Diversity and Node cooperation in Wireless Ad Hoc and Sensor Networks

EE360 Paper Summary on Ad Hoc and Sensor Networks

Submitted by

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Introduction: Cooperation among nodes in wireless Ad Hoc and sensor networks can be used for a variety of purposes including improving energy efficiency, capacity improvements and exploiting spatial diversity in the network. A number of cooperative techniques have been proposed in literature such as cooperative scheduling of resources, cooperative routing, cluster based cooperative MIMO etc. In this paper summary, I will summarize papers that use node cooperation for the purpose of relaying, exploiting spatial diversity in the network and to increase coverage in the network.

The three papers that I am summarizing are listed below:

1. "Exploiting Macrodiversity in Dense Multihop Networks and Relay channels", Valenti M.C, Correal N., IEEE Wireless Communications and Networking Conference, Vol. 3, March 2003, Pages 1877 – 1882.
2. "Space-Time Processing for Cooperative Relay Networks", Hammerstroem I., Kuhn M., Rankov B., Wittneben A., IEEE Vehicular Technology Conference (VTC), Vol. 1, October 2003, Pages 404 – 408.
3. "Opportunistic Large Arrays: Cooperative Transmission in Wireless Multihop Ad Hoc Networks to Reach Far Distances", Scaglione A., Yao-Win Hong, IEEE Transactions on Signal Processing, Vol. 51 , Issue 8 , August 2003, Pages 2082 – 2092.

The Summaries: The papers mentioned above will be summarized in this section.

"Exploiting Macrodiversity in Dense Multihop Networks and Relay channels"
Valenti M.C, Correal N.

Assumptions: A relay channel is assumed where a source must send a message to a destination but has insufficient power to transmit directly. A circular cloud of *M* randomly placed transceivers (Fig. 1) is located halfway between the source and the destination is used in order to relay this message.

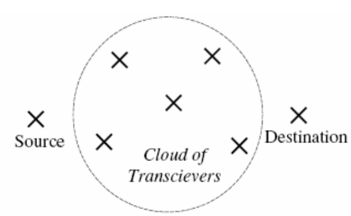


Fig. 1. A dense double-hop network.

Each node is assumed to have only a single antenna and the nodes operate at extremely low power.

Analytic techniques: There are no key analytical techniques involved in this paper. It is primarily based on the author's intuition and simulation results are presented in order to verify their claims.

Main ideas: The authors compare two different relaying schemes in order to bring out the advantage of exploiting macrodiversity in sensor networks. In scheme 1 which is called the *receiver-directed* transmission scheme, the source transmits to a predetermined relay node (chosen from the *M* available relays) and the spatial redundancy due to the presence of the other *M*-1 relays is wasted. If the relay is not able to forward the message successfully, then the message is lost and the source will have to retransmit the message again. Thus retransmissions from the source will require extra energy to be expended. If the source does not retransmit the message, an error is logged at the destination node and the BER will increase. In order to reduce the BER, we will need to increase the transmitted power. Therefore we can view the extra energy in terms of either the energy needed for retransmissions or the extra energy required in order to maintain a certain BER at the destination node.

Instead the source can broadcast its message to the cloud of transceivers thereby allowing possibly multiple nodes (called potential relays) to receive the message. The potential relays will determine the order in which they will forward the message to the destination by means of a negotiation which can be embedded into the MAC/Network layer protocol. The potential relay with the best average SNR is elected to forward the message. If the initially selected relay fails to transmit successfully to the destination, then one of the other potential relays can be used to retransmit the packet. Therefore an energy saving can been achieved as compared to the *receiver-directed* scheme by avoiding retransmissions by the source. Also the extra energy required for retransmission from the potential relays is distributed over the entire cloud and this is the additional benefit of this scheme.

Results: The two schemes were simulated for packets of length N = 80 bits transmitted at 1 Mbaud over a quasi-static Rayleigh fading channel using non coherently detected frequency shift keying (NFSK). The quasi-static Rayleigh fading assumption is made as the channel SNR is assumed to remain constant for the duration of each packet but varies independently from packet to packet according to an exponential distribution. The transmit powers of the source (P_1) and each relay (P_2) were varied in order to obtain an end-to-end probability of error of 10^{-2} for both the schemes. The total transmit power (P_1+P_2) required to maintain this BER for the 2 schemes is given in the following table for different number of nodes *M* in the cloud.

M	receiver-directed	best avg. SNR
1	6.692 mW	6.692 mW
2	5.968 mW	1.611 mW
3	5.623 mW	0.990 mW
5	5.047 mW	0.642 mW
10	4.798 mW	0.382 mW

We can see that the energy efficiency of the *receiver-directed* scheme improves slightly with increasing *M*. This improvement is observed because the cloud becomes denser and the forwarding relay node is more likely to be at the cloud's center. The improvement is not due to any diversity advantage. On the other hand, the energy efficiency of the broadcast scheme improves dramatically with *M* as it uses the macroscopic diversity available in the system.

Contributions: The paper has presented the concept of cooperation between nodes in a sensor network in order to exploit the macrodiversity available in the network. Although the authors have presented their ideas in an intuitive manner, it would have been better to formulate the problem analytically so that the optimality of the scheme could be verified.

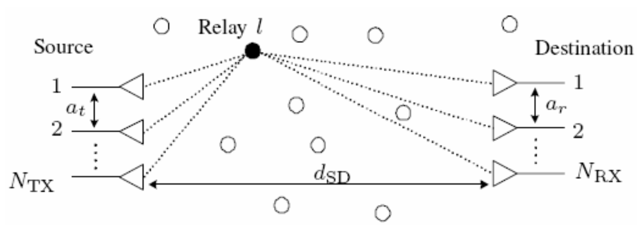
Possible extensions: The assumptions in the paper seem to be reasonable. However, the work can be extended to Ricean and Nakagami fading channels which are more realistic than the Rayleigh model. The method can be extended to multihop networks as the paper considers only double hops. Other energy costs apart from the transmit energy such as the circuit energy can be brought into the model. The problem of sleep states has not been addressed in the paper and it will be interesting to see how macrodiversity can be exploited when nodes are allowed to go into sleep states.

<u>"Space-Time Processing for Cooperative Relay Networks"</u>
<u>Hammerstroem I., Kuhn M., Rankov B., Wittneben A.</u>

Assumptions: The transmit and receive nodes are assumed to have antenna arrays. The relay nodes are equipped with single antennas and perform amplify and forward functions.

Analytic techniques: General Matrix theory

Main ideas: It is well known that the use of multiple antennas at the transmitter and receiver can lead to great capacity improvements in a rich scattering environment. However, in a line of sight environment the MIMO channel is rank deficient and hence the capacity increase diminishes. The key idea in this paper is to use two hops for each transmission, one hop from the source antenna array to a relay node and the next hop from the relay node to the receive antenna array as shown below



The composite MIMO channel formed over the two time slots will have a higher rank than the actual MIMO channel between the source and the destination antenna arrays. Essentially, the trick is to use the relay node (which performs amplify and forward) in order to simulate a NLOS environment. Consequently the rank of the composite channel increases.

Next, the authors use linear scalable dispersion (LSD) codes in order to exploit the capacity of the composite MIMO channel. The code consists of two concatenated but decoupled linear block codes, the time-variant inner code and the time-invariant outer code. The inner code is adapted to the configuration of the MIMO system and the channel statistics and the outer code is used to achieve high diversity gain in a fading environment. Therefore, the structure of the code allows a flexible trade-off between spatial multiplexing gain and diversity gain. The authors present simulation results that show this flexibility as well as the capacity improvement in the system using the cooperative relaying scheme described above.

Contributions: The paper has presented a novel cooperative scheme using amplify and forward relays in order to increase the rank of the MIMO channel and thereby enable us to use powerful MIMO techniques such as space time coding. Furthermore, high rate adaptive space time codes have been used which can exploit the capacity of the MIMO channel using spatial multiplexing and can also obtain diversity gain.

Possible extensions: The author has assumed a kind of an asymmetry in the network as the source and destination nodes are equipped with antenna array while the relay nodes have only single antennas. This assumption does not seem to be valid as it would then mean that we are placing single antenna nodes in the network for the specific purpose of relaying. In general, the relay nodes must be similar to the transmit and receive nodes as they may also be transmitting their own data. Hence, the analysis in the paper must be extended to the case where the relay node also has multiple antennas.

<u>"Opportunistic Large Arrays: Cooperative Transmission in Wireless Multihop Ad Hoc Networks to Reach Far Distances"</u>
<u>Scaglione A., Yao-Win Hong</u>

Assumptions: There are N nodes in the network. Each node is part of a multiple stage relay of a single source transmitting toward a remote receiver whose position is unknown to all the nodes. No node is powerful enough to communicate reliably with the remote receiver.

Analytic techniques: General Matrix theory, Mean squared error estimation

Main ideas: The goal of this paper is to design a cooperative transmission scheme in order to communicate reliably with the remote receiver from any source node. An opportunistic large array (OLA) is formed by having nodes in the network respond to the signal of the node that is designated to be the leading transmitter (leader or source). The avalanche of responses of the nodes increases the SNR of the signal and therefore the strengthened signal can be detected and decoded by the remote receiver.

The transmission of the OLA is led by a predetermined source node in the network. All the other nodes form multiple stages of relays to either flood the network with the information from the source, or just to pass the information to a remote receiver. The intermediate nodes in OLA have a choice of whether to relay or not, depending on the performance at that node. This adaptive relaying method is analogous to adaptive decode-and-forward or amplify-and-forward algorithms.

The remote receiver keeps track of the mobility of the transmitters by adaptively tracking their signatures. Using these signatures and the received composite signal, the receiver can estimate the transmitted bits using standard mean squared error estimation techniques. The author also introduces variations of the scheme where the receiver can have an initial training phase before the estimation phase or the receiver can just perform blind estimation of the bits.

Contributions: The paper introduces a new flooding scheme in order to reach a remote receiver from any node in a wireless network. The papers assume a lot of importance as traditional flooding schemes are modifications of schemes that were developed for wired networks and may perform poorly in a wireless scenario.

Possible extensions: A theoretical analysis can be performed in order to quantify the gains of the technique proposed in the paper.

Conclusion: Three different forms of node cooperation in wireless Ad Hoc and sensor networks have been summarized. We can see that there is a plentitude of cooperative techniques available to us and therefore it is of interest to investigate the optimum cooperation schemes for each objective (reduce BER, increase capacity etc.) in future.