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A Hierarchical Energy Efficient Reliable Transport Protocol for Wireless Sensor Networks

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Abstract The two important requirements for many Wireless Senor Networks (WSNs) are prolonged network lifetime and end-to-end reliability. The sensor nodes consume more energy during data transmission than the data sensing. In WSN, the redundant data increase the energy consumption, latency and reduce reliability during data transmission. Therefore, it is important to support energy efficient reliable data transport in WSNs. In this paper, we present a Hierarchical Energy Efficient Reliable Transport Protocol (HEERTP) for the data transmission within the WSN. This protocol maximises the network lifetime by controlling the redundant data transmission with the co-ordination of Base Station (BS). The proposed protocol also achieves end-to-end reliability using a hop-by-hop acknowledgement scheme. We evaluate the performance of the proposed protocol through simulation. The simulation results reveal that our proposed protocol achieves better performance in terms of energy efficiency, latency and reliability than the existing protocols.

1. Introduction

The Wireless Sensor Network (WSN) is a network of hundreds or thousands of tiny, resource constrained, inexpensive nodes that can sense a phenomenon, process and transmit sensed data over a wireless medium. The WSN finds its applications in various domains such as agriculture or environmental sensing, object tracking, wild life monitoring, health care, military surveillance, industrial control, home automation and security [1–3]. Since the WSNs are deployed in an unattended environment, the WSN applications require high reliability. The reliability of WSN is influenced by the data redundancy. The redundant data in WSN are caused either due to the slow change in phenomena or due to the same data sensed by multiple sensors. The data redundancy can be broadly classified as spatial and temporal redundancy. The spatial redundancy is caused due to multiple sensor nodes having same sensed data. The temporal redundancy is caused due to a sensor node producing same sensing value over a period. The redundant data drain the energy of the nodes, increase congestion, communication and computational overhead. The malicious nodes may take the advantage of duplicate data and cause energy drain by injecting redundant data in the network (i.e. replay attack [4]). That may lead to routing holes [5]. In WSNs, the redundant data are handled by packet sequence numbers. This technique helps the receiver to identify the duplicate data and discard it. However, a packet sequence number cannot help a

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sender to control redundant data transmission. The data aggregation is another technique to eliminate redundant data. The routing schemes may use structured architecture such as cluster-based [6] or tree based [7] or structure free architecture [8,9] for data aggregation. In structured data aggregation [6,7], multiple sources send their data to the aggregation point which eliminates redundant data using various methods [10] such as statistical approaches [11,12], probabilistic approaches [13–17] and artificial intelligence [18,19]. The structure free approaches [8,9] perform dynamic data aggregation using local information so that the energy spent to build a structure can be saved. However, the energy spent due to the data transmission by the sensor nodes and data aggregation at the aggregation point cannot be avoided.

The frequency of the data sensing can be reduced to minimise the data redundancy in WSN. However, this may affect the accuracy of the data. Thus, the data should be sensed periodically and it is important to handle redundant data in WSN. Further, the reliable data transport to the sink node must be handled by an efficient transport protocol mechanism. In this paper, we propose a framework to maximise the network lifetime and achieve end-to-end reliability by controlling the redundant data transmission with the co-ordination of BS. Our proposed framework works in two folds. First it constructs a hierarchical cluster of sensor nodes. Each cluster has a cluster head (CH) which receives the data from all the members of the cluster, aggregates the similar data and forwards it to the next level CH. This clustering technique handles the spatial redundancy. Secondly, the temporal redundancy is handled by not transmitting the temporal redundant data to the CH. The BS uses a time-out mechanism to identify the redundant data at its own side. It uses both implicit and explicit acknowledgement schemes to achieve end-to-end reliability for all the data. We propose an algorithm for BS that computes and generates an acknowledgement for each data even for redundant data without being received.

The paper is organised as follows. Section 2 presents the works done on reliable data transport over WSN. The proposed hierarchical energy efficient reliable transport control protocol is presented in Section 3. The simulation results and analysis is presented in Section 4. The summary of conclusion is presented in Section 5.

2. Related work

Many reliable transport protocols [20] have been proposed for reliable data transmission in WSNs. These are Reliable Multi-Segment Transport (RMST) [21], Event to Sink Reliable Transport (ESRT) [22], Asymmetric Reliable Transport (ART) [23], Rate-controlled Reliable Transport protocol (RCRT) [24], Flush [25], Energy-efficient and Reliable Transport Protocol (ERTP) [26], Pump Slowly Fetch Quickly (PSFQ) [27], Improved PSFQ [28] and Data-Reliable Energy Efficient Transport Layer Protocol (DREET) [29] and Distributed Caching for Sensor Network (DTSN) [30,31]. These transport protocols are analysed on the basis of reliability and energy efficiency. It is observed that protocols such as ESRT, RMST, ART, RCRT, PSFQ, Improved PSFQ and DTSN are not energy efficient.

The RMST [21] is a NACK-based upstream protocol (sensors to sink), which employs primarily timer-driven loss detection and repair mechanisms. It supports reliability with hop-by-hop recovery scheme. It introduces two modes of operation that is caching mode and non-caching mode. In caching mode, the sink node and all intermediate nodes cache the data segments and check the cache periodically for missing segments. When a node detects missing segments, it generates a NACK message which travels back to the source along the established path. In non-caching mode, the source and the sink maintain the cache and the base station monitors the integrity of the RMST data segment of the received fragments. The RMST is only suitable for reliable delivery of large blocks of data consisting of multiple segments such as JPEG image that is fragmented at the source and reassembled at the base station.

The ESRT [22] aims to provide both upstream event reliability and congestion control with minimum energy consumption. It can also reliably deliver multiple concurrent events to the base station. The ESRT guarantees only the end-to-end reliable delivery of individual event, not individual packet from each sensor node. It measures reliability by the number of packets carrying information about a particular event that are delivered to the sink. The ESRT configures the reporting frequency rate to achieve the desired event detection accuracy with minimum energy consumption. The ESRT always regulates the reporting frequency of all sources regardless of the congestion region. It neither prevents all losses nor retransmits lost packets. The ESRT assumes that the sink is one-hop away from all the sensor nodes, which might not be applicable to real environments.

The ART [23] is designed to provide bidirectional reliability i.e. both upstream (sensor to sink) end-to-end reliability and downstream (sink to sensor) query reliability. It also provides upstream congestion control mechanism in a decentralized way and regulates the data flow of intermediate nodes in an efficient way. A subset of sensor nodes are selected on the basis of their residual energy as essential nodes (E-nodes) to cover the domain that are required to be sensed in an energy efficient manner. A light weight ACK mechanism is adopted to guarantee reliability between E-node and sink. If ACK is not received from the sink by the E-nodes within the particular time period then the E-nodes assume congestion in the network. The E-nodes regulate the flow of the data by restraining its neighbouring non-E-nodes from sending data until the congestion is cleared.

The RCRT [24] is an upstream multipoint-to-point reliable transport protocol, which includes congestion control and explicit rate adaptation functions. The RCRT ensures reliability by using explicit end-to-end loss recovery. It implements NACK-based retransmission mechanism for end to end loss recovery, where each node along the path cache packets to support on demand loss recovery. The sink centrally performs congestion detection, recovery and rate adaptation operation. The RCRT provides end-to-end reliability of all data transmitted by each sensor to a sink. However, the RCRT reliability depends on the MAC layer retransmission which is not efficient. A single packet loss may force rate reduction as the congestion detection depends on loss recovery time. The RCRT does not address the issue of contention.

The Flush [25] is a reliable high good put bulk data transport protocol that provides end-to-end reliability. In Flush, the sink schedules the data transfer for each node in a round robin fashion to support single data flow and to avoid inter-path interference. To improve channel utilisation, the rate