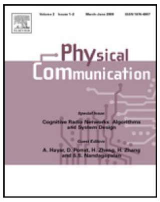
Physical Communication 26 (2018) 149–155

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom



Full length article

A low-interference decision-gathering scheme for critical event detection in clustered wireless sensor network

Saud Althunibat [a,*], Ala Khalifeh [b], Raed Mesleh [b]

[a] Communications Engineering Department, Faculty of Engineering, Al-Hussein Bin Talal University, Ma'an, Jordan
[b] German Jordanian University, Communications Engineering Department, School of Computer Engineering and Information Technology, Amman Madaba Street, P.O. Box 35247, Amman 11180, Jordan

ARTICLE INFO

Article history:
Received 23 July 2017
Received in revised form 17 November 2017
Accepted 15 December 2017
Available online 20 December 2017

Keywords:
Wireless sensor networks
Target detection
Co-channel interference
Decision gathering

ABSTRACT

This paper presents a new decision-gathering scheme that aims at detecting a critical event in an Area of Interests (AoI), where a wireless sensor network is deployed in a group of clusters. The proposed scheme assigns a single time slot for each cluster, where all cluster members simultaneously report their binary decisions to the cluster head on that time slot. As the cluster head is interested in the sum of the binary decisions (not the exact binary decisions), the performance loss due to the concurrent transmission is insignificant compared to the co-channel interference induced from other clusters based on conventional schemes. The main advantage of the proposed scheme is that it avoids the co-channel interference between different clusters and assures minimal delay in detecting the critical event, which is very crucial in many security related applications and scenarios. Both simulation and mathematical analysis of the overall decision-error probability of the proposed scheme are carried out, which demonstrate the effectiveness of the proposed scheme.

1. Introduction

In the advent of new technologies such as the Internet of Things (IoT), many new applications have evolved in different domains. The utilization of Wireless Sensor Networks (WSN) for remote monitoring and boarder security is an emerging example of such technologies [1]. WSN consists of a group of nodes, where each node has a sensor that can be used to detect the event of interests and a processor that extracts the captured data and analyzes its criticality. If a critical event is detected, an alert message is sent via a wireless communication module to a destination node for decision making. Ordinarily, wireless sensors are grouped in the forms of clusters, where a Cluster Head (CH) node is chosen for the purpose of inter-cluster communication [2]. This scheme not only saves energy, but it also reduces transmission errors and delay [2,3]. This is because cluster nodes have to send their captured data to the CH, which in turns relay it to the other CHs, until reaching the final destination node. If, for instance, there exists no clustering hierarchy, all nodes have to send their data to other remote nodes, which consume battery resources and cause significant interference and packet loss.

In the literature, different approaches have been proposed to organize both the inter-and intra-cluster communication. The main objective is to find mechanisms to coordinate between the nodes in order to minimize the interference among them. One approach, as in IEEE 802.15.4 standard, utilizes time division multiple access scheme to organize the communication among different nodes within the cluster [4]. However, the protocol does not consider the coordination with other clusters and requires proper time synchronization. Hence, intra-cluster communication will be prone to interference from the other clusters, which may affect the transmission quality. In [5], based on a prior knowledge of the interference impact at the intended receiver, a distributive algorithm for controlling the transmit power is proposed, which is shown to reduce the interference impact on the overall performance of the WSN. Another approach is to manage the network topology for the purpose of mitigating the co-channel interference among nodes as in [6]. Using directional antennas as smart solution to overcome the co-channel interference in WSNs is presented in [7]. Other schemes that include channel hooping [8] and interference-aware scheduling [9], aim at reducing the co-channel interference by limiting the number of concurrent transmissions on the same channel.

The optimal decision fusion rule is referred to as *Chair–Varshney* (CV) rule [10]. It includes a comparison of the weighted sum of the received binary decision from all sensors to an optimized threshold. However, the sensor weights used in CV rule require a knowledge of the local performance of each sensor. In case that the prior knowledge is not available at the CH, the optimal

---

[*] Corresponding author.
E-mail addresses: saud.althunibat@ahu.edu.jo (S. Althunibat), ala.khalifeh@gju.edu.jo (A. Khalifeh), raed.mesleh@gju.edu.jo (R. Mesleh).

https://doi.org/10.1016/j.phycom.2017.12.010
1874-4907/

decision is the *Counting Rule* (CR) [11], where binary decisions are summed (without weighting) and compared to a threshold. However, compared to CV rule, CR causes a significant degradation in the overall performance [12]. Several works attempt to enhance the performance. For example, neighboring sensors exchange their decisions and correct them before making a global decision as reported in [13]. Alternatively, [14] proposes to optimize the detection threshold. Other works have focused on the energy efficiency of clustered WSNs. For instance, the overall performance and the energy consumption have been optimized in large-scale surveillance WSNs by proposing efficient decision and fusion strategies in [15]. Also, in [16], a trade-off between the decision reliability and the energy efficiency is suggested by adapting the channel coding based on the channel condition and inter-node distance. A stochastic geometry approach is followed in [17] for deriving the optimal fusion rule at the cluster level, which has been shown to approach the CV rule performance. Finally, a combination of clustering, trail generation, and sleep scheduling is proposed in [18] in order to prolong the WSN lifetime.

In this work, a decision-gathering scheme for critical event detection is proposed, in which orthogonal time slots are allocated to each CH in the network. As such, intra-cluster interference is entirely avoided. However, during the cluster time slot, all the nodes within the cluster are allowed to transmit their binary decision messages associated with the detection of a critical event to the CH. Accordingly, inter-channel interference will occur among the nodes within each cluster. Yet, it is shown that the induced interference will not adversely affect the sensors functionality on reporting the event and will assure minimal notification time. This is because a binary decision of the detection of a critical event is targeted. A mathematical derivation for the upper bound of the average decision error rate at the CH is deduced and validated through Monte Carlo simulation results.

The decision fusion rule proposed in [19] is related to our proposal. In [19], the decision rule, called *decode then fuse*, implies that the received decisions are first decoded and then passed to the fusion process. The same procedure is followed in our proposed approach. However, our scheme is a decision-gathering scheme proposed for cluster-based WSNs, and all sensors within a cluster are allowed to report simultaneously. The main aim of the proposed scheme is to avoid the co-channel interference induced from other clusters. Moreover, as mentioned earlier, a mathematical derivation of the decision error probability is presented in our work, which has not been shown in [19].

With reference to existing literature, the contributions of this work are three folds:

1. A novel decision gathering scheme that allows the cluster members to share the same time slot is proposed.
2. An upper bound formula for the decision error rate of the proposed scheme is derived and discussed.
3. Monte Carlo simulations are provided to corroborate conducted analysis and to study the influence of different system parameters.

The remaining of the paper is organized as follows: Section 2 introduces the proposed system model. Section 3 describes the data gathering process and demonstrates the mathematical analysis. Section 4 presents the simulation results and discusses them. Finally, Section 5 concludes the paper.

2. System model

A WSN of C clusters is considered in this study. Each cluster includes $N+1$ nodes, one of which acts as a CH while other nodes are cluster members [20]. All cluster members are assumed to have a single transmit antenna, while the CH is equipped with N_r receive antennas. All nodes are in charge of monitoring an intended target and monitored statuses are periodically reported to the CH using binary decision ($d_n = \{0, 1\}$, $n = 1, 2, \ldots, N$), with $d_n = 0$ denoting that the target is absent, and $d_n = 1$ indicates that the target is present. As we focus on the reporting process, the local sensing performance is identical for all nodes. Binary phase shift keying (BPSK) modulation is used at each node to modulate the obtained decision and transmit it towards the CH. It is assumed that for the whole WSN, only a single frequency channel is dedicated for the decision gathering process [21,22].

At the CH level, the detected decisions ($b'_n = \{0, 1\}$, $n = 1, 2, \ldots, N$) are summed up in order to make a global cluster decision. Specifically, the sum of the detected decisions, denoted by S'_c ($c = 1, 2, \ldots, C$), is compared to a pre-determined threshold λ. If $S'_c < \lambda$, the CH decides that the target is absent [23]. Otherwise, the target is present. Denoting the cluster decision by D'_c ($c = 1, 2, \ldots, C$), it can be mathematically formulated as

$$D'_c = \begin{cases} 1, & \text{if } S'_c \geq \lambda \\ 0, & \text{if } S'_c < \lambda, \end{cases} \tag{1}$$

where $S'_c = \sum_{n=1}^{N} b'_n$. Notice that the CH may make an incorrect decision due to the probable detection error in the received decisions. Thus, aiming at evaluating the cluster decision, we define the correct cluster decision D_c as

$$D_c = \begin{cases} 1, & \text{if } S_c \geq \lambda \\ 0, & \text{if } S_c < \lambda, \end{cases} \tag{2}$$

where $S_c = \sum_{n=1}^{N} d_n$.

Consequently, the decision gathering process can be assessed by the average *decision error probability* (DER), denoted by η and given by

$$\eta = \Pr\left[D'_c \neq D_c\right]. \tag{3}$$

3. Decision gathering scheme

As discussed earlier, conventional gathering schemes in clustered WSNs suffer from the presence of co-channel interference. In this work, a different gathering scheme is considered that eliminates co-channel interference between clusters and allows its presence within each cluster. In particular, orthogonal time slots are assigned to the clusters and the nodes in each cluster transmit their decisions to the corresponding CH at that specific time slot. Concurrent transmission within the same cluster will degrade the detection of the individual decisions of the cluster members. However, based on the considered model, the CH is interested only in the sum of the individual decisions and not in their actual values. As such, the performance loss due to the proposed scheme is minimal and can be ignored as will be shown in the sequel.

To accomplish the proposed scheme, the frequency channel is divided into C time slots, where each time slot is allocated for gathering the local decisions of a single cluster. Considering a single cluster, the transmission vector of all the cluster members is formulated as $\mathbf{X} = [x_1, x_2, \ldots, x_N]$, where x_n represents the modulated symbol of the binary decision of the nth node. As BPSK is used, $x_n = +1$ if $d_n = 1$, or $x_n = -1$ if $d_n = 0$. Accordingly, the received vector at the CH, denoted by $\mathbf{Y}$, is expressed as

$$\mathbf{Y} = \mathbf{H}\mathbf{X} + \mathbf{w} \tag{4}$$

where $\mathbf{H} = \begin{bmatrix} \mathbf{h_1} & \mathbf{h_2} & \cdots & \mathbf{h_N} \end{bmatrix}$ denotes the channel matrix between the N nodes within a cluster and the N_r receive antennas of the CH with $\mathbf{h}_n$ being the channel vector between the nth node and the CH with each element being modeled as a complex Gaussian random variable with zero mean and unit variance (*i.e.*, $h_i \sim \mathcal{CN}(0, 1)$) and