Receiver Diversity for Distributed Detection in Wireless Sensor Networks

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ABSTRACT

In this paper, parallel distributed detection in wireless sensor network (WSN) is considered where the sensors process the observations to make local decisions and send these decisions to a central device called fusion center. Receiver diversity technique is proposed here for the distributed detection system in order to enhance the system reliability by improving the detection performance. The fusion center is assumed to be multiple antennas device in order to imply the idea of receiver diversity. Different combining schemes at the fusion center side are used to reduce the fading effects in the case of receiver diversity. Transmitter diversity is also considered in this paper. Cooperative sensors are assumed in order to obtain Alamouti space time block codes. Optimal and sub-optimal fusion rules are derived for each case study. Simulation results show the performance improvement obtained as compared to the conventional distributed detection system in which no diversity is used.

Keywords: Distributed Detection, Diversity, Fusion Center, Fusion Rule, Wireless Sensor Network

1. INTRODUCTION

The main goal in a decentralized detection system is to detect the event of interest as accurate as possible while efficiently using of network resources, such as; spectral bandwidth and power.

Recently, WSNs have attracted much attention and interest and it became an active research area (Hall & Llinas, 2001; Swami, Zhao, Hong, & Tong, 2007; Varshney, 1997). WSNs have wide applications in military surveillance, security, monitoring environment, and cognitive radio networks due to their high flexibility, enhanced surveillance coverage, mobility, and cost effectiveness (Swami et al., 2007; Varshney, 1997). Generally speaking, a WSN consists of a large number of low-cost and low-power sensors, which are deployed in an environment to collect observations and preprocess them to obtain local decisions. WSNs have different architectures depending on the communications

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between sensors themselves and between the sensors and fusion center. Among various types of WSNs, the decentralized parallel WSN has attracted many of authors because each sensor node has a limited communication capability that allows it to communicate with other sensor nodes and/or the fusion center via a wireless channel (Thomopoulos, Viswanathan, & Bougoulias, 1987; Kam, Zhu, & Gray, 1992; Nageswara, 1993; Rago, Willett, & Bar-Shalom, 1996; Drakopoulos & Lee, 1991).

Tenny and Sandell (1981) formed the Baysian detection problem for multiple sensor system and derived the optimal fusion rules for the individual sensors. The fusion center rule that combines the local decisions from sensors while minimizing the overall error probability was derived by Chair and Varshney (1986). The optimization of decentralized detection problem, which can be realized by a large number of independent identical sensor nodes, was considered by Tsitsiklis (1988). He has shown that it is optimal to have all sensors perform an identical likelihood ratio test in the case of two hypotheses testing problem. He has derived the fusion rule where sensors transmit a finite-valued function of their observations to a fusion center.

Some sensing techniques have been proposed to enhance the distributed detection system performance, such as; censoring sensors (Rago, Willett, & Bar-Shalom, 1996), and consultation schemes (Thomopoulos & Okello, 1992; Al-Ibrahim & Al-Ababneh, 1998). The impact of sensor nodes density on system performance was studied by Chamberland and Veeravalli (2004). They made asymptotic analysis for two cases using the large deviation theorem results: One case is when the signal is deterministic under each hypothesis, and the other one is when the signal is a correlated Gaussian process under each hypothesis. They proposed a framework that offers a guideline to how dense a sensor network should be, how much power each node should use, and how far apart adjacent nodes should be. Cooperative WSNs have been studied more recently to enhance system reliability and optimize the consumed power (Tarasak, Minn, & Bhargava, 2005). Virtual space-time coding (STC) for WSNs is studied extensively in the literature (Cui, Goldsmith, & Bahai, 2004; Laneman & Wornell, 2003; Wang, Yao, & Giannakis, 2006).

The WSN with non-ideal channels is considered in the literature. The fusion rules of decisions sent through wireless Rayleigh fading channel is considered and the fusion rules is derived in Niu, Chen, and Varshney (2006). The performance limits of WSNs have been studied in Cheng, Chen, and Varshney (2006). Vosoughi and Ahmadi (2009) assumed cooperative sensor pairs to send their local decisions as Alamouti space time block codes (Alamouti, 1998).

One of the main challenges factors for the communication systems is the fading effects that can degrade the system performance. In this paper, the distributed detection system that incorporates the receiver diversity concept is proposed and the corresponding fusion rules are derived. Incorporating this concept is an appropriate solution for the communication systems where the fading takes place and affects the signal. Thus, diversity concept can improve the detection performance of the distributed detection systems. Moreover, the results obtained by Vosoughi and Ahmadi (2009) are not accurate and more accurate results are presented in this paper.

The rest of the paper is organized as follows. In Section 2, the hypothesis testing problem is discussed and three layer system model is presented as well. In Section 3, the fusion center layer is discussed in more details. Optimal and suboptimal fusion rules for different schemes of receiver diversity are derived adopting Neyman- Pearson criterion (Neyman, & Pearson, 1933; Van Trees, 1986). Simulation results of the distributed detection system using the diversity schemes are presented in Section 4 and compared with their counterparts for the conventional case. These results are also compared with the results of a system where cooperative sensors are assumed in order to get space time block codes. Finally, the paper is concluded in Section 5.
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