Virtualization in Wireless Sensor Network: Challenges and Opportunities

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Abstract—**Wireless Sensor Networks (WSNs) are gaining importance for their broad range of commercial applications such as in home automation, health-care and industrial automation. In these applications multi-vendor and heterogeneous sensor nodes are deployed. Due to strict administrative control over the WSN domains, communication barrier, conflicting goal & economic interest of different vendors of sensor node in WSN make it difficult to introduce a large scale federated WSN. By allowing heterogeneous wireless sensor networks to coexist on a shared physical substrate, virtualization in sensor network may provide flexibility, promote diversity, ensure security and increase manageability. This paper surveys the novel approach of using the large scale federated WSN resources in a sensor virtualization environment. In this paper we propose sensor virtualization architecture and focus on the challenges and opportunities of research in the field of sensor network virtualization as well as to illustrate a picture of current researches in this field.**

Index Terms—**Virtualization in WSN, Physical substrate, 6LoWPAN, IP-WSN, Ossification.**

I. Introduction

Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short distances. A sensor network consists of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it [1-5]. Due to the rapid advancement of electronics tiny sensor nodes are capable of supporting IP protocol stack. 6LoWPAN ensures the IPv6 communication over low power and low cost sensor nodes [5-7]. IP enabled sensor node has opened the door for further research to the advanced and distributed applications in sensor network [5]. The excuse of resource constraints of tiny sensor node cannot stop the advancement of researches in the field of sensor network. Very recent, network virtualization has created a resonance among the network research community. The concept of WSN virtualization has also attracted a great deal of attention from industry and academia [7] [10]. WSN virtualization renaissance has been originated mainly from the realization that it can provide a common platform upon which novel federated sensor network architectures can be built, experimented and evaluated, freed from legacy technology constraints[13][15][16]. In addition, virtualization in WSN is expected to provide a separation of services and infrastructure and facilitate new ways of doing business by allowing the trading of network resources among multiple service providers and customers [18-19].

Virtualization on sensor network (VSN) can be defined by separating the roles of the traditional WSN service provider into two parts: sensor infrastructure provider (SInP), who manages the physical infrastructure, and sensor virtualization network service provider (SVNSP), who develops VSN by aggregating resources from multiple SInPs and offer end to end services. This type of virtual environment can ensure the coexisting heterogeneous WSN at the physical level that are free from the limitations of existing multi vendor sensor networks [19]. The main contributions of this paper are as follows:

- We propose novel virtual sensor network architecture. We pointed out challenges and opportunities of this protocol architecture. We also focus on the current solutions and contemporary research in this field.
- We discuss some open research issues and finally justify application of VSN in the battlefield scenario and in monitoring rock slides and animal crossing within a mountainous terrain.

The rest of the paper is organized as follows. Section 2 proposes the virtual sensor network protocol architecture. Section 3 describes related works. Section 4 presents the challenges of the protocol architecture. Section 5 discusses opportunities. Section 6 depicts the case study related to VSN. Section 7 presents evaluation. Section 8 shows the future research scope and finally section 9 concludes the paper.

II. VIRTUAL SENSOR NETWORK

A Virtual Sensor Network is formed by a subset of sensor nodes of a WSN. The subset is dedicated to a certain task or an application at a given time [19] [22]. In WSN, all the nodes in the network collaborate more or less as equal partners to achieve the result. In contrast, the subset of nodes belonging to the VSN collaborates to

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carry out a given specific task. Thus VSN depends on the remaining nodes providing VSN support functionality to create, maintain and operate VSNs. In the proposed approach, multiple VSNs may exist simultaneously on a physical wireless sensor network, and the membership of a VSN may change over time. As the nodes in a VSN may be distributed over the physical network, they may not be able to communicate directly with each other. In Figure 1 two Virtual Sensor Networks coexist over the same physical sensor network infrastructure.

A. *VSN Protocol Architecture*

In WSN, infrastructure provider and service provider are same entity. But increasing demand of WSN in different state-of-the-technology applications makes it necessary to differentiate between the roles of WSN infrastructure providers and service providers. The objective behind this is to minimize the establishment cost, to reduce the manageability cost etc. The main difference between the participants in the sensor network virtualization model and the traditional model is the presence of two different roles, SInP and SVNSP, as opposed of the WSN provider as a whole. In the proposed architecture, VSN environment is a collection of multiple heterogeneous sensor networks from different SInP. Each SVNSP hires resources from one or more SInPs to form VSN, and deploys customized protocol and services over the hired VSN resources. Now we will discuss the individual modules of the proposed architecture with the help of Figure 1.

A.1 Sensor Infrastructure Provider (SInP)

SInP deploys and manages the substrate physical sensor network resources in the field. These resources include different types of sensor nodes. Among the sensor nodes there are few sensor gateway routers (SGR) that act as the sink node. All the SGR has sufficient power supply and other resources such as memory and computing power. All the SGR are connected through high speed wireless network. SGR can host different virtual sensor gateway router (VSGR). They offer their resources through programmable interfaces to different SVNSP. SInPs distinguish themselves through type of services they provide. Different Vendor Company can deploy sensor node and can make their individual infrastructure which can be used by the company or can be leased to different virtual service providing company to run their individual applications. It helps the effective utilization of physical sensor node in a large scale federated sensor network. In Figure 1 different type of sensor nodes are deployed by different company to create a federated sensor network. But service consumer may require specific types of service. This specific service may be available to the consumer through virtual sensor gateway router.

A.2 Sensor Virtualization Network Service Provider (SVNSP)

SVNSP leases resources like memory, processing power and bandwidth from multiple SInPs. It creates and deploys VSN. In Figure 1 there are two SVNSP: SVNSP-1 and SVNSP-2. Both SVNSP consist of leased resources from SInP. Both SVNSP provides different types of virtual network services to the service consumers in transparent mode. The virtual link between the two VSGR are also the leased wireless link from SInP. An SVNSP can provide network services to multiple SVNSPs and it can be used in a recursive way.

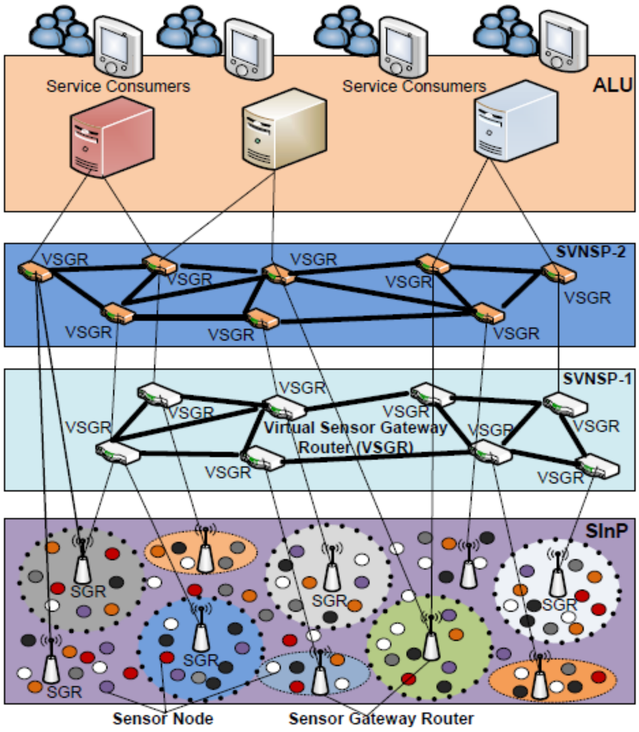

Figure 1. Virtual sensor network architecture

A.3 Application Level User (ALU)

ALU in VSN architecture are similar to those of the existing WSN, except that the existence of multiple SVNSPs from competing SInPs provides a wide range of choice. Any end user can connect to multiple VSNs from different SInP for multiple applications. In Figure 1 service consumer uses different types of information ALU interface. VSN hides all the complexity of the underlying SInP to service level consumers.

III. RELATED WORKS

In the recent past the research community mostly paid attention to issues of sensor networks, such as energy efficient routing issues, security and reliable transmission and data aggregation[1-2]. But recently a numbers of related researches have been performed on the virtualization of sensor network [7] [10] [13]. Table I addresses many research projects that are going on in this field and the respective research areas. Among the related researches most of them have two approaches. Few researchers focused on gateway based and overlay based concepts. In VIP Bridge based ubiquitous sensor network [7], the authors propose an approach of using bridge to integrate several different sensor networks into one virtual sensor network. Gateway based sensor-grid application is also discussed in [7-8]. In [10] authors proposed a tiny virtual machine for a Sensor Network called Maté. Its code is broken up into small capsules of 24 instructions allowing complex program to be under 100 bytes. In [11] [12] authors discussed dynamic resource discovery and programming WSN with logical neighborhood in details.

In [18] authors proposed a system called Melete which is based on Maté virtual machine. Melete system enables reliable storage and execution of concurrent applications on a single sensor node. In [22] proposes the concepts of sensor virtualization for heterogeneous sensor network platforms. In [17] [25] authors propose a simple and robust virtual infrastructure for massively deployed wireless sensor networks that is simple and can be leveraged by a number of different protocols. In [9] virtual position based geographic routing has been addressed to take over the problem of the existing geographic routing. Table I summarizes research directions of sensor network virtualization in different contemporary projects.

IV. CHALLENGES

In the recent past it was a general thinking that tiny sensor node with its little processing capability could be applicable in very specific areas with very specific purposes. But with the rapid advancement of micro electro mechanical systems, the concept of the researcher has been dramatically changed. Now the IP based WSN (IP-WSN) and implementation of 6LoWPAN sensor node have been used in different field such as health care, facility management, building and home automation, personal sports and entertainment, asset management, environmental monitoring, security and safety and industrial automation. In these applications sensor network virtualization concept can be effectively utilized. For the implantation of VSN in the above mentioned areas, a few challenging issues are addressed below:

A. Interfacing

SVNSP uses physical resources from one or more infrastructure provider to create sensor virtual networks. SInPs must provide well-defined interfaces to allow virtual service providers to communicate and express their requirements. For interoperability, such interfaces should follow a standard that should be able to express sensor virtualization request in terms of virtual sensor gateway router nodes and virtual wireless links along with their corresponding attributes.

B. Resource Allocation

Resource allocation in a sensor network virtualization environment refers to static or dynamic allocation of virtual sensor gateway router nodes and links on physical nodes and paths, respectively. It may be known as the virtual sensor network embedding. Embedding of virtual sensor networks, with constraints on nodes and links, can be reduced to the NP-hard problem even all virtual network requests are known in advance. The embedding problem has been discussed in different way for the virtual networking environment. But embedding approach of traditional network cannot be implemented in WSN. For this reason, it needs comprehensive research for efficient embedding of virtual sensor network request to the physical WSN.

C. Resource Discovery

In order to allocate resources for requests from different virtual service providers, infrastructure providers must be able to determine the topology of the sensor networks they manage as well as the status of the corresponding sensor network elements. Moreover, adjacent infrastructure providers must also share reach ability information to be able to establish links between their networks to enable inter domain sensor virtual network instantiation.

D. Virtual Nodes and Virtual Links Embedding

Scalability of a sensor network virtualization environment is closely tied to the scalability of the physical sensor gateway. Commercial sensor gateway vendor may design and implement gateway that can hold multiple virtual sensor gateway. To increase network manageability and to handle network failure, migration of virtual sensor gateway can be an effective solution. But finding probable destination for a migrating virtual gateway is restricted by multiple physical constraints like change of latency, link capacity, platform compatibility issues, and even capabilities of destination physical gateway. Virtual link and node embedding is an open research issue in VSN.

E. Service Level Agreement

The service level agreement represents contractual obligations and includes a description of the service as well as the specific guarantees given to assure the availability of resources and service qualities. It is the most challenging issues in the virtual sensor network architecture. SVNSP should ensure service level agreement to the application level users. Since the same substrate physical sensor network provide different types services to virtual service provider, SVNSP should not violate the service level agreement. If there is any violation then there should have penalty. Designing of such type of interface is still almost unexplored.

These are the typical challenging areas of research. This is a quite new and unexplored area of research.

V. OPPORTUNITY

The concept of the sensor network virtualization may be interesting from the technical point of view, but it will only become a reality in commercial environments if there are enough business opportunities for SInP and SVNSP. Some opportunities in which an infrastructure provider can benefit from implementing sensor network virtualization are discussed below:

A. Sharing Sensor Network

The most important opportunity behind sensor network virtualization is the sharing of substrate physical infrastructure. Along with a cost-reduction strategy, network operators are steadily exploring the deployment of common infrastructures to share capital investments. Especially in the time of economic recession, VSN can save a lot in terms of money and human labor in different critical situation like natural disaster management, battlefield surveillance and collecting resources form mine, building sky scrapers and large bridge.

B. Reducing complexity and cost of Overlay proliferations

For a variety of reasons like organizational issues, security, scalability, and quality of experience guarantees providers are forced to deploy sensor network. Deployment of separate sensor nodes in target area for specific purposes is not cost effective. If a single sensor network can serve multiple purposes then it becomes very cost effective. Virtualization of sensor network satisfies this purpose by providing the options to use a single physical infrastructure for different application level users through virtualization. In this way virtualization in sensor network can reduce complexity and cost sensor overlay proliferations.

TABLE I. SENSOR NETWORK VIRTUALIZATION RESEARCH IN DIFFERENT PROJECTS.

Project	Research Area	URL
FRESnel	To build a large scale federated sensor network framework with multiple applications sharing the same resources.	http://www.cl.cam.ac.uk/research/srg/netos/fresnel/index.html
VSNs	Random routing, virtual coordinates, and VSN support functions	http://www.cnrl.colostate.edu/Project/VSNs/vsns.html
SensorPlanet	SensorPlanet is a Nokia-initiated cooperation, a global research framework, on mobile device-centric large-scale Wireless Sensor Networks.	http://www.sensorplanet.org/
ViSE	Virtualization of sensor/actuator system, creating customized virtual sensor network test beds	http://groups.geni.net/geni/wiki/ViSE
STONE	Energy-efficient Storage for sensors	http://sensors.cs.umass.edu/projects/essense/
DVM	To build a system that supports software reconfiguration in embedded sensor networks at multiple levels	http://nesl.ee.ucla.edu/project/show/51
PRESTO	Takes a fresh look at the design of tiered large-scale sensor networks	http://presto.cs.umass.edu/
SensEye	Multi-tier multi-modal sensor networks	http://sensors.cs.umass.edu/projects/senseye/
SenQ	Complex virtual sensors and user-created streams can be dynamically	http://www.cs.virginia.edu/wsn/medical/projects/senq
WebDust	Multiple, heterogeneous, wireless sensor networks can be controlled as a single, unified, virtual sensor network.	http://ru1.cti.gr/projects/webdust/wiki/JWebDust_application_ enviroment

C. Managed services

Large scale WSN operators are increasingly focusing their growth strategies toward services delivery, customer orientation and product marketing. In this context, a potential approach would be the externalization of infrastructure to better focus on their core service oriented business. A third party could in this context become an infrastructure provider, and could therefore benefit from virtualization techniques to better capitalize its investments in new network deployments. The same approach could be followed by governments or public entities aiming at deploying federated WSN infrastructure, to promote the development of the digital society.

D. Simplified architecture

VSN allows a simplified architecture that serves all of the applications and networks such as sensing sound, temperature, motion, object monitoring, monitoring the environment etc that previously required individual dedicated sensor networks and unnecessary duplication. So VSN provide a simplified heterogeneous architecture of sensor network.

E. New business models

The virtualization in sensor network allows for new business models. Several virtual sensor network service providers can launch diversified services and application instead of investing on the physical sensor network. This can provide an economy of scale business model for the end users as well as the service providers.

VI. CASE STUDY FOR VSN

One of the major areas of wireless sensor network virtualization is battlefield surveillance [20-21]. Consider a scenario in a mountain area battlefield where different types of target group such as civilian, enemy, soldiers, important establishment and animals coexists as depicted in Figure 2. In such a situation military operation from aircraft is very much sensitive which usually cause detrimental effect on the society. In such a case virtualization in sensor network can serve the multiple purposes for sensing the environment, civilian, soldier, animals and other sort of important establishment. Deployment of sensor node in the particular area and its effective utilization through virtualization can be very much cost effective approach in now a day's battlefield. Through the virtualization of sensor network same physical substrate sensor node can be used in different virtual network for sensing temperature, sound, humidity, image, differentiating civilian, opponents and soldiers[24][25]. Sensor network virtualization in the battlefield can efficiently incorporate the overall scenario in a battle field. Soldiers can observe the battlefield by overseeing the scenario from virtual service provider for detecting sound, identification of the civilian and enemy, animal folk and the destructive weapon in the battle field. This scheme can enhance battlefield scenario as well as can decrease the cost of war budget and can save the establishment and the innocent lives of the civilian. Different types of devices that detect these phenomena can relay each other for data transfer without having to deploy separate networks.

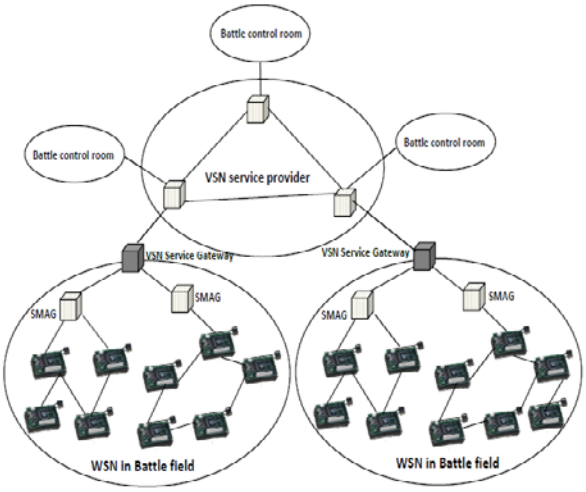

Figure 2. Virtual Sensor Network based battlefield

In Figure 2, SMAG stands for Sensor Mobile Access Gateway. It is the fully functional gateway of the sensor nodes in a particular WSN domain. A battlefield consists of many SMAGs which offer virtualization services for hosting different types of surveillance information.

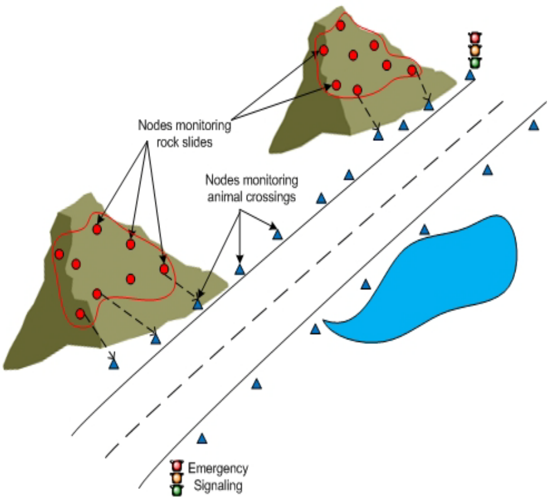

Figure 3. Monitoring rock slides and animal crossing

Application service gateway communicates with individual SMAG through Virtual Service gateway. Finally soldiers get information from application gateways.

In Figure 3 a single WSN is deployed but it is inherited by two VSN. One VSN monitor rock sliding and another VSN monitor animal crossing in a mountainous retain. Each application use nodes from the other application to relay its data to the signaling systems and/or to its members [23]. In this scenario only two applications have been considered. This type of scenario can also be applicable in disaster management.

VII. Evaluation

For evaluation we, consider battlefield and rock sliding & animal crossing scenario. Based on the above two case studies we perform cost analysis. We consider one square kilometer area for simulation environment. There are around 10 motes per square meter. So for 1000X1000 meter space we need to deploy 10X1000= 10,000 motes. The experiments were conducted on a computer with AMD Athlon ™ 2.5 GHz CPU and 2 GB primary memory. We use Visual C++ to implement the algorithm under windows XP environment. The cost of each mote for animal crossing and rock sliding scenario is around 10,000 won. Figure 4 shows the number of motes versus cost scenario. Figure 4 also depicts that in terms of costs VSN approach outperform the traditional approach which consist of individual mote deployment for animal crossing and rock sliding. For battlefield scenario we consider different type of motes. Cost of the mote for sound detection is 3000 won, for temperature detection is 2000 won, for humidity detection is 2500 won, for image detection is 5000 won, for VSN detection is 8000 won. The currency is South Korean won.

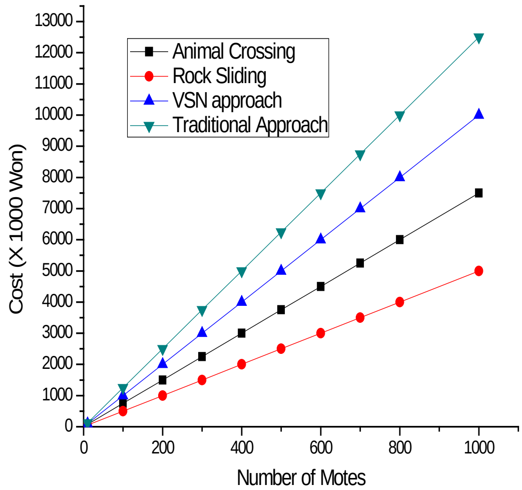

Figure 4. Rock slides and animal crossing scenario

Figure 5 depicts cost analysis of battlefield scenario where different types of target group such as civilian, enemy, soldiers, important establishment and animals coexists. It represents cost based analysis of different cases. Although the cost of VSN approach is comparatively high, it covers all type of detection such as temperature, humidity, sound and image. In this case also, in terms cost VSN approach outperform traditional approach. Here traditional approach means individual deployment of sound, temperature, humidity and video sensor individually.

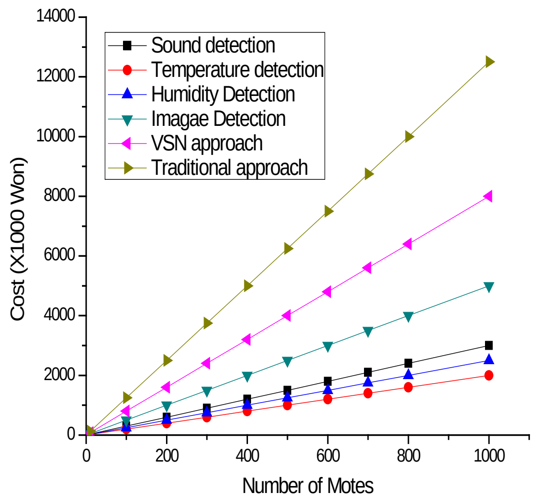

Figure 5. Battlefield scenario

VIII. FUTURE RESEARCH SCOPE

Virtualization has opened a new dimension in different research fields especially in WSN. The whole world is facing economic recession. So virtualization in sensor network can be a promising research issue in the field of wireless sensor network. Among the future research scopes few of them may be developing convenient operating system for tiny sensor which can support virtualization in sensor network. Managing resources, scheduling the sensing activities, minimizing energy consumption are few of the future research area in sensor network virtualization. Large scale federated sensor network framework with multiple applications sharing the same physical resources has already attracted the researchers.

IX. CONCLUSION

In this paper we present a survey of virtualization in sensor network. Virtualization in sensor network can be effective in home automation, patient monitoring, battlefield surveillance, rock sliding and animal crossing in a mountainous retain. Multi vendor sensor network architecture can be deployed for efficient utilization of physical sensor infrastructure. However, communication barrier, conflicting goal & economic interest of individual vendor and the gradual ossification problem of WSN make it difficult to introduce a large scale federated WSN. By allowing multiple heterogeneous wireless sensor network architecture to coexist on a shared physical substrate, virtualization in sensor network may provide flexibility, promote diversity, ensure security and increase manageability. Here we discuss different challenges and opportunities of using the large scale federated WSN resources in a sensor virtualization environment. Our future interest is to emphasize on building a large scale federated sensor network framework with multiple applications sharing the same physical resources.

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