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https://hdl.handle.net/2324/6260

出版情報：IEICE, Technical Report, VLD2005. 105 (441), pp.21-24, 2005-11. IEICE
バージョン：
権利関係：

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THE INSTITUTE OF ELECTRONICS,
INFORMATION AND COMMUNICATION ENGINEERS

信学技報
TECHNICAL REPORT OF IEICE

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Low Power Design for IEEE 802.11 WLAN at the
Medium Access Control Layer

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Abstract The convenience and easiness to implement and use of wireless local area networks , such as IEEE 802.11, is contrasted by the high energy consumption of mobile computers due to collisions and interferences occurring on the wireless medium and leading to a high number of retransmissions a station must perform before there can be a successful transmission of a packet. Mobile stations being essentially battery-driven, it is important to ensure a long lifetime for these batteries and therefore energy-efficiency is an increasingly vital issue in the design of these systems. In this paper, we propose a novel approach to improve the Collision Avoidance mechanism specified in the IEEE 802.11 standard as a part of its Medium Access Control (MAC) protocol, by dynamically reducing the number of retransmissions required after a collision occurs on the medium.

Keyword Energy Efficiency, WLAN, MAC protocol, DCF, CSMA/CA, RTS/CTS

1. Introduction

Wireless local area networks (WLAN) standards provide a convenient and easy way to allow communication between mobile computers by forming an ad hoc wireless network or an infrastructure network in which the mobile stations communicate with each other through an Access Point (AP) that manages the stations and can connect to a backbone network, generally Ethernet, allowing the mobile stations to use the services of the wired network such as Internet. The most popular standard is IEEE 802.11.

The goal of IEEE 802.11 standard [1] is to develop and maintain specifications for wireless connectivity for fixed, portable and moving stations within a local area. It provides MAC and physical layer (PHY) functionality.

IEEE 802.11 has two main configurations:

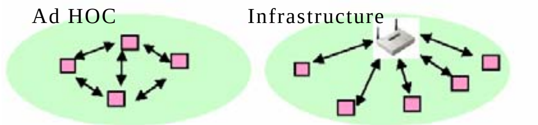

Fig.1 WLAN Ad-Hoc and Infrastructure Networks

1. Infrastructure: Nodes communicate with each other, and with an infrastructure wired network, through an Access Point (AP).
2. Independent(Ad-Hoc): Nodes communicate directly with each other, without an AP.

Since mobile stations are battery-driven systems and knowing the gap between the projected improvements in battery technologies and those of portable microelectronics systems [1, 2], energy efficiency design is becoming an increasingly important issue in the design of these systems.

Experimental results show that the maximum energy consumption in a wireless network interface card (NIC) occurs during the transmission activity [3, 4, and 5].

The IEEE 802.11 standard defines a Power Saving Mechanism (PSM) [6].In PSM, time is divided into beacon interval. Nodes are powered on at the start of each beacon interval for a TIM (Traffic Indication message) period after which they enter to a sleep mode, consuming theoretically zero electrical power, for the rest of the beacon interval. E. Jung et al in [7] propose an energy-efficient PSM where nodes can dynamically adjust the size of TIM based on observed network conditions.

Other power-management policies [8, 9, and 10] have been proposed to force a WLAN device to enter the sleep mode adaptively at appropriate moments to save batter energy.

The physical layer's potential of power saving has been shown through methods that use TPC (Transmit Power Control) in WLAN systems as in [11, 12, and 13].

However, we think it is valuable and meaningful to consider energy-efficiency design at the MAC algorithm level since it is there where channel access is regulated and decided and since it is the contention for the channel that dissipates the maximum energy in a wireless network because it is very probable that two or more stations attempt to transmit at the same time, thinking that the medium is idle when it is not, and thus leading to a collision leading to a retransmission and thus to a higher energy dissipation. In a wireless data network, such as WLAN, the Medium Access Control is essential to manage and share the resources of the wireless channel among different users.

In this paper we propose modifications to the IEEE 802.11 MAC algorithm for energy-efficiency, our approach is based on the assumptions that:

1. The energy consumption is dominated by the communication activity which consumes much more energy that the computation activity,
2. The high energy consumption of the communication activity is due to the high number of retransmissions required after collisions , errors or interferences on the wireless channel,

Reducing the number of retransmissions would certainly lead to an important energy saving, but we don't have a method to predict the probability of a collision of a frame and therefore to predict if there will have to be a retransmission.

Adding to the above assumptions the fact that:

3. Because control frames have a much smaller size than Data frames, if a retransmission has to happen then retransmitting a control frame (such as RTS = Request To Send) will not affect energy-efficiency as bad as retransmitting a Data frame would.

Our method is to set dynamically the value of RTS_Threshold (see Section 2) when the backoff mechanism is requiring high energy consumption, i.e. when the number of required retransmissions is considerably high. Details of the method are presented in Section 5.

The rest of the paper is organised as follows: Section 2 reviews IEEE 802.11 Medium Access Control Layer (MAC) and the Distributed Coordination Function (DCF). Section 3 describes the energy model used and the simulation environment. Section 4 introduces our proposed method. Simulation of our method and results are presented in Section 5. We conclude the paper in Section 6.

2. Related Work

IEEE 802.11 addresses energy efficiency by defining a Power Saving Mechanism (PSM) where stations are powered off (sleep mode) at periodic intervals [6]. E. Jung et al in [7] propose an energy-efficient PSM where nodes can dynamically adjust the size of their sleeping interval based on observed network conditions.

Reducing the WNIC's energy consumption can also be done at the physical level. For example by reducing the energy consumed by its RF parts (transmitter and receiver).

The receiver consumes energy when receiving packets and when sensing the channel. To conserve energy, IEEE 802.11 switches off the receiver periodically for nodes in PSM [6].

The transmitter consumes energy when transmitting packets or forwarding a packet in a multi-hop ad-hoc network. TPC (Transmit Power Control) methods aim at reducing the energy consumption by reducing the RF transmission power. But reduction of RF transmission power causes a higher bit error rate leading to collisions. The MAC reacts with retransmission of corrupted packets causing a higher power drain because of multiple retransmissions of the same packet. Increasing RF power results in higher channel reliability, therefore decreasing the bit error rate and the probability of retransmissions. But a higher RF power increases energy consumption. J.-P. Ebert and A. Wolisz in [4] find that there is an optimum transmission power for a certain packet size and propose an algorithm where the MAC layer can tune to the appropriate power according to the packet size and channel characteristics.

3. Estimation of Energy Consumption

The radio can be in one state of the following: Transmitting, i.e. radio is transmitting data; Receiving, i.e. radio is effectively receiving data; Overhearing, i.e. radio is receiving data that is not destined to the node; Idle, i.e. radio is ready to receive or transmit; Sensing, i.e. radio has detected some signal but is not able to receive it; Sleeping, i.e. radio is in low power mode and thus is not able to receive or transmit. Sensing and overhearing are a special case of the receiving state. The radio can be in sleeping state only when the station is in the Power Saving Mode (PSM).

The next diagram summarizes the transition between these states:

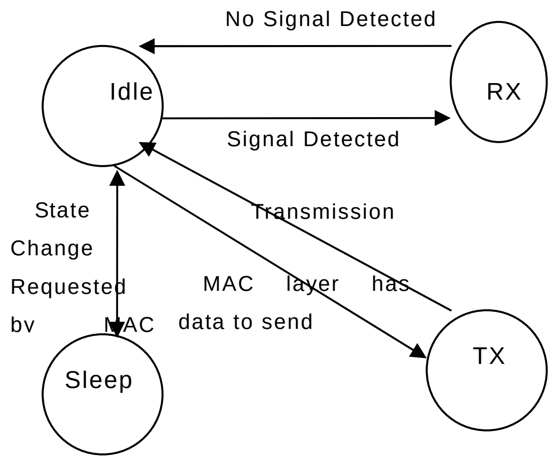

Fig. 2 MAC State Transition Diagram

For each state, the energy consumed is as Ey = Py * Ty, where Py is the power dissipated by the radio while in state y, and Ty the time spent in state y. State y can be transmission, reception, idle, sleep or sensing.

The values of Py for each state y, used in the simulation, are given in section 5.

4. Proposed Method

The main reason behind the high energy cost of the communication activity is the high number of retransmissions. These are due to an erroneous channel, interferences or collisions because of simultaneous transmissions. The first two causes of errors are not considered in this paper, frames are received in error only when they encounter collisions due to other simultaneous transmissions.

Follows that reducing the energy wasted in retransmissions would reduce the energy cost of the wireless communication activity and thus result in an energy saving for the overall system.

Therefore the goal of the method proposed in this paper is to reduce the energy wasted in retransmissions due to collisions occurring on the wireless medium. This can be achieved by limiting the number of retransmissions a data frame must endure before a successful transmission.

The method proposed in the paper opts for an orthodox way which is to not allow a second retransmission of a frame, while still competing to reserve the channel for transmitting the same frame. To do this, the paper proposes to implement the DCF such that it starts with the basic access scheme (no RTS/CTS) and when a collision happens, it switches to the RTS/CTS mechanism, stays in this mode until the frame has been successfully transmitted or the maximum number of allowed trials is reached, in which case the paper suggests to go back to the basic access scheme.

- The reason for this choice is that, because the sizes of RTS and CTS control frames are much smaller than the data frames', retransmitting these control frames is less energy consuming than retransmitting the whole data frames.

5. Simulation and Results

The simulation is conducted in NS2 [14]. The energy consumed by a wireless ad-hoc network composed of N = 2, 3 ...30 nodes is calculated and compared in each of the three cases of:

1- Basic Scheme: (No RTS/CTS used)
2- RTS/CTS: (RTS_Threshold is set to a default value of 512 bytes)
3- The Proposed Method: Automatically adjust RTS_Threshold to a minimal value after collisions (so as to activate RTS/CTS exchange) and to a maximum value after every successful transmission of a frame (to go back to the basic access scheme)

The channel bit rate was set at 11 Mbps and control frames were transmitted at the basic rate of 1 Mbps. The simulation time is 360 seconds and CBR (Constant Bit Rate) traffic is set between each pair of nodes in the network every 1 second, with all packets having the same size 1000 bytes.

The powers to transmit and to receive are 2.2 Watts and 1.35 Watts respectively, and no station is operating in the power save mode (PSM).

While it is important to evaluate the effect of the proposed method on the power consumption of the network, the power consumption alone is not enough to reflect the performance of the wireless LAN; for instance, if the network interface is constantly in a sleep mode, then the power consumption is at its lower level while actually no data is being transmitted. Therefore, we evaluate also the energy per good-put, defined as:

$$E_{\text{bit\_good}}\ [J/Bit] = \frac{\text{Average\_Consumed\_Power}\ [W]}{\text{Goodput}\ [Bit/s]}. \qquad (1)$$

The following two graphs draw respectively the average power consumption per node and the energy per goodput in function of the number of nodes in the network:

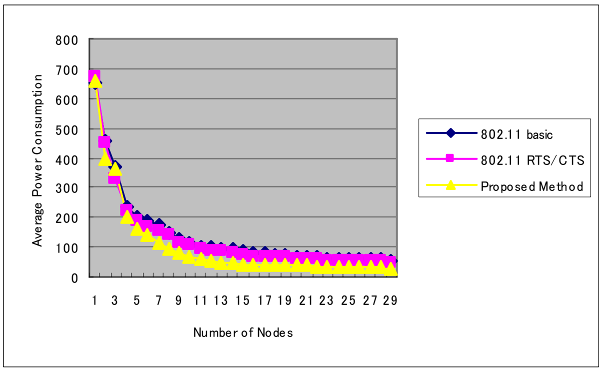

Fig.3 Average Power Consumption

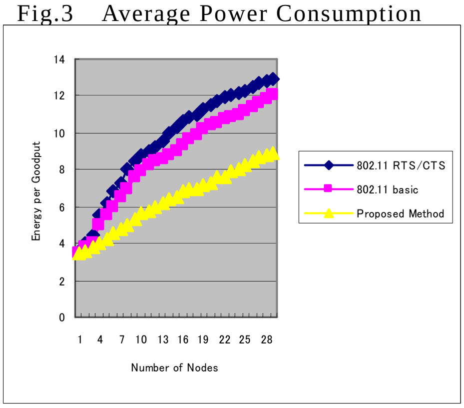

Fig.4 Energy per Goodput

VI. Conclusion

The proposed method performs better than both the basic access and the RTS/CTS mode, with an energy saving of about 40% in average, especially for a number of nodes higher than 5.

ACKNOWLEDGEMENT

This work has been supported by the Grant-in-Aid for the 21st Century COE program. We are grateful for their contribution.

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