An MAC Protocol based on Code Status Sensing and Acquisition Indication in CDMA Networks

Intaek Lim, *Member, KIMICS*

Abstract—In this paper, a CSSMA/AI MAC protocol in packet CDMA network is presented. The main features of this protocol are the code status sensing and reservation for reducing the packet collision. The base station broadcasts the code status on a frame-by-frame basis just before the beginning of each preamble transmission, and the mobile station transmits a preamble for reserving a code based on the received code status. After having transmitted the preamble, the mobile station listens to the downlink of the selected code and waits the base station reply. If this reply indicates that the code has been correctly acquired, it continues the packet transmission for the rest of the frame. If there are other packets waiting for transmission, the base station broadcasts the status of the code as reserved, and the mobile station transmits a packet on a reserved code for the successive frames.

Index Terms—Acquisition Indication, CDMA, Medium access control protocol, Random Access, Slotted ALOHA.

I. INTRODUCTION

Third-generation mobile communications systems will be focused on providing wireless access to different kinds of multimedia services, thus needing traffic sources of different statistical nature with similar capabilities to those of the wired backbone network. Also, it must be designed to support wideband services at data rates as high as 2Mbps. In these contexts, DS-CDMA packet radio networks play an important role thanks to their inherent statistical multiplexing capability [1][2]. This is shown in that most proposals for radio transmission technology (RTT) in IMT-2000 are based on CDMA [3][4].

Spreading code protocol in CDMA packet radio networks, which is a policy for choosing a spreading code to be used given that a mobile station has a packet to transmit, can be classified into shared and dedicated code methods [5][6][7]. In the shared code method, all the mobile stations share a finite number of spreading codes to communicate with the base station. Whenever a mobile station has a packet to transmit, it will randomly choose one spreading code and transmit its packet. Hence, when more than one mobile station selects the same code, collisions can occur [8][9]. On the other hand, in the dedicated code method, a unique spreading code is assigned to each mobile station. It allows several mobile stations to transmit their packet at the same time using a different spreading code for each one [10]. Therefore, unsuccessful transmissions due to a collision never occur, but the number of simultaneously transmitting packets influences the performance.

The random access protocol currently defined in UTRA (UMTS Terrestrial Radio Access) is based on S-ALOHA CDMA [11]. Whenever a mobile station wants to transmit a packet, it randomly selects a code from the shared access codes and starts the transmission. A collision may occur if two or more stations select the same code and transmit their packets at the same time. This protocol is very efficient for light traffic loads. But as the load becomes high, it has a problem that the system performance becomes decreased due to a higher number of collisions. This problem may arise mainly from the fact that mobile stations do not have knowledge as to whether or not there are other stations transmitting with the selected code.

This paper is intended to improve the system performance achieved with CDMA packet radio networks when a high load is offered to the system. For this purpose, this paper proposes a MAC protocol, called CSSMA/AI (Code Status Sensing Multiple Access with Acquisition Indication). The main features of this protocol are the code status sensing and code reservation for reducing the packet collision. The base station broadcasts the status of the available code sequences just before mobile stations begin their preamble transmissions. The mobile station transmits a preamble for reserving a randomly selected code based on the received code status. It allows a mobile station that successfully transmitted a packet on a certain code to keep it until the end of the current message transmission.

This paper is organized as follows. In Section II, the frame structure for the proposed protocol and CSSMA/AI protocol are presented. Section III presents the simulation results. Finally, Section IV presents the conclusions.

II. PROTOCOL DESCRIPTIONS

Manuscript received April 26, 2007.

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)

A. Frame Structure

It is assumed that the system for the proposed protocol is a centralized CDMA packet radio network. The CSSMA/AI protocol is designed to allow a given number of N mobile stations to share a set of K spreading codes. Mobile stations, which are synchronized with the frame structure of the base station, are working in packet-switched mode. The channels consist of uplink and downlink code channels and a broadcast channel. The frame structures are illustrated in Fig. 1.

As depicted in figure, a frame structure consists of T_f ms frames, which are subdivided into N_s time slots. The base station indicates the status of the available code sequences in the current frame on a frame-by frame basis through the first slot S of the downlink broadcast channel. If the status of the uplink code channel C_i is indicated as free, the second slot P in the code C_i is used to transmit an initial preamble that mobile stations attempt to reserve the code. Therefore, if two or more mobile stations select the same code and transmit their preambles at the same time, a collision should occur and as a result they experience the code-reservation failure. The second slot R in the corresponding downlink code C_i is intended to transmit an AI (Acquisition Indication) reply as an acknowledgement of the correct reception of the preamble. On the other hand, the first slot A is used to acknowledge a packet transmitted in the previous frame.

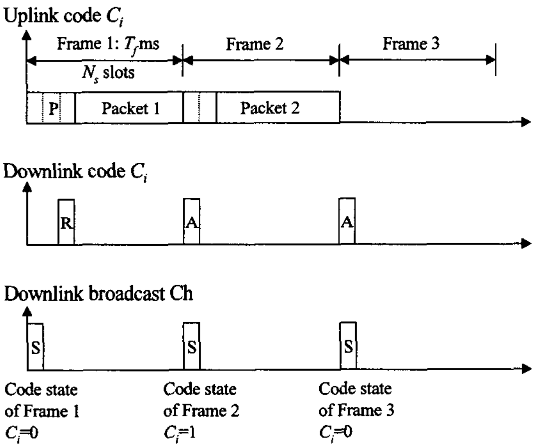

Fig. 1 Frame structures.

B. Protocol Description

The protocol operation for the proposed CSSMA/AI protocol is shown in Fig. 2. Mobile stations remain in an idle state while they have no packets to be transmitted. When the mobile station in the idle state generates a new message, it enters into the contention state (CON) and attempts to reserve an uplink code channel in the next frame. Whenever a new message is generated, it is split into fixed length L-bit packets, and they are stored in the packet buffer.

The mobile station in the contention state listens to the first slot of the downlink broadcast channel in order to determine the available code sequences. Then, the mobile station randomly selects one of these codes and transmits a preamble at the second slot for reserving the selected code. If another station has selected the same code sequence, a collision occurs. If the packet is successfully received and the mobile station receives an AI reply, it will change to the transmission state (TX) and transmit the first packet for the remaining slots of the frame. If a collision occurs in the preamble transmission or if the preamble is corrupted due to the multiple access interference, the mobile station will change to the backlogged state (BACKLOG) and again attempt access with a certain probability P_b in the next frame.

If the packet is successfully received and the packet buffer contains other packets to be sent, the mobile station will remain in the transmission state, and the base station will broadcast the selected code as busy. On the other hand, if it is the end of the packet transmission, the mobile station will change to the idle state. If a received packet contains errors due to the multiple access interference, the mobile station will retain the selected code, but it will change to the retransmission state (RETX). The mobile station in the retransmission state attempts to transmit the corrupted packet in the next frame by applying a certain retransmission probability P_r.

In order to indicate when a reserved code will be released, each transmitted packet should include a bit indicating whether or not there are other packets waiting for transmission in the buffer. Then the base station can confirm when the message transmission ends and when it has to broadcast the code state as free again. If the last packet is successfully received, the base station will acknowledge it through the corresponding downlink code channel and broadcast the code status as free.

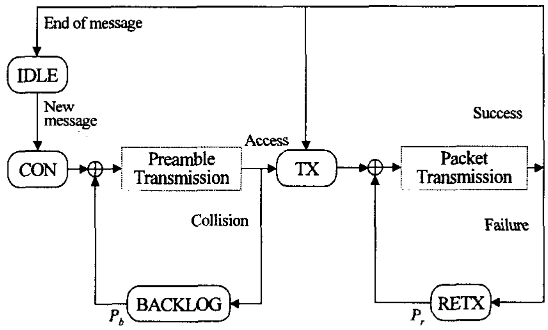

Fig. 2 Protocol operation.

The main advantages of the proposed protocol are as follows; i) a collision cannot occur in the packet transmission because mobile stations transmit their packet with the reserved code sequence; ii) it allows detection of a collision just after the short preamble transmission even though the shared code method is applied as the spreading code protocol; and iii) the preamble transmission does not interfere in the packet transmission.

III. SIMULATION RESULT

In this paper, the comparison between the proposed CSSMA/AI protocol and the S-ALOHA CDMA protocol defined in 3GPP UTRA (3[rd] Generation Partnership Project UMTS Terrestrial Radio Access) for the transmission of short packets in the PRACH (Physical Random Access Channel) is presented in order to show the good behavior of the CSSMA/AI protocol. The performance evaluation has been performed by means of computer simulations, and the simulation parameters are shown in Table 1.

It is assumed that the number of mobile stations (N) is 200, each of them in the idle state generating a new message according to a Poisson process with the mean arrival rate λ. Message length follows an exponential distribution with the mean L_p packets, and the packet length (L) is 320 bits. The number of code sequences (K) in the system is 70, and the spreading factor (S_f) of DS-CDMA channel is considered as 128.

Table 1 System Parameters For Simulation.

Parameters	Value
Number of mobile stations (N)	200
Packet length (L)	320 bits
Mean message length (L_p)	10 packets
Number of codes (K)	70
Spreading factor (S_f)	128
Frame duration (T_f)	10 ms
Number of slots (N_s)	8

In the S-ALOHA CDMA protocol, mobile stations are allowed to access in each of the eight slots of a frame. Therefore, several mobile stations can share the came code by accessing at the different time offsets. On the other hand, mobile stations in the CSSMA/AI protocol cannot share a code sequence because they are only allowed to select a code during the second slot of each frame.

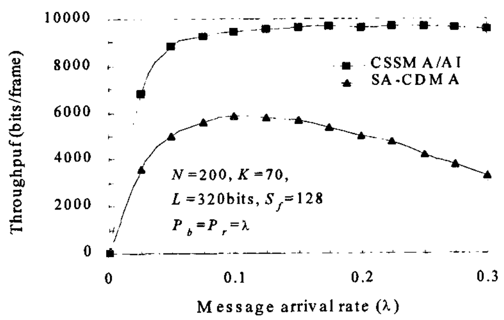

Fig. 3 Throughput versus message arrival rate.

Fig. 3 and Fig. 4 show the system throughput and message delay performance according to the different message arrival rate between the CSSMA/AI protocol and the S-ALOHA CDMA protocol, respectively. As shown in the figures, it can be observed that CSSMA/AI protocol outperforms S-ALOHA CDMA in terms of both throughput and message delay.

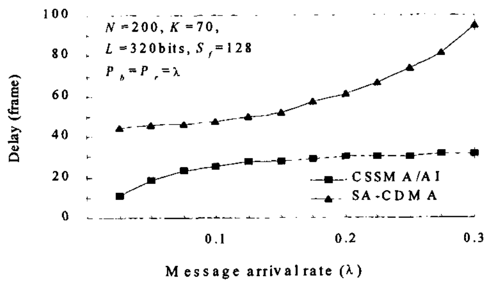

Fig. 4 Delay versus message arrival rate.

This is due to the fact that CSSMA/AI protocol provides mobile stations with knowledge about the code status and avoids collisions once a code has been reserved. Furthermore, the preamble transmission for reserving a code does not interfere in the packet transmission. While in S-ALOHA CDMA collisions can occur in every packet of the message and thus the number of retransmission and the delay increase.

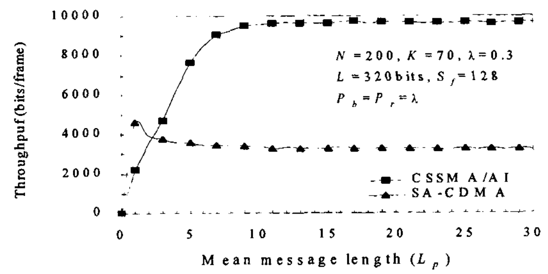

Fig. 5 Throughput versus message length.

In Fig. 5 the system throughput according to the different message lengths is shown for λ=0.3 to observe the effect of different message lengths. As shown in figure, CSSMA/AI protocol outperforms about 2.8 times S-ALOHA CDMA when messages contain more than 5 packets. On the other hand, it should be pointed out that the differences between two protocols decrease when the message length decreases. The reason for this is that when transmitting short messages, mobile stations take less advantage of the code status sensing and reservation process for maintaining code during a shorter period of time.

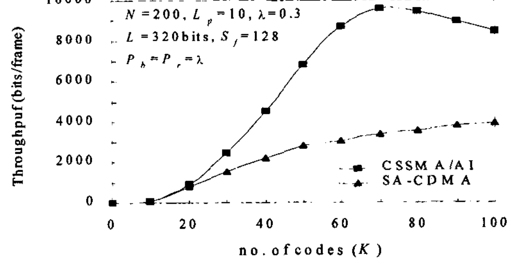

Fig. 6 Throughput versus number of codes.

In the extreme case when messages consist of a single packet, S-ALOHA CDMA is better than CSSMA/AI since in S-ALOHA CDMA it allows mobile stations share the same code with N_s time slots and also the code status in the downlink broadcast channel of CSSMA/AI is useless. One of the most important parameters in CDMA system is the number of code sequences. Fig. 6 compares the throughput between two protocols in terms of the number of ode sequences for λ=0.3, and Fig. 7 presents the throughput of CSSMA/AI for different values of the number of codes according to the message arrival rate. It can be observed that the throughput of S-ALOHA CDMA linearly increases in accordance with the increase of *K* since in S-ALOHA CDMA the number of codes has a great influence over the probability of collision. In CSSMA/AI, when the number of codes increases, the packet error probability increases since the number of mobile stations that have been reserved a code will increase. Therefore, as shown in figure, the throughput of CSSMA/AI significantly increases when *K* reaches up to 70 codes, but it decreases when *K* is more than 70 codes. The result shown in figures implies that S-ALOHA CDMA is limited by collisions, but CSSMA/AI is limited not only by collisions for the low value of *K* but also by the multiple access interference for the high value of *K*.

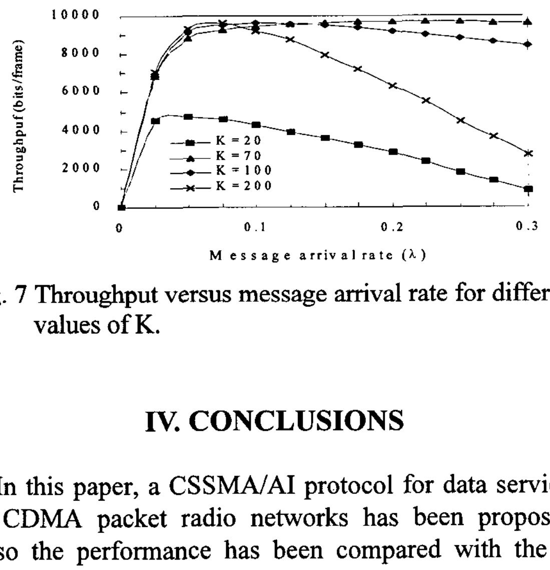

Fig. 7 Throughput versus message arrival rate for different values of K.

IV. CONCLUSIONS

In this paper, a CSSMA/AI protocol for data services in CDMA packet radio networks has been proposed. Also the performance has been compared with the S-ALOHA CDMA protocol defined in the UTRA proposal. A significant improvement in terms of the system throughput and message delay has been obtained thanks to the knowledge about the code status provided by the base station and the code reservation scheme. From the simulation results, it has been found that the S-ALOHA protocol gives a good performance for short packet transmissions, while the proposed CSSMA/AI protocol efficiently handles longer message lengths thanks to its ability to maintain the reserved code.

ACKNOWLEDGMENT

This paper was supported by the research grants of the Pusan University of Foreign Studies in 2006.

REFERENCES

[1] W. C. Y. Lee, "Overview of cellular CDMA," *IEEE Trans. Veh. Tech.*, vol.40, pp.291-302, 1991.

[2] M. B. Pursley, "The role of spread spectrum in packet radio networks," *Proc. of IEEE*, vol.75, no.1, pp.116-134, 1987.

[3] J. W. So, I. Han, B. C. Shin, and D. H. Cho, "Performance analysis of DS/SSMA unslotted ALOHA system with variable length data traffic," *IEEE J. Select. Areas Commun.*, vol.19, no.11, pp.2215-2224, Nov. 2001.

[4] TIA TR45.5, "The CDMA2000 RTT candidate submission to ITU-R," Draft Document, June 1998.

[5] E. Sousa, and J. A. Silvester, "Spreading code protocols for distributed spread- spectrum packet radio networks," *IEEE Trans. Commun.*, vol.36, no.3, pp.272-280, Mar. 1988.

[6] O. Sallent, and R. Agusti, "A proposal for an adaptive S-ALOHA access system for a mobile CDMA environment," *IEEE Trans. Veh. Tech.*, vol.47, no.3, pp.977-986, Aug. 1998.

[7] D. Raychaudhuri, "Performance analysis of random access packet switched code division multiple access systems," *IEEE Trans. Commun.*, vol.COM-29, no.6, pp.859-901, Jun. 1981.

[8] In-Taek Lim, "Joint Packet Reservation and Status Sensing Multiple Access for Voice/Data Integrated CDMA Networks," *IEICE Trans. Commun.*, vol.E84-B, no.4, pp.975-983, Apr. 2001.

[9] S. Choi, and Kang G. Shin, " Unified architecture of wireless networks for real-time and non-real-time communication services," *IEEE/ACM Trans. Networking*, vol.8, no.1, pp.44-59, Feb. 2000.

[10] In-Taek Lim, "Centralized Transmission Probability Control Scheme for Fair Packet Data Services in CDMA S-ALOHA System," *IEE Elec. Letters*, vol.39, no.16, pp.1207-1209, Aug.2003.

[11] 3GPP TS 25.321, V5.4.0, "MAC Protocol Specification," March 2003.

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.