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A Survey on Energy Efficient Network Coding for Multi-hop Routing in Wireless Sensor Networks

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Abstract

Network coding consists of intelligently aggregating data packets by means of binary or linear combinations. Recently, network coding has been proposed as a complementary solution for energy efficient multi-hop routing in Wireless Sensor Networks (WSNs). This is because network coding, through the aggregation of packets, considerably reduces the number of transmissions throughout the network. Although numerous network coding techniques for energy efficient routing have been developed in the literature, not much is known about a single survey article reporting on such energy efficient network coding within multi-hop WSNs. As a result, this paper addresses this gap by first classifying and discussing the recent developed energy efficient network coding techniques. The paper then identifies and explains open research opportunities based on analysis of merits of such techniques. This survey aims at providing the reader with a brief and concise idea on the current state-of-art research on network coding mainly focusing on its applications for energy efficient WSNs.

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Keywords: Wireless Sensor Networks; Aggregating; Network Coding; Energy Efficiency; Random; Linear; Coding Opportunities; Coding Challenges; Coding Metrics.

1. Introduction

The limited energy resource is known to be one of the major issues faced by WSNs. In addition to the energy problem, WSNs just like any other wireless networks suffer from a variety of unique problems such as low throughput, little or no connectivity and inadequate support for mobility out of range[3]. In most multi-hop routing, information packets are broadcast in order to update the network's status so as to improve throughput, enhance connectivity and enable high mobility. Although information broadcasts require very little computation at the level of sensor nodes, duplications of packets (resulting in considerable energy wastage, load imbalance, high network traffic and low network throughput) are often common. Fortunately, the modern sensor nodes have been equipped with fast and powerful processors that can make possible network coding implementation. Such network coding techniques are capable of trading more computation for smart techniques to aggregate packets in order to reduce the number of transmissions thereby lowing the overall energy wastage in the WSN.

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Conventionally, network coding has been considered as one of the possible solutions to the current energy wastage, low throughput, non-connectivity and mobility support problems in WSNs. However, practical challenges facing the integration of such designs into the network stack remain unresolved in the literature [14]. The network coding challenges arise when attempting to simultaneously achieve low complexity, fast coding, small memory usage, high data rates and adaptation to the unknown channel conditions [3]. Of these challenges, fast coding, compulsory reliability and real time constraint are specific to energy efficient network coding for multi-hop routing in WSNs. They are discussed as follows.

1.1. Fast coding

While the complexity of the *inter-flow* coding is usually low, the computation cost of the linear *intra-flow* coding in WSNs is most often expensive. In most cases, linear encoding algorithms require polynomial time complexity. This polynomial time complexity has been proven to be bounded to $O(n^2)$ with n being the number of linearly combined packets and considerably increases the computational energy consumption of sensor nodes.

1.2. Compulsory reliability

The transmission reliability of the encoded packet is mandatory for a successful operation of any network coding algorithm. Therefore, receiving $n-1$ linear combinations of n linearly combined packets is practically useless because successful decoding of an encoded packet requires at least n encoded packets. Should, reliable transmission not be guaranteed, more retransmission attempts are experienced and therefore more energy is wasted.

1.3. Real time constraint

The decoding of packets is only possible upon collection of at least n linearly combined packets. This naturally introduces time delays in the operation of the WSN and results in high energy consumption [4].

Based on these key challenges, this paper contributes in classifying and discussing some of the recently proposed energy efficient network coding techniques by identifying their merits and demerits towards creating future research opportunities.

The rest of the paper is organised as follows. Section 2 classifies and discusses energy efficient network coding for multi-hops routing in WSNs. In section 3, network coding metrics are presented. Section 4 analyses the energy efficient network coding opportunities in multi-hop WSNs and Section 5 concludes the paper.

Throughout the paper, we adopt the following nomenclature:

Nomenclature

WSNs	Wireless Sensor Networks	**GF**	Galois Field	**NACK**	Negative Acknowledge
RLNC	Random Linear Network Coding	**GBR**	Gradient Based Routing	**PDR**	Packet Delivery Ratio

2. Energy efficient Network coding protocols for multi-hop WSNs

There are two main classification approaches for the existing network coding techniques for muti-hop routing in WSNs. On one hand, network coding protocols in WSNs can be classified as **local** or **global** coding depending on whether the decoding of aggregated packets is performed at each sensor node level or only at destination nodes level respectively [5]. On the other hand, network coding techniques for muti-hop routing in WSNs can be classified as **intra-session** or **inter-session** depending on whether the relay sensor nodes only encode packets from the **same session** (source nodes) or encode packets from **different sessions** (sources). Most often, the intra-session network coding protocols in WSNs are designed to address the packet loss problem while the inter-session network coding protocols are designed in order to reduce the number of packets transmissions. Both network coding protocols classified as local or global can be further classified as either be **binary** (*XOR*) or **Random Linear** (*RL*).

Some of the most commonly known network coding approaches for WSNs are discussed as follows.