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Enhanced Throughput Based Transmission Strategy for Wireless Sensor Networks

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Abstract: Wireless sensor networks operate in a strict energy constrained environment. This operation exists until there is an operation of fractional number of nodes in the varying wireless channel condition. The transmission between operational WSNs is done in opportunistic nature over this fading wireless channel. This will lead to reduction in energy efficiency, since we are maintaining longer latency. This further reduces the throughput of the transmission. The Low Latency based transmission strategy for Wireless Sensor Networks utilizes Binary Decision Based Transmission algorithm and Channel Aware Backoff Adjustment algorithm. The Binary Decision based Transmission algorithm, decides to transmit according to the threshold which is formulated by Markov Decision Process. The threshold specifies the channel quality and whenever this value exceeds the threshold value the transmission performed. The Channel Aware Back off Adjustment algorithm favors the nodes and leads them to access the channel. Both these algorithms are combined and the latency between the functional nodes is reduced. This further increases the throughput and energy efficiency of the Wireless Sensor Nodes. Simulations are performed using NS-2 simulator to verify the performance of the proposal.

KEYWORDS: Wireless sensor networks, energy efficiency, BDT, CBA, latency.

I. INTRODUCTION

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance.

In wireless sensor networks (WSNs) a number of sensor nodes are deployed for data gathering with a small battery that is difficult to replace. Since the WSN may function until a significant fraction of sensor nodes are operational, energy efficiency is a key technical issue in the design of WSN. The nodes operate over the time-varying wireless channel whose quality significantly fluctuates over time due to fading and interference. Such time-varying nature of wireless channel imposes many constraints in designing an energy-efficient transmission scheme. For instance, a transmission attempt, when the wireless channel is temporarily bad, is highly likely to be failed and may lead to a waste of energy. To avoid this, the sender may wait until the channel becomes better. However, deferring the transmissions until the channel becomes better may decrease throughput, or equivalently cause a longer latency.

An efficient transmission scheme for the WSNs must be able to adapt to variation of the wireless channel while maintaining a good balance between these two conflicting measures. The scheme basically takes an opportunistic transmission approach in which transmissions are attempted only under good channel conditions whenever possible. This idea is realized into two parts of Medium Access Control (MAC) protocol: a Binary-Decision Based Transmission (BDT) and a Channel-Aware Backoff Adjustment (CBA). By exchanging the control messages like RTS and CTS in the 802.11 standard for channel measurement and its feedback, respectively, the receiver can measure the channel quality and the sender can retrieve such information piggybacked in the return message. To continuously monitor the channel condition, data message and its acknowledgement message are also used to measure and piggyback the channel information. The Binary Decision is obtained by threshold formulation using MDP. The, CBA algorithm is introduced to favor the sensor nodes with better channel conditions. For those sensor nodes which see a better channel recently, a smaller contention window (CW) is assigned to access the channel faster, whereas a relatively Larger CW is given for the opposite cases.

The main goal is to form a reduced latency based transmission strategy in WSNS. The BDT algorithm initiates transmission according to the channel quality and the CBA favors the nodes for the operation over the channel. To overcome the drawbacks of the transmission over fading wireless channel the combining of these two algorithms should be done. The increased throughput and reduced latency between the operational nodes must be focused in order to obtain high efficiency in energy. The paper is organized as follows. Section 2 discusses about the transmission strategy approach used in Wireless Sensor Networks (WSNs). Section 3 is devoted

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to the algorithm used. Section 4 deals with the Results and analysis. Section 5 deals with the Conclusion.

II. TRANSMISSION APPROACH

The wireless sensor nodes are deployed for data gathering with a small battery that is difficult to replace. The WSN will function until a significant fraction of sensor nodes are operational, energy efficiency is a key technical issue in the design of WSN. The nodes operate in the time-varying wireless channel. Their quality significantly fluctuates with respect time due to fading and interference. Such time-varying nature of wireless channel imposes many constraints in designing an energy-efficient transmission scheme. For instance, a transmission attempt, when the wireless channel is temporarily bad, is highly likely to be failed and may lead to a waste of energy. To avoid this, the sender may wait until the channel becomes better. However, deferring the transmissions until the channel becomes better may decrease throughput, or equivalently cause a longer latency. An efficient transmission scheme for the WSNs must be able to adapt to variation of the wireless channel while maintaining a good balance between these two conflicting measures. The scheme basically takes an opportunistic transmission approach in which transmissions are attempted only under good channel conditions whenever possible. This idea is realized into two parts of Medium Access Control (MAC) protocol: a Binary-Decision Based Transmission (BDT) and a Channel-Aware Backoff Adjustment (CBA).

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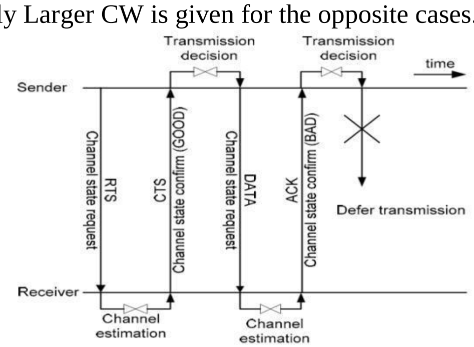

Fig. 2.1 Channel measurement of and feedback via exchanges of control messages

Transmission schemes are implemented on IEEE 802.11 DCF standard with some necessary modifications. The modifications are associated with channel measurement and a mechanism for its feedback.802.11 MAC protocols may not be suitable for WSNs; here the work is employed to demonstrate effectiveness of transmission schemes. Since schemes require only exchange of short control messages or piggybacking in normal data messages for delivery of channel-related information, they are readily applicable to different MAC protocols other than IEEE 802.11 DCF protocol.

The transmission algorithms are applied to IEEE 802.11 Distributed Coordination Function (DCF) standard with some necessary modifications. The algorithm consists of two components: BDT and CBA. The designing of algorithms in order to achieve high energy efficiency is explained in the fore coming chapters.

A. Binary-Decision Based Transmission

In this scheme the sensor node takes either of two actions: *Transmit* and *Defer*, corresponding to transmitting the data and deferring the transmission, respectively. The thresholds formulated using the MDP The SNR threshold used to classify the channel states is determined using the Markov decision process (MDP).

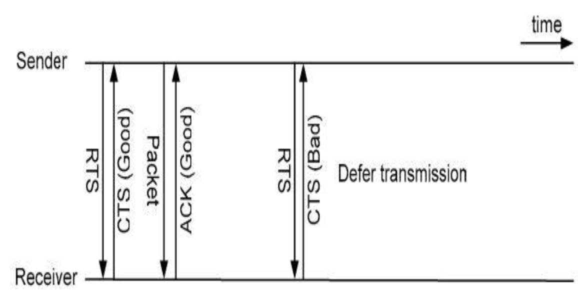

Fig. 2.2 BDT Based Transmission

B. Channel-Aware Backoff Adjustment

In IEEE 802.11 DCF standard, the Binary Exponential Backoff (BEB) algorithm is used for contention resolution The CBA scheme is based on the BEB algorithm, but some modifications are made to enhance energy efficiency by exploiting the time varying nature of wireless channel. The CBA algorithm is used to favor the operating nodes. The current wireless channel is measured at the receiver via RTS or Data frame, and is classified into one of two states including Good and Bad based on the received SNR. This information is notified back to the sender by embedding it in the return frame, i.e., CTS or ACK frame. Under slow fading channel, the wireless channel varies slowly over time. If the channel is good at present, then it is more likely that the channel remains good in the near future. This characteristic is exploited in algorithm by prioritizing the sensor nodes, currently or recently seeing a good channel, in terms of channel access.

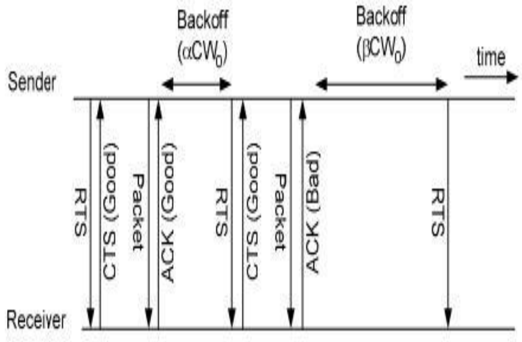

Fig. 2.3 Prioritization in BDT Based Transmission

Such differentiation is realized by assigning different sizes of contention window (CW) to the sensor nodes based on the channel quality. Every sensor node maintains a table called Link State Table that lists up the channel states of each link to its neighbors and their validity information. For each link, a pair of (Channel State, Validity) information is maintained. Such information in this table is updated when the sensor node gets a new channel information state via an exchange of messages, or when a specified validity period elapses from the last update.

III. TRANSMISSION ALGORITHM

The transmission algorithms are applied to IEEE 802.11 Distributed Coordination Function (DCF) standard with some necessary modifications. The algorithm consists of two components: BDT and CBA. The designing of algorithms in order to achieve high energy efficiency is explained in the fore coming chapters.

A. BDT Initialization

In this scheme the sensor node takes either of two actions: *Transmit* and *Defer*, corresponding to transmitting the data and deferring the transmission, respectively. The thresholds formulated using the MDP The SNR threshold used to classify the channel states is determined using the Markov decision process (MDP).

B. MDP Formulation in BDT

The optimum thresholds for successful transmission are formulated using the MDP. For both BDT and FT, the optimum operation policy in terms of energy efficiency is obtained. For the sake of tractable analysis, it is assumed that time is divided into time slots of equals length of *T* seconds. In addition, the time slot is assumed to be sufficiently short and the traffic load is light such that a frame arrives at each time slot following a Bernoulli distribution with parameter λ. To consider the applications that require up-to-date sensing data under light traffic load, here it is assume that the buffer can hold at most one frame. Thus any new coming frame preempts the existing one and the existing frame is dropped. It is also assumed that the outcome of transmission is immediately available at the end of transmission.

System States: denote the set of possible system states by **S** in which **S** is a finite set. The system state *s* at time slot *i* is given by

$$S_i = (g_i, ti)$$

where gi is the channel state at time slot i, $0 = g_i < K$, and t is the state of sensor node at time slot i. The possible states of the sensor node include *Idle* and *Active*. The sensor node is said to be in *Active* state when a frame is in the buffer waiting for transmission and in *idle* state when no frame is present.

Control Actions: Depending on system state s, sensor node determines to transmit or to defer transmission. Let $A\ (s_i)$ denote the set of all possible control actions in state s be the control action executed at time slot i. Each action in $A(si)$ corresponds to the following values

$$\alpha_i = \begin{cases} 0, & transmit \\ 1, & Defer \end{cases}$$

Cost of Actions: In *Idle* state, the sensor node takes no actions and thus the cost of actions equals zero. In *Active* state, the immediate cost incurred at time slot i is defined as

$$C_i(s_i,a_i)=E_c+L_e(g_i,\ a_i)E_t+\delta L_d(g_i,\ a_i)$$

where E_c and E_t are energy consumption per bit for sending control packet and data packet, respectively; d is a weighting factor that indicates a relative importance of frame loss over energy consumption; $Le(g_i,\ a_i)$ is the expected frame error rate; and $L_d(g_i,\ a_i)$ is the expected number of frame losses due to buffer overflow. $L\ (g_i,\ a_i)$ is given by

$$L_e\ (g_i,\ a_i) = a_i\ p$$

Where $P_f\ (gi)$ is the frame error rate when the channel state is gi. Assuming independent bit errors, the frame error rate $P_f\ (g_i)$ for frame size L and the channel state g is given by

$$P_f\ (g_i) = 1\text{-}(1\text{-}P_b\ (g_i))^{\ l}$$

Where $P_b\ (g_i)$ is obtained. $L_D\ (g_i,\ a_i)$ is given by

$$L_D\ (g_i,\ a_i) = \lambda\ ((1\text{-}a_i) + a_iP_f\ (g_i))$$

System Dynamics: Given the system state $s_i = \langle g_i \rangle$ and a control action a, the probability of the system being state $s_{i+1} = \langle g_{i+1}, t_{i+1} \rangle$ in next time slot is:

$$P_r\,[S_{i+1} = \langle g_{i+1}, t_{i+1} \rangle | S_i = \langle g_i, ti \rangle, a_{i} = a] = P_g\,(g_i, gi_{+1})\, P\,(t_i, ti_{+1,}\, a)$$

Where $P_g\ (g_i,\ g_{i+1})$ is the transition probability from channel state g_i to g_{i+1} and $P_t\ (t_i,\ t_{i+1},\ a)$ is the transition probability of sensor node state from t_i *to* t_{i+1} to under the given control action a. Here the state diagram of the behavior of sensor node in which the transition probability $P_t(t_i,\ t_{\ i+1},\ a)$ and the corresponding cost of action is provided.

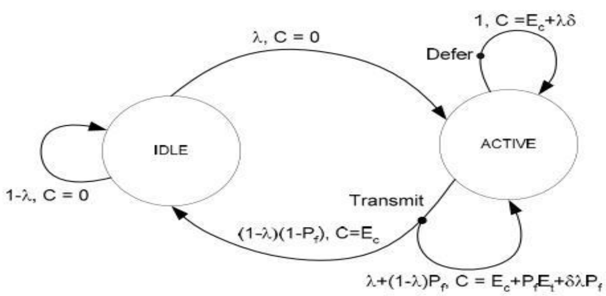

Fig. 3.1 State diagram of the BDT scheme

Let π = {μ0, μ1, μ2…,} be a policy which maps system states into control actions. Objective is to minimize over all policies π with μ. μ →∈ for i and s, the average cost per stage

$$J_\pi = \lim_{T\to\infty} \frac{1}{T}\ \{\textstyle\sum_{i=0}^{T-1} C\ (Si,\ \mu(Si))\ \ |So = S\}$$

The model is a unichain MDP model. Therefore, a stationary policy and an optimal average cost for this problem can be obtained by using the relative value iteration algorithm in the dynamic programming techniques.

C. Channel-Aware Backoff Adjustment

In CBA the validity period is set to channel coherence time that can be estimated from on-line measurements. The initial CW is set according to the channel state. It is defined as

$$CW = \begin{cases} \propto (t).CW0, & \text{Upon good Channel} \\ CW0, & \text{Upon Medium Channel} \\ \beta(t).CW0, & \text{Upon Bad Channel} \end{cases}$$

Here α(t) and β(t) are multiplicative constants for prioritizing the nodes seeing good and bad channel, respectively, and t is a timer value, initially set to the validity period T, decremented over time. The validity period T is assumed same as the average fade duration. If the timer expires, α (t) and β (t) set to 1 and the validity field in Link State Table is set to invalid. Note that α (t) and β (t) remain effective even after consecutive collisions as long as the timer does not expire. It is assumed that α (t) = ½ and β (t) = 3/2 unless stated otherwise. An exact analysis of these settings will be investigated elsewhere. The Binary Decision based Transmission algorithm, decides to transmit according to the threshold which is formulated by Markov Decision Process. The threshold specifies the channel quality and whenever the channel quality value exceeds the threshold value the transmission performed. The Channel quality monitoring is reduced between the nodes such that the threshold value is reduced in this approach. The Channel Aware Back off Adjustment prioritizes the operating sensor nodes which are looking on for a opportunistic transmission. The Channel state value in the link state table is reduced in order to prioritize the functional nodes in ode to achieve the low latency between the functional nodes. The CBA algorithm favors the nodes and leads them to access the channel. Both these algorithms are combined and the latency between the functional nodes is reduced. This further increases the Throughput and the conflict between the Throughput and energy efficiency is reduced here.

IV. RESULTS AND DISCUSSIONS

The simulations have been with ns-2 simulator to verify the performance of the schemes in terms of energy efficiency and throughput. 30 nodes are randomly dispersed over a network field (100m × 100m) and 1 sink node located at the center. These sensor nodes generate a frame of 128 bytes, destined to the sink node directly, every 1 second. Wireless fading channel is modeled by 20-state Markov chain model. The T_f in the simulation is configured to match the period in which sending and receiving nodes complete the exchange of RTS, CTS, DATA, and ACK frames using RTS/CTS mechanism. The additive parts of 802.11 such as IP header and MAC header are tripped off in the simulation. This Table summarizes the values of the various parameters used in the simulation.

Table 4.1 Simulation Parameters

Parameters	Value
Number of Sensor Nodes	30
Frame Transmission Time	1ms
Transmission range of sensor node	75m
Traffic model of sensor nodes	CBR
Packet interval	1s
Packet size (including headers) (L)	128 (bytes)
Control packet size	10 (bytes)

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Simulation time	1000 s

A. Performance Metrics analyzed.

Delay: The Delay refers to the time taken for a packet to be transmitted across a network from source to destination.

Energy Efficiency: The Energy Efficiency is defined as the average transmission energy for each successful transmission

Throughput: Throughput or network throughput is the average rate of successful message delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

The transmission will be initialized between the source and destination nodes monitoring the channel condition. The source and sink are assigned for packet transmission. Then the opportunistic transmission can be formed. The channel state is monitored continuously. When the channel quality value exceeds the threshold value formulated using MDP, the transmission between the source and sink takes place. These sensor nodes generate a frame of 128 bytes, destined to the sink node directly, every 1 second.

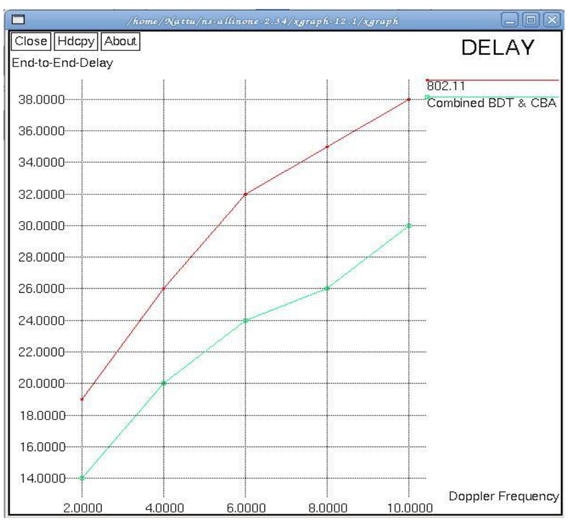

Fig. 4.1 End To End Delay Comparisons

The Fig. 4.1 shows the time delay between the transmissions of packets is less in the combined BDT and CBA transmission strategy when compared with the 802.11 transmission strategy.

The Fig. 4.2 shows the energy efficiency comparisons between 802.11 and combined BDT and CBA algorithm. The Combined BDT & CBA algorithm proves better than the 802.11 transmission approach. The Fig. 4.3 below shows the comparison of throughput.

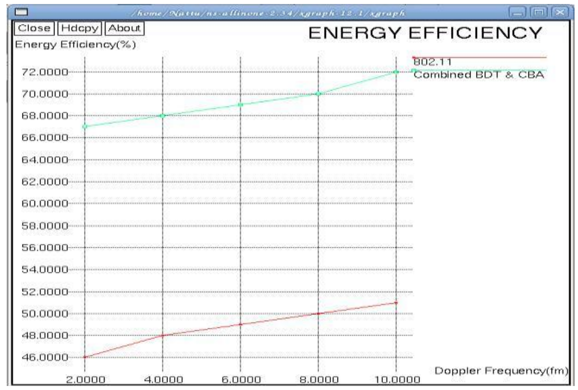

Fig. 4.2 Energy Efficiency Comparisons

Energy efficiency is approached in the efficiency is approached in balance with the of throughput. The throughput achieved in this approach is comparatively high than the 802.11 transmission mechanism since lower latency period is maintained.

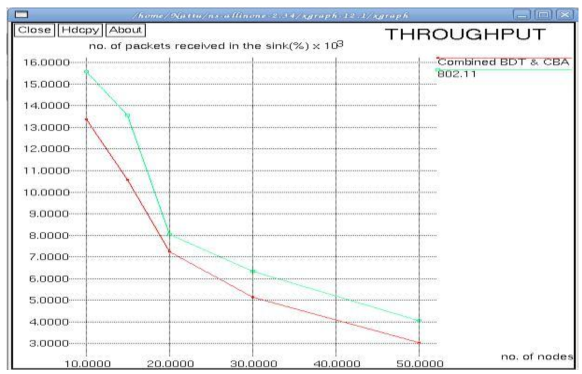

Fig. 4.3 Throughput Comparisons

The obtained result from the implementations shows that the latency period between the source and sink nodes maintained were less and the throughput obtained was very high. The balanced energy efficiency is obtained without any loss in the throughput.

V. CONCLUSION

Here we have presented a Low latency based transmission strategy for wireless sensor networks. We carried out the design of transmission scheme for wireless networks over the fading wireless channel. The transmission algorithms used here are Binary Decision Based Transmission and Channel Aware Back off Adjustment algorithms. These algorithms help in transmission over the fading wireless channel in opportunistic manner. We have focused on achieving energy efficiency without the expense of throughput by maintaining low latency between the source and sink nodes. The work has achieved high energy efficiency and throughput compared to existing approaches. The results obtained from the simulation of this transmission strategy have shown that the approach is better than the previous approaches. The Low Latency based Transmission scheme using combined BDT and CBA formulated using MDP achieves a total energy efficiency of 95% compared to the IEEE 802.11 protocol transmission and a balanced Throughput. The Enhanced Throughput with the increased energy efficiency helps wireless sensor networks in efficient management of resources.

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