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Scheduling Adjustment of Mac Protocols on Cross Layer for Sensornets

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Abstract: A number of recent advances in MAC protocols for wireless sensor networks have been proposed to decrease idle listening. Low-Power-Listening (LPL) protocols transmit data packets for the inter-listening interval, for this reason, allowing sensor nodes to sleep for long periods of time between channel probes. The inter-listening interval as well as the particular type of LPL protocol ought to well match the network conditions. Some LPL protocols break communication between the sender and the receiver after the data packet has been successfully received. In this study, a novel variable rate based time frame scheduling scheme is proposed to further reduce collisions and improve energy saving in wireless sensor networks. During this pre-schedule slot, each node knows exactly the schedule of other neighbor nodes. Multi-rate and power scaling are adopted to achieve further energy saving by employing an acceptable rate rather than the maximum rate. Data rate is dynamically adjusted according to the traffic load of sending nodes in an energy efficient data rate to retrench energy. Compared with Z-MAC, performance in the present study proves to have better ability of local framing pre-schedule and multi-rate achieves better energy efficiency. Our results show that using the improved method of the MAC schedule provides up the enhancement of lifetime for different traffic scenarios.

Key words: Rate based scheduling, MAC, low-power-listening, wireless sensor network

INTRODUCTION

Applications of Wireless Sensor Networks (WSNs, which we call sensornets hereafter) are becoming increasingly complex and they require the network to keep a satisfying level of operation for extended periods of time. Therefore, sensornets cannot but make the best possible use of their initial energy resources, specifically by continually suiting protocols to the changing conditions in the network. Both protocol-specific and cross-layer schemes have provided a plethora of energy reducing techniques. Particularly, there are several protocols that focus on reducing energy at the data link/MAC layer, which constitutes the scope of this study, In this study, we investigated how to efficiently improve the energy-conserving ability in sleep mode for as long as possible. The idea presented in this study discusses switching between MAC schedules to adopt the most energy-efficient pattern of packet transmissions and receptions. Since, different areas of the network undergo different traffic loads, the MAC protocol should exploit the schedule most economically for the local situations.

In new sensornets platforms, a simple observation was made that idle listening, far from being negligible, was a main source of energy consumption. The LPL and Preamble Sampling (PS) MAC protocols were introduced as a result. In his taxonomy of MAC protocols, Langendoen identifies LPL and PS protocols as two branches of random access MAC protocols, with the only difference that LPL MAC protocols need not know anything about their neighbors and their wake-up schedules. Both types of MAC protocols, including B-MAC (Polastre *et al*., 2004), WiseMAC (El-Hoiydi and Decotignie, 2004) , SyncWUF (Shi and Stromberg, 2007) and X-MAC (Buettner *et al*., 2006), use the insight behind Aloha with PS (El-Hoiydi, 2002): the sending node occupies the medium for long intervals to signal its imminent packet transmission. Receiving nodes are thus allowed to sleep for at most the duration of this preamble and are required to hold awake while they sense a busy medium until the packet transfer is accompished. In this study, we consider only the LPL branch of the Langendoen taxonomy (although many of our results can be transposed to other MAC protocols) and we define (LPL) MAC schedule as the pattern of packet transmissions occurring within the interval.

Researchers are forced to abandon B-MAC and a few other LPL protocols because of radios changes: Although, it paved the way to new MAC protocols, B-MAC, which uses a variable-length preamble to signal the impending packet transmission, can no longer be implemented as proposed on the new IEEE 802.15.4 compliant platforms since this standard has a

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fixed preamble length of only a few bytes. After the introduction of new radios, researchers introduced new LPL and PS protocols: X-MAC , C-MAC (Liu *et al*., 2007), WiseMAC, CSMA-MPS (Mahlknecht and Bock, 2004) and SpeckMac (Wong and Arvind, 2006) are among the most popular contributions. These protocols are based on repeating either the data packet itself (SpeckMAC and CSMA-MPS), or an advertisement packet (X-MAC/C-MAC), in place of a long preamble.

A large number of more sophisticated mobility models for WSNs research have been presented (Le Boudec and Vojnovic, 2005; Jardosh *et al*., 2005; Carlson *et al*., 2004). The most widely adopted models of such kind are based on random individual movement, the simplest of which, the random walk mobility model (similar to Brownian motion), is adopted to represent pure random movements of the entities of a system (Einstein, 1956). Environment monitoring and battle field surveillance require the sensor nodes to be operated in low power to extend life time (Le Boudec and Vojnovic, 2005). Taking the inborn nature of wireless sensor network into consideration, we should first pay attention to energy efficiency and then the high throughput, low latency and fairness (Chatzigiannakis *et al*., 2005; Calì *et al*., 2000). The smooth operation and energy efficiency of any wireless sensor network depends, to a large extent, on the effectiveness of Medium Access Control (MAC) layer's responsibility. In this paper, an MAC layer approach is adopted to achieve energy efficiency.

Wireless channel accessing schemes can be classified into two broad categories by tradition: contention-based and reservation-based (Wu and Biswas, 2005). A commonly-used MAC paradigm in wireless networks is CSMA (Carrier Sense Multiple Access), which is a contention-based medium access. It gains high popularity due to its simplicity and robustness. It does not require much infrastructure support (Rhee *et al*., 2005). Collision can occur in any two hop neighbors. RTS/CTS can alleviate the hidden terminal problem, but it incurs high overhead (Woo and Culler, 2001; Polastre *et al*., 2004). The proposed Z-MAC (Rhee *et al*., 2005) that combined CSMA and TDMA. In the low level, CSMA is generally adopted; while in the high contention level, a TDMA hint is desired to enhance contention resolution. However, there is no multi-rate functionality in Z-MAC.

In this study, multi-rate functionality is introduced into Z-MAC to reduce contention and collision. Since, each node knows its schedule and neighbors' schedules, it can smartly sleep to achieve further energy saving. Simultaneously, we also have finished the relative earlier research study (Gao *et al*., 2009, 2010; Wei and Wang, 2009; Wei *et al*., 2007a, b, 2008a, b).

Aloha with PS is one of the first channel-probing schemes proposed for sensornets (El-Hoiydi, 2002). As a consequence, El-Hoiydi introduced WiseMAC. We show that explicit scheduling between nodes is unnecessary because it can be achieved implicitly with X-MAC, C-MAC, or MX-MAC. B-MAC with LPL is the first MAC protocol to introduce LPL schedules for recent radios (with WiseMAC being the first for PS MAC protocols). Authours thoroughly compare B-MAC to S-MAC and T-MAC (Van Dam and Langendoen, 2003). The 802.11 family MAC provides multi-rate functionalities, but energy consumption is very high in these MAC. They are not suitable to wireless sensor works. S-MAC (Wei *et al*., 2002) is a low power contention based MAC protocol. The B-MAC allows application to implement its own MAC through a well defined interface. It also adopts LPL (Low Power Listening) and CCA (Clear Channel Assessment) to achieve higher throughput and energy efficiency. The Z-MAC is based on B-MAC, uses CSMA as the baseline MAC scheme, but uses a TDMA schedule as a hint to enhance contention resolution. In Z-MAC, a time slot assignment is performed at the time of deployment. Higher overhead is incurred at the beginning. Its design philosophy is that high initial overhead is amortized over a long period of network operation, eventually compensated by improved throughput and energy efficiency.

Most studies have been dedicated to the task of adapting MAC protocols to conditions in the local neighborhood of a node. Watteyne et al. propose several variants of one-hop MAC, which is a receiver-based cross-layer routing and MAC protocol. Additionally, MiX-MAC considers schedules for broadcast packets. In El-Hoiydi (2002) and Van Dam and Langendoen (2003) propose to improve S-MAC by a novel adaptive active/sleep duty cycle. Pham and Jha introduce MS-MAC, an S-MAC-based protocol that adapts S-MAC's listening, sleeping and synchronization cycles to anticipated node movements.

In this study, based on Z-MAC, we establish the past body of work, utilizing the idea of adapting to network different situations and specifically focusing on pre-schedule about LPL MAC protocols, which have proven quite energy efficient for the practical sensornets applications. We use a novel multi-rate solution to reduce contention by trying to limit the transmission confined in the owner slot. This approach greatly reduces contention and hence reduces energy consumption.

CROSS LAYER DESIGN SCENARIOS

The concept of cross layer design is not new in the networking area. In the early study (Jardosh *et al*., 2005), (Tseng *et al*., 2004) , cross layer design has been proved to be effective in networks. Cross layer design principles have greater importance in ad hoc networks because of the unique features of these environments. Different layers are more likely to adopt the same information in decision making, for example, the link and channel states, locations of the nodes, neighbor list and topology information of the network are frequently adopted by both the routing and the MAC layers in decision making. In addition, different layers (especially routing layer and MAC layer) need to cooperate closely to meet the requirements of the applications in a fast changing wireless environment. This goal can be better achieved when the routing layer shares the MAC-layer information such as channel condition, neighbor information, etc.

Cross-layer design allows interaction between any layers. A layer can interact with layers in the protocol stack. The study by Chatzigiannakis *et al*. (2005) discussed the positive effects of cross layer information sharing on the mobile device. It also proposed a framework to realize efficient cross layer information sharing.

PROCESS DESCRIPTION

Normally, the signal processing applications (such as DSC: Distributed Source Coding) running on the sensor nodes will sample data from the environment. The sampled data is to be transmitted to a sink node many hops afar. The DSP data is submitted to the application adaptation component; with corresponding end to end rate requirements and destination node's indication (the default destination is the sink node, keeping this as a variable parameter for the flexibility). The application adaptation component pushes the data in the queue of the FIFO management component. It also gives end-to-end rate hint to routing component. The routing component will pack the data into TOS_Msg format in the FIFO management component without the memory copy and find next hop neighbour in the local database component. Then routing selection and rate parameters are passed to MAC component. MAC component will pack data into MAC frame format (again, without memory copy). And then it will calculate the transmit power according to the channel condition and data rate and then set data rate and supply power to physical layer. After that, the physical layer will start data transmission, sending data from FIFO to radio. This process is shown in Fig. 1.

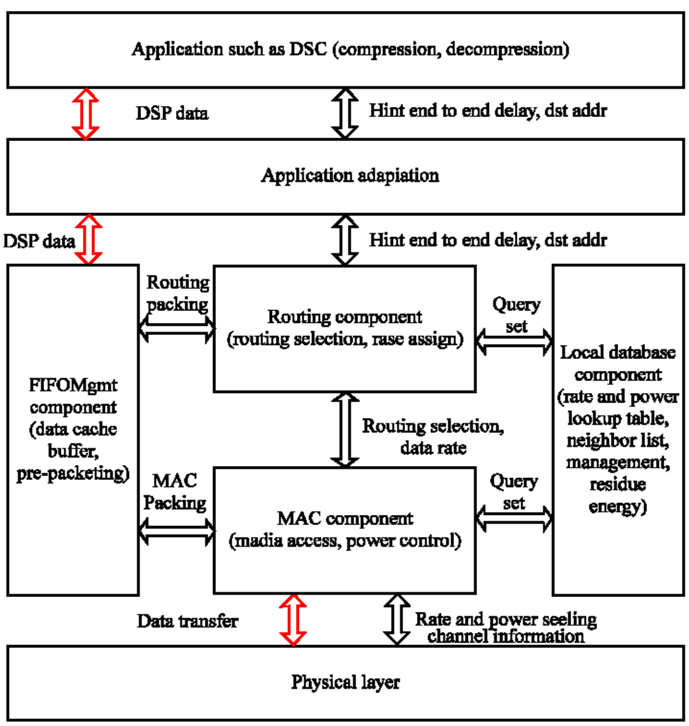

Fig. 1: Diagram of components in the framework

CROSS LAYER CONTROL

Multi-rate MAC: The multi-rate MAC component is based on T-MAC. It adopts T-MAC to perform the Media Access Control functionality and node sleep/wakeup. We add multi-rate functionality into the MAC component. The multi-rate in MAC component is achieved by dynamically adjusting:

```
interface IMultiRateMAC {
  command result_t SendPacket(void * pPacket, \
uint16_t nPacketLen, uint16_t nDstAddr, \
uint16_t nDataRate);
 event result_t SendPacketDone(result_t success);
 event void OnReceivePacket(void * pPacket, \
uint16_t nPacketLen, uint16_t nDstAddr, \
unit16_t nSrcAddr);}
```

MAC scenario description: When the routing component calls the command of sending packets to MAC component, the data packets have already been well packed in advance in sending FIFO (the data packets stored in FIFO have their headers in TOS_Msg format). The MAC component then packs MAC header and CRC tail to the TOS_Msg, of course, without memory copy. After that, it chooses a proper modulation scheme according to the data rate and sets transmit radio power based on the modulation scheme and channel lost between sender and receiver. Then it starts radio for data transmission. When a packet is captured by the physical layer, it will be stored in the FIFO after header and tail processing.

Simulation: To evaluate the effectiveness of the Local Framing Pre-schedule, we simulated this functionality in MATLAB and compared it with original Z-MAC. The test benchmark adopted in this simulation is the same as Fig. 1. Node 0 sends data to node 1 and node 4 sends data to node 5. Data sent by these nodes has variable length to test the performance under different traffic loads. The experimental parameters are presented in Table 1.

The experimental parameters are the same as adopted in Z-MAC and B-MAC. Traffic data lengths adopted in simulation are: 413 bytes, 836 bytes, 1278 bytes, 1689 bytes, 2206 bytes and 2538 bytes, respectively. The total energy consumptions are acquired and compared. The research by Schurgers *et al*. (2001) has proposed that, to maintain the same receiving signal strength, the transmitting power is proportional to the symbol rate and the modulation constellation size:

$$Ps = Cs \cdot Rs \cdot (2^b - 1) \tag{1}$$

Normally, multi-rate is achieved by modulation scaling by keeping symbol rate the same, while scaling the constellation size. In order to keep the same receiver SNR, the transmit current should be proportional to a power of two of the transmission rate. Based on parameters of B-MAC, the transmit current for data rate 19.2 kbps is 20 mA and if Eq. 1 is used, we can get scaled transmit current of multiple rates in Table 2. Both the original Z-MAC and Z-MAC with pre-schedule scheme transmit data at a full rate. The total energy consumption in one round is presented and compared in Fig. 2. The total energy consumption increases with the increase of the traffic amount. The heavier the traffic, the higher total energy consumption. Z-MAC has already achieved excellent energy saving, even without pre-schedule scheme which has already been proved in (Tseng *et al*., 2004). By introducing a pre-schedule scheme, total energy consumption is reduced by eliminating unnecessary low power listening. The pre-schedule scheme works well under relatively low traffic level. While in high traffic level, the difference between pre-schedule and no pre-schedule becomes little. This is because the unnecessary low power listening drops under higher traffic level.

Table 1: Experimental parameters in simulation

Notation	Parameter	Value
CSleep	Sleep current (mA)	0.03
CInitRadio	Initialize radio (mA)	6.00
CRx	Receive current (mA)	15.00
Vol	Voltage (V)	3.00
NPreamble	Preamble length (bytes)	271.00
NPacket	Packet length (bytes)	413.00
TSlotSize	TDMA slot size (ms)	50.00
TLPLIntv	LPL check Interval (ms)	10.00
TInitRadio	Radio initialize time (ms)	0.50

Table 2: Data rate lookup table adopted in simulation

Rate description	Value (kbps)	Transmit current (mA)
BASIC_RATE	19.2	20
NORMAL_RATE	38.4	60
HIGH_RATE	57.6	140
FULL_RATE	76.8	300

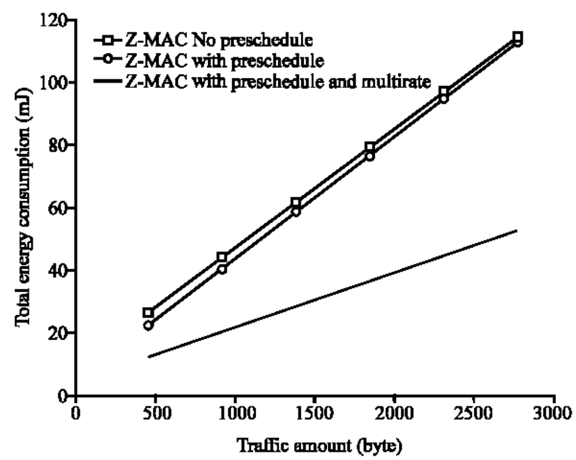

Fig. 2: Total energy consumption

By introducing multi-rate, a node can choose a slow rate instead of full rate to transmit data as long as the buffered data can be successfully transmitted in a round. Transmitting data at high rate will cause more energy consumption, while this multi-rate approach achieves considerable energy saving. The multi-rate scheme works well especially in high traffic scenarios.

CONCLUSION AND FUTURE WORK

In this study, a novel multi-rate local framing pre-schedule scheme based on Z-MAC is proposed to further reduce energy consumption although, Z-MAC achieved excellent energy conservation, the local framing pre-schedule scheme gracefully reduced unnecessary low power listening. The local framing pre-schedule scheme further improves energy saving. Multi-rate solution gives multiple choices in transmission because power transmission is related to the data rate in modulation scaling and transmitting data at the low rate achieves lower energy consumption; therefore, as long as a node can finish its data transmission in a round, choosing a lower rate is better than transmitting at full rate in terms of energy saving. This can achieve better performance, especially in high traffic level. In future, we plan to raise the number of parameters and metrics to switch MAC schedules. We also plan to explore further node synchronization for special node deployment cases. This will require developing cross-layer routing protocols and applications enable to utilize the MAC schedules.

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