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Exchange of Information in Wireless Sensor Networks using Network Coding

S.K.Rajalakshmi[*1],S.Senthilnathan[2], A.P.Prabakaran[3]
[*1, 2, 3] Assistant Professor, A.V.C College of Engineering, India
raji.paramu@gmail.com

Abstract

The exchange of independent information between two nodes in a wireless network can be viewed as two unicast sessions, corresponding to information trans-fer along one direction and the opposite direction.. Many schemes are applied to achieve this say Conventional scheme and Cooperative Diversity Scheme. In this paper we propose a scheme called Network coding where, instead of simply relaying the packets of information they receive, the nodes of a network will take several packets and combine them together for transmission. This can be used to attain the maximum possible information flow in a network. Network coding is a field of information theory and coding theory. The observations show that network coding scheme has better energy efficiency than the other schemes.

Keywords: Cooperative diversity scheme, network coding scheme, sensors, block error rate, CRC.

Introduction

A Wireless Sensor Network consists of spatially distributed autonomous sensors to monitor physical and environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on. The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting.The information exchange in a Wireless sensor Network is shown in fig.1. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network.

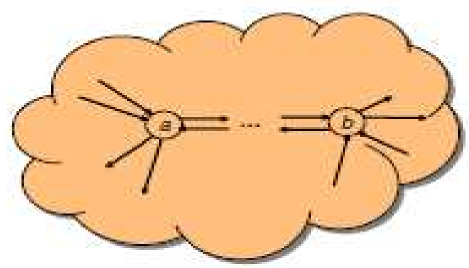

Figure.1 An example scenario of information exchange, a &b are two wireless routers, each having packets to be routed to other

Cooperative diversity allows a collection of radio terminals that relay signals for each other to emulate an antenna array and exploit spatial diversity in wireless fading channels. Cooperative diversity allows wireless terminals to obtain improved reliability and substantial energy savings by relaying messages for each other in order to propagate redundant signals over multiple paths in the network. This redundancy allows the ultimate receivers to essentially average spatial channel variations resulting from physical channel effects such as fading and shadowing or from interference caused by intentional jamming.

The core idea of network coding is that each node in the network combines previously received packets and forwards the combination to neighboring nodes, instead of storing and forwarding individual packet. This leads to fewer transmissions and thus helps

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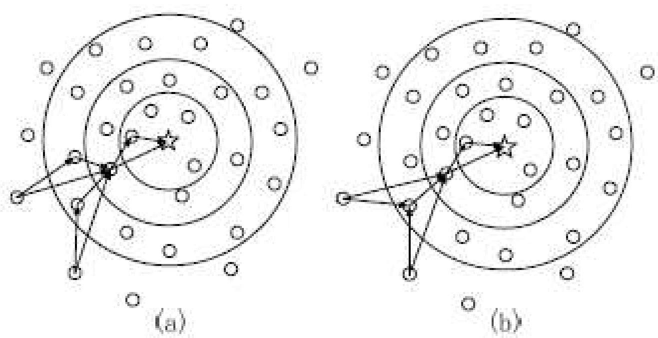
to save transmission and reception energy. It has been shown that considerable capacity gain and energy saving can be obtained in many wireless networks. The combination of network coding and WSN in this project will not only reduce energy consumption, but also enhance the reliability and security of WSN.

Architecture

A. Schemes in WSN

Taking the dynamic environment of WSN into consideration, network coding is brought forward to WSN system in this paper. Figure 2 shows the cooperative diversity scheme and network coding scheme. Under the combination of network coding and multi-path data transmission, multiple copies of independent data encoded from the same set of data are transmitted through multiple paths to ensure the reliability of data transmission.



Different schemes in WSN (a)Cooperative diversity scheme; (b)Network coding scheme

Cooperative diversity is a cooperative multiple antenna technique for improving or maximising total network channel capacities for any given set of bandwidths which exploits user diversity by decoding the combined signal of the relayed signal and the direct signal in wireless multihop networks. A conventional single hop system uses direct transmission where a receiver decodes the information only based on the direct signal while regarding the relayed signal as interference, whereas the cooperative diversity considers the other signal as contribution. That is, cooperative diversity decodes the information from the combination of two signals. Hence, it can be seen that cooperative diversity is an antenna diversity that uses distributed antennas belonging to each node in a wireless network. Note that user cooperation is another definition of cooperative diversity. User cooperation considers an additional fact that each user relays the other user's signal while cooperative diversity can be also achieved by multi-hop relay networking systems. For cooperative decoding, the destination node combines two signals received from the source and the relay nodes which results in the diversity advantage. The whole received signal vector at the destination node can be modeled as:

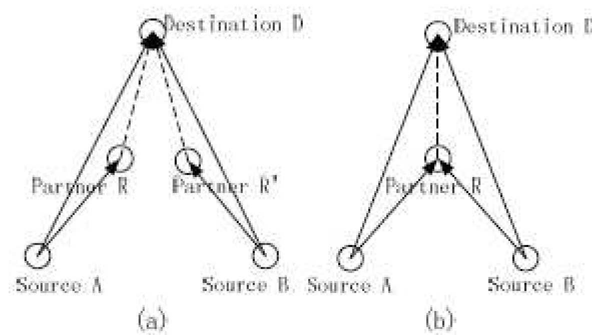
$$\mathbf{r} = [r_{d,s} \quad r_{d,r}]^T = [h_{d,s} \quad h_{d,r}h_{r,s}]^T x_s + \left[1 \quad \sqrt{|h_{d,r}|^2+1}\right]^T n_d = \mathbf{h}x_s + \mathbf{q}n_d \tag{1}$$

where $r_{d,s}$ and $r_{d,r}$ are the signals received at the destination node from the source and relay nodes, respectively. As a linear decoding technique, the destination combines elements of the received signal vector as follows:

$$y = \mathbf{w}^H \mathbf{r} \tag{2}$$

where $\mathbf{w}$ is the linear combining weight which can be obtained to maximize signal-to-noise ratio (SNR) of the combined signals subject to given the complexity level of the weight calculation.

Cooperative relaying can be used to reduce the energy consumption in sensor nodes, hence lifetime of sensor network increases. Due to nature of wireless medium, communication through weaker channels requires huge energy as compared to relatively stronger channels. Careful incorporation of relay cooperation into routing process can selects better communication links and precious battery power can be saved.



Cooperative diversity scheme and network coding scheme

The cooperative system consists of 2 source nodes, 1 destination receiver and 2 partner nodes (Figure 3(a)), operating under the selection decode-and-forward cooperative diversity scheme. In the first phase of selection decode-and-forward, the source-to-destination transmission is also received and decoded by the partner. If the partner is able to decode the source’s message correctly, as determined by a CRC check, it forwards message to the destination in the second phase, otherwise the partner does not retransmit the source’s message. We assume that the destination receiver combines the messages it receives from the source and partner using optimal diversity combining.

In a Linear Network coding problem, a group of nodes P are involved in moving the data from S source nodes to K sink nodes. Each node generates a new packet, which is a linear combination of the earlier received packets on the link, by coefficients in the finite field.

A message generated so X_k is related to the received messages M_i by the relation:

$$X_k = \sum_{i=1}^{S} g_k^i \cdot M_i \quad (3)$$

Each node forwards the computed value X_k along with all the coefficients used in the kth level, The values are the coefficients from the Galois field GF(2s). Since the operations are computed in the finite field, the result of the operation is also of the same length, as the size of each vector M.

Each node produces a similar output, as computed above.This yields a linear problem of the type X = GM, where with the knowledge of theX,G we need to compute M. Each of the receivers in K, try to solve this linear equation, and for which at least packets must be received. The received packets are continually used in the Gaussian elimination method to reduce G matrix into the row-echelon form. Finally the resulting values of X = GechelonM are solved to obtain M.

B. Performance Analysis of the cooperative diversity scheme and network coding scheme

We can get the *BLER* (block error rate) of Cooperative diversity scheme as

$$BLER_{COOP}=BLER_{AR}BLER_{AD}+(1-BLER_{AR}).BLER_{AD}BLER_{RD} \quad (4)$$

where $BLER_{AR}$ is the *BLER* of the source A-to-partner R transmission, $BLER_{AD}$ is the *BLER* of the source A-to-destination D transmission, and $BLER_{RD}$ is the *BLER* of the partner R-to-destination D transmission.

In the network coding scheme, With only one partner R, the information transmitted from both A and B can now be retrieved correctly. For example, if the destination fails to decode X_A , yet X_B and X_R both arrive correctly, then the destination D can recover X_A. Similarly, if the transmission from B fails, X_B can be retrieved if neither X_A nor X_R fails. We assume that source A and B only transmit one message block (100bits) separately in our study. The BLER of source A can then be computed as:

$$BLER_{NC}=BLER_{AD}(BLER_{AR}+(1-BLER_{AR})(BLER_{RD}BLER_{BR}+(1-BLER_{RD})(BLER_{BR}+(1-BLER_{BR})BLER_{BD}))) \quad (5)$$

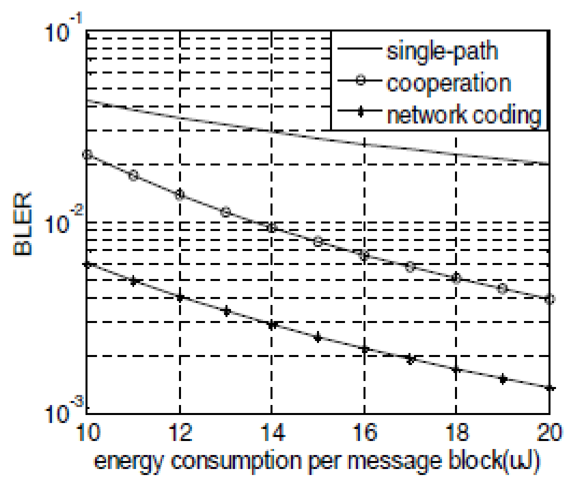
where $BLER_{AR}(BLER_{BR})$ is the BLER of the source A(B)-partner R transmission, $BLER_{AD}(BLER_{BD})$ is the BLER of the source A(B)-to-destination D transmission, and $BLER_{RD}$ is the BLER of the partner R-to-destination D transmission. In the two systems, we assume that the source-to-destination, source-to-partner, and partner-to-destination communication channels are independent flat Rayleigh slow fading channels. And BPSK modulation is used throughout the systems. A closed-form expression for the exact BLER of BPSK in Rayleigh fading is given; thus we adopt a high-SNR approximation for BLER :

$$BLER = K / SNR \quad (6)$$

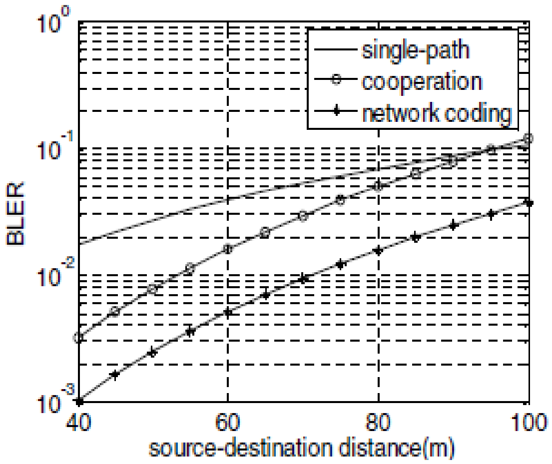
where K is a scaling factor and $K = 3.2$ for a message block size of 100 bits.

Performance Evaluation

In this section, we present the numerical results for the systems discussed in the previous sections. For simplicity, no coding (such as distributed channel coding) is used other than the network coding. All channels are modeled as normalized Rayleigh fading and the transmission distance *d* is set to 50m. System *BLER* of direct transmission scheme, cooperative diversity scheme and network coding scheme with the change of total energy consumption *E* per message block are show in Figure 4. From the result, we can learn that the *BLER* of network coding scheme has better performance than cooperative diversity scheme, when the transmission power(per block) is in a relatively low level, the *BLER* performance of network coding scheme is still at a good level. So network coding scheme is more suitable for low-power transmission in WSN.



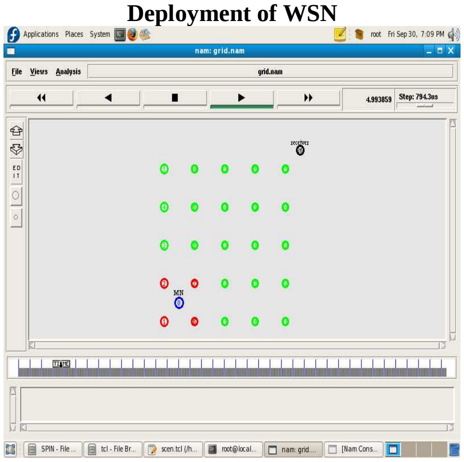
System BLER versus energy consumption for d=50m



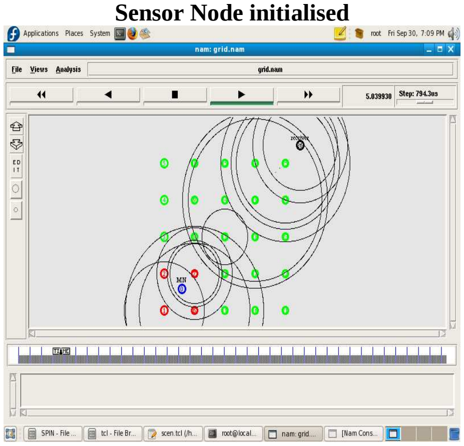
System BLER versus transmission distance for E=15uJ

Figure 5 shows the system *BLER* with the change of transmission distance *d* , where *E* is set to 15uJ. From the result, we can easily see that network coding scheme has better performance. The greater the distance is, the greater advantage network coding scheme gets than cooperative diversity scheme.

Deployment of WSN



Sensor Node initialised



Decode and Forward to Destination Node

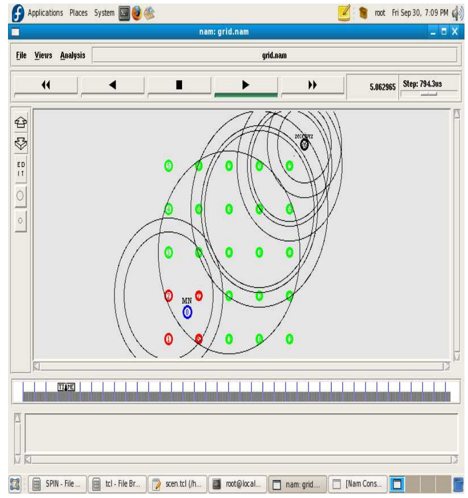
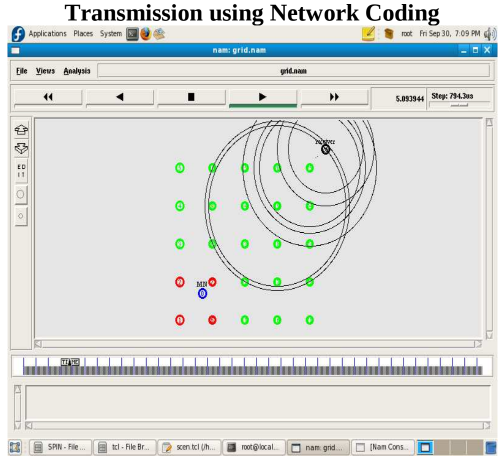


Fig 6 to 9 shows the overall implementation of a network coding and represents the transmission of data using network coding method. This leads to fewer transmissions and thus helps to save transmission and reception energy. It has been shown that considerable capacity gain and energy saving can be obtained. We have given a network coding solution for information exchange, assuming synchronization is available, links are lossless, and links have unit capacity and unit delay. In real networks, however, packet transmissions are subject to random delays and losses on every link, and links have essentially unknown capacities, which vary as competing communication sessions begin and end.

Transmission using Network Coding



Conclusion

In this paper, we identified information exchange in wireless networks as a new application scenario where network coding can over unique advantages over conventional routing. Network coding, together with the physical layer broadcast property

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offered by the wireless medium, can improve the efficiency in using resources by facilitating physical piggybacking. To realize the advantages in practice, it is possible to make use of the practical network coding system, since information exchange can be treated as a virtual multicast session. Observing the special structural features of the current problem, in this paper we proposed a distributed and robust scheme that is simpler to implement and incurs less overhead than the practical network coding system.

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