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Clustering synchronisation of wireless sensor network based on intersection schedules

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ABSTRACT

Wireless sensor network (WSN) technology has gained in importance due to its potential support for a wide range of applications. Most of the WSN applications consist of a large number of distributed nodes that work together to achieve common objectives. Running a large number of nodes requires an efficient mechanism to bring them all together in order to form a multi-hop wireless network that can accomplish specific tasks. Even with the recent developments made in WSN technology, a number of important challenges still create vulnerabilities for WSNs, including: energy waste sources; synchronisation leaks; low network capacity; and self-configuration difficulties. However, energy efficiency perhaps remains both the most challenging and highest priority problem due to the scarce energy resources available in sensor nodes. Synchronization by means of scheduling clusters allows the nodes to cooperate and transmit traffic in a scheduled manner under the duty cycle mechanism. This paper aims to make further advances in this area of work by achieving higher accuracy and precision in time synchronisation through controlling the network topology, self-configuration and estimation of the clock errors between the nodes and finally correcting the nodes' clock to the estimated value. Furthermore, the target in designing energy efficient protocol relies on synchronized duty cycle mechanism and requires a precise synchronisation algorithm that can schedule a group of nodes to cooperate by communicating together in a scheduled manner. These techniques are considered as parameters in the proposed OLS-MAC algorithm. This algorithm has been designed with the objective of ensuring the schedules of the clusters overlap by introducing a small shift in time between the adjacent clusters' schedules to compensate for the clock drift. The OLS-MAC algorithm is simulated in NS-2 and compared to some S-MAC derived protocols. The simulation results verified that the proposed algorithm outperforms previous protocols in number of performance criterion.

1. Introduction

Wireless sensor network (WSN) technology has gained in importance due to its potential support for a wide range of applications including military operations, industrial manufacturing, surveillance, targeting systems, health needs and monitoring disaster areas amongst many other applications [1,2]. Depending on the application services, WSN generally consists of a large number of distributed nodes that work together to achieve objectives. Running a large number of nodes ultimately

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requires an efficient mechanism to bring them all together in order to form a multi-hop wireless network that can accomplish a common task. Typically, most of the WSNs are formed by random deployment of the sensor nodes without human intervention. This type of sensor network is strongly dependent upon the battery life of the sensor nodes, however it is not always feasible to replace the battery once it expires. WSNs are expected to last for long periods of time, typically years, without needing to replace the batteries within the nodes. Therefore WSNs must be highly energy efficient in order to prolong the network life time. There are various mechanisms designed specifically to consider the limited source attributes of WSNs [3–32]. Among them, the techniques that make nodes operate with low duty cycles is considered an effective solution for when the traffic load is light [33]. Putting nodes into periodic listen/sleep can significantly reduce the power waste caused by idle listening, which is identified as one of the main sources for energy waste [23]. Power consumption during idle listening has been defined as having the same order as a receiving mode. In addition to idle listening there are a number of issues that have been addressed in relationship to energy expenditure [23] including, collisions, processing overhead and overhearing. These concerns and other operations like synchronisation and clustering in WSNs are handled by the medium access control (MAC) layer protocols. MAC protocols are designed specifically for wireless sensor networks and have the additional responsibility of managing radio activity to conserve energy. Conversely traditional MAC protocols mainly focused on balancing throughput, delay, and fairness matters [34].

Designing an energy efficient protocol relies on a duty cycle mechanism and requires a precise synchronisation algorithm which can schedule a group of nodes to cooperate in communicating together in a scheduled manner (duty cycle). Forcing neighbour nodes to be active on an agreed specific time can make traffic travel more freely even when nodes are operating with a low duty cycle. However, the lack of time accuracy can significantly reduce the network's lifetime. The functionality of any protocol based on a clustering concept depends mainly on the accuracy of the clustering process, which is affected greatly by the synchronisation leaks. Several factors cause synchronisation errors, among them being the clock drift that accumulates over time at each hop. A number of techniques [5,9,11,19,20,26,29,35,36] have been proposed for WSN synchronisation but do not focus on the precision of the synchronisation period.

The work of a MAC layer in WSN can generally be divided into two major categories, contention based MAC protocols (Carrier Sense Multiple Access CSMA) and time division multiple access (TDMA) MAC protocols [37]. The later approaches require a tight synchronisation mechanism in order to assign time slots to each node. Furthermore, dividing the time into slots according to the number of nodes that are sharing the same medium is not practical for a large number of nodes.

The architecture of the CSMA class is more appropriate for WSNs in terms of the concern of energy efficiency. Nodes can enter the sleep state in order to save energy and only wake up when there is information ready to be sent. The virtual clustering scheme introduced by [4] is another feature that is supported by the contention based algorithms where nodes are grouped into a flat manner without coordination or control by any cluster heads. Nodes are communicating with each other in the form of peer-to-peer style within the cycle periods.

This paper consider synchronised scheme aims to make further advances by achieving more accuracy and precision in time synchronisation through controlling the network topology, self-configuration and estimating the clock errors between the nodes and ultimately correcting the nodes' clock to the estimated value. Observations from the literature indicate that synchronisation and clustering can have significant influence on network functionality, which in turn reflects on overall network performance and in particular, energy efficiency.

Periodic listening and sleep cycles organize the network into clusters and maintain the synchronisation. These are the main attributes for consideration when designing a new medium access control (MAC) algorithm. With these attributes in mind, the developed algorithm is termed the Overlapped Schedules MAC (OLS-MAC). In addition, the OLS-MAC algorithm is designed with three main input parameters: the starter point, the number of hops per cluster and the overlap ratio between clusters which enable us to control the topology and the size of the network. Energy efficiency is accomplished in the OLS-MAC by adopting duty cycle schemes by means of putting the node radio transceiver into periodic listen/sleep, which is an effective mechanism for saving energy and therefore extends the network lifetime [23]. The OLS-MAC algorithm portions the network into clusters initiated by a starter node, which can be the sink for instance. All nodes of the same cluster follow the same schedule and communicate in peer-to-peer mode. The schedules of different clusters are not exactly the same, but sufficiently overlap to make communication between these clusters more feasible with less delay. In the design of the OLS-MAC algorithm, a small shift time is introduced between the adjacent clusters which is used to avoid synchronisation errors, i.e. clock drift which is accumulated at each hop over time. OLS-MAC adopts the virtual clustering concept in which no cluster head is involved in order to establish scalability to a large number of distributed sensor nodes. In brief, the OLS-MAC algorithm aims to generate connected overlapped clusters with a constant depth (number of hops) that covers the entire sensor network without having border nodes as a bridge between clusters.

Different values for the algorithm parameters are selected through using simulation experiments to achieve the clustering process objectives with central synchronisation. Moreover, the results show that the OLS-MAC algorithm incurs low overhead in terms of broadcasted SYNC messages used for network synchronisation, and produces controlled sized clusters, which allows distributing the load evenly over the different clusters.

The rest of this paper is organized as follows: Section 2 presents related work regarding MAC layer protocols for WSNs. Section 3 covers the design of OLS-MAC, describing the main input parameters used with OLS-MAC including the synchronisation start point, the clusters' radius and the schedules' overlap ratio. Section 4 introduces the clustering shapes and schedules produced by OLS-MAC as well as the duty cycle and data communication concepts followed OLS-MAC. Section 5 presents OLS-MAC Features including scalability, overlapped schedules and handling clock drift. Section 6 describes