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Decision fusion in mobile wireless sensor networks using cooperative multiple symbol differential space time coding



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ABSTRACT

In this article, we propose a cooperative scheme for differential space-time codes (DSTCs) to be applied for mobile wireless sensor networks (WSNs) in order to mitigate multipath fading effect. We assume that sensors make independent local decisions about the existing hypothesis and report their decisions to a fusion center, where the final decision is made. Sensors are divided into groups with two sensors each, where sensors in each pair cooperate to send their decisions as a DSTC. Differential modulation scheme, which does not require knowledge of the instantaneous fading gains, is considered to avoid the channel estimation overhead at the cooperating sensors and the fusion center. Channels between sensors and the fusion center are assumed independent identically distributed (*i.i.d.*) Rayleigh fading channels. Moreover, Jakes-Clarks' channel model is considered to model the mobility of sensors and/or the fusion center. Since the complexity of the optimal fusion rule grows up exponentially with the observation interval, suboptimal fusion rules are derived and discussed. Finally, simulation results of the proposed cooperative scheme are provided and the detection capabilities of the derived decision fusion rules are compared.

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1. Introduction

Since WSNs are broadly applicable in many modern applications, i.e., military, internet of things (IoT), cloud computing, mobile computing, security, industry and medical, they have attracted many researchers in the literature [1–7]. Consequently, the problem of fusing many sensory decisions has been raised in different fields, and the essential need for introducing adequate sensing and fusion rules has been realized [8–31]. Decision fusion rules for WSNs have been derived taking into account the effect of fading channels [8–14]. In addition, different ways to resist attenuation caused by the wireless transmission have been introduced in the literature. In this context, different diversity schemes have been proposed to enhance the detection performance of the distributed detection systems assuming multiple antennas at the fusion center side [15–17]. However, using multiple antennas is not recommended for WSNs due to restrictions on the cost and size of sensors, so cooperative transmissions have been proposed [18–22]. Furthermore, some recent work on WSNs considered the problem of vehicular network where sensors and/or the fusion

center are moving [23–25]. Decision fusion rules have been derived in [25] for mobile WSNs, where multiple symbol differential phase shift keying (MSDPSK) was considered. In addition, the need of efficient image fusion techniques has been realized where they help to obtain more informative images. Image fusion is applicable in many real time fields, i.e., medical imaging, computer vision systems and remote sensing [26–31]. Since WSNs are subject to energy and bandwidth constraints, efficient routing protocols have been addressed in [32–40] to improve the quality of service (QoS) and increase the coverage area for the network. Moreover, compressive sensing has been proposed recently to reduce energy consumption, and thus increase the life time of sensor nodes [41].

However, non-coherent differential modulation is sometimes preferred for signalling over time varying fading channels because it does not require instantaneous channel state information (CSI) for detection. In this context, DSTBCs were introduced in the literature for point to point communication [42,43]. Furthermore, multiple symbol differential detection for space time block codes (STBCs) was proposed to compensate the performance loss caused by non-coherent detection [44]. In [44], authors assumed slow Rayleigh fading channel, whereas fast Rayleigh fading channel was considered in [45,46].

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In this paper, we propose a cooperative scheme used by sensors to form multiple symbol DSTC (MSDSTC). Moreover, the optimal decision fusion rule for an observation interval of T blocks is derived. Due to the complexity of the optimal fusion rule, less complex suboptimal rules are derived and discussed. Rayleigh fading channel is assumed, where channels are modeled using Jakes-Clarkes' model in order to reflect the mobility of sensors and/or the fusion center [25].

The rest of the paper is organized as following. In Section 2, system model and problem formulation are discussed. In Section 3, the optimal fusion rule is derived and discussed while suboptimal fusion rules are derived and discussed in Section 4. Furthermore, performance analysis of fusion rules is discussed in Section 5. Section 6 shows the simulation results of the decision fusion system using the proposed cooperative MSDSTC. Finally, conclusion and future work are provided in Section 7.

2. System model and problem formulation

In this section, the problem formulation and the three layer system model are introduced.

2.1. Hypothesis testing problem

The multi-hypothesis testing problem is considered in this paper where N sensors are used to inquire about which one of the M possible hypotheses is present. Observations of sensors are assumed *i.i.d* conditioned on each hypothesis. Although wireless sensor networks could be implemented in many topologies, i.e., serial topology, parallel topology, hierarchal topology, we considered decentralized parallel topology. In decentralized parallel architecture, sensor can process observations to obtain a local decision which is transmitted to a fusion center.

2.2. System model

In this section, a three layer model is provided and each layer is discussed separately [8]. In order to obtain STBCs, N sensors are grouped into pairs where sensors in each pair cooperate to act like a two-antenna transmitter [19]. To clarify the cooperative transmission, we are going to explain the idea for one group

(two sensors) because other groups manage the transmission in the same way. Assuming that each sensor has the last encoded space time block code, the MSDSTCs can be simply generated. Then, sensors in each pair cooperate to send these block codes to the fusion center where the global decision is made. Fig. 1 below shows the considered network topology and the proposed cooperative MSDSTC transmission scheme.

2.2.1. Local sensor layer

A total number of N sensors are deployed in the region of interest (RoI) where each sensor makes its own decision about the most possible existing hypothesis $\mathcal{H} \triangleq \{H_m, m \in \mathcal{M}\}$, where $\mathcal{M} = \{0, 1, \dots, M-1\}$. The a priori probability of hypothesis H_m is denoted by $P(H_m)$. Without loss of generality, we assume that the modulation order equals the total number of possible hypotheses M . After making the decision, it is modulated using M -ary PSK, i.e., $u_i \in \{w_m \triangleq 1/\sqrt{2}e^{j2\pi m/M} | m \in \mathcal{M}\}$. The modulated decision is saved in the sensor's memory, and transmitted to its neighbor in the pair. Each sensor in the pair saves both decisions in its memory; its own decision and the neighbor's decision. These two decisions will be used later for differential encoding. We assume that each sensor knows its neighbor in advance. However, many algorithms have been proposed in [47], and references within, to discover neighbors. Binary hypothesis testing problem (BHTP), i.e., $M = 2$, has become recently a very important case study because of its being an essential part of cognitive radio networks [48,49]. For BHTP, the performance of the i -th sensor is characterized by its detection probability $P_{d,i}$ and false alarm probability $P_{fa,i}$.

$$P_{fa,i} = P(u_i = 1 | H_0) \quad (1-a)$$

$$P_{d,i} = P(u_i = 1 | H_1) \quad (1-b)$$

The differential encoding scheme used in this paper is similar to that one used in [44,45] for point to point communication systems. To implement this idea in WSNs, the last encoded decisions $c_{l,k-1}^{(1)}$ and $c_{l,k-1}^{(2)}$ are assumed saved in the memory of both cooperating sensors. Furthermore, the channel between the cooperating sensors is assumed an error free channel. Once the cooperating sensor receives the local decision of its neighbor, the decision is decoded and the entries of the matrix code are calculated, i.e., $c_{l,k}^{(1)}$ and $c_{l,k}^{(2)}$

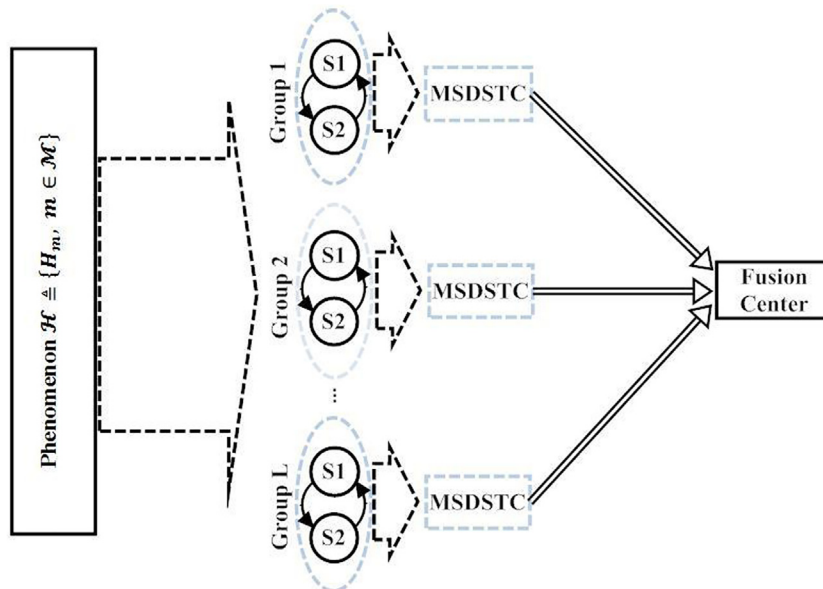


Fig. 1. Network topology and the proposed cooperative transmission scheme.

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