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Bandwidth efficient cluster-based data aggregation for Wireless Sensor Network ☆

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ABSTRACT

A fundamental challenge in the design of Wireless Sensor Network (WSNs) is the proper utilization of resources that are scarce. The critical challenge is to maximize the bandwidth utilization in data gathering and forwarding from sensor nodes to the sink. The main design objective is to utilize the available bandwidth efficiently. The proposed Bandwidth Efficient Cluster-based Data Aggregation (BECDA) algorithm presents the solution for the effective data gathering with in-network aggregation. It considers the network with heterogeneous nodes in terms of energy and mobile sink to aggregate the data packets. The optimal approach is achieved by intra and inter-cluster aggregation on the randomly distributed nodes with the variable data generation rate. The proposed algorithm uses the correlation of data within the packet for applying the aggregation function on the data generated by nodes. BECDA shows significant improvement in PDR (67.44% and 26.79%) and throughput (41.25% and 26.16%) as compared to the state-of-the-art solutions.

1. Introduction

Recent advances in technologies allowed the development of small devices with the capability of sensing, processing and transmission.

These devices act as sensors and can be integrated into Wireless Sensor Network (WSNs). Many applications have been emerged to use WSNs especially for the environmental, health monitoring, vehicle tracking system, military surveillance, and earthquake observation [1]. The most-distinguishing attributes of nodes used in WSNs are the limited power supply, storage capacity and communication bandwidth required. In WSN, bandwidth utilization and energy saving is a very important criterion for any existing and new applications. Normally, data collected from WSNs are large which makes it essential to eliminate redundant data, minimize the number of transmissions and improve the energy consumption. The effort to reduce the number of data packet transmission with the in-network processing is called data aggregation. The elimination of redundant data by use of aggregation at cluster head (CH) results in a reduction of communication cost. In this context, the energy consumption, network lifetime, communication bandwidth and transmission cost of the WSN affect significantly. The variation in lifetime and bandwidth also depends on the changes in network topology and the method of aggregating data packets.

BECDA considers the WSN model that refers to cluster-based aggregation, since clustering improves the scalability by stabilizing the network topology [2,3]. The additive and divisible aggregation function at CH results in a decrease of data packet

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count from the node to the sink. It saves energy, improves the network lifetime and bandwidth utilization [4]. Also, data aggregation with in-network processing makes it possible to enable energy savings with better bandwidth utilizations.

The paper proposes a novel BECDA to reduce the number of transmissions of data packets from nodes to the mobile sink. It focuses on the symmetric aggregation functions at cluster head, which are perfectly compressible. The aggregation function considers the correlation of random data generated by cluster member nodes in the cluster region. Each node in the network generates data by use of a random function with the standard deviation in the range of 0 and 1. The performance of BECDA is measured by aggregating the variable rate of data packets generated with consideration of throughput, energy consumption, PDR, and bandwidth utilization. BECDA shows significant improvement in throughput and PDR as compared with TTCDA and EECDA with aggregation of data packets.

The remaining part of the work is elaborated in different sections as follows; Section 2 presents a review of related works. Section 3 described the assumptions and proposed network model used for BECDA. Section 4 discusses the details of the BECDA. Section 5 gives the parameters used in the simulation and evaluates the results. Finally, paper is concluded in Section 6 with future works.

2. Related works

WSN applications commonly use hierarchical approaches to aggregate the data generated by sensor nodes. It helps to reduce the computational load and data redundancy for the energy consumption. In [4], TTCDA analytically proves that aggregation of data packet reduces the energy consumption and data redundancy by using the additive and divisible aggregation functions. In order to increase the depth of aggregation with efficient cluster head election a survey of many cluster-based algorithms are explored in [5,6]. Select cast [7], considers the optimal tradeoff between aggregation throughput and gathering efficiency using the spatial correlation between data collected from the sensor with lower bound as the threshold value for the gathering efficiency and throughput. Ref. [8] presents the hybrid approach for cluster-based aggregation, which adaptively selects the appropriate data aggregation function. This paper shows an improvement in energy consumption with the velocity of the target. Dynamic clustering shows better performance when velocity of the target is high. In [9], authors consider the grouping of cluster for reducing the energy consumption. In [10], Stable Election Protocol (SEP) considers that some percentages of nodes are equipped with higher energy and studied the impact of heterogeneity; authors show that the network stabilizes and prolongs the life before death of the first node. In [11], an Energy efficient Data Gathering Protocol (EDGA) is proposed to reduce the energy consumption by considering the residual energy of a node as computational metric. In [12], EECDA protocol uses the heterogeneous nodes in terms of energy for improving the network lifetime and stability. In [13], authors configure the heterogeneous nodes as advanced and super with variation in energy to improve the network lifetime and reduce energy consumption. Performance is tested for the static nodes. In [14], secure identity-based lossy aggregation integrity scheme based on the weight of the sensor node is proposed. The proposed algorithm considers the sensed data of equal length and the possibility of the losses is more if variable data is sent by the node. In [15], Management Architecture for Heterogeneous WSN (MARWIS) is presented for the heterogeneous WSNs; authors propose to subdivide the large network into small subgroups, which contains the sensor node of the same type for improving the resource utilization. Ref. [16] indicates the use of mobile data collector in large WSNs with a restriction of single hop. When the network size increases, data collectors increases, thus increasing the usage of energy. The paper [17] shows performance of WSN for the energy efficiency by considering static and mobile sink with duty cycle as computation metric.

3. Proposed network model

3.1. Assumptions

To simplify the network model, following assumptions are considered based on [12,13].

3.1.1. Node Assumptions

- Nodes [normal, advanced, super] are heterogeneous in terms of energy and are equal in numbers.
- The data generation rate of each node is different and not known to each other.
- All the nodes in the cluster are at one hop for intra-cluster aggregation and are synchronized.
- Each node generates the random data in the range of zero and 1.

3.1.2. Network assumptions

- Network is divided into regions of 25×25 m with each region having one CH and many cluster members (CM).
- All heterogeneous nodes are randomly distributed with equal density and are stationary with mobile sink.
- Clusters are considered as multi-hop and have mixed links, unidirectional for intra-cluster and bi-directional for the inter-cluster aggregation in the network.