Energy – Efficient MAC Protocol (EE-MAC Protocol)

Garima Bhardwaj, Vasudha Vashishtha

Abstract- Because of the difficulty in recharging or replacing the batteries of each node in a Wireless Sensor Network, the energy efficiency of the system is a major issue in the area of network design. Other critical parameters such as delay, adaptability to traffic conditions, scalability, system fairness, and throughput and bandwidth utilization are mostly dealt as secondary objectives. Some sensor network applications adopt IEEE 802.11-like MAC protocol, which is however, not a good solution for sensor network applications because it suffers from energy inefficiency problem. The adaptive Sensor-MAC (S-MAC) proposes enhanced schemes such as periodic sleep and overhearing avoidance to provide a better choice for different sensor network applications.

In this research paper we propose an energy efficient MAC (EE-MAC) protocol, which is based on adaptive S-MAC with added transmission power control techniques. The main contribution of our work is to introduce a controlled power transmission of RTS, CTS, DATA and ACK frames according to the adaptive S-MAC protocol.

We simulate our proposed protocol i.e., EE-MAC protocol using ns-2.33 simulator for two parameters energy consumption and throughput, for determining

the behavior of the proposed protocol. The simulation results show that our proposed EE-MAC protocol performs better than adaptive S-MAC protocol in terms of energy consumption and throughput.

Keywords: IEEE802.11, S-Mac Protocol, Transmission Power Control, Wireless Sensor Network

I. INTRODUCTION

Wireless sensor networks (WSNs) have gained world-wide attention in recent years due to the current advancements in the area of digital circuitry (i.e., micro-electro-mechanical systems (MEMS) technology) that has facilitated the development of smart sensors.

The sensor networks are highly distributed networks of small, lightweight wireless nodes, deployed in large numbers to sense, measure, and gather information about some physical parameters such as temperature, pressure, or relative humidity, and characteristics of objects and their motion from the environment and based on some local decision process; they can transmit the sensed data to the user.

Each node of the sensor network consists of following four subsystems:

A. **Sensor Subsystem:** It senses the environment.

B. **Processing Subsystem:** It performs local computations on the sensed data.

C. **Communication Subsystem:** It is responsible for message exchange between neighboring sensor nodes.

D. **Power Subsystem:** It provides power for accomplishing above tasks.

Unlike, traditional networks, a WSN have its own design and resource constraints. Design constraints are application dependent and are based on the monitoring environment. Resource constraints include a limited amount of energy, short communication range, bandwidth, limited processing and storage in each node. The distinct features that makes wireless sensor network different from traditional wireless ad hoc networks are outlined below:

A. The number of sensor nodes in a sensor network can be of several orders of magnitude higher than the nodes in an ad hoc network.

B. Sensor nodes are usually densely deployed.

C. Sensor nodes are more prone to failures.

D. Network topology changes very frequently.

E. Sensor nodes mainly use broadcast communication pattern whereas most ad hoc networks are based on point-to-point communications.

F. Sensor nodes are limited in power, computational capacities, and memory.

II. FUNDAMENTALS OF MAC PROTOCOL FOR WSNs

For maximizing the network lifetime, the proposed MAC protocol must be energy efficient. This can be achieved by reducing the potential energy wastes. Types of communication patterns present the behavior of the sensor network traffic that has to be handled by a given MAC protocol; the properties that must be possessed by a MAC protocol to suit a sensor network environment are outlined below:

A.   COMMUNICATION PATTERNS
B.   PERFORMANCE REQUIREMENTS
C.   SOURCES OF ENERGY WASTE

III. RELATED WORK IEEE 802.11

IEEE 802.11 is the standard MAC layer protocol which is proposed for wireless LANs.

This scheme is a contention-based protocol which employs RTS/CTS control packets in order to reduce collision which may occur due to hidden and exposed node problem. Beside, this, it uses both physical and virtual carrier sense mechanism to indicate the free channel. Now we define the terms *transmission range* and *carrier sensing zone* which are used for clear understanding of the proposed protocol.

A. Transmission range: It is the distance between sender node and its neighboring nodes that can receive and correctly decode the packets coming from the sender node. The level of power used in transmission and radio propagation properties (i.e., attenuation) determines the transmission range.

B. Carrier sensing zone: When a node is within the carrier sensing zone, it can sense the signal but cannot decode it correctly. It does not include transmission range because nodes in transmission range can definitely sense the transmission as well as decode it correctly.

However, the IEEE 802.11 technique suffers from energy inefficiency problem. This problem is solved by S-MAC protocol which combines the features of both Contention based as well as TDMA protocols which have been considered as the best provider for energy saving. The TDMA approach schedule transmission times of neighboring nodes to occur at different times. However, the major disadvantage of this technique is that it is not well adaptable to topology changes.
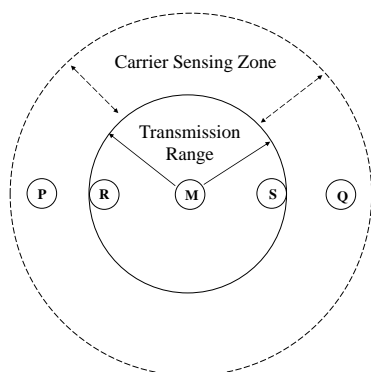

Nodes in the transmission range can receive and decode packets correctly, whereas nodes in the carrier sensing zone can sense a transmission, but cannot decode it correctly.

IV. S-MAC PROTOCOL

The S-MAC protocol is considered to be the first standard MAC protocol which is proposed for WSNs in order to reduce energy consumption by all the sources of energy wastage i.e., idle listening, collision, control overhead, overhearing, and over emitting that were discussed earlier. In exchange the protocol incurs some performance reduction in per-hop fairness and latency. The S-MAC uses multiple techniques to reduce energy consumption, control overhead, and latency, in order to improve application-level performance.

A. Periodic listen and sleep: In S-MAC the energy lost caused by idle listening is reduced by letting nodes to go to in sleep mode periodically (as shown in below *fig.*), instead of constantly listening to an idle channel. When a node is in sleep mode its radio will be turned off, thus conserving energy.
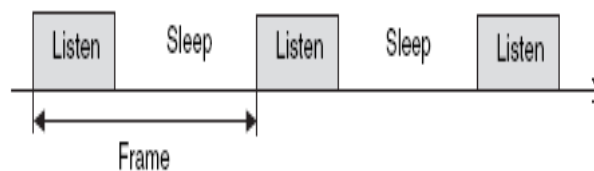
Periodic listen and sleep

B. We call a complete cycle of the listen and sleep intervals, a frame. So,

$$T_{Frame} = T_{Listen} + T_{Sleep}$$

C. Synchronizing schedules: Synchronization between neighboring nodes is accomplished by means of broadcasting SYNC packets which are exchanged periodically between neighboring nodes. In this way, nodes make a cluster sharing in the same schedule. This mechanism allows S-MAC to reduce control packets overhead. Each node in the network is free to choose its own or other nodes schedule by following the steps mentioned below:
  i.   Listen to sufficient amount of time to hear the existing schedule, if not, then, the node chooses its own schedule and broadcasts to its neighbors.
  ii. If a schedule is reserved, it will be followed by the node, then broadcast after a random amount of time to avoid collisions between SYNC packets issued from nodes which select the same schedule.
  iii. Two schedules will be followed if a new schedule is received, and another is followed and broadcasted.

D. Overhearing avoidance: radios are turned off while the shared media is used for transmission between other nodes. However, when a node hears a RTS or a CTS packet and doesn't present the data recipient, it goes to sleep until the current transmission ends.

E. Message passing: This scheme is used to reduce contention latency for sensor network applications requiring store-and-forward processing as data are moved through the network. In S-MAC, the RTS packet allocates the shared medium for transmitting the entire message instead of reserving the medium just for the first fragment like in IEEE 802.11. In later, each fragment and its ACK play the role of RTS/CTS sequence for the next fragment.

A closer look at the periodic listen and sleep scheme reveals that a message may incur increased latency as it is stored and forwarded between adjacent network nodes. To address this shortcoming, the protocol uses a technique referred to as adaptive listening. The basic idea is to let the node which overhears its neighbor's transmissions (ideally only RTS or CTS) wake up for a short period of time at the end of the transmission. In this way, if the node is the next-hop node, its neighbor is able to immediately pass the data to it instead of waiting for its scheduled listen time. If the node does not receive anything during the adaptive listening, it will go back to sleep until its next scheduled listen time.
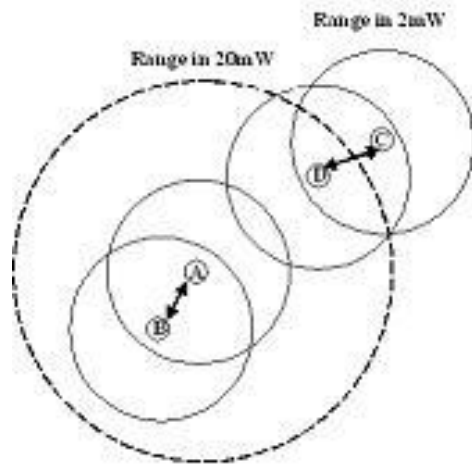
The need for power control

V. TRANSMISSION POWER CONTROL (TPC)

To further reduce the energy consumption TPC techniques need to be applied. It is important in WSN for at least two reasons:

A. It can affect the battery life of the nodes.

B. It can affect the traffic carrying capacity of the network.

TPC techniques improve the performance of the network in several aspects:

A. It improves the reliability of a link by increasing the transmission power upon detecting that the link reliability is below a certain threshold.

B. Only nodes which share the same space will contend to access the medium thereby decreasing the amount of collisions, latency, hidden and exposed terminal in the network while enhancing network utilization.

C. By using a higher transmission power, the physical layer increase the bandwidth in the presence of heavy traffic and by decreasing, it maximizes the energy savings.

A power control mechanism that can be incorporated into the IEEE 802.11 RTS-CTS handshake is proposed in to perform the handshake at the maximum initial power level to avoid packet collision from the interfering nodes. However DATA and ACK packet may be sent at a lower power level. BASIC scheme consumes less energy than IEEE 802.11 MAC protocol.

Until now, the primary goal for wireless sensor networks in general and mainly in MAC has been energy efficiency. Although TPC techniques present an effective mechanism to reduce energy consumption they are still not implemented in any existing MAC protocol because of highly imprecise nature of transceiver readings and limited resources of sensor nodes. This enables us to propose a new *Energy Efficiency MAC (EE-MAC)* protocol which uses the techniques employed in adaptive SMAC with added transmission power control functionality to combine the strengths while offsetting their weaknesses.

VI. PROPOSED ENERGY EFFICIENT MAC (EE-MAC) PROTOCOL

It is based on adaptive S-MAC protocol with transmission power control mechanism. It consist of following steps-

A. Firstly node A in the network broadcast SYNC packet with maximum transmission power i.e. P_{TX_MAX} in order to synchronize its schedule for reducing control overhead. After choosing its schedule either by receiving SYNC-REC packet from one of its neighbors or according to conditions. However, here we assume that each time the node selects its own schedule.

B. When synchronization is done, we divide the transmission power to different levels i.e., from P_{TX_MIN} to P_{TX_MAX}; node A sends an RTS packet to node B, using maximum power.

The power received by destination node separated from sender node by distance *d* is calculated by two-ray ground or two-path model which is as follows:

$$P_r = P_t G_t G_r h_t{}^2 h_r{}^2 / d^4 L$$

Where,

P_t = Transmission power
P_r = Receiving power
G_t = Antenna gains of transmitter
G_r = Antenna gains of receiver
h_t = Height of transmitting antenna
h_r = Height of receiving antenna
L = System loss

The minimum transmission power P_{TX_MIN} that can be received by a node must satisfy the equation (1) and (2):

$$P_{TX\_MAX}/P_r = P_{TX\_MIN}/P_{r\_threshold} \text{ ---------------- (1)}$$
$$P_{TX\_MIN} = (P_{TX\_MAX} * P_{r\_threshold})/P \text{ ----------------- (2)}$$

Where,
$P_{r\_threshold}$ is the minimum necessary received signal strength,
P_{TX_MAX} is the maximum power transmitted, and
P_{TX_MIN} is the minimum power transmitted.

A. The receiver upon receiving the RTS packet calculates the minimum required transmission power level of it i.e., P_{TX_MIN} by using equation (2).The receiver sends the CTS frame with maximum power along with P_{TX_MIN}. Thus nodes M and N that are located in the carrier sensing zones of nodes A and B defer their transmission for a sufficient period of time i.e., EIFS **so** as not to interfere with the RTS-CTS exchange as illustrated in *fig*.

273
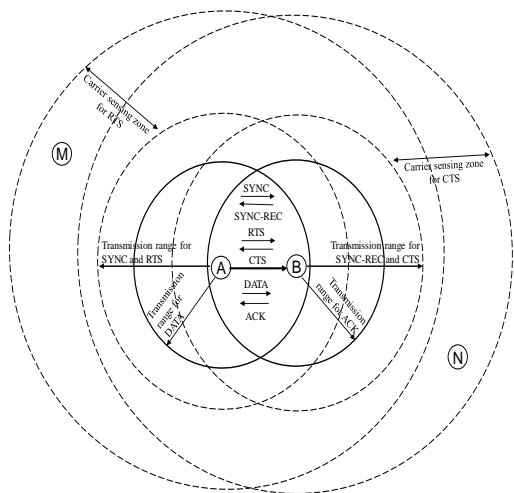
Packet Transmission in EE-MAC Protocol

B. After the RTS-CTS handshake the sender node has the information of the required minimum transmission power. Therefore the DATA and ACK frames are transmitted at minimum required power level.

When source and destination nodes transmit RTS and CTS packets, nodes in the transmission range correctly receive these packets and set their NAVs for the duration of the whole packet transmission. However, nodes in the carrier sensing zone only sense the signal and cannot decode it correctly, so these nodes set their NAVs for EIFS duration (when they sense the channel changing state from busy to idle). The purpose of EIFS is to protect an ACK frame at the source node. The NAV setting and the power level changes for SYNC– SYNC- REC– RTS– CTS– DATA– ACK transmissions are depicted in *fig*.
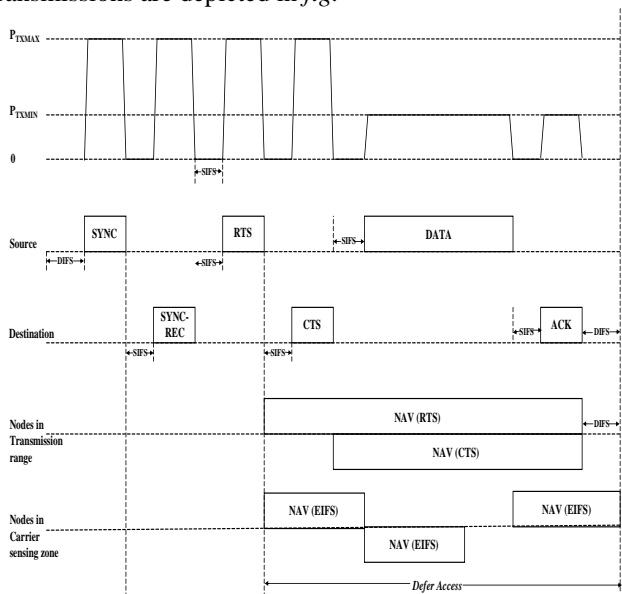
NAV setting and Transmission Power Pattern in EE-MAC Protocol

Building and Updating Power Control Table: Each sensor node stores the values of P_{TX_MIN} for its neighbor and the corresponding P_{TX_MIN} to transmit DATA and ACK frames in the next communication cycle. For this we need power control table as shown in *fig*. below:

neigh_node_id	power_level

Transmission Power Control Table

VI. MODIFIED ENERGY MODEL

To support the simulation of our proposed EE-MAC protocol, we have modified the extended energy model. Major changes have been made in the physical layer (ns-2/mac/wireless-phy.{h, cc}) and the energy model (ns-2/mobile/energy-model.{h, cc}). Energy model is a node attribute that has an initial value which represents the level of energy, the node has at the beginning of the simulation known as *initialEnergy_*. It also gives energy usage for every packet it transmits and receives, known as *txPower_* and *rxPower_* respectively.

VII. CONCLUSION

Wireless sensor networks must be designed keeping energy efficiency in mind. Several protocols have been developed for this purpose, but none can actually fulfill the changing application needs. The S-MAC protocol which is a standard protocol, has received considerable attention due to its energy saving schemes designed for sensor network. The S-MAC protocol saves energy but sacrifices latency. To improve latency, adaptive S-MAC protocol has been developed. In order to further increase the energy savings, we add the transmission power control to the adaptive S-MAC protocol. The adjustment of the transmission power, performed by TPC protocols, is a technique to lessen energy consumption in the communication.

Keeping the same idea in mind, we propose an energy efficient MAC (EE-MAC) protocol which saves energy by broadcasting RTS and CTS packets using full transmission power whereas DATA and ACK packets are sent using minimum required transmission power. For this purpose, we change the energy model of the adaptive S-MAC protocol. We simulate our proposed EE-MAC protocol using ns-2. Our experimental results show that in comparison to adaptive S-MAC protocol, EE-MAC protocol achieves more energy saving and higher throughput.

The work carried out in this research paper gives insight into the performance of the adaptive S-MAC protocol after modifying it by adding transmission power control technique. It can be concluded that current work can contribute to the knowledge in a modest way by simulating and realizing that adaptive S-MAC protocol, indeed will perform better by using controlled transmission power, both by saving energy and increasing throughput.

FUTURE WORK

We modified the adaptive S-MAC protocol by adding transmission power control technique and evaluated its performance in a limited scenario. However, further modifications can be made to evaluate its performance in a larger network context. Some of the modifications are suggested below:
A. The number of nodes can be increased to investigate the protocol behavior under realistic sensor network environments.

B. The proposed protocol can be evaluated for mobile scenarios.

C. TPC algorithm can be devised in mobile application environment.

REFERENCES

1. J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," Copyright © 2008 Elsevier, pp. 2292-2330.
2. C. Shiva Ram Murthy, and B. S. Manoj, "Ad-hoc Wireless Networks: Architectures and Protocols," Copyright © 2004 by Pearson education, Inc.
3. S. S. Kulkarni, "TDMA Services for Sensor Networks," Proc. 24th Int'l. Conf. Distrib. Comp. Sys. Wksps., Mar. 2004, pp. 604-09.
4. Wei Ye, John Heidmann, "Medium Access Control in Wireless Sensor Networks" USC/ISI TECHNICAL REPORT ISI-TR-580, OCTOBER 2003.
5. I. Demirkol, C. Ersoy, F. Alagoz. "MAC protocols for Wireless Sensor Networks: A Survey" IEEE communication magazine, pages 115-121, April 2006.
6. Koen Langendoen, "Medium access control in wireless sensor networks," Vol. II: Practice and Standards edited by H. Wu and Y. Pan, published by Nova Science Publishers © 2007.
7. P. Naik, K. Sivalingam, "A Survey of MAC Protocols for Wireless Sensor Networks," in: C. Raghavendra, K. Sivalingam, T. Znati (Eds.), Wireless Sensor Networks, Kluwer Academic Publishers, 2004.
8. W. Ye, J. Heidemann, and D. Estrin, "An energy efficient MAC protocol for Wireless Sensor Networks," in Proceedings of the 21st International Annual Joint Conference of the IEEE Computer and Communication Societies (INFOCOM 2002), New York, USA, June 2002, pp. 1567-1576.
9. IEEE 802.11, Wireless LAN media access controls (MAC) and physical layer (PHY) specifications, 1999.
10. W. Ye, J. Heidemann, and D. Estrin, "Medium Access Control with Coordinated Adaptive Sleeping for Wireless Sensor Networks," in IEEE/ACM Transactions on Networking, June 2004, pp. 493-506.
11. Jian Xiao, and Fengqi Yu, "An Efficient Transmission Power Control Algorithm in Wireless Sensor Networks," in Proceedings of, 2007, pp. 2767-2770.
12. H. W. Tseng, S. H. Yang, P. Y. Chuang, E. H. Kuang Wu and G. H. Chen, "An Energy Consumption Analytic Model for A Wireless Sensor MAC Protocol", in Proceedings of the IEEE Vehicular Technology Conference (VTC'2004), September 2004, pp. 4533-4537.
13. T. Ezzedine, M. Miladi, and R. Bouallegue, "An Energy-Latency-Efficient MAC Protocol for Wireless Sensor Networks," in Proceedings of International Journal of Electronics, Communications and Computer Engineering, January 2009, pp. 30-35.
14. J. Gomez and A.T. Campbell, M. Naghshineh, and C. Bisdikian, "Conserving Transmission Power in Wireless Ad Hoc Networks," in ICNP'01, November 2001.
15. S. Agarwal, S. Krishnamurthy, R. H. Katz, and S. K. Dao, "Distributed Power Control in Ad-hoc Wireless Networks," in PIMRC, 2001.

AUTHORS PROFILE

Garima Bhardwaj, received B.Tech hons. Degree in Computer Science & Engineering from Uttar Pradesh Technical University in 2009 and is pursuing M.Tech. in CSE from Lingaya's University,Faridabad . Presently, she is working as an Assistant Professor in Computer Science & Engineering department at Lord Krishna College Of Engineering, Ghaziabad. Her area of interest is Network Security.

Vasudha Vashishtha, working as an Assistant Professor in Computer Science & Engineering department at Lingaya's University, Faridabad. Her area of interest is Network Security.