CHAPTER 9

Cooperative Systems for Sensor Networks

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9.1. Introduction

On wireless fading channel transmission, multi-antenna techniques (MIMO) have been shown to have the potential of greatly increasing the channel capacity [1]. Under the same Signal to Noise Ratio (SNR), MIMO systems can be far more reliable than Single-Input Single-Output (SISO) systems and they need less transmission energy for the same Bit Error Rate (BER) requirement. The MIMO energy-efficiency transmission scheme is particularly useful for Wireless Sensor Network (WSN) where each wireless node has to operate without battery replacement for a long time and energy consumption is the most important constraint. However, the direct application of multi-antenna technique to WSN is impractical due to the limited physical size of sensor nodes which can typically support a single antenna. Fortunately, some individual sensor nodes can cooperate for the transmission and the reception in order to set up a cooperative-MIMO scheme. Power minimization strategies in different layers of the protocol stack of cooperative network have motivated intensive research interests in recent years. In particular, energy-efficient design in various aspects of communication systems, such as modulation [2], coding [3], and routing [4].

Cooperative MIMO (C-MIMO) scheme can deploy the energy-efficiency of MIMO technique which plays an important role in long range transmission where transmit energy is dominant in the total consumption. In various applications, such as area surveillance for military operations, monitoring of agriculture related farm duties or intelligent transportation systems, middle and long range transmissions are indeed often required because of the large covered area of the wireless sensor networks. Nonetheless, C-MIMO scheme requires extra energy for the local cooperative data exchange, extra circuit consumption of the cooperative nodes, and extra energy of the more complex digital processing [5]. Therefore, it is not practical for short range transmission in which circuit energy consumption is dominant in the total energy consumption. The energy-efficiency of C-MIMO scheme versus non multi-hop SISO scheme was shown [6] for various values of transmission distance. The result is limited to the case of 2 antennas using Alamouti Space-Time Block Code (STBC) [7]. Depending on the energy model of [2], an illustrative example of this cooperative principle to MIMO systems with 3 to 8 antennas using Tarokh orthogonal STBC [8] will be presented, in which an energy-efficient antenna subset selection that depends on the cluster load is performed followed by an iterative rate selection algorithm that selects the transmission rate for uniform cluster energy consumption.

![Figure 9.1. Cooperative communication](image-url)
9.2. Cooperative MIMO and Space-Time Block Codes for Wireless Sensor Networks

9.2.1. Cooperative MIMO Scheme

To reduce the transmit energy in long distance (d) transmission between source node S and destination node D we opt cooperative MIMO communications instead of SISO transmission. On the transmit side, node S can cooperate with its neighbors and exchange its data (the distance between cooperating nodes dc << d as shown in Figure 9.1). MIMO techniques (STBC, STTC, Spatial Multiplexing ...) are then employed to transmit their data simultaneously to the destination node (or multi-destination cooperative nodes) like a multi-antenna diversity system (each cooperative node plays a role of one antenna of MIMO system). In the reception side the cooperative neighbors of destination node D receive the MIMO modulated symbols and respectively re-transmit them to the destination node D for joint MIMO signals combination.

However, if the C-MIMO scheme can exploit the energy-efficient transmission of MIMO technique, the local data transmission at TX and RX sides of C-MIMO scheme costs an extra transmission energy due to the extra circuit consumption of the cooperative nodes and the more complex MIMO digital signal processing. For short range transmission, this extra energy consumption can be greater than the transmission energy saved by using C-MIMO (or MISO) instead of SISO technique. Another C-MIMO trade-off is the delay of the cooperative local data transmission. Nevertheless, transmission delay is a less important design criterion than energy consumption and in comparison to multi-hop technique.

9.2.2. Application of STBC

Among MIMO diversity coding techniques (Space-Time Block or Trellis Codes, Spatial Multiplexing), STBC is the most practical for WSN [9]. The simplicity of ST coding and combination is very interesting due to the calculation limitation of the sensor node (decoding algorithm of STBC is only based on linear processing).

For systems with 2 transmission antennas, the diversity Alamouti code [7] is used, whereas the orthogonal STBC developed by Tarokh for complex symbol signal [8] is used for systems with 3 to 8 transmission antennas.

Due to the diversity of transmission and reception, BER performance of MIMO STBC can easily outperform SISO system under the same Signal-to-Noise Ratio $E_b/N_0$. In other words, with the same BER requirement, MIMO system requires less energy for the transmission than SISO system.

9.3. Energy Consumption in Cooperative Communication

Cooperative communication is a hybrid type of communication which includes both direct transmission and MIMO transmission.

9.3.1. Energy Consumption in Direct Communications

The total power consumption of typical RF transmission system consists of two components: the transmission power $P_{\text{out}}$ of the power amplifier and the circuit power $P_{\text{circuit}}$ of all RF circuit blocks. $P_{\text{out}}$ is dependent on the transmit power $P_{\text{out}}$. If the channel is 1-law path loss, it can be calculated as follows

$$P_{\text{out}} = \overline{E_b} R_b d^l K$$  \hspace{1cm} (9.1)

where $K$ is a constant depends upon transmit and receive antenna gains, carrier frequency, link margin and power spectral density (PSD) of the total effective noise at receiver input [2], $\overline{E_b}$ is average received bit energy, $R_b$ is transmission rate in bits per second, ’$d$’ is the transmission distance and ’$l$’ is the path loss exponent [10] $P_{\text{out}}$ can be approximated as