A concurrent MAC protocol based on location information in wireless sensor networks

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Received 1January 2014, www.tsi.lv

Abstract

The traditional CSMA MAC node simply blocks its transmission if the medium is sensed to be busy. Thus, it is inefficient in terms of the network throughput due to overcautious estimation of the interference. In this paper, we propose a novel location-aware medium access protocol for data intensive wireless sensor networks. In this protocol, the contending nodes make use of their location information to achieve the concurrent transmission of exposed terminal so as to reduce collisions and improve the overall performance. We evaluate it in terms of delay and throughput and compare it with S-AMC using simulations. Results show that the proposed MAC protocol can take advantage of the location distribution of nodes to improve the average throughput of the network, reducing data transmission delay, and effectively improving the efficiency and performance in data intensive wireless sensor networks compared to S-AMC.

Keywords: exposed terminal, MAC protocol, wireless sensor networks, concurrent transmission.

1 Introduction

In wireless sensor networks, different users try to access the same medium. Thus, contention becomes a limiting factor of the MAC layer performance, and managing spatial reuse is a critical issue. IEEE 802.11 MAC protocol [1] is becoming the most popular protocol for wireless networks. As all carrier sense multiple access with collision avoidance (CSMA/CA) based MAC protocols, DCF suffers from hidden and exposed terminal problems. The basic mechanism of DCF is that a station may transmit only when the medium is sensed to be idle since any station may cause interference to an ongoing transmission occupying the medium. More specifically, if a station has data to transmit but a busy carrier has been detected, a blocking mechanism is performed (i.e., the transmission is delayed).

On the other hand, it was shown that the DCF is inefficient with respect to the network throughput [2]-[6]. This is because the unnecessary blocking of concurrent transmission is occurred when a station senses the medium busy or it receives a channel reservation frame from other station. Actually, in many cases, the station accessing the channel may not produce sufficient interference to inhibit ongoing transmission to the intended receiver.

To deal with this problem of the DCF algorithm, various intensive research works have been reported in the literature. Among them, we will review several previous works closely related to our study. First, the authors of [2] has adjusted the timing of RTS/CTS/DATA/ACK frame sequence and attempted to synchronize one hop neighbours for concurrent transmission. The authors of [3] proposed a new blocking condition, which obstructs the transmission only when both RTS and CTS frames are received. However, these approaches have a main drawback that is feasible only for some special network topology. Secondly, [4] introduced the method that embeds the measured signal to interference and noise ratio (SINR) using the RTS frame into the CTS frame in order to exploit spatial resource. However, in that schemes, the only the DATA frame was considered during the concurrent transmission. In practice, all DATA frames in medium access control (MAC) layer get an acknowledgement (ACK) receipt to provide adequate link reliability. In addition, they did not consider the contention between opportunistic transmissions that causes the performance degradation. Finally, per-packet power control mechanism was suggested to leverage the channel spatial reuse (e.g., [5]). According to these methods, the concurrent transmission is possible in the same vicinity of a receiver by the local broadcast of collision avoidance information over a separate control channel. However, these schemes have a constraint that the station must be equipped with two transceivers and needs two orthogonal separate channels.

Location awareness of wireless nodes is increasingly common in many wireless network applications. In this paper, we propose a new approach to improve spatial reuse in multihop wireless sensor networks. This approach exploits location information to schedule concurrent transmissions. The objective is to allow an exposed node to schedule concurrent transmissions to improve network throughput and delay performance. We

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assume that each node has its location information, either through the Global Positioning System or many available localization algorithms [6]-[7]. We further assume that each node is able to exchange location information with its neighbours.

2 Related work

IEEE 802.11 uses the so-called virtual carrier sensing mechanism to resolve the hidden-terminal problem. However, the so-called "exposed-terminal" problem still remains.

In Figure1 we suppose node A is transmitting to node B and after some time node C wants to transmit to D. According to the CSMA protocol, node C senses the medium, finds that node A is transmitting and waits (node C) until node A is finished with its transmission. This occurrence is known as exposed terminal problem which is responsible for degrading the network performance [8], because from the above scenario we find that node C could transmit to node D without collision and hence save a significant amount of time.

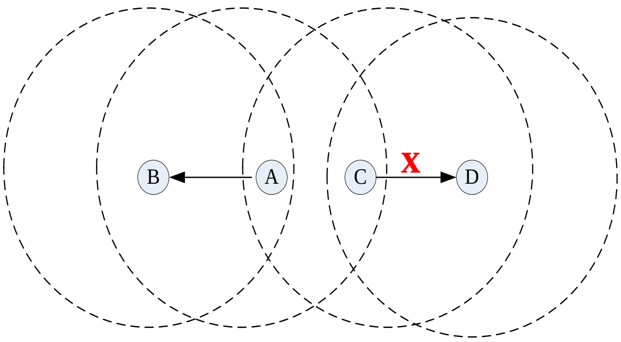

FIGURE 1 Exposed terminal problem

Recently there have been considerable efforts on improving the throughput of wireless networks by enhancing DCF [9-16]. A relatively simple scheme is presented in [17], which enables nodes to identify themselves as exposed terminals and opportunistically schedule transmission of a small frame without RTS-CTS exchange. In [13], Acharya et al. proposed a new MAC protocol, called MACA-P. The key idea of this protocol is to introduce an extra gap between the RTS/CTS frames and the subsequent DATA frames in addition to the short inter-frame space (SIFS) of the IEEE 802.11 MAC protocol. This extra gap allows all the neighbouring nodes to exchange the RTS/CTS frames for the purpose of concurrent transmission. After successfully exchanging the RTS/CTS frames by the end of this extra gap, the links with concurrent transmission opportunity, such as the links B → A and C → D in Fig. 1, can start transmitting their DATA frames. For concurrent transmissions, extra information bits are added in the RTS and CTS frames to indicate the start time of the DATA frame and the ACK frame. Hence, the two concurrent transmission links can synchronize their starting time. Similarly, the virtual-carrier exposed node issue can be solved by the MACA-P MAC scheme.

The improvement of concurrent transmission opportunity from the MACP-P MAC protocol comes at the price of memory cost and incompatibility. The wireless ad hoc network adopting the MACA-P MAC protocol requires a larger memory size for storing the scheduled transmission time of all the neighbouring nodes. More importantly, the MACA-P MAC protocol is not compatible with the IEEE 802.11 DCF MAC protocol.

In [18] Shukla et al. proposed a parallel-MAC (P-MAC) protocol to increase the concurrent transmission opportunity of a short packet together with a long packet. The basic idea of the P-MAC protocol is to apply the RTS/CTS/DATA/ACK four-way handshaking procedure and the DATA/ACK two-way handshaking procedure for long packets and for short packets, respectively. Based on this MAC protocol, if overhearing an RTS frame under the condition that no CTS frame is received, a node can establish another link to send a small-sized packet based on the DATA/ACK two-way handshaking procedure. With the NAV value in the overheard RTS frame of other nodes, the sender of the second link can schedule the transmission of the DATA frame to be synchronized with that of the first link. Similarly, the transmission time of the ACK frames in both the first link and the second link can be synchronized. The P-MAC protocol can achieve the objective of concurrent transmissions by simply not using RTS/CTS in the sending small-sized packets. Because approximately 50% of packets have a size smaller than 100 bytes in the Internet, the P-MAC protocol is quite suitable for delivering the traffic in the Internet.

To summarize, the P-MAC protocol can solve the virtual-carrier hidden node problem of Fig. 1. This MAC protocol can also overcome the physical-carrier exposed node problem of Figure 1 because the RTS/CTS handshaking mechanism is employed. Nevertheless, the virtual-carrier exposed node problem still cannot be alleviated by adopting the P-MAC protocol.

3 The proposed MAC protocol

In this section, we describe the proposed protocol in detail. We present a location-assisted media access control (MAC) protocol that exploits location information to validate potential concurrent transmissions. Such a scheduled transmission should not interfere with the current transmission, and it should not be corrupted by the current transmission. The scheduling of concurrent transmissions is transparent to the current sender–receiver pair, making it backward comparable with the original IEEE 802.11 MAC and S-MAC.

3.1 ACQUIRING LOCATING INFORMATION OF NODES

Nodes can get its location information, either through the Global Positioning System or many available localization algorithms. All nodes in the networks broadcast their location information, so each node can get location information for all neighbour nodes. Neighbour nodes add location information status field in the node list in order to store location information of node coordinates. Position in the node when that information is broadcast within the hop neighbour position, when the node location information changes, the node can update the neighbour list of neighbour location information value, so that each node will be saved within the two hop neighbour nodes.

3.2 CONFIRMING EXPOSED TERMINAL NODES

When a node first overhears an RTS and then a DATA frame from the same transmitter, it can be identified as an exposed terminal with regard to the overheard transmission. In practice, however, information such as frame type will only be available at the MAC layer after the entire frame is received and verified by checking the frame check sequence trailer.

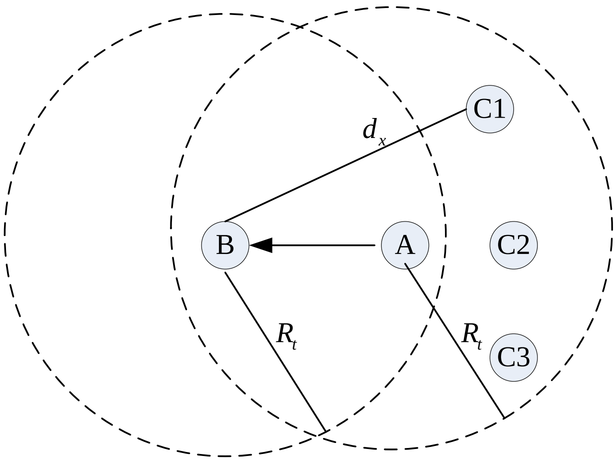

FIGURE 2 Identifying an Exposed Terminal

When a node recognizes itself as an exposed terminal in this manner, it will be too late to schedule any concurrent transmission. To schedule concurrent transmissions, exposed terminals should be identified before the current DATA frame transmission begins. At the same time according location information of nodes transmission distance can be calculated from the master node and receiving node. In Figure 2, if $d_x > R_t$, we can confirm C1, C2 and C3 are exposed terminals.

3.3 CHECKING CONCURRENT TRANSMISSION

All nodes are assumed to have the same type of radio and identical transmit power. We consider the two-ray ground propagation model. Under this model, the relation between the transmit power P_t and the received power P_r is given by:

$$P_r = \frac{P_t G_t G_r (h_t h_r)^2}{d_4}, \tag{1}$$

where G_t and G_r are the gains of the transmit and receive antennas, respectively; h_t and h_t are the heights of transmit and receive antennas, respectively; and d is the distance between the transmitter and the receiver.

For a target receiver, let P_r denote the received transmit power and P_i denote the received interference power. For successful reception, the signal-to-interference ratio *(SIR*) at the receiver should be greater than a threshold SIR_T:

$$SIR = \frac{P_r}{P_i} \geq SIR_T > 1 \cdot \tag{2}$$

From the two-ray ground model and (1), the interference range R_i is defined as:

$$R_i = d_t \sqrt[4]{SIR_T}\ . \tag{3}$$

We focus on the successful transmission range when a scheduled transmission is allowed. Based on (2), boundary points of the area within which the scheduled transmission will not be interfered by the current transmission can be calculated from $n\sqrt{x^2+y^2} \leq \sqrt{(x-d_0)^2+y^2}$. Rearranging the aforementioned equation, we obtain:

$$(\frac{nd}{n^2-1})^2 \leq (x + \frac{d_0}{n^2-1})^2 + y^2\ . \tag{4}$$

That is, this region is a disk cantered at $\left(-d_0/n^2-1{,}0\right)$ with a radius $nd/\left(n^2-1\right)$. On the other hand, the scheduled receiver should be located within the scheduled transmitter's transmission range to correctly receive the frame, i.e.:

$$R_t^{\,2} \geq x_2 + y_2\ . \tag{5}$$

Nodes that are out of the dashed circle cannot successfully decode the scheduled transmission, even if the concurrent transmission is absent.

3.4 EXECUTING CONCURRENT TRANSMISSION

By exploiting location information, we can correctly identify scheduled transmissions that will not be interfered by the concurrent transmission in Figure 3 Furthermore, for both DATA frames to be successfully delivered, the corresponding ACK transmissions should not interfere with each other either. In the case of ACK transmission, the roles of transmitter and receiver are switched, as shown in Figure 3. Therefore, to prevent collisions between the two ACK frames, the current receiver should be out of the interference range of the scheduled transmitter, and the scheduled receiver should be out of the interference range of the concurrent transmitter.

In Figure 3 d_{AD} is the distance between the scheduled transmitter and the current receiver, d_{BC} is the distance between the current transmitter and the scheduled receiver. These can easily be computed from the coordinates of these nodes. R_B and R_D are the interference ranges of the current receiver and the scheduled receiver, respectively. If $d_{AD} > R_B$ and $d_{BC} > R_D$ then exposed terminal C and D can successfully execute scheduled transmission which should not interfere with the current transmission, and it should not be corrupted by the current transmission.

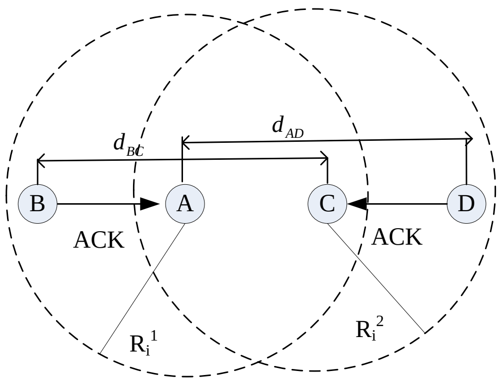

FIGURE 3 Transmitting ACK Frame when Concurrent Transmission

4 Simulation results

In this section, the performance of the proposed MAC protocol is evaluated via simulations and compared with S-AMC. Together with overhearing avoidance and message passing, S-MAC obtains significant energy savings compared with IEEE 802.11-like protocols without sleeping. In the simulation we take into account throughput and delay of the network. We suppose that each node has data frame to be constantly sent, i.e. the system is saturated.

In our work, we simulate network throughput and transmission delay by changing the network load. Firstly, we randomly distributed five scenarios with different number nodes without loss of generality in the network. We consider a 1000m*1000m area, and put sink node in the centre of network region. Simulation parameter settings are as follows:

TABLE 1 Simulation Parameter Settings

Parameter statement	**value**	**Parameter statement**	**value**
Data frame length	1024bytes	Channel rate	1MB/s
MAC heads length	224bits	SIFS interval	10us
ACK frame length	304bits	DIFS frame interval	50us
RTS frame length	352bits	Minimum contention window	31
CTS frame length	304bits	Maximum contention window	1023
PHY frame length	192bits	Slot length	20us

Figure 4 shows the analysis of end-to-end throughput with five different scenarios. We can see that with increasing the number of nodes in the network, the proposed MAC achieve the more chance for parallel transmission of exposed terminal and the end to end throughput increase too. However, due to S-MAC with carrier sensing mechanism prevents nodes from the parallel transmission, so only one of them can access the channel at any time. As shown in Fig.4, there is not much change in the average throughput of S-MAC. Experimental results show that compared with S-MAC, the throughput of the proposed protocol has significantly improved. Therefore, the proposed protocol can better solve the traditional problem of low throughput of MAC protocol.

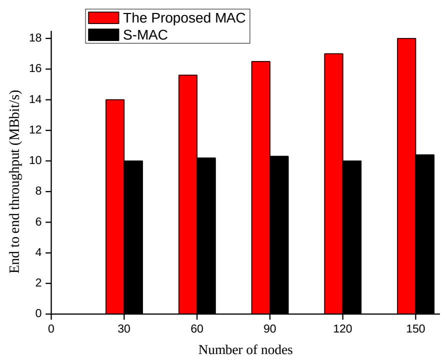

FIGURE 4 The analysis of end to end throughput with five different scenarios

Figure 5 shows the end-to-end delay with five different scenarios. We can see there is only one effective link for transmission of S-MAC, with increasing the number of nodes in the network, channel competition becomes fierce. S-MAC can get the channel after times of group competition, meanwhile, the networks increase the number of accumulated packets the conflicts increase as well, which led high retransmission rate, and packet transmission delay is in high state. Adopting the proposed MAC, exposed terminals can transmit concurrently so the end to end delay can be decreased largely. We find in

Figure 5 that the ratios of the end-to-end delay with he proposed protocol to that with the S-MAC are 64.28%, 60.6%, 70%, 80% and 78.57%.The proposed MAC works well in multi-hop wireless networks.

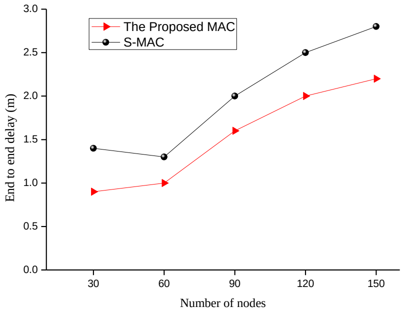

FIGURE 5 The analysis of end to end delay with five different scenarios

Secondly, the simulation study is performed with the chain network topology, where the distance between any two adjacent nodes is set to 200m. In the simulation, the forward flow (from Node 1 to Node N) is a constant-bit-rate (CBR) session with a stream of 1000-byte frames, whereas the backward flow (from Node N to Node 1) is a CBR session with a smaller packet size.

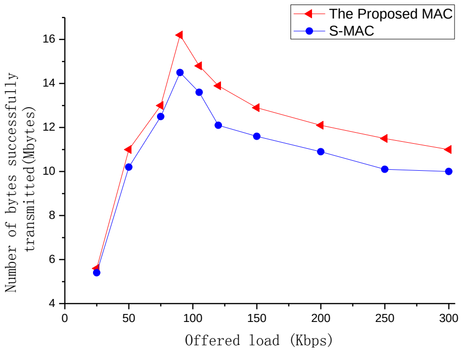

FIGURE 6 Throughput versus with offered load

We first plot the throughput versus offered load for an ten node chain network in Figure 6. For both schemes, we find that the throughput first increases with offered load in the under load region, due to the more data available for transmission. In the overload region, however, the throughput decreases with offered load due to congestion. We find that both MACs achieve the largest throughput when offered load is 90 kb/s.

Figure 7 shows the simulation results for chain networks with various packet sizes for the backward flow. Here, the data rates of the flows for the 8-, 10- ,12- ,14-, 16-node chain networks are set to 100kb/s, 90kb/s, 80kb/s, 70kb/s and 55kb/s, respectively. For the 8-,10-,12-,14-,16-node chain networks, the normalized improvements achieved by the proposed scheme are found to be 56.78%, 32.13%, 37.26% and 39.67%, respectively. When the packet size of the backward flow is reduced, the improvement ratio tends to be smaller. For example, when the packet size of the backward flow is 550 bytes, the throughput improvement ratio ranges from 26.35% to 63.47% for chain networks with increasing number of nodes. When the packet size of the backward flow is 300 bytes, the throughput improvement ratio ranges from 15.28% to 58.39% for the chain networks.

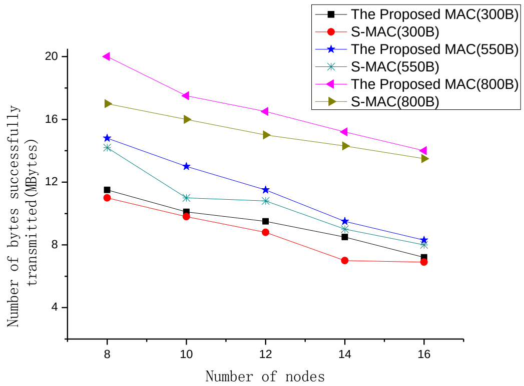

FIGURE 7 Throughput versus various packet sizes for backward flow

In Figure 8, we observe significantly reduced average end-to-end delays when the proposed MAC is used. Significant delay improvement is also achieved for other chain networks we examined, when the packet size of the backward flow is equal to 800 bytes for the 8-, 10-, 12-, 14- and 16-node networks, respectively.

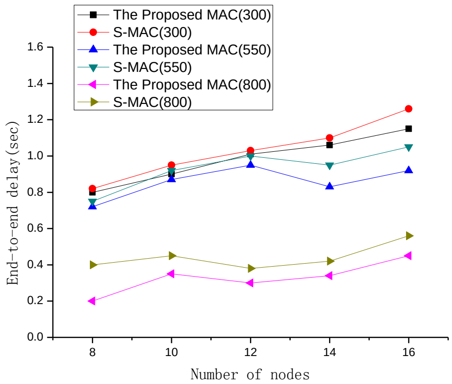

FIGURE 8 End-to-end delay versus various packet sizes for backward Flow

5 Conclusions

In wireless sensor network environment, it has been shown that traditional CSMA media access control suffers from a low-throughput problem, which is largely due to the inefficiency in carrier sensing and spatial reuse. In this paper, we present a location-assisted MAC protocol that schedules "feasible" concurrent transmissions in wireless sensor network. A simple procedure based on location information is adopted in the proposed MAC to validate the feasibility of a concurrent transmission. Our simulation results show that the proposed scheme can effectively increase the throughput and reduce the average end-to-end delay of wireless sensor networks.

Acknowledgments

This work is supported by Natural Science Foundation of Heilongjiang Province (F201104), Heilongjiang Province Education Department Foundation (12521416) and the Innovation Foundation of Harbin Bureau of Science and Technology (2011RFDXG005).

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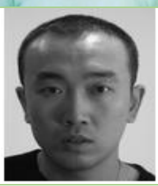

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