ENERGY-EFFICIENT COMMUNICATION PROTOCOL IN LINEAR WIRELESS SENSOR NETWORKS

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Abstract
Wireless sensor networks (WSNs) have been widely recognized as a promising technology that can enhance various aspects of structure monitoring and border surveillance. Typical applications, such as sensors embedded in the outer surface of a pipeline or mounted along the supporting structure of a bridge, feature a linear sensor arrangement. Economical power use of sensor nodes is essential for long-lasting operation. In this paper, we present wireless High-Level Data Link Control (HDLC) a novel approach to energy-efficient data routing to a single control center in a linear sensor topology. Applying a standard data layer along with a time division multiple access (TDMA)-based Medium Access Control (MAC) and time synchronization technique specifically designed for the linear topology, we address the interoperability problem with guaranteed energy efficiency and data link performance in linear sensor topology.

Keywords: *wireless sensor networks; linear topology; interoperability.*

INTRODUCTION

Most of them routing protocols that have been designed for wireless sensor networks [1] consider sensor nodes that operate in a mesh topology. For specific application scenarios, however, a mesh topology may not be appropriate or simply not feasible. This can be due to physical structure, measuring point distribution or other criteria. In many of these applications, direct transmission from data source to sinks is usually not practical because the Sensor Nodes (SNs) have a limited communication range and data sources are generally far away from the sinks. Therefore, a multi-hop network is a good choice for data routing, and clustering topology is appropriate to achieve network scalability [2]. So far, little focus has been given to low-power WSNs for linear topologies. Some papers present linear wireless networks for bridge [3], pipeline [4] or overhead transmission lines [5]-[7] application, but the systems described in these works are proprietary solutions, following no particular standard for communication and arising interoperability problems.

Topology design, power usage minimization and installation cost are very important for successful deployment of WSNs while meeting the application requirements. This paper proposes a new WSN technology for long-term continuous monitoring of linear sensor topology. In these WSNs, SNs are installed on the critical linear infrastructure equipment's. However, the power supply constraints of these WSN pose great challenges in the energy consumption. Hence, there is a need for a reliable and low-power linear WSN for long-lasting operation. Therefore, WSNs based on IEEE 802.15.4 standard for low-power wireless transceiver technology need to be used [8]. Generally, the transmission range of the nodes is assumed to be 10–100m with data rates of 20 to 250 kbps [9]. Hence, large network, and multi-hop communication is required so that nodes relay the information to the data collector, i.e., the sink. Moreover, these networks have to combines power and routing awareness, communicates power efficiently through the wireless medium, integrates data with networking protocols, and promotes cooperative efforts of SNs [1].

DETAILED DESCRIPTION

The proposed WSN adopts the IEEE 802.15.4 PHY layer but define a new TDMA-based MAC, network and transport layers based on HDLC standard. The issue regarding synchronization of nodes along the network is addressed by applying any of the time synchronization techniques such as: TPSN (Timing-sync Protocol for Sensor Networks) [10] or PTP (Precision Time Protocol) [11]. The chain of short-ranged wireless sensors creates a virtual wired link by means of an ad-hoc network. The system does not require complex routing techniques. The proposed WSN supports half duplex communication providing a bidirectional link between the SNs and the primary station. The communication is done in rounds, one time from the sink node (primary station) to the last node in the network (end node) and one time from the end node to the sink. The bidirectional link acting as a virtual conveyor belt can be used to collect data from different sensors along the path or send data from the base station to different sensors in the network. The data from multiple devices is encoded as HDLC frames [12] and is collected in the available space of the IEEE802.15.4 standard packet up to a maximum size of 125 octets [8]. In this way various nodes can send variable length packages in one communication round of the transmission grid, following a standard form.

Figure 1 illustrates the proposed half-duplex communication model suitable for low-power WSN and the handling of downstream and upstream data flows. The upstream data flow is generated by the primary station and flows up to the last node in the network. The downstream data flow is generated by the last node in the network and starts when the upstream flow reaches this node. In this way a two way communication cycle is generated which repeats itself along the time based on network communication period. This data flow has a strict staggered pattern: each node will calculate the time for receive and transmit time slot based on the total number of hops. The upstream IEEE802.15.4 packet transmitted by the primary station contains HDLC frames with data, commands or timing information to SNs. The downstream packet is a collection of HDLC frames with the responses from SNs to the primary station commands. If a sensor node does not receive commands from the primary station it will work as a router, and will transmit the downstream packet to the next node.

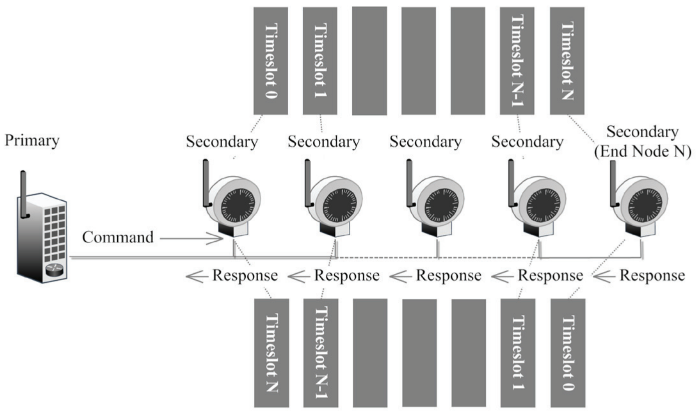

Figure 1. Bidirectional communication for low-power linear WSNs

IMPLEMENTATION AND PERFORMANCE EVALUATION

The wireless HDLC protocol stack consists of four major modules: timer, TDMA function, HDLC framer and the state machine. The timer module provides accurate timing to ensure the correct operating of the system. The timer module has been designed as a real time clock capable to provide accurate triggers for wake-up, measure, receive or transmit states of the sensor nodes and also to keep the time slots in synchronization.

Based on the prototype stack, we develop a demonstration network for monitoring environmental parameters. The demonstration network contains one primary station (master node) and seventeen SNs deployed with a gap varying from 50m to 100m as shown in Figure 2. Each node can communicate with two nodes to the left and two nodes to the right.

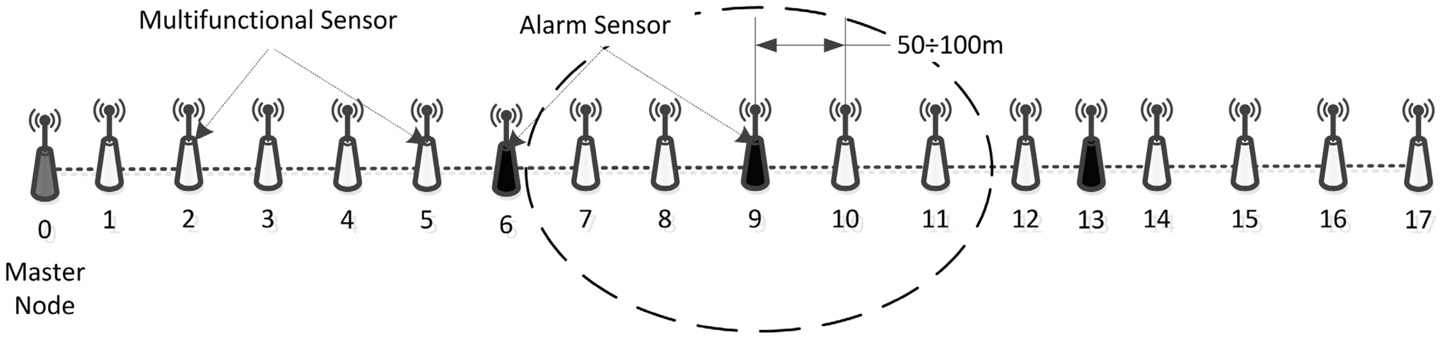

Figure 2. Each node can communicate with four nodes

Figure 3 shows the communication energy consumption for the network setup described above. In this figure it is illustrated the energy consumption for two communication rounds, in order to obtain data from all the 17 SNs in the network. Moreover, it provides energy consumption for each query from primary station and for the SNs responses.

Sending primary station-to-SNs commands has a high fixed cost due to the use of multicast commands for the different types of SNs. Receiving data from the first group of SNs and the alert sensors has a lower cost for the last SNs in the linear network who maximize the idle period in the TDMA slots. Receiving data from the second group of SNs and the alert sensors has a fixed cost for the first SNs and an incremental cost for the last SNs based on the total size of the superframe. The higher energy consumption for the SNs situated close to the primary station is exactly as expected, because of the routing functionality of these nodes and the size of the superframe when gets close to the primary station.

CONCLUSION

In this paper, the HDLC standard protocol in low-power linear WSNs was presented and evaluated. This protocol is evaluated in order to meet the objectives of interoperability, efficiency and reliability in WSNs. Using the HDLC protocol a user can interact at any time with different nodes in the network and can collect various types of data from many sensors at one time, which is an important capability for a linear network. Another advantage for low-power wireless networks is that the HDLC does not increase significantly the size of messages and it does not introduce complex headers or field to sensors data. Therefore, the HDLC based WSN is a low power wireless network for long-lasting operation.

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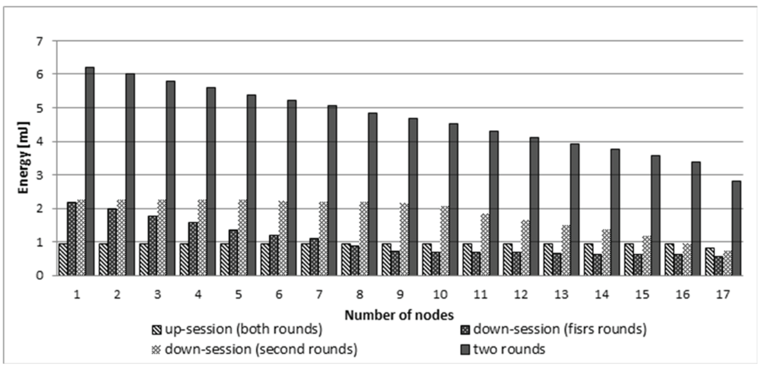

Figure 3. WSN Communication energy consumption