A cluster based on demand time synchronization in wireless sensor networks

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Abstract — Time synchronization is extremely important for wireless sensor networks. Since the sensors have very limited energy resources and it is very difficult to change batteries for the sensor nodes, energy efficiency is one of primary importance for a sensor network. To prolong the lifetime of a sensor network, we proposed a cluster based on demand time synchronization in wireless sensor networks (COD). In this protocol many nodes are set to “sleep” modes in most cases, for the formation of clustering and time synchronization procedure is initiated only when the event is detected. Compared to other clock synchronization protocols, the COD simulation results show that it is more energy efficient than RBS and FTSP.

Keywords — wireless sensor networks; time synchronization; cluster; on demand;

I. INTRODUCTION

A wireless sensor network is composed of a number of sensors. Each node needs common norms to send and receive their own information. Especially, time message is important for any collaborative system [1]. Energy efficiency must be considered in almost every aspect of sensor network as the nodes are usually battery-powered, which operate without attendance for a long time [2].

An energy efficient network algorithm can save energy significantly in individual sensor nodes and prolong the lifetime of the entire network. However, most existent networks for traditional wireless Ad Hoc networks can not effectively address the power constraint [3], which make it necessary to develop various energy efficient network schemes to prolong the nodes lifetime in the whole network.

In recent years, many network synchronization schemes have been proposed. In RBS [4] algorithm, the neighboring nodes use the broadcast beacon’s arrival time as the reference point for comparing the clock readings. The local timestamps are exchanged between neighboring peers in order to calculate the drifts and synchronize clocks. RBS removes several non-deterministic sources from traditional time synchronization [5].

The Flooding Time Synchronization Protocol (FTSP) [8] is proposed to achieve time synchronization in a wireless sensor network. It uses MAC layer timestamp capabilities to eliminate several errors sources on the synchronization process, and employ linear regression to compensate for the possible drifts in the clocks [9].

II. SYSTEM MODEL

A. Network Model

As shown in Figure 1, Each cluster is composed of a cluster head, and several cluster members in the network. The cluster head, which maintains local membership and global topology information, is responsible for transmitting data to the Base Station. The cluster numbers are responsible for collecting, congressing and processing parameters of the detecting area then transmitting them to their cluster head. In order to simplify the network model, we assume that all sensors are deployed in an area randomly, a sensor can compute the distance if the transmission power is given, and the communication is based on the single-hop [10].
B. Energy model

As shown in Fig. 2, In this paper, we assume a simplified model for the radio hardware energy dissipation, the receiver dissipates energy to run the radio electronics, both the free space and the multipath fading channel models were used, depending on the distance between the transmitter and receiver [11]. To transmit a message, the energy expends [12].

\[
E_{\text{Tx}}(l, d) = E_{\text{Tx-elec}}(l) + E_{\text{Tx-amp}}(l, d) = \begin{cases} 
    lE_{\text{elec}} + l_{\text{ef}}d^2 & d < d_0 \\
    lE_{\text{elec}} + l_{\text{amp}}d^4 & d \geq d_0
\end{cases}
\]

When receiving the data, the radio expends:

\[
E_{\text{Rx}}(l) = E_{\text{elec}} \times l
\]

III. A CLUSTER BASED ON DEMAND TIME SYNCHRONIZATION (COD)

The algorithm is composed of two phases: cluster construction phase and time synchronization phase. In order to save energy in wireless sensor networks, sensors hardware are usually designed in “sleep” mode. In this paper we assume that all nodes in the sensor network are deployed randomly and set to “sleep” mode if there is no event occurs. If there is an event, the nodes which detect the events wake up the transmitting and processing units on demand afterwards, the cluster construction phase stares.

A. cluster construction phase

The cluster head election is the basis of cluster formation. To prolong the lifetime of wireless sensor networks, the cluster heads need to update periodically. At present, the head election method always base on principals as follows: (1) the reserved energy of the node (2) the distance between the head and BS (3) the position of the head [13].

Firstly, In order to avoid unnecessary transmission, all nodes which are set to “awake” wait for Tx amount of time before they send out a broadcast message, but all nodes can receive messages during the time, such as, REPLY and JOIN, the Tx on node x using a zero mean Gaussian[14]:

\[
T_x = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{x^2}{2\sigma^2}}
\]

Where \( e_x \) is the available energy of node x and \( \sigma \) is the standard deviation, the amount of Tx lies on the remaining energy of the node. A node will increase its transmission power to the next level and broadcast REQUEST again if the node receives no message before a certain time[14]. Afterwards, the cluster heads broadcast CLUSTER_JOIN message over the network.

B. time synchronization phase

Before we propose the time synchronization process, as shown in Figure 3, we describes a pair-wise synchronization between the transmitter and receiver nodes. A is assigned as a parent node and B is a child node, node A sends a synchronization pulse to B, timestamped at \( T_1 \). When node B receives the pulse, it timestamps at \( T_2 \) and sends an ack packet back to A at \( T_4 \). The parent nodes receive the ack packet and timestamps one last time at \( T_3 \).

These timestamps present estimation of clock offset \( d \) and propagation delay \( D \) [12]:

\[
\begin{align*}
    d &= \frac{(T_2 - T_1) - (T_4 - T_3)}{2} \\
    D &= \frac{(T_2 - T_1) + (T_4 - T_3)}{2}
\end{align*}
\]

After the cluster construction, the cluster heads are synchronizes with Base station by pair-wise packet exchange and the cluster members may synchronize with cluster head by an improved method.

Firstly, the Base Station broadcast synchronization initial message to cluster headers, then calculate the propagation delay \( D \) and clock offset according to pair-wise algorithm. We assume that all nodes are stationary after the events, which means that the propagation delay \( D \) is invariable for each cluster heads. In order to decrease the number of packets transmitted, every cluster head H record the propagation delay DH after the first synchronization, so in the next round, the BS can calculate \( d_h \) by the following formula:

\[
d_n = T_m - D_m - T'.
\]
Secondly, as shown in Figure 4, the synchronization of the clusters begins[15].

Step 1: the cluster head broadcast Synch bg message at time T1, all members of the cluster record the received timestamp of the packet and specify one cluster member M.

Step 2: the cluster member M record the receive time \( T_m \) and synchronize with cluster head by a pair-wise method. The cluster head calculate the propagation delay \( D_m \) and clock offset \( d_m \).

Step 3: the cluster head send Synch msg at \( T' \), which contains the information of \( D_m \). When other cluster member N receive the Synch_toall at \( T_n' \), \( d_n = T_m - D_m - T' \), then adjust their clocks by \( d_n \).

IV. PERFORMANCE EVALUATIONS

To evaluate the performance of COD, we place sensor nodes uniformly in a 100m *100 m square field, the BS which keeps accurate time is deployed at the center of the field. The radio range is 10m, the clock frequency is 12.8MHz and the precision of oscillator is \( 10^{-7} \). Each data message was 500 bytes long, and the packet header for each type of packet was 25 bytes long. The parameters of the model are usually set as:

\[
E_{\text{elec}} = 50\text{nJ/bit} \quad \varepsilon_{\text{amp}} = 0.0013\text{pJ/bit/m}^4 \\
\varepsilon_{\text{fj}} = 10\text{pJ/bit/m}^2 \quad E_{\text{d4}} = 5\text{pJ/bit/signal}
\]

Firstly, we evaluate how the number of nodes are affected the performance of protocol. We compare the COD with FTSP and RBS and result is as follows:

In Figure 5, we change the number of the nodes from 50 to 500. The interval of event is set as 5 min. After 500 min, we demonstrate that total energy consumption increases as the number of nodes increases. That’s because the network become very dense when the number of nodes is large and more nodes will be waken up on demand if an event occurs, which means that more the network should consume more energy to send or receive message. Besides, as bring on demand mechanism in COD, the protocol consumes less energy than FTSP and RBS.

In order to evaluate how the interval of event affect the lifetime of COD, we change the interval from 5 min to 60 min. As shown in figure, in periodical protocols, such as TPSN and RBS, we can obtain that the energy consumption of the network is hardly changed as the interval of event makes little affect on them. But in COD, the network consumes more energy as the interval increases. The reason for that when the event occurs more frequently, the nodes should be waken up more times and consume more energy.

V. CONCLUSIONS

Time synchronization is critical in wireless sensor network, for applications, as energy limited it is an obvious...
peculiarity in the sensor networks and various communications, listening, consumes energy. So efficient usage of node energy is useful to prolong the network lifetime. In this paper, we propose a cluster based on demand time synchronization, nodes may be asleep or woken up when necessary. The protocol consists of two parts: cluster construction and time synchronization. Simulation results show that COD is more energy efficient than other time synchronization schemes in applications when the interval of events is large.

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