Collision Free and Energy Efficient MAC protocol for Wireless Networks

Muhammad Ali Malik†, Dongha Shin††

†R&D Department, MarkAny Inc., Seoul, 100-400 Korea
††Division of Computer Software, Sangmyung University, Seoul, 110-743 Korea

Summary
In Wireless networks, energy saving is a very important research issue to increase the life time of these networks. In this paper, we propose ES-MAC, a collision free energy efficient MAC protocol for wireless networks. ES-MAC is based on IEEE 802.11. ES-MAC uses power saving mechanism of IEEE 802.11 to save energy consumption. IEEE 802.11 squanders energy and increases latency because of overhearing, over-transmission and packet collisions. IEEE 802.11 does not eliminate the hidden and the exposed terminal problems in multi-hop environment which causes energy consumption and throughput degradation. ES-MAC eliminates these problems by informing, all nodes having logical 2-hop distance from the receiver node, about the data transmission. The receiver centric logical 2-hop message passing mechanism in ES-MAC eradicates the hidden terminal and the exposed terminal problems, which is a key advantage of ES-MAC.
Key words:
MAC protocol, Wireless network, Over-hearing, Over-transmission, Packet collision

1. Introduction

Wireless network devices have limited energy resources. To increase the life time of these networks, energy should be saved at each level. In last few years many research groups have tried to find out the techniques to reduce the energy consumption and to increase the throughput. These research groups have investigated energy preserving mechanism at various layer of the protocol stack including routing layer, MAC layer and transport layer. This paper focuses on MAC layer to reduce the energy consumption and to increase the throughput by eliminating the hidden terminal and the exposed terminal problems during the data transmission.

Energy is very limited in wireless devices and should be saved at each layer of the protocol stack. We propose the ES-MAC protocol which not only saves the energy but also minimizes the latency in a multi-hop environment. ES-MAC is based on IEEE 802.11 protocol and the main focus of ES-MAC is to minimize the packet collisions during the data transmission. IEEE 802.11 protocol has some deficiencies which causes packet collisions and throughput degradation during the data transmission. These packet collisions increase the energy consumption and the latency in wireless networks.

There are three major sources of unnecessary energy consumption. The first one is packet collision. When packet collides at the destination node, it has to be discarded and follow on retransmissions of that packet increases energy consumption and latency. The second source is overhearing, meaning that the node may receive packets which are not destined for it. The third source is over transmission, meaning that the node may transmit packets when the destination node is busy or in a sleeping state. A considerable amount of energy can be saved by eliminating these problems.

In our proposed protocol, we try to minimize overhearing, over transmission and packet collisions by using a 2-hop receiver centric message passing mechanism. 2-hop receiver centric message passing mechanism eliminates the hidden terminal and the exposed terminal problems in a multi-hop environment.

2. Related Work

In IEEE 802.11 PSM, time is divided into beacon intervals. Each node wakes up at the start of each beacon period for a specific time interval called ad-hoc traffic indication map (ATIM) window. Normally ATIM window size is long enough to transmit and receive many ATIM packets [1]. If any node has packets to transmit, it announces packets request during the ATIM window. After receiving the packet announcement, the destination node transmits the acknowledgement packet and both nodes remains awake during the beacon interval. In IEEE 802.11 ATIM window size is fixed. Throughput can be increased by adjusting ATIM window size dynamically [2]. During the ATIM window, control packets are transmitted by using CSMA/CA mechanism. After the ATIM window time period, the nodes start transmitting data packets by using the standard back off procedure.

IEEE 802.11 PSM mechanism has three major problems; fixed ATIM window size, data collision due to the hidden terminal problem and throughput degradation due to the exposed terminal problem. For example, in

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figure 1, when node A has some packets to transmit to node B, it sends the RTS packet to node B. Node C can not hear that packet because node C is out of the sensing range of the RTS packet. In repose to the RTS packet node B transmits the CTS packet. Node C can hear the CTS packet but can not decode it because node C is out of the CTS data range and within the CTS sensing range. Node C would not be able to perform the virtual carrier sensing as it is unable to decode the CTS packet and also unable to perform the physical carrier sensing as it is out of the RTS data range. Node C assumes that medium is idle and may start the data transmission. Data transmission of node C results packet collisions at node B as node B is within the sensing rage of node C. Packet collision increases the energy consumption and decreases the throughput.

In figure 1, while node A is transmitting packets to node B then at that time node D is not able to transmit data packets to any node. Even though node D's transmission does not effect or collide at the receiving node B. This exposed terminal problem in IEEE 802.11 degrades the throughout.

[3] studied three power management protocol based on IEEE 802.11. [4] proposed MAC protocol by using the dual channel radio setup. [5] proposed power saving MAC protocol by allowing nodes to go to sleep mode early, without the need to be awake for the whole ATIM window period. [6] proposed energy efficient traffic adoptive MAC protocol by reducing the packets collisions and by placing the nodes into the sleep mode when they are not transmitting or receiving.

3. Proposed Scheme

ES-MAC is based on IEEE 802.11 DCF mechanism. IEEE 802.11 power saving mechanism divides the time into two intervals, the ATIM window and the data transmission time. During the ATIM window all nodes inform their communication partners to stay awake during the data transmission. All nodes that participate in the data transmission stay awake and all other nodes go to sleep mode during the data transmission time.

IEEE 802.11 wastes energy and increase latency in multi-hop environment. Figure 1 shows the logical partitioning of the transmission area which includes the data range of RTS where RTS packets can be decoded, the data range of CTS where CTS packets can be decoded, the sensing area of RTS where RTS packets can be listened but can not be decoded, the sensing area of CTS where CTS packets can be listened but can not be decoded, the packet collision area where nodes can not perform physical or virtual carrier sensing, the exposed terminal area where nodes can not start transmission even their transmissions do not collide at the destination node. If any node within the packet collision area starts transmitting packets while existing transmission then the packet collision occurs at the destination node. In the exposed terminal area, nodes do not start transmission due to the physical carrier sensing during the data transmission in the RTS range which degrades the throughput.

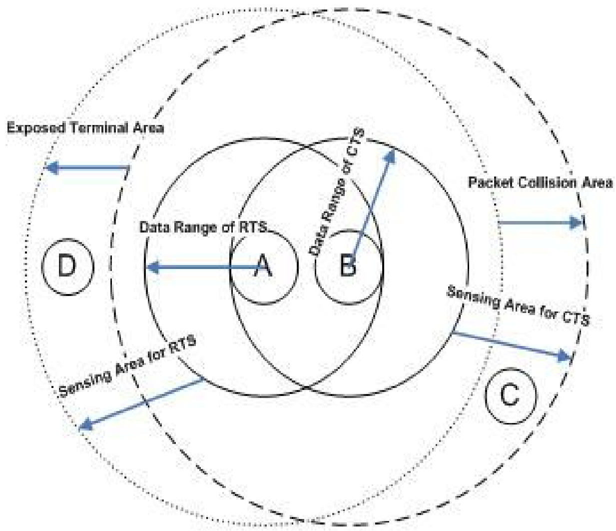

Fig. 1 Quantization procedure for measurement of noise level fluctuation.

ES-MAC uses logical 2-hop receiver centric message passing mechanism to minimize the collision during the data transmission and to increase the network throughput. During the ATIM window, nodes transfer control packets to their communication partners to inform about the data transmission. So all those nodes stay awake after the ATIM window, which participate in the data transmission.

ES-MAC uses a receiver centric 2-hop message passing mechanism. Each node within logical 2-hop distance from the receiver node must be informed about the data transmission. During the ATIM window, the sender node transfers control packet to the receiver node including the time duration required for the data transmission. The receiver nodes transfer ACK packet including the time duration to the sender node. Due to the broadcast nature of the wireless medium, all neighboring nodes receive that control message and use this time duration for virtual carrier sensing. Due to CSMA/CA mechanism in IEEE 802.11, nodes use virtual and physical carrier sensing to detect the data transmission. So all those nodes, which receive the control message use virtual carrier sensing and go to sleep mode during the data transmission. Fig. 1 shows, all nodes with in the data range of the RTS packet receive the control packet from the sender node. All nodes with in the data range of CTS, receive the control packet from the receiver node. In Fig.1 the node C and the node D do not receive message as both nodes are out of the data rang of the control packets. The node C and the node D can only use physical carrier sensing to detect the data transmission. ES-MAC uses 2-hop receiver centric message passing mechanism to inform all nodes having logical 2-hop distance from the receiver node. The control packet, from the receiver node, transfer to all nodes having logical 2-hop distance from the receiver node. Fig. 2 explains the basic mechanism of 2-hop receiver centric message passing. All nodes in fig. 2 are 1-hop away from each other. E.g. in fig. 2, the node B is 1-hop away from the node A and the node C is 2-hop away from the node A. If the node A transmits the ATIM-REQ packet to the node B and the node B transmits the ATIM-ACK packet to the node B then ES-MAC transfers ATIM-ACK packet to the nodes A, C, D and E. All theses nodes are with in the 2-hop distance from the receiver node B. The node F is 3-hop away from the receiver node B and it does not receive ATIM-ACK packet from the node B. The node F uses only physical carrier sensing to determine the data transmission.

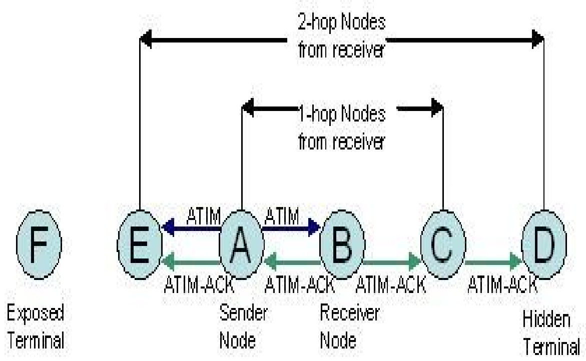

Fig. 2 In ES-MAC; ATIM-ACK packet will be broadcast to all nodes having 2-hop distance from receiver node.

ES-MAC eliminates the hidden and the exposed terminal problems by using a receiver centric 2-hop message passing mechanism. Fig.1 shows the logical partitioning of the transmission area. Any node from the hidden terminal area starts transmission during the current transmission in the RTS data range causes the collision at the receiver node. For example, a packet collision occurs at the receiving node B if node C and node A start transmission at the same time. All nodes in the hidden terminal area have a maximum logical 2-hop distance from the receiver node B. All nodes in the hidden terminal area should be updated about the current data transmission between node A and node B. ES-MAC updates all nodes having a logical 2-hop distance from the receiver node which includes all nodes in the hidden terminal area. Any node from the hidden terminal area does not start transmission as it is updated about the current data transmission. ES-MAC eliminates the exposed terminal problems by informing to all those nodes having a logical 2-hop distance from the receiver node. Fig.1 shows that exposed terminal area is out of the CTS sensing range, which indicates that all nodes in the exposed terminal area are out of 2-hop distance from the receiver node. All nodes in the exposed terminal area can start transmission during the current transmission between node A and node B. For example, node D may start transmission while node A is transmitting data to node B. Node D's data transmission does not cause any collision at the receiver node B as node B is out of the sensing range of the node D. The exposed terminal problem does not occur in ES-MAC.

We can use three different approaches to update nodes having logical 2-hop distance from destination node. We can use blind flooding technique to update nodes. But blind flooding will cause over head due to its blind nature. We can use efficient flooding technique, as proposed in [7], at MAC layer to minimize overhead caused by blind flooding. But this technique requires building neighboring information at MAC layer which can lead toward duplicate information at MAC and routing layer if routing layer is also using this technique. Third we can use efficient flooding by using information from routing layer. We can eliminate over head caused by blind flooding and also eliminate duplicate information at MAC layer by using this method. Drawback of this technique is tight coupling between routing layer and MAC layer. In our simulation we use blind flooding to cover 2-hop neighbors

4. Theoretical Analysis

In this section we provide mathematical analysis of the energy consumption in IEEE 802.11 and ES-MAC protocol.

3.1 Energy Consumption of IEEE 802.11

Total energy consumption of any node is the sum of the energy consumption during the ATIM window time and the time after the ATIM window i.e. (beacon time – ATIM window time), we call it data time T_{data}. We can calculate total energy consumption at any node by using equation 1.

$$E_{node} = E_{ATIM} + E_{data} \qquad (1)$$

E_{ATIM} is the energy consumption during the ATIM window. EATIM can be expressed as

$$E_{ATIM} = E_{tbeacon} + E_{rbeacon} + E_{tctrl} + E_{rctrl} + E_{idle} \qquad (2)$$

Equation 2 shows that the energy consumption during the ATIM windsow is the sum of the energy consumption while transmitting, receiving beacon packets, transmitting, receiving control packets and the energy consumption during the idle state. E_{idle} is the time in which node does not participate in any communication during the ATIM window period. E_{idle} (energy consumption during idle state) can be represented as

$$E_{idle} = P_{idle} * (T_{ATIM} - (T_{tbeacon} + T_{rbeacon} + T_{tctrl} + T_{rctrl})) \quad (3)$$

Where $T_{tbeacon}$, $T_{rbeacon}$, T_{tctrl} and T_{rctrl} are the time required to transmit beacon packets, receive beacon packets, transmit control packets and receive control packets respectively. P_{idle} is the power used by the wireless node during the idle state.

After the ATIM window period, node can go to sleep mode or can involve in the data transmission depending on the control packet exchange during the ATIM window. If the node goes to sleep mode after the ATIM window then the energy consumption of that node will be

$$E_{data\_sleep} = P_{sleep} * T_{data} \quad (4)$$

Where P_{sleep} is the power used by the wireless node during the sleeping state.

If the node does not go to sleep mode after the ATIM window then the node can have any one of three states. Node can be involved in data transmission, data receiving and idle state. Total time after the ATIM window i.e. T_{data} will be

$$T_{data} = T_{tdata} + T_{rdata} + T_{tcts} + T_{rcts} + T_{trts} + T_{rrts} + T_{idle} \quad (5)$$

Where T_{tdata}, T_{rdata}, T_{tcts}, T_{rcts}, T_{trts}, T_{rrts} and T_{idle} are the times used in transmitting data packets, receiving data packets, transmitting CTS packets, receiving CTS packets, transmitting RTS packets, receiving RTS packets and in the idle state respectively. Energy consumption during T_{data} time will be as

$$\begin{aligned} E_{data\_PSM} &= (P_{rdata} * T_{rdata}) + (P_{tdata} * T_{tdata}) \\ &+ (P_{rcts} * T_{rcts}) + (P_{tcts} * T_{tcts}) \\ &+ (P_{rrts} * T_{rrts}) + (P_{trts} * T_{trts}) \\ &+ P_C * ((P_{rdata} * T_{rdata}) + (P_{tdata} * T_{tdata}) \\ &+ (P_{rcts} * T_{rcts}) + (P_{tcts} * T_{tcts}) \\ &+ (P_{rrts} * T_{rrts}) + (P_{trts} * T_{trts})) \\ &+ (P_{idle} * T_{idle}) \end{aligned} \quad (6)$$

Where P_{rdata}, P_{tdata}, P_{rcts}, P_{tcts} P_{rrts} and P_{trts} are the powers used by the wireless nodes while data packets receiving, data packets transmitting, CTS packets receiving, CTS packets transmitting, RTS packets receiving, RTS packets transmitting respectively. PC is the probability of the collision during the data transmission.

3.2 Energy Consumption of ES-MAC

Energy consumption during the ATIM window is slightly higher than IEEE 802.11 if we implement ES-MAC by using the fixed ATIM window. Extra energy is required to pass message with in a 2-hop distance.

$$E_{ATIM\_ES} = E_{tbeaacon} + E_{rbeacon} + E_{tctrl} + E_{rctrl} + E_{msg} + E_{idle} \quad (7)$$

E_{msg} is the energy required to pass message within 2-hop distance from the receiver node.

Energy consumption during T_{data} is lesser than IEEE 802.11 which can be calculated as

$$E_{data\_ES} = (P_{rdata} * T_{rdata}) + (P_{tdata} + T_{tdata}) + (P_{sleep} * T_{Sleep}) \quad (8)$$

So our proposed ES-MAC protocol saves energy as there is no probability of packet collision during the data transmission.

Energy gain of ES-MAC over IEEE 802.11 is the difference of energy consumption by IEEE 802.11 and ES-MAC.

$$E_{gain\_over802.11} = E_{data\_PSM} - E_{data\_ES} - E_{msg} \quad (9)$$

If we subtract equation 8 and Emsg from equation 6, we can get energy gain of ES-MAC over IEEE 802.11

$$\begin{aligned} E_{gain\_over802.11} &= (P_C * ((P_{rdata} * T_{rdata}) \\ &+ (P_{tdata} * T_{tdata}) + (P_{rcts} * T_{rcts}) \\ &+ (P_{tcts} * T_{tcts}) + (P_{rrts} * T_{rrts}) + \\ &(P_{trts} * T_{trts}))) + E_{idle} - E_{msg} \end{aligned} \quad (10)$$

E_{sleep} is a very small amount so we can neglect that amount. Energy gain will be positive if the energy consumption due to the packet collisions and the idle state in IEEE 802.11 will be greater than the energy consumption during the 2-hop message passing in the ES-MAC.

5. Performance Evaluation

5.1 Simulation Environment

In our simulation environment we modified Glomosim[8]. We perform each simulation for 50 seconds based on 30 nodes. Nodes are uniformly distributed in the area and any node can contact to another node within 3-hop distance.

We have assumed that maximum bit rate is 1 Mbps and each node has data transmission range approximately 250m. Sensing rang is almost double than the data transmission range of each node. We used 1.65W, 1.4mW and 0.045W as power used by MAC layer while transmitting, receiving and in sleep state respectively. We used the fix ATM window size as in IEEE 802.11. We use fixed packet size of 512 bytes during our simulation.

5.2 Simulation Result

Figure 3 shows the total number of packets generated by the simulation. These packets include Beacon, ATM, ATM-ACK, RTS, CTS, Data and ACK packets. In the case of ES-MAC, total number of packets generated is lesser than IEEE 802.11 due to absence of the collision during the data transmission.

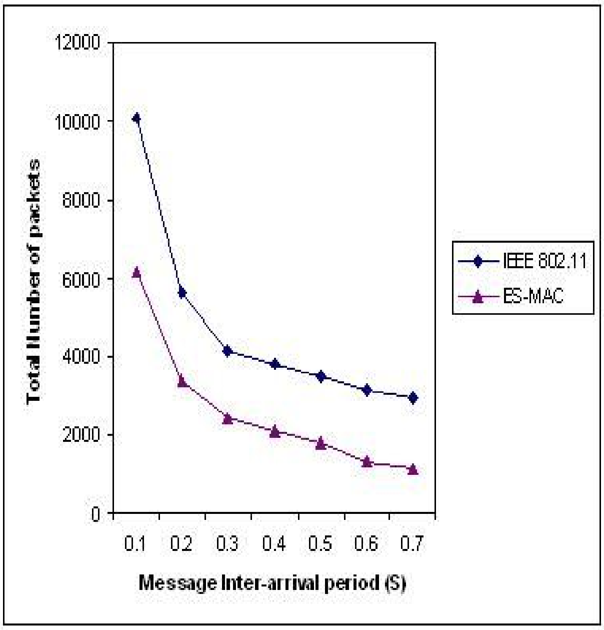

Fig. 3 Total Number of Packets generated by IEEE 802.11 and ES_MAC.

Figure 4 shows the total energy consumption in term of power of IEEE 802.11 and ES-MAC during simulation. ES-MAC consumes less energy than IEEE 802.11 due to less amount of over hearing and packet collisions. ES-MAC saves considerable amount of energy as compare to IEEE 802.11.

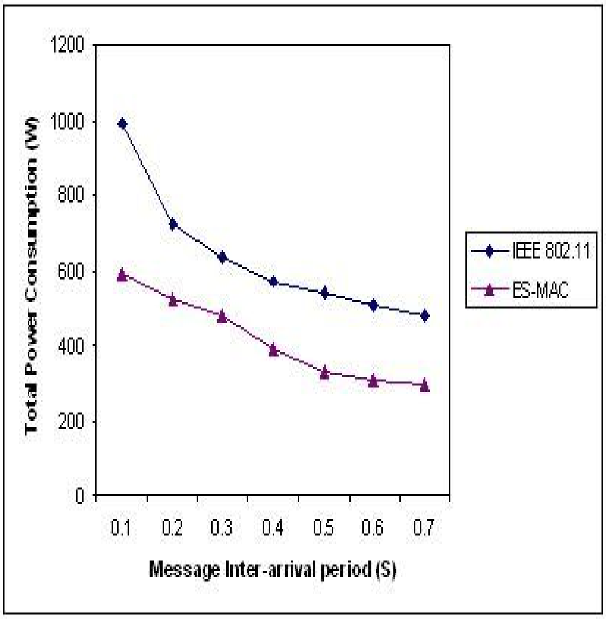

Fig. 4 Total Number of Packets generated by IEEE 802.11 and ES_MAC.

6. Conclusion

In this paper we proposed MAC protocol, ES-MAC, based on IEEE 802.11. IEEE 802.11 has some deficiencies in multi-hop environment. IEEE 802.11 wastes energy resources and decrease throughput due to the hidden terminal and the exposed terminal problems in multi-hop environment. ES-MAC saves energy and increase through put by minimizing packet collision and by eliminating exposed terminal problem. We verified our MAC protocol effectiveness through simulation.

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Muhammad Ali Malik received the B.S. and M.S in Computer Science from University of Management and Technology, Pakistan in 2001 and 2004 respectively. He also received the M.S. in Computer Science from Ajou University, Korea in 2007. He has been a researcher at MarkAny Inc., Korea. His main research interests include Mobile Computing, Ubiquitous Computing and Virtualization.

Dongha Shin received the Ph.D. degree in Computer Science from University of South Carolina in 1994. He received M.S. degree in Computer Engineering from Seoul National University in 1982 and B.S. degree in Electronics from Kyungpook National University in 1980. After working as a member of technical staff in Electronics and Telecommunication Research Institute in Daejeon, Korea from 1982 to 1996, he has been an associate professor of Sangmyung University, Seoul, Korea from 1997. His research interests include Embedded Computing, Compiler Construction, and Virtualization.