International Journal of Informatics and Communication Technology (IJ-ICT)
Vol. 5, No. 2, August 2016, pp. 79~85
ISSN: 2252-8776

Adaptive Duty Cycle Medium Access Control Protocol for Wireless Sensor Networks

Anandbabu*, Siddaraju**
* Department of CSE, Assistant Professor, Kapatatu College of Engineering, VTU, Tiptur, India
** Department of CSE, professor, Ambedkar institute of Technology,VTU,Bangalore, India

Article Info

Article history:

Received Mar 2, 2016
Revised Jun 26, 2016
Accepted Jul 16, 2016

Keyword:

Adaptive duty cycle
MAC
WSNs

ABSTRACT

To increase the network lifetime of WSNs is a major concern. Network lifetime can be increased by reducing energy consumptions through MAC protocols periodic and a- periodic sleep mode mechanisms. The short duty cycle makes sensors have low energy consumption rate but increases the transmission delay and long duty cycle makes the sensor to increase the energy consumption and reduce the delay. Duty cycle need to be adaptively varied to reduce the idle listening. In the proposed Adaptive Duty cycle MAC (ADMAC) protocol, duty cycle is varied by taking nodes rate of energy consumption and filled queue length in account. It reduces the delay and energy spent by reducing the idle listening. ADMAC is realized in NS2 and its performance is compared with SMAC.

Corresponding Author:

Anandbabu,
Department of CSE,
Kapatatu College of Engineering, VTU, Tiptur, India.
Email: anandbabu1383@gmail.com

1. INTRODUCTION

Wireless Sensor Networks (WSNs) is a new computing paradigm evolved in past few years. The tiny sensors can be deployed in the phenomena where each can sense information and communicate each other or sink node. WSNs users extract useful information from the communicated data [1][2][3].

A sensor node would drain its battery faster in the absence of energy efficient techniques. This fact triggered researchers to design protocols and mechanisms to reduce energy utilization in the WSNs. Many researchers proposed study on energy efficiency techniques in MAC layer, routing layer, transport and application layer separately.

In WSNs energy spent in the communications is much higher than the data sensing and processing. The energy spent in the data transmit is 14.88mW & receive is 12.50mW. The energy spent in idle mode is 12.36mW [5]. Minimum amount of energy is spent in sensing, sleeping & processing mode. Even these processes need to be energy-efficient in WSNs.

Optimum use of limited available power source is needed in WSNs to prolong the operational network lifetime. In WSNs, the energy expense can be minimized in all the layers of the protocol stack. In Physical layer, the node energy can be saved through reducing the data size, effective data rate and efficient energy model. In MAC layer, designing energy efficient MAC duty cycle mechanisms and packet scheduling [2]. Energy efficient routing protocol can be designed to reduce the energy consumption in the network layer. An effective congestion control, congestion avoidance and load sharing mechanisms are needed to enhance the WSNs network lifetime. Effective Data placement and asynchronous multicasting techniques contributes in reducing energy expenses at application layer.

The MAC layer has to be responsible for reliability, energy efficiency, high throughput & low access delay to optimally utilize the energy-limited resources of sensor nodes. Maximum amount of energy wasted in MAC protocol operations like collision, overhearing, control packet overhead and interference. To minimize the energy expenditure at WSNs energy efficient MAC techniques like duty cycling, packet scheduling adaptive transmission range, and adaptive transmission period are to be studied [6-9].

Many research attempted to save the power in WSNs through MAC layer protocols [10-19]. Active mode is used for data transmission and in sleep mode sensors turns off their radios to save the power. In SMAC, sensor nodes operate at low duty cycle and frequently toggles between active and sleep modes. In static duty cycle MAC protocols it does not adapt to the traffic through the node. It introduces additional delay in the processing of data at MAC layer. Effective Duty-cycling in WSNs is considered as one of the approach for energy conservation [20]. A dynamic duty cycle scheduling is needed to improve the energy efficiency and reduce the delay in the WSNs. Optimizing duty cycling is also can be viewed as multiobjective optimization problem[21].

In this paper, we propose an adaptive duty cycle adjustment MAC protocol named “ADMAC” which can adjust sensor’s duty cycle adaptively according to status buffer filled queue lenght, node rate of energy consumption. After the information of a sensor is obtained, the sensor adaptively adjusts the duty cycle for sending and receiving packets. This protocol focus on to reduce the energy spent and end to end delay. Each node adaptively varies its duty cycle if the node has data to transmit. The sensors that which failed to send data due to radio channel competition, these sensors will go to sleep state for energy conserving and wait for next wake-up time to compete the radio channel again for transmitting data.

The rest of the paper is organized as follows. Section 2 describes the related works. Section 3 presents the proposed Adaptive duty cycle MAC protocol. Section 4 presents the results and its analysis. Section 5 concludes the proposed MAC scheme.

2. RELATED WORKS

To conserve energy in MAC layer, sensor nodes change from sleep to wake up mode or vice versa in a duty cycle. When communication is not required in the WSNs, MAC layer changes their mode of operation from wake up to sleep mode. It is required to put off the node radio when there is no data is available to send or receive and it should put on when the data is ready to transmit or receive. A duty cycle is a mechanism which makes sensor node to change their mode from active mode to sleep mode.

SMAC stands for Sensor MAC [22]. SMAC contains the original duty cycling concept to reduce the overhead of idle listening. SMAC is more energy efficient than the full wake IEEE 802.11 MAC protocol. SMAC reduce energy consumption due to overhearing, idle listening and collision. SMAC has two states, sleep state and active state. SMAC employs a periodic wake up scheme. In listen mode, a sensor node can either transmit or receive data. In SMAC synchronizes the listen periods of neighboring nodes. The listen period is the time during which a node is awake, rest of the time node is sleeping. The listen period of a node is divided into three phases as shown in the Figure 1. SMAC has fixed sleep and listen intervals.

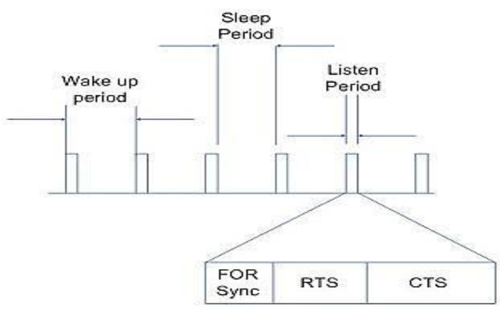

Figure 1. Duty Cycle in SMACz

The listen period has sync phase, RTS phase and CTS phase. The neighboring node synchronizestheir listen periods in sync phase. In RTS phase, a node which wishing to send data sends RTS and destination node acknowledges RTS in CTS even when node is in sleep mode. A common sleep schedule is setup in neighboring nodes using virtual cluster. SMAC results in idle listening and overhearing, when two nodes present in adjacent virtual clusters. It also increases energy consumption and introduces high end to end delay. Sensor nodes in the network may not have same traffic through the node. Maintaining uniform duty cycle across the network, results in idle hearing which leads to energy waste and end to end delay.

Shu et al proposed Routing-Enhanced MAC (RMAC) [23]. RMAC uses setup control frame called PION can travel across multiple hops and schedule the upcoming data packet delivery along that route. Each intermediate relaying node for the data packet along these hops sleeps and intelligently wakes up at a scheduled time, so that its upstream node can send the data packet to it and it can immediately forward the data packet to its downstream node. An operational cycle of a sensor node in RMAC can be divided into three stages: SYNC, DATA, and SLEEP. Most importantly, a node transmits a single PION to confirm receipt of a PION from its upstream node and to simultaneously request communication from a downstream node. This dual function makes the multihop relaying of PIONs very efficient. RMAC reduces end-to-end delivery latency with a duty cycle. Most importantly, a node transmits a single PION to confirm receipt of a PION from its upstream node and to simultaneously request communication from a downstream node. This dual function makes the multihop relaying of PIONs very efficient. RMAC suffers improper duty cycle synchronization among the nodes on the routing path between source node and sink node. It increases idle hearing and waiting for the next duty cycle in the neighboring node increases delay.

Yang et al[24] proposed Utilization based-MAC protocol (U-MAC). U-MAC fixes duty cycle according to the traffic loads of sensor nodes. U-MAC evaluates utilization function of a sensor node based on its traffic handling.

The nod adopts its duty cycle according to the calculated node utilization and then communicates it to its neighboring through broadcasting. and then broadcasts the new schedule to its neighbors.
UMAC saves more energy than SMAC when traffic loading is low. If the senders duty cycle is higher than the receiver, then data may in the queue of the receiver or it may be lost when its queue is full. It not only reduces the throughput but also increases delay.

In the most of adaptive dynamic duty cycle mechanisms attempted to vary the sleep time or active time of the sensor node. As we know that sensor node operates in active, idle and sleep mode. Dynamic duty cycle MAC tried to reduce the energy utilization in the network. However, many researcher proposed they fails to consider filled queue length, rate of energy consumption and common duty cycle assignment between source and next hop node on the path to the sink node. It effectively adapts the duty cycle period which reduces energy expenditure and end to end delay in the network.

3. ADAPTIVE DUTY CYCLE MECHANISM IN MAC (ADMAC) FOR WSNS

The proposed Adaptive Duty cycle Mechanism in MAC for WSNs is designed under the following assumptions:

i. Each node consists of the communication module and sensing module.
ii. The energy consumption during sensing is negligible compared to wireless communication.
iii. All the nodes in network synchronizes for active and sleep mode operation.
iv. In the wireless communication, the main energy consumption is used for idle listening, instead of packet transmission and reception.

Symbol	Meaning
DC	Duty Cycle
DCmin	Minimum Duty Cycle
DCmax	Maximum Duty Cycle
Dccurrent	Next hop node Duty cycle
SC	Sleep cycle
FQL	Filled Queue Length
Qmax	Maximum Queue length
WR	Working rate
WRhigh	Working rate high
WRlow	Working rate low
Ttx	Total transmission time
Trx	Total receive time
Tidle	Total idle time
REC	Residual Energy Consumption
RECthreshold	Residual Energy Consumption Threshold
N	Number of data pkts

“ADMAC” that can adjust duty cycle adaptively according to status of sensor’s sending/receiving buffer, rate of energy consumption and traffic loading. The proposed adaptive duty cycle MAC protocol fairly updates the duty cycle to the maximum level which has the enough battery capacity and its rate of energy consumption is lower than the threshold rate of energy consumption and taking number of packets in the buffer into account. This mechanism increases the network lifetime by spending the node energy uniformly among the nodes which may participate in the routing. It also avoids network to get partitioned by a node which has minimum residual energy and maximum rate of energy consumption. The sender and receiver need to synchronize their active state and duty cycle to reduce the end to end delay. It also reduces idle listening of the Neighboring or next hop node.

The working of the Adaptive Duty cycle MAC is assumed to be source node knows the complete path to the destination or sink node. Along the control packet which synchronizes the next hop node duty cycle also carries the complete path to the destination. Adaptive duty cycle MAC protocol designed in 2 phases.

First, the duty cycle setting at the current node and next hop node. The current node or source node changes its duty cycle by reading at the current node buffer fill capacity, rate of energy consumption, and working rate of the sensor node. Secondly, duty cycle for all the nodes is set to be minimum.

At sender:

1. Initial DC :DCmin and SC=$\sum_{i=1}^{n} SC_i$/N
2. While a SYNC packet is sent do
3. WR = Ttx +Trx/(Ttx +Trx +Tidle)
4. If FQL ≥ Qmax && DC < DCmax and REC> RECThreshold && WR ≥ WRhigh then
5. DC = DC * (1 + (*FQL/REC)*WR*)
6. Else if WR ≤ WR1ow and DCmax > DC > DCmin && SC<SCThreshold then
7. DC = DC * (1 –(*FQL/REC)*WR*)
8. Unicast-to-nexthop-node (DC)
9. End if
10. End while

At receiver:

11. SC=$\sum_{i=1}^{n} SC_i$/N
12. while a SYNC packet is received do
13. If DC>DCcurrent and REC< RECThreshold and FQL < Qmax and WR ≤ WR1ow then
14. DCcurrent=DC
15. End it
16. if WR ≥ WR1ow and DCmax > DCcurrent > DC && SC<SCThreshold then
17. DCcurrent = DCcurrent * (1 - (*FQL/REC)*WR*)
18. end if
19. end while

A synchronization packet is sent to next hop node and with updated duty cycle from current node. If the filled queue length of the buffer is more than the maximum queue capacity, current duty cycle less than the duty cycle maximum and rate of energy consumption is greater than the its threshold value and working rate is lesser than its upper limit, Then duty cycle is increased by a ratio of its capacity which can handle the current traffic with current residual energy and its rate of energy consumption. The duty cycle is reduced by ratio of filled queue length, and the rate of energy with the working rate of the sensor node. Then the modified duty cycle is communicated to next hop node.

The next hop node which received the modified duty cycle and checks its duty cycle is less than the received duty cycle and their residual energy and rate of energy consumption is lower than the its threshold and filled queue length is lesser than the queue length, working rate of the receiving sensor node is lesser than the working rate threshold than its duty cycle is updated to received duty cycle. If the received duty cycle is lesser than its current duty cycle, and its sleep cycle is lesser than the threshold its duty cycle is reduced according to the rate of its energy consumption, filled queue length and working rate.

4. PERFORMANCE EVALUATION

To evaluate the performance of the proposed adaptive duty cycle MAC for WSNs, NS2 (Network Simulator - 2) is used. It is a discrete event simulator. There is 100 nodes are organized in grid fashion. The transmission range of the sensor node is set to be 20 meters. The bandwidth is fixed to 100kbps. Each data packet size is 100 bytes and 4 bytes for control packets including RTS, CTS, and SYNC. Table 1 shows the different parameters set during the simulation, It is set as similar TA-MAC.

Table 1. Simulation parameters set

Queue	100
Sleep power	0.02mA
Transmission power	10mA
Receive power	4mA
Simulation time	300 s
Bandwidth	100 Kbps
Data packet size	100 byte
SYNC period	10 s
Frame time	1 s
Initial duty cycle	10%
DCmax	40%
DCmin	10%
Transmission range	20M
Node	10 to 100
Uhigh	0.08
WRhigh	8%
Ulow	0.04
WRlow	4%
DCmax	1.8
Residual Energy	3J

End to end delay is the cumulative average delay by all the packets to reach the destination or sink node. Figure 2 shows that end to end delay comparison between SMAC and proposed ADMAC. The delay is analyzed by varying the number of nodes between 10 to 100 nodes. It is observed that end to end delay is keep on increasing as the number of number of nodes are increased. It is due to as the number of nodes increases the number of hops between source and destination also increases and results in delay. There is a reduction of 46.72 % of delay in ADMAC compared with SMAC. It is because of the complete path to the destination is sent along with sync packets and It also synchronizes the next hop node active mode before sending the data packet.

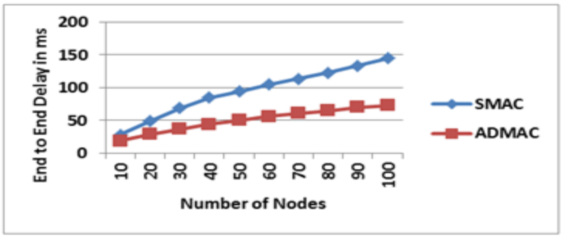

Figure 2. Number of Nodes Vs End to End Delay in ms

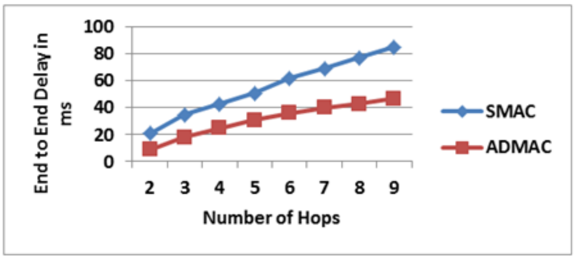

Figure 3. Number of Hops Vs End to End Delay in ms

Figure 3 shows that end to end delay in SMAC and ADMAC when the number of hops between source node to destination is taken into account. It is observed from the Figure 3 that the end to end delay is increasing when the number of hops is increasing. The reduction of delay when the number of nodes between source and destination is considered it is 44%. Since the SMAC follows the periodic sleep and wake up scheme, it makes the source node to wait for the next active mode to receive the data. As the number of hops is increasing, the number of waiting for the active mode nodes is also increasing.

Energy spent is the average cumulative expenditure of energy among all the nodes in the network. Figure 4 and 5 shows that energy spent in the network are compared with SMAC and ADMAC. When the number of nodes is increasing energy spent in SMAC grows in steep compared to ADMAC. There is a reduction of reduction of 44.9% energy spent in ADMAC when compared with SMAC. It is because of SMAC follows periodic listen and sleep scheme to reduce idle listening. When the node need to transmit the next hop node in the sleep state, then source node need to wait till next active mode. The energy is spent in idle sensing the next hop node availability is reduced. As the number of hops is increasing energy spending the idle listening is reduced. Node with high work load will not be considered as intermediate node to forward the data in ADMAC. Hence energy spent in such nodes is reduced.

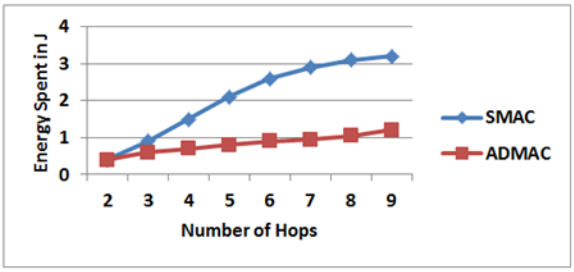

Figure 4. Number of hops Vs Energy spent in J

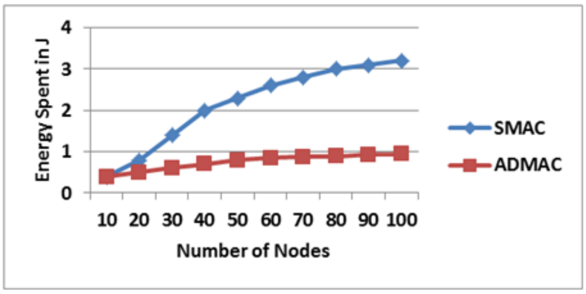

Figure 5. Number of Nodes Vs Energy Spent in J

5. CONCLUSION

To increase the network lifetime of WSNs is a major concern. It can be increased by reducing energy consumptions through MAC protocols periodic and a- periodic sleep mode mechanisms. In the proposed ADMAC duty cycle is varied by taking nodes rate of energy consumption and filled queue length in account. It allows the nodes which have data to send and if the node has less data to communicate its duty cycle is reduced accordingly. It reduces the delay and energy spent by reducing the idle listening. ADMAC is compared with SMAC for performance parameters like energy spent and end to end to delay. ADMAC reduces 46.72% of end to end delay and 44.9% of energy spent in the network. The performance of the ADMAC still needs to be analyzed for various scenarios and performance metrics.

REFERENCES

[1] Christophe J. Merlin, Wendi B, "Heinzelman, Schedule Adaptation of Low-Power-Listening Protocols for Wireless Sensor Networks", *IEEE Transactions on Mobile Computing*, Vol. 9, No. 5, pp. 672-685, May 2010

[2] Ricardo C. Carrano, Diego Passos, Luiz C. S. Magalh˜aes, C´elio V. N. Albuquerque, "Survey and Taxonomy of Duty Cycling Mechanisms in Wireless Sensor Networks", *IEEE Communications Surveys & Tutorials*, Vol. 16, No. 1, pp.181-194, 2014

[3] Somnath Ghosh, Prakash Veeraraghavan, Samar Singh, Lei Zhang, "Performance of a Wireless Sensor Network MAC Protocol with a Global Sleep Schedule", *International Journal of Multimedia and Ubiquitous Engineering*, Vol. 4, No. 2, April, 2009

[4] V. Raghunathan, C. Schurgers, Park.S, M.B. Srivastava, "Energy-aware Wireless Microsensor Networks," *IEEE Signal Processing Magazine*, Vol. 19 No. 2 , Page(s): 40 –50, March 2002

[5] Shweta Agarwal, Varsha Jain, Kuldeep Goswami "Energy Efficient Mac Protocols For Wireless Sensor Network", *International Journal on Computational Sciences & Applications (IJCSA)*, Vol.4, No.1, February 2014

[6] Mo Sha, Gregory Hackmann, Chenyang Lu, "Energy-Efficient Low Power Listening for Wireless Sensor Networks in Noisy Environments", *IPSN 2013*, April 8–11, 2013, Philadelphia, Pennsylvania, USA

[7] Mayank Awasthi, Swati Sharma,"Energy Efficient Traffic Aware MAC Protocols for Delay-Sensitive Wireless Sensor networks", *International Journal of Computer Applications*, Vol. 63, No.10, February 2013

[8] Abayomi M. Ajofoyinbo, " Energy Efficient Packet-Duration-Value Based MAC Protocol for Wireless Sensor Networks", *Wireless Sensor Network Scintific Research*, pp.194-202, 2013

[9] Lin P, Qiao C, Wang X, "*Medium Access Control with a Dynamic Duty Cycle for Sensor Networks*," Proc. IEEE Wireless Comm. and Networking Conf. (WCNC), Vol. 3, No. 7, pp. 1534-1539,2014

[10] A. Bachir, M. Dohler, T. Watteyne, and K.K. Leung, "MAC Essentials for Wireless Sensor Networks", *IEEE Comm. Surveys and Tutorials*, Vol. 12, No. 2, pp. 222-248, Apr.-June 2010

[11] S. Liu, K-W. Fan, P. Sinha, "*CMAC: And Energy Efficient MAC Layer Protocol Using Convergent Packet Forwarding for Wireless Sensor Networks*," Proc. High Performance Computing Conf. (HIPC), pp. 11-20, 2007

[12] W. Ye, J. Heidemann, D. Estrin, "*An Energy-Efficient MAC Protocol for Wireless Sensor Networks*," Proc. IEEE INFOCOM, pp. 1567-1576, July 2002

[13] T. Van Dam, K. Langendoen, "*An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks*," Proc. Int'l Conf. Embedded Networked Sensor Systems (SenSys), pp. 171-180, Nov. 2003

[14] W. Ye, J. Heidemann, D. Estrin, "Medium Access Control with Coordinated, Adaptive Sleeping for Wireless Sensor Network," *IEEE Trans. Networking*, Vol. 12, No. 3, pp. 493-506, June 2004

[15] P. Lin, C. Qiao, X. Wang, "*Medium Access Control with a Dynamic Duty Cycle for Sensor Networks*," Proc. IEEE Wireless Comm. and Networking Conf. (WCNC), Vol. 3, pp. 1534-1539, 2004

[16] Lu, G.; Krishnamachari, B.; Raghavendra, C.S., "*An Adaptive Energy-Efficient and Low-Latency MAC for Data Gathering in Wireless Sensor Networks*," in Parallel and Distributed Processing Symposium, *2004.* Proceedings. 18th International , pp.26-30, 2004

[17] N. Vasanthi and S. Annadurai, "*Energy Efficient Sleep Schedule for Achieving Minimum Latency in Query Based Sensor Networks*," Proc. IEEE Int'l Conf. Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC), 2006

[18] C.J. Merlin, W.B. Heinzelman, "Duty Cycle Control for Low-Power-Listening MAC Protocols," *IEEE Trans. Mobile Computing,* Vol. 9, No. 11, pp. 1508-1521, Nov. 2010

[19] X. Wang, G. Xing, and Y. Yao, "*Dynamic Duty Cycle Control for End-to-End Delay Guarantees in Wireless Sensor Networks*," Proc. Int'l Workshop Quality of Service (IWQoS), 2010, pp. 1-9

[20] Kai Han, Jun Luo, Yang Liu, Athanasios V. Vasilakos, "Algorithm Design for Data Communications in Duty-Cycled Wireless Sensor Networks: A survey", *IEEE Communication Magzine,* Vol.51, No. 7, 2013

[21] Sengupta, S., Das, S.; Nasir, M., Vasilakos, A.V.; Pedrycz, W., "An Evolutionary Multiobjective Sleep-Scheduling Scheme for Differentiated Coverage in Wireless Sensor Networks," in *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on* , Vol.42, No.6, pp.1093-1102, Nov. 2012

[22] W. Ye, J. Heidemann, and D. Estrin, "*An Energy Efficient MAC Protocol for Wireless Sensor Networks*," in Proceedings of the IEEE International Conference on Computer Communications (IEEE INFOCOM '02, Vol. 3, pp. 1567–1576

[23] Shu Du Amit Kumar Saha David B. Johnson, "*RMAC A Routing-Enhanced Duty-Cycle MAC Protocol for Wireless Sensor Networks*", IEEE INFOCOM 2007 proceedings, pp1478-1486

[24] Shih-Hsien Yang, Hung-Wei Tseng, Eric Hsiao-Kuang, "Utilization Based Duty Cycle Tuning MAC Protocol for Wireless Sensor Networks", *IEEE GLOBECOM 2005,* pp 3258-3262