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Improved Energy and Latency Efficient MAC Scheme for Dense Wireless Sensor Networks

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Abstract - The sensor nodes in the wireless sensor networks have limited battery power, which motivates to work on energy conserved MAC schemes for better lifetime and latency efficient. Previous work carried out in energy conserved MAC schemes are limit the idle listening time, reduces overhearing (sensor node hear a packet destined for other nodes) and minimizing the used control packet size. The current existing work presented ELE-MAC (i.e. Energy Latency Efficient MAC) which adopts less control packets to preserve energy in sparsely distributed sensor nodes of the wireless sensor networks. It performs statistically the same or better latency characteristic compared to adaptive SMAC. ELE-MAC follows the adaptive listening technique, which reduce the sleep delay introduced by the periodic sleep of each node in case of a multi-hops network. The proposal in this work, extends the ELE-MAC to work efficiently with wireless sensor network comprises of high node density by combining the RTS and SYNC control packets. The extended version uses two separate frequencies for data and control packets to avoid the use of handshake mechanisms (e.g. RTS/CTS) in order to reduce energy consumption and packet delay. It enables a receiver to send a busy tone signal on the control channel and notify the neighbors about the ongoing reception of data in progress. This process avoids packet collisions and in turn improves the node lifetime and throughput. The nodes in a sensor network have their own different traffic loads according to the tasks assigned and their locations. The extension of ELE MAC adopts the different traffic loads of each node as performance metric for reducing the latency. Each sensor node calculates its utilization after the last synchronization time, and adjusts its duty cycle according to the calculated utilization, and then send new schedule to its neighbors via broadcasting.

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IMPROVED ENERGY AND LATENCY EFFICIENT MAC SCHEME FOR DENSE WIRELESS SENSOR NETWORKS

Strictly as per the compliance and regulations of:

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The proposal in this work, extends the ELE-MAC to work efficiently with wireless sensor network comprises of high node density by combining the RTS and SYNC control packets. The extended version uses two separate frequencies for data and control packets to avoid the use of handshake mechanisms (e.g. RTS/CTS) in order to reduce energy consumption and packet delay. It enables a receiver to send a busy tone signal on the control channel and notify the neighbors about the ongoing reception of data in progress. This process avoids packet collisions and in turn improves the node lifetime and throughput.

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I. Introduction

Wireless sensor network (WSN) is a collection of sensor nodes that interact with each other intentionally to gather information from the surveillance area. Sensor nodes support unattended operation for long duration, usually in remote areas. WSN applications such as environmental monitoring [1], object tracking [2] and intelligent buildings [3] require a reliable data transmission and can endure long periods of operation. The limitation of sensor nodes are low processing capabilities (delay attenuation), low power battery and low memory capacities which initiates to improve those constraints in increasing the network life time of wireless sensor networks.

Medium access control (MAC) layer manages the medium accessibility to minimize collision among transmitting packets. Packet collision requires node to retransmit the packet, hence consuming additional energy. MAC layer controls the physical (radio transceiver) layer which has greater effect on overall energy consumption and lifetime of a node. The nodes sometimes falsely assumed that the channel is in idle condition and start the transmission which results in data collision lead to more energy requirement. In some cases nodes are exposed due to out of receiver range which leads to overhearing and increases the delay of transmission. In few other cases nodes receive one of two simultaneous transmissions, which creates complex traffic load control. The idle listening of a sensor node due to continuous listening of the channel to receive a potential packet from its neighboring nodes consumes more energy.

Energy inefficiency caused by the idle-listening problem and high collision probability can be avoided in Time Division Multiple Access (TDMA) based MAC protocols. The existing work presented an ELE-MAC Energy Latency Efficient MAC with distributed TDMA mechanism which possesses an active/sleep mechanism for efficient energy usage with predefined duty cycle. However the ELE-MAC work on different traffic load condition affects the overall network lifetime of the sensor network. In this paper, we presented an improved version of ELE-MAC which works on balancing the different traffic load conditions of the sensor node transmission on the target object being detected.

II. Literature Review

MAC protocol is classified into random access and conflict-free multiple access. Traditional MAC protocols such as ALOHA [5], CSMA [6], and MACA [7], are designed based on contention based random access approach. The classic ALOHA protocol uses simple transmission mechanism where node transmits a packet when it is generated. However, its simplicity comes at an expense of very high probability of packet collision; hence increases the energy expenditure due to packet retransmission. Therefore, Carrier Sense Multiple

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Access (CSMA) protocol is developed [6] with the objective of minimizing collision by implementing a small time for channel listening in order to detect channel activity. However, the protocol cannot solve the hidden terminal problem which normally occurs in ad-hoc networks where the radio range is not large enough to allow communication between arbitrary nodes and two or more nodes may share a common neighbor while being out of each other's reach. The MACA protocol introduces a three-way handshake mechanism to make hidden nodes aware of upcoming transmission, so collision at neighboring nodes can be avoided. However, the handshaking mechanism causes overhead on control packet.

All these protocols require all nodes to continuously listen to the channel due to unpredictable packet transmission by its neighboring nodes, hence introducing a problem called idle-listening problem. This situation causes a node to expend a lot of wasteful energy causing the implementation of these protocols in WSN inefficient. Sensor-MAC (SMAC) protocol [8] attempted to solve the problems by introducing active-sleep cycles in the presence of random access channel. Node will execute a variant of MACA contention-based MAC protocol during active period to minimize the hidden terminal problem, while turning its radio off during sleep period to reduce idle listening problem. However SMAC implements neighbors' information variables called Network Allocation Vector (NAV) [9] for its collision avoidance technique. Node checks the NAV value before sending the RTS message. Nevertheless, implementing contention based mechanism is still vulnerable to collision due to random mechanism in its data packet transmission.

Energy inefficiency caused by the idle-listening problem and high collision probability can be avoided in Time Division Multiple Access (TDMA) based protocols. In TDMA-based protocol such as HiperLan-II [10], time is divided into several frames, and a frame is divided into a number of time slots. Since all transmissions within the frame are pre-scheduled, it is possible for a node to sleep when it is not expected to transmit or receive any packets. Thus, the TDMA-based MAC protocol can clearly avoid the over-emitting problem. Since only the owner of the time slot is allowed to transmit a packet, collision problem can be avoided significantly.

Tahar et al.,[1] presented an energy efficient MAC protocol which realizes both energy efficiency and improve the channel utilization compared to the already existed techniques. For this they provided ELE-MAC with the inputs from adaptive SMAC scheme. In this a control packet strategy which presented a packet exchange sequence aiming to minimize the energy wasted by control packets and to decrease latency.

However different traffic load condition of the sensor nodes on transmission of target detected objects at any given time also further increases the latency and energy. The proposal in this work present an another variant of ELE-MAC which handles the different load conditions based on load distribution and scheduling mechanism of each and every sensor nodes of the network to improve the overall lifetime.

III. Load Balanced ELE-MAC

In the wireless sensor network, the control packet has greater impact on the network power consumption which is comparable to the size of data packets. Energy consumption is reduced by optimizing the exchanged control packets. This motivates to present energy efficient MAC protocol that minimizes the exchanged control packets (ELE-MAC) compared to that of adaptive SMAC protocol. ELE-MAC control packets shown in Fig 2 as compared with normal control packets (in Fig 1) present the operations of how energy conservation happens in wireless sensor networks.

The ELE-MAC control packet provides two additional fields (i.e. ACK destination Node Address and ACK flag) which allow the new RTS packet to play the role at the same time of an ACK and a RTS. This new packet will be exchanged only when data are sent adaptively (i.e. not at the scheduled listen time). Thus, no ACK packet will be emitted in that case. The transmission is performed normally (i.e. at the scheduled listen time). Each data packet received is followed by an ACK to the sender.

The operation of ELE-MAC shown in Fig 3 explains the operation that node A has data to be transmitted to node B to end in node C which is the sink of the illustrated topology. The ELE-MAC scheme starts the adaptive wake up period immediately after receiving the data packet instead of waiting for the ACK packet like for the SMAC adaptive listening mechanism. This modification is made for allowing a receiver to inform its neighbors about the data reception through the ACK flag field. Also, this packet allows the receiver to mention its need to transmit the received data packet to the next-hop if it exists (i.e. send RTS).

The most common workload in sensor networks consists on small periodic data packets. Thus, ELE-MAC doesn't propose a fragmentation mechanism. Like IEEE 802.11 and SMAC, broadcast packets are sent only when virtual and physical carrier sense indicate that the medium is free. In addition, these packets will not be preceded by RTS/CTS and will not be acknowledged by their recipients.

The load balance scheme proposed for ELE-MAC to multi-hop multi-channel sensor networks. Based on the load distribution of all sensor nodes, it algorithm dynamically alternates the communication channels. As a result, the extra load from over-loaded channels is directed to under-loaded channels with a computed switch probability.

In addition a high throughput is achieved with stabilized load conditions on the sensor nodes during the transmission of more number of target objects being detected. The performance of the load balance algorithm is evaluated through simulation studies on both ELE-MAC of energy variant and load variant.

Original RTS Packet

Type	Length	Destination node address	Source node address	Duration	CRC

Fig 1: Wireless Sensor Network Normal RTS Control Packet

ELE-MAC RTS Packet

Type	Length	RTS destination node address	*ACK destination node address*	Source node address	*ACK Flag*	Duration	CRC

Fig 2 : Wireless Sensor Network ELE-MAC RTS Control Packets

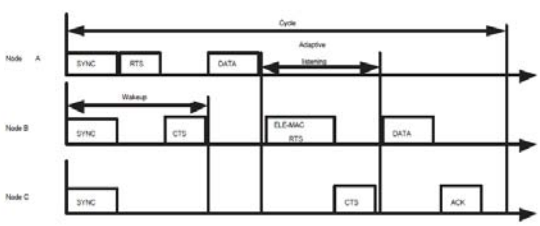

Fig 3 : ELE-MAC Operations

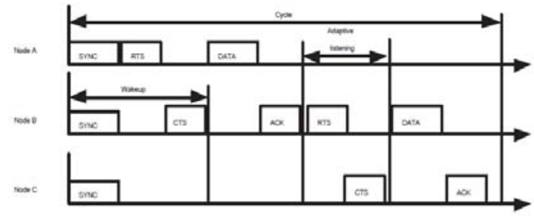

Fig 4 : Adaptive SMAC

IV. Experimental Evaluation of Improved ELE-MAC

The simulation is carried for improve load balanced ELE-MAC with existing ELE-MAC in NS-2. By comparing with SMAC (in its two alternatives), it is shown that load balance variant of ELE-MAC shows better lifetime of the sensor network in terms of load stability, latency and energy consumption. The adaptive SMAC implementation deployed in this NS's version doesn't provide us with the correctly nodes' energy consumption. Further, the problem resides in the implemented Energy Model. This is because it doesn't take into consideration the energy wasted by idle listening (i.e. doesn't drain energy in the sleep/wakeup methods). Henceforth, to enable the right tracking of the energy consumed by each node at any time, we tune the energy model and the SMAC sources.

The behavior of the proposed load variant ELE-MAC when varying the traffic load and because of the limited transmission range of wireless network interfaces (i.e. multiple network hops may be required for one node to exchange data) a multi-hops environment is required. Similar to the test bed realized for evaluating SMAC on a multi-hop networks, a linear topology composed from 40 to 60 nodes with only one source and a sink which is chosen the later node in the multi-hops chain. This simple topology allows us to concentrate on the inherent properties of load variant and energy variant ELE-MAC.

Type	Length	RTS Destination node address	Target object load rate	ACK Destination node address	Source node address	ACK flag	Load flag	Duration	CRC

Fig 5 : Load Distribution & Scheduling Packet

The routing protocol makes greedy forwarding decisions using information about a router's immediate neighbors in the network topology. In fact, to let each node hear only its next neighbor, we put nodes distant by 100 meters taking into account that the transmission range in NS-2 is set to 150 meters. No mobility is assumed in our simulation scenarios. As the goal of our simulation is to compare the performance of SMAC with ELE-MAC, we choose our traffic source to be constant bit rate (CBR) source. The NS-2 ELE-MAC and load variant simulation parameters are analyzed to extract the useful traces and to compute the energy consumption as well as the latency with TCL scripts. The simulation is carried out for several pause time to obtain significant statistical results.

The Control packets analysis show the resultant of energy variant and load variant ELE-MAC with different traffic rate sources on the wireless sensor network. Energy variant ELE-MAC exchanges few control packets compared with load variant initially however on continuous simulation load variant shows better result than energy variant. Fig.6 presents the energy consumption performance of Energy variant and Load variant ELE-MAC. Conserve the energy which would be lost by the control packets overhead by maintaining the stability of load on all the sensor nodes.

The Latency analysis handles the end-to-end delay quantification from the simulation viewpoint. ELE-MAC energy and load variant measure the total time required to transmit the generated data packets. Load ELE-MAC achieves better latency performance compared to that of energy ELE-MAC.

Fig.7 plots the latency performance of Energy variant and Load variant ELE-MAC. The load distribution and scheduling policy of load variant ELE-MAC reduces the listening time of the sensor node in the MAC layer which in turn reduces overhearing and latency. As can be seen in Fig.8 the scheduling policy of load variant ELE-MAC helps the node transmission stability to its optimal level.

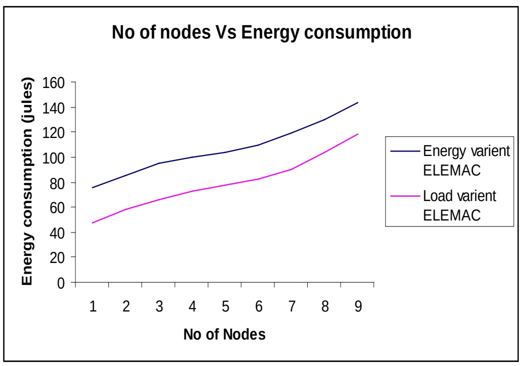

Fig 6 : Energy consumption performance

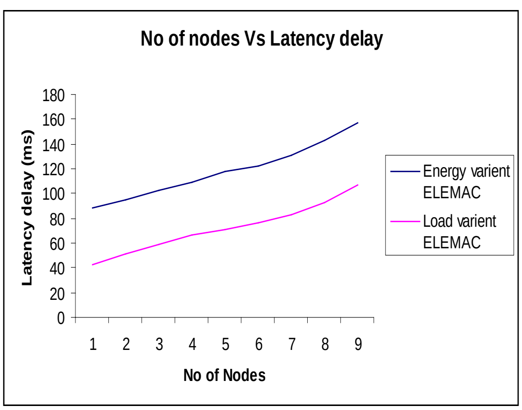

Fig 7 : Energy Latency performance

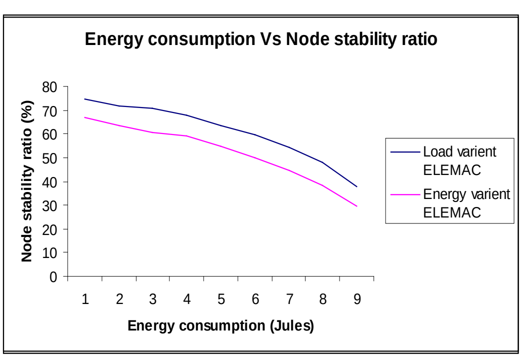

Fig 8 : Node Stability performance

V. Conclusion

The improved variant of ELE-MAC which balances the different load condition of the sensor nodes by load scheduling and distribution scheme improves the overall sensor network lifetime. The simulation of Load balanced ELE-MAC in the test bed consisting of 100 sensor nodes is carried to evaluate the performance of energy consumption levels, latency and load rate of each sensors. The performance results shows that the proposed load balanced ELE-MAC shows better sensor node stability (nearly 10%) in transmitting the detected target objects with less energy consumption (decreases to 15%) and latency (decreased to 23%) compared to that of existing ELE-MAC.

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