Design and Development Cross Layer MAC-Routing Protocol framework for Wireless Sensor Networks

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***Abstract*— The performance of Cross Layer MAC protocol for wireless sensor networks evaluated in different networks scenarios. We compare the performance of Sensor-MAC (S-MAC) and Cross Layer MAC protocol using NS2 Simulations. An efficient cross layer Medium Access Control (MAC) protocol is critical for the performance of a Wireless Sensor Network (WSN), especially in terms of energy consumption and self configuration. The interactions between MAC and Routing layers are fully exploited to achieve energy efficiency for wireless sensor networks. In Sensor Networks environments per-node fairness and latency is less important. S-MAC uses in-channel signaling to avoid overhearing unnecessary traffic. The paper presents performance analysis of S-MAC protocol and Cross Layer MAC with varying traffic load and network density. Our result shows that Cross MAC obtain significant energy savings compared with an S-MAC MAC without sleeping. The source node with cross layer MAC consumes less energy than S-MAC for different traffic loads, use this document as an instruction set.**

***Index Terms*—S-Mac, Energy Efficiency, Medium Access Control, Sensor Network, Cross Layer, Routing Protocol**

I. INTRODUCTION

IMPROVEMENTS in hardware technology have resulted in low cost sensor nodes, which are composed of a single chip embedded with memory, a processor and a transceiver. These devices are multiprocessing sensors, which are able to process data and communicate in a wireless manner, within short distances, with each other. Low-power capacities lead to limited coverage and communication range for sensor nodes compared to other mobile devices. WSNs have met a huge growth and have significant future prospects of evolution, meeting applications from medical, environmental surveillance, robotics, military, smart vehicles and domestic areas. The main reasons for this growth are the high fault tolerance, fast deployment and self-organizing capabilities of WSNs, as well as their low cost and high density of deployment, which does not affect the functionality of the application when sensor nodes fail or are destroyed. Other business applications of WSNs include climate control in buildings and interactive games. Hence, for example, in target tracking and border surveillance applications, sensor networks must include a large number of nodes in order to cover the target area successfully. The primary objective in wireless sensor networks design is maximizing node/network lifetime, leaving the other performance metrics as secondary objectives. Since the communication of sensor nodes will be more energy consuming than their computation, it is a primary concern to minimize communication while achieving the desired network operation.

The medium access decision within a dense network composed of nodes with low duty-cycles is a challenging problem that must be solved in an energy-efficient manner. Keeping this in mind, we first emphasize the peculiar features of sensor networks, including reasons for potential energy waste at medium-access communication.

WSNs consist of tens to thousands of distributed autonomous nodes, which form a wireless multi-hop network and are placed near or inside the area of interest. Each node contains the sensor or sensors unit, a digital-to-analog converter, a processor, a low consumption transceiver and a power supplier [1]. They might also contain a Global Positioning System (GPS) system, a power generator or a motion system. The deployment phase in most cases is random, which means that protocols for WSNs must provide self-organizing capabilities. All nodes are trying to coordinate with their closest neighbors in order to achieve a common task. The network processing is used to reduce the size of traffic.

Regarding communication protocols, many solutions have been proposed from the scope of ad-hoc networks, but they cannot meet the needs of WSNs because sensor nodes are prone to failures, have constrained processing capabilities and energy, the number is often significantly larger than the corresponding number of nodes in ad-hoc networks, they have a high level of denseness and their topology changes often.

Moreover, sensor nodes use broadcast communication with each other while in ad-hoc networks point-to-point communication is preferred. Also sensor nodes may not have a global ID because of their large number and in order to reduce overhead.

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An efficient MAC protocol for WSNs should minimize collisions and give priority to the reduction of the nodes' energy consumption, thus prolonging network lifetime. MAC protocols should also provide reduced latencies, high throughput and bandwidth utilization.

There has been recent trend on developing energy efficient MAC protocols in wireless sensor networks [25]. They are generally based on a mechanism of turning off their radio transceivers whenever they are not involved in transmission. They mainly focused on how to optimize the MAC layer's energy efficiency without fully exploiting the potential synergies of the interaction among different layers. In this paper, we instead follow a cross-layer design approach and propose a new MAC protocol framework that utilizes a routing policy information from the network layer. This increases the overall performance gain in terms of energy efficiency which be maximized. The basic idea of the proposed Cross Layer MAC is to minimize the number of nodes that are supposed to wake up when their NAV (Network Allocation Vector) value expires. Remind that, by using NAV information of RTS/CTS packets sent by a data source and a destination, a shared wireless medium can be reserved during the time for exchanging their data packets. Other nodes except for these two communicating nodes are supposed to enter a sleep mode, which is very good for saving their energy sources.

The provision of energy-awareness resides next to the reduction of energy consumption by the nodes. To accomplish that, a MAC protocol must reduce collisions, overhearing, control packet overhead and idle listening. The last factor is especially significant, as nodes often need to hear the channel for possible reception of data, like in the 802.11 family of protocols. The research group of the CROSS MACb showed that the consumed energy ratios are *1:2:2.5* for *idle listening: reception: transmission*, respectively [2]. As WSNs need to support applications for long periods of time, sensor nodes must "sleep" for as long as they can. The trade-off between minimized energy consumption and deterioration in delays, throughput and efficiency is clear and different from the CROSS MAC family of protocols, where bandwidth utilization is the primary target. A power-save mode, such as the one used in CROSS MAC, is necessary but in WSNs a more aggressive policy is needed to ensure maximum energy conservation.

In this work we discuss the efficiency of Cross Layer MAC and S-MAC [3], a well known MAC protocol especially designed for Wireless Sensor Networks, and we do the study on the protocol via an extensive simulation, in both the cases of simple and complicated topologies, Cross Layer MAC outperforms SMAC in terms of energy conservation. The section II of this paper describes the overview of MAC protocols used in our simulation. Section III provides description of the simulation environment, Section IV gives the results and finally we conclude the paper.

II. MAC PROTOCOLS

A. Sensor MAC Protocol (S-MAC)

Sensor MAC (S-MAC) protocol is a new MAC protocol explicitly designed for wireless sensor networks. While reducing energy consumption is the primary goal in our design, our protocol also has good scalability and collision avoidance capability. It achieves good scalability and collision avoidance by utilizing a combined scheduling and contention scheme. To achieve the primary goal of energy efficiency, we need to identify what are the main sources that cause inefficient use of energy as well as what trade-offs we can make to reduce energy consumption.

We have identified the following major sources of energy waste. The first one is *collision*. When a transmitted packet is corrupted it has to be discarded, and the follow-on retransmissions increase energy consumption. Collision increases latency as well. The second source is *overhearing*, meaning that a node picks up packets that are destined to other nodes. The third source is *control packet overhead*. Sending and receiving control packets consumes energy too, and less useful data packets can be transmitted. 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, nodes are in idle mode for most of the time.

An important feature of wireless sensor networks is the in network data processing. It can greatly reduce energy consumption compared to transmitting all the *raw* data to the end node. In-network processing requires store-and-forward processing of messages. A message is a meaningful unit of data that a node can process (average or filter, *etc.*). It may be long and consists of many small fragments. In this case, MAC protocols that promote fragment-level fairness actually increase message-level latency for the application. In contrast, message passing reduces message-level latency by trading off the fragment-level fairness.

B. Cross Layer MAC

To provide an efficient and robust network in a wireless environment for a collection of mobile stations, the CROSS MAC working group has chosen the *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA) protocol as the standard protocol for wireless *local area networks* (LANs). The CSMA/CA protocol is a random access protocol that is subjected to collisions. In the case of a collision, each mobile station executes the *Binary Exponential Backoff* (BEB) retransmission algorithm to resolve the collision and maintain the stability of the CSMA/CA channel. The standardization of the CROSS MAC *Medium Access Control* (MAC) protocol has triggered significant research on the evaluation of its performance [2-5].

According to CROSS MAC, stations access the channel using a *basic access method*, or an optional *four-way handshaking access method* with an additional Request-To-Send/Clear-To-Send (RTS/CTS) message exchange. Under

the basic access method, a station, when ready for a new data frame transmission, first senses the channel status. If the channel is found to be busy, the station defers its transmission and continues to sense the channel until it is idle. After the channel is idle for a specified period of time called the distributed inter frame space (DIFS) period, the station choose a random number as a backoff timer. Note that the time immediately after the DIFS period is slotted. As shown in Figure 1, the timeslot duration is at least the time required for a station to detect an idle channel plus the time required switching from listening to transmitting mode. The backoff timer is decreased by one for each idle slot, stopped if the channel is sensed busy, and then reactivated if the channel is idle again and remains idle for more than a DIFS time duration. When the backoff timer reaches zero, the data frame is transmitted.

The choice of the random number for the backoff timer is based on the binary exponential backoff algorithm, where a station chooses any of the numbers between 0 and *CW*-1 randomly with equal probability. The Contention Window (*CW*) is set to be *CWmin* for every new data frame transmission. *CW* is doubled each time when the transmission is unsuccessful, until it reaches *CWmax*, then it remains at *CWmax*. To determine whether a data frame transmission is successful, after its completion, a positive acknowledgement (ACK) is transmitted by the receiver. ACK is transmitted after a short inter frame space (SIFS) period when successfully receiving the entire data frame. If ACK is not detected within a SIFS period after the completion of the data frame transmission, the transmission is assumed to be unsuccessful, and a retransmission is required.

The basic of idea of Cross Layer MAC is to minimize the number of nodes that are supposed to wake up when their NAV (Network Allocation Vector) value expires. When the node NAV timers expire, all the sleeping nodes must be awake regardless whether they are willing to participate in the packet transmission or not. This mandatory and compulsory wake-up strategy may cause some negative effect on energy saving when some nodes which are not supposed to be involved in the upcoming transmission phase and they will come back to their sleep mode again. This problem is solved by making only a subset of nodes perform such a compulsory wake-up. The subset nodes are the ones whose NAV value becomes expired but also the current location is along a routing path from source to a destination. The other nodes which do not belong to the routing path can stay in their sleep mode until the beginning of the next duty cycle. The cross layer design approach is used to decide which node is on the routing path and routing information is utilized by the MAC layer.

The proposed Cross MAC scheme make use of NAV timer and CTS/RTS control frames at MAC layer and it also adds routing information through routing agent. The modification of control frames is done to inform a node the fact that its state is changed to listen or sleep period. The modified control frames carries routing information about the next hop addresses and congestion status. The receivers routing agent will be able search for next hop related details.

III. Simulation Environment

A. Performance Metrics

We have considered energy consumption (in Joules) as important metrics for the analysis of the results obtained. The main goal of the experimentation is to measure the energy consumption and Life Time generated when node density, traffic and pause time are varied. The energy consumption is measured for two MAC protocols: S-MAC and Cross Layer MAC. To measure the energy consumption on the node, we measure the amount of time that node spent in different modes: sleep, idle, receiving or transmitting. The energy consumption in each mode is then calculated or traced at the end of the simulation. We measure the energy consumption of each node when utilizing different MAC protocols and under different traffic loads. The topology is created for two nodes in the beginning and nodes are added gradually into the network. The traffic is changed as and when nodes are added into the networks.

B. Simulation Setup

The network consists of 100 nodes initially in a 1500m x 1000m rectangular field. The nodes density is increased to 200, 300, 400 and 500 nodes. The MAC layer was based on Cross MAC and S-MAC protocols. The interface queue at MAC layer could hold 150 packets. The nominal bit rate is 1 Mbps and transmission range is 150 m. The routing buffer at the network layer could store up to 256 data packets. The random waypoint model was used with maximum node speed of 5 m/s. The traffic loads can be illustrated either varying the number of connections with fixed packet rate or varying the packet rate with fixed number of connections. The simulations were run for 900 seconds with multiple connections generated. For each connection, the source generated 512-byte data packets at a constant bit rate (CBR).

IV. Results and Analysis

In figure 1 the energy consumption of nodes using S-MAC is very less when compared to the Cross MAC. In the beginning the nodes show moderate or same level that of S-MAC, but later there is significant drop of energy consumption in case of Cross MAC. The energy consumption is almost consistent.

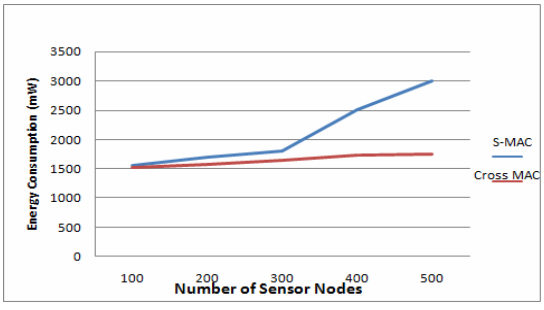


Fig 1. Energy Consumption vs. Number of Nodes

This is because of more energy consumption by the CROSS MAC. In the CROSS MAC the fragments of messages are not sent in burst. This creates lots of CTS/RTS frames which consume more energy. In case of S-MAC module with periodic sleep, each node is configured to operate in 50% duty cycle.

The fig 2 shows the enhancement of Life time during the simulation. The AODV routing protocol is used in the experiment. The increase in the nodes results in less life time when traditional S-MAC is used.

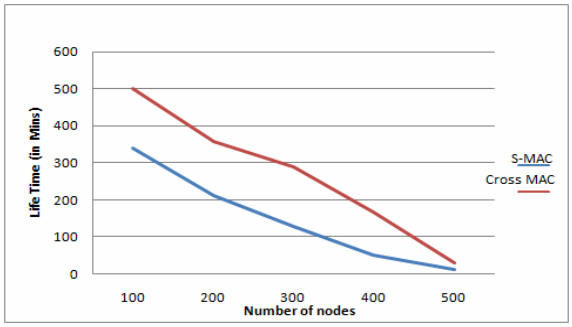


Fig 2. Life time vs. Number of Nodes

When Cross MAC is used, the life time of sensor nodes are very high and consumption of energy is less. This is because, Cross MAC adopts saving of energy levels and overhearing during transmission.

In another scenario, the energy consumption and Life Time are measured with respect to the traffic generated in the network. In fig 3, energy consumption is measured against varying the traffic loads. The many sources are added to the network and energy consumption is measured. When many sources are added, there may be a constraint situation where traffic is routed to one destination. The CROSS-MAC shows no change or less change in energy consumption when compared to S-MAC. This is due to increase in the traffic load which leads to low bandwidth utilization and Listen significantly longer than clock drift resulting in poor performance.

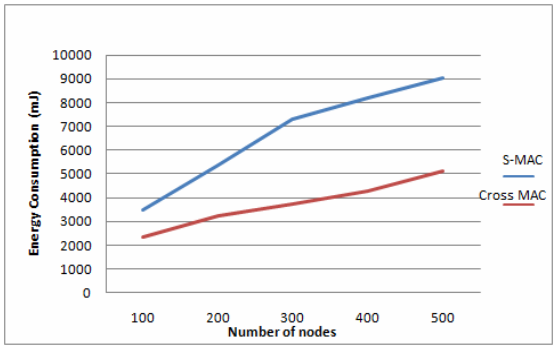
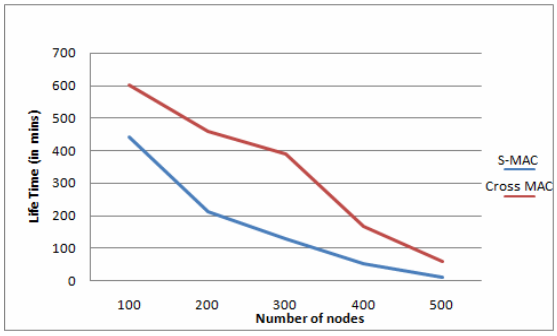


Fig.3. Energy Consumption vs. Number of Sources (Constraint Case)

The fig 4 shows the enhancement of Life Time during the simulation in constraint case. The AODV routing protocol is used in the experiment. The increase in the sources results in lesser Life Time of sensors when traditional S-MAC is used.

Fig.4. Life Time vs. Number of Sources (Constraint Case)



When compared with S-MAC, message passing with overhearing avoidance saves almost the same amount of energy under all traffic conditions. The CROSS-MAC with adaptive listen achieves better energy efficiency than the one without adaptive listen, especially when traffic load is heavy. The main reason is that the adaptive listen largely reduces the overall time needed to pass the fixed amount of data through the Cross layer of the network.

V. Conclusion

Wireless sensor networks use battery-operated computing and sensing devices. A network of these devices will collaborate for a common application such as environmental monitoring. We expect sensor networks to be deployed in an ad hoc fashion, with individual nodes remaining largely inactive for long periods of time, but then becoming suddenly active when something is detected. These characteristics of sensor networks and applications motivate a MAC that is different from traditional wireless MACs such as CROSS MAC in almost every way: energy conservation and self-configuration are primary goals, while per-node fairness and latency are less important. CROSS MAC uses three novel techniques to reduce energy consumption and support self-configuration. The results show that there is minimum amount of energy consumption as compared to S-MAC. CROSS MAC is an excellent choice for communication within a sensor network. It is suitable for a variety of applications including as path tracing, sensing some changes in an environment etc.

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