Energy-saving MAC Protocol for Wireless Sensor Network

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Abstract
Dramatical change sometimes happens to network load in specific environment. Therefore we tend to use new nonstationary interception and dormancy methods so as to realize fairness between energy and delay. The authors propose the new energy-saving MAC protocol which is applicable to network load mutation. This new energy-saving MAC protocol suitable for network load mutation may dynamically adjust interception and dormancy time of nodes according to the changes of network load. Utilize NS2 namely Network Simulator Version 2 to do comparative analysis on energy consumption, time delay and throughput of network. Simulation results explain that the new protocol solves unfairness problem between energy consumption and delay. It would satisfy complex and ever-changing network environment better and express its superior performance in the application of wireless sensor network.
Key words: IEEE 802.11, MAC, S-MAC, ENERGY-SAVING, MAC PROTOCOL, LOAD MUTATION

1. Introduction

Being different from the existing data network, wireless sensor network keeps its unique feature [1] including limited node energy, application specific, strong collaboration, great scale of network, high density, high redundancy of data, data-centric, etc. Being limited by hardware condition, sensor nodes have the feature of miniaturization. Generally they use batteries for power supply whose energy is restricted. Meanwhile they are conditioned by physical factors leading it difficult to replace batteries for nodes. Therefore survival time of nodes directly influences working and survival lifetime of network. It is thus clear that saving network nodes' energy is an important problem for sensor network design. MAC layer is mainly responsible for access of nodes' shared media which keeps important influences on some main properties such as energy consumption, delay, reliability, fairness and so on. MAC Protocol of this layer chooses application of network channel and assigns wireless communication resources to sensor nodes which directly influence the whole property of network. This is the key issue for the research on wireless sensor network.

Wireless sensor network relies on large numbers of nodes cooperatively working to reach a specific application target. It is a sort of energy limited self-organizing network. In order to best assign wireless communication resources to nodes, MAC Protocol takes usage mode of wireless channel into consideration. As the bottom layer of wireless sensor network protocol, MAC Protocol is a type of significant protocol guaranteeing the energy-saving and high-efficiency communication of wireless sensor network which determines network performance [2]. The main functions of MAC Protocol are to assure the disappearance of mutual effect of nodes' data transmission, provide multiple nodes with the way accessing wireless channel and handle the collision of nodes after they access channel. The main design target of MAC Protocol of wireless sensor network data link layer is to utilize simple algorithms to reduce energy consumption of network, improve its expansibility and realize specific application requirements of clients.

At present many scholars have designed several types of MAC Protocols from different angles. These protocols are generally classified into schedule-based [2] [3-5] and contention-based schemas. Protocol of this design utilizes the latter. The following content describes two representative contention-based MAC Protocols.

Sift-MAC Protocol [2] is a MAC Protocol of WSN proposed for meeting event-drive. Spatial correlation exists among the events perceived by nodes. Therefore just a part of nodes is needed to transmit data aiming at the same event. If N sensor nodes sharing wireless channel simultaneously perceive an event, its data information is successfully transmitted without conflict during the shortest period of time by just R nodes. Here R is less than or equal to N. Then the other nodes do not transmit information. This protocol uses the fixed value of contention window length. Nodes apply different transmission probabilities in different time slots thus choose the victorious node from all contestant nodes according to different probabilities.

CC-MAC Protocol [6] is a type of MAC protocol based on spatial correlation. It was designed by M.C. Vuran et al. Utilizing INS algorithm, this protocol leads the whole sensor network to be divided into many small regions named correlation regions. For each small region, only single node is chosen to transmit information which eliminates spatial correlation of node collecting data and makes conflicts of competing channel among network nodes become less thus saving energy. In Literature [6], M main nodes are chosen under the condition of satisfying certain distortion of node data. When main nodes are chosen, reliability of node perceiving data is never taken into account in which just the nodes firstly competing channel are named important ones. This result in inaccurate estimation of sink node on event source.

Comparing with MAC Protocol of IEEE802.11, S-MAC Protocol keeps the following advantages. Through periodic interception and dormancy strategy, it lengthens sleeping time of nodes and reduces their energy consumption. It also keeps good expansibility to adapt to the changing network topology. However, it has some disadvantages [7]. Firstly, nodes are never classified. S-MAC Protocol uses the same mechanism to work on all nodes. In practical application, the information perceived by some nodes may be unreliable. Even if some nodes could collect reliable data information, the information keeps high similarity. Under the condition of meeting certain network characteristics, corresponding nodes may be selected to transmit information. All nodes in S-MAC Protocol join in competing wireless channel leading energy to be wasted. Secondly, nodes cannot cater for dynamic change of network flow. Through using periodic interception and dormancy method, S-MAC prolongs dormancy time of nodes. Length of cycle time, interception time and dormancy time remains unchanged [8]. That is to say, nodes' interception and dormancy time could not appropriately adjust with the dynamic change of network flow. Under circumstance of network flow being too high, there's not enough time for data to be fully transmitted. While if network flow is too low, nodes would be in the state of interception leading much energy to be wasted. Thirdly, delay of nodes' data transmission is long. S-MAC Protocol keeps periodic interception and dormancy strategy. During one scheduling cycle, one node just sends one piece of information. Therefore transmission delay would be very high with the increasing of transmission hop count during multi-hop data communication process.

2. Energy-saving MAC Protocol Applying to Network Load Mutation

Wireless sensor network generally operates in dynamically changing physical environment. External environment always changes. The happening of some emergencies would make sensor network load greatly change which seriously influences performance of network system. Therefore it seems very important to design energy-saving MAC Protocol coping with network load mutation.

Sensor nodes need to use energy in wireless communication unit, sensor unit and processor unit. Among them wireless communication unit consumes the most energy [9]. Energy consumed by one bit of information communicating for distance of 100 meters almost equals to energy needed by 3000 pieces of operational orders. While network is running, wireless communication unit may be under four different energy states including sending, receiving, free interception and dormancy. Energy needed by wireless communication unit under free interception is far higher than that under dormancy. According to analysis on S-MAC, it is seen that nodes communicate with their neighbor ones in interception stage and cached message queue is transmitted. As interception and dormancy durations are fixed values which could not adapt to constantly changing performance of network load.

In practical environment, network load keeps dynamically changing. When load is low, we hope that interception time may be short thus saving energy. On the contrary, we hope that dormancy would be short so that delay may be reduced. Therefore length of interception or dormancy period of nodes may be properly regulated with the changing of node load to reach the goals of saving energy and reducing delay.

Single time frame of sensor node includes interception and dormancy stages. Fig.1 shows periodic interception and dormancy comparisons between S-MAC Protocol and improved protocol.

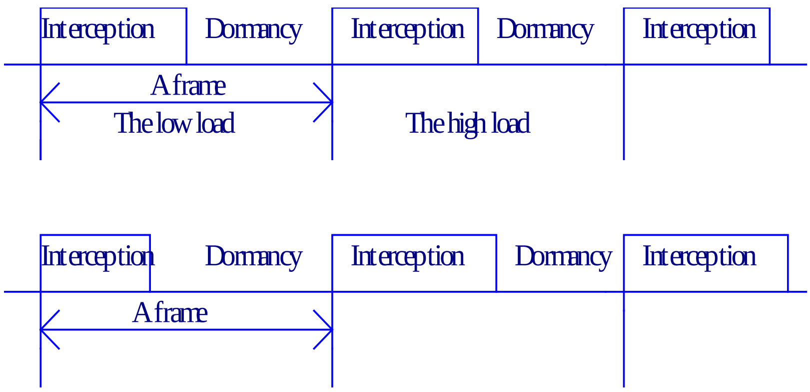

Figure 1. Comparative Figure of Periodic Interception and Dormancy between S-MAC Protocol and Improved Protocol

3. Algorithm Steps of Improved Protocol

The first step is to calculate size of network load. It is measured by load rate. Load rate m of nodes is defined through the number of data package of the sent message queue. That is to say, load rate m is ratio of the number of data package waiting for being sent and the maximum number of data package which could be sent.

In the second step, network load stays moderate if the value of load rate m is between the fixed load minimum value and maximum value. New duty cycle of node is t% of the fixed duty cycle of S-MAC.

In the third step, network load is low if load rate m is less than the fixed minimum value of network load. In order to reduce energy consumption, we need to shorten free interception time of nodes. The new duty cycle is the fixed duty cycle of S-MAC minus k% in which size of k is determined by load rate m of node. If new duty cycle is less than the fixed minimum one, they are equal. Otherwise the new duty cycle remains unchanged.

In the fourth step, network load shows to be high if load rate m is greater than the fixed maximum value of network load. For the purpose of decreasing delay time of message, we need to increase free interception time of nodes. New duty cycle is the fixed duty cycle of S-MAC plus k% in which size of k is determined by load rate m of nodes. If new duty cycle is larger than the fixed maximum one, they are equal. Otherwise the new duty cycle keeps unchanged.

It is obvious that we may acquire the value of network load according to the size of m thus properly adjusting lengths of interception cycle and dormancy cycle of nodes. Finally new schedule information of nodes would be transmitted to neighbor nodes through broadcast. Here *n* stands for duty cycle of new protocol. Unchanged duty cycle of S-MAC Protocol is t. During the whole cycle, node has a period of minimum free interception time so as to form virtual clusters. It is larger than those of node sending SYNC and RTS messages. Meanwhile node also has a period of maximum free interception time in for the sake of saving energy. Therefore we see that duty cycle is controlled within the range of $[n_{\min}, n_{\max}]$ in which size of k is set by load rate m of nodes. Size of nodes' load is defined by threshold value of load rate. When $m \prec m_{small}$, network load is low. While $m \succ m_{l\,\mathrm{arg}\,e}$, it's high.

Fig.2 is the flow diagram of improved algorithm.

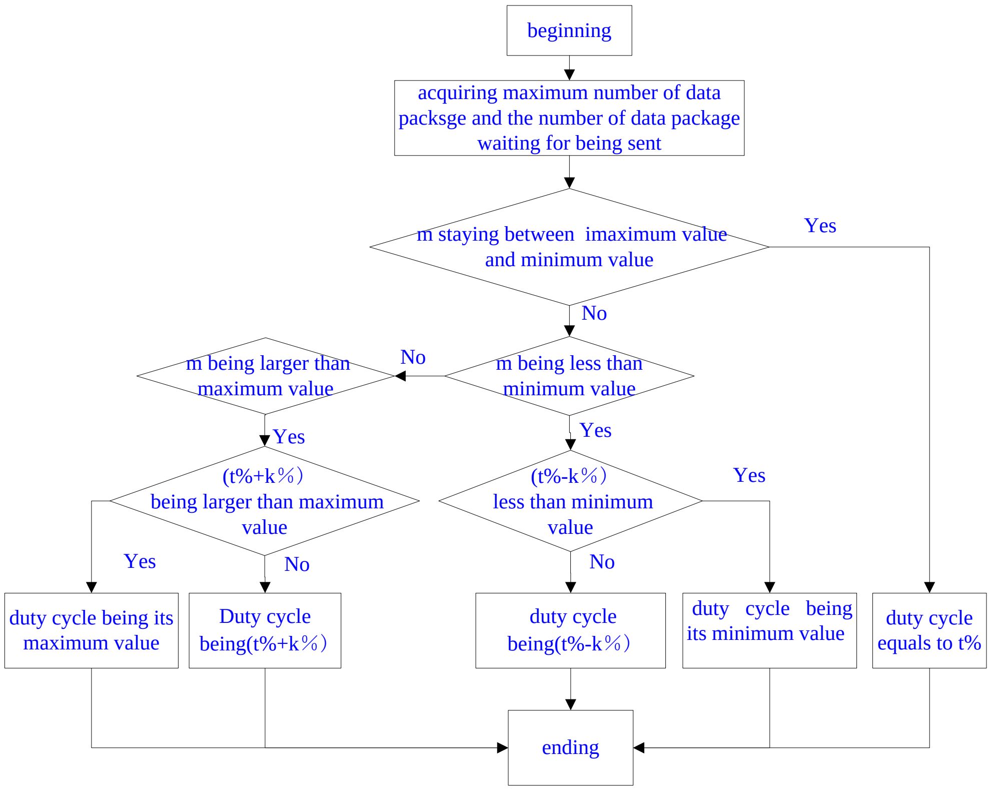

Figure 2. Flow Diagram of Improved Algorithm

4. Simulation of Energy-saving MAC Protocol Applicable to Network Load Mutation

4.1. Network Topology and Simulation Parameter Configuration

Experiment utilizes NS2 Software to do simulation. During simulation process, nodes in network are defined to be non-movable. With the purpose of acquiring better comparison among different protocols, we use the same simulation topology in improved energy-saving MAC Protocol and S-MAC Protocol.

Six nodes are deployed in simulation scene. Distance between neighbor nodes in simulation topology is set to be 150m and communication distance of nodes is 250m guaranteeing data transmission of single hop. In terms of each node in sensor, we set their initial energy to be 1000J. Under sending state, 0.48J energy is needed. It is 0.46J under receiving state. Free interception consumes 0.44J energy and dormancy needs 0.0001J. Simulation time is 1000s and its time range is 500*500m.

Fixed duty cycle of S-MAC is 50%. Minimum value of duty cycle of new energy-saving MAC Protocol is 25% and its maximum value is 75%. It is defined that nodes send single data package on a 20s cycle which gradually increases to be 120s one leading network load to be different.

4.2. Simulation Experiment Results and Analysis

Do comparisons on IEEE802.11 Protocol, S-MAC Protocol and the improved protocol from three aspects of energy consumption, delay and throughput. Network energy consumption is energy difference between pre-simulation and post-simulation of all nodes. Delay is ratio between time difference from source node sending the first data package to destination node receiving the last one and the whole number of all sent data packages. Throughput equals to ratio of the whole sent data volume and time difference. Fig.3 is comparison diagram of energy consumptions. Fig.4 is comparison diagram of delays. Fig.5 is comparison diagram of throughputs.

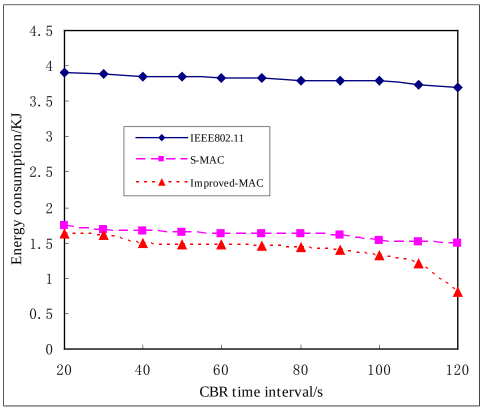

Figure 3. Comparison Diagram of Energy Consumptions

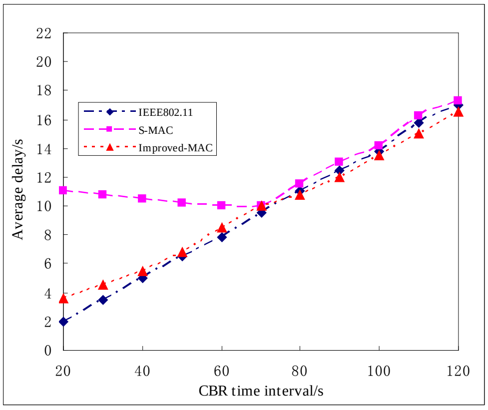

Figure 4. Comparison Diagram of Delays

It is expressed in Fig.3 that new energy-saving MAC Protocol consumes the least energy. When network load is low, its energy consumption is about 29% lower than that of S-MAC Protocol. Under the condition of load being low, new protocol dynamically regulates duty cycle to be small thus lengthening nodes' dormancy time and realizing energy reduction. For the situation of load being high, new protocol increases value of duty cycle which helps prolong nodes' interception time. Meanwhile energy consumption becomes higher. However, the improved protocol does selection on nodes to lead high-redundancy ones to enter dormancy situation making energy consumption become lower. Therefore energy consumption of New-MAC Protocol is slightly below that of S-MAC Protocol. Overall, new protocol better saves energy of sensor network comparing with the other two protocols.

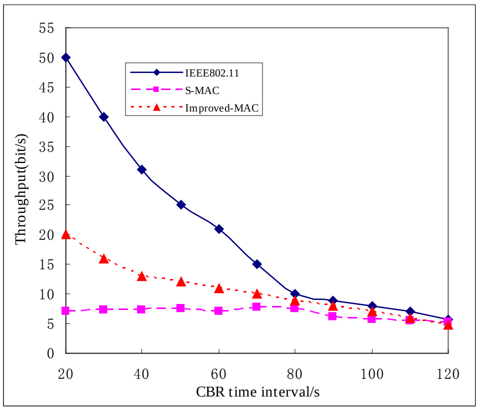

Figure 5. Comparison Diagram of Throughputs

We see from Fig.4 that sensor nodes of IEEE802.11 Protocol stays in interception situation when network load is high. Therefore its delay is the least of all without dormancy. New protocol increases value of duty cycle which leads its dormancy time to be less and makes its delay be far less than that of S-MAC. When network load gradually becomes low, delay of data packages queuing up would be ignored. At this moment delays of three protocols are approximate. Although delay and throughput properties of IEEE802.11 Protocol are good, it consumes a lot of energy. Therefore it is not applicable to wireless sensor network.

Fig.5 explains that IEEE802.11 Protocol has the highest throughput because its nodes keep intercepting all the time. Comparing with S-MAC Protocol, the improved protocol better regulates duty cycle when network load becomes high. This reduces data collision retransmission times and leads network throughput to increase. While network load gradually becomes low, transmitted data is less thus greatly decreasing competition and collision among nodes. Sizes of throughputs also become similar.

5. Conclusions

IEEE802.11 Protocol keeps good throughput and delay properties while its energy consumption is high. As energy of sensor nodes is limited, IEEE802.11 is not applicable to sensor network. New energy-saving MAC Protocol dynamically modulates nodes' interception and dormancy time according to the change of network load. This protocol would meet the constantly changing complex environment. Meanwhile, energy consumption of improved energy-saving MAC Protocol is less than that of traditional S-MAC Protocol. It also presents obvious improvements on throughput and delay properties.

Acknowledgements

This work is supported by "Design of Supervision System of Logistic Transporters" and "Design and Realization of Short Distance Simple Energy Saving Protocol of Networking", the projects of Scientific and Technological Research Program of Chongqing Municipal Education Commission(Grant No. KJ1503202, KJ1403105).

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