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LETTER

A collaborative event detection scheme using fuzzy logic in clustered wireless sensor networks

Thuc Kieu-Xuan, Insoo Koo*

School of Electrical Engineering, University of Ulsan Mugeo 2-dong, Nam-gu, Ulsan 680-749, Republic of Korea

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ABSTRACT

Event detection is a critical issue in wireless sensor networks. In this letter, a novel collaborative event detection scheme using fuzzy logic in clustered wireless sensor networks is proposed. Unlike previous research in which every sensor node or cluster is treated equally during the decision making process, in this letter we evaluate the credibility of clusters by using fuzzy logic and take them into account when the final decision is made at the fusion center. Simulation results show that the proposed scheme can provide better accuracy than conventional approaches.

1. Introduction

In recent years, wireless sensor networks (WSNs) have been used in a wide variety of applications including industrial control, home automation, security and military sensing, health monitoring, intelligent agriculture and environmental sensing. In many applications of WSN, event detection is one of the critical issues. Distributed event detection in WSNs is the process of observing and evaluating an event using multiple sensor nodes, in which the global decision is made by fusing local decisions from nodes to increase event detection accuracy and reduce communication overhead and risk of network node failures. There have been many papers on this field. In Refs. [1,2], optimal fusion rules have been determined under a conditional independence assumption. Making global decision with correlated observations has been handled in Refs. [3,4]. Most of these papers are based on the assumption that either the signal-to-noise ratio (SNR) of local sensor nodes or their performance, namely detection probability and false alarm probability, are known to the fusion center. However, it is very difficult for local sensor nodes to estimate these parameters since they are time-varying. Even if the local sensor node can estimate these parameters in real-time, it will be very expensive to transmit them to the fusion center, especially for WSNs with very limited energy and bandwidth. Consequently, all local sensor nodes usually transmit only their local binary decisions to the fusion center. The fusion center is forced to treat every sensor node equally [5,6]. However, the received signal decays very fast as the distance from the event increases. As a result, only a small fraction of the sensor nodes can detect the signal from the event and most sensors' measurements are just pure noise. Since local decisions from these nodes do not convey much information about the event, the detection performance will be degraded if the fusion center treats every sensor node equally.

In addition, organizing a collection of sensor nodes into single- or multi-hop clusters is a common approach to gathering and processing information in WSNs because WSNs usually consist of a large number of energy-constrained sensor nodes. The clustering approach can minimize communication cost such that various clustering algorithms for sensor networks have been proposed and analyzed [7–9]. In Ref. [10], Tian and Coyle investigated an optimal decision at cluster heads by determining the weights in the optimal weighted order static filter for cluster heads in a multi-hop clusters. However, the final decision fusion rule and global detection performance were not mentioned.

In this letter, we propose an event detection scheme for clustered WSNs that utilizes fuzzy logic to evaluate the credibility of clusters. Compared with Bayesian theory, fuzzy logic feels closer to natural decision making logic of human. Its capacity to assign uncertainty or ignorance to propositions is a powerful tool for dealing with a large range of problems, especially in the case of fast changing RF environment of WSNs. Therefore, fuzzy logic can supply a useful method to evaluate the credibility of clusters. In our proposal, a fuzzy logic rule-based system is exploited to evaluate the credibility of each clusters. At the fusion center, instead of treating all clusters equally, the credibility of each cluster is taken into account when the fusion center makes the final decision. By exploit-

* Corresponding author. Tel.: +82 52 259 1249; fax: +82 52 259 1686.
E-mail address: iskoo@ulsan.ac.kr (K. Insoo).

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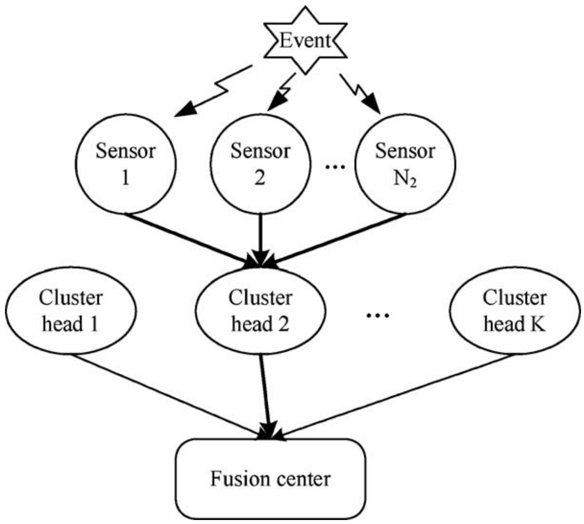

Fig. 1. The structure of clustered wireless sensor network.

ing this aspect, the event detection algorithm can maximize the detection accuracy.

The remainder of this paper is organized as follows. The system model is described in Section 2. In Section 3, we propose a collaborative event detection scheme using fuzzy comprehensive credibility evaluation. The simulation results are drawn and analyzed in Section 4. Finally, in Section 5, we present our conclusion.

2. System description

We assume that the clustering has been done by the upper layers. Sensor nodes that are close to each other will form a cluster and each cluster has its own cluster head, which has more powerful computation and communication capabilities than a sensor node and serves as a local fusion center. Each cluster is in charge of the surveillance of a sub-region of the whole region of interest. Therefore, instead of transmitting data to a faraway decision fusion center, sensor nodes will send local decisions to their corresponding cluster head. At the cluster head of a sub-region, the decision about event presence/absence within this sub-region will be made based on local decisions transmitted from sensor nodes within this cluster. The decisions from all cluster heads will then be transmitted to the fusion center along with their detection performance. The fusion center will make the final decision with consideration of the credibility of clusters. The structure of clustered WSN for event detection is illustrated in Fig. 1.

3. Proposed collaborative event detection scheme

The proposed collaborative event detection scheme can be modeled in three stages: (1) local detection at sensor nodes; (2) optimal decision fusion at cluster heads; and (3) fuzzy decision fusion at the fusion center.

3.1. Local detection at sensor nodes

We assume that noises at local sensor nodes are *i.i.d* and follow the standard Gaussian distribution with zero mean and unit variance:

$$n_i \sim N(0, 1). \tag{1}$$

For a local sensor node i, the binary hypothesis testing problem is:

$$\begin{aligned} H_1 &: s_i = a_i + n_i, \\ H_0 &: s_i = n_i, \end{aligned} \tag{2}$$

where H_0 and H_1 correspond to hypotheses of absence and presence of the event respectively, s_i is the received signal at the sensor i, and a_i is the amplitude of the signal that is emitted by the event and is received at sensor node i. We assume that the signal power emitted by the event decays as the distance from the event increases, and the model of signal power attenuation is:

$$a_i = \sqrt{\frac{P_0}{1 + d_i^{\alpha}}}, \tag{3}$$

where P_0 is the signal power emitted by the event at distance zero, d_i is the distance between the event and the sensor node i, and α is the signal decay exponent and takes value from 2 to 3.

The local detection decision of the node i is made as follows:

$$H_i = \begin{cases} H_1 : & s_i \geq \tau_i \\ H_0 : & \text{otherwise} \end{cases}, \tag{4}$$

where τ_i is the decision threshold of the i-th node. Assuming that all the sensor nodes use the identical threshold τ to make a local decision, we have the probability of detection and identical probability of false alarm [5] as follows:

$$p_{d_i} = \int_{\tau}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-(t-a_i)^2/2} dt = Q(\tau - a_i), \tag{5}$$

$$p_{fa} = \int_{\tau}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt = Q(\tau), \tag{6}$$

where $Q(.)$ is the complementary Gaussian cumulative distribution function. These parameters will be calculated and used in the next stage.

3.2. Optimal decision fusion at cluster heads

We denote the binary decision from local sensor node i of the j-th cluster as $I_{j,i}$, $1 \leq j \leq K$. $I_{j,i}$ becomes 1 if there is a detection; otherwise, it becomes 0. At the head of the j-th cluster, a cluster decision is made based on the N_j local decisions $I_{j,1}, I_{j,2}, \cdots, I_{j,N_j}$ from N_j local sensor nodes of this cluster. We denote I_j as the number of 1s out of these local decisions:

$$I_j = \sum_{i=1}^{N_j} I_{j,i}. \tag{7}$$

Let p be the prior probability, $p = P[H = H1]$. With the assumption that all local sensor nodes of a cluster have the same *SNR*, we have the same local detection probability for all sensor nodes in the j-th cluster, denoted as p_{d_j}. The decision fusion rule used to make the cluster decision at the cluster head is the optimal decision fusion rule [6]:

$$H = \begin{cases} H_1, & \text{if} \quad I_j \geq th_j \\ H_0, & \text{if} \quad I_j < th_j \end{cases} \tag{8}$$

where th_j is the decision threshold also given by:

$$th_j = \frac{\ln((1-p)/p) + N_j \ln((1-p_{fa})/(1-p_{d_j}))}{\ln((p_{d_j}(1-p_{fa}))/(p_{fa}(1-p_{d_j})))}. \tag{9}$$