A Content Based Scheduling Approach for Wireless Sensor Network MACs

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Abstract: MAC protocols have direct control over radio which is the most energy consuming part of a wireless sensor node. TDMA based WSN MAC protocols are more energy-efficient than contention based counterparts. However, classical TDMA based protocols are not appropriate for event driven WSN applications. There are some MAC protocols assigning time slots to only source nodes. Our proposed protocol assigns a time slot to one of the source nodes with same data. As a result it reduces data redundancy achieving energy savings. The analytical expressions are given for the proposed MAC and its performance is compared to the conventional E-TDMA protocol.

Keywords: Wireless Sensor Network, MAC, energy efficiency, event driven applications

1. Introduction

A WSN consists of many low-power, low-cost and multi-functional sensor nodes which can be densely deployed either inside the phenomenon or very close to it (Akyildiz, 2002). The applications of WSNs are so diverse such that the application range is only limited by the imagination (Sohraby, 2007). In these applications, a number of sensor nodes are deployed in harsh networking environments. It is not easy and even impossible to recharge or replace the batteries of the nodes (Kredo, 2007). Thus energy efficiency becomes one of the most important design criteria for WSNs. There are many medium access control (MAC) protocols considering energy efficiency as the primary goal in the literature since MAC has direct control over the radio that is the most energy consuming part of a sensor node (Kredo, 2007).

A WSN MAC protocol manages how and when its nodes access the wireless channel to be able to use the shared medium effectively and fairly. The sources of energy waste are idle listening, collision, overhearing and control packet overhead (Ye, 2003). A collision occurs if two or more nodes attempt to transmit data at the same time. Idle listening is another serious kind of energy waste, occurring when a sensor node listens the channel to check whether there is data related to it. Overhearing takes place when a node receives messages that are transmitted to other nodes. Transmitting control packets also causes energy waste since these packets do not carry useful data. In designing an energy-efficient MAC protocol, these subjects should be carefully taken into consideration.

In event driven WSN applications, nodes are prompted to transmit the related measurement values when the specific conditions occur according to the application requirements (e.g. temperature threshold exceeds). The neighbor nodes close to the phenomenon may sense and also might have to transmit the same data. This data redundancy consequently results in energy waste. Then the slot assignment to only source nodes is not the desired solution. A more energy efficient protocol is achieved by allocating slots to the only one of the nodes with same data. The aim of this presented study is to propose a new idea for energy efficient TDMA-based MAC protocols by assigning slots to only the nodes that have different data in event driven WSN applications.

2. Related Work

In energy-efficient TDMA (E-TDMA) protocol, the energy consumption in idle mode is reduced by letting the non-source nodes turn off their transceivers in their own slots (Li and Lazarou, 2004).

Bit-map assisted (BMA) MAC (Li, 2004) (Li and Lazarou, 2004) is also schedule-based. BMA is designed for event driven WSN applications in which sensor nodes transmit data only when they sense significant/predefined events. The operation of BMA is also divided into rounds including a set-up and a steady-state phase. The steady-state phase is partitioned into sub sessions consisting of contention period, data transmission period and idle period (Figure 1). The size of the data transmission period is variable because every node does not always data to send. On the other hand, the sum of the data transmission and idle periods is equal to a constant value. All of the nodes turns their radios on during every contention period. The contention period follows a TDMA-like schedule. Each node is assigned a time slot and it transmits 1-bit control message if it has data. Otherwise, it leaves that slot empty. After contention period completed, the CH knows the source nodes, prepares a transmission schedule and broadcasts it. The system followed enters the data transmission period. If none of the member nodes has data to transmit, the system enters the idle period until the next session. Throughout data transmission period, source nodes turn on their radios in their allocated slots and transmit the data to the CH. The other member nodes keep their radios off during the data transmission. In idle period, the radios of all the member nodes are off. BMA is an appropriate protocol for low traffic conditions since it easily outperforms TDMA and E-TDMA in low and medium traffic loads.

3. The Basics of the Proposed Method

The proposed idea for the MAC protocols consists of rounds including set-up and steady-state phases as in the other scheduled protocols. In set-up phase, cluster head is chosen and the cluster is formed according to a specific mechanism. There is a contention period as in BMA in steady state phase (Figure 2). However, source nodes transmit the difference data between the threshold and measurement values instead of declaring whether they have data or not by sending 1-bit in BMA. Therefore 4-bits slot is allocated to each node. When the nodes sense the values equal or bigger than the predefined threshold value, called as source nodes, they transmit the difference data between the threshold and measurement values in those 4-bits slots. Thanks to this, the CH not only knows the source nodes but also the nodes having same data and assigns data slots according to this knowledge.

A large number of nodes with predetermined temperature threshold in an example application are deployed randomly and densely by plane over the forest. The nodes which measure at least the threshold value are called source nodes. The source nodes transmit the difference data during contention period. The non-source nodes are in idle mode in their own 4-bits slots. The CH compares the difference data from source nodes and assigns data slot to the only one of the nodes having same data. In this way, different measurements are transmitted in data transmission period after the contention period.

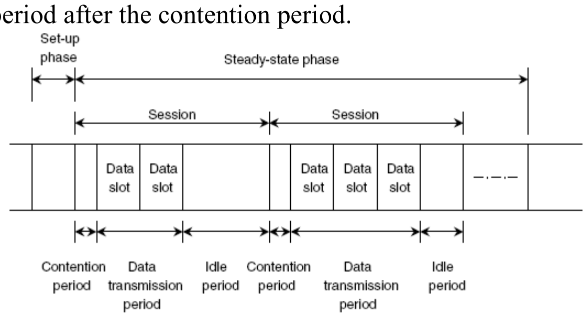

Figure 2. Illustration of single round for BMA protocol (Li, 2004).

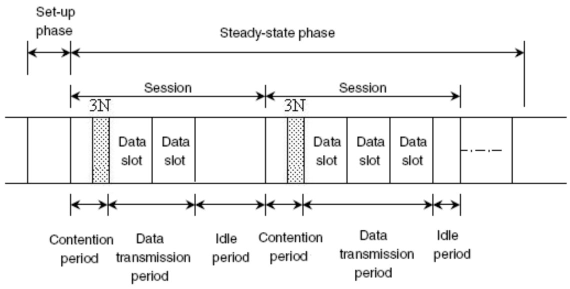

Figure 2. Illustration of single round for our proposed protocol.

P_t: transmit mode power consumption
T_d: time required to transmit/receive a data packet
E_{in}: energy consumption of an idle node
P_i: power consumption of an idle node
P_r: receive mode power consumption
T_c: time required to transmit/receive a control packet
T_{ch}: time required for the CH to transmit a control packet
l: number of frames
N: number of nodes
p: probability
n: number of source nodes n=Np

3.1. Our Proposed Method Used in a Simple MAC

p' : probability
m: number of source nodes which are assigned data slots (number of source nodes having different data)

$$m= np' \quad (1)$$

Energy consumed by a source node in a frame

$$E_{dn} = P_t(T_c+(3N/\text{ data rate}))+ (N-1) P_i T_c+(3N/\text{ data rate})) + P_tT_d + P_rT_{ch} \quad (2)$$

Energy consumed by a non-source node in a frame

$$E_{in}= NP_i(T_c+(3N/\text{ data rate})) + P_rT_{ch} \quad (3)$$

The CH consumes $nP_r (T_c+(3N/\text{ data rate})) + (N-n) P_i (T_c+(3N/\text{ data rate})) + P_tT_{ch}$ and mP_rT_d in the data transmission period

$$E_{ch} = nP_r (T_c+(3N/\text{data rate}))+ mP_rT_d + (N-n) P_i (T_c+(3N/\text{data rate})) + P_tT_{ch} \quad (4)$$

Total energy consumed during a round in the proposed protocol

$$E_{PROPOSED} = l[n(P_t(T_c+(3N/\text{ data rate}))+ (N-1) P_i (Tc+(3N/\text{ data rate})) + P_rT_{ch})+ mP_tT_d + (N-n)(NP_i(T_c+(3N/\text{ data rate}))+ P_rT_{ch})+ nP_r(T_c+(3N/\text{ data rate}))+ mP_rT_d + (N-n) P_i (T_c+(3N/\text{ data rate})) + P_tT_{ch}] \quad (5)$$

3.2. E-TDMA Protocol

Energy consumed by a source node in a frame

$$E_{dn}= P_t T_d \quad (6)$$

Energy consumed by the cluster head

$$E_{ch}= nP_rT_d + (N-n) P_iT_d \quad (7)$$

Energy consumed by the cluster head to transmit a control packet

$$E_{ch}= P_tT_c \quad (8)$$

Energy consumed by each node to receive a control packet

$$E_n= P_rT_c \quad (9)$$

In set-up phase, total energy consumption

$$E_C = P_tT_c + NP_rT_c \quad (10)$$

Total energy consumed during a round in E-TDMA protocol

$$E_{E\text{-}TDMA} = P_tT_c + NP_rT_c + l\,[nP_t T_d + (N-n) P_i T_d + nP_rT_d] \quad (11)$$

4. Performance Analysis

Rockwell's WINS model (Raghunathan, 2002) is used for numerical analysis. Transmitting power is 462 mW, receiving power is 346 mW, idle listening power is 330 mW and data rate is 24 kbps for transceiver. Assume a data packet size of 250 bytes, a control packet size of 18 bytes and $P_i=P_e$, $T_{ch}=T_c$. The graph of energy consumption versus p and p' probabilities are shown in Figure 3 for number of frames (l) 2 and number of nodes (N) 10.

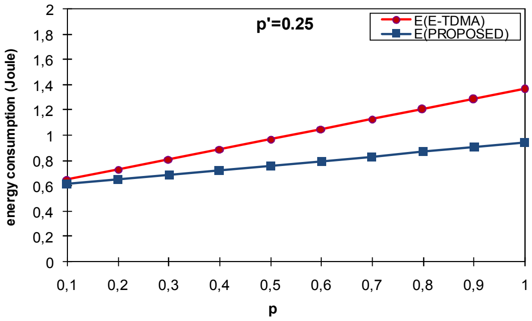

Figure 3. Energy consumption versus probability.

The energy consumed by the CH for comparing difference data from source nodes is ignored in energy computations. Transmitting 1 kb data over 100 meters is approximately the same as executing 3 million instructions (Pottie, 2000). Considering the energy consumption in communication is higher than the one in computation, it is clear that the proposed protocol will provide energy-efficient results even the energy consumption of computation is included.

Although the source-to-cluster-head control message is only 1-bit long in BMA protocol, control packet includes other MAC level overhead information plus 1-bit control message (Lazarou, 2007). In computations, three times the number of nodes (3N) bits are added to the control packet length to allocate 4-bit slot for each node since the contents of the control packet is unknown and it has already N bits.

The p' denotes the probability what fraction of the source nodes have the same data and hence the percentage of the source nodes assigned data slots. Since slot assignment is realized without considering the contents of the data in E-TDMA protocol, energy consumption values of E-TDMA does not vary with p'. The effect of the p' on our proposed protocol is seen in the graph. The more p', the more source nodes assigned data slots and the more source nodes having different data. The 25% of the source nodes transmits data, this protocol is more energy efficient than E-TDMA.

5. Final Remarks

We present an idea for TDMA-based MAC protocols which offer data slot assignment by considering source nodes transmitting same data in event driven WSN applications in this paper. In this approach, contention period is increased because of transmitting difference data in 4-bits slots instead of 1-bit slot. On the other hand, number of assigned data slots is decreased, which results in energy saving. The energy efficiency of the proposed method is shown by comparing to the E-TDMA.

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