Chapter 11

Cooperative Diversity Techniques for Energy Efficient Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks can be used for a multitude of applications, but they all have in common that they need to send their collected data to some central processing node. If the sensors are located at a long distance from a processing node, the transmission might need the combined transmitter power of several sensors. In this chapter, the authors investigate the use of various cooperative diversity techniques in wireless sensor networks to increase the transmission range, minimize power consumption, and maximize network lifetime.

INTRODUCTION

Wireless Sensor Networks (WSN) have been attracting great attention recently. They are relatively low cost to be deployed and to be used in many promising applications, such as biomedical sensor monitoring (e.g., cardiac patient monitoring), habitat monitoring (e.g., animal tracking), weather monitoring (temperature, humidity, etc.), seismic sensing, environment preservation and natural disaster detection/monitoring (e.g., flooding and fire) (Lewis, 2004; Tubaishat & Madria, 2003; Stankovic, Abdelzaher, Sha & Hou, 2003; Akyildiz, Sankarasubramaniam & Cayirci, 2002; Rashid-Farrokhi, Tassiulas & Liu, 1998).

An important design feature of WSN is the low energy consumption of each individual transmitting node and thereby also of the total sensor network energy consumption. The 'bottleneck' in the WSN, from an energy point of view, is when

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the nodes need to communicate with a distant base station to forward the collected data. Since the distance to the base station usually is several magnitudes greater than the distance between the individual nodes within the network, each node would need a much more powerful transmitter than necessary considering the distances within the WSN (Singh & Prasanna, 2003). One technique for achieving this is to use cooperative space-time processing to combine the transmitting power of all the nodes into a distributed non-uniform antenna array. For example in (Cui, Goldsmith, & Bahai, 2004) the energy efficiency using cooperative multiple-input multiple-output (MIMO) system was investigated and compared with the results obtained by the reference single-input single-output (SISO) system.

The WSN applications analyzed in this chapter have a topology where a large number of wireless sensor nodes are spread out over a large or small geographic area (e.g., disaster regions, indoor factory, large sports event areas, etc.). In this topology, an inefficient use of bandwidth and transmitter power resources is resulted if each wireless sensor is transmitting its measurement data to the base station (processing central). In this case, each sensor node would have to be assigned its own frequency channel and, if the base station is located a long distance from the sensor nodes, it would also demand a higher than average sensor node transmitter power. By using a coordinating cluster head, for each cluster of wireless sensor nodes, we can instead use the combined transmitter power of the node cluster through the use of beamforming to increase the transmitter-receiver separation and/or to improve the signal-to-noise ratio (SNR) of the communication link. Another advantage of using this cooperative transmission is that we can exert power control to minimize the power consumption of each individual sensor node, and thus maximizing network lifetime. In addition, in a cooperative network the measurement data could be sent by using time division multiplexing (TDM) instead of frequency division multiplexing (FDM) which improves the overall bandwidth efficiency of the system.

The spatial properties of wireless communication channels are extremely important in determining the performance of the systems. Thus, there has been great interest in the application of classical beamforming technique and the recently popular modern multiantenna diversity techniques, using various forms of array systems, since they can offer a broad range of ways and benefits to improve wireless systems performance. For instance, diversity techniques such as multiple-input single-output (MISO), single-input multiple-output (SIMO) and multiple-input multiple-output (MIMO) can enhance the capacity, coverage, quality and energy efficiency of wireless communication systems. These spatial diversity techniques can be exploited to improve the energy efficiency since it is one of the key requirements in many WSN applications. This is particularly crucial for WSN deployed in inaccessible or disaster environments in which battery recharging and replacement is not a viable option. Thus, in this chapter we first propose to use a cooperative beamforming approach in wireless sensor networks to increase the transmission range, minimize power consumption and maximize network lifetime. This will be of particular interest for outdoor applications, especially when monitoring remote areas using aerial vehicle, such as a High Altitude Platform (HAP) or Unmanned Aerial Vehicle (UAV), as a platform for the data collecting base station. We will investigate how the required transmitter power of each sensor node is affected by the number of cooperating transmission nodes in the network. In addition, we present a comparison in the use of beamforming with the different forms of modern multiantenna diversity techniques (MISO, SIMO and MIMO) for the same purpose of achieving a longer transmission distance (or range) while maintaining a low energy consumption. The required node transmit power is calculated and comparisons are performed for different distances from the base station and various propagation environments by varying the

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