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Network coding and competitive approach for gradient based routing in wireless sensor networks

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ABSTRACT

Energy efficiency is a key design criterion for routing protocols in wireless sensor networks since sensor nodes are strongly constrained in terms of energy supply. Gradient-Based Routing (GBR) is a well known energy efficient routing protocol that is used in WSNs. However, there exist shortcomings in the GBR scheme such as: (1) sinks make use of flooding to broadcast interest messages which leads to a lot of duplication packets which are transmitted. This leads to the waste of a lot of energy in the network and (2) nodes deliver messages in a point to point manner. As a result, the potential of data retransmissions in the network is high due to the unstable network environment in WSNs. In this study, network coding and a competitive approach are proposed to solve the above two problems. Firstly, an energy efficient broadcast algorithm using network coding for GBR (GBR-NC) is proposed. This algorithm aims to reduce network traffic, and furthermore, reduce the energy consumption and prolong the lifetime of the network. Secondly, two competing algorithms (GBR-C and auto-adaptable GBR-C) are proposed for GBR. The basic idea of the proposed competing algorithms is to reduce the retransmission attempts and save the energy by considering two forward candidates. Simulation results show that the proposed schemes give better results when compared to the traditional GBR in terms of energy efficiency.

1. Introduction

Wireless Sensor Networks (WSNs) consist of a large number of nodes which are randomly deployed with sensing, computation, and communication capabilities. They have emerged widely and are considered as a promising technique in a number of areas of application such as military surveillance [1], habitat monitoring [2], structural monitoring [3], and medical applications [4]. WSNs are strongly constrained in terms of energy, computational, and storage capacities. Therefore, they are the subject of large research activities that consider energy optimisation with one of the core objectives being the prolonging of network lifetime (or lifespan).

This study focuses on data routing under energy constraints. Several routing strategies have been proposed in literatures that focus on data dissemination, reliability, network load balancing, and the reduction in the number of transmissions in order to save energy. Geographic Adaptive Fidelity (GAF) [5], Low Energy Adaptive Clustering Hierarchy (LEACH) [6], Threshold sensitive Energy Efficient Network protocol (TEEN) [7], and Gradient-Based Routing (GBR) [8] are among the routing strategies proposed in literature. LEATH and TEEN are cluster-based routing protocols. The extra overheads of forming clusters diminish the gain in energy consumption. GAF and GBR are location-based routing protocols. In GAF, the GPS information is needed by each node to set its location which consequently increases the cost of each node. GBR is developed from the Directed Diffusion protocol [9]. The main concept in GBR is to record the number of hops when a node receives an interest message; subsequently, each node sets up its height according to the minimum number of hops. The heights' difference between a node and its neighbours forms the gradient on the corresponding link. The packet is

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forwarded on the link with the largest gradient. This means that the packet is always transmitted along the shortest path. In GBR, the location is set via the propagation of interest message. No extra overhead or GPS device is needed. In [10], the authors show that GBR is reliable in choosing the shortest route to a sink while balancing the energy of the whole network.

However, shortcomings still exist in the GBR scheme such as the use of flooding at the sinks to broadcast the interest messages. As a result, duplicated packets are transmitted which wastes energy in the network. In the GBR scheme, each node has to broadcast the interest message to ensure that every node can record all of its neighbours and set an accurate height which corresponds to the minimum number of hops to the sink. The traffic of GBR cannot be reduced by simply reducing the transmission probability of some nodes. Network coding has been proposed to reduce and balance the traffic in a given network exploiting the communication scenario (one-To-one, one-To-many, many-To-many) and the computation and storage capacities [11]. Thus, network-coding strategy depends on the context, and in the case of WSNs, should make use of the broadcast nature of the medium and consider the capacity limitation of the nodes. The network coding techniques proposed for wired and wireless networks cannot be applied to WSN [12] mainly due to the memory limitation problem. In the case of WSNs, any data aggregation strategy based on some coding technique must consider the stochastic nature of the WSN environment [13]. In contrast to existing approaches, this study proposes the use of a simple coding technique in conjunction with GBR protocol to make full use of the broadcast nature of WSNs taking into account that in network coding schemes, the transmission of encoded packets obtained by a linear combination of some given packets has the potential of reducing the amount of traffic. This characteristic can be used by GBR to reduce the traffic without affecting the height set progress, which can impact on the energy saving that can be achieved in the network.

Furthermore, in the GBR protocol, the nodes deliver messages in a point-to-point manner and do not make use of the broadcast nature of the WSN. In WSNs, sensor nodes are usually equipped with omnidirectional antennas and are placed in environments where the potential of data retransmissions are high. This in turn creates significant multipath transmissions so that if one node sends a message, all its neighbours have the potential of receiving this message. However, due to the characteristics of the wireless channel, the number of retransmission greatly affects the energy consumption of the network. The retransmission can be reduced if the best node, which has already received this message, can be selected from its neighbours to transmit this message forward.

The objective of this paper is to overcome the abovementioned shortcomings of GBR protocol by combining: (i) a network coding algorithm to reduce the broadcast traffic during the interest message propagation and (ii) a competitive algorithm to reduce the data delivery traffic during the data collection. As a result, the above could lead to the improvement of the GBR protocol in terms of energy efficiency.

The rest of the paper is organised as follows. Section 2 discusses related work to the topic of this paper. The network coding approach is presented in Section 3. In Section 4, the competitive approach is presented. The simulation scenarios and results are presented in Section 5. In Section 6, conclusions and future work are given.

2. Related work

The aim of this paper is to apply network coding and competitive algorithm to improve GBR in terms of energy efficiency. Since, the proposed approach in this paper targets the overcoming of the drawbacks of the GBR protocol by making use of network coding and competitive techniques, related works to both these areas are presented consequently.

In [14,15], network coding algorithms are combined with multipath routing to deliver the message from source to sink. In [14], the essential idea of this algorithm is to forward the encoded packet based on multipath. The sink then decodes the message from the received packet. Before the source node forwards the messages, the path number needs to be aware of the source. The advantage of this algorithm is that the same reliability is guaranteed with significantly reduced energy consumption by decreasing the number of paths needed to deliver data. However, an accurate path number is difficult to obtain. In [15], an Energy Efficient Reliable Multipath Routing Using Network Coding (NC-EERMR) routing protocol is proposed. NC-EERMR employs a hop-by-hop method to form multipath. Each node only maintains the paths from local nodes to the next hop without establishment of end-to-end paths. It is indicated that NC-EERMR protocol can reduce the required transmission path number and redundant data, and hence, reduces node energy consumption.

In [16], the authors propose a coding algorithm which focuses on the intra-cluster information exchange problem. The basic idea of this algorithm is that the cluster head simply XORs two packets which are broadcasted from two cluster nodes and then broadcasts the coded packet. The energy can be saved due to the network coding algorithm reducing the number of transmissions.

In [17,18], network coding algorithms are proposed to handle the security problem. In [17], a Location-aware Network Coding Security (LNCS) protocol is proposed for WSNs. In this algorithm, the location information is used to divide the area into non-overlapping cells and the information is aggregated and divided into several shares that are forwarded towards the sink in a cell-by-cell manner. To provide data availability, the aggregated information is encoded linearly and every node broadcasts only a few encoded packets. In [18], the authors propose a Security Broadcast based on Linear Network Coding (SBLNC) in WSNs that can identify the false data and drop them in the intermediate nodes.

In [19,12], the adaptive network coding algorithm is presented. In [19], the authors propose an adaptive network coding approach to enhance reliability in WSNs by considering redundancy. An analytic model is then proposed to estimate the proper amount of redundancy. Further, they