Data Predicted Wakeup Based Duty Cycle MAC for Wireless Sensor Networks

Muhammad Mostafa Monowar[1], Md. Obaidur Rahman[1], Choong Seon Hong[1], Cho Jin Woong, Lee[2] Hyun Seok[2]
[1]Networking Lab, Department of Computer Engineering, Kyung Hee University
1 Seocheon, Giheung, Yongin, Gyeonggi, 449 - 701 South Korea.
[2]Korea Electronics Technology Institute
South Korea.
{ monowar, rupam}@networking.khu.ac.kr and cshong@khu.ac.kr, chojw@keti.re.kr, hslee75@keti.re.kr

Abstract

Presuming energy as a crucial resource, several duty cycle based MAC protocol have been proposed for wireless sensor network. However, these protocols have long latency problem for paying more attention on energy efficiency. In this paper, we propose Data Predicted Wakeup Based Duty Cycle MAC (DPW-MAC) for Wireless Sensor Networks for delay sensitive periodic applications in which timely delivery of data is a major concern with the maintenance of duty cycle.

1. Introduction

Wireless sensor network typically incorporates wide range of periodic real time applications (structural health monitoring, surveillance application) which requires the meeting of a certain QoS (i.e., delay) under severe resource constraints. Again, another most striking issue in designing MAC protocol for wireless sensor network is energy efficiency. The design of energy efficient MAC protocols faces several key challenges- First, sensor network must maintain sufficient Quality of Service (i.e. delay) in addition to maintaining lower duty cycle. Especially, the time critical application requires the data delivery to the sink within a strict time constraint. For example, health monitoring system demands the timely delivery of data to the sink for taking action at the appropriate time. But the provision of keeping sleep schedules for energy efficiency is a threat to maintain the low latency if not designed appropriately. Second, the design of sensor MAC should reflect high medium time utilization. In particular, the sender should transmit data as soon as it arrives to it and the receiver needs to be awake at the reception time of data. Being motivated with these problems, in this paper we propose Data Predicted Wake-up based duty cycle MAC (DPW-MAC) for Wireless Sensor Networks considering delay sensitive periodic applications and exploiting the periodicity of the data packet. Simulation result shows the effectiveness of our approach.

2. DPW-MAC Design

In this mechanism, initially, all the nodes in the network will remain active for a particular period. Each source node in the network starts data generation at t_0, which is determined by the sink. The source nodes generate data periodically at every t_p seconds. The t_p varies from source to source depending on the application flow requirements. Every non leaf nodes send beacon to its immediate upstream nodes at t_0. All the nodes who received beacon from their downstream nodes will adjust their clock with respect to the clock of the downstream nodes and start data generation immediately if its clock time lags behind from the clock time of the upstream node. After that beacon, all the source nodes will perform a random back off within a fixed contention window CW. After back off expires the node will immediately send the packet. The node will continue sending the back to back packets if it has any which is bounded by the TxOP limit. In this case, the TxOP value for node i, $TxOP^i$ can be calculated as

$$TxOP^i = RxOP / N_C^{P_i}$$

Where, $N_C^{P_i}$ is the number of child nodes of the parent of node i. and RxOP is the maximum duration the receiver is allowed to receive packets from the contending senders. The beacon packet contains the information of $N_C^{P_i}$. Every sender is aware of its receiver's RxOP limit. During the back off period, if the sender's waiting time exceeds receiver's RxOP limit it will postpone the transmission and queue the packet. It will wait for the next reception of packet and send the previously pending packets with the newly arrived packets if it is intermediate node and wait for the next packet generation to transmit along with it if it is source node. If a sender fails to transmit a packet for long waiting time it will decrease the CW value to increase its probability of getting the medium access for the next cycle as-

$$CW_{now} = CW_{prev}/2^i$$

Where i is the number of missing transmission within receiver's RxOP limit and CWnow>=CWmin

In our protocol every node contains a counter (RxOP counter) which decrements its value by one after every slot based on the default RxOP value. The counter value is reinitialized when it becomes zero or when a node gets beacon packet from its downstream node (in the receiving state). The counter run always irrespective of a node is in sending state or receiving state. Every RxOP has its corresponding id. Hence, after sending the packets the sender the node will wait for the remaining time until RxOP counter becomes zero and then turns into receiving state. As we are considering periodic application, a number of reception opportunities form a cycle in which every RxOP has differences in sender's id. The cycle is determined by the maximum data generation interval among the source nodes. It takes n number of RxOP cycles to accurately measure the number of the senders in each opportunity if any misses for wireless error or large medium access delay.

After observing n number of RxOP cycles the receiver will determine its wake up time. For a particular RxOP say, i^{th} RxOP if receiver receives any packet during the n number of cycles it determines the starting time for that RxOP as its wake up time. As

This research is supported by the Ubiquitous Computing and Network(UCN) Project, Knowledge and Economy Frontier R&D Program of the Ministry of Knowledge Economy(MKE) in Korea and a result of subproject UCN 09C1-C2-10M

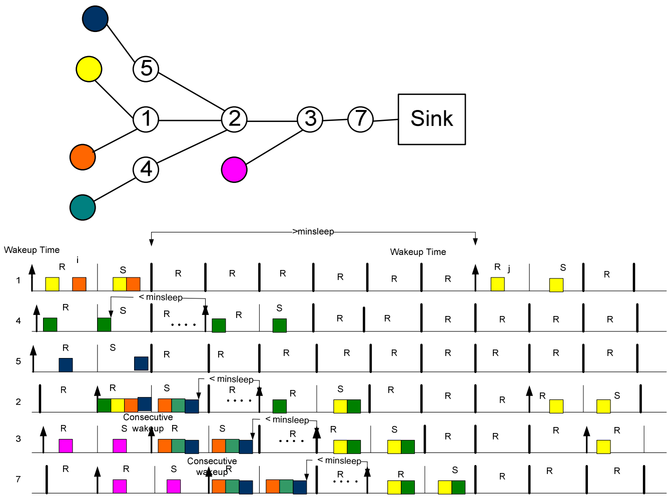

Figure 1: Determination of Wakeup time. The "arrow" indicates the wakeup time for that RxOP as well as beacon transmission time and highlighted bar indicates the beacon transmission only. Node1 sets is wake up time at jth RxOP as $d^{ij}_{inter} >= \min_{sleep}$, but for node 2,4,3 and 7 it becomes, $d^{ij}_{inter} < \min_{sleep}$. Node 3 and node 7 has packet reception in the consecutive RxOP just after sending the packets.

energy saving is the main concern for WSN, the selection for next wake up time should address this issue. Nodes should have a minimum sleep interval, $\min_{sleep}$ to save energy. After *n* RxOP cycles each receiving node will determine its energy conserving wake up time as follows:

Let t^{i+1}_{last} be the time when last packet is sent after i[th] RxOP (t^{i+1}_{last} is determined as the largest sending time within n cycles of RxOP) and t^{j}_{wake} be the wake up time of j[th] RxOP which contains packet. Let d^{ij}_{inter} be the time difference between t^{i+1}_{last} and t^{j}_{wake}.

If $d^{ij}_{inter} <=$ RxOP then the node continues listening and receive data for jth RxOP and determine its wake up time at (j+n)[th] RxOP which has the data.

If $d^{ij}_{inter} >= \min_{sleep}$, then t^{j}_{wake} will be selected as the next wake up time. Otherwise, after the i[th] RxOP limit and performing the send operation the node will sleep for $\min_{sleep}$ interval and then wakes up at the next closest period when RxOP limit counter value is reinitialized. In this case, the node will inform to its downstream nodes about its delayed RxOP starts by setting a flag in the beacon packet. After receiving the beacon the downstream node can determine its next wake up time as follows:

$$t^{j}_{wakeNew} = t^{j}_{wakeOld} + \min sleep$$

Set $t^{j}_{wakeupNew}$ = start time of jth RxOP.

All the downstream nodes up to the sink then eventually determine their wake up time.

As after performing *n* RxOP cycles every receiver is aware of the number of senders which participate in the related RxOP id, the receiver will notify the upstream nodes regarding the number of active senders in the particular RxOP through the beacon packet. After receiving the the information, the upstream nodes will determine the TxOP value for that RxOP as-

$$TxOP^{j}_{i} = RxOP\_\lim it / N^{j}_{active}$$

Where, $TxOP^{j}_{i}$ is the TxOP value to be determined for node i in RxOP j. N^{j}_{active} is the number of active senders for that j[th] RxOP which will be included in the beacon packet. The determination of TxOP is performed at the same period while determining the wakeup time. Figure 1 illustrates the data prediction based wake-up mechanism.

3. Simulation

We have performed simulations to evaluate the performance of DPWS mechanism. The simulation parameters are described as follows: 200 sensors are randomly deployed in 100x100 m^2 sensor field. The transmission range of the sensors is 30 m. We compare our protocol with RI-MAC [3] due to its similarity with respect to receiver driven approach and simulation parameters are also taken as presented in RI-MAC for fair comparison.

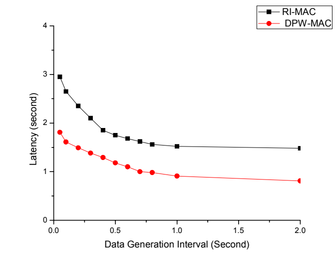

Figure 2: Data Generation Interval vs Delay

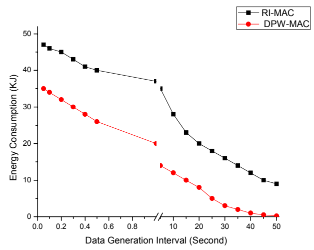

Figure3: Data Generation Interval vs Energy

Figure 2 shows the impact of delay varying data generation interval. DPW-MAC outperforms RI-MAC as wake up is based on sender's data arrival and packets are delivered in almost staggered way. Similarly, DPW-MAC also shows better performance in case of energy savings than RI-MAC in low traffic rate as receiver does not wake up unnecessarily and in high traffic also as sender does not perform idle listening as it does in RI-MAC.

4. Conclusion

We present a delay and energy efficient MAC for wireless sensor network for periodic applications. The data prediction based wake-up approach shows optimal delay gain and also energy efficiency in different traffic load.

5. References

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," Computer Networks, vol. 38, no. 4, pp. 393–422, 2002.

[2] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks," in Proc. 2nd International Conference on Embedded Networked Sensor Systems, New York, NY, USA, 2004, pp.95–107.

[3] Y. Sun, O. Gurewitz, David B, Johnson," RI-MAC: A Receiver-Initiated Asynchronous MAC Protocol for Dynamic Traffic Loads in Wireless Sensor Networks", in Proc. Of 6th ACM Conference on Embedded network sensor systems, Raleigh, NC, USA, pp. 1-14.

[4] M. Buettner, G. V. Yee, E. Anderson, and R. Han, "X-MAC: A short preamble mac protocol for duty-cycled wireless sensor networks," in SenSys '06: Proceedings of the 4th international conference on Embedded networked sensor systems. New York, NY, USA: ACM, 2006, pp. 307-320.

[5] W. Ye, J. Heidemann, and D. Estrin, "Medium access control with coordinated adaptive sleeping for wireless sensor networks," IEEE/ACM Trans. Networking, vol. 12, no. 3, pp. 493–506, 2004.

[6] K. Kredo and P. Mohapatra, "Medium access control in wireless sensor networks," Computer Networks, vol. 51, no. 4, pp. 961–994, 2007.