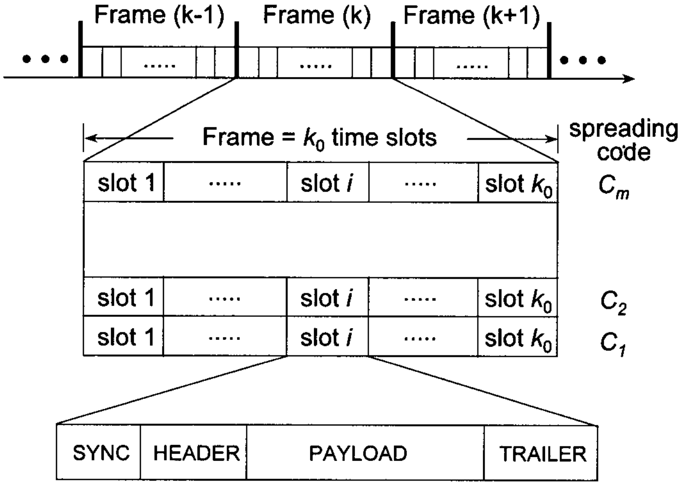

Fig. 1 Backward logical channel and packet structure.

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Intaek Lim is with the Department of Computer Engineering, Pusan University of Foreign Studies, Busan, 608-738, Korea (Tel: +82-51-640-3423, Fax: +82-51-640-3038, Email: itlim@pufs.ac.kr)

As depicted in Fig.1, the backward logical channel consists of the frame-based time slots and the spreading codes for each time slot. The frame rate is identical to the arrival rate of voice packets. The packets are transmitted during a time slot with a spreading code. A frame is composed of k_0 time slots and m spreading codes $\{C_i, i=1, ..., m\}$, orthogonal to each other. If m is equal to one, SS-RRA protocol is the same as RRA protocol in TDMA system.

The packet structure at the air interface is also illustrated in Fig.1. A packet length is equal to a slot size. The SYNC field is used for the receiver to acquisition a spreading code. The header contains a field indicating the type of packets and other control fields, while the trailer contains an error control field.

B. Protocol Description

The detailed description of SS-RRA protocols for the mobile station and the base station are illustrated in Fig.2 and 3. The base station broadcasts the status of the backward logical channels. When a voice terminal starts a new talkspurt, it transmits a reservation request packet (RR_pkt) with one of the available spreading codes at the next slot and waits an acknowledgment (RR_ack). If the base station successfully receives the RR_pkt, it broadcasts an RR_ack. If the terminal receives an RR_ack, it transmits voice packets through the reserved channel until the talkspurt terminates. When the voice terminal finishes its talkspurt, it loses its reservation rights. In the case of voice traffic, the reservation scheme eliminates the need of contention for a large percentage of packets, thus it reduces the number of wasted channels due to collisions.

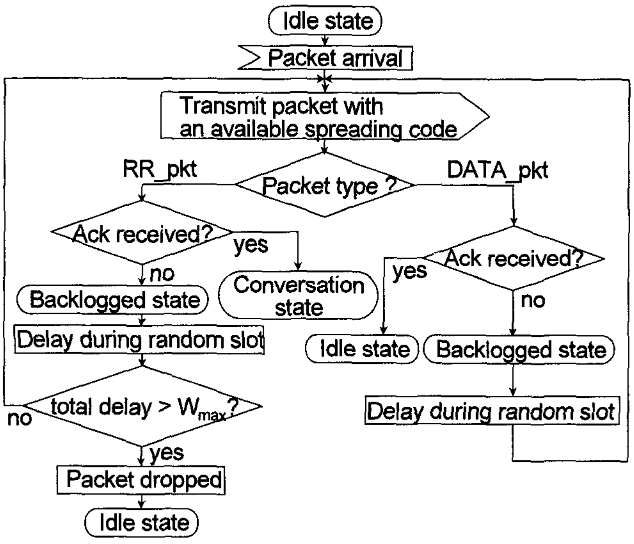

Fig. 2 Flow descriptions of mobile station.

On the other hand, the data terminal operates with a slotted CDMA_ALOHA scheme [6]. When a data terminal generates a packet, it transmits a packet (DATA_pkt) through one of the available spreading codes.

The packet transmission fails if either or both of the following conditions occur:

(1) All of the channels are reserved.

(2) The packet collision occurs.

The mobile terminal that fails to transmit a packet changes its state to the backlogged state and retransmits the same packet after a random delay. A voice packet that fails to transmit more than W_{max} slots will be dropped.

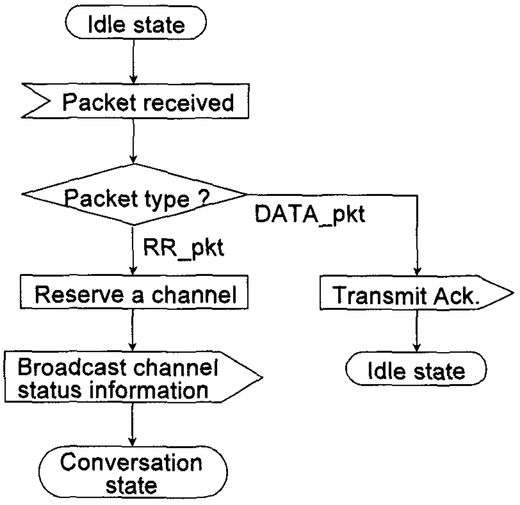

Fig. 3 Flow descriptions of base station.

III. PERFORMANCE ANALYSIS

A. Markov Analysis

For the voice terminal with a speech activity detector (SAD), the speech source can be characterized as a two-state model. The transition probability from the talking state to the silence state α_v and the inverse transition probability γ_v are represented as [3]. Let N_v and N_d be the number of voice and data terminals, respectively. A voice terminal in the backlogged state retransmit its RR_pkt with probability β_v. Let α_d denote the probability that the data terminal generates a data packet in a slot and β_d the retransmission probability of the data packet in a slot.

Let the system state be the number of backlogged data terminals and the number of backlogged voice terminals in a slot. Then the state transition probability $Q_{ij,br}(k)$, given that there are k reserved voice terminals, can be derived as follows

$$Q_{ij,br}(k) = \sum_{x=0}^{m} \sum_{v_r=0}^{j} \sum_{v_i=0}^{N_v-k-j} \sum_{d_b=0}^{i} \sum_{d_i=0}^{N_d-i} \begin{Bmatrix} \Phi(x,k,k_0,m)\Gamma_R(v_r \mid j)\Gamma_V(v_i \mid k,j)\Gamma_B(d_b \mid i)\times \\ \Gamma_D(d_i \mid i)S(S_v+S_d \mid v_r+v_i+d_b+d_i,x) \end{Bmatrix} \tag{1a}$$

Where

$$\begin{aligned} &S_v = j-r+v_i \quad ,0 \le S_v \le Min\{x,v_r+v_i\} \\ &S_d = i-b+d_i \quad ,0 \le S_d \le Min\{x,d_b+d_i\} \\ &0 \le S_v+S_d \le Min\{x,v_r+v_i+d_b+d_i\} \end{aligned} \tag{1b}$$

In equation (1a), the term $\Phi(x,k,k_0,m)$ is the probability that under the condition of k reserved voice terminals x ($0 \le x \le m$) spreading codes are available in a slot. And the term $S(s|n,x)$ is the conditional probability that s packets out of n are successfully transmitted through x spreading codes. The term $\Gamma_R(v_r|j)$, $\Gamma_V(v_i|k,j)$, $\Gamma_B(d_b|i)$, and $\Gamma_D(d_i|i)$ are defined as follows.

$$\begin{aligned}
\Gamma_R(v_r \mid j) &= \binom{j}{v_r}\beta_v^{v_r}(1-\beta_v)^{j-v_r} \\
\Gamma_V(v_i \mid k,j) &= \binom{N_v-k-j}{v_i}\alpha_v{}^{v_i}(1-\alpha_v)^{N_v-k-j-v_i} \\
\Gamma_B(d_b \mid i) &= \binom{i}{d_b}\beta_d{}^{d_b}(1-\beta_d)^{i-d_b} \\
\Gamma_D(d_i \mid i) &= \binom{N_d-i}{d_i}\alpha_d{}^{d_i}(1-\alpha_d)^{N_d-i-d_i}
\end{aligned} \tag{2}$$

The conditional probability $S(s|n,x)$ can be defined recursively by

$$\begin{aligned}
S(s \mid n,x) = \left(1-\frac{1}{x}\right)^n S(s \mid n,x-1) + \sum_{j=1}^{n}\binom{n}{j}\left(\frac{1}{x}\right)^j\left(1-\frac{1}{x}\right)^{n-j} \\
\left\{\zeta_j S(s-1 \mid n-j,-1) + (1-\zeta_j)S(s \mid n-j,x-1)\right\}
\end{aligned} \tag{3}$$

where $\zeta_1=1$, and $\zeta_j=0$ ($j \ne 1$).

The initial conditions for $S(s|n,x)$ are as follows

$$\begin{array}{ll}
S(0 \mid 0,x)=1,\ S(1 \mid 0,x)=0, & \text{for } x \ge 0 \\
S(0 \mid n,0)=1,\ S(1 \mid n,0)=0, & \text{for } n \ge 0 \\
S(0 \mid 1,x)=0,\ S(1 \mid 1,x)=1, & \text{for } x \ge 1 \\
S(1 \mid n,1)=0,\ S(0 \mid n,1)=1, & \text{for } n \ge 2 \\
S(s \mid n,x)=0, & \text{for } s > \min(n,x)
\end{array} \tag{4}$$

To derive $\Phi(x,k,k_0,m)$, let $D(k,k_0,m)$ be the number of ways of distributing k indistinguishable voice terminals into k_0 distinguishable slots under the restriction of m-code occupancy per slot. According to [7], $D(k,k_0,m)$ and $\Phi(x,k,k_0,m)$ are given by

$$D(k,k_0,m) = \sum_{i=0}^{k_0}(-1)^i\binom{k_0}{i}\binom{k+k_0-i(m+1)-1}{k_0-1} \tag{5}$$

$$\Phi(x,k,k_0,m) = \frac{D(k-m+x,k_0-1,m)}{D(k,k_0,m)} \tag{6}$$

where $k \le mk_0$, $0 \le x \le m$, $k_0 \ge 1$.

Once the probability $Q_{ij,br}(k)$ is obtained, the steady state probability $\Pi(br|k)$ and the probability $\Pi^v(r|k)$ that r voice terminals are in the backlogged state can be derived. Then the dynamics of the reserved voice terminals can be modeled as a generalized Birth-Death process. Let λ_k be the probability that an idle or backlogged voice terminal will reserve a channel successfully under the condition of k reserved voice terminals in the system. Then this is the effective arrival rate of a voice terminal to the system and is defined by

$$\begin{aligned}
\lambda_k = \sum_{r=0}^{N_v-k}\sum_{x=1}^{m}\sum_{v_r=0}^{r}\sum_{v_i=0}^{N_v-k-r} \\
\left\{\begin{array}{l}
\Phi(x,k,k_0,m)\cdot\binom{r}{v_r}\beta_v^{v_r}(1-\beta_v)^{r-v_r}\cdot\binom{N_v-k-r}{v_i} \\
\alpha_v^{v_i}(1-\alpha_v)^{N_v-k-r-v_i}\cdot S(1 \mid v_r+v_i,x)\cdot\Pi^v(r \mid k)
\end{array}\right\}
\end{aligned} \tag{7}$$

Let L be a random variable representing the length of a talkspurt. It is assumed that L is geometrically distributed with parameter γ_v. If k voice terminals are reserved, the conditional average departure rate of a voice terminal μ_k is $\gamma_v k/k_0$ [7]. In the case of Poisson arrivals with exponential service time, this process can be modeled by M/M/1/k queuing system. Thus the probability $P_e^v(k)$ that there are k reserved voice terminals at steady state can be represented as [8]

$$\begin{aligned}
P_e^v(k) &= P_e^v(0)\prod_{i=0}^{k-1}\frac{\lambda_i}{\mu_{i+1}} \\
P_e^v(0) &= \left[1+\sum_{k=1}^{Min\{N_v,mk_0\}}\prod_{i=0}^{k-1}\frac{\lambda_i}{\mu_{i+1}}\right]^{-1}
\end{aligned} \tag{8}$$

B. Performance Measures

One measure of SS_RRA performance is the voice packet dropping probability. The descriptive mechanisms for the packet dropping are as follows. Let L be the number of packets in a talkspurt. In a talkspurt, no packets are dropped if the voice terminal reserves before W_{max} slots. After waiting W_{max} slots, the terminal drops the first packet of the talkspurt. The second packet is generated exactly k_0 slots after the first packet. Therefore, the terminal drops if it is still contending for a reservation after $W_{max}+k_0$ slots. If the terminal can not reserve after $W_{max}+(L-1)k_0$ slots, it drops the entire packets of a talkspurt. The packet dropping probability is defined as the ratio of dropped packets to the total number of generated voice packets. Let S_{nv} be the probabilities that an idle voice terminal reserve a channel in the first attempt and S_{rv} the probability that a backlogged terminal succeeds a channel reservation. Then the packet dropping probability is given by

$$P_{drop} = \gamma_f\cdot\frac{(1-S_{nv})(1-S_{rv})^{W_{\max}-1}}{1-(1-\gamma_f)(1-S_{rv})^{k_0}} \tag{9}$$

where γ_f is the probability that a talkspurt ends in a frame and S_{nv} and S_{rv} are defined by

$$S_{nv} = \sum_{k=0}^{Min\{N_v,mk_0\}} \sum_{r=0}^{N_v-k} \sum_{v_i=0}^{N_v-k-r} \sum_{x=1}^{m} \begin{Bmatrix} \Phi(x,k,k_0,m)\cdot(1-\beta_v)^r \cdot \binom{N_v-k-r}{v_i} \alpha_v^{v_i} \\ (1-\alpha_v)^{N_v-k-r-v_i} \cdot S(v_i \mid v_i,x)\cdot \Pi^v(r \mid k)\cdot P_e^v(k) \end{Bmatrix} \tag{10}$$

$$S_{rv} = \sum_{k=0}^{Min\{N_v,mk_0\}} \sum_{r=0}^{N_v-k} \sum_{v_r=0}^{r} \sum_{x=1}^{m} \begin{Bmatrix} \Phi(x,k,k_0,m)\cdot(1-\alpha_v)^{N_v-k-r} \cdot \binom{r}{v_r} \beta_v^{v_r} \\ (1-\beta_v)^{r-v_r} \cdot S(v_r \mid v_r,x)\cdot \Pi^v(r \mid k)\cdot P_e^v(k) \end{Bmatrix} \tag{11}$$

Let the system throughput be the total number of packets successfully transmitted in a slot. Then the system throughput η can be defined as follows

$$\eta = \sum_{k=0}^{Min\{N_v,mk_0\}} \frac{k}{k_0} P_e^v(k) + \\ +\alpha_d \left(N_d - \sum_{k=0}^{Min\{N_v,mk_0\}} \sum_{b=0}^{N_d} \sum_{r=0}^{N_v-k} b\Pi(br \mid k) P_e^v(k) \right) \tag{12}$$

In equation (11), the first term is the number of reserved voice terminals in a slot, and the second is the data traffic throughput (η_d). Let the average packet delay D_d be the elapsed time a data packet from the generation of a data packet to the successful transmission. Then the average packet delay can be defined as

$$D_d = \frac{N_d}{\eta_d} - \frac{1}{\alpha_d} + 1 \tag{13}$$

C. Numerical Results

The numerical results are presented to evaluate the suitability of SS_RRA protocol in the integrated voice and data environment. The system parameters used in the numerical analysis are listed in Table 1.

Table 1 System parameters for numerical analysis.

System Parameters	Value
Number of slots per a frame (k_0)	5 slots
Time slot duration	4 msec
Voice packet delay constraint (W_{max})	10 slots
Average silence duration	1.35 sec
Average talkspurt duration	1.00 sec

As described in Table 1, it is assumed that voice packets delayed over 10 slots are dropped.

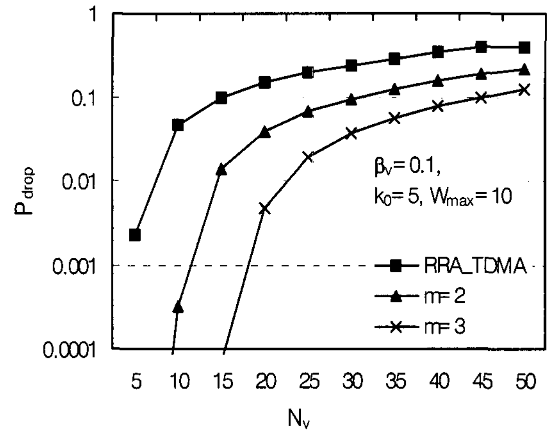

Fig. 4 Packet dropping probability for m=1, 2, and 3.

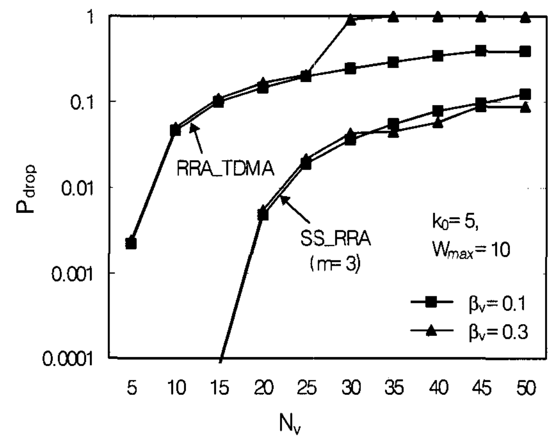

Fig. 5 Packet dropping probability for β_v=0.1 and 0.3.

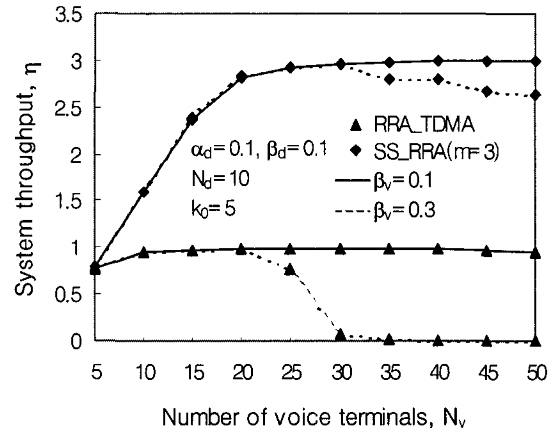

Fig. 6 System throughput.

Fig.4 shows the voice packet dropping probability versus the number of voice users according to the various numbers of spreading codes. As shown in the figure, P_{drop} is closely related to the number of spreading codes. In examining system performance, this paper will focus on the system capacity at the 10% packet dropping probability. For m=1, SS_RRA protocol is the same as RRA protocol of TDMA system, and the system can support up to only 15 voice users. But for m=3, the system can accommodate 45 voice users, which are about three times RRA_TDMA.

The stability of SS_RRA protocol is depicted in Fig.5 and Fig.6. In RRA_TDMA protocol, increasing β_v to 0.3 allows voice terminals to contend more frequently, decrease the waiting time before a reservation and therefore increases rapidly the packet dropping probability. But the proposed protocol gives the stable performance over the various values of β_v.

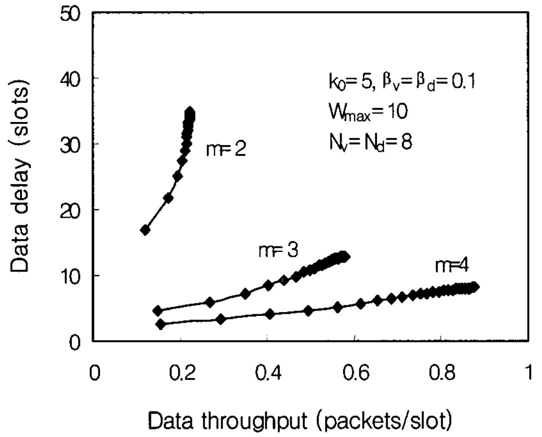

Fig. 7 Delay performance of data traffic.

Fig.7 shows the delay performance of data traffic according to the number of spreading codes. When decreasing the number of spreading codes, almost all the channels are reserved for voice terminals. Therefore it leads data terminals to the excessive collision. But the delay performance is significantly improved when increasing the number of channels.

IV. CONCLUSIONS

This paper proposed an SS_RRA protocol for the integrated voice and data services and analyzed the packet dropping probability under the various traffic loads. This protocol accommodates the advantages of reservation scheme for the voice traffic, the simplicity of random access scheme for the data traffic, and the multiple access capability of CDMA. The numerical results show that the voice packet dropping probability can be significantly improved by a few distinct spreading codes.

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Intaek Lim
received the B.S. degree in computer science from University of Ulsan, Ulsan, Korea, in 1984, and the M.S. degree in computer science and statistics from Seoul National University, Seoul, Korea, in 1986. He received the Ph. D. degree in computer engineering from University of Ulsan, Ulsan, Korea, in 1998. From 1986 to 1993, he was a Senior Researcher at Samsung Electronics Co., Ltd. From 1993 to 1998, he was an Assistant Professor at Dong Pusan College. In 1998, he joined the faculty at Pusan University of Foreign Studies, Pusan, Korea, where he is currently an Associate Professor in the Department of Computer Engineering. His research interests include the MAC protocol design, ad-hoc network, and mobile computing.