Scalable and Energy Efficient Medium Access Control Protocol for Wireless Sensor Networks

[1]Abdul Razaque, *Member IEEE*
Wireless & Mobile Communication Laboratory
University of Bridgeport
Bridgeport, CT-06604, USA
[1]arazaque@my.bridgeport.edu

[2]Khaled Elleithy, Senior Member IEEE
Wireless & Mobile Communication Laboratory
University of Bridgeport
Bridgeport, CT-06604, USA
[1]arazaque@my.bridgeport.edu

Abstract— **Scalable and efficient Medium Access Control (MAC) protocol has been of the paramount significance for boosting the performance of wireless sensor networks (WSNs). In this paper, scalable and efficient medium access control (SE-MAC) protocol is introduced for WSNs. The Goal of SE-MAC is to reduce the communication delay time, channel delay time and control delays caused by acknowledgment packets, request-to-send (RTS), clear-to-send (CTS) etc. Thus, reducing the delays, SE-MAC incorporates the adaptable application independent aggregation (AAIA) model to achieve the expected goals. Furthermore, SE-MAC is supported with handoff process feature, which helps extend the network lifetime. AAIA model for SE-MAC plays a role of cross-layering that extensively reduces the different delays incurred at MAC sub-layer and network layer.**

Evaluation of SE-MAC is conducted using network simulator-2 (NS2) then compared with known MAC protocols: Zebra medium access control (Z-MAC), receiver-initiated asynchronous duty cycle MAC (RI-MAC) and an energy-efficient multi-channel mac (Y-MAC). Based on the initial Simulation results, we demonstrate that SE-MAC protocol saves extra 9.8- 15% time and energy resources for channel delays as compared with other MAC protocols.

General terms: Design; Experimentation; Performance; Algorithms.

Keywords—*MAC protocols; SE-MAC protocol; delays; Wireless sensor networks; adaptable application independent aggregation.*

I. INTRODUCTION

Wireless Sensor networks have been appealing research area since last decade [1] [2]. WSNs comprises of a large number of sensor nodes disseminated in the field of interest for monitoring the different events and activities. WSNs can be deployed from the environmental monitoring to battle field applications [3], [4], [5]. WSNs have not only improved the living standard, but they experience the problems due to limited battery power caused by several delays including channel delays, transmission delays and control delays. The delays affect the channel bandwidth and cause the additional energy consumption. Reducing the delays, the MAC protocols could play an important role in the WSNs when node shares the communication channels.

The significance work is available in [6], [7], [8], [9] to reduce the sleep delays, carrier sense delays, scheduling delays for extending the network lifetime. However, the delays that caused by the data aggregation are not properly handle. A few contributions in [10], [11] attempted to reduce the data aggregation delays, but limited with the MAC sub-layer. Furthermore, some work for handling the data aggregation delays is proposed in [12], [13]. However, restricted with only network layer. Thus, there is a lack of mechanism to reduce the possible delays at MAC and network layers simultaneously when data are being aggregated.

Existing MAC protocols are not capable to cope with such kinds of delays. As result, WSNs experience an additional energy depletion and scalability issues. On the other hand, achieving the quality of service (QoS) provisioning and energy efficiency under assorted traffic conditions; the multi-channel MAC protocols; (Z-MAC), (Y-MAC) and (RI-MAC) for WSNs are introduced to reduce the channel delays .However, these protocols focused on an idle listening and overhearing delays, but marginally touched to the cross-layering delays when aggregating the data.

These are some of the challenges, which need to be addressed when designing scalable and efficient MAC protocol for data aggregation. To address the cross-layering delays such as communication delays, channel delays and control delays; SE-MAC is introduced with support of AAIA model and handoff feature, which focus on the cross-layering delays when aggregating the data from MAC layer to network layer. This contribution reduces the different delays by reducing the energy consumption and prolonging the network lifetime. The remaining of this paper is organized as follows. In section 2, an intra-regional handoff communication process is explained. In section 3, AAIA model is presented. In section 4, initial experimental results are demonstrated and conclusion of the paper is given in section 5.

II. INTRA-REGIONAL HANDOFF COMMUNICATION PROCESS

SE-MAC reduces the communication delays, channel delays and control delays. The communication process follows the 1-hop destination used in [17], [18].

During this process, each node sends a short permeable asynchronously prior to sending the data. This short preamble alerts to 1-hop neighbor nodes to be ready for receiving the data packets. The communication process continues between the sender and 1-hop neighborhood node until the receiver initiates the handoff process. When a node wants to leave the communication or node has to be a short of the energy, then node incorporates the flag in the last sent packets to inform the receiver about its current status. Once, a transmitter receives the packets, then it assumes that the 1-hop communicating node has to leave the communication (handoff) or will lose the energy shortly. As, this situation helps the receiver side to choose another alternate 1-hop neighborhood node prior to happen this situation depicted in Figure 1. Hence, the sensor node is enabled to maintain the QoS by choosing the alternate node before discontinuing the communication with current node. In addition, this process also helps the nodes either join or leave the network that could improve the network scalability. The handoff process is explained in algorithm 1.

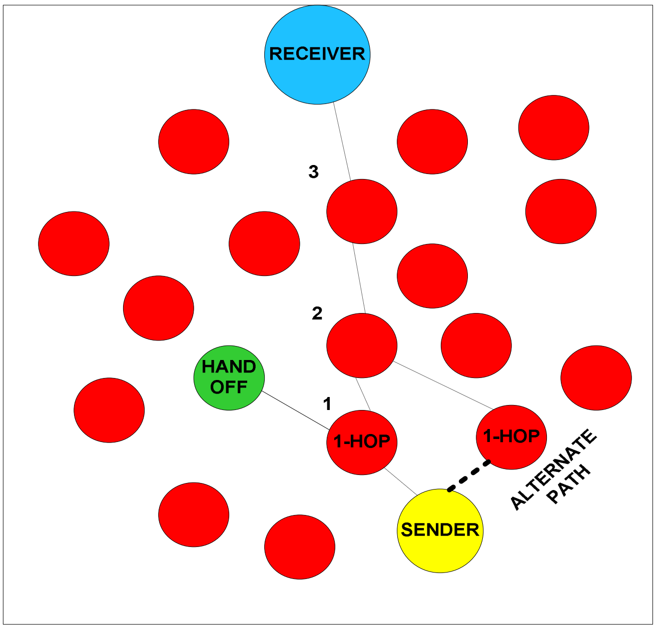

Figure 1: Intra-regional communication handoff process

Algorithm 1: Handoff Process for QoS and Scalability

1. **Input**(S_n: Sender node, R_n: Receiver node, N_n: 1-hop neighbor node)
2. **Output** (A_p: Alternate path)
3. **Parameters** (F_s: Flag signal, E_{loss}: Energy loss , $N_{handoff}$: Handoff process)
4. **Set** S_n initiates the communication with R_n
5. **Set** S_n uses N_n
6. **if** N_n intends to $N_{handoff}$ or has a E_{loss} then;
7. N_n sends F_s embedded in the last packet to S_n
8. **Set** an advance detection process for A_p
9. **else if** S_n continues a communication through N_n
10. **end if**
11. **end else**

In line 4-5, sender node sends the data to the receiver node using 1-hop neighbor node. In line 6-7, if 1-hop neighbor node wants to leave the communication (handoff) or node is lacking the energy, then it embeds the flag signal in the last sent packet. The flag signal indicates to the sender that the node has to handoff or lacks the energy. Subsequently, a sender node starts detecting alternate path to continue the communication without any disturbance explained in line 8. As, this process helps improve the QoS and scalability. In line 9, the sender continues the communication with another alternate 1-hop neighbor node.

III. ADAPTIVE APPLICATION INDEPENDENT AGGREGATION MODEL

We introduce AAIA model to support SE-MAC. The AAIA resides between network layer and MAC sub-layer to provide the cross-layered support for data aggregation. AAIA is entirely independent of application. The primary objective of this AAIA is to address the issues of energy limitation, low bandwidth inherited by sensor technology. Another goal is to employ the AAIA model to utilize the communication channel efficiently. The AAIA aggregates with network layer to reduce the overhead experienced by acknowledgment and other delays.

A. AAIA Design Components

AAIA consists of following three components, which collectively perform the joint task of data aggregation depicted in Figure 2.

- Processing Unit
- Aggregation Function Unit
- Service Access Unit

The processing unit performs the task of packet aggregation and de-aggregation. Whereas, service access unit controls timer setting and fine-tunes to perform the required data aggregation. Once outgoing packets come from the network layer, which are sent to the processing unit. Subsequently, the processing unit forwards the packets to aggregation function unit. The responsibility of aggregation function unit is to apply one of the four addressing methodologies for building the aggregate including anycasting, multicasting, Unicasting, and Broadcasting. Finally, the built aggregated is forwarded to the MAC sub-layer for transmission.

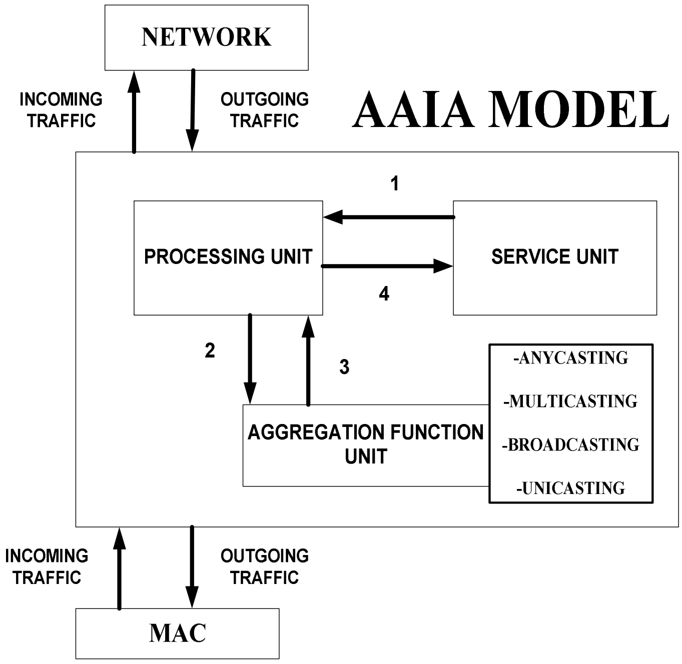

Figure 2: Adaptive application independent aggregation model

The service access unit has to decide how many packets need to be aggregated and when forwarding to MAC sub-layer. Incoming traffic is similar to the out-coming traffic sent by the MAC sub-layer and then forwarded to AAIA. As a result, AAIA re-fragments the coming data packets into its original network unit, then it passes to the router at the network layer. The multiple network unit aggregation turns into a single aggregation to transmit the data, which causes the reduction in channel overhead, transmission overhead and including control overhead packets such as RTS/CTS/ACK and acknowledgment. Single aggregation helps save the contention time on each transmission. Let us calculate the delays incurred by the MAC protocol.

$$\mathbf{M\Delta = M\nexists_c + \sum_{k=0}^{n} k[(\varphi_2) + (\varphi_2), \dots, (\varphi_n) \times t \times C_{delay_{rt}}]} \quad (1)$$

where $M\Delta$: MAC delay for the packets, $M\nexists_c$: MAC delay without collision, $\boldsymbol{\varphi}$: Successful transmission during the number of collisions in period of time ‘t’ and $\boldsymbol{C_{delay\_rt}}$: Total time for collision delay including time incurred for resolving the collision.

Let us assume that several packets from different sensor nodes in particular time interval $'t_{int}'$ are ready for transmission. However, AAIA sends only an average number of packets P_{avg} to compete for the channel to avoid the possible collision. Thus, the number of transmitted packets$'_{tr}'$ at given time with respect to an average collision probability $'P_{col}'$ can be obtained as

$$P_{col} = \{1 - (1 - {}_{tr})^{\frac{1-t_{int}}{P_{avg}}}\} \quad (2)$$

We need to identify the number of an average transmission for the successful packet transmission $'P_{str}'$ that is obtained as

$$P_{str} = \frac{1}{(1 - P_{col})} \quad (3)$$

After successful packet transmission, there is a need to detect an expected number of collision $'E_{col}'$ against each successful packet transmission, which can be calculated as follows

$$E_{col} = \frac{1}{\{1 - (1 - {}_{tr})^{1 - t_{int}/P_{avg}}\}} \quad (4)$$

Combining the equations (1) & (2), we can obtain the approximate correlation $'C_{MAC}'$ between number of aggregated packets and possible protocol delays.

$$C_{MAC} = M\nexists_c + \sum_{k=0}^{n} k[(\varphi_1) + (\varphi_2), \dots, (\varphi_n) \times t \times C_{delay_{rt}}] + \left\{\frac{1}{\{1 - (1 - {}_{tr})^{1 - t_{int}/P_{avg}}\}}\right\} \quad (5)$$

In equation (5), we determine the total delay for communication, channel delay and acknowledgment delay are calculated.

IV. SIMULATION SETUP AND EXPERIMENTAL RESULTS

We simulate SE-MAC, Z-MAC, Y-MAC and RI-MAC using NS2 with Ubuntu 15.04 operating system. The network consists of 270 sensor nodes that are randomly dispersed in the 400 × 400 square meter area. When the simulation starts, the mobile sensor nodes move back and forth in the network area. Each simulation continues for 20 minutes. We deploy the pheromone termite (PT) routing protocol to route the data to detect the shortest route as explained in [19].

We use different size of packets and consider a sensor application module with a constant bit-rate source that helps maintaining the QoS requirements. The detail of simulation parameters is presented in Table 1.

TABLE 1: Simulation parameters and corresponding values

PARAMTERS	VALUE
Size of WSN	400 × 400 square meters
Number of nodes	270
Medium Access Control Protocol	Z-MAC, SE-MAC, (Y-MAC) and (RI-MAC)
Queue-Capacity	40 Packets
Number of aggregation	90
Maximum number of retransmissions allowed	03
Event distances	30 meters
Size of Packets	64, 128,192, 256 bytes
Initial energy of node	4.0 Joules
Sensing Range of node	30 meters
Transmitter Power	13 mW
Receiver Power	14.2 mW
Maximum bandwidth	260 kilobytes/second
Simulation time	20 minutes
Average Simulation Run	12

Based on the simulation, we obtained the initial results to demonstrate the performance of the SE-MAC, Z-MAC, Y-MAC and RI-MAC:

- Time saving based on different number of aggregation and packet sizes.
- Energy saving at different number of aggregation.

A. Time-saving

To validate the AAIA, Figure 3 demonstrates the saving time vs. number of aggregation on the different packet sizes. From the Figure 3, we observe that as the number of aggregation increases, the average saving time also increases significantly. Furthermore, we also observe that as packet size increases, then, time-saving also decreases. This situation happens when data transmission time becomes a high ratio of the entire transmission time. We discovered that when we used a small packet size then we saved more time. As, this discovery confirms if we need to forward the small amount of data over the WSNs, then we need to pick small sized packet.

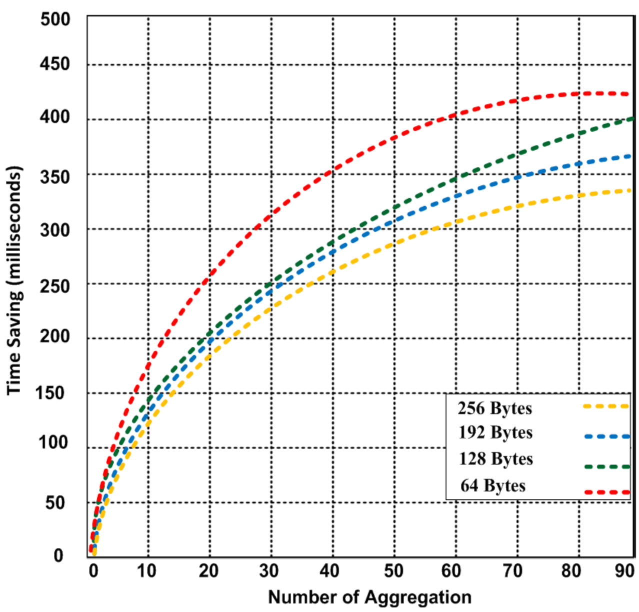

Figure 3: Number of aggregation VS time saving at different packet sizes

B. Energy-saving

In this experiment, we compared the energy-saving capability of SE-MAC, Z-MAC, Y-MAC and RI-MAC using variable number of aggregations. We observed in Figure 4 that SE-MAC saves 0.8 joules as compared with other competing

MAC protocols as saved 0.64- 0.70 joules when increasing the number of aggregations. The initially energy of node is set 5.5 joules for performing 20 complete monitoring cycles. As, the number of aggregation increases then each protocol saves the energy.

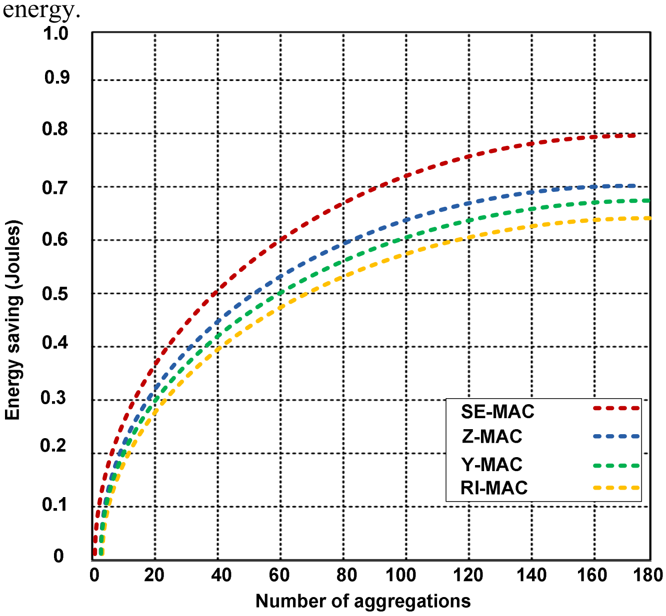

Figure 4: Number of aggregation VS energy- saving with 256 packet size

V. CONCLUSIONS

This paper introduces a SE-MAC protocol to reduce the communication delays, channel delays and control delays over the WSNs. SE-MAC uses AAIA model to reduce these delays. The handoff process is handled using intra-regional handoff communication process. This process could help improving the QoS and scalability.

To demonstrate the soundness of the proposed SE-MAC, we reported some exciting results by using ns2.35-RC7. We have measured the performance of SE-MAC using different number of aggregation and variable data packet-sizes. Based on simulation, we discovered the small-sized packets save more time that could be good choice for improving the QoS in case we require to send small amount of data over the WSNs. Furthermore, SE-MAC is compared with known delay-reducing MAC protocols; Z-MAC, (Y-MAC) and (RI-MAC). Simulation results demonstrate that SE-MAC has consumed less energy as compared with other competing MAC protocols. SE-MAC has saved 9.8-15% more energy resources than other MAC protocols. In the future, we plan to analyze different features of SE-MAC protocol in detail.

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