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Divide-and-conquer architecture based collaborative sensing for target monitoring in wireless sensor networks

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ABSTRACT

Most surveillance applications in wireless sensor network (WSN) have stringent accuracy requirements in targets surveillance with maximized system lifetime, while large amount of continuous sensing data and limited resource in WSNs pose great challenges. So it is necessary to select appropriate sensors that can collaboratively work with each other in order to obtain balance between accuracy and system lifetime. However, because of sensing diversity and big data from WSN, most existing methods can not select appropriate sensors to cover all critical monitoring locations in large scale real deployments. Accordingly, an AdaBoost based algorithm is first proposed to identify valid sensors with contribution towards accuracy improvement, which can reduce computation and communication overhead by excluding invalid sensors. The valid sensors are combined and work in a collaborative way, which can obtain better performance than other ways. Then, because of independence of each monitoring location, a divide-and-conquer architecture based method (EasiSS) is proposed to select the most informative sensor clusters from the valid sensors for critical monitoring locations. EasiSS can obtain higher classification accuracy at different user requirement. Finally, according to the experiment on real data, we demonstrate that our proposed method can get a better performance of sensor selection, comparing with traditional methods.

1. Introduction

Many wireless sensor networks (WSN) based surveillance applications [1], such as WSN based vehicle classification [2], body sensor network based health monitoring [3], and WSN based military surveillance, require the WSNs based sensing system to be as intelligent as possible in order to accurately sense and recognize interested targets. However, because WSN is energy limited as well as target surveillance require continuous sensing data, it is necessary to build an energy efficient method for WSN, that save energy usage while maintaining classification accuracy that meet user requirements. In this paper, we take target classification as an example and target monitoring means target classification.

Generally, WSNs has two universal characteristics: one is the existence of a large number of redundant nodes in real deployment; another is the existence of heterogeneous diversity. Thus, wireless sensor network can provide extra advantage-redundant sensor nodes which enable target classification to perform in a collaborative way, and sensor sensing capabilities are diversity. In previous works, sensor nodes near the target yield measurements and perform classification tasks independently [4,5]. The final decision is made on fusion node which fuses decisions gathered from neighbor nodes. In order to make a good balance between accuracy and energy consumption, it is necessary to select a subset of sensors to join target classification process instead of taking all the sensors into the process. However, most existing works select sensors only basing on the distance between the sensors and target, and these selected sensors sometimes are not the most important sensors with great capabilities for sensing diversity in dynamic environments. Thus, they cannot cluster appropriate sensors to meet user requirements and save energy.

As sensing diversity is ubiquitous in WSNs for target detection [6], sensor capability in dynamic environments is implied by sensing diversity. Thus, we try to utilize sensing diversity for target classification in WSNs. Sensing diversity includes the sensing ability among different sensors with same or different modalities. This is caused by the difference of cheap off-the-shelf motes and in-situ reality of a specific deployment [7]. Many existing works [8] do not take the sensing diversity into consideration. They assume the whole sensor have similar sensing capabilities, while other works attempt to overcome sensing diversity by correcting for the differences in readings from different sensors [6,9]. But they select sensor nodes according to their importance defined as the sum of all

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contributions on the node for all of its sensors and sensitive locations in its fusion range. Thus, the most important node may not be the most informative for all its sensitive locations or some sensor nodes with less sensing capability also participate in perception for some monitoring locations, which will bring unnecessary overhead for new sensors are needed to join. Difference from previous works, we make full use of the sensing capability difference among sensors and divide-and-conquer architecture based method to achieve user accuracy requirements for all critical monitoring locations. But there are challenges in target monitoring with sensor possessing various abilities. These challenges are summarized as follows.

- **On-demand collaborative sensing.** It is important to decide when individual sensors are sufficient and when the additive sensors are need to collaborate with each other, because such collaboration can save valuable resources and meet user accuracy requirements. Especially, some sensors with little contribution towards accuracy improvement should be identified and excluded to reduce system overhead.
- **Distributed sensor clusters selection to cover all monitoring locations.** Because of sensing diversity and limited resource in WSNs, it is difficult to select right sensor clusters to cover large amounts of monitoring locations in large-scale deployment while minimizing energy consumption. Besides, because of dynamic environments, a distributed scheme is need to adapt to changes more efficient.

Through machine learning method, we explore sensing diversity in a heterogeneous sensor networks for vehicle classification to meet the user classification accuracy requirements. We show that sensing capabilities are significant differences among sensors in real deployments. When additive sensors or nodes are needed to collaborate with each other, arbitrary sensor selection often fails to meet user classification accuracy requirements. Besides, there are some sensors with little contribution towards accuracy improvement, while AdaBoost algorithm can calculate the sensor weight from training and such sensor weight can reflect the sensor sensing capability of the exiting sensor cluster. Thus, we use AdaBoost based method to identify the sensors with little contribution via the sensor weight. Then, a divide-and-conquer architecture based collaborative sensing scheme EasiSS is proposed to divide all monitoring locations into single monitoring location and select appropriate sensor cluster for each location independently. A distributed online sensor selection method named CSSM is present as basic algorithm for the single monitoring location, which utilizes sensing diversity for use in practical deployments. And it can cluster appropriate sensors collaborating with each other to meet user classification accuracy requirements and minimize energy usage when individual sensors are not accurate enough. Besides, during running time, CSSM algorithm can adapt to environmental changes that cause accuracy decrease. Specially, it adjusts the member of collaborative sensors or train new classifiers adaptively. The contributions of this paper are summarized as follows.

- We propose an AdaBoost algorithm based method (SensorBoost method) via computing sensor weight to identify valid sensors and exclude invalid sensors with little contribution towards accuracy improvement. Thus, SensorBoost method can reduce communication and computation overhead. In addition, we make theoretical analysis to performance of valid sensors via combining classifiers trained by these valid sensors.
- We provide a divide-and-conquer architecture based collaborative sensing scheme (EasiSS scheme) to select appropriate sensor clusters from valid sensors for all critical locations. In particular, EasiSS divides all monitoring locations into single monitoring location according to their fusion range. The basic algorithm (CSSM) is presented to cluster appropriate sensors for single location and it is a distributed sensor selection method basing on sensing diversity of individual sensor and sensor cluster. What is more, CSSM method can adapt to dynamic environments and provide user accuracy requirements, while minimizing energy consumption.

The rest of the paper is organized as follows. Section 2 and 3 review related work and presents motivation respectively. Section 4 introduces an overview design. Section 5 introduces SensorBoost algorithm and related theoretical analysis. Section 6 presents the divide-and-conquer based method and its basic algorithm CSSM. Section 7 and 8 presents fully experiments on real data and concludes this paper respectively.

2. Related work

There are many research works about target monitoring, such as [4,10] that focus on the target detection and classification. For example, target classification result is achieved by a static classifier in a centralized manner in [9]. A proposed classifier in [10] uses a simple distributed architecture as follows: local hard decisions from each sensor node are communicated over noisy links to a manager node; then the manger node optimally fuses this information to make final decision. However, these works mainly focus on detecting or tracking objects, while omitting the details of collaborative sensing scheme design.

Most existing works utilize distance-based collaborative sensing schemes to cluster appropriate sensors for target monitoring. For example, [11] proposes distance-based decision fusion scheme via exploiting the relationships among the sensor node to target distance, classification rate, and signal to noise ratio. The classification of moving ground vehicles is addressed in [12]. They present a distributed framework to classify vehicles based on FFT (fast Fourier transform) and PSD (power spectral density) features, and proposed three distributed algorithms which are based on k-nearest neighbor (*k*-NN) method. The authors of [13] propose a binary classification tree based framework for distributed target classification in multimedia sensor networks. It takes the advantage of both efficient computation of the classification tree and the high classification accuracy of SVM. These works evaluate node importance basing on distance between sensor and target, and sometimes cannot cluster right sensors for sensing diversity.

Some other works attempt to solve sensing diversity by accounting for sensing differences in different sensors but cannot provide user accuracy requirements [14] or some sensors with less information also participate in perception bringing unnecessary overhead. Besides, some existing works use sensing diversity based collaborative sensing schemes to cover critical monitoring locations. For example, sensing diversity is utilized to cluster sensors for providing sensing confidence in [15], but it is a centralized sensor selection method. A collaborative sensor selection approach [16] is provided to training a composite classifier for shared classification of human activities. But it does not fully explore the effects of sensing diversity to cluster appropriate sensors for target monitoring. The most related work is the sensor cluster selection method for target monitoring proposed in [6]. It selects the most important sensor node according to sensing diversity and the importance is defined as the sum of all contributions on the node for all of its sensors and sensitive locations. However, the most important node may not be the most important for its all sensitive locations. Therefore, when the most important node with less contributions for some sensitive locations, there will be needed more nodes taking part in the process of detection with the increase of the user classification requirements, which often will cause more sensing and communication energy usage.