Chapter 4.5
Data Gathering in Correlated Wireless Sensor Networks with Cooperative Transmission

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ABSTRACT

This chapter considers the problem of data gathering in correlated wireless sensor networks with distributed source coding (DSC), and virtual multiple input and multiple output (MIMO) based cooperative transmission. Using the concepts of super and sub modularity on a lattice, we analytically quantify as how the optimal constellation size, and optimal number of cooperating nodes, vary with respect to the correlation coefficient. In particular, we show that the optimal constellation size is an increasing function of the correlation coefficient. For the virtual MIMO transmission case, the optimal number of cooperating nodes is a decreasing function of the correlation coefficient. We also prove that in a virtual MIMO based transmission scheme, the optimal constellation size adopted by each cooperating node is a decreasing function of number of cooperating nodes. Also it is shown that, the optimal number of cooperating nodes is a decreasing function of the constellation size adopted by each cooperating node. We also study numerically that for short distance ranges, SISO transmission achieves better energy-mutual information (MI) tradeoff. However, for medium and large distance ranges, the virtual MIMO transmission achieves better energy-MI tradeoff.

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INTRODUCTION

A wireless sensor network (WSN) consists of large number of spatially distributed devices called *nodes,* which cooperate to accomplish various high level tasks. These nodes find applications in a wide range of remote sensing and environmental applications. Each of these nodes are equipped with a sensor and wireless transceiver, to perform sensing and communication tasks respectively. Typically the nodes are equipped with small batteries, and therefore are subject to severe energy constraints. Consequently, the main objective of sensor network research is to design energy-efficient devices and algorithms to support various aspects of network operation. The μ AMP project at MIT (Chandrakasan, Min, Bharadwaj, Cho & Wang, 2002), and the PicoRadio project at Berkeley (Rabaey, Ammer, dasilva, Patel & Roundy, 2000) are efforts in this direction. Another unique feature of WSNs is, the high degree of spatial correlation in the data sensed by the nodes, owing to their close proximity. We refer the readers to (Akyildiz, Su, Sankarasubramaniam & Cayirci, 2002), for a detailed discussion on WSNs and their applications.

Typically in a WSN, the nodes cooperate to accomplish a common task (unlike a conventional wireless network), therefore the idea of cooperation is central to the design of a WSN. The cooperation among WSNs can be of two types: *implicit* and *explicit*. In implicit cooperation, the nodes of a WSN cooperate implicitly based on the information obtained apriori. The concept of distributed source coding (DSC) where the sensor nodes determine their encoding rates, based on the prior information obtained on spatial correlation, is an instance of implicit cooperation. On the other hand, in the explicit cooperation, the nodes cooperate explicitly by sharing information. The concept of virtual multiple input and multiple output (MIMO) (or cooperative) transmission, where the sensor nodes share information and transmit cooperatively, is an instance of explicit cooperation. In this chapter, we consider an architecture based on implicit and explicit cooperation for WSNs. Specifically, we consider an architecture that employs, virtual MIMO to reduce the energy consumption of each sensor node and DSC to exploit the spatial correlation.

The concept of virtual MIMO aims to exploit the benefits of popular MIMO antenna techniques for WSNs. Direct application of the popular MIMO techniques to WSNs is not possible, owing to the relatively small size of the sensor nodes. However, by allowing the nodes to exchange their information, one can create a virtual MIMO system. We focus on *orthogonal* space-time block codes (STBC) (Tarokh, Jafarkhani & Calderbank, 1999) as a way to implement virtual MIMO in WSNs. The orthogonal STBCs are attractive because they facilitate simple decoding at the receiver. However, the orthogonal STBCs are bandwidth inefficient, especially if the number of cooperating nodes is greater than two. The reason for this bandwidth inefficiency can be attributed to the fact that, it may not be possible to design orthogonal STBCs with spatial rate equal to one, if the number of sensor nodes is greater than two (Liang, 2003). Thus it is of interest to know the effect of using an STBC with spatial rate less than one, on the energy efficiency of a WSN. To this end, we formulate the problem of minimum energy data gathering in correlated WSNs. We also study the tradeoff between energy-Mutual Information (MI) and energy-mean square error (MSE), for single input and single output (SISO) and virtual MIMO based transmission schemes in correlated WSNs.

An important aspect of our work is, we analytically study the effect of data correlation on physical layer design variables such as, constellation size and number of cooperating nodes, which was not considered before. In general, the energy expended by a sensor node is a function of constellation size. *Constellation size* represents the number of bits that can be transmitted in a given modulation symbol. Further in cases where the nodes cooper-

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