ISSN: 0976-3031

Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 9, Issue, 10(B), pp. 29131-29134, October, 2018

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

RESEARCH AND IMPLEMENTATION OF A HYBRID MAC PROTOCOL FOR WIRELESS SENSOR NETWORKS BASED ON CLUSTERING STRUCTURE

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DOI: http://dx.doi.org/10.24327/ijrsr.2018.0910.2798

ARTICLE INFO

Article History:
Received 6th July, 2018
Received in revised form 15th August, 2018
Accepted 12th September, 2018
Published online 28th October, 2018

Key Words:

WSN, MAC, Full random multiple access, TDMA

ABSTRACT

In this paper, a hybrid MAC protocol for wireless sensor networks with clustering structure is proposed. Full random multiple access is used within the cluster, and each node competes for the channel. The TDMA scheduling mechanism is adopted between the clusters, and the nodes transmit and receive data in respective time slots according to the pre-assigned time slot table, thereby implementing collision-free communication. The simulation is used to verify the correctness and performance of the protocol. The CC2530 node is used to build a real wireless sensor network. The protocol is designed based on Z-Stack, and the protocol is implemented on the hardware. The results show that the system using this protocol can operate correctly, and the throughput and average delay are in line with the theoretical values.

INTRODUCTION

Wireless sensor networks (WSNs) are widely used in various fields, and the MAC protocol is a research hotspot[1]. Many researchers have proposed a number of MAC protocols for different wireless sensor network applications. Contention-based MAC protocols include S-MAC [2], T-MAC [3], B-MAC [4], etc. The schedule-based MAC is mainly Time Division Multiple Access (TDMA), which is periodically allocated to each node for one time slot for data reception and transmission, and other nodes can enter sleep at this time, thereby saving energy [2]. The Z-MAC [5] protocol is a hybrid protocol combining TDMA and Carrier Sense Multiple Access (CSMA) to access time slots according to priority. It pre-allocates a different time slot to each node in the two-hop neighbor, and controls the node's access to the time slot according to different contention control conditions according to different contention conditions [6]. Later scholars have more improved protocols, but basically they use simulation software for verification, and they are not really used in wireless sensor networks. In this paper, a hybrid MAC protocol is proposed for clustered hierarchical network structure. The full random access method is adopted in the cluster, and each sub-node randomly accesses the channel. The TDMA mechanism is adopted between the clusters, and the sink node allocates a time slot to each node according to the preset time slot table[7], and each cluster transmits and receives data without conflict in a fixed time slot. On the basis of simulation, a real wireless sensor network was built using CC2530 nodes, and the actual test was carried out.

Network Topology

The hybrid MAC protocol proposed in this paper is applicable to hierarchical network structure with uniform clustering, as shown in Figure 1. Each node contains the same number of nodes below, and the model in this paper is five child nodes. The sink node and its five child nodes form a first-level cluster, the sink node is a first-level cluster head, and the second-level cluster head and the common node form a second-level cluster. The sink node is the initiator and maintainer of the entire network, and is responsible for receiving and processing the messages of the secondary cluster head. The secondary cluster head has the function of routing and data fusion, and listens to the data sent by the receiving child node, performs corresponding data processing, and then forwards the data to the sink node. The ordinary node is responsible for data collection, and under the control of the cluster head, it alternates under the working state of sleep, transmission, and the like.

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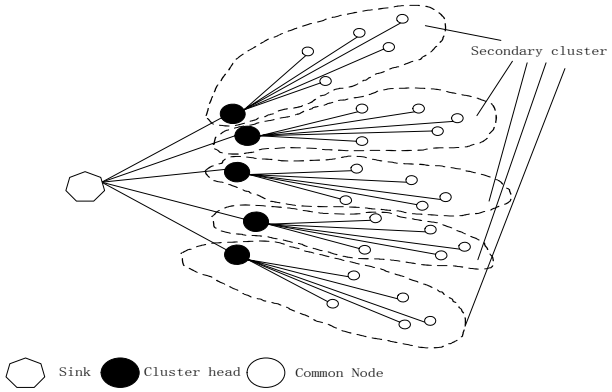

Figure 1 Uniformly clustered hierarchical network structure

Implementation of hybrid MAC protocol

The protocol described herein combines full random multiple access and TDMA. Full random multiple access is used in the cluster, and each sub-node randomly preempts the channel and transmits data. The TDMA mechanism is used in the cluster to allocate one time slot for each cluster head, and each cluster head transmits data to the sink node in a fixed time slot, thereby avoiding conflicts.

Full random multiple access

The fully random multiple access protocol system is shown in Figure 2. Each terminal node of the system randomly transmits data packets at the beginning of each time slot, and the node has two states: transmitting and not transmitting. If two terminal nodes simultaneously send packets in the same time slot, then the two packets are collision will occur and the receiver will not receive the message. When only one terminal node in this time slot transmits data, the receiver can correctly receive the packet. If no terminal node sends a packet in the current time slot, the time slot is idle.

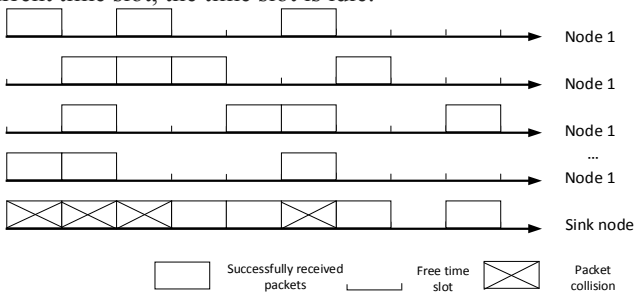

Figure 2 Full random multiple access

The throughput theoretical expression of full slotted random multiple access can be expressed as $S = Ge^{-G}$, where S represents throughput, $G=Np$, G represents the arrival rate of the information packet, N is the number of terminal nodes, and p is the probability that the terminal node transmits the data packet. Deriving the derivative on both sides of the equation, $S' = e^{-G} - Ge^{-G} = (1-G)e^{-G}$ When G = 1, the maximum throughput is obtained $1/e$, that is 0.368. Figure 3 shows the throughput of the number of terminal nodes being 5.

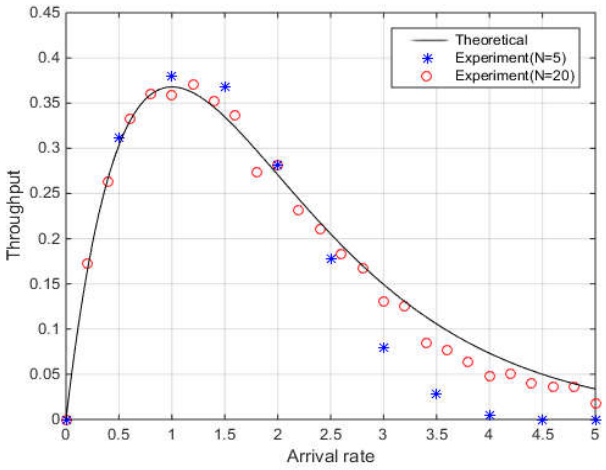

Figure 3 throughput simulation at N=5 and N=20

It can be seen from the figure that the theoretical maximum throughput of the fully random multiple access protocol is 0.368. When the number of terminal nodes is 5, the simulated throughput curve and the theoretical curve have errors, and the error is caused by the small number of nodes. As the number of nodes increases, the simulated value will gradually approach the theoretical value.

TDMA

The basic principle of TDMA is to divide time by period, and each time frame is divided into several time slots, and these time slots are allocated to nodes according to a certain allocation principle, so that each node transmits in a fixed time slot in one time frame. The data sent by each node does not interfere with each other. On the receiving side, since each node transmits data in a certain order, as long as it is received in the same time slot, the data of each node can be correctly received. Figure 4 shows a sequence diagram of the time frame of TDMA. In each time frame, as time progresses, each node transmits data according to a pre-allocated time slot, and at most one node in each time slot is transmitting data.

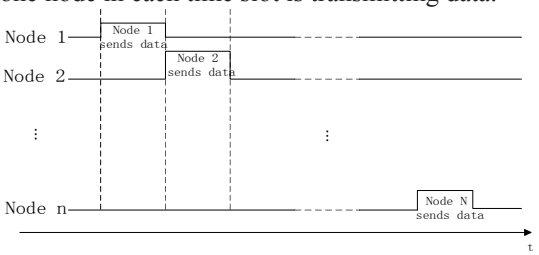

Figure 4 Wireless sensor node TDMA timing diagram

For the clustered sensor network of this paper, the TDMA mechanism is applied to the communication between the cluster head and the sink node. The strategy for the cluster head to forward packets depends on the status of the received packets. When only one packet of the terminal is received in one cycle, it is forwarded. In other cases, it is considered to be a collision or the terminal does not send data. That is, the arrival rate of the cluster head information packet is the throughput within the cluster.

Implementation of the Experiment

Experiment with 31 cc2530 nodes, modify the relevant parameters of the protocol stack, and build a two-level clustering topology. The 25 common nodes are numbered A-Y.

The five nodes are cluster heads, numbered 2-6. Node 2 is connected to the computer through the serial port. One node acts as a sink node and is connected to the computer through the serial port. Press the button and the entire network starts working. It can be seen that the serial output of node 2 is "A0B1D0C1E0", which means that the three nodes of ADE do not send data, and the BC node sends data. Each output is random. The sink node outputs periodically according to the preset time slot table 2→3→4→5→6. The 0 after the number indicates that no data has been received, and 1 indicates that the data has been received.

Data Processing and Performance Analysis

The experimental data analysis method in this paper is to use the python program to read the serial output of the router and the coordinator separately and store them as two text files. After the corresponding processing, the throughput and average delay of the system can be calculated. The experimental values of the throughput and average delay of the system are calculated as follows:

$$\text{Throughput experiment value} = \frac{\text{number of successfully received information packets}}{\text{total time slot length}}$$

$$\text{Average delay} = \frac{\text{total time slot length}}{\text{number of successfully received information packets}}$$

The theoretical formula for the average delay is $T = 1/S$, where T is the average delay and S is the throughput. The actual throughput of intra-cluster communication is shown in Figure 6.

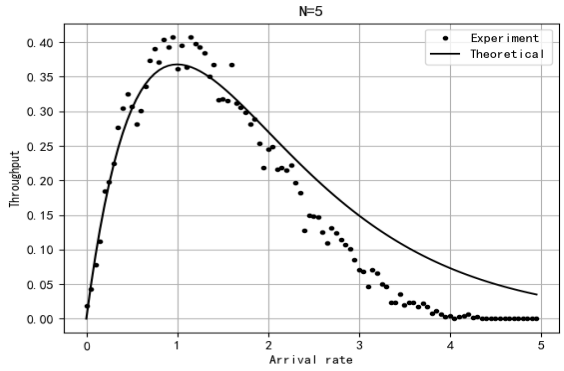

Figure 6 Actual throughput of intra-cluster communication

As can be seen from the figure, when the arrival rate is 1, that is, when the terminal transmits a data packet with a probability of 0.2, the throughput of the system reaches the maximum, and the maximum value is 0.407. Compared with the theoretical value line, there is an error, which is acceptable considering the interference during the actual transmission and other hardware reasons.

Table 1 System average delay theoretical, simulation and experimental value

ArrivalRate	Theoretical	Simulation	Experimental
0.2	2.7697	2.4038	2.3923
0.25	2.7193	2.3641	2.4875
0.5	3.0043	3.0120	3.3557
0.7	3.2716	3.3557	3.5087
1	3.4211	4.0984	4.0485
1.25	3.3470	3.5842	3.9682
1.5	3.1854	3.1546	3.0487
1.75	3.0086	2.8409	2.6666
2.16	2.7898	2.3641	2.4691
2.25	2.7604	2.5000	2.4154
2.5	2.7192	2.5707	2.6954

It can be seen from the table that the average delay of the hybrid clustered MAC protocol implemented in this paper has some errors between the simulated values and the experimental values and the theory, but both fluctuate around the theoretical value. When the arrival rates are 0.25 and 2.16, The average delay of the system is the smallest. At this time, the system has the largest throughput and the best transmission performance. To reduce the error can be achieved by increasing the number of nodes and the number of information packets, but the collection of experimental data required takes longer.

CONCLUSION

In view of the current research on the wireless sensor network MAC protocol, most of them stay in the software simulation stage. This paper chooses a simpler full random multiple access, and combines TDMA to design a hybrid MAC protocol, which is applied to real sensors. In the network. The results show that this application method can correctly implement the protocol, and the performance index is basically consistent with the theory, which lays a foundation for the hardware implementation of more complex protocols in the future.

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How to cite this article:

Fazhi Dong *et al*., 2018, Research And Implementation of A Hybrid Mac Protocol For Wireless Sensor Networks Based On Clustering Structure. *Int J Recent Sci Res.* 9(10), pp. 29131-29134. DOI: http://dx.doi.org/10.24327/ijrsr.2018.0910.2798

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