Abstract

Wireless sensor networks (WSNs) have emerged as an attractive and key research area over the last decade. Time synchronization is a vital part of infrastructure for any distributed system. In embedded sensor networks, time synchronization is an essential service for correlating data among nodes and communication scheduling. This is realized by exchanging messages that are time stamped using the local clocks on the nodes. Various time synchronization protocols have been proposed aiming to attain high synchronization accuracy, high efficiency and low communication overhead. However, it requires that the time between resynchronization intervals to be as large as possible to obtain a system which is energy efficient having low communication overhead. This paper presents a simple but effective skew compensation algorithm that measures the skew rate of the sensor nodes with respect to the reference node and calibrates itself to compensate for the difference in the frequencies of the nodes. The proposed method can be incorporated with any existing time synchronization protocol for WSNs.

1. Introduction

In recent years, WSNs have established a massive interest due to their promising applications in a range of areas such as military, scientific and environmental monitoring, medical, home networks, surveillance and tracking, health monitoring, inventory location monitoring, industrial and process automations and agriculture. Time synchronization is one of the fundamental middleware services for sensor networks. Synchronizing two embedded systems over a wireless channel is an exigent problem as several error sources such as the accuracy of time stamping of events, message loss over the channel due to fading and shadowing, changes in the clock frequency due to environmental changes, etc. has to be considered. In addition to this, WSNs add yet other challenges into the equation such as energy efficiency and communication overhead. To address these problems, several synchronization protocols such as Reference Broadcast Synchronization (RBS, [1]), Flooding Time Synchronization Protocol (FTSP, [1]), Timing-sync Protocol for Sensor Networks (TPSN, [1]), etc. have been reported.

WSN nodes generally comprises of low cost crystal resonators/oscillators that is used to clock the timers. The frequency of these devices changes due to a number of factors such as temperature, humidity, crystal aging and noise leading to contradictory frequencies on different nodes. There two major challenges for maintaining an accurate time on the nodes: (1) the crystals providing the clock at each node may be running at different frequencies thus allowing the clock values to diverge over time (clock skew) and (2) the crystal frequencies may change considerably over time due to environmental conditions (clock drift). To tackle the problem of clock drift, several methods such as Temperature Driven Time Synchronization (TDTS, [1]) and Temperature Compensated Algorithm (TCA, [1]) has been reported.

2. The proposed Skew Compensation Algorithm

The Skew Compensation Algorithm proposed in this paper aims to increase the resynchronization interval between the synchronizing nodes. Though most of the reported researches have aimed to obtain greater synchronization accuracy, clock drift and clock skew are of equal importance. This is due to the fact that wireless sensor nodes are low powered devices and energy consumption is a major challenge. If the clock drift and clock skew are not taken into account and compensated for, the synchronized time between the nodes will diverge quickly and thus will need to be
resynchronized very often. Hence, the sensor nodes will have to wake up very often for resynchronization which will lead to increased energy consumption and greater communication overhead. Sensor networks are usually deployed in large numbers depending on the application, hence it is not wise to measure the skew of all the nodes and correct it before deployment. Hence it is desirable to develop an algorithm, which will calculate and compensate for the clock skew of the slave nodes with respect to the reference node. In this research, a simple method which evaluates the skew rate between two successive beacons and compensates for the offset is presented. Initially, when the nodes are deployed and turned on, several time-stamped synchronization beacons are sent by the reference node to the slave nodes at an interval less than the resynchronization interval. This is to quickly compensate for the difference in frequencies of the slave nodes. These beacons are sent at different intervals, which are pre-known to both the reference node and the slave nodes, slowly increasing the interval thus approaching the final desired resynchronization interval. Once the interval between the beacons reaches the resynchronization interval, all the following resynchronization messages are sent at the resynchronization interval. The starting interval and the number of beacons sent at an interval lower than the synchronization interval depends on the application requirements.

3. Results and Discussion
The sensor nodes used for the purpose of this research comprises of the Nordic NFR24L01+ single chip 2.4GHz radio module at 250kbps air data rate together with 16MHz Arduino Mega 2560 as its micro-controller unit (MCU). Firstly, the slave nodes were synchronized by the reference node and the skew drift over and interval of 30 minutes was recorded over different operating voltages. This was repeated several times and the average skew rate for the nodes were calculated. Due to limited number of sensor nodes available in the lab, only 4 nodes were used with Node A as the reference and Nodes B, C, and D as slave nodes. The results were plotted using MATLAB as shown in figure 1.

![Fig. 1: Clock skew of the slave nodes with respect to Node A after synchronization.](image)

From figure 1, it can be concluded that all the sensor nodes are initially operating at different frequencies as mentioned earlier. Most of the applications requires an accuracy of 1ms, hence in this research the intervals selected were such that the nodes synchronized time are always within the 1ms range. Thus the beacons were sent at 1s, 2s, 5s, 10s, 20s, 40s, 80s, 160s and then at resynchronization interval of 200s. The skew rates were again recorded and the results plotted as shown in figure 2. It can be noted that after the skew compensation algorithm is applied, the slave nodes clock drift rate with respect to each other is within 5ppm and within 37ppm with respect to the reference node, Node A.

![Fig. 2: Clock drift of the slave nodes with respect to the reference node, Node A](image)

4. Conclusion
This paper proposed a simple but effective algorithm for skew compensation which reduced the skew between the slave nodes to less than 5ppm. The method only used 7 extra beacons to compensate for the initial skew after which, it takes advantage of the resynchronization messages to compensate for the skew rate. Thus, this method also accounts for any change in frequency of the nodes due to environmental changes. Hence, there shall be no need for another compensation algorithm to account for the frequency changes due to environmental conditions.

Acknowledgment
This work was supported by Priority Research Centers Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology(2009-0093228) “This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency)”(NIPA-2013-H0301-13-2005)

Reference


