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Sensor virtualization for underwater event detection

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ABSTRACT

Distributed event detection is a popular application in Underwater Wireless Sensor Networks (UWSNs). The Base Station (BS) collects the measurements from multiple sensor nodes, and makes a decision based on the sensors' reports. However, due to the unpredictable moving of underwater sensor nodes and interference among multiple events, it is difficult to guarantee the accuracy of event detection. In this paper, we propose a sensor virtualization approach to deal with the event detection problem in UWSNs. The final decision making at the BS will be implemented with the reports of multiple virtual sensors. Although the events may happen in a large scale, the locations where the events happen are relatively sparse in the underwater environment. Consider the sparse property of events, we employ the technique of compressive sensing to recover the original signal from the correlated sensors' measurements. Through a proper signal reconstruction, the accurate event detection can be reached with a remarkable low sensing overhead. We implement the sensor virtualization based on the compressive sensing technique. Our approach is suitable for the high dynamic topology of UWSN, and it can improve the accuracy of event detection and reduce energy consumption in UWSNs.

1. Introduction

Underwater Sensor Networks (UWSNs) are used in increasing underwater scenarios, and event detection is a popular application. An event may be anything from a malfunction of monitored machinery to an intrusion into the underwater area. For example, oil leak detection using UWSN is quite important in the sub sea pipeline transportation. If the leakage occurs, the Base Station (BS) must know it immediately. Other underwater environmental parameters, such as temperature, pressure and so on, can also be monitored using UWSNs.

Once the BS receives the underwater sensors' reports, it should not only judge whether an event happens, but also locate all the events. However, the localization for underwater event is quite difficult. Due to the water current, the locations of underwater sensor nodes change frequently. Because of the sensor mobility, the position information of an event collected by underwater sensor nodes is not trustable. One method to improve the reliability of position information provided is frequently implementing underwater node localization. Because the velocity of water current is usually small, the moving distance will not be too large in a short period. Once the locations of sensor nodes can be updated frequently, the position information provided by the underwater sensor nodes will be trustable. However, frequent underwater node localization brings large communication overhead and is not energy-efficient. In UWSNs, in which the underwater nodes usually cannot be charged, frequent node localization is not expected. Therefore, the BS has to estimate the events' locations with unreliable position information. Moreover, the measurements of different events are coupled, it is difficult to judge the event source with the physical sensors' measurements. Therefore, the multiple event detection is a challenging problem in UWSNs.

Recently, the idea compressive sensing is applied to the multiple-event detection [1–3] in sensor networks. Compressive sensing can be used to recover the original signal with insufficient measurements if the original signal is sparse enough. If most entries of a signal is close to zero, the signal is sparse. Because the locations of events are sparse in the sensing area, the corresponding uncorrelated measurements of different events source can form a sparse signal. Through compressive sensing approach, it is possible to formulate the uncorrelated measurement of each event. However, the existing multiple event detection based on compressive sensing is designed for the terrestrial sensor networks, which is not quite suitable for UWSNs. In this paper, we employ the idea of compressive sensing to implement the sensor virtualization. The event detection is implemented with the data of virtual

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sensors rather than directly with the physical sensors' measurements. The virtual sensor can be thought as an abstraction of physical sensors. The basic idea of virtual sensor is similar to *Virtual Machine* (VM). In sensor networks, virtual sensor refers to a software entity with advanced functions using physical sensor entities [4]. Some works on sensor virtualization are introduced in recently years [5–11]. In [5], the virtual sensors are constructed for the flight control system. In [6,7], the Bayesian networks are used to design virtual sensors. In [8,9], the virtual sensor technique is applied to the wearable sensor system. In [10], the approach of virtual sensor is employed to deliver aggregated air quality observations on-demand in the Sensor Web. In [11], the virtual sensor is formulated for the fault-tolerant control in electric vehicles. Since the BS just requires the accurate measurements of events and does not need to know the actual property of physical sensors, formulating virtual sensors is suitable for underwater event detection. However, the existing sensor virtualization approaches cannot be applied to underwater event detection. In the distributed event detection, the BS requires the underwater nodes to report whether and where the event happens. However, the task cannot be fulfilled directly by physical sensors. In this paper, we try to formulate such virtual sensors for distributed underwater event detection. Our contributions can be concluded as follows:

- The idea of virtual sensors are introduced to implement the event detection. The virtual sensors can provide the function that physical sensors do not have.
- The compressive sensing approach is employed in this paper. We have proved that the requirements of compressive sensing can be guaranteed in the underwater event detection scenario.
- Our approach can solve the multiple-event detection problem. Since physical sensors' measurements are coupled, multiple-event detection is very difficult. The virtual sensors can give the uncoupled measurements of different events.

The paper is organized as follows: In Section 2, we introduce the basic system model and give some assumptions in this paper. In Section 3, the sensor virtualization is implemented based on compressive sensing. In Section 4, the event detection approach with virtual sensors' measurements is introduced. The simulation results and discussions are shown in Section 5. In Section 6, we conclude the paper.

2. Basic model and assumption

2.1. Network architecture

An UWSN usually consists of a surface BS and many underwater sensor nodes. We assume N underwater sensor nodes are deployed in the 3-D sensing area. The underwater sensor nodes sense the environment and report their measurements to the BS. The measurements among different sensor nodes are assumed uncorrelated in this paper. Due to the underwater node mobility, the topology of an UWSN is not stationary.

The underwater nodes are grouped into clusters, and they can be divided into two types: cluster-head nodes and cluster-member nodes. The cluster-member nodes sense the environment and transmit the local data to the cluster-heads. A cluster-head node should collect the data from cluster-members and transmit the aggregated data to the BS. There are many routing protocols for UWSNs. Pompili et al. propose a routing algorithm for delay-sensitive UWSNs [12]. In [12], authors employ a probability model to describe the propagation delay of a link, and select the proper intermediate nodes to relay the packets. In our past work, a low delay energy-efficient UWSN routing protocol is proposed. Different from [12], a complete protocol is described in [13]. However, the routing schemes in [12,13] are not designed for the cluster-based network architecture. In [14], a routing scheme based on multipopulation firefly algorithm is proposed. Considering the data correlation, the redundant information can be reduced with proper packet merging in the work of [14]. For the event detection problem in this paper, underwater sensor nodes need to report their observation periodically. So the packets to be transmitted cannot be reduced with data correlation knowledge. Therefore, the cluster-based routing protocol is the best choice. Many cluster-based routing schemes have been proposed for sensor networks, such as LEACH [15], PEGASIS [16], HEED [17], MCCP [18] and DUCS [19]. The routing protocol design is out of range of this paper. We employ the classical LEACH protocol to implement the clustering.

2.2. Background of virtual sensor

The virtualization is achieved by inserting a layer of software between the high level applications and the underlying hardware. The idea of VM has found its way into mainstream applications and is arguably the driving forces behind the cloud computing paradigm [20]. It is abstracted from the underlying hardware and emulates the physical machine in software. In sensor networks, there exists some researches on sensor virtualization [5–9,11]. Similar to VM, the term virtual sensor can be defined as a software entity that can serve like a physical sensor. A virtual sensor is an aggregation point of multiple physical sensors, and it employs physical sensor entities and a computational model to combine their measurements. The general architecture of sensor virtualization is shown in Fig. 1.

The physical underwater sensor nodes first transmit their measurements to the cluster-heads. The cluster-heads abstract multiple virtual sensors based on different physical sensors. Then the BS implements some advanced tasks with virtual sensors' data. The BS side does not need to know the underlying hardware of sensor nodes, and it just uses virtual sensors' measurements directly. In the underwater event detection, the BS should determine the locations of events with virtual sensors' measurements.

2.3. Energy model

The underwater nodes are equipped with acoustic modems and they can communicate with each other through acoustic links. The energy consumption for an underwater node consists of circuit

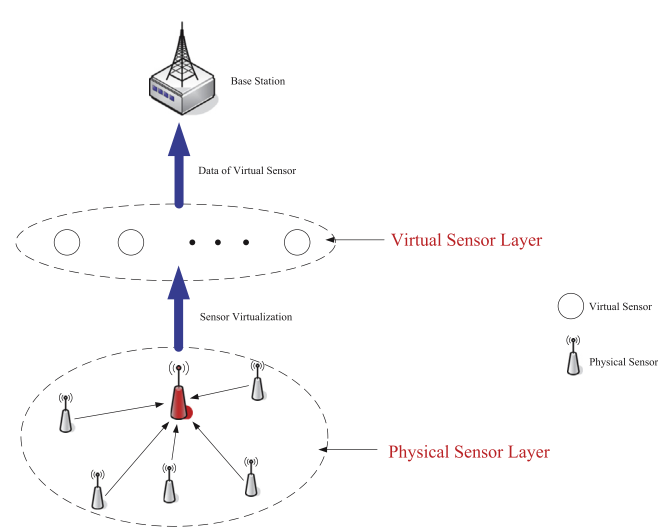

Fig. 1. Sensor virtualization.