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Fast and Reliable Code Dissemination in Wsns

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Abstract*: *In spite of the extensive research on Wireless Sensor Networks (WSNs) in recent times, it still remains a challenging field of study due to the resource constraints in such networks. While packet-level network coding has been studied widely in the context of wireless networks for improving network throughput, its application for WSNs is limited due to the amount of resources (time, memory and energy) needed. In this paper, we propose an a protocol called FRCode that uses network coding for code dissemination, which is an important and periodic task in WSNs. The proposed protocol minimizes the number of transmissions for code dissemination, while disseminating the code updates reliably. At the same time, it consumes much lesser time and energy compared to dissemination using other network coding schemes. This results in better network lifetime and faster code dissemination. The benefits of the proposed protocol are proportional to the density of nodes in the network. Hence FRCode is most suitable for dense WSNs.

Key words*: *code dissemination, energy efficiency, network coding, wireless sensor networks.

I. INTRODUCTION

Due to a wide range of possible applications, the area of Wireless Sensor Networks (WSNs) has attracted many researchers in the last decade. While a host of applications such as earthquake detection, patient monitoring systems and forest fire detection are possible for WSNs, designing such networks is an interesting task. This is because the nodes in WSNs have limited memory and battery life. A sensor network typically has several such nodes that sense some physical parameter and send this value to a base station.

Network coding is a technique in which nodes code the packets by performing some arithmetic or boolean operation on the contents of two or more packets. Network coding has shown promising results in improving the network throughput and increasing reliability in wireless networks. However, this improvement comes at the price of the energy and time of the nodes. Coding packets also requires more buffer space than simple store-and-forward technique of packet switched networks.

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Also, since this task may be done many times during the life-span of the network, it should consume as little resources as possible. Linear network coding is a type of coding in which nodes form coded packets as a linear combination of the received packets. Though WSNs are generally used for data gathering, periodic code updates need to be sent to the nodes by the base station. Since the node not receiving the code update may not function properly, code dissemination must be reliable.

In this paper, we propose FRCode, which is a protocol for using linear network coding for code dissemination in WSNs. Our algorithm requires lesser number of transmissions and energy compared to non-coded dissemination or dissemination using other network coding techniques. Our algorithm is different from others in two aspects:

• Our protocol gives a guideline as to what packets should be coded and how the coding has to done, in order to reduce the number of packet transmissions necessary for code dissemination.

• For making code dissemination reliable, our algorithm uses NACK (negative acknowledgements). We suggest when nodes should send an NACK and what the response of a node receiving an NACK should be.

• To reduce the number of operations necessary for extracting data from coded packets, we use Cholesky decomposition. This cuts down the time and memory required to decode the packets by half. Thus, nodes spend lesser energy for decoding.

The rest of the paper is organized as follows. In Section II, we discuss related work in the area of network coding in WSNs, followed by Section III in which we explain the working of our algorithm. In Section IV, we conclude the paper.

II. RELATED WORK

Coding packets by performing the XOR operation was suggested by [1]. However, they do not consider one-to-many transmission of data, which is typical of code update flow in WSNs.

Network coding for WSNs was studied by some researchers in the recent past. [2], [3] and [4] propose network coding for storing data while gathering data in WSNs. In Deluge [5], a sender broadcasts several packets to the receivers and uses NACKs for reliable transmission of these packets. Deluge achieves 100% data reliability, but does not focus on the number of transmissions necessary.

While [6] suggests threads for faster data dissemination, Rateless Deluge [7] forms a linear combination of packets. A receiving node can decode the packets using Gaussian Elimination, if it receives enough coded packets. Otherwise, another coded packet can be transmitted and the receiver tries to decode again. In [8], the authors propose AdapCode, a protocol for code updates in sensor networks. The main contribution of this work is to dynamically change the number of packets coded based on the number of neighbors. The authors give a heuristic that suggests how many packets should coded to improve the throughput and reliability.

Authors of CodeDrip [9] propose the use of small values(packets) to be coded. In [10], the authors propose a way to minimize the energy spent for network coding by determining the coefficients that lead a full-rank transmission matrix.

The authors of [12] propose a weighted Vandermonde echelon fast coding scheme based on an analysis of various coding schemes such as random and linear network coding.

In this paper, we propose FRCode to reduce the number of transmissions while disseminating code reliably. We propose to coding of packets by forming a linear combination, which is decoded using Cholesky decomposition. To the best of our knowledge, none of the previous work has focussed both on reducing the number of transmissions and the complexity of decoding, while achieving reliable code dissemination.

III. FRCODE - FAST AND RELIABLE DATA DISSEMINATION USING NETWORK CODING

A. *Topology*

For code dissemination in WSNs, the base station sends some packets containing the code or code update and these packets should be received by all the nodes in the network. In a dense network, if each node retransmits all packets sent by the base station, the number of transmissions for the code to propagate through the network is large due to repeated transmissions and collisions. WSNs typically have a tree topology as shown in Figure 1, where the base station is at $level_0$. Nodes which are within the transmission range of the base station form $level_1$. Each of these nodes in turn is heard by other nodes within their transmission range, but not within the base station's transmission range. In Figure 1, data propagates from the nodes upwards to the base station along the solid lines, whereas a dashed line between two nodes indicates that the two nodes are within each other's transmission range.

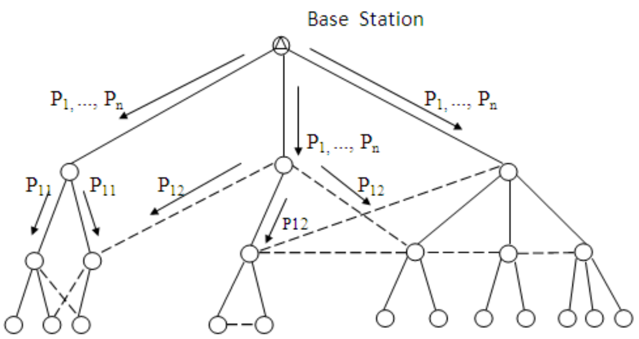

Fig. 1: A simple routing tree

B. *Sending and Receiving Packets in FRCode*

When the base station has some code to send, it sends n packets (P_1 , P_2 , · · · , P_n) of the code in a burst. For fast code distribution, we choose n to be the minimum number of nodes of any level i that are within the range of a node of $level_{i+1}$ (across the entire network). $Node_{11}$ at level $_1$ receives these packets and computes and transmits just one coded packet P_{11}, which is a linear combination of n packets received as below:

$$P_{11} = a_{11} P_1 + a_{12} P_2 + \dots + a_{1n} P_n \quad (1)$$

The coefficients (a_{11} , a_{12} , · · · , a_{1n}) are prime numbers chosen randomly from the range (0, n − 1]. Similarly, $node_{12}$ computes and transmits a different coded packet P_{12} . Once a node of $level_2$ receives at least n such coded packets, it will decode them using Cholesky decomposition (described below), to retrieve the original n packets. It then forms a coded packet of its own and transmits it. This process is repeated till all the nodes receive the packets.

In case a node cannot receive enough coded packets to decode them, it will not be able to retrieve the original packets. This may happen in two cases:

- it receives less than n coded packets or
- it receives n or more coded packets, but does not receive n combinations that are linearly independent.

In this case, the node waits for time T and then broadcasts an NACK. Any node which is able to decode the n packets sends a new coded packet upon receiving an NACK. As the coefficients of coding are randomly chosen, the sender of the NACK will ideally get one or more new coded packets and will be able to decode the packets. The behaviour of a receiver node during code dissemination is depicted in Figure 3 and that of a sending node is in Figure 2.

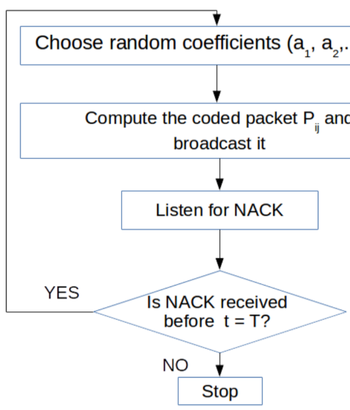

Fig. 2: Flowchart for sending coded packets

C. *Choosing the protocol parameters*

Two points are worth investigating here - the knowledge of n and the value of T .

In a network where the entire network topology is known to the base station, the base station can find n trivially. If this is not the case, but the deployment is uniform with a node density α nodes/sq.m., the base station can estimate the value of n in an area of radius R, where R is the transmission range.

If neither the deployment is of uniform density nor the base station knows the topology graph, the base station can start the initial code dissemination with a small value of n. The code dissemination phase is generally followed by the data gathering phase.

During this phase, each node can maintain a count of the number of distinct nodes from which it has received any kind of data. This count is then piggybacked on a data packet and sent to the base station. For subsequent code updates, the minimum of the received counts can be chosen to be n. Note that since the number of packets sent by the base station in one burst cannot be more than n, which means a large sized code update may require more than one such waves of code distribution.

If the network is dense, the value of n is more, which means more number of packets can be coded into a single packet. The receiving nodes can decode the coded packets as they can get enough coded packets from their neighbors. Hence, the reduction in the number of packets transmitted using FRCode compared to that with no network coding is directly proportional to the node density. This makes FRCode more attractive for dense WSNs.

A guideline for choosing a value of T (the time after which an NACK should be sent) can be given depending on the channel access scheme. Code dissemination may be done using TDMA or CSMA. If TDMA is used for code dissemination, the entire dissemination process should be over after (n + m) slots, where m is the number of nodes in the network. This is because the base station requires n slots for n packets and each of the other nodes requires just one slot for sending the coded packet. On the other hand, if CSMA is used, the worst case time T for which a node has to wait to receive n distinct coded packets before sending an NACK can be estimated based on the channel loss probability.

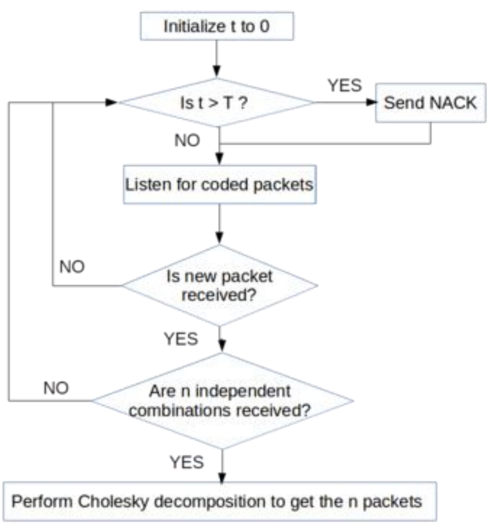

Fig. 3: Flowchart for receiving coded packets

D. Decoding of the received packets

Given a system of linear equations **Ax = b** as shown below, Gaussian elimination can be used to solve it and takes approximately $2n^3/3$ floating point operations(flops).

$$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = b_1$$

$$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n = b_2$$

$$\vdots$$

$$a_{n1}x_1 + a_{n2}x_2 + \ldots + a_{nn}x_n = b_n$$

Instead of using Gaussian elimination, we propose the use of Cholesky decomposition. The Cholesky decomposition of a positive definite matrix A is such that -

$$A = L * L^T \quad (2)$$

Here, matrix **L** is a lower triangular matrix called the Cholesky factor of **A** and $\mathbf{L}^T$ is **L**'s conjugate transpose. When **A** has all real values, **L** also has all real values. In this case, $\mathbf{L}^T$ is just the transpose of **L**.

Matrix **A** can be decomposed into **L** and $\mathbf{L}^T$ as below:

$$L_{jj} = \sqrt{\left(A_{jj} - \sum_{k=1}^{j-1} L_{jk}^2\right)} \quad \text{for } i = j, \quad (3)$$

$$L_{ij} = \frac{1}{L_{jj}}\left(A_{ij} - \sum_{k=1}^{j-1} L_{ik} L_{jk}\right) \quad \text{otherwise} \quad (4)$$

Now, forward substitution can be done to solve the below equation to get matrix **y** as below:

$$Ly = b \quad (5)$$

After getting **y** from Equation 5, backward substitution can be used to solve for **x** as below:

$$L^T x = y \quad (6)$$

In all, decoding individual packets (the variables in the above equations) from a set of coded packets takes approximately $n^3/3$ flops. This results in major saving in time and energy compared to other ways of decoding. For example, finding the inverse of **A** and then using backward substitution to get **x** would take $2n^3/3$ flops. Hence, using Cholesky decomposition can decode the packets in half the time. Hence, the energy spent for decoding the packets is also halved. It also requires only half the space as only the lower triangular part of **A** and **L** need to be stored.

IV. RESULTS

We simulated a WSN topology in a 1000 x 1000 m area using NS3. The nodes were randomly distributed with the base station roughly at the centre of the network. Simulations were run for 500 seconds to check the energy spent only for packet decoding with varying number of nodes. The results are presented in Figure 4. As can be seen, FRCode reduces energy spent for packet decoding approximately by half.

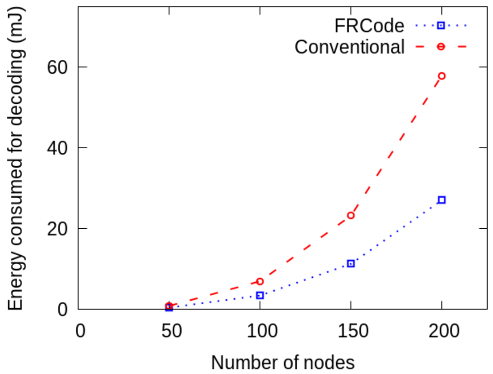

Fig. 4: Energy spent for decoding

V. CONCLUSIONS

We presented an fast and reliable protocol (FRCode) for code dissemination in WSNs. The proposed code dissemination algorithm sends packets coded as a linear combination. When a node receives enough coded packets, it decodes them to get the actual packets sent by the base station using Cholesky decomposition. FRCode achieves reliability using NACKs. We give a guideline for choosing the number of packets to be coded and for transmitting the NACK. The proposed protocol results in reduction of the number of packets to be transmitted for code dissemination. As the density of the network increases, this benefit also increases as more packets are coded into a single packet. Simulation results show that by decoding the packets using Cholesky decomposition, the energy for decoding substantially compared to that of other methods.

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