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Simulation of Hybrid MAC Protocol Design for WSN

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Abstract: With the rapid proliferation of mobile wireless sensors networks (WSNs), which are widely deployed in the Internet of things, the Internet of vehicles, and flying ad hoc networks, more and more researchers are making the effort to improve energy efficiency and throughput of WSNs. In recent years, many protocols have been proposed to solve the energy shortage problem. Some of the protocols are based on cooperative or allocation schemes, some are based on contending schemes, and others are based on the foundation of hybrid schemes. However, it is still difficult to improve the energy efficiency and networks throughput simultaneously.. Compared to existing protocols, the proposed protocol can efficiently reduce the energy consumption and significantly improve the throughput, especially for high-speed mobile WSN in the many-to-one communication paradigm. Extensive simulation results prove the performance of the protocol.

Keywords: Energy Efficiency, Hybrid Protocol, Medium Access Control (MAC) Layer, WSN.

I. INTRODUCTION

As an attractive research topic, wireless sensor networks (WSN) have broaden its application areas in wireless ad hoc networks (WANET), the Internet of things (IoT), the Internet of vehicles (IoV), flying ad hoc networks (FANET), body area networks and many other networks systems. However, the energy efficiency of WSN still needs to be improved without the negative influence on other performance like networks throughput. It would be better if both of energy efficiency and network throughput are improved. Medium access control (MAC) protocol has been targeted to overcome the problem, for it plays a significantly important role in energy management of nodes in WSN. Many contention MAC protocols are proposed for WSN to enhance the performance [1], most of which are based on carrier sense multiple access/collision avoidance (CSMA/CA) scheme. However, these protocols are designed for small-scale networks with less than 100 sensor nodes. In large-scale networks with more than 100 sensor nodes, the contention-based MAC protocols lead to a high collision rate [2]. Meanwhile, some other allocation and cooperation based protocols, such as presented in [3], are proposed on the foundation of time division multiple access (TDMA) scheme which can actually solve the collision problem in large-scale networks. But in small-scale networks, these protocols lead to a waste of slot resource and a decrease on throughput.

In addition, there are some cross-layer orhybrid protocols designed to improve the energy efficiency combining the advantages of both contention and allocation protocols [4-5]. Unfortunately, these protocols mainly focus on improving the performance of static WSN instead of mobile WSN [6]. In this letter, we design a CSMA/CA and TDMA based hybrid MAC layer protocol (CTh-MAC) for three-dimensional (3D) mobile WSN to improve the energy efficiency. The features of CTh-MAC are summarized as follows: a. First, we allocate all nodes into several subsets in a novel method depend on the transmission distance from sensor nodes to sink node. In addition, we utilize position prediction in the subsets allocation. b. Second, all subsets transmit data with sink node in TDMA scheme with the fixed time slot. In each subset, all sensor nodes contending for transmission based on CSMA/CA scheme. c. Finally, we present the details of slots allocation for the protocol in both TDMA and CSMA/CA scheme. Simulation results show that the proposed protocol presents a desirable performance in energy efficiency and network throughput.

II. DESCRIPTION OF THE PROTOCOL

Assumptions The assumptions of the network system for proposed protocol are described as follows. 1) The network is many-to-one communication paradigm, which means a sink node takes charge of multiple sensor nodes' transmission tasks in WSN. The transmission range of sink node is R. All the sensor nodes have an equal transmission range, which is represented as

A. Protocol details

The proposed protocol is a CSMA/CA-TDMA hybrid one with two schemes. One is the sink node allocates time slots to every subset for communication based on TDMA scheme. The other is all nodes of a same subset contending for transmission opportunity in the allocated slot of its own subset based on CSMA/CA scheme. The processing steps of the two schemes in CTh-MAC are presented in the following. The TDMA scheme is presented as shown in Fig.3. The main function of this scheme is dividing subsets and allocating time slots to every subset for communications. The up arrow means waking up of the nodes and down arrow means the nodes become sleep. At first, the sink node broadcasts a wake up frame to all nodes according to its transmission range. After that, the sink node broadcasts a preamble includes its coordinate and the value of m . Then, all of the sensor nodes send an information acknowledgement (IACK) to the sink node. The IACK of one sensor node (we assume it is node i) includes the following information, All nodes transmit IACK in TDMA scheme subset by subset and node by node. After that, the data transmissions begin in TDMA scheme. The first one that communicates with sink node is the subset m, which is the outermost subset. Meanwhile, other subsets start the relay mode, in which all sensor nodes stay in sleep mode except their receiving devices. As soon as a sensor node receives data from outer nodes, it wakes up and relays the data to inner nodes. In this way, not only the energy efficiency is improved, but also can relay transmission from outer subsets to the sink node. As shown in Fig.3, the data transmission order of subsets is from outside one to inside one. As thus, energy can be saved since the outer sensor nodes have less time to be relay node and they can stay in total sleep more than inner nodes.

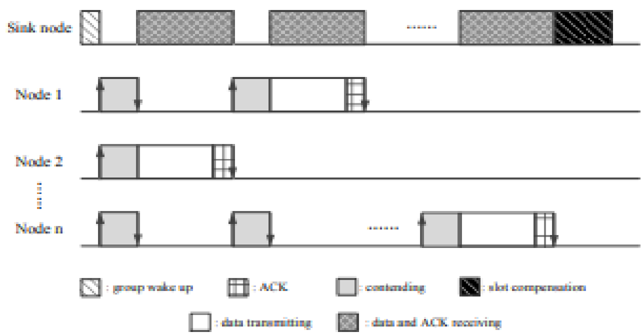

Fig.1. The time slot allocation of TDMA-based scheme in the proposed protocol.

In addition, the time slots allocated to each subset are in same length. For instance, the nodes in subset m start their data transmission with sink node. At the same time, other subsets are in relay mode help sensor nodes transmitting data to sink node, because the transmission range of sensor nodes is much less than that of sink node. When subset m finishes data transmission, all nodes switch to sleep mode. Then the data transmission slot of subset 1–m comes. All nodes in subset 1 to m-2 are in relay mode. This transmission processing repeats until subset 1 finishes the transmission. Finally, the TDMA scheme transmission is finish. The details of subset transmission are described in following based on CSMA/CA scheme.

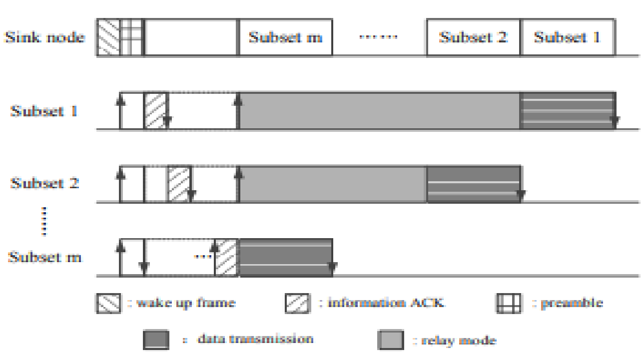

Fig. 2. The time slot allocation of contending-based scheme in the proposed protocol for subsets internal transmission.

In each subset transmission slot, all nodes in the subset contend for the transmission with the sink node based on CSMA/CA scheme. The details of slots allocation in a subset transmission slot are shown in Fig.4. At the beginning of the slot, the sink node sends a group wake up beacon to activate all sensor nodes in the subset. For different subsets, beyond assuring successful transmission As shown in Fig.4, we assume the node 2 wins and sends data to sink node. If it cannot transmit to sink node directly, the nodes in inner subsets will help to transmit as relay nodes. When node 2 is in the data transmission period, to save energy, other nodes turn off except monitoring the channel. As soon as node 2 finishes the transmission with an acknowledgement (ACK), other nodes start to contend again for the transmission. In a similar way, we assume node 1 wins in the contending for transmission. When a node completes the transmission, it switches to sleep mode. Because the time slots for every subset is equal and fixed, at the end of each subset slot, there is a slot compensation frame to fill the time.

III. ANALYSIS OF THE PROFORMANCE

First of all, we analyze the performance of the proposed protocol based on the following assumptions: The sensor nodes are randomly deployed in a area around the sink node whose transmission. The data arrival probability fits the Poisson distribution. The retransmission data packets are assumed as truncated Poisson process. Then, for a specific sensor node i SN , the probability that it has data packet to transmit is P_{ti}. Therefore, the probability that the j^{th} $(1 \le j \le m)$ subset j S has data packet to transmit is obtained as

$$P_{tj} = n_{sj} P_{ti} (1 - P_{ti})^{n_{sj} - 1} \quad (1)$$

where the number of sensor nodes in the jth subset. In the proposed protocol, we define Lj as the length of data packets which are transmitted in the jth subset. Also, Tslot represents the time for every subset transmission. As a result, the throughput is obtained as

$$E_{sj} = E_{contj} + E_{trj} + E_{ACKj} + E_{wj} \quad (2)$$

where E_{contj} , E_{trj} , E_{ACKj} and E_{wj} are denoted as the energy consumption of contending, data transmitting, IACK and waking up in the jth subset, respectively. As a result

$$E_{sT} = \sum_{j=1}^{m} E_{sj} = \sum_{j=1}^{m} (E_{contj} + E_{trj} + E_{ACKj} + E_{wj}) \quad (3)$$

In addition, ErT is the total energy consumed on relay transmission of all subsets which is expressed as

$$E_{rT} = \sum_{j=2}^{m} \sum_{k=1}^{j-1} E_{rk} \quad (4)$$

IV. SIMULATION

The CTh-MAC, we use NS-2 to simulate and com- pare the performance of hybrid TDMA/CSMA MAC protocol (HTC- MAC), low delay cross-layer MAC protocol (LDCMAC), and CTh- MAC, in terms of their energy consumption and throughput. For com- paring in details, we vary the number and the speed of sensor nodes in the simulations. The values of parameters, which are used in the simulations, are given in Table 1. The network throughput and energy consumption versus the number of nodes and the average speed of nodes are shown in this section, respectively. When the number of nodes is varying, the average speed is set at 120 km/h. On the other hand, when the average is varying, the number of nodes in the network is fixed at 150. The values of average speed, which we select, are 60, 120, 180, 240, and 300 km/h.To evaluate the performance the SMAC and LDAMAC protocol and compared the simulation results using the NS-2 simulator.

Table1. Simulation Parameters

Parameter	Value
Network Simulator	NS (v2.35)
Size of physical Topology	1000 m * 1000 m
Number of Nodes	10, 15, 20, 25, 30
Data Rate	1 Mbps
Interface Queue Length	50 packet
MAC	SMAC, LDAMAC
Transport Layer Protocol	TCP Packet Size 1200 Bytes
Traffic	CBR Packet Interval 0.005, Size 1100 Bytes
Channel	Frequency 2.5 Ghz Data Rate: 11 Mbps
Simulation Time	8 sec

simulation parameters In this section we are going to show the simulation results at different conditions By varying number of nodes Parameters under consideration are

A. Average end to end delay

Average end-to-end delay is the total delay from the time application at the sender side generates a packet to the time the application at the receiver side receives it. It includes all types of delays that occur during transmission like transmission delay, propagation delay and any queuing delays.

B. Packet delivery ratio

Packet Delivery Ratio (PDR) is the ratio between the number of packets transmitted by a traffic source and the number of packets received by a traffic sink It represents the maximum throughput that the network can achieve. A high packet delivery ratio is desired inPacket

$$\text{Delivery Fraction: } \frac{\text{Receivedpackets}}{\text{Sentpackets}} \times 100$$

C. Throughput

Throughput is the amount of data transferred over the period of time expressedin kilobits per second (Kbps).or Throughput is the total packets successfully delivered to individual destinations over total time.

D. Overhead

Number of additional control packets. simulation results obtained by varying number of nodes In the first set of the simulations, the numbers of sensor nodes are varied in the wireless sensor network. Here to analyse performance of network based on node density on the protocols. The no. of sensor nodes is gradually increased in the WSN and takes values for corresponding nodes 10,15,20,25 and 30.The mobility speed has the 10 m/s, and the packet rate no. of connections are fixed at 5.Other parameters remain fixed for the evaluation of the SMAC and LDAMAC protocols for WLAN. sensor networks (WAN).

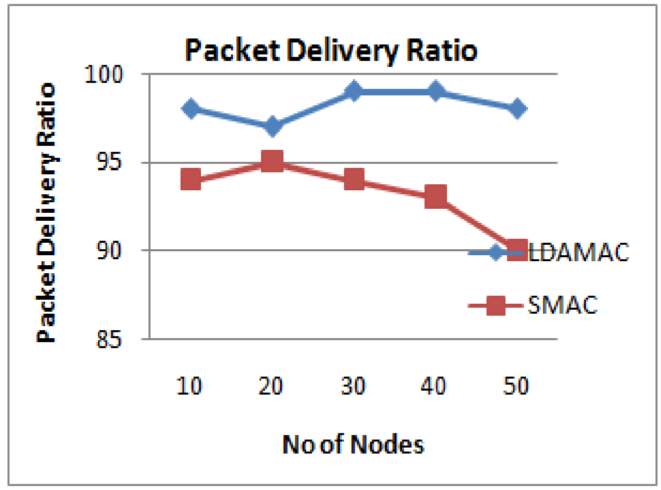

Fig.3.

In the above graph as the number of nodes are increased then packet delivery ratio is almost constant because the number of connections are fixed. Packet delivery fraction is almost constant. LDAMAC has high packet delivery ratio compared with SMAC.

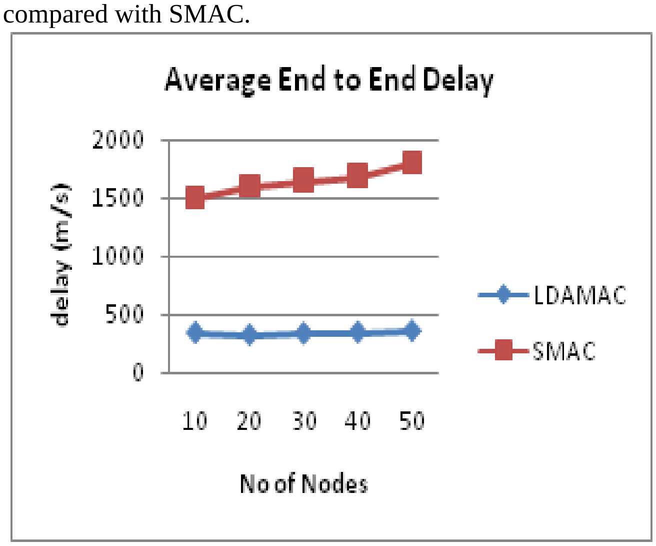

Fig4. Average End to End Delay Vs Number of Nodes.

In the above graph as the numbers of connections are fixed nodes are increasing then the control packets are increased, and control packets given the highest priority when compared with data packets so delay increases. LDAMAC protocol has a lesser amount of delay compared with SMAC.

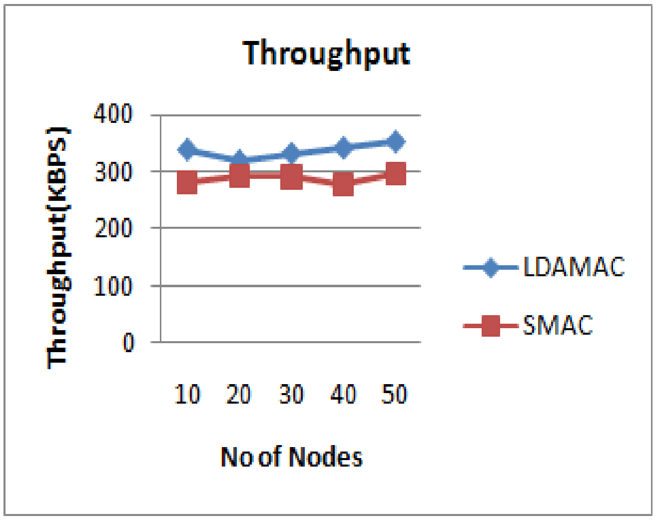

Fig5. Throughput Vs Number of Nodes.

In the above graph as the no. of nodes is increased but the number of sources is fixed so, Throughput is almost constant with respect to the number of nodes LDAMAC has high Throughput compared with SMAC.

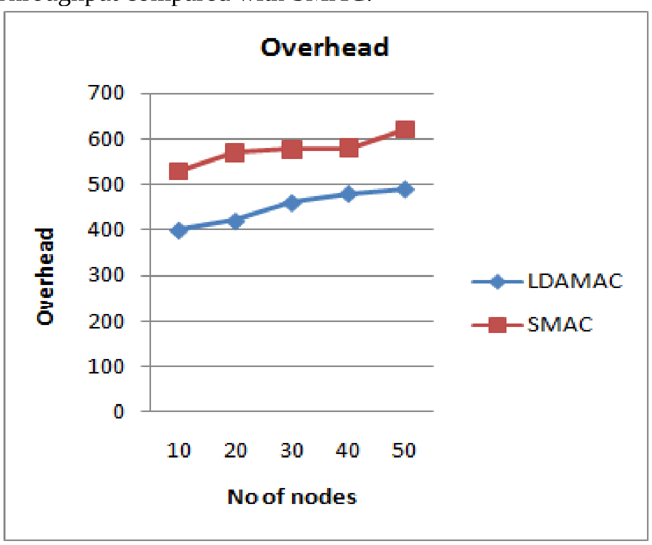

Fig6. Overhead Vs Number of Nodes.

In the Above graph as the number of sources is fixed Nodes are varied so as the number of nodes increases control packets increase so overhead increases. LDAMAC has almost equal overhead when compared with SMAC. It is clear that the throughput increases with the increasing of the number of nodes and average speed. Among the three protocols in the simulations, the CTh-MAC has the best performance. When the number of nodes is small (less than 150), the throughput values of them are almost the same. However, when the network is in large scale, the proposed protocol shows its ad- vantage with 12% and 15% more throughput than the HTC-MAC and the LDMAC due to the subset design. The proposed transmission scheme can efficiently utilize the time slot subset-by-subset. It can also reduce the pressure of contending in the internal subset, compared to the whole nodes' contending in the networks, because the number of nodes in subset is much less than the total number of the networks. In Fig. 5(b), the CTh-MAC shows its superiority in high-speed mobile transmission because of the position prediction algorithm. With the increase in speed, the throughput decrease of the CTh-MAC is much less than the other two protocols. It has as much as 20% and 25% more throughput than the LDMAC and the HTC-MAC, respectively.

The simulation results of consumed energy versus the number of nodes and average speed. It is obvious that more nodes or the higher speed lead to higher energy consumption in the network. Compared with the other two protocols, the CTh-MAC saves more energy, especially in a large-scale network with 200 or more sensor nodes. The main reason for energy saving is the hybrid scheme makes full use of slot and sensor nodes can sleep when they do not have transmission task. Also, the subset division design can re- duce the collisions and retransmission, resulting in energy saving. In high-speed mobile transmission (more than 180 km/h), the proposed protocol is obviously superior to the HTC-MAC and LDCMAC. The position prediction part of CTh-MAC efficiently reduces the probability of out-synchronous transmission and collision; thereby, the energy consumed on retransmission and slot allocation decreases. The CTh-MAC reduces as much as 30% and 35% energy consumption than LDCMAC and HTC-MAC in the high-speed mobile transmission model.

V. CONCLUSION

In this article, we propose a MAC layer protocol based on a CSMA/TDMA hybrid transmission scheme for mobile WSN. We divide the sensor nodes into subsets for efficient transmission and design the transmission slot in the protocol. The main contribution of CTh-MAC is reducing the energy consumption in high-speed mo- bile transmission model. In addition, we improve the throughput of the networks compared with the LDCMAC and HTC-MAC. According to the simulation results, the CTh-MAC efficiently improves the throughput and reduces the energy consumption in mobile WSNs.

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