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Research Article

An Efficient Model for Smart Home by the Virtualization of Wireless Sensor Network

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Wireless sensor networks (WSNs) are gaining tremendous importance thanks to their broad range of commercial applications. Out of the contemporary fields of research in WSNs, the virtualization of wireless sensor network (VSN) is a brand new research approach. In this age of economic recession, this state-of-the-art technology can provide the opportunity to build an economic business model for application area such as smart home. Building smart home is a big challenge for worldwide increasing elderly populations which are the largest demographic group of developed countries. In this paper, we propose a VSN based business model for implementing smart home for the rapidly growing elderly populations of the world in a cost-effective way. We also propose the virtualization architecture of fully functional sensor node known as sensor gateway router and mathematical model for the embedding of VSN node and link to the physical sensor node and links. Finally, we have implemented and evaluated the sensor virtualization scheme in embedded Linux environment. The evaluation method shows that the virtualization of sensor network technology reduces the overall cost and complexity significantly for the implementation of smart home.

1. Introduction

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 over short distances. A sensor network consists of a large number of sensor nodes that are densely deployed either inside the phenomenon of interest or very close to it [1, 2]. Due to the rapid advancement of microelectronics, tiny sensor nodes are capable of supporting IP protocol stack. 6LoWPAN facilitates the IPv6 communication over low-power and low-cost sensor nodes [3, 4].

In the past, applications of sensor networks were thought to be very specific. The communication protocols of sensor networks were also very simple and straightforward. Some researchers were even against the use of the compatible internetworking protocol architecture in WSNs. There were different reasons behind that such as the resource constraints for layered architecture, the problems of configuring large number of devices, and the essence of sensor nodes' distinct identity. But with the advent of the Internet of Things and federated IP-WSNs, this demand is going to be blurred. The huge numbers of IPv6 addresses, the necessity for end-to-end communication and advances in microelectronics have changed the concepts of the research community. Now, a tiny sensor node can hold a compatible TCP/IP protocol stack, so we can now think of using the concept of internetworking protocols in IP-WSNs [3].

IP-enabled sensor nodes have opened the door for further research into advanced and distributed applications in sensor networks [4]. Recently, network virtualization has created a renaissance among the network based research communities. The concept of sensor virtualization has also attracted a great deal of attention from industry and academia [5]. Virtualization of wireless sensor network (VSN) can be defined as the separation of the function for the traditional WSNs service provider into two parts: sensor infrastructure provider (SInP) that manages the physical sensor infrastructure and sensor virtualization network service provider (SVNSP) that develops the VSN by aggregating resources from multiple SInPs and offers services to the application level users (ALU).

Since most of the sensor nodes remain idle for the maximum periods of its lifetime, VSN is one of the best ways to utilize the physical sensor node resources efficiently. VSN can provide a platform upon which novel sensor network architectures can be built, experimented, and evaluated [5]. In addition, virtualization in WSNs is expected to provide a clean separation of services and infrastructure and facilitate new ways of doing business by allowing the trading of sensor network resources among multiple service providers and application level users.

This type of VSN environment can be ensured from the coexisting heterogeneous WSNs architectures that are free from the limitations of existing multivendor sensor networks. The importance of sensor virtualization is manifold in this age of worldwide economic recession. VSN can provide cost-effective and green technology solutions to design smart homes and cities [5, 6]. In a smart home, all sort of the state-of-the- art technologies are used. To deploy these technologies, it needs a lot of sensor nodes in which individual sensor network performs individual task such as monitoring temperature, humidity, light, video/image, and movement. This traditional approach of using WSNs incurs a huge cost involvement which is the main obstacle for an affordable business model of smart home. VSN may be the most appropriate technology in this regard. By deploying VSN technology, a single federated WSNs can provide multiple services for the smart home. This paper deals with providing an efficient model for smart home by using VSN approach. The main contributions of this paper are as follows.

(a) Business model and architecture of VSN for smart homes have been proposed.

(b) Sensor nodes architecture for VSN has been depicted.

(c) A mathematical model for virtual resource allocation has been demonstrated.

(d) We have evaluated the VSN in smart home application designing with respect to cost and system resources utilization.

(e) Finally, we have discussed future research scopes in the field of VSN.

The remainder of the paper is organized as follows. Section 2 reviews the background related to virtual sensor network, VSN business models for smart home, and related works. In Section 3, we discuss VSN system architecture and software architecture. Section 4 describes the mathematical model for VSN resource allocations. Section 5 demonstrates the performance evaluation. Section 6 discusses future research scope in the field of VSN. And finally, Section 7 concludes the paper.

2. Backgrounds

VSN is a brand new research approach in the field of WSNs. Before proceeding further, we need to clarify few basic concepts and the difference between traditional WSNs, conventional virtual sensor network, and VSN. In traditional sensor network, all nodes in the network perform more or less as equal partners to achieve the goal of deploying sensor nodes [1]. In this paper, VSN means virtualization of WSNs as defined in Section 1 and in Section 2.3. The term VSN is synonymously used for the process of virtualization of sensor network and for the sensor network that support virtualization.

2.1. Virtual Sensor Network. Virtual sensor network consists of collaborative wireless sensor network. It is formed by a subset of sensor nodes of a wireless sensor network, with the subset being dedicated to a certain task or an application at a given time [7, 8]. In contrast, the subset of nodes belonging to this type of network collaborates to carry out a given application at a specific time. It can be formed by providing logical connectivity among collaborative sensor nodes. Nodes can be grouped into different virtual sensor networks based on the phenomenon they track or the task they perform. The protocols for this type of network should provide the functionality for network formation, usage, adaptation, and maintenance of subset of sensors collaborating on a specific task [9].

2.2. Overlay Sensor Network. An overlay sensor network is a type of sensor network that creates a virtual topology on top of the physical topology of a wireless sensor network. Nodes in an overlay network are connected through virtual links which correspond to paths in the underlying network. Overlays are typically implemented in the application layer, though various implementations at lower layers of the network stack do exist [10].

2.3. VSN and Its Business Model for Smart Home. Unlike WSNs, the VSN environment has a collection of multiple heterogeneous sensor network resources that coexist in the same physical space. There are different types of physical sensor networks and many SInPs indicated by different circles in the lower layer of Figure 1. There are two SVNSPs in the model. Each SVNSP hires resources from one or more SInPs to form VSNs and deploys customized protocol and services. Based on necessity, the number of SVNSPs can be more than two. In traditional WSNs, the infrastructure provider and service provider are the same entity, but VSN differentiate between the infrastructures and service provider's perspective. The motivation behind this is to minimize the cost of establishment and to reduce the manageability effort. The difference between the VSN model and the traditional WSNs model is the presence of two specific roles, SInP and SVNSP.

SInPs deploy and manage the substrate physical sensor network resources. They offer their resources through programmable interfaces to different SVNSPs. The salient features for distinguishing different SInPs are: (i) Types of services for the corresponding SInP. (ii) The vendor specifications and communication protocol of the sensor nodes. Different vendors can deploy sensor nodes and make their individual infrastructure which can be used by the specific

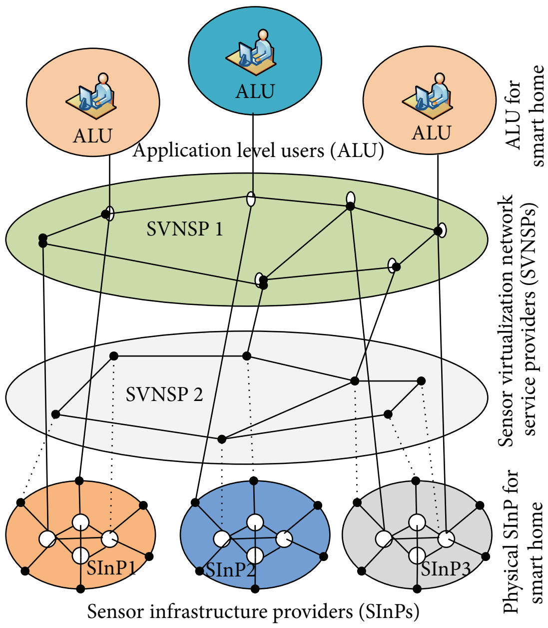

Figure 1: Sensor network virtualization in smart home.

entity or can be leased to different virtual service providing companies to run their individual applications. It helps the effective utilization of the physical sensor node on a broader scale.

SVNSP leases resources from multiple SInPs to create and deploy VSNs by sharing allocated virtualized network resources to offer end-to-end application user services. SVNSP can achieve network services from multiple SInPs. The resources used by the SVNSP can be reused by the other SVNSPs when it is required.

ALUs in the VSN model are similar to those of the existing WSNs, except that the existence of multiple SVNSPs from competing SInPs provides a wide range of choices. Any end user can connect to multiple SVNSPs from different SInPs for using multiple applications. In this smart home application model ALU plays an important role, since this model provide different services such as video/image, temperature humidity, and light detection services through the VSN architecture.

2.4. Related Works. Currently, there are few approaches in the WSNs [7–13] that focus on the virtual and overlay sensor network rather than the purist view of VSN approach introduced in this paper. Table 1 summarizes the area of a few of research projects that act as the background of the proposed research approach. It demonstrates the contemporary research directions in the field of the virtualization of sensor network in general.

Recently federated secure sensor network laboratory (FRESnel) aims to build a large-scale sensor framework. The goal of this project is to offer an environment that can support multiple applications running on each sensor node [11]. It provides an execution environment that hides the system details from the running applications. The system operates in a shared environment. The key characteristics of this approach are a virtualization layer that is running on each sensor node and provides abstracts access to sensor resources which allows the management of these resources through policies expressed by the infrastructure owner. A runtime environment on each node allows multiple applications to run inside the sensor node. It also provides policy based application deployment that enables multiple applications to be deployed over the shared infrastructure. SenShare [12] is another platform that attempts to address the technical challenge of supporting multiple corunning applications in the sensor node. Here, each application operates in an isolated environment consisting of an in-node hardware abstraction layer and a dedicated overlay sensor network. Instead of using virtual machine, SenShare uses a hardware abstraction layer. It is a set of routine in software that emulates some platform specific details, giving programs direct access to the hardware. In MMSPEED [13], a novel packet delivery mechanism has been proposed. It provides QoS differentiation in two quality domains such as timeliness and reliability. This approach is based on multiple logical speed layers over a physical sensor network which is based on conventional virtual sensor network. Based on the speed, it considers different virtual overlay. For virtual layering, it employs virtual isolation among the speed layers. It is accomplished by classifying incoming packets according to their speed classes and placing them into the appropriate priority queue. The abovementioned approaches are based on either traditional virtual sensor network or overlay sensor network rather than purist view of virtualization. Mate [14] and Melete [15] systems are based on the virtual machine approach that provides reliable storage and enables execution of concurrent applications on a single sensor node. VSN approach proposed in this paper is based on Mate and Melete systems. We name this modified version of virtual machine as VSNware. VSNware provides environment to support different application for smart home designing such as temperature, humidity, sound, and video. VSNware helps to provide the purist view of virtualization concept. It does so by dint of separation between SInP and VSNSP which is discussed in the previous sections. To the best of our knowledge, none of the research articles explores VSN approach for designing smart home.

3. VSN Architecture of Smart Home

3.1. System Architecture. Here, we briefly describe the detailed system architecture and software architecture of the sensor virtualization scheme in smart home perspective. In the following sections, we will explain the architecture in details. The system architecture consists of three major layers such as SInP, SVNSP, and ALU. The software architecture describes the virtualization of the sensor gateway router (SGR). To develop the architecture, we found different models very useful such as those in [11, 12, 14, 15].

3.1.1. SInP. The SInP consists of a huge collection of heterogeneous sensor nodes. Since these sensor nodes are serving different purpose of sensing the environment of the smart home, they are of different types such as temperature,

Table 1: VSN research related projects.

Projects	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/Projects/VSNs/vsns.html
Sensor planet	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
DVM	To build a system that supports software reconfiguration in embedded sensor networks at multiple levels	http://nesl.ee.ucla.edu/project/show/51
SensEye	Multitier multimodal sensor networks	http://sensors.cs.umass.edu/projects/senseye/
SenQ	Complex virtual sensors and user-created streams can be dynamically discovered and shared	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

humidity, light, sound, movement, and camera sensors. To sense the environment in the sensor virtualization of a smart home we consider two types of sensor nodes, the fully functional device (FFD) and the reduced functional device (RFD) sensor nodes. SInPs are deployed in the area of interest in a uniformly distributed manner. Each group of sensor nodes are divided into different logical area which is identified by the dotted circles as depicted in figure 2. We call it as SGR domain. Each SGR domain may consist of one or more SGR which is an FFD sensor node. Each SGR supports sensor virtualization environment. In each SGR domain, there are many RFD sensor nodes which perform sensing. RFD is more resource constrained than SGR. Since most of the time sensor nodes are in sleep mode, VSN technique can efficiently utilize the resources of SInP. In this scheme, we use FFD and SGR synonymously.

3.1.2. SVNSP. SVNSP is the virtual sensor network service providing entity. It consists of many virtual SGRs (VSGRs). VSGR is the representation of processing, storage, and other shareable resources of the SGR. And the links between VSGR are the fully or semidedicated channels between the wireless sensor nodes. Each SVNSP provides specific service to the ALU. In Figure 2, we only depict two SVNSPs. There may be as many SVNSPs as the SInP can support and it is based on the ALU requirement.

3.1.3. ALU. ALU is the application level users or consumers of the smart home. Based on the application requirement, ALU connects with the particular SVNSP. In Figure 2, individual user uses multiple SVNSP resources at the same time. Users may be a machine in the case of a machine-to-machine communication. And machine can be individual computers and any other consumer electronics of the smart home.

3.2. Software Architecture for SGR Virtualization. SGR is one of the key components in VSN architecture. The main objective of the virtualization of SGR is to provide an alternative and cost-effective business model for implementing state-of-the-art technology based smart home. As the SGR supports the sensor virtualization environment, the other sensor nodes under SGR only perform sensing activities. Through the virtualization of sensor network technology, an SGR that is a fully functional sensor node can support multiple applications. Figure 3 represents the software architecture of sensor virtualization of a single SGR sensor node. It shows the layered approach of the virtualization of the SGR node. It consists of physical layer, sensor network operating system layer, virtualization layer, and application layer. The lower layer consists of the physical sensor resources such as central processing unit (CPU), USB module, RF module, and storage module. The sensor operating system layer consists of a typical multitasking sensor network operating system. In this model, we use Embedded Linux. It provides the environment to run and execute VSNware. VSNware is the Mate based virtual machine that supports VSN approach in SGR and helps concurrent applications deployment. VSNware layer includes network management module, input/output module, and application management module. The virtualization layer of RFD sensor nodes only senses the smart home environment and sends the data to the SGR node. Finally, the application layer runs multiple smart home applications on the VSNware based SGR sensor node such as temperature sensing application, humidity sensing application, and sound and video sensing application. A

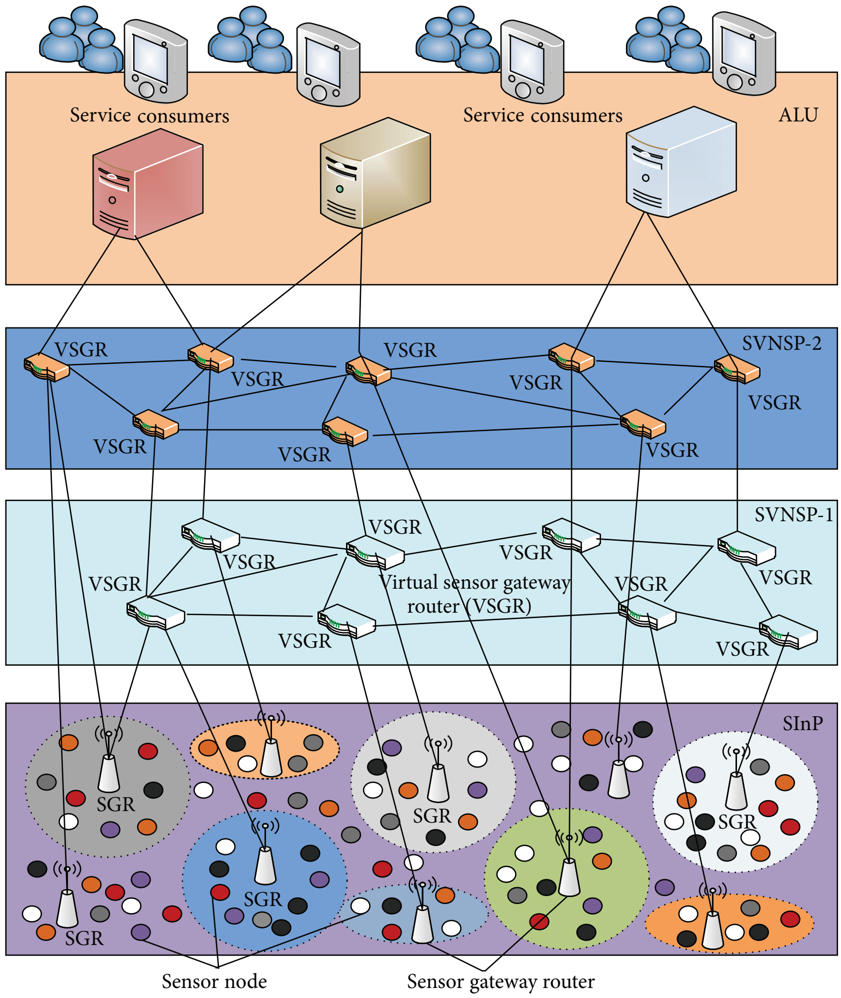

FIGURE 2: System architecture.

complete design and implementation of the state-of-the-art smart home are available at [16].

4. Network Model

We consider densely deployed large-scale and heterogeneous wireless sensor network. In fact, networking in such WSNs is very dynamic. It differs from the traditional wired network. Node in WSNs is very tiny which consists of small processing and storage system. Since VSN is based on WSNs, it inherits most of the properties of WSNs. Link in VSN is different dedicated channels used in WSNs. In this section, we describe the network model of WSNs by using graph theory that follows procedure discussed in [17]. We also discuss the VSN node and VSN link embedding. Virtual node embedding is pretty straightforward like the traditional network embedding. Since the link is wireless so we use different strategy for VSN link embedding.

4.1. SInP. We model the sensor infrastructure provider network as a weighted undirected graph and denote it by $G^{\mathrm{SInP}} = (N^{\mathrm{SInP}}, L^{\mathrm{SInP}})$, where N^{SInP} is the set of physical sensor nodes and L^{SInP} is associated links. SInP sensor nodes are divided into two functionalities based on their processing capability and storage space, that is, common widely deployed sensor nodes and sensor gateway router. Each sensor gateway router in the SInP is associated with the CPU capacity weight value $C(N^{\mathrm{SInP}})$ and its GPS location $\mathrm{loc}(N^{\mathrm{SInP}})$ on a globally understood coordinate system. Each substrate link $l^{\mathrm{SInP}}(i, j) \in L^{\mathrm{SInP}}$ between two substrate gateway router nodes i and j is associated with the bandwidth capacity weight value $b(l^{\mathrm{SInP}})$ denoting the total amount of bandwidth. We denote the set of all substrate paths by P^s and the set of substrate paths from the source node s to the destination node d by $P^s\ (s, d)$. Figure 2 shows the substrate SInP network, where the sensing node is indicated by small circles of different color, and sensor gateway routers are indicated by node with wireless antenna.

4.2. VSN Request by ALU. As we discuss the graph based description of SInP, we also model VSN request as weighted undirected graphs and denote VN requests in terms of service request as the $G^{\mathrm{vsn}}\ (N^{\mathrm{vsn}}, L^{\mathrm{vsn}})$. We mention the requirement

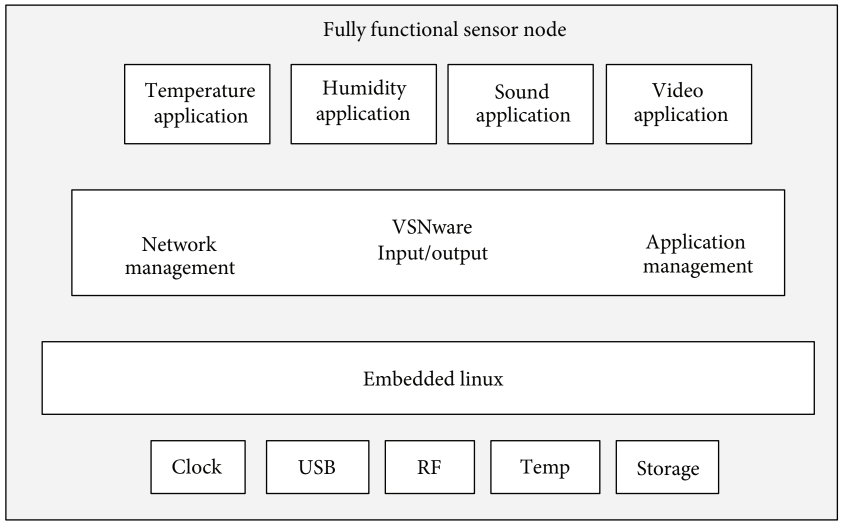

FIGURE 3: Software architecture virtualization of the SGR.

on virtual nodes and links of the substrate physical sensor network. Each VN request has an associated nonnegative value D^{v} expressing how far a virtual node $n^{\text{vsn}} \in N^{\text{vsn}}$ can be embedded from its preferred location $\text{loc}(n^{\text{vsn}})$. D^{v} is expressed naturally as link delay or round-trip time from the $\text{loc}(n^{\text{vsn}})$.

4.3. SInP Network Resources Measurement. To measure the different types of resource usage of the SInP, we use the notion of utility. The substrate SInP node utility $U_{n}^{\text{SInP}}\ (n^{\text{SInP}})$ is defined as the total amount processing power allocated to different virtual sensor nodes hosted on the substrate SInP node $n^{\text{SInP}} \in N^{\text{SInP}}$:

$$U_{n^{\text{SInP}}}\left(n^{\text{SInP}}\right) = \sum c\left(n^{\text{vsn}}\right). \quad (1)$$

The substrate SInP link utility $U_{l}^{\text{SInP}}\ (l^{\text{SInP}})$ is defined as the total amount of link usage by different virtual sensor nodes hosted on the substrate SInP node $n^{\text{SInP}} \in N^{\text{SInP}}$. It is actually the dedicated channel utilization to specific virtual sensor node:

$$U_{l^{\text{SInP}}} = \sum b\left(l^{\text{vsn}}\right). \quad (2)$$

The substrate SInP storage or memory utility $U_{m}^{\text{SInP}}\ (m^{\text{SInP}})$ is defined as the total amount storage usage by different virtual sensor nodes hosted on the substrate SInP node $n^{\text{SInP}} \in N^{\text{SInP}}$. It is actually the memory utilization of different virtual sensor node:

$$U_{m^{\text{SInP}}} = \sum s\left(m^{\text{vsn}}\right). \quad (3)$$

Total utility of processing power, link, and storage can be calculated by summing up the above three equations (1), (2), and (3). Here α, β, and γ are the weighted value to express the node, link, and storage capacity by single utility:

$$U_{T^{\text{SInP}}} = \alpha \sum c\left(n^{\text{vsn}}\right) + \beta \sum b\left(l^{\text{vsn}}\right) + \gamma \sum s\left(m^{\text{vsn}}\right). \quad (4)$$

4.4. Residual Resources Measurement. Residual resources management is performed by measuring the available remaining resources after utilization. In this section, we have given the mathematical formulation of the remaining resources of SInP sensor node, corresponding link, and storage only. The residual capacity of the SInP sensor nodes is defined as the total processing capacity of the sensor nodes which is explained by (5):

$$R_{n^{\text{SInP}}}\left(n^{\text{SInP}}\right) = \sum_{n \in N} c\left(n^{\text{SInP}}\right) - U_{n^{\text{SInP}}}\left(n^{\text{SInP}}\right). \quad (5)$$

In wireless sensor network, communication is performed by wireless links. By link, here, we mean wireless between different SGR nodes. We allocate different channel of a particular wireless link to a particular application in the virtualization of sensor network. Equation (6) represents the residual channels capacity in the underlying SInP:

$$R_{l^{\text{SInP}}}\left(l^{\text{SInP}}\right) = \sum_{l \in L} b\left(l^{\text{SInP}}\right) - U_{l^{\text{SInP}}}\left(l^{\text{SInP}}\right). \quad (6)$$

There are two types of storage in the underlying SInPs such as flash memory and SDRAM. In this mathematical model, we only consider the SDRAM which is only physical memory shared by different applications in the VSN applications. Equation (7) shows the total remaining residual storage for further applications:

$$R_{s^{\text{SInP}}}\left(s^{\text{SInP}}\right) = \sum_{m \in M} s\left(m^{\text{vsn}}\right) - U_{m^{\text{SInP}}}\left(m^{\text{SInP}}\right). \quad (7)$$

4.5. VSN Node and Link Embedding. In this work, VSN node and link embedding is very much restricted to SGR and wireless link between different SGRs. Different SVNSP nodes share the same or different SGR of the SInP. The typical sharing depends on the storage limit of the SGR. For wireless link embedding, we consider the efficient channel utilization. Individual SVNSP provides particular services.

Table 2: System specifications.

Type	Specifications
Sensor node	Imote2
CPU	Marvel PXA27x ARM
CPU speed	400 MHz
Operating system	Embedded Linux
OS version	2.6.29
VM	VSNware
Flash size	32 MB
SDRAM size	32 MB
Interface	USB
Bandwidth	256 Kbps
Radio	IEEE 802.15.4

For example, SVNSP-1 provides sound detection services and uses channel-1; SVNSP-2 provides temperature monitoring services and uses channel-2. In this way the same SInP may be used by different SVNSP.

5. Performance Evaluations

In this section, we discuss the simulation environment and evaluation results. We have implemented and evaluated the VSNware on the Imote2 sensor node. The Imote2 sensor node has Marvel PXA27x ARM processor with 400 MHz clock speed, 32 MB Flash, and 32 MB SDRAM. We have selected Imote2 as the sensor node for its advanced features such as memory size and CPU speed. In this evaluation, sensor node runs Embedded Linux as its operating system. The detailed system specifications are given in Table 2. VSNware environment restricts access to all physical devices on the node, thus ensuring that applications are only allowed to access the hardware through the VSNware. VSNware is installed in all sensor nodes running as a process. VSNware supports concurrent application execution and dynamic application deployment, although it may be extended to work with operating systems that support dynamically loadable modules. The VSNware supports applications implemented in high-level scripts, thereby enabling low-cost multitasking of the sensor network. For evaluations, we compare the proposed VSN approach with SenShare [12] and traditional WSNs approach. SenShare provides a clear decoupling between sensor infrastructure provider and the running applications, building the concept of overlay network. Traditional WSNs approach in this evaluation process is used to emulate the exact scenario which is provided by the proposed VSN approach. We have divided the evaluation section in two parts. The first part focuses on the cost based evaluations and the second part focuses on the VSNware based system evaluations. Cost based evaluation simply evaluates VSN deployment based on the price of the sensor mote.

5.1. Cost Based Evaluations. For cost based evaluation, we consider 100-square meter area. There is one sensor mote per square meter. So for 100-square meter space we need to deploy 100 sensor motes. We first consider 2 typical types of application such as image processing and single data sensing application scenario. Then, we consider 4-application scenario for smart home designing. The cost based analysis of the two cases is shown in Figures 4 and 5. The approximate cost of each mote for typical two-application scenario is given in Table 3.

Table 3: Cost parameter for two applications.

Type of sensor	Scenarios	Costs
Image processing	Single data sensing	75 $
Data sensing	Single data sensing	50 $
VSN application	VSN	100 $
Traditional approach	Traditional	125 $

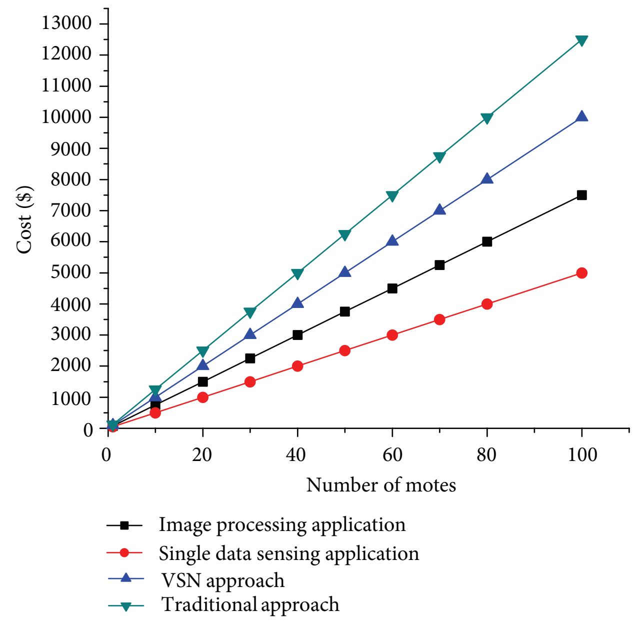

Figure 4: Cost model for 2 applications in VSN environment.

Figure 4 shows the number of motes versus cost for typical two-application scenario. It also depicts that in, terms of costs, VSN approach outperforms the traditional approach.

The analysis shows that proposed VSN approach reduces costing by 56% compared to traditional WSNs approach for two applications. The reason behind this performance is simple and straightforward. Since a single mote supported by VSN approach provides multiple services. But in the traditional approach, to provide the same services like VSN approach, it needs to deploy individual sensor nodes. Figure 4 also shows the single data sensing outperforms the VSN approach, since it costs less for sensing individual data.

The approximate cost of the specific mote for typical four-application scenario is given in Table 4. The cost parameters vary a little due to the specifications of individual mote. Figure 5 depicts four-application scenario for smart home designing. The scenario compares cost involvement of single data sensing, VSN and traditional approach. For this case also VSN approach minimizes cost compared to traditional approach. The analysis shows that proposed VSN, approach

Table 4: Cost parameter for four applications.

Type of sensors	Scenarios	Cost
Temperature	Single data sensing	20 $
Humidity	Single data sensing	25 $
Sound	Single data sensing	30 $
Image	Single data sensing	30 $
VSN application	VSN approach	80 $
Traditional approach	Traditional	125 $

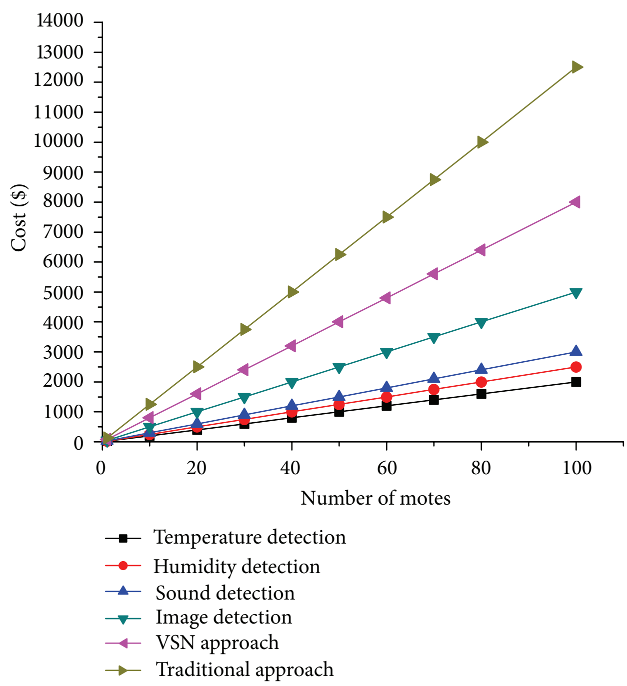

Figure 5: Cost model for 4 applications in VSN environment.

reduces costing by 61% compared to the traditional WNS approach for four applications. From the typical two and four-application scenario, we can infer that with the increases of application in VSN approach, the costing is reduced significantly.

5.2. VSNware System Based Evaluation. In this case, utilization of VSNware is the technical point of VSN based system evaluation for smart home. In this evaluation process, we focus on different issues such as memory utilization, CPU utilization, and execution times of individual applications. Memory and CPU utilization in an efficient way is the main concern of VSN approach. Execution time and CPU utilization are related to each other. In the following, we have compared the memory and CPU utilization of our proposed VSN scheme to the SenShare and traditional approaches.

In Figure 6, we plot memory usage of the traditional approach, SenShare, and VSN approach. The sensor virtualization version includes the overhead of the applications due to additional usage of memory of a single sensor node. However, the overhead is linear and increases slowly based on the deployment of the number of applications. In comparison

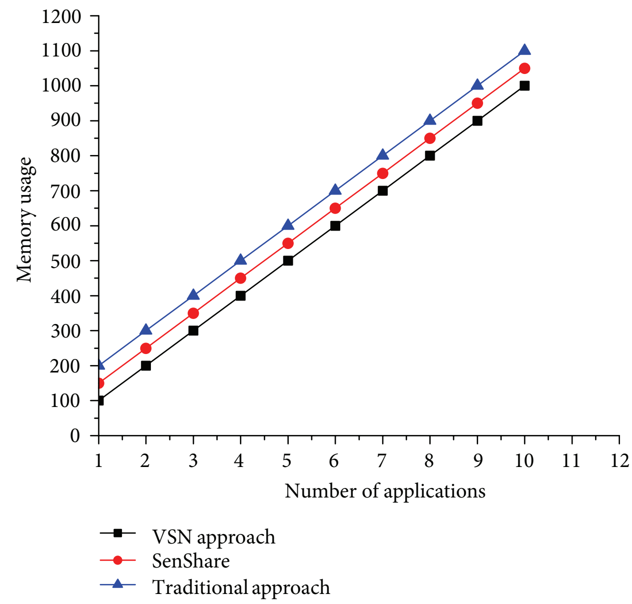

Figure 6: Comparative memory usage versus number of applications.

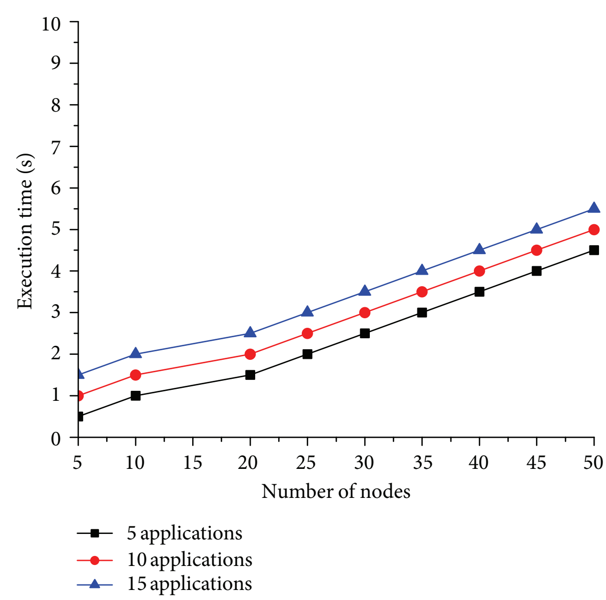

Figure 7: Execution time versus number of nodes.

to SenShare and traditional approaches, the proposed VSN approach provides better performances. The performance evaluation shows that the proposed VSN approach reduces 53% and 56% of average memory utilization than the SenShare and traditional approach, respectively.

In Figure 7, we plot execution time of different applications in different number of virtualized sensor nodes. The figure shows execution time of 5, 10, and 15 applications based on the virtualization of sensor network methodology. Execution time increases linearly based on the number of application in a sensor node.

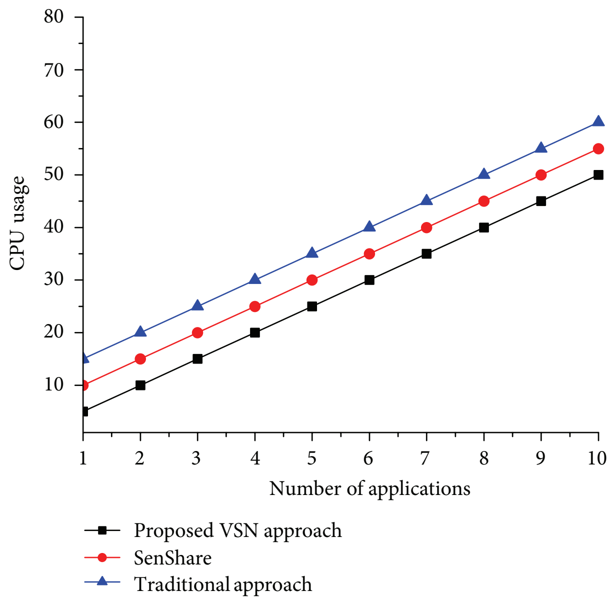

FIGURE 8: Comparative CPU usage versus number of applications.

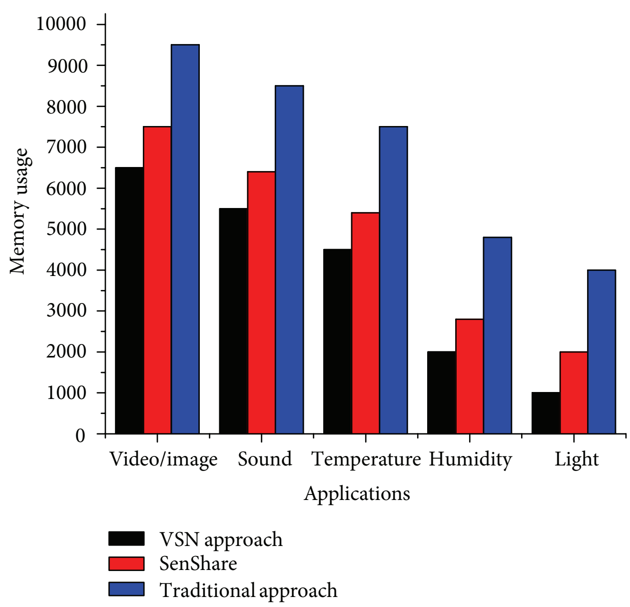

FIGURE 9: Comparative memory usage by applications.

In Figure 8, we plot the CPU utilization versus the number of applications in the traditional approach, SenShare approach, and in the virtualization of sensor network scenario. CPU utilization increases linearly in all the cases. In this scenario, the VSN approach uses CPU resources efficiently, since it executes different application on the same sensor node. The performance evaluation result shows that the proposed VSN approach reduces 56% and 60% of average CPU utilization than the SenShare and traditional approach, respectively.

In Figure 9, we depict the memory usage of different typical applications such as video/image, sound, temperature, humidity, and light detections. Video/image applications use more memory than other applications such as sound, temperature, humidity, and light. Since the total memory in Imote2 sensor node is 32 MB, it can provide the environment for the execution and running of the typical applications. The figure also demonstrates the comparative memory usage of different applications in SenShare scheme, traditional WSNs, and proposed VSN approach. In all the cases the proposed VSN scheme uses memory in an efficient way than other conventional schemes.

6. Future Research Scope

Virtualization has opened a new dimension in different research areas especially in the field of WSNs. The whole world is facing recession, and at the same time, elderly people are increasing rapidly in the developed countries. To take care of the elderly people, smart home can provide a feasible alternative which is also not very much affordable. To provide cost-effective business model of smart home researchers are paying significant attentions. In this regard, virtualization in sensor network can be a promising future research issue for large-scale sensor network deployment in smart home. Among the future research scopes, a few of them may be developing convenient operating system which can support virtualization in sensor network. Managing resources, scheduling the sensing activities, and minimizing energy consumption are also a few of the innovative research areas for sensor network virtualization in connection with smart home [16, 18–23]. Large-scale federated sensor network framework for smart home and smart city with multiple applications sharing the same physical resources has already attracted the researchers. There are a lot of challenges and opportunities in this field that may be explored in the near future.

7. Conclusions

In this paper, we present virtualization approach in wireless sensor network concerning its application in smart home. By allowing multiple heterogeneous nodes in different sensor network architecture to coexist on a shared physical substrate, virtualization approach may provide flexibility, promote diversity, ensure security, and increase manageability for smart home applications. Here, we propose a business model of smart home based on VSN, protocol architecture of a virtualized sensor node, mathematical model for resource allocation and measurement and evaluate the model for smart home implementation. Our future interest is to emphasize and building a large-scale federated sensor network framework with multiple applications sharing the same physical resources that will facilitate the rapid deployment of the emerging smart home.

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