

Network Coding based Energy Efficient Routing Algorithm in Wireless Sensor Networks

Xiang Jian Ji

Department of Computer Science, Wuhan City Vocational College, Hubei Province, China
jjxiang@sina.com

Abstract - Wireless sensor networks (WSNs) have received significant attention recently. Wireless sensors are deployed to achieve network load balancing, prolonging network lifetime, and improving network coverage. To achieve these goals, energy efficiency directly affects battery life and thus is a critical design parameter for WSNs. In this paper, we propose an Network Coding based Energy Efficient Routing Algorithm in WSNs to prolong lifetime (NC-ER), which is able to dramatically prolong network lifetime while effectively improve energy efficient. We also present an algorithm for deciding the network lifetime scheme for a node to further improve energy efficient by minimizing redundant packet transmissions. Simulation results show that, with the proposed NC-ER Algorithm in WSN throughput, network lifetime and energy efficiency can be improved in most of cases. It is an available approach to routing decision.

Index Terms – WSN, throughput, network lifetime, energy efficient, multicast routing

1. Introduction

Wireless sensor network (WSN) consists of many small, inexpensive distributed sensor nodes that organize themselves into a multi-hop wireless sensor network. WSNs are important for a number of pervasive applications such as coordinated target detection, surveillance, and localization. In such networks, the nodes are often powered by battery, and energy efficient operations are critical to prolong the lifetime of the connections. Designing an energy efficient and maximize lifetime for such networks is a challenging issue [1-12]. However, for real-time sensing, latency and reliability are of paramount importance, whereas in battery powered sensor networks, energy efficiency is an important metric.

In the WSN, sensor nodes are constrained in energy supply. A sensor node is unable to function while its energy is exhausted. The network being wireless operate on batteries which have limited life. The wireless devices have limited bandwidth and the network provides unreliable service resulting in high packet loss and throughput. These networks are not scalable. As a mobile device, the limited battery volume cannot supply the durable power to the sensor node [1], known as power wall. Depending on the applications, the sensors are deployed randomly or using a systematic approach to gather the information from the environment [2]. Wang *et al.* [3] propose an energy efficient and collision aware (EECA) node-disjoint multipath routing algorithm. The data collection rate in pervasive healthcare systems is high. The development of efficient data and energy processing techniques are of great importance. One of the bottlenecks of sensor devices is the batteries. Considering the likelihood of forgetting to recharge the batteries of several sensors, this is a significant issue to be

solved. Although there is much effort on designing low-power sensors to minimize this bottleneck [4], we still need energy scavenging techniques.

The Network Coding (NC) [5, 6] technique emerged at the beginning of the previous decade with the primary aim of improving the throughput of communication networks. Network coding can reduce transmission times and thus help to save transmission and reception energy in many WSNs. These benefits are possible not only in the case of the effective capacity of networks, but also for other network traffic configurations, such as energy efficient routing communications. Wireless NC exploits the broadcast nature of a wireless channel, and Sengupta *et al.* [7] have pointed out that conventional use of NC within a wireless scenario can significantly increase network throughput, when compared to non-NC transmission in wireless networks.

Energy efficiency directly affects battery life and thus is a critical design parameter for WSNs. Optimizing routing for energy efficiency has been extensively studied during the last decade. The problem of minimum energy broadcasting is NP-complete [8] and a large number of approximation algorithms exist. The new ingredient in this problem is that we can apply ideas from the area of network coding. Use of network coding has been examined in the literature in conjunction with multicasting, when a single source transmits common information to a subset of the nodes of the network. If we allow intermediate nodes to code, the problem of minimizing the energy per bit when multicasting can be formulated as a linear program and thus accepts a polynomial-time solution [9].

In this paper we show that use of network coding allows to realize energy savings when routing in WSNs. By routing we refer to the problem where each node is a source node that wants to transmit packet to destination node.

The rest of the paper is organized as follows: In section 2, we briefly review related work. Section 3 presents network coding and energy consumption scheme in WSN. Some simulating results are provided in section 4. Finally, the paper concludes and future work in section 5.

2. Related Works

In WSN, the power issue is one of the critical topics that has attracted both academic as well as industry researchers. Energy efficient and maximize lifetime routing in WSNs is a challenging problem because of its resource constraints and the nature of operation. Research works on energy model of WSN mainly focus on energy model and estimation. Many proposals have been made so far addressing these problems.

Tariq *et al.* [9] proposes a comprehensive energy model to estimate the overall energy consumption through power dissipation, for both static and mobile sensors in the potential sensor fields. Rizk *et al.* [11] proposes a distributed energy balanced algorithm for data routing in WSNs. This method introduces two different cascaded algorithms to prolong the network's lifetime. Liu [12] propose an approach to balance energy consumption and maximize network lifetime for uniformly deployed gradient-sinking sensor networks. Our approach differs from the ones proposed in previous works in that it not only balances the energy consumption among nodes in different gradient, but also balances the energy consumption of nodes in the same gradient. Sinha *et al.* [13] proposes an energy efficient multi-level aggregation strategy which considers data sensing as continuous stochastic process. This proposed strategy performs filtration of sensed data by removing the redundancy in the sensed data pattern of the sensor node using Brownian motion. Liu *et al.* [14] proposes an energy efficient routing protocol (BERR) for real-time, reliable communication for wireless sensor networks. It uses the joint performance of real-time, energy efficiency, reliability and the retransmission mechanism with link error rate to choose the next hop node.

PARO [15] is a power-aware routing algorithm that aims to increase the path length to reduce the total transmission power. PARO attempts to reduce the individual hop's distance to reduce the overall power consumption. NC is however an energy-demanding application, especially when the coding operations are performed over high order fields such as $GF(2^8)$, hence the need for energy-efficient NC schemes. Angelopoulos *et al.* [16] showed that energy efficient NC is feasible also on mobile devices, but only at the price of using ad hoc designed hardware. Chen *et al.* [17] consider a three-node, two-way relay system with digital network coding. The aim is to minimize total energy consumption while ensuring queue stability at all nodes, for a given pair of random packet arrival rates. Concluding, the existing literature shows that NC over $GF(2^8)$ results in low decoder throughput and high computational loads on mobile devices, prompting the research for computationally lighter solutions.

3. Network Coding and Energy Consumption Scheme

A. Network Model and Network Coding

The network is represented by a directed acyclic graph $G=(V, E)$ with $V = |V|$ nodes and $E = |E|$ edges. There are r independent, discrete source nodes $s \subset V$ processes with messages belonging to $GF(2^8)$, and destination node $d \in V$ ($d > 1$) receivers. Each receiver node has $L > r$ incoming edges. The multicast requirement is that each receiver node can decode every source message from the signals on its incident edges. If the min-cut value to each receiver is d , then there exists a multicast transmission scheme over a large enough finite field $GF(2^8)$, in which intermediate network nodes linearly combine their incoming information symbols over $GF(2^8)$ and are responsible to deliver the information from the sources simultaneously to each receiver at a rate equal to d .

For example, a wireless network coding scheme depicted in Figure 1. We consider three nodes, 1, 2, and 3. Node 1 wants to send a packet x to node 3, while node 3 wants to send a packet y to node 1. Due to the limitation of transmission range, both of these packets have to pass through an intermediate node 2. In case of the non-NC scheduling based scheme, four time slots are required to complete these transmissions as shown in Figure 1(a). Using XOR operation (on packet x and y), node 2 generates a new packet $x \oplus y$ and broadcasts it to both node 1 and node 3 as shown in Figure 1(b). This simple example of wireless NC demonstrates that through the application of NC, three instead of four (in traditional routing) transmissions achieve the same packet transfer effect, and therefore improves the network throughput and save energy.

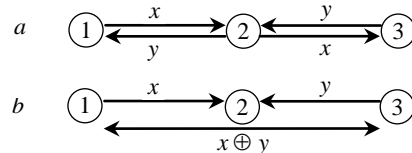


Figure 1. Wireless Network Coding.

The binary symbol $x \oplus y$ is a mathematical function of x and y . Calculation of a function from received data is called coding. This shows the merit of mixed coding among multiple messages at an intermediate node. This is called network coding (NC). In algebra, $x \oplus y$ is called the binary sum of x and y . Interpreting in more general terms of linear algebra, this is the linear sum $1 \cdot x + 1 \cdot y$ over the binary field. Thus, the calculation of $x \oplus y$ is not only a form of coding but also belongs to the more restricted form of linear coding.

Network coding in dynamic environments is a challenging research topic. Random linear network coding has proved to be very promising in coping with network topology changes, the encoding coefficients are chosen randomly from a finite field, as it does not require the knowledge of the entire network topology [1, 2, 16-18]. However, in these random linear network coding studies the minimization of coding resources is not a concern and each node has to communicate its coding weights throughout the network, which means that not all of the network capacity will be available to transmit the signals sent by the source. Therefore, whilst the advantages of random linear network coding should be acknowledged, it is still necessary to investigate how to improve network coding based on the entire network topology.

B. Energy Consumption Model

In this section, we derive the energy efficient gains that can be achieved. We assume that the source node S , needs to transmit symbols to the destination node D . Without loss of generality, it is assumed that the symbol period for each symbol is normalized to one second.

In a WSN network, each sensor node can operate in a role-dependent (source, destination or router) state that changes temporarily. These states include one of the following:

If the transmit power of a node reaches the destination node and receiving nodes around the thermal noise power ratio in

line with the required SNR that there is a link between two nodes,

$$P_i \geq r_j \times d_{ij}^\alpha \quad (1)$$

where P_i is the transmission power of node i , d_{ij} the distance between node i and node j , and α the link attenuation coefficient with the value from 2 to 4, r_j signal to noise ratio (SNR) for node j .

The energy consumption of the multicast tree for all involved in the multicast nodes in the network transmit power to minimize this value is our goal.

$$Sum_p = P_1 + P_2 + \dots + P_n \quad (2)$$

where Sum_p represents to all the sending nodes of the sum power of the multicast tree, P_1, P_2, \dots, P_n is representative of the transmit power of each sending node of the multicast tree.

In order to calculate the energy consumption of the multicast tree or link set, we specially defined the energy consumption expressions, as equation (3) (4) below, where P_{link} represents the power consumption of each link:

$$Sum_p = P_{link_1} + P_{link_2} + \dots + P_{link_k} \quad (3)$$

$$P_{link_i} = d_{ij}^\alpha \times r_j \quad (4)$$

C. Energy Consumption Analysis

In this section, we have performed the analysis of energy consumed by the sensors in the network. In the analysis, we have considered the energy consumed in packets communication as well as computations required for data aggregation. N sensor nodes are distributed according to two dimensional Poisson process with intensity λ in squared sensing region with each side $2a$ units. Hence the area (\mathbf{R}^2) of the sensing region becomes $4a^2$ square units.

Now, we calculate the energy consumption of a wireless sensor node i . Every sensor node is supposed to consist of a set of member nodes that only involves in sampling and transmitting the aggregate of sampled data. The radio propagation within a sensor node is assumed to free space, i.e. the transmission signal attenuates over the square of distance towards the sensor node. The energy used in transmission for sending b bits of packet to the node i is:

$$P_i(b, d) = b(P_i + \varepsilon d^2) \quad (5)$$

where, ε signifies the energy used by the amplifier module. Now, we estimated distance $E[d^2]$ between the wireless sensor node x and the other nodes for Poisson Distributed nodes.

$$E[d^2] = \int_{\mathbf{R}^2} [(x - c_x)^2 + (y - c_y)^2] \cdot \phi_{posn} \cdot d\mathbf{R}^2 \quad (6)$$

4. Simulation Experiments

In this section, we present the numerical results for the systems discussed in the previous sections. We consider a network of randomly distributed nodes within a specified square area. The source and the destination nodes are located in the diagonal corners of the network.

A. Simulation Model and Performance Metrics

To conduct the simulation studies, we have used randomly generated networks on which the algorithms were executed [19]. This ensures that the simulation results are independent of the characteristics of any particular network topology.

The sensing area is assumed to be a square region with dimension $1000 \times 1000 \text{m}^2$. The sensors are Poisson distributed and initially have identical communication radius of 250m. The number of node is in the range of 10 to 100 in WSNs. Its initial value corresponds to the node energy level at the beginning of the simulation. We also assumed that the energy required to receive a message is the sum of the fixed cost of powering the antenna plus the fixed processing cost. When the node energy level goes down to zero, the node dies out, that is no more packets can be received or transmitted by the node. The initial energy of each node battery is 30J in the reference scenario.

So, a propagation model is used to determine the Signal to Noise Ratio (SNR) at the receiving node. SNR is defined as the ratio of power of the receiving signal to the noise power at the receiver.

To effectively evaluate NC-ER's performance, we compare it with other famous multipath routing protocols, EECA [3] for cost to control information, average link-connect time, the success rate to find the path and the feature of data transmission. Table 1 lists the simulation parameters which are used as default values unless otherwise specified.

TABLE 1 Simulation Parameters

Number of nodes	100	Initial node energy	40 J
Terrain range	1000m \times 1000m	Correct receive threshold	3.652×10^{-10} W
Transmission range	250 m	Threshold to avoid collisions	1.559×10^{-11} W
Average node degree	3-5	Channel bandwidth	1-3 Mbps
Simulation time	600 S	Traffic type	CBR
Maximum transmit power T_i^{\max}	0.282 W	Examined routing protocol	EECA

We will compare the performance of two routing methods under the same energy model and communication models. Performance metrics we have used in our experiments are throughput, network lifetime and energy efficiency.

B. Simulation Results

In order to evaluate and validate our proposed model, we executed extensive simulations using Network Simulator version 2 (NS-2) [20]. NS-2 is a discrete event simulator targeted at networking research. NS-2 provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless networks.

Figure 2 represents the energy consumption for the NC-ER algorithm with EECA under different network size, which the network topology of each network size of the algorithms is the same. We observe that energy efficient outperforms the other schemes: it achieves the lowest energy consumption for most

of the number of nodes. we can obtain that the energy saving effect of the NC-ER algorithm can achieve about 20%.

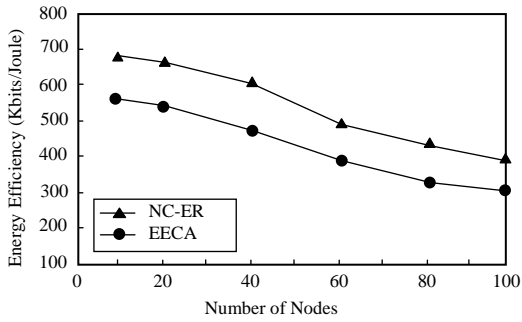


Figure 2. Comparison of Energy Efficiency

Figure 3 shows the network throughput with varying network density. Throughput of the NC-ER is comparatively high for different network densities compared to EECA. When the network traffic is increased, there is no congestion, more packets are delivered and thus network throughput is increased.

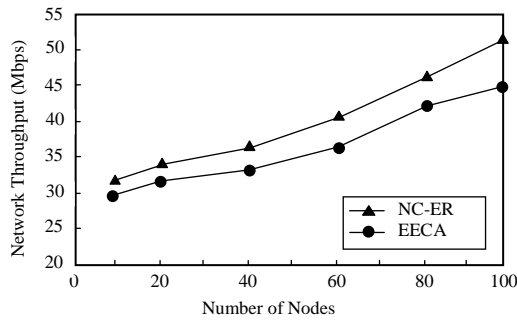


Figure 2. Comparison of Network Throughput

For maximizing the network lifetime, we consider interference free communication model in the sense that at each time instance only one node may transmit. Figure 4 shows the network lifetime with varying network density. It clearly shows the increase in network lifetime with the proposed algorithm NC-ER with varying threshold probability as compared to existing EECA routing protocol. It is also observed that as the threshold probability is decreased, energy consumption is reduced and network lifetime is increased.

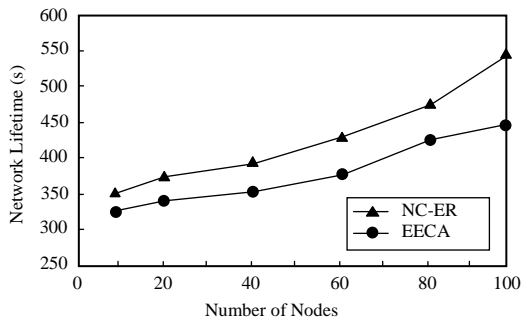


Figure 4. Comparison of Network Lifetime

5. Conclusion and Future Work

Different energy efficiency and network lifetime definitions have been considered in the literature for WSNs. This paper discusses energy efficiency, network coding, routing and problem, which may deal with the network coding model for researching the WSN routing problem. In this paper, we propose a Network Coding based Energy Efficient Routing Algorithm in WSNs to prolong lifetime (NC-ER). Then we evaluate the performance of various schemes through simulation. Numerical results show that network coding scheme has better performance in throughput, network lifetime and energy efficiency.

In terms of future work, we would definitely consider optimizing the timeout values and other parameters used in NC-ER for further evaluation via simulation. Use of the network coding and energy efficiency in parallel to improve the performance and increase the network utilization, is left as our future work.

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