Minislot Reservation Mac Protocol with Co-operative Channel (MRMA/COCH) for Wireless Packet Networks

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Abstract A multiple access protocol with a co-operative channel (COCH) and a COCH allocation scheme to improve the delay and throughput of a minislot ALOHA reservation protocol is proposed. In it, the request access (RA) message of a mobile terminal (MT) is randomly piggybacked to the base station (BS) through a COCH minislot in the uplink (UL) provided by its assistor MT which is assigned by the BS. The simulation results show that the performance of a two minislot ALOHA reservation protocol is improved by combining itself with a protocol which has one ALOHA RA minislot plus one COCH RA minislot. Under heavy RA traffic load, replacing one ALOHA RA minislot with one COCH RA minislot in a multiple access protocol which has multiple (>3) RA minislots will stabilise the delay-throughput performance of the MRMA protocol even at the normalised throughput of 99%; the average packet delay is nearly at the same level under light throughput. The overhead of one COCH minislot is 1 bit information plus guard time.

1 Introduction

In a wireless cell shown in Figure 1, multiple MTs communicate with one BS by using a multiple access protocol. The BS is linked to a wired network. Demand assignment reservation protocols have a more efficient use of the UL bandwidth, which is a rare resource in a wireless environment. Some reservation protocols use packet reservation multiple access (PRMA) [1-4]. Others use separate RA minislots for the MTs to reserve bandwidth from the BS, possibly in contention with other MTs. We classify these protocols as minislot reservation MAC (MRMA) protocols in this paper.

We consider TDMA/TDD with the MRMA protocol. The downlink (DL) timeframe consists of transmission permission (Xmt_Perm) slots, RA acknowledgement (ACK) slots and data slots, and the UL frame consists of and data slots, one piggyback bit and RA minislots. The protocol operations require that, when needing service, an MT changes from an *empty phase* to a *reservation phase* to send bandwidth requests to the BS

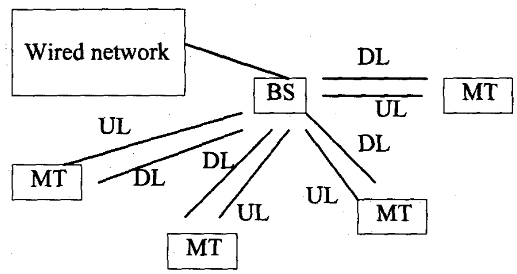

Figure 1 A BS-MT system (cell) in a wireless packet network

through the RA channel. The BS sends a collision (or no-collision) feedback message in the immediate next DL ACK slot. If a collision occurs, the MT will backoff some timeframes and try again. If no collision occurs, the MT will change into *transmission phase* and wait for its Xmt_Perm to be broadcast in one of the following DL Xmt_Perm slots. Upon "hearing" its Xmt_Perm, the MT will transmit a packet in the immediate next UL data slot and return to the *empty* state if there is no more data to send.

The design of the MRMA protocols requires that the UL data channel access delay should be minimised to improve the quality of services. Reducing contention in the RA channels minimises the channel access delay. Many efforts have therefore been made: e.g. slotting the RA channel [5], converting an idle UL data channel into multiple RA channels and piggybacking a short update RA request along with a data packet [6] and controlling the RA channel access permission [7], etc. Our method is using a transmitted data packet of an MT (A) to "piggyback" the RA request of a MT (B) contention-free. A and B are different MTs.

Section 2 presents the basic idea of the COCH channel. Section 3 presents a COCH allocation scheme. Section 4 describes the MRMA/COCH protocol. Section 5 reports the simulation environment. Section 6 describes the simulation results. Section 7 concludes the paper.

2 Basic Idea of the COCH Channel

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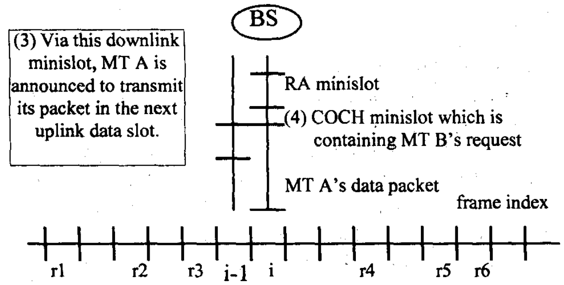

(1) r1--r6 are MT B's possible retry slots for sending its reservation request.

(2) The MT B has an RA request. The MT A is its assistor.

Figure 2 The effect of the COCH minislot on reducing packet delay

Figure 2 provides an instance on how the COCH idea works. Assume that the MT B needs service at the timeframe *r1*; and that all reservation retries failed from the timeframe *r1* to *r5* and succeeded at timeframe *r6*. Without COCH channel, the reservation delay *d* would be:

$$d = r6 - r1 \text{ (frames)} \quad (1)$$

With a COCH scheme, assume that the MT A is appointed by the BS to be an AM of the MT B. The BS broadcasts one *Xmt_Perm* (an access ID, aID in short) in every DL. In every timeframe from *r1* to *r6*, the MT B compares the *Xmt_Perm* aID with the aID of its AM (assistor MT). At the *(i - 1)th* frame, assume that the BS permits A is to transmit its data packet in the *ith* timeframe. Then, at the *ith* frame, MT B will set the COCH channel in the UL, thus B's reservation request is transmitted to the BS. Since only B is allowed use the COCH minislot in data slot allocated to A, the transmission is contention-free. The reservation delay d_c became:

$$d_c = i - r1 \text{ (frames)} \quad (2)$$

which can be less than $d = r6 - r1$ in formula *(1)*. The MT B is called *COCH user MT* (UM); the MT A is called *assistor MT* (AM). The assisting relationship is denoted as A → B.

The delay-throughput performance of a COCH multiple access protocol largely depends on the stipulated assisting relationship among MTs which can be setup and dynamically changed by the BS. A scheme which reflects the assisting relationship is called a COCH allocation scheme. A good COCH allocation scheme reduces the RA channel contention efficiently.

3 A COCH Allocation Scheme

Figure 3 shows a single COCH scheme. Each MT has only one AM and each MT has only one UM too. ALL MTs in the cell are linked together to form a ring.

Multiple COCH schemes are possible. A MT can be the assistor of *j* (*j* = 1, 2, 3, ...) MTs as long as the protocol UL provides *j* COCH minislots. There are at most *M*-1 assistors for each MT in a cell which has *M* MTs. Figure 4 is a multiple COCH scheme where *j* = 2. It can be noted that the UL subframe provides two COCH minislots. Each MT has two AMs and each MT has two UMs too. All the MTs are also linked together to form a closed loop.

Each MT has an assistor table which records the aIDs of its AMs. The BS keeps all the assistor tables which reflect the overall configuration. The assistor allocation scheme is a static allocation scheme.

4 MRMA/COCH Protocol

The MRMA/COCH protocol requires that the UL subframe has *j* COCH RA minislot(s), the length of which is 1-bit information plus guard time.

We add some new operations in the *reservation phase* of the MRMA/COCH, shown in the following pseudo codes. Assume that MT_i keeps an array denoted as $assArr_i[j]$ which stores the aID of the *j*th AM.

```
// Pseudo codes for the COCH operation in the
reservation phase {
    // MT_i checks every DL Xmt_Perm channel

    if (Xmt_Perm = assArr_i[j]) then {
        // In the next UL:
        The MT_i set the jth COCH channel to pass
         the reservation request to the BS
         contention-free;
        The MT_i enters the transmission phase;
    }
    else {
        Normal MRMA reservation
         operation;
    }
} // end of reservation phase and pseudo code.
```

5 Simulation Environment

Each MT provides 1% G load data traffic and generates packet bursts at the same rate. The burst interval is exponentially distributed. Each burst contains 1 packet constantly.

Both the UL subframe and the DL subframe contain one data slot. The UL piggyback bit is not included.

1-slot, 2-slot, and 3-slot ALOHA [8, 9] are used in the RA slots of the MRMA and the MRMA/COCH as the random access protocol. The backoff retry algorithm is exponential (1/2, 1/4, 1/8, 1/16, 1/32 ...).

In the BS, the scheduling algorithm uses a token generator. When the BS receives a successful reservation request from an MT, an Announcement Token (AT) recording the aID of that MT is generated and put into a FIFO queue, called AT queue. For each downlink, the BS will check the AT queue; if the AT queue buffer is not empty, the BS will, through the *Xmt_Perm* channel, announce the MT's aID recorded on the first AT in the queue and then delete it.

In the simulations, the number of MTs ranges from 10 to 100. Each MT provides 1% uplink G load. Average packet delay statistics are calculated from at least 3,000,000 packets.

6 Simulation Results

The MRMA protocol with *m* slot(s) slotted ALOHA as random access protocol is denoted as "*m*s-ALOHA"; the MRMA protocol with *m* slot(s) slotted ALOHA as random access protocol and with *n* COCH slot(s) is denoted as "*m*s-ALOHA/ *n* COCH" in this paper.

Shown in Figure 5, the 2s-ALOHA and the 1s-ALOHA/1COCH are comparable because both the ALOHA RA slot and the COCH RA slot need guard time. A remarkable effect is shown that, when the traffic load becomes heavier (throughput >55%), the 1s-ALOHA/1COCH protocol out-performs the 2s-ALOHA protocol greatly in terms of packet average delays. From this comparison, it can be concluded that the 2s-ALOHA and the 1s-ALOHA/1COCH can be combined to form an adaptive MAC protocol with automatic swap, ie., when the throughput is under 50% or so, the uplink adopts the 2s-ALOHA; when the throughput is above 50%, the uplink adopts the 1s-ALOHA/1COCH.

For the same reason, the 3s-ALOHA, the 2s-ALOHA/1COCH and the 1s-ALOHA/2COCH are comparable. The results are shown in Figure 6 The 1s-ALOHA/2COCH has the longest average delay compared to the other two. This shows that excessive COCH slots are not beneficial. When the throughput is less than 80% or so, the delay of the 3s-ALOHA is a bit smaller than the 2s-ALOHA/1COCH. When the throughput is larger than 80%, the 3s-ALOHA enters an unstable state while the 2s-ALOHA/1COCH is still very stable until 99% throughput.

7 Conclusions

In this paper, we presented an MT cooperation mechanism for MRMA MAC protocols for wireless packet networks. An MT's access requests are randomly piggybacked to the BS through a COCH channel in the UL provided by its assistor MT. The simulation results show that the two slot slotted ALOHA reservation protocol can be improved by combining itself with the one slot ALOHA reservation protocol which has one COCH slot to form an adaptive protocol. Under heavy RA traffic load, replacing one ALOHA RA minislot with a COCH minislot in a multiple access protocol which has multiple (>3) RA minislots stabilises the delay-throughput performance of the MRMA protocol, while the average packet delay can be kept nearly at the same level under lighter RA traffic load.

Another point is that the COCH scheme can be developed into a prioritised random access protocol. If an MT is allocated with more assistor MTs, its medium access delay will be shorter; otherwise, its medium access delay will be longer. A prioritised random access protocol is needed by multi-class wireless packet traffics.

The COCH protocols supplement the existing reservation protocols by realising cooperation in a contention environment. System resources are further exploited with a small overhead. Cooperation methods under multi-class traffic will also be studied and more cooperation protocols could be developed in the future.

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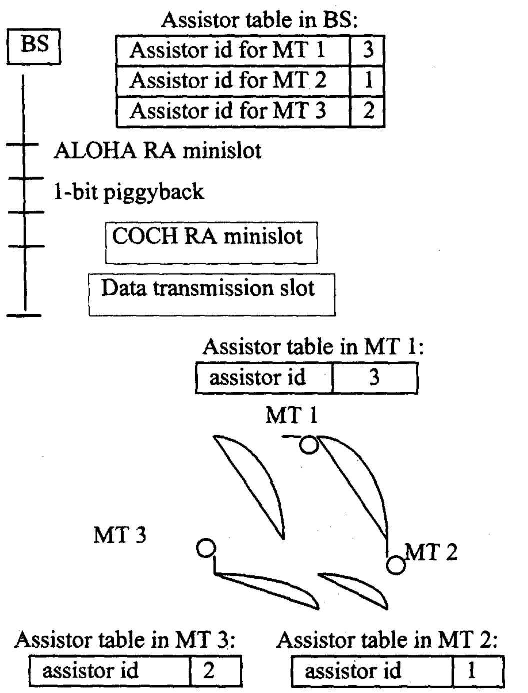

Figure 3 An one COCH system assistor allocation

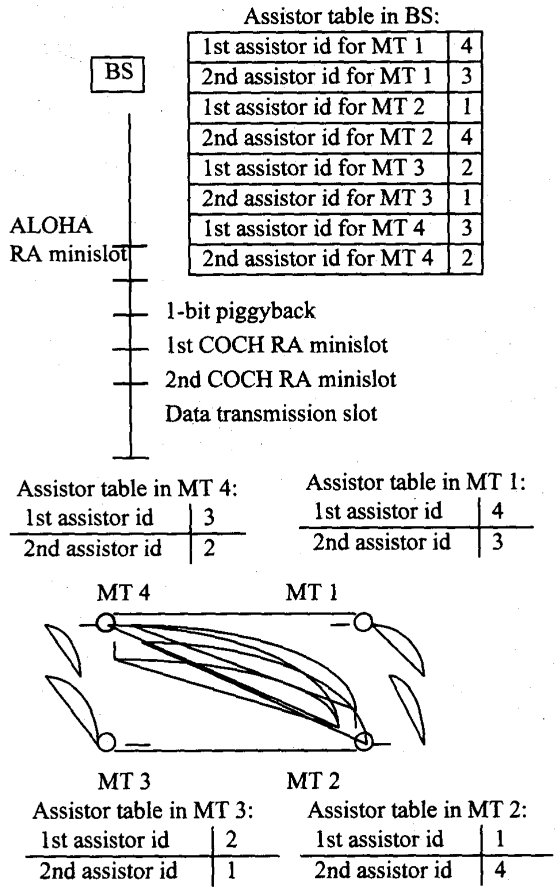

Figure 4 A two COCH system assistor allocation

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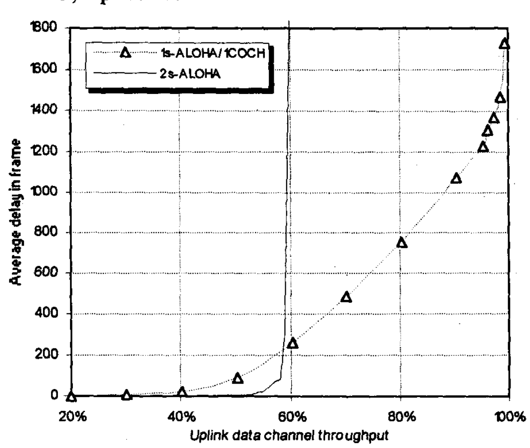

Figure 5 Average packet delay comparison

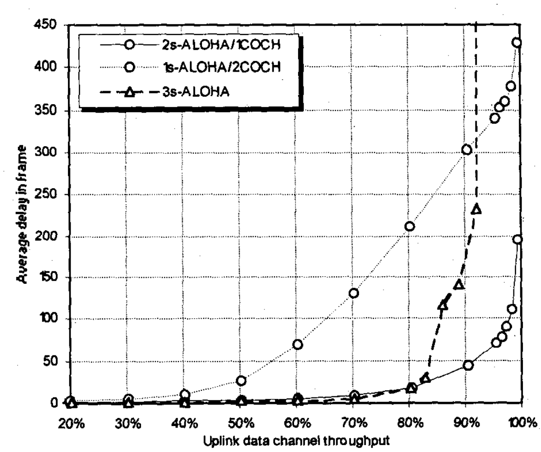

Figure 6 Average packet delay Comparison