A MAC Algorithm for Energy-limited Ad-hoc Networks

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Abstract

Energy efficiency is an important issue in ad-hoc wireless networks since the battery power of terminals is limited. In this paper, we propose energy efficient MAC algorithm based on reservation and scheduling for ad-hoc wireless networks. The performance of our proposed MAC scheme is evaluated in view of the number of delayed slots, the channel utilization, and the energy efficiency.

1. Introduction

An ad-hoc wireless network consists of wireless mobile terminals forming a temporary network without any deployed infrastructure or centralized administration. Each mobile terminal that communicates with the others has a autonomous algorithm. Ad-hoc networks are evolved largely from the DA-RPA packet-radio network program [1]. Recently, the ad-hoc networks are expected to play an important role in commercial and military environments. Especially, the ad-hoc networks are very useful in situations where it is very difficult to provide the infrastructures and it is required to be rapidly deployed because of earthquake environment, robot cooperation for jobs in inland places, and military operations etc. The architecture of ad-hoc wireless networks can be either hierarchical or flat. In hierarchical networks, the network elements are partitioned into several clusters that have a clusterhead which is selected to manage all the other nodes within the cluster. In flat networks, all nodes are in the equal rank [2], [5].

A general constraint we face is the short lifetime of mobile terminal batteries. Hence, energy efficient protocols are needed to reduce the effect of this constraint in many ad-hoc wireless networks. The terminals usually operate with a limited battery energy in ad-hoc wireless networks. So, a system design considering power saving is important [3]. It has recently been recognized that media access control (MAC) protocols could significantly reduce the power consumption of mobile terminals in ad-hoc wireless networks. In general, the radio module consumes more power in the tx. mode than in the rx. mode. In the idle mode, least power is consumed by the radio module. If mobile terminal A transmits data to mobile terminal B, the neighbor mobile terminals don't need to listen the data from mobile terminal A to prevent unnecessary rx. power consumption. Collision needs to be removed as soon as possible since it causes retransmissions that result in unnecessary power consumption. The existing works on ad-hoc wireless networks are almost biased toward routing protocols but there is a need for energy efficient MAC protocols.

The rest of the paper is organized as follows. The next section presents the proposed energy efficienct MAC scheme in ad-hoc wireless networks. Section III provides the performance analysis and section IV concludes this paper.

2. The proposed energy efficient MAC

In this paper, we propose a MAC algorithm considering limited battery energy in single hop ad-hoc wireless networks based on the CDMA/TDMA. The proposed MAC algorithm is based on reservation and scheduling method that informs each terminal when to wake up from idle mode or when to go to idle mode for its power saving.

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There are two sorts of mobile terminals with full duplex operation in the proposed MAC scheme, i.e. pseudo base station (PBS) and normal mobile terminals. The PBS among mobile terminals is elected according to battery power level. Every terminal can be qualified to a PBS. The PBS collects the requests of mobile terminals and allocates the CDMA code and the TDMA slots considering a priority and battery level of terminals. Transmission procedure in the proposed MAC is performed based on frames and the PBS controls the frames. The frames are handled at multiple phases using the CDMA codes and TDMA slots. The protocol in terms of multiple phases has been researched [4], [6]. The new features of the proposed MAC scheme are support for single hop ad-hoc wireless networks, the easy combination with the hierarchical ad-hoc networks, consideration for limited battery energy, and efficient direct communication.

The frame consists of four phases that are the Frame Synchronization phase, the Request/Update-/New Mobile phase, the Scheduling phase, and the DataTxRx phase. Terminals that want to transmit packets should send requests to the PBS in the Request/Update/New Mobile phase and listens scheduling message in the Scheduling phase. Then, terminals transmit packets using scheduled TDMA slots and CDMA codes. Also, terminals that don't have any packets to receive and to transmit stay in idle mode in the Request/Update/New Mobile phase and stay in the rx. mode in Scheduling phase. We show the frame structure in Figure 1. In each phase of a frame, the PBS and normal terminals operate as following.

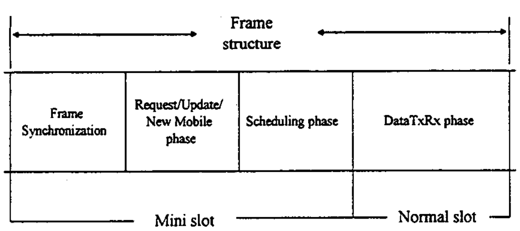

Figure 1. Frame structure

Frame synchronization phase

At the start of each frame, the PBS transmits the frame synchronization message to the terminals. This message contains synchronization information and the order information for packet transmission. Hence, there is no contention in Request/Update/New Mobile phase. Hence, power saving could be obtained. The PBS and other mobiles are in the wake-up mode.

Request/Update/New Mobile phase

The Request/Update/New Mobile phase is composed of the requests and power level update from the terminals. The PBS consumes rx. power during this phase and the mobile terminals that have traffics to send consume tx. power during one minislot. The mobile terminals that don't have traffics to transmit are in the idle mode. A new mobile terminal registers the PBS at last minislot time of this phase.

Scheduling phase

Every terminal operates with full duplex mode. Therefore, it can't receive or transmit packets from or to two terminals at the same time. The scheduling is based on a simple priority round robin. The PBS broadcasts a scheduling message that contains the TDMA slots and CDMA code permission for the subsequent phase. The PBS consumes tx. power during this phase and the others consume rx. power during one mini-slot and are in the idle mode during the others.

DataTxRx phase

The mobile terminals including the PBS communicate with each other by using allocated TDMA slots and CDMA codes avoiding collisions. The terminals that don't have traffics to send or to receive consume idle power. Terminals transmit and receive traffics directly without the PBS. Hence, we can acquire power saving effect.

We show the proposed MAC algorithm in Figure 2. A terminal can move to the other group and join it.

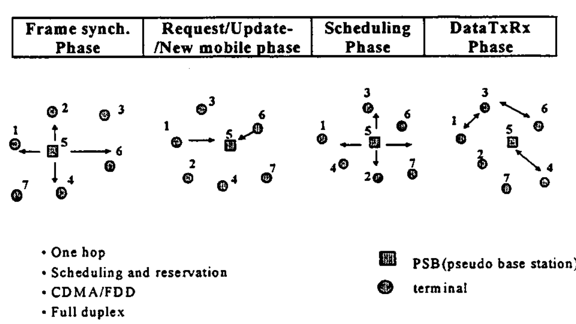

Figure 2. The proposed MAC Algorithm

3. Simulation results and Discussion

Simulations are performed to analyze single hop ad-hoc wireless networks adopting our proposed MAC algorithm. The terminals are classified into high power (HP) or low power (LP) terminals according to battery energy level. The proposed MAC scheme is designed to use the mini-slots for the channel request and scheduling since they require the lower battery energy than slots in the DataTxRx phase. If the battery energy of a LP terminal is particularly lower than the threshold, it is classified into LP terminal. We give the priority for scheduling to the LP terminal.

3.1 Simulation parameters

There are N terminals including PBS terminal. The Frame Synchronization phase has M_1 mini-slots and the Request/Update/New Mobile phase M_2 mini-slots and Scheduling phase M_3 mini-slots and DataTxRx phase M_4 slots. In the DataTxRx phase, there are Q codes. The α mini-slots are equal to one normal slot in the DataTxRx phase. We define frame period such that

$$P_{frame} = \frac{M_1 + M_2 + M_3}{\alpha} + M_4 \tag{1}$$

We assume that there are no packet losses by wireless links. Each terminal generates the data traffics that have ON or OFF traffic model. During ON period, arrival packet of the terminal has Poisson distribution with rate λ. The probability that a terminal i transmits n slots to a terminal j is given by

$$P(x_{i,j} = n) = e^{-\lambda} \frac{\lambda^n}{n!} \cdot \frac{1}{N-1} \qquad i = 1,2,3,\cdots,N \quad i \neq j \tag{2}$$

Let y_i be number of slots to be destined for a terminal i. The PBS is requested to allocate y_i slots. Then, y_i is can be expressed by

$$y_i = \sum_{\substack{l=1 \\ l \neq i}}^{N} x_{l,i} \tag{3}$$

The delay happens in two cases. First, the delay occurs because a terminal y_i can get the maximum M_4 slots. Second, when total slots requested is more than system capacity that is the product of M_4 by Q. The delayed slots are scheduled with high priority. The parameters used for simulations are listed in Table 1.

Table 1. Simulation parameters

Name	Value	Description
λ	10	Arrival rate in Poisson distribution
α	3	Mini-slot ratio
M1	10	No. of slots in frame synchronization phase
M2	N+1	No. of slots in request/update-/new mobile phase
M3	N	No. of slots in scheduling phase
M4	30	No. of slots in DataTxRx phase
Q	5	No. of codes
P_{tx}	0.1	Energy consumption in the tx. mode
P_{rx}	0.5	Energy consumption in the rx. mode
P_{idle}	0.01	Energy consumption in the idle mode

3.2 Simulation results

In our simulation, the 30% of all terminals are LP terminals. We define the energy efficiency as the ratio of total energy consumed to total slots used in the DataTxRx phase. The channel utilization is defined as the ratio of total slots used in the DataTxRx phase to the total system capacity. The total system capacity is the product of total slots P_{frame} by total code Q in a frame. The performance of our MAC scheme is studied through the number of delayed slots, the channel utilization, and the energy efficiency. The simulation ends when a battery energy level of some terminal equals to zero.

The number of delayed slots for LP and HP terminals show that LP terminals have lower values. Since LP terminals have priority when allocating slots and code, the gap between LP terminals and HP terminals is larger as number of terminals is increasing.

Figure 4 provides channel utilization curve that shows no difference when number of terminals is small. The larger load to system causes the degradation of the channel utilization since the channel resources are limited.

Figure 5 shows the energy efficiency curve that LP terminals consume lower battery energy than HP terminals. For HP terminals, the energy efficiency is lower as number of terminals is increasing because the overhead for the request and the scheduling in frames are smaller relatively. However, we see that the energy efficiency for HP terminals is higher in heavily-loaded case. It is due to the additive energy consumption caused by the retransmission. LP terminals have the priority compared with HP terminals. So, It makes LP terminals communicate with small battery energy consumption.

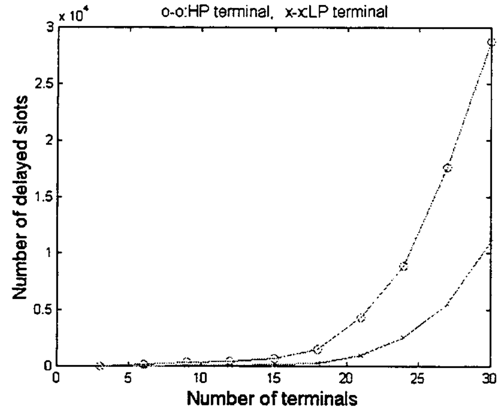

Figure 3. Number of delayed slots

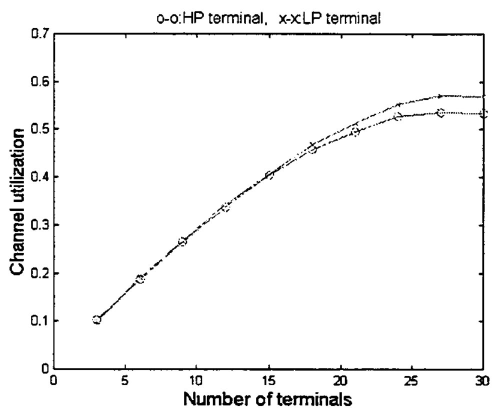

Figure 4. Channel utilization

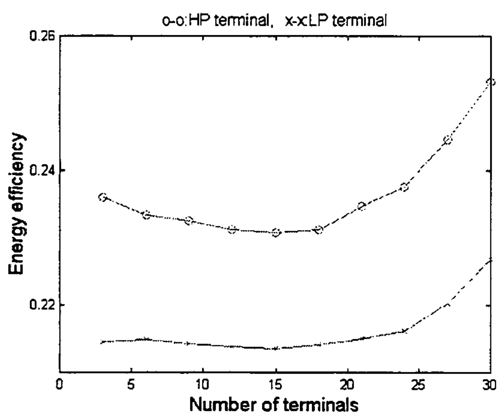

Figure 5. Energy efficiency

4. Conclusions

In this paper, we propose the energy efficient MAC algorithm based on scheduling and reservation for single hop ad-hoc wireless networks. When the data traffics are generated heavily, the proposed MAC scheme prevents terminals from collisions and retransmissions that cause additive battery energy consumption and also informs terminals of when to transmit and when to receive packets. Our reservation-based approach provides reduced battery energy consumption over wireless links. We evaluate the performance analysis of the MAC scheme with respect to the number of delayed slots, the channel utilization, and the energy efficiency versus number of mobile terminals, i.e. the traffic load. We show that LP terminals can take communications with the efficient energy consumption and experience smaller delay than HP terminals.

For further study, the proposed MAC scheme can be easily combined with hierarchical routing schemes, for example clusterhead gateway switch routing (CGSR) because the PBS can control a group of ad-hoc mobile terminals like a clusterhead in the CGSR. The operation protocols among PBSs need to be developed.

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