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I-MAC with Minimum Delay and Cross Layer Optimization for Wireless Sensor Networks

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ABSTRACT: Reducing the end to end delay is one of the main challenges in the Wireless Sensor Networks. Scheduling of the medium access control plays an important role in enhancing the performance of wireless sensor networks. In Sleep/wake up scheduling technique, nodes are operating in a low duty cycle and reduce end to end delay thus save energy and extend the network lifetime. I-MAC that involves the assignment of slots for each packet, wake up-sleep scheduling when combined with cross layer optimization would effectively reduce the end to end delay and thereby ensures energy efficient operation. Based on optimum energy flow at the cross layer the frame length could be revised and by this slots could be reused by TDMA Scheduling.

KEYWORDS: Wireless sensor network; End to End delay; Sleep/wake up scheduling; cross layer optimization.

I. INTRODUCTION

Wireless sensor networks consist of a number of sensors which are deployed densely and randomly. Sensor nodes are less weight and low cost with the capability of sensing, processing and transmission. Sensor nodes are limited by the battery power impractical to charge or replace the exhausted battery, which leads to limited lifetime of a sensor network. Maximizing the network lifetime is the common objective of sensor network research. Design of a MAC layer protocol for wireless sensor network is a challenging task due to limited battery power and limited bandwidth [1].

TDMA protocols reduce data retransmissions because collision does not occur in TDMA protocol [3]. In addition to energy efficiency, quality of service (QoS) metrics such as end-to-end delay needs to be taken into account in some applications or under certain scenarios, for instance, delivering real-time data [2]. Main objective of our paper is minimizing network wide energy consumption and also reduce end-to-end delay for increasing the lifetime of the network. Cross layer optimization and minimum delay scheduling using Intelligence hybrid MAC (I-MAC) to achieve link reliability, high data rate and reduce end to end delay in WSN.

II. RELATED WORK

In wireless sensor network, the authors of [7] obtain one of the new works in contention based MAC protocol. S-MAC nodes operate in low duty cycle and energy efficiency is achieved by periodic sleeping. The author of [8] improves the energy efficiency of S-MAC by adaptive duty cycle. T-MAC reduces the idle listening by transmitting all messages in burst of variable length and sleeping between bursts and maintains an optimal active time under variable load by enthusiastically determining its length. The authors of [9] consider MAC for Mica2. B-MAC allow an application to execute its own MAC through a well-defined interface also adopt Low power listening and engineer the clear channel sensing technique to improve channel utilization. The authors of [3] consider the number of packets being sent at every node and provide an algorithm to obtain the shortest schedules by eliminating the nodes without packets to send at each loop, these algorithms require global topology information, which may be difficult for large size networks. Interference-free TDMA schedules are calculated in [10] for a small-scale network by joint optimization of the physical, MAC, and network layers. The authors use convex optimization to solve the cross-layer-based network lifetime optimization problem, employing the interior point method.

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III. PROPOSED METHOD

The concept of link scheduling and broadcast scheduling is combined, which is introduced by I-MAC protocol [1]. Cross-layer design is minimizing the network-wide energy consumption. A Time slot is defined as the periodic interval, it consists of an active period and a sleep period. A duty cycle is the ratio of active period to the entire cycle time. A rendezvous slot is defined as a time slot clearly dedicated to a pair of nodes to communicate with each other. In rendezvous, a node forms a channel for transmission and reception with one of its neighbors. The source node knows the degree of importance of the sensed data and accordingly the application layer sets the priority. TDMA schedules with optimized power consumption and minimum latency in clustered WSNs.

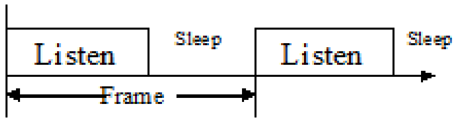

Figure 1: Periodic listen and sleep of a sensor node

IV. CROSS LAYER OPTIMIZATION

In this part, the physical, MAC and network layer models that serve as input to the cross layer optimization. In resource constrained WSN's, the lifetime of the network can be increased by optimization which can be achieved by exchanging the information across all the layers. The nodes in the network are divided into clusters, each consisting of a cluster head (CH) and a gateway (GW). The members of the cluster communicate with the cluster head via one hop. The transmission range of the cluster heads and gateways is not restricted to one hop. The clustering scheme presented in [3] can be used to form clusters.

The analysis is simplified by using the virtual link to represent the traffic from a cluster member to the corresponding cluster. Thus the TDMA schedule is derived considering only the backbone network consisting of cluster heads and gateways.

A graph G (V, L) is used to denote the backbone network consisting of CH's and GW's including sink, V represents the set of nodes and L represents the set of links. The total number of nodes in the network is n = |V|. The sink is considered as node 1. The links are considered to be unidirectional so that the link (i, j) is different from the link (j, i). We assume that the sensor nodes are stationary in the network. Physical layer links various parameters such as power, Signal to Noise ratio (SNR) and bit error rate together by considering the propagation model, modulation and demodulation, encoding and decoding techniques. The path loss model is:

$$Pl(d) = Pl\,(d0)\ 10\ \gamma \log 10(d/d0) \qquad (1)$$

Where d is the distance between the transmitter and receiver, d0 is the reference distance and γ is the path loss component. The bit error rate expressed as a function of SNR for the non-coherent FSK MODEM scheme used in Mica2 motes is given by,

$$P_e = ½\,(e^{SNR/2 * B_N /R}) \qquad (2)$$

Where R is the data rate in bits per second (bps), and B_N is the noise bandwidth. The SNR at the receiver is located at a distance d from the transmitter is given by:

$$SNR\,(d)_{dB} = P_{tr\ dBm} - Pl\,(d)_{dB} - P_{n\ dBm} \qquad (3)$$

Where the parameters on the right side are the transmission power, the average path loss at the distance d, and the noise floor. Considering the length of the packet as L bytes and the encoding data rate is r, then the packet loss rate p on each link is defined as the probability that at least one transmitted bit in a packet is corrupted is given by [2],

$$p = 1 - (1 - P_e^{8rL}) \qquad (4)$$

The energy consumed for sensing is assumed to be small and is ignored. The average transmission energy consumption by node a, to transmit a data bit to node *b* with transmit power $P_{tx,ab} = P_{cir,tx} + P_{tx}(d_{ab})$, is given by [2],

$$E\,(P_{tx,\,ab}) = 1/R\,(P_{cir,\,tx} + P_{tx}\,(d_{ab})) \qquad (5)$$

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Where $P_{cir, tx}$ power consumed by the transmitter circuits (excluding the power consumed by the power amplifier circuit), which is a constant. $P_{tx}(d_{ab})$: Power consumed by the power amplifier circuit to transmit a distance d_{ab}, $P_{tx,ab}$ is variable depending on the transmission distance d_{xy} and the packet loss rate. The average receiving energy consumption per bit at receive power P_{rx} is fixed and is calculated by: $E (P_{rx}) = P_{rx} / R$, where P_{rx} is the power consumed by the receiver circuits. The MAC layer protocol employed in the data relay phase is TDMA. TDMA frame consists of a number of slots, each with fixed length □*t*. Increasing the transmission power can reduce the bit error rate. This shows that an optimal transmission power exists for each and every link[3].

Multihop, multipath routing is performed on the network layer. The sink provides the information to the next hop and the proportion of data traffic to the next hop to every CH or GW after deriving the optimal schedules at the end of the initialization phase of every round. The combination of all the three layers gives the cross layer design. A cross-layer optimization can be formulated as in [2].

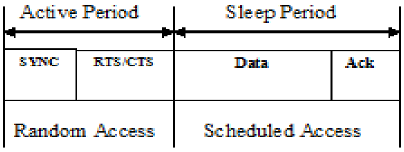

Figure 2: Slot for the proposed method

Each slot starts with a SYNC period. The purpose of the SYNC packet is to maintain the synchronization between the nodes within the same virtual cluster. The next part of the active period of the frame is a reservation slot which is used for the data slot reservation. Then the last part is used for data and ACK transmission by sensor nodes. The SYNC packet contains the time until the next frame starts. If the node during start up hears a SYNC packet from one to another node, it follows the schedule in that SYNC packet and transmits its own SYNC accordingly [1].

V. STATE DIAGRAM

The state diagram of the I-MAC protocol is shown in the fig 3: during the sleep state the nodes turns off its radio and start a timer whose duration is predefined according to the duty cycle of the protocol with consideration of the prolongation of rendezvous communication between any pair of nodes. When the timer expires, the node goes to wake-up state. It turns on its radio and switches to listen to the data channel and its goes to idle listening state. If the node has any data to send or receive it goes in the CSMA/CA state otherwise after them out it goes to sleep state. If the sender node wins the contention both the sender and the intended receiver go to the T x/Rx state and go to sleep state after successful communication. Nodes that fail contention go to sleep state. The node will first broadcast the declaration of its making rendezvous slot. The declaration message contains how many slots will be used as rendezvous slot, and between whom the rendezvous will be done. So, remaining neighboring nodes can calculate locally about the slot so that they need not to wake up during those slots. For each rendezvous slot since all the neighbors of both sender and receiver will be in sleep mode, there will be no hidden or exposed terminal problem.

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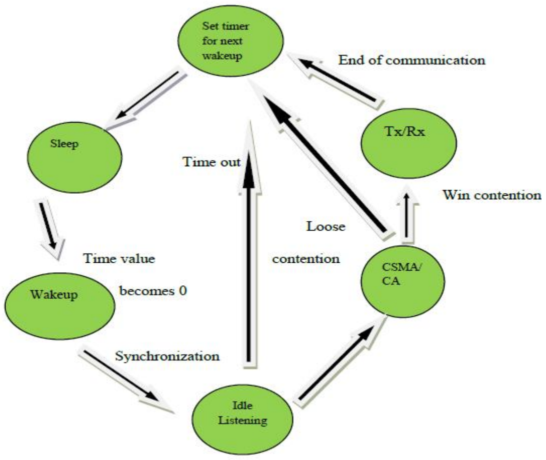

Figure 3: State diagram of sensor nodes working on I-MAC

The node will first broadcast the declaration of its making rendezvous slot. The declaration message contains how many slots will be used as rendezvous slot, and between whom the rendezvous will be done. So, remaining neighboring nodes can calculate locally about the slot so that they need not to wake up during those slots. For each rendezvous slot since all the neighbors of both sender and receiver will be in sleep mode, there will be no hidden or exposed terminal problem.

VI. TDMA DELAY SCHEDULING ALGORITHM

Based on scheduling the optimal values of transmission power and the flow distribution on every link for the energy efficient data relay can be obtained as in [2]. Here, we adopt a simple method to calculate the TDMA schedule that has the shortest length. The algorithm starts from any of the backbone nodes (CH or GW). Slots are first assigned to the virtual link if the node is a CH and then to all the outgoing links on the node. The algorithm checks all the links that are previously assigned before assigning the slots to any succeeding nodes to ensure that there is no conflict. The three conditions that must be satisfied before assigning slots to any link of the node i [3].

Condition I: The current node should neither be the sender or receiver of a previously scheduled link using slot s, and the receiver of this link must not be any link scheduled with slot *s*.
Condition II: There should be no interference to the slot scheduled by node i with the links already scheduled to use slot *s*.
Condition III: The sender of the scheduled link using slot s should cause negligible interference to the current receiver if it is using slot s on one of the node i links.

The TDMA delay scheduling algorithm can be described as:
Step: 1 For each node i ($i \neq sink$) of V.
Step: 2 For each required slot m in M_i, Start from slot s = 1.
Step: 3 verify for the satisfaction of the three conditions.
Step: 4 If all the three conditions are satisfied, verify the distance between the current node and all the nodes to which the slot was previously assigned.
Step: 5 If the distance between nodes > 42m, s=1 can be reused and assigned to current node.
Step: 6 Else s = s + 1 and repeat steps 3 to 5.
Step: 7 Store the id of the last slot *s* assigned to node i, Last slot $id_i = s$.

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Step: 8 Calculate the frame length M = max (Last slot id_i), for all i [2, N].

Step: 9 Check M $\Delta t \leq 1$. If M $\Delta t > 1$, decrease the value of Δt and repeat the algorithm for the new value of Δt until M $\Delta t \leq 1$.

VII . SIMULATION RESULTS

We validate our analysis and performance of the proposed method using the NS2 simulator. The most important metric of our performance evaluation is end to end delay. We measure all source nodes successfully send data packets to sink. We consider the area of dimension is 1200x1500 and packet size is 512 bytes. Fig.4 shows that I-MAC with MDCL consumes the less energy than S-MAC and I-MAC.S-MAC protocol node has a fixed listen/sleep cycle, so a node must be waked up when its sleep period expires, even if the node hasn't any activity, resulting in unnecessary energy consumption. I-MAC with MDCL Energy consumption, which is low due to use TDMA. Cross layer optimization effectively minimizes the usage of energy level.

TABLE-I

SIMULATION PARAMETERS

PARAMETER	**VALUE**
Simulator	NS 2.34
Area Dimension	1200*1500
Channel type	Wireless channel IEEE 802.11
Packet size	512 bytes
Transmission range	250m
Simulation time	100sec
Number of nodes	125
Routing protocol	AODV
Channel bandwidth	2 Mbps
Idle power	1.0 m watts
Sleeping power	0.001 m watts
Transmitting power	3.0 m watts
Receiving Power	2.1 m watts

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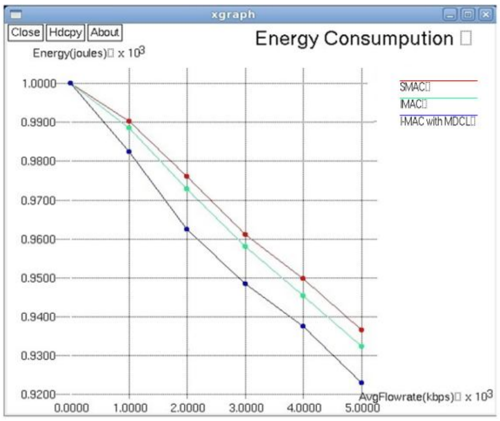

Figure 4: Energy consumption

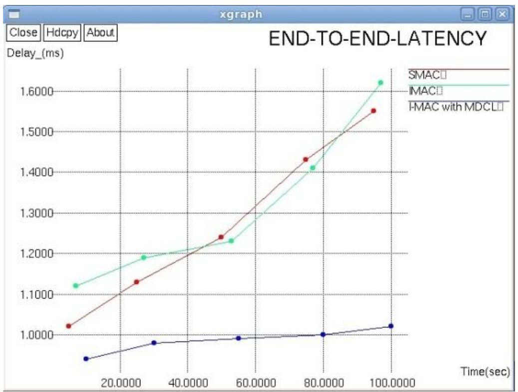

Figure 5: End to end delay

In Fig 5. The end-to-end delay time, proposed method I-MAC with MDCL yields better performance than S-MAC and I-MAC, due sensor nodes adjustment in higher duty cycles, when network traffic is high. S-MAC and I-MAC yield higher delay, since node starts to send/receive data until its sleep period expires.

VIII. CONCLUSION

Intelligence hybrid MAC (I-MAC) with Minimum Delay and Cross Layer Optimization, which reduces the per bit energy consumption, that has been used to schedule a TDMA frame of minimum length. The result makes the effectiveness of scheduling algorithm in the reduction of the TDMA frame length and percentage of delay reduction. Here, considering the distance between the nodes where the slots are reused, low energy consumption scheduling algorithm is intended and results are indicating that the delay is reduced significantly.

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