Random Access, Reservation and Polling Multiaccess Protocol for Wireless Data Systems

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Abstract

This paper propose a Medium Access Control (MAC) protocol for wireless data networks. The main feature of this protocol is the combination of Polling and Slotted ALOHA contention in the multiaccess environment to insure stability and robustness. The frame structure in Advanced TDMA is used to guarantee that polling or random access are allocated with timeslots in every frame. The performance of such protocol is evaluated using simulation and Transient Fluid Approximation (TFA). It is shown that the protocol is adaptive to varying access rates when the system is near or in the overload region.

Keywords

wireless data, reservation, polling, random access, ALOHA, Transient Fluid Approximation

1 INTRODUCTION

Reservation protocols are found to be attractive in wireless data systems where the traffic is characterized as non-continuous. Under this assumption, the terminals alternate between silence and active modes depending on the users' activity. Protocols that exploit this feature combine random access and reservation in order for the busy terminals to transmit longer messages thereby increasing the efficiency of the radio resource. For simplicity, the random access mechanism commonly used is Slotted ALOHA. Examples of these protocols are Reservation ALOHA (Lam,1980), Packet Reservation Multiple Access (Goodman et al, 1989) and Reserved- Idle Signal Multiple Access (Wu et.al., 1994). However, reservation protocols suffer from decreased throughput if the average message length is relatively short. As described by Tobagi (1980) adaptive protocols are required to maintain the performance.

In the wireless environment, a substitute for random access is **polling**. Polling ensures stability but it endures large access delay even if the system is under light load conditions. Conversely, random access algorithms are prone to instability or unfairness problems but attains short access delay in the low load region. To mention, Slotted is unstable in some region but it attains a certain level of fairness. In contrast, stack algorithm is very stable but it exhibit unfairness due to its LCFS counter discipline. In this paper a marriage between random access and polling is investigated. The random access will provide short access delay under light loads while polling will enhance the access performance at high load. The use of combined polling and random access was proposed in (Lu and Chen, 1994), and later in (Li and Merakos, 1994) all for integrated voice/data wireless system. In those protocols, the use of polling is mainly for high priority users. In this paper, we combine polling, random access and reservation to develop an **adaptive reservation protocol**.

2 PROTOCOL DESCRIPTION

In this paper, we named the proposed protocol as **SCARP** which stands for **Silence-Contention-Acknowledgment-Reservation-with-Polling**. This protocol is a variant of Advanced TDMA in which the addition of a polling state has a threefold advantage. First is its stability which provide fast recovery of the Slotted ALOHA when it operates in the high delay stable operating point or in the unstable region. In this case, a higher retransmission probability parameter can be used in the Slotted ALOHA thereby improving its performance in the underload region. Secondly, the frame structure does not have to be optimized according to the traffic statistics since the polling mechanism enhances its adaptability to various traffic types as it provides extra capacity to the access rate. So the SCARP protocol can manage to maintain higher throughput even if the average message length is relatively short.. And thirdly is the ability for the base station (central control) to poll immediately users that has just finished transmitting if in case some packets are erroneous. If this function is incorporated in the random access, this will cause system overload if the probability of packet error is high.

2.1 Channel Structure

The channel structure of Advanced TDMA is used with the exception of the Fast Paging Acknowledgment slot. In an n -slot TDMA frame, random access (r) slots are allocated for random access in the uplink. These r slots are distributed in the frame to minimize the latency and to provide enough time for acknowledgment. As explained in Dunlop et al (1994), every r slot is paired with an a slot for acknowledgment and slot allocation. The random access feedback requires only a small portion of the information field. Therefore most of the information field in the a slots are mainly used for slot allocation purposes. Thus, it is possible to provide multiple acknowledgment in one a slot. Also, a time shift is provided for the uplink and downlink greater than the round trip propagation delay + processing time for the contention process. The slot size is uniform with a duration of τ .

2.2 State Transition Cycle

In the protocol, we assume that data information are generated by multiple users registered to a single base station. During the initial transmission, the terminal listens to one of the radio channels in the nearest base station and synchronize in order to contend together with the existing users. In the random access, the terminal identify itself as a new user and is subject for authentication. Upon authentication, a terminal identity, TI is allocated to every terminal in the base station. The TI must include a base station identifier in order to avoid confusion with the neighboring cells. With the limited length of the information field, only one access is allowed in every r slot.

Figure 1 State Transition Cycle of SCARP

Figure 2 Simplified Markov Model

The terminal activity is assumed to be alternating between *idle* and *active* modes. A terminal is said to be idle if it has no packet in its buffer. We describe the protocol cycle by starting with a user in the idle mode. An idle user is identified as in the silent state (S). When it becomes active, it goes to the contention state (C) and attempts for contention in the first incoming r slot in the TDMA frame. The contention process is Slotted ALOHA with no capture. Unsuccessful users retransmit in the next r slot with a probability p .

After a successful contention, the terminal goes to the acknowledgment state (A) and waits for a slot to be allocated. When a slot is available during the contention, the terminal is assigned immediately with a slot in the first a slot. Otherwise it waits on a first come first serve basis. A priority assignment is also possible as well as multislot allocation can be implemented. When a slot is allocated, the terminal moves to the reservation state (R) and start transmitting its packets. After all the packets in its buffer are transmitted, the terminal loose its reservation and goes to the polling state (P). At the polling state a terminal waits for the acknowledgment if all the packets are transmitted correctly. If all packets are succesfully transmitted, the terminal goes back to the S state. Terminals in the silent and contention states are polled with lower priorities than the terminals in the polling state. This allows terminals in the contention states have two access mechanisms. If the packet error probability is low, the rate of polling for contending terminals is high thereby reducing the average access delay.

3 PERFORMANCE APPROXIMATION

Here we present an approximation based on TFA as in (Wu et al,1995). In TFA the transition intensities are similar to the Semi-Markov Flow Graph therefore its accuracy is subject to the distribution of the time a user spend in a state. Another thing to consider in flow graphs is that every process must be unique and exclusive to a state resulting to an imbedded Markov chain

(Clymer,1990). Since the polling mechanism involves a common process to both the A and P states. The Markov model of the state transitions are simplified in the Figure 2. The exclusion of the polling state is due to two reasons. One is due to the assumption of a noiseless channel. The other is the small probability that a user in the polling state will become active and attempt a random access then become successful. From the model in Figure 2 the following stationary transition probabilities are assumed to be exponentially distributed:

$$\sigma = 1 - e^{(-\tau/Ts)} \quad (1)$$

$$\gamma = 1 - e^{(-\tau/Tr)} \quad (2)$$

In TFA, we are interested in the system state in the k th iteration. Therefore the nonstationary transition probabilities must be solved in each iteration as follows:

$$\mu_{(k)} = C_{(k-1)}p(1-p)^{C_{(k-1)}-1}(1-\sigma)^{S_{(k-1)}} + S_{(k-1)}\sigma(1-\sigma)^{S_{(k-1)}-1}(1-p)^{C_{(k-1)}} \quad (3)$$

$$\zeta_{(k)} = \min \left\{ \left[\frac{Ni - R_{(k-1)}}{Na} + R_{(k-1)}\gamma \right], A_{(k-1)} \right\} \quad (4)$$

The calculation of ρ assumed a *last out first serve* polling sequence. Therefore we are interested in calculating the probability that a polled user is busy and has not successfully contended in the r slots it has passed. First, the polling cycle has to be calculated as

$$t_{p(k)} = \left\lfloor \frac{\frac{S_{(k-1)} + C_{(k-1)}}{(Ni - R_{(k-1)})} + R_{(k-1)} - \mu_{(k)}}{Na} \right\rfloor \quad (5)$$

The probability that a particular user will be successful in the access slots is

$$\rho_{s(k)} = \frac{\mu_{(k)}}{C_{(k-1)} + S_{(k-1)}\sigma} \quad (6)$$

Thus the probability that a user becomes successful in the u th access slot after it becomes active is geometrically distributed expressed in (7).

$$P_s(t)_k = \rho_{s(k)}(1 - \rho_{s(k)})^{t-1} \quad (7)$$

where $t = \{1, 2, 3, \dots, t_p\}$. Then the probability that the user is successful before it is polled U_p , is expressed in (8) and (9) and the probability of succesful polling is in (10).

$$F(t)_k = 1 - \exp\left(-t/T_s\right) \quad (8)$$

$$U_p(t_p)_k = \frac{\sum_{z=1}^{t_p} \sum_{m=1}^{t_p-z} P_s(m)_k F(z)_k}{\sum_x F(x)_k} \quad (9)$$

$$\rho_{f(k)} = F(t_p)_k \left(1 - U_p(t_p)_k\right) \left(1 - \left[\frac{\mu_{(k)}}{C_{(k-1)} + S_{(k-1)}\sigma}\right]\right) \quad (10)$$

From (10) we can calculate the rate of successful polling as the product of the probability of successful polling and the rate of polling in (11). The successful polling rate is subject to (12)

$$\tilde{\rho}_{(k)} = \rho_{f(k)} \left[\left[\frac{Ni - R_{(k-1)}}{Na} \right] - \zeta_{(k)} + R_{(k-1)}\gamma \right] \quad (11)$$

$$\rho_{(k)} = \min\{\tilde{\rho}_{(k)}, (C_{(k-1)} + S_{(k-1)}\sigma - \mu)\} \quad (12)$$

From the above transition probabilities, the number of users in each state for the k th iteration is the sum of the flow minus the sum of the outflow added to the value in the previous iteration conditioned that the total number of users in all states, M is fixed. Then we have

$$S_k = S_{(k-1)} - S_{(k-1)}\sigma + R_{(k-1)}\gamma \quad (13)$$

$$C_k = C_{(k-1)} - \mu_{(k)} + S_{(k-1)}\sigma - \rho_{(k)} \quad (14)$$

$$A_k = A_{(k-1)} - \zeta_{(k)} + \mu_{(k)} \quad (15)$$

$$R_k = R_{(k-1)} - R_{(k-1)}\gamma + \zeta_{(k)} + \rho_{(k)}. \quad (16)$$

After calculating the mean values of the state population, the access delay is calculated as the averaging of polling and of contention and acknowledgment delays expresses in (17).

$$\overline{D_a} = \left[\frac{C_\infty + S_\infty\sigma}{C_\infty} + \frac{\left(\frac{\mu_\infty}{\mu_\infty + \rho_\infty} \right)}{\left(1 - \frac{R_\infty}{Ni} \right)} \right] N_f \quad (17)$$

The parameter $\frac{\mu_{\infty}}{\mu_{\infty} + \rho_{\infty}}$ is also a measure of the proportion of random access against polling.

And lastly, the throughput is calculated as the mean number of users transmitting divided by the number of slots per frame, ($T = R_{\infty}/N$).

4 SIMULATION MODEL

In the simulation, a noiseless channel is used with 16 slots per TDMA frame (see Figure 3). Two access slots were allocated sufficient to provided fast access with minimum overhead with the used traffic statistics. The process starts with all users in the silent state. Since a single arrival model is used for message generation, a user is allowed to wait indefinitely if it is either in the contention and acknowledgment states. In the case of polling, a Last Out First Served (LOFS) discipline is used. Users just being polled and users just finished transmitting are held at the end of the polling sequence. Since a noiseless channel is assumed, only users in the silent and contention states are polled.

5 OBSERVATIONS

The advantage of using combined polling and random access is clearly shown in the comparison with SCARP and ATDMA. From the results, the ATDMA is unstable when the access rate is high caused by the reduction of the average message length. Also, when the operating point of the Slotted ALOHA is already close to the maximum throughput (0.36), the tendency that the contention process to flip-flop between the two stable regions cannot be avoided causing a large access delay. Even when the access rate is relatively low, the SCARP protocol still exhibit superior delay performance. Polling compensates the contention process when the S-ALOHA operated in the high delay region as it pulls back the operating point to the low delay region. Under the SCARP protocol, it is also possible to use higher retransmission probabilities since the contention process can already avoid the unstable state. This enable the system to obtain shorter access delays. The results are plotted in Figures 4-8.

6 CONCLUSION AND RECOMMENDATION

In this paper, combined polling, random access and reservation shows a significant advantage for access protocols where the traffic statistics is unpredictable. The effectiveness of polling in the overload region prevents the system from operating in the unstable region thus allowing the operating point to return to the low delay region during time of low access rates. The simulation shows that the polling shares more than 75 percent of the successful access in the overload region. Also, the bistable characteristics disappear in the combined access scheme where the polling mechanism exploits the high delay region. In this paper, a noiseless channel is considered. However, it is necessary to evaluate the performance of this protocol under a noisy channel. It is also recommended to test the performance under bursty traffic.

7 REFERENCES

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8 FIGURES

Figure 3 Frame Structure of 16-slot TDMA

Figure 4 Access Delay in Advanced TDMA Protocol

Figure 5 Access Delay in SCARP

Figure 6 Plot of delay against various retransmission probabilities

Figure 7 Access delay for Different Message Length

Figure 8 Plot of the Percentage of Polling in Making Reservation

9 BIOGRAPHY

Theodore Buot received the B.S.(Eng.) in Electronics and Communications from the Cebu Institute of Technology, Cebu, Philippines, in 1989 and the M.Eng. in Telecommunications from the Asian Institute of Technology, Bangkok, Thailand, in 1992 under the grant of the Government of The Netherlands. In 1993, he worked as a research engineer in TMX International. In 1994 he received a grant for postgraduate study at The University of Adelaide. Currently, he is enrolled as a PhD student at the university's Centre for Telecommunications Information Networking (CTIn). His interests include integrated systems, access protocols and teletraffic engineering. He is a Student Member of IEEE.