A Study on Optimizing Wireless Sensor Networks Through Network Coding Algorithms

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Abstract

A wireless sensor network is a type of ad hoc network designed to monitor various environmental attributes for applications such as military and environmental monitoring. Commonly, these networks gather and transmit historical data from all sensor nodes within the network to a central base station. In this study, we introduce a novel network coding technique and assess its impact on reducing time and energy consumption. Our findings indicate that this new technique significantly enhances the performance of sensor networks, particularly those with a smaller number of nodes.

Keywords- Computer Modeling, Mobile Communication Systems, Channel of Communication.

I. INTRODUCTION

Wireless Sensor Networks (WSN) consist of sensor nodes responsible for sensing tasks in a distributed way, according to the client applications. These networks act as data acquisition systems environment, allowing monitor physical or environmental phenomena, such as temperature, sound, pressure and vibration. The sensor nodes collect data and forward them to an exit point of the network, called the sink node, destination node, or base station (depending on the application), to be analyzed and processed. In conventional sensor networks, the propagation of information is traditionally performed by a method called routing, where the information is stored by the intermediary nodes and then forwarded until it reaches its destination. It was believed, until a few years ago, that the information processing in the intermediary nodes do not bring any benefits in the replication and dissemination of data. However, in [4], Ahlswede, Cai, Li & Yeung demonstrated that applying such a processing it is possible to achieve higher data throughput. The processing of information in intermediary nodes is denominated network coding. The topology of wireless sensor networks consists of multiple source nodes and a sink node – base station. This originates problems such as data congestion and limited resources. Consequently, it is important to apply techniques for data reduction so that fewer bits are transmitted into the wireless channel [1]. Network coding is a technique that can be used for this. The technique combines algebraically by using "exclusive or" operation (denoted by the symbol "$\oplus$" or by the word "XOR"), over the received packets [2]. This strategy reduces the traffic of packets in the network communication channels and, consequently, the data congestion. Also, the capacity and transmission speed of the network are increased without need of complex routing algorithms.

The research which is considered the work demonstrates that the problem of transmission of wireless sensor networks, described above can be soften through network coding, remains to know whether in practice this technique has the same efficiency that achieved by simulation.This paper is organized as follows. The next section provides a brief discussion of the network coding technique. Section III presents the methodology used, defines and evaluates the technique proposed in this paper. For comparison purposes, Section IV describes a previous technique found in the literature. The technique proposed in this paper is shown in Section V. Results are presented in Section VI, which is followed by the conclusions.

II. NETWORK CODING

Some of the advantages of network coding were introduced in terms of flow in a butterfly network [1]. This kind of network represents a communication network as a directed graph in which the vertices correspond to the network nodes (terminals) and the edges represent the channels as shown in Fig. 1. The network is composed of two source nodes (A and B) and two destination nodes (R1 and R2). It is assumed that the sources A and B can only send one bit at each time interval. Hence, it would take more than one time interval to transmit a bit from "A" and "B" to nodes R1 e R2. In contrast, by using network coding, there is the possibility of processing the bits at the intermediary node "X". Such processing enables the reception of bits from nodes "A" and "B" in one time interval. The node R1, which receives the bits from node A and $A \oplus B$, obtains the bit from node B by calculating $A \oplus (A \oplus B) = B$. Similarly, the node R2 is also able to decode the bit information from nodes A and B [3]. Hence, there is a benefit in terms of throughput when the processing of information is allowed at the intermediary network nodes, therefore, justifying the use of network coding. Practical implementation of network coding is fully described in [6], [7].

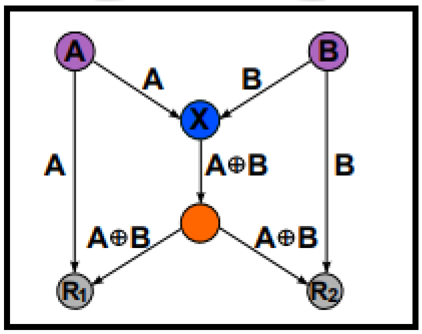

Fig. 1. Representation of the Butterfly Network

III. METHODOLOGY

The encoding process described in the previous section is employed in this work to obtain a higher transmission data rate in wireless sensor networks. The direction of transmission is from sensors towards the base station (receiver). The nodes of the network are deployed in a systematic way aiming an efficient coding of information by the intermediate nodes called encoders. We have considered two different network sizes: (A) the first one, denominated network type A, has a smaller number of nodes (around 20 nodes); (B) the second one, denominated network type B, has a large number of nodes (40 nodes). These two different sizes of network allow us to evaluate, by means of time delay comparison, the throughput of the network.

In this work, we assume that, in addition to sensor nodes, the networks are formed by intermediary nodes called "relays", which relay the information from other nodes toward the base station. Some "relays" perform the "XOR" operation on received data and, therefore, are called encoders.

Simulations were implemented and performed on a Mathematical Software by using normalized transmission rates and data frames. A representation of the network is illustrated in Fig. 2.

In this work we simulated two coding techniques. Technique 1 was previously proposed by [1]. It employs network coding and is efficient for sensor networks with a large number of nodes. Nevertheless, its performance is similar to conventional wireless sensor networks (no network coding) for a network with a smaller number of nodes. This technique is described in the next section. In order to improve the performance of this technique, especially for smaller networks, this paper proposes Technique 2, which is presented in Section V.

IV. TECHNIQUE

1 A. System Model

The sensor nodes collect data from the environment and transmit them to relay nodes. At the relay nodes the data is evaluated in order to verify the need to perform network coding. The data is then forwarded to the receiving node. The necessity to perform network coding is evaluated by using function f, which is defined as follow: Let p and q be

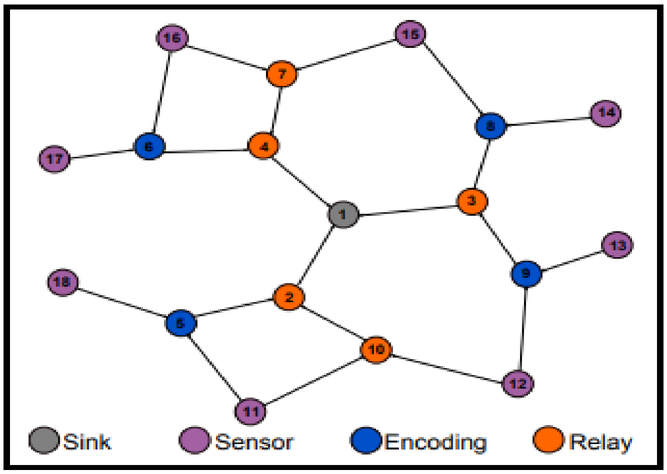

Fig. 2. Representation of Sensor Network

the two data received by a encoder node and f a binomial function that calculates the significant difference between two data packets and returns true or false. If p and q do not differ more than a threshold γ, then the value of the function f is false (0), otherwise it returns true (1). The absolute value of difference is denoted by [5]:

$$d = p - q; \qquad f : \begin{cases} 0, & d < \gamma; \\ 1, & \text{otherwise.} \end{cases} \qquad (1)$$

B. Description

Assume that sensor nodes 17 and 16 have some information to send to the network, as shown in Fig. 2. Node 16 sends information to node 7 and to the node 6 (relay encoder). Sensor node 17 transmits its information only to node 6. Node 7 only transmits the information towards the receiving node. However, encoder node 6 has two packets to transmit, then it employs function f. If function f returns true, node 6 encodes the packets using the XOR operation and forwards the result towards node 4. Now node 4 has two packets: one is a data packet transmitted by node 7 and the other one is a coded packet transmitted by node 6. Node 4 transmits a packet at each time interval, and the same procedure is adopted to the others non-coding relay nodes when there is more than one packet to retransmit. When these packets reach the receive node, they decode a packet at a time using XOR operation. In this study it was considered that the difference between two data packets is always greater than the threshold γ. In other words, a pair of packets is always encoded by an encoder node.

C. Algorithm

When an encoder node has to encode two packets, for instance, pkt1 and pkt2, the following procedure is adopted: XOR operation is performed on these two packets and the result is encapsulated in a new packet, which is routed forward to the receiver. The receiver decodes the data by using XOR operation on the appropriate packets. When an encoder node receives data from sensor nodes, it calculates the difference between the data using function f. If the difference is less than γ, then there is no need for coding and a randomly selected data is routed towards the receiving node. If the difference is greater than γ then the encoder node encodes and forwards the data to the receiver. A bit is used to confirm if encoding will be performed on the data. The algorithm that was implemented in the coding nodes in [4] is described in Algorithm 1.

```
Algorithm 1: Technique 1(packet pkt1, packet pkt2)
//pkt1i and pkt2i is ith packet sent by leaf node 1 and
leaf node 2 respectively.
{
If f(data(pkt1i), data(pkt2i)) == 0
   {
     Select either packet and transmit
   }
Else
   {
     Perform network coding on pkt1 and pkt2
     Transmit data obtained by encoding in previous
step
   }
}
//End of Algorithm
```

V. TECHNIQUE 2

A. System Model

In our proposed technique (Technique 2), each encoder node receives and processes data from a pair of sensor nodes. Moreover, only a single sensor node from that pair sends information to a relay node, as shown in 3. The information of this sensor (marked in Fig.3) is used to decode the data across the network. This technique does not use function f, and thus the nodes encoders always perform encoding.

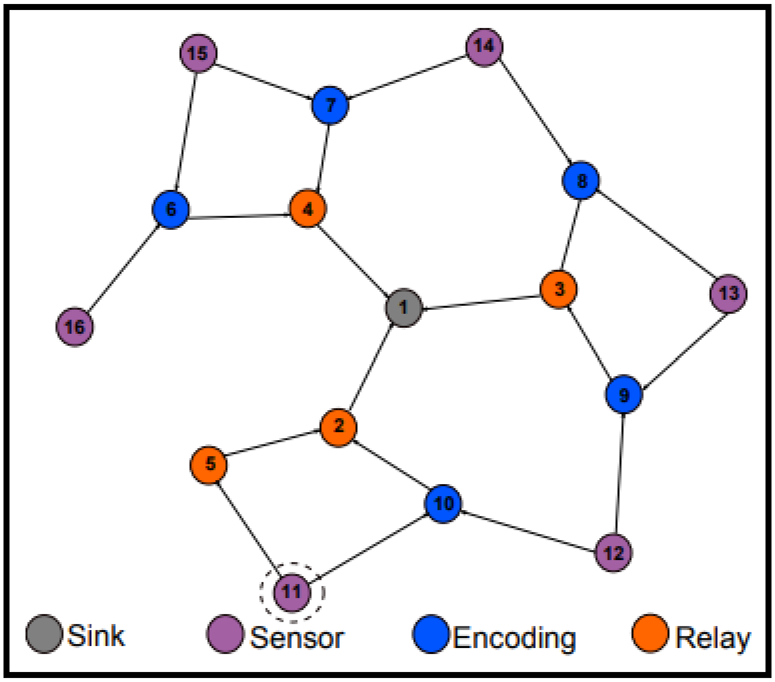

Fig. 3. Representation of Sensor Networks using Technique 2

B. Description

Observing Fig. 3, it is assumed that sensor nodes 16 and 15 have some information to send through the network. Node 16 transmits the information to the encoder node 6, while sensor node 15 transmits its information to the encoder's nodes 6 and 7. Encoder node 6 performs XOR operation on data received from sensors 16 and 15. Node 7 will encode the data received from sensors 15 and 14. The other subsequent encoder nodes execute similar procedure until sensor 11 is reached, which sends its data to the encoder node 10 and to relay node 5. The information sent to relay node 5 will be used to decode the entire network, by using exclusive OR operation among successive pairs of data in the receiver.

C. Algorithm

An encoding node in Technique 2 (proposed in this paper), as well as in Technique 1, has to encode a pair of packets, namely, pkt1 and pkt2. This is done as following: XOR operation is executed on pkt1 and pkt2, the result is encapsulated in a new packet that is routed forward. The decoding procedure is accomplished by using XOR operation on the appropriate packet.

It is relevant to notice that in this technique, every encoder node always applies XOR operation on two received packets. The encoder node does not evaluate the difference between a pair of packets by employing function f. Due to this fact, the algorithm becomes simpler, consisting only of a XOR operation on a pair of data packets. Algorithm 2 presents the proposed algorithm for the encoding procedure.

```
Algorithm 2: Technical 2(packet pkt1, packet pkt2)
//pkt1i and pkt2i is sent by leaf node 1 and leaf node
2 respectively.
  {
   Perform network coding on pkt1 and pkt2
   Transmit data obtained by encoding in previous step
  }
//End of Algorithm
```

VI. RESULTS

Table 1 shows the results for three types of wireless sensor networks: (1) network with no encoding, (2) considering the Technique 1 and (3) considering the proposed technique (Technique 2). For data analysis, the following definitions are used: cycle is the time interval in which the information from all sensors arrives at the receiver node; transmission delay is the time required for data being exchanged between two nodes; NN is the number of network nodes; B is the amount of data arriving at the receiver in a time interval necessary for the network with no encoding to complete a cycle; T D represents the transmission delay needed to complete one network cycle; NT is the number of transmissions required to complete a cycle; R is the transmission rate given in bits/nodes/time.

Technique 2, which is proposed in this work, is more effective for a network size of type A. In other words, it has a higher transmission rate, requires a smaller number

TABLE I
COMPARISON RESULTS

Network Type A	NN	B	TD	NT	R
Without coding	18	8	5	24	0.08889
Technique 1	18	8	5	24	0.08889
Technique 2	16	9	4	18	0.11250
Network Type B	NN	B	AT	NT	R
Without coding	38	16	8	64	0.05263
Technique 1	38	19	9	64	0.0625
Technique 2	34	15	7	48	0.05514

of transmissions, and presents a smaller number of nodes in the network. Hence, Technique 2 leads to a saving of time and energy in the transmission of information. Technique 1 does not provide advantages when a network of type A is considered. Considering a network of type B, we see that the Technique 2 has a loss of performance, but still performs better than sensor networks with no coding. However, Technique 1 begins to have a better performance than the others techniques. In this scenario, Technique 1 presents a higher transmission rate and a decreasing in the number of network transmissions related to the number of data information arriving at the base station. Its performance increases as the network size increases, being a good technique for large networks.

VII. CONCLUSION AND FUTURE WORK

In this paper, we compared and analyzed two robust implementation of network coding for transmission in sensor networks, denominated Technique 1 and Technique 2. Technique 1 was already discussed in [4]. Technique 2 is proposed in this work, which allowed a better network performance and a reduction in the number of messages transmitted on the network. It was observed that the network coding applied to wireless network, considering both methods, has advantages over the conventional transmission techniques (no encoding techniques).

Technique 2 presented a performance improvement on small sensor networks. The proposed technique allows data compression and concatenation of the data path to the base station in some aggregation points. However, as the network size increases, Technique 2 becomes less efficient. In contrast, Technique 1, which in small sensor networks has no advantages, has its performance improved as the network size increases. This is due to the number of collisions on the network, that is, in a network with no encoding there is a higher number of collisions when compared to an encoded network.

For the next steps of the research is necessary to create a protocol that can be implemented in practice in wireless sensor networks, in order to have a more precise calculation of the gain technique, and variables to calculate performance as due to processing delays obtained protocol, bits of overhead, packet loss and others.

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