Energy-Aware SCC Mac Protocol Design For Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks (WSN) is mainly characterized by dense deployment of sensor nodes which collectively transmit information about sensed events to the sink. Energy efficiency is a major concern in the design of Wireless Sensor Networks. Due to the spatial correlation between sensor nodes subject to observed events, it may not be necessary for every sensor node to transmit its data. Hence the spatial correlation can be exploited on the Medium Access Control (MAC) layer. The spatial correlation- based collaborative MAC (SCC-MAC) protocol which aims to reduce the energy consumption of the network by exploiting spatial correlation in WSN. Here the number of nodes sending information about an event is decreased by spatial correlation properties.

The performance of SCC-MAC, SMAC and IEEE802.11a based on Energy Consumption, Packet Delivery Rate and Goodput using Network Simulator (ns-2 v2.29) is analyzed in this project. Sensor-Medium Access Control (SMAC) is a contention-based protocol designed specifically for WSN. In which nodes take turns to sleep and wake-up to listen for a while. In IEEE 802.11, each node keeps listening to all transmissions from its neighbors in order to perform effective virtual carrier sensing. The results show according to Energy Consumption, SCC-MAC is better than SMAC and IEEE802.11a the number of nodes sending information about an event is decreased so less energy is consumed here. Also by considering Packet Delivery Rate, SCC-MAC is better than SMAC and IEEE802.11a because due to less number of packets transmitted to sink collusion is reduced here.

1. INTRODUCTION

Wireless Sensor Networks (WSN) is event based systems that rely on the collective effort of several micro sensor nodes observing a physical phenomenon. Typical WSN applications require spatially dense sensor deployment in order to achieve satisfactory coverage. As a result, several sensor nodes record information about a single event in a sensor field. Due to the high density in the network topology, the sensor records may be spatially correlated subject to an event. The degree of spatial correlation increases with the decreasing inter node separation. Wireless sensor nodes can be powered by batteries, or some form of ambient energy (e.g. temperature differences). Since batteries have only a limited capacity, and ambient energy is limited itself, energy consumption is central in the design of wireless sensor hardware and software.

1.1 RELATED WORK

The information theoretical aspects of the correlation are explored in depth in [8]. More recently, the relation between distortion, spatio-temporal bandwidth and power for large sensor networks is investigated. However, no correlation (spatial or temporal) between sensor observations is considered in [9]. Moreover, none of the above solutions develop communication network protocols.

1.1.1 Spatial correlation

Typical WSN applications require spatially dense sensor deployment in order to achieve satisfactory coverage. As a result, multiple sensors record information about a single event in the sensor field. Due to high density in the network topology, spatially proximal sensors observations are highly correlated with the degree of correlation increasing with decreasing inter node separation.

1.1.2 Temporal correlation

The nature of the energy-radiating physical phenomenon constitutes the temporal correlation between each consecutive observation of a sensor node. The degree of correlation between consecutive sensor measurements may vary according to the temporal variation characteristics of the phenomenon.

2. MAC PROTOCOL DESIGN

2.1 CLASSIFICATIONS

The MAC protocol is classified into two different types: Contention-Free and Contention-Based.

2.1.1 Contention-free MAC

It is based on reservation and scheduling. Each node announces a time slot that it wants to use the coordinator of the network. This coordinator schedules requests and allocates each node its respective time slot. In this way, a node can access the channel without colliding with others because it is the only node which can transmit during its time slot. Bluetooth, TRAMA and LEACH are examples of this type of MAC. This technique guarantees low energy consumption because each node in the network works only during its time slot therefore no collisions. The major disadvantage of this technique is that it is not well adaptable to topology changes and is therefore non-scalable. This MAC protocols for WSN are designed to support low energy consumption. Hence, they do not take the multi-hop latency into account.

2.1.2 Contention-based MAC

It is a protocol where every node accesses the channel in competition. Before transmitting a message, a node listens to the channel to see whether there is already a transmission in the medium. If the channel is busy, it waits for a random time and retries to check out the channel later. If the channel is free, it transmits the message. The most well-known example of this technique is the IEEE 802.11 for wireless LAN network. However, in a sensor network, the devices are small and very sensitive to energy consumption. Therefore, the MAC technique of IEEE 802.11 is not suitable for sensor networks.

S-MAC is considered to be the first MAC protocol proposal for sensor networks which tries to reduce energy consumption. In S-MAC, nodes are periodically set in listen and sleep mode, where the listen time is approximately 10% of the sleep time. In sleep mode, sensors switch off the radio to save energy. Hence, they can save up to 90% of energy compared to the normal protocols where nodes always stay active. Sensors synchronize their communication during the listen period. If a node does not have any messages to send, it switches its radio off during the sleep mode. On the contrary, it switches its radio on to transmit or receive messages. During listen time, sensors access the channel using the carrier sense multiple access with collision avoidance method (CSMA/CA).

2.2 MAC PROTOCOL DESIGN CHALLENGES

2.2.1 Major Sources of Energy consumption

- Collision: The first one is the collision. When a transmitted packet is corrupted due to interference, it has to be discarded and the follow on retransmissions increase energy consumption. Collision increases latency also.

- Overhearing: The second is overhearing, meaning that a node picks up packets that are destined to other nodes.

- Packet Overhead: The third source is control packet overhead. Sending and receiving control packets consumes energy too and less useful data packets can be transmitted.

- Idle listening: The last major source of inefficiency is idle listening i.e., listening to receive possible traffic that is not sent. This is especially true in many sensor network applications. If nothing is sensed, the sensor node will be in idle state for most of the time. The main goal of any MAC protocol for sensor network is to minimize the energy waste due to idle listening, overhearing and collision.

2.2.2 MAC Performance Matrices

- Energy Consumption per bit: The energy efficiency of the sensor nodes can be defined as the total energy consumed / total bits transmitted.

- Average Delivery Ratio: The average packet delivery ratio is number of packets received to the number of packets sent averaged over all the nodes.

- Network Throughput: The network throughput is defined as the total number of packets delivered at the sink node per time unit. This is also called as Goodput.

3. PROPOSED SPATIAL CORRELATION-BASED COLLABORATIVE MEDIUM ACCESS CONTROL (SCC-MAC)

As the nodes exhibit spatial correlation not all the nodes are required to transmit the sensed information to the base station. A SCC-MAC protocol is proposed for spatially correlated wireless sensor network. This protocol based on the correlation selects which of the sensor node has to transmit data to the sink. This node is called the representative node. Iterative Node Selection Algorithm (INS) is executed for each simulation so that representative nodes can easily be identified. Fig: 1 shows block diagram of SCC-MAC protocol. After execution of INS algorithm the representative node executes E-MAC when it has to transmit the data or it executes N-MAC algorithm when it receives a packet which has to be forwarded to the base station.

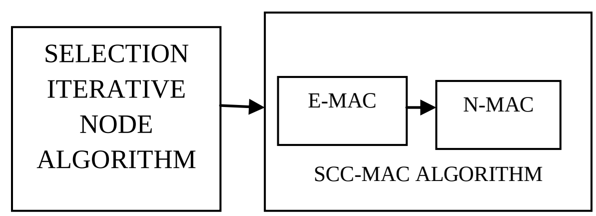

Fig: 1 BLOCKS DIAGRAM FOR PROPOSED SCC-MAC PROTOCOL

3.1 THE ITERATIVE NODE SELECTION (INS) ALGORITHM

The Iterative Node Selection (INS) algorithm is used to find the number and location of the representative nodes in WSN. INS tries to find the ideal locations of representative sensor nodes such that the required distortion can be maintained at the sink. Based on the INS Algorithm results, the SCC-MAC protocol is performed distributive by each sensor node to achieve the required performance. The INS algorithm requires only the statistical properties of the node distribution as input and provides a correlation radius value for distributed operation as output.In order to exploit the spatial correlation between sensor nodes and to improve the performance of the WSN, our MAC protocol tries to create the correlation regions distributive. Note that the INS algorithm determines the representative nodes that would achieve the minimum distortion given the number of representative nodes. However, since this centralized information is not suitable for distributed control, only the correlation radius, r_{corr}, is informed to the individual nodes, so that they try to form the correlation regions in a distributed manner and choose the representative nodes, accordingly. Since the INS algorithm resides at the sink and requires no location information, no additional energy consumption is introduced at the sensor nodes which perform only the SCC-MAC protocol.

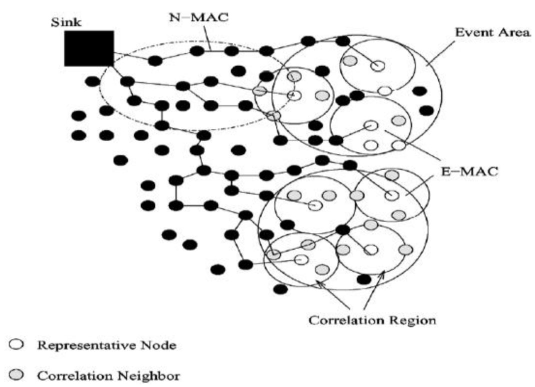

Fig: 2 E-MAC and N-MAC.

3.2 PROPOSED SCC-MAC PROTOCOL DESIGN

The spatial SCC-MAC protocol aims to collaboratively regulate sensor node transmissions. The distortion constraint can be achieved even though the number of nodes sending information about an event is decreased. In order to achieve these goals, the INS algorithm, which resides at the sink, determines the correlation radius, for a distortion constraint. This information is then broadcast to each sensor node during the network setup. The SCC-MAC protocol, which is implemented at each sensor node, then performs MAC distributive. SCC-MAC exploits spatial correlation in the MAC layer by using the correlation radius, to suppress the redundant information from being injected into the WSN. When a specific source node, transmits its event record to the sink, all of its correlation neighbors have redundant information with respect to the distortion constraint. This redundant information, if sent, increases the overall latency and contention within the correlation region, as well as wasting scarce WSN energy resources. Hence, the medium access is performed for two reasons:

- **Source Function:** Source nodes with event information perform medium access in order to transmit their packets to the sink.

- **Router Function:** Sensor nodes perform medium access in order to forward the packets received from other nodes to the next destination in the multi-hop path to the sink.

SCC-MAC protocol contains two components corresponding to the source and router functionalities.

- **Event MAC (E-MAC)** filters out the correlated records

- **Network MAC (N-MAC)** ensures prioritization of route-thru packets.

3.2.1 Packet Structure

The RA of the RTS frame is the address of the STA on the wireless medium that is the intended immediate recipient of the next Data or Management frame. The TA is the address of the STA transmitting the RTS frame. The Duration value is the time, in microseconds, required to transmit the next Data or Management frame, plus one CTS frame, plus one ACK frame, plus three SIFS intervals.

RTS Packet Structure CTS Packets Structure

FRAME CONTROL	DURATION	RA	TA	**FH**	**FCS**

FRAME CONTROL	DURATION	RA	**FH**	FCS

DATA Packet Structure

MAC HEADER	**FH**	FRAME BODY	FCS

Fig.3 Structures for RTS, CTS and DATA packets

When a sensor node records an event, it sets the FH field of the RTS and DATA packets related to the transmission of the sensor record. All nodes overhearing the RTS with FH field set, determine that the transmission is related to source functionality and perform E-MAC. Once a node receives the DATA packet, it clears the FH field, indicating that the packet is a route-thru packet. The node, then, simply forwards the packet to the next hop. Nodes accessing the medium for router functionality do not set the FH field in their RTS packets and perform N-MAC.

3.3.2 Event MAC (E-MAC)

All sensor nodes contend for the medium for the first time so that the representative nodes are selected by the help of the spatial-reuse property of the wireless channel. This initial phase is called as the first contention phase and is explained as follows.

• First Contention Phase (FCP): In the first contention phase, all nodes with event information contend for the medium for the first time using

RTS/CTS/DATA/ACK structure. Access the channel while others have to backoff.

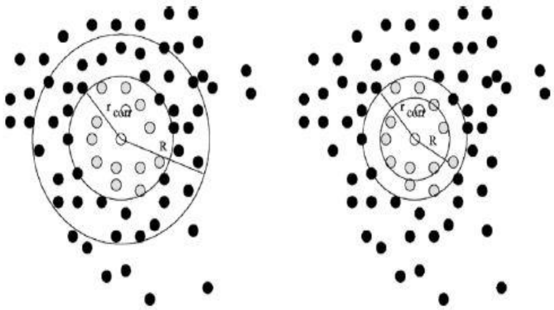

Fig. 4 Two cases for E-MAC. The figure shows two cases for correlation region, r, and transmission region, R.

The protocol procedure for the correlation neighbors depends on the relation between the transmission range, R, of the sensor nodes and the correlation radius, r_{corr}. Hence, all the correlation neighbors of the node can hear the transmission of node n_i. As a result, the redundancy due to correlation can be totally removed by the already ongoing transmission from the representative node. However, in the case when $r_{corr} > R$, some of the correlation neighbors of node cannot hear the transmission of node . Hence, the redundancy cannot be filtered out completely with respect to the total distortion constraint.

3.3.3 Network MAC (N-MAC)

When a packet is routed to the sink, it may traverse through nodes corresponding to other concurrent events. However, since the correlation has already been filtered out using E-MAC, the route-thru packet must be given priority over the packets generated by another concurrent event. This is the reason why we need a Network MAC (N-MAC) component.When an intermediate node receives a DATA packet, it performs N-MAC to further forward that packet to the next hop. The route-thru packet is given precedence in two phases. When a correlation neighbor receives an RTS regarding a route-thru packet during the random listening period of the SSS, it switches from SSS to receive state and receives the packet. During the transmission, the representative node defers its transmission and the route-thru packet is received by the correlation neighbor.

6. RESULT AND CONCLUSION

6.1 RESULT

Proposed SCC-MAC protocol is implemented in NS2 simulator and it is compared with already existing MAC S-MAC and IEEE 802.11 protocol.The following parameters were considered for simulation

Table 6.1 Parameters to be considered

Channel	Wireless channel
Propagation	Two Ray propagation
MAC protocol	SMAC,IEEE802.11&SCC-MAC
Queue	Priority queue
Queue length	150
Antenna	Omni antenna
Area	1000*1000
Number of nodes	10,20,30,40and50
Initial Energy	1000 joules
Routing protocol	AODV
Simulation time	20 seconds

The simulation results for sensor topology of 10 nodes and 50 nodes randomly deployed in a sensor field is presented. The sensor nodes are modeled according to the wireless node module and energy model. The transmission range of each node is 100 m. Each simulation is performed for 20 s.

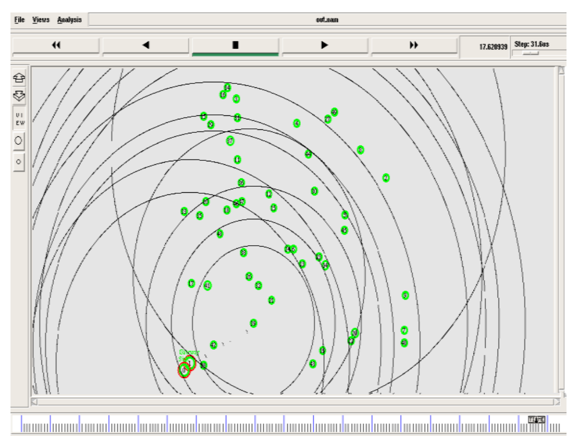

Figure.5 50nodes transmitting data to sink node

Figure.5 shows there are 50 sensor nodes transmitting their packets to sink node, before packet transmission acknowledgement signals are transmitted.

6.1.1 Average Energy Consumption

Average energy of a node is computed. From Fig.6, In IEEE 802.11, each node keeps listening all transmissions from its neighbors in order to perform effective virtual carrier sensing, which is a significant waste of energy. In S-MAC nodes go into periodic sleep mode during which it switches the radio off and sets a timer to awake later. The energy consumption is reduced in SCC-

MAC number of nodes sending the information is reduced due to correlation of the data.

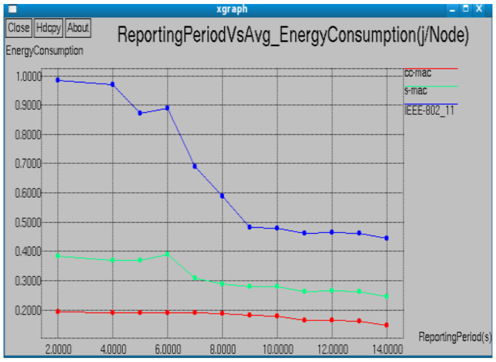

Figure 6 Average Energy consumption

6.1.3 Packet Drop Rate

This metric shows the performance of the MAC protocol in terms of medium access overhead introduced in terms of wasted number of packets. Packet drop ratio is inversely proportional to packet delivery.

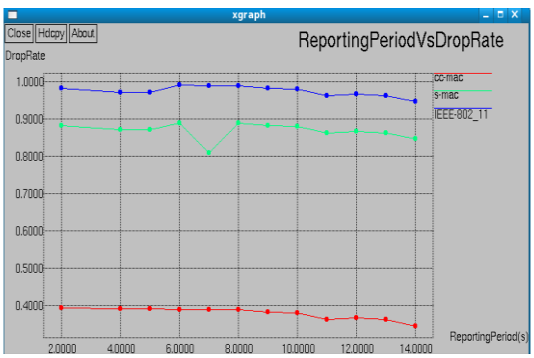

Figure.7 Packet Drop Rate

From Fig.7 SMAC nodes go into periodic sleep mode during which it switches the radio off and sets a timer to awake later so that it leads to drop some of the packets during its sleep mode but in SCC-MAC the nodes are always in active so it never drops the packets

6.2 CONCLUSION

Exploiting spatial correlation at the MAC layer is a powerful means of reducing the energy consumption in WSN under collective performance limits. This can be achieved by collaboratively regulating medium access so that redundant transmissions from correlation neighbors are suppressed. By allowing only a subset of sensor nodes to transmit their data to the sink, the proposed MAC protocol not only conserves energy, but also minimizes unnecessary channel access contention and thereby improves the packet drop rate without compromising the event detection latency.

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