Energy Efficient S-MAC Protocol Using Sleep Scheduling Algorithm

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Abstract-An analytic model to evaluate the energy consumption of sensor-medium access control (S-MAC) protocol, one of the well-known MAC protocols for wireless sensor networks (WSNs), are based on the network model using sleep scheduling algorithm As we know, energy efficient Medium Access Control (MAC) protocol is critical for the performance of a Wireless Sensor Network (WSN), especially in terms of energy consumption. Here by discussing the efficiency of S-MAC, a well-known MAC protocol for WSNs, and propose an improvement on the protocol. The current classical protocol of WSN media access control, uses the sleeping/schedule mechanism to reduce the energy lose on the nodes effectively, but at the same time, it also bring time delay problem, and when the system overloaded, it works with low efficient and high time-delay. In this article, we optimize the protocol from two sides: firstly, according to the size of the node load to setting priority. Secondly, in order to reduce the time competition in the channel, By using a sleep schedule technique, S-MAC can reduce the energy consumption in a wireless sensor network by breaking the network into a virtual cluster. This paper aims to investigate energy consumption factors for the wireless sensors networks (WSNs) in terms of the average node number, trade off factor and the packet delivery ratio.

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I. INTRODUCTION

WSNs have met a huge growth and have significant future prospects of evolution, meeting applications from medical, environmental surveillance, robotics, military, smart vehicles and domestic areas. The main reasons for this growth are the high fault tolerance, fast deployment and self-organizing capabilities of WSNs, as well as their low cost and high density of deployment, which does not affect the functionality of the application when sensor nodes fail or are destroyed. WSNs consist of tens to thousands of distributed autonomous nodes, which form a wireless multi hop network and are placed near or inside the area of interest. Each node contains the sensor or sensors unit, a digital-to-analog converter, a processor, a low consumption transceiver and a power supplier [1] Wireless Sensor Networks (WSNs) are known as very limited capacity ad hoc networks, where a node is composed of a low-computation CPU, a low power transmitter, and limited battery energy. Energy of each node is significantly spent for running a circuit for computation and for transmitting data. Therefore, WSNs are normally working together as a large group that consists of hundreds or thousands of nodes in order to minimize the energy used for computation and transmission. To further reduce the energy usage, nodes are divided into clusters. Only nodes in a cluster "wake up" at the same time to convey information while other nodes "sleep" to save energy. Normally, while waking up, a node spends more energy than while sleeping. However, the number of clusters becomes an issue of energy saving. In a large cluster, a great number of nodes would wake up, and this would cause many nodes spend energy while waking up. However, with a large number of nodes, transmission range can be short or more effective, and this would reduce the energy for transmission. An efficient MAC protocol for WSNs should give priority to the reduction of the nodes' energy consumption, thus prolonging network lifetime.[4] To accomplish that, a MAC protocol must reduce collisions, overhearing, control packet overhead and idle listening.

II. MAC PROTOCOLS FOR WSNs

MAC protocols for WSNs provide primarily energy conservation, and secondly quality of sensors and fair bandwidth allocation. Classic demand-based MAC schemes are inappropriate for WSNs because of their large overhead and the significant start uptime of the links. A common solution is the use of power-save modes and time-outs instead of acknowledgments; however these solutions increase delays and reduce channel throughput. The most well-known MAC protocols for WSNs can be divided in two main categories:

a. Contention or Demand-based
b. TDMA/FDMA-based.

A major representative protocol of the first category is DCF (Distributed Coordinated Function) [3] of the IEEE 802.11. It is based on the MACAW [4] project and is well-suited especially for ad-hoc networks because of its simplicity and robustness. However, it does not succeed in the area of energy conservation. TDMA and FDMA-based MAC protocols have the inherent advantage of the low duty cycle of the transceiver and the absence of collisions between neighboring nodes. Still, TDMA forces nodes to form clusters, thus introducing complexity as inter clustering communication is not an easy task

III. S-MAC

S-MAC or Sensor-MAC is a well-known medium access control protocol for WSNs [1]. Basically, it is designed to reduce the sensor node energy consumption and to extend the network lifetime by reducing the number of events that could waste energy by pressing nodes to sleep without any loss of data from transmission. Important design features for medium access control protocols in a WSN are:

- **Energy:** Each node is nominally battery operated. Energy efficiency is a critical issue in order to prolong the network lifetime, because it is often not feasible to replace or recharge batteries for sensor nodes. In particular, MAC protocols must minimize the radio energy costs in sensor nodes.
- **Latency:** The latency requirements depend on the applications or network systems. In the case of a network monitoring system, an event detected needs to be reported to a sink in real time, so that appropriate action can be taken promptly
- **Throughput:** The throughput requirements also vary with the application or network system. For example, applications for measuring the variation of temperature need to be designed so that the sink node receives the messages from the nodes periodically. In other systems, such as fire detection systems, it may suffice for a single report to arrive at the sink.
- **Scalability:** Considering that sensors are movable, semor networks must allow for scalability in the sense that nodes may be added to the network or removed if their battery is entirely consumed.

Among these important requirements for MACs, energy efficiency is typically the prime goal in WSNs. Previous works IEEE 802.11 protocol identified idle listening as a major SOUlCe of energy wastage [1]. As the traffic load in many sensor network applications is very light most of the time, it is often desirable to off the radio when a node does not participate in any data delivery. Therefore, S-MAC [2] provides a tunable periodic active/sleep cycle for sensor nodes.

The common events in wireless networking that could waste the energy are :

- (i) *the collision of data packets*
- (ii) *the overhearing* – sensor nodes receive the packets belonging to other nodes,
- (iii) *the control packet overhead* – the overhead is used to control sensor node communication
- (iv) *the idle listening* – sensor nodes stay in idle, and no data packet is transmitted at this state. S-MAC assumes that WSNs are low traffic load networks.

Sensor nodes stay idle for a long time, and start transmitting a data packet when they have detected particular events from sensing. Therefore, the sensor nodes do not need to listen to a communication channel all the time. S-MAC introduced a sleep scheduling algorithm that sensor nodes sleep for most of the time and wake up only to send data and to synchronize with networks. Thus, one S-MAC cycle time was divided into a sleeping period and a wakeup period. The wakeup period consists of SYNC period, RTS/CTS period, and data transmission period. In every SYNC period, sensor nodes broadcast a SYNC packet to neighbor nodes. Nodes also use the receiving SYNC packets to synchronize with neighbor nodes in the network. The SYNC packet contains sender's next sleeping time which tells receiving nodes when the next transmission would take place for the next cycle. The RTS/CTS period was used to request for transmission and to response with a permission to transmit. Then, sensor nodes can send or receive data. The sleep schedule starts when sensor nodes are deployed to the workspace. Then every node keeps listening to the channel for a random time period from their neighboring nodes for a SYNC packet. If a sensor node does not receive any SYNC packet at the end of the period, it will generate a sleep schedule, and then broadcast the schedule within a SYNC packet. Sensor nodes receiving a SYNC packet during the listening period will use the sleep schedule attached in the SYNC packet. The node which generates a sleep schedule is known as *a synchronizer node*, while the node which uses the sleep schedule is called a *follower node*. The sleep schedule is randomly generated, depending on the first random listening period. Thus, there would be many sleep schedules, and they are later arranged into several virtual clusters, each of which has a different sleep schedule. In the case where a node receives more than one SYNC packet, the node will have more than one schedule and it is called a *border node*. This node has to be active in every schedule because it works as a joint between each virtual cluster. Being active, this node consumes more energy than the other two nodes—a synchronizer node and a follower node. The sleep schedule in S-MAC can reduce the network energy consumption by introducing a low duty cycle for each node. By using the sleep schedule, S-MAC can trade off the latency with the energy saving. However, S-MAC performance would be decreased when using it in a network that does not match with the S-MAC network assumption, for example, a quick response network with a high duty cycle such as an emergency response network or the first responder network. Thus, S-MAC still has such disadvantages such as large latency or uncontrollable sensing data delivery time.

IV. RELATED WORK

Lots of work has been done in the field and there were several solutions to the problem of energy wastage due to idle listening. In general, some kind of duty cycle was involved, with each node having active/sleep cycles. For example, TDMA-based protocols are naturally energy preserving, because they have a duty cycle built-in, and do not suffer from collisions [4]. However, maintaining a TDMA schedule ad-hoc networks was not an easy and require much complexity in the nodes. Keeping a list of neighbor's schedules takes valuable memory capacity. Allocating TDMA slots was a complex problem that requires coordination. Further more, as TDMA divides time into very small slots, the effect of clock drift can be disastrous; exact timing was critical. Another way of energy saving was to use an extra radio, so-called wake-up radio, which operates on a different frequency than the radio used for communication [5]. As the wake-up radio was only for waking up other nodes, it needs no data processing and therefore uses much less energy. However, it requires an extra component on node and it doesn't have a positive effect on the energy efficiency, because the wakeup radio consumes energy constantly. Therefore, most wireless sensor nodes currently used in research only have a single radio that operates on a single frequency.

S-MAC has been developed to minimize energy consumption as much as possible without any control of delivery time in a network. Using the sleep schedule induces the delay time to the network while the sleep delay proportionally increases to the number of data hops which was also proportionally increase to the number of clusters. The energy consumption model for S-MAC had been proposed to help the protocol designer [2]. From this model, we can estimate S-MAC network energy consumption in different parameters such as a duty cycle and a packet inter-arrival period. However, the large latency is still the biggest disadvantage of S-MAC.S-MAC algorithm has been improved to solve the latency problem. The adaptive sleeping algorithm was added to original S-MAC [3]. Its main idea was to wake up the node to receive the control overhead packet (RTS, CTS) to pass on to a next hop node. This algorithm can reduce the sleep delay time by increasing a number of nodes to hear the control overhead packet of approximately a half of nodes in a network. AC-MAC has been developed from the S-MAC concept with an algorithm to reduce the sleep delay time [4]. The difference is that AC-MAC can adapt the duty cycle according to the traffic load. AC-MAC uses the packet queue at the MAC layer to make a decision whether congestion occurs, and then adapts the duty cycle according to the decision. This method can save energy more efficiently than the S-MAC. Another MAC protocol, TEEM uses the adaptive duty cycle like AC-MAC, but TEEM has 2 different SYNC periods, one is when there is data to be sent and the other is when no data is to be sent [5]. This algorithm lets the sensor node sleep early if it is not part of the packet transmission path. Some studies extend the simulation to the real topology of sensor networks and proposed an algorithm to save even more energy [6][7]. The virtual cluster in the S-MAC network was a cause of the border node problem. The border node is active for every schedule it knows; thus, consuming more energy, and later becoming a dead border node. In a large WSN, there would be more border nodes; hence, the overall energy-efficient performance could then be degraded. Additionally, a black hole could occur when border nodes die. Global Schedule Algorithm (GSA) has been introduced to solve the border node problem [8]. GSA forces every node in the network to use the same sleep schedule. GSA uses the schedule age to specify which sleep schedule should exist in a network. The most age sleep schedule has been selected as the only one to be used in the network. Schedule Unifying Algorithm (SUA) also forces nodes to use a unique schedule, that is, SUA uses the schedule which is generated from the highest priority address synchronizer as a unique schedule in the network [9]. Another development scenario is applying S-MAC to a mobile sensor network such as MS-MAC [10], MMAC [11], and MOBMAC [12] that utilize in environments where sensor nodes are mobile.

V. SIMULATION WORK

In simulation, the S-MAC virtual clusters were randomly generated; depending on which sensor nodes win the contention of the channel, and broadcast the SYNC packet first. By estimated the transmission distance from the propagation model, and know the number of nodes receiving the packet for each transmission power level. If expected cluster size was large, then they had to increase the transmission power. There were seven transmission power levels each of which was calculated according to the propagation distance between each node in the network .By plotting the result versus the transmission power, they found the average node number increase when transmission power increases but not linearly. From the topology and the propagation model, the average node number was still lower than expected node number in transmission radius.

The adaptive sleeping S-MAC had an algorithm to prevent a cluster from having only one node inside. The sensor nodes can detect how many nodes use the same sleep schedule from the SYNC packet. If it was the only one which uses this schedule, it will abandon and adapt itself to use other SYNC schedules the other nodes use. From the simulation, this algorithm cannot work correctly. If sensor nodes generate the sleep schedule and broadcast the SYNC packet to neighboring nodes, this sensor node becomes a synchronizer while the neighboring node was a follower, which then broadcasts the SYNC packet to the synchronizer. However, this packet cannot reach the synchronizer because it was in sleep mode. Afterwards, the synchronizer wakes up and receives the packet from other neighboring nodes. That was, the synchronizer decides to abandon its schedule and use a new schedule packet from received SYNC packet. The old follower becomes the only one which uses the schedule and still understands it was not the only one in this schedule. The algorithm error could make the average node number lower than we expect. The result clearly shows that if we want a bigger cluster we should increase the transmission power. To study the effect of the virtual cluster size on the SMAC network performance, we propose a trade-off factor.

The trade-off factor (K) was calculated by means of average end-to-end delay time (l), average energy consumption (E) and a successful rate (S). If the network can completely pass the packet along the route, the route node should consume more energy since the packet is dropped at the queue buffer or when a collision occurs. Our assumption was the average energy consumption proportional to the successful rate.

$$E = S \quad (2)$$
$$E = K_1 S \quad (3)$$

Not only the successful rate but also the average energy consumption are inversely proportional to the average end to- end delay was calculated. If the S-MAC network can send packets from a source to a destination with low latency, the S-MAC network had to reduce the sleep time, which means the S-MAC network consumes more energy.

$$E = 1/l \quad (4)$$
$$E = K_2/l \quad (5)$$

Combining the effect of the average end-to-end delay and the successful rate by multiplying with some factor, then the trade-off factor as follows.

$$E_2 = KS/l \quad (6)$$
$$K = E/(S/l)_{1/2} \quad (7)$$

The trade-off factor indicates the network performance in terms of the average end-to-end delay time, the successful rate and the average energy consumption. If the trade-off factor is lower, it means we can obtain a better network performance since it consumes less energy, has a lower average end-to-end delay and achieves more successful rate.

VI. CONCLUSION AND FURTURE WORK

In conclusion, increasing transmission power could change the average number of nodes in a cluster, or making a cluster size larger. In previous work also shown that by increasing the transmission power the trade-off factor was increased. It means less delay and more energy consumption. However, this advantage was exponentially reduced as the transmission power was increased due to more packet collision in a larger cluster of nodes. For our future work, modification of the S-MAC algorithm to support multiple sleep schedules will be studied because each schedule corresponds to different transmission power. Swapping the multi-sleep schedules in S-MAC to match with the traffic load is also suggested. Lastly, the collision problem in a large virtual cluster is another worthwhile issue as it affects the performance of energy efficiency and latency

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