Network Coding for Ultra Wideband Communication

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Abstract : - Network coding is a novel concept in the field of Information theory which is used for obtaining maximum information flow in a network. Network coding has been shown to offer considerable improvements in the throughput of the network. In this paper we explore the use of network coding in a Ultra-Wide Band (UWB) environment. We have analyzed UWB environment for a sensor based network, where the nodes could be stationery or mobile. We have also analyzed the impact of change in path loss exponent on the throughput when network coding is used. In all these cases, we observe a reduction of up to 40 % in the number of transmissions, which leads to significant power saving for these nodes. We also derive mathematical relationship between number of transmissions and the path loss exponent.

Key-Words: - Network Coding, Ultra Wideband Communications, Path Loss Exponent

1 Introduction

Network coding is an efficient process of sending data from source nodes to sink nodes [1-5]. In network coding, each node generates a new packet, which is a linear combination of the earlier received packets on the link. The coefficients belong to a Galois field $GF(2^s)$. Each generated message X_k is related to the received messages Mi by the relation

$$X_k = \sum_{i=1}^{S} g_k{}^i M_i \tag{1}$$

Each node then forwards to its neighboring nodes, the computed value X_k along with the all the coefficients used in the kth level $g_k{}^i$, as a single encapsulated packet. Each node produces a similar output, as computed above. This for the source node, yields a linear problem of the type $X = GM$, where X is the final set of received packets, G is the corresponding set of Galois field coefficients and M is the original intended message. M can be computed with the knowledge of X and G. Each of the receiver nodes tries to solve this linear equation, which is done using Gaussian Elimination.

Ultra-Wideband (UWB) is a technology for transmitting information spread over a large bandwidth, which is transmitted in the frequency range of 3.1–10.6 GHz [6]. This is intended to provide an efficient use of scarce radio bandwidth while enabling both high data rate personal-area network (PAN) wireless connectivity and longer-range, low data rate applications as well as radar and imaging systems [6-9].

The organization of this paper is as follows. In Section 2, we consider a UWB sensor network and evaluate the performance of network coding in the network. In Section 3, we consider the case when the nodes of the sensor network are mobile. We evaluate the performance of network coding in such a network and compare it with the static nodes case. In Section 4, we vary the path loss exponent of the channel, and observe its impact on the throughput. In Section 5, we discuss the results and draw conclusions.

2 UWB Sensor Network

An outdoor sensor network is a network with nodes that sense and receive data from a node or a group of nodes. Sensor networks typically contain a large number of nodes placed over a big geographical area. UWB can be used as a medium for data transmission in sensor networks [13]. Since sensor networks contain a large number of nodes, network coding can result in improvements in throughput over the network.

2.1 System model

We have considered a realistic UWB sensor network with a certain number of fixed nodes (n) and a certain number of nodes that are variable (m). These nodes are dispersed over a square area d^2. For our case, $m > n$. We assume that the seed node has data of p packets long that has to be sent over the network. A single packet is a unit of transmission over the network.

In the first step, the seed node calculates a new packet from the p packets it already holds, which is given as:

$$X_k = \sum_{i=1}^{S} g_k{}^i M_i \qquad (2)$$

Here, g_k^i is a coefficient from GF(2), which is generated randomly. An encapsulated packet is generated which holds the value X_k , along with the p coefficients g_k^i. This new packet is now transmitted within the network, and it reaches all its neighbors. The neighboring nodes of a node are defined as all those nodes to which the transmitted data doesn't attenuate below the sensitivity of the receiver.

The condition may be mathematically represented as,

$$(P_{tr} - P_l - P_n) > P_{rx} \qquad (3)$$

where, P_{tr} = Transmitted power.
P_l = Path loss.
P_n = Noise power.
P_{rx} = Receiver sensitivity.

If this condition is true, then a given node is a neighbor of the node under consideration otherwise not.

The attenuation over the network is computed using UWB channel characteristics, and we use the standard UWB path loss model to determine if a node would qualify as the neighbor of another node. This would depend on the distance between the nodes as well as the noise. The path loss is modeled as:

$$PL(d) = \left[PL_0 + 10\lambda \log_{10}\left(\frac{d}{d_0}\right) \right] + S; \qquad (4)$$

Here, d_o is a reference distance. Bracketed term is a least-squares fit to path loss, PL_0 (intercept) and λ (path loss exponent) are chosen to minimize S^2. S is the random scatter about the regression line, assumed to be a zero-mean Gaussian random variable with standard deviation s dB [12]

The transmitted data is received in the network by the neighbors of the seed node. Since the operations are computed in the finite field, the result of the operation is of the same length. The new packet length, does have an overhead now (of p additional bits), which though is not significant when compared to length of the packet. When the neighbors of the source node receive the encoded single packet, along with the p coefficients, these nodes store this packet in a matrix (an internally maintained data structure by each node to store all incoming packets). When a node receives a 2nd network coding encoded packet of the same data, it also adds this packet to the matrix, and keeps doing so until the rank of matrix becomes equal to the length of the data, which is p. After a node gets 2 unique packets, it transmits to the network a random combination of these 2 packets, along-with its code coefficients in the network. This process now gets repeated over for all the nodes in the network. After a certain number of transmissions, all the nodes receive all the packets in much lesser no. of transmissions when compared to any other routing method.

The time taken to send a packet to a neighboring node, t_n is given by (5). We have used these time values to sort the events of transmission and reception of packets.

$$t_n = t_c + d/c + t_j \qquad (5)$$

t_n = time taken to send a packet to a neighboring node.
t_c = circuit latency, time taken by the internal circuitry to generate the encapsulated packet.
d = distance between two nodes.
c = speed of light.
t_j = random jitter.

For a UWB sensor network with a large number of geographically dispersed nodes, we have two parameters of interest: One is the power consumption and the other is time taken for complete transmission. The power consumed by the sensor network, P_s, is directly proportional to number of transmissions T_s.

$$P_s \; \alpha \; T_s$$
$$or, \; P_s = k_1 T_s \qquad (6)$$

The time taken by the sensor network to achieve complete transmission, t_s, is also directly proportional to the number of transmissions T_s.

$$t_s \; \alpha \; T_s$$
$$or, \; t_s = k_2 T_s \qquad (7)$$

where, k_1 *and* k_2 are constants.

2.2 Simulation results

We perform a simulation on the system model defined in 2.1 using the following values:

n = number of fixed nodes = 5
m = number of variable nodes = between 50 and 150
N = total number of nodes = $n + m$
p = size of data in packets = 10
d = length of a side of the square area in which nodes are located = 250m
t_c = circuit latency = 0.01 ms
t_j = random jitter = uniform over [0,0.001 ms]
P_{tr} = Transmitted power = -10dBm
P_l = Path loss = determined from (4).
P_{rx} = Receiver Sensitivity = -85 dBm

The values we have taken for the path loss components are used from [12].

Table 1 Path Loss Parameters for UWB Channel

	Mean	**Std. Dev.**
PL_0(dB)	47	NA
λ	1.7	0.3
s (dB)	1.6	0.5

The simulation results are shown in Figure 1. We observe an improvement of 20% to 40% in the number of transmissions required as we increase the number of nodes in the network. This reduction in the number of transmissions helps reduce the power requirements of sensor networks by up to 40%.

If we model the number of transmissions versus the number of nodes for the case of network coding by a straight line, we get

$$Ts = \alpha N + \beta \qquad (8)$$

where, α and β are constants. From calculations, α = 5.28 and β = 185.82.

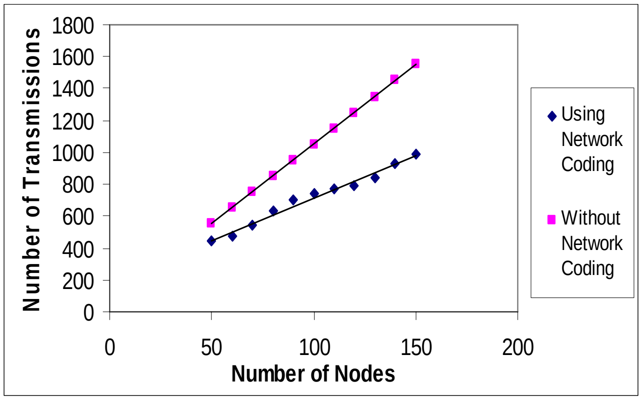

Fig. 1: Effect of network coding on the number of transmissions.

The percentage saving by using network coding can be expressed as,

$$S_{\%} = \frac{(AN-B)*100}{N+C} \qquad (9)$$

where, A,B,C and are determined to be, A = 0.47, B= 13.5, C = 5.

For our case, we obtain percentage saving as

$$S_{\%} = \frac{100(0.47N - 13.5)}{N+5} \qquad (10)$$

3 UWB Sensor Network with Mobile Nodes

The nodes of a sensor network may not be always static. There may be cases where the nodes may be moving randomly within the area of interest. This is true for many real life sensor network applications. For example their may be a sensor network which needs to send data to multiple moving cars about the traffic conditions in the neighborhood of these cars.

3.1 System Model

We simulate such an environment, where transmissions using network coding takes place, and after specific instants of time, we change the addresses of some nodes. The goal of the coding scheme is to be strong enough to deal with the mobility and not offer a substantial down gradation in the performance.

The mobility environment is modeled as follows. After a certain number of transmissions have taken place, we change the addresses of some nodes. For each node we randomly decide whether or not to update its address. The selected nodes address is then updated by a random number. This is done periodically.

3.2 Simulation Results

We carry out our simulation for different number of nodes within the sensor network, with their addresses changing regularly. We obtain the following results as shown in Figure 2.

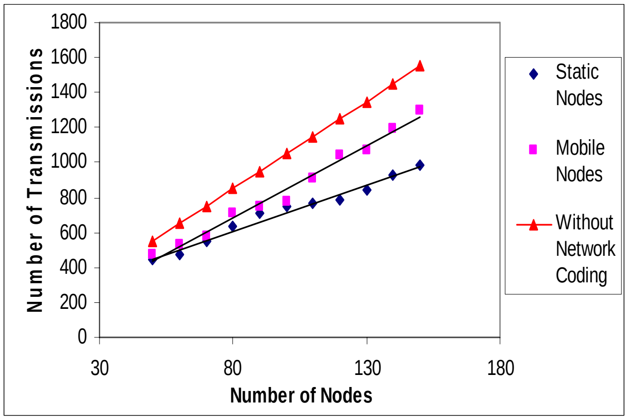

Figure 2: Performance of mobile nodes with network coding

The number of transmissions for mobile nodes, may again be modeled as a straight line

$$T_s = \alpha N + \beta \qquad (10)$$

For our case, $\alpha = 8.23$ and $\beta = 26.45$.

We observe that even in the case of a dynamic network with non stationery nodes, we are still able to achieve significant improvements using network coding. Hence, we can deduce that network coding is a robust coding method which can be used for non stationery nodes too. We also observe that with the same number of nodes, number of transmissions required for dynamic nodes is more than static nodes. This is expected because while in motion some nodes would get far off from some sensor nodes and would get closer to more nodes after some time. This period, where the node moves between two neighboring locations causes the increase in number of transmissions.

4 Effect of path loss exponent

Path loss (or path attenuation) is the reduction in power density of an electromagnetic wave as it propagates through space. It can be represented by the path loss exponent (4). For UWB Channels, depending on the environment, the path loss may vary up to a value of 5.

We simulate a network coding environment for different values of path loss exponent to estimate the performance in different environments. By having a higher value of path loss, we will have fewer neighbors for a node. So an increase in path loss will lead to an increase in the number of transmissions.

4.1 Simulation Results

We assume following values for the simulation environment:

n = number of fixed nodes = 5
m = number of variable nodes = between 100 and 250
p = size of data in packets = 10
d = length of a side of the square area = 100m
P_{tr} = Transmitted power = 0 dBm
P_{rx} = Receiver Sensitivity = -85 dBm

The effect of varying the path loss exponent is shown in Figure 3. The curve is plotted for different number of nodes in the network. The relationship between number of transmissions, T_s, and mean of the path loss exponent, λ, is found to be approximately logarithmic and can be approximated by (11):

$$T_s = E\, ln(\lambda - 1) + F \qquad (11)$$

The values for *E* and *F* are shown in Table 2.

Table 2 Values of *E* and *F*

Number of nodes	***E***	***F***
100	714	305
150	1014	376
200	1384	534
250	1786	509

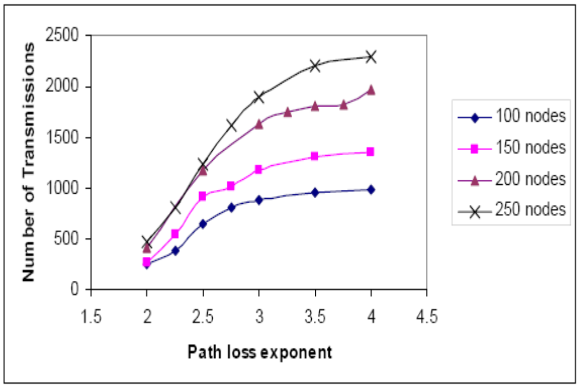

Figure 3: The effect of path loss exponent on the number of transmissions.

5 Conclusion

We have explored the use of network coding for UWB Networks. We have obtained up to 40% reduction in number of transmissions using network coding for sensor networks. We have expressed mathematically the percentage saving by using network coding and the relation between number of nodes and number of transmissions. We have simulated the case for mobile nodes too, and proved that network coding is a robust scheme to be used in such an environment too. We have also analyzed the effect of change in path loss exponent on transmission in such an environment. The variation of the number of transmissions with respect to the path loss exponent is found to be approximately logarithmic.

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