Achieving full diversity order by means of a cooperative-ARQ protocol

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Abstract

Cooperative protocols are a new and promising research field that can lead to a better understanding of wireless ad-hoc networking. In this paper we focus on cooperative hop-by-hop ARQ (automatic repeat request) protocols. The main objective of a hop-by-hop ARQ is to prevent, by means of frame retransmission, the loss of frames due to transmission errors. Classically, when the receiver node detects errors in the received frame, it asks for a frame retransmission to the transmitter node. The key idea of cooperative ARQ is that nodes others than transmitter and receiver can play a role in the protocol operation, exploiting some of the characteristics of wireless media such as natural broadcast of wireless transmission, and leading to significant improvements in protocol performance.

Examples of cooperative hop-by-hop ARQ protocol are [2], [3], [4] and [6]. In all cases, authors report significant improvements in terms of transmission power, transmission range or throughput.

Cooperative ARQ protocols exploit receiver diversity [1], a well-known wireless transmission technique. The classical optimal way of exploiting receiver diversity is Maximal Ratio Combining (MRC). In MRC, nodes use an array of antennas with a minimal separation of around half wavelength. Signals received by each antenna are coherently combined before detection, using an estimate of the received SNR as weight for each branch. For Rayleigh channels, for instance, it can be shown that the Bit Error Rate (BER) versus ?, the average Signal to Noise Ratio (SNR), is given by:

$$BER \approx k\left(\frac{1}{g}\right)^{M'}$$

where M' is the number of antennas. As the exponent in this expression is equal to M', it is said that MRC achieves *full diversity order.*

Given the complexity of building nodes with several antennas with minimal separation requirements, several schemes have been devised where nodes share hardware resources (antennas and RF chains) of other nodes. Cooperative transmission techniques (see [5] and references therein) are an example of this.

Cooperative ARQ goes one step further simplifying the requirements of cooperative transmission -such as for instance node synchronization at physical level reception or coherent detection- by resorting to cooperation at data link level. In other words, cooperation is introduced after symbol detection, meaning that no special hardware is required, as all complexity is kept in the protocol processing.

In [4] the relationship between receiver diversity and cooperative ARQ with Majority Voting bit combining is discussed, showing for example that in a Rayleigh channel, using M=2M'-1 cooperating nodes is equivalent to using MRC with M' antennas.

The main contribution of the work presented in this paper is to show that in Rayleigh channels we can achieve full diversity gain if cooperating nodes exchange information about average SNR during frame reception. Average SNR, with different levels of accuracy, is already provided by many of the wireless NICs used in current ad-hoc networks, and it is easily available to the Operating System software through commands such as iwspy in Linux.

As an example of the implications of the work presented in this paper, we obtain that for BPSK signalling, Rayleigh channels, and average ?=10, BER without cooperation would be around 0.025. If we use cooperative ARQ with M=3 cooperating nodes, BER is reduced to $6x10^{-4}$, and if M=4, BER would decrease up to a level of 10^{-4}.

References

[1] A. Goldsmith: "Wireless Communications", Cambridge University Press.

[2] A. Miu, H. Balakrishnan, C. E. Koksal, "Improving Loss Resilience with Multi-Radio Diversity in Wireless Networks", ACM Mobicom 2005, Cologne.

[3] P. Monti, M. Tacca, A. Fumagalli, "Optimized Transmission Power Levels in a Cooperative ARQ Protocol for Microwave Recharged Wireless Sensors", IEEE ICC'05, 2005.

[4] J. Morillo-Pozo, J. García-Vidal, A. Pérez-Neira, "Collaborative ARQ in Wireless Energy-Constrained Networks", ACM-SIGMOBILE DIAL-M-POMC International Workshop on Foundation of Mobile Computing, September 2, 2005, Cologne, Germany.

[5] A. Nosratinia, T.E. Hunter and A. Hedayat, "Cooperative communication in wireless networks", *IEEE Communications Magazine*, vol. 42, no. 10, October 2004, pp. 68-73.

[6] B. Zhao, M. C. Valenti, "Practical Relay Networks: A Generalization of Hybrid-ARQ", IEEE JSAC, Vol. 23, No. 1, January 2005.