Towards Developing Smart Environment using Wireless Sensor and Ad Hoc Networks

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Abstract. The miniaturization process of various sensing devices has become a reality by enormous research and advancements accomplished in MEMS (Micro Electro-Mechanical Systems) and VLSI (Very Large Scale Integration) lithography. With the advancements of such optimization techniques for hardware, algorithms, and protocols for networking, various wireless technologies have also emerged. The attractive features of these modern technologies have attracted many researchers to work on the design, application and utilization of systems benefited by these high-tech equipments. As a consequence, the idea of smart environment has been come into vision. The focus of this paper is to propose a framework for developing a smart environment aided with the wireless technologies which not only aims at smartening the surrounding environment but also could facilitate the use of a number of smart systems.

1 Introduction

Smart environments represent the future evolutionary development step for the real world environment of present time. With the continuing advances of extremely small, low-power computing and wireless communications technologies, we are beginning to see a proliferation of small, portable information appliances for individuals and powerful sensors that can be embedded and networked in environments [1]. The advancements of these technologies have shown promise to smarten our surrounding environment and eventually the concept of smart environment has been emerged. Such environments are expected to be aware of the activities performed within it and will be capable of supporting these activities without increasing the cognitive load on the users in the space [2]. A smart environment, like any conscious organism, relies first and foremost on sensory data acquired from multiple sensors in distributed locations of real world. It gathers information about its surroundings as well as about its internal workings [3].

The intent of this paper is to propose a framework to design a smart environment with the utilization of various wireless technologies. For our usability study we have considered a developing country Bangladesh, as a model. We extended the mere definition of smart environment and proposed a framework not only to design a smart environment but also to extend its usage for some practical purposes.

The organization of this paper is as follows: Following the section 1, Section 2 discusses the related works, Section 3 gives an overview of the emerging wireless sensor network and wireless ad hoc network technologies. We also discuss the major benefits of these two types of technologies and strengthen the appeal of using these technologies for designing the framework which eventually aims at developing smart environment as well as smart systems. Section 4 deals with various parts of the proposed framework, Section 5 talks about the applicability of such a framework for some practical purposes which would be functioning together to develop the overall smart environment and Section 6 contains the concluding remarks along with some predictable technical or operational challenges to implement such a system in a developing country like Bangladesh.

2 Related Works

[4] presents an overview of ad-hoc smart environments and mentions a number of research issues and challenges for designing such environments. In [5] the authors mention the value of handheld devices in smart environment. They identify the key roles of the smart handheld and wireless devices in a smart environment. [1] discusses inter-disciplinary research issues and the need for effective testbeds for researching smart environments. [2] tells about ubiquitous sensing for smart and aware environment. Their work mainly focuses on the development of various types of intelligent environments like smart classrooms, smart living room, meeting room, smart office etc. [6] aims at developing a large-scale smart environment and discusses a software infrastructure to support the smart activities. In [7] sensor-based wireless networks are used for smart developmental problem-solving environment which mainly targets the improvement of early children education.

Our work is different from all of the above studies as we incorporate several smart systems to work with smart wireless technologies to design a large-scale smart environment. While some other research works [8], [9], [10] focused on specific smart applications, we propose a generic framework of smart environment which integrates advanced and emerging wireless applications with other emerging smart systems and services.

3 Wireless Sensor and Ad Hoc Networks – A Background

3.1 Overview of Wireless Sensor and Wireless Ad Hoc Networks

A wireless sensor network (WSN) is a combination of a number of sensor nodes connected via wireless communications. Recent advancements in the commercial IC (Integrated Circuit) fabrication technology and wireless technologies have made it possible to integrate sensing, signal processing and wireless communication in one integrated circuit [11], [12]. These devices are popularly known as wireless integrated network sensors (WINS) [13]. Sensors can monitor temperature, pressure, humidity, soil makeup, vehicular movement, noise levels, lighting conditions, the presence or absence of certain kinds of objects or substances, mechanical stress levels on attached objects, and other properties [14], [15]. Their mechanism may be seismic, magnetic, thermal, visual, infrared, acoustic or radar [16], [17].When networked, such sensor nodes could build up the part of larger systems, providing data, as well as performing and controlling multitude of tasks and functions (for example, surveillance, target tracking etc). In practical, large number of sensor nodes could be dispersed on demand at any time at designated locations, referred to as area of interest (AOI), or at random at specified areas. Figure 1(a) shows a graphical view of a wireless sensor network.

Wireless ad hoc networks, on the other hand are self-organizing, dynamic topology networks formed by a collection of mobile nodes through radio links [18]. Minimal configuration, absence of infrastructure and quick deployment make them convenient for emergency situations such as natural or human-induced disasters, medical emergency or military conflicts. Some of the characteristics of ad hoc networks are: wireless connection among the nodes within the network, mobile nodes within the network, infrastructure less or semi-infrastructure, dynamically changing topology, no centralized access point, energy constrained nodes and multi-hop communication. Figure 1(b) shows the conceptual view of a wireless ad hoc network.

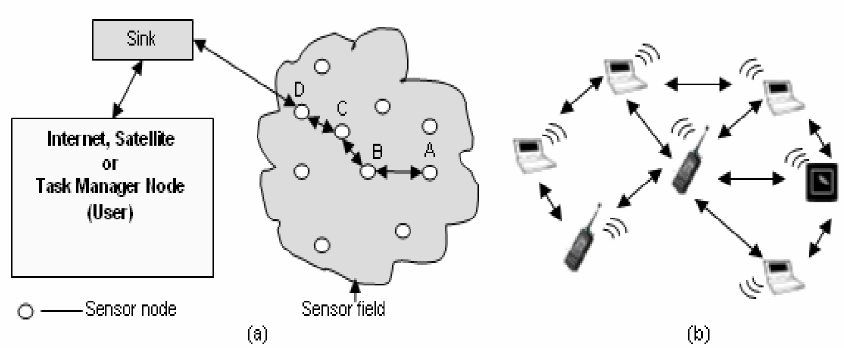

Fig. 1. (a) Sensors in a sensor network (b) Wireless ad hoc network

3.2 Benefits of Wireless Sensor Networks

Fundamental objectives of sensor networks are reliability, accuracy, flexibility, cost effectiveness and ease of deployment. The benefits of WSNs are outlined below:

- **Sensing accuracy:** The utilization of a larger number and variety of sensor nodes provides potential for greater accuracy in the information gathered as compared to that obtained from a single sensor.
- **Area coverage:** This implies that fast and efficient sensor network could span a greater geographical area without adverse impact on the overall network cost.
- **Fault tolerance:** Device redundancy and consequently information redundancy can be utilized to ensure a level of fault tolerance in individual sensors.
- **Connectivity:** Multiple sensor networks may be connected through sink nodes (see Figure 1(a)), along with existing wired networks (e.g. Internet). The clustering of networks enables each individual network to focus on specific areas or events and share only relevant information.
- **Minimal human interaction:** Having minimum human interaction makes the possibility of having less interruption of the system.
- **Operability in harsh environments:** Sensor nodes, consisting of robust sensor design, integrated with high levels of fault tolerance can be deployed in harsh environments that make the sensor networks more effective.
- **Dynamic sensor scheduling:** Implying some scheduling scheme, sensor network is capable of setting priority for data transmission.

3.3 Benefits of Wireless Ad Hoc Networks

Like wireless sensor networks, wireless ad hoc networks also have some attractive benefits. The significant benefits of ad hoc networks are:

- **Ease of Deployment:** Ad hoc networks are easily deployable as they do not need any fixed infrastructure of central administration.
- **Speed of Deployment:** Ad hoc networks are deployable on the fly. They are autonomous and infrastructure-less or semi-infrastructure.
- **Cost of Deployment:** There is no incremental cost for deployment; however, costs may rise depending upon the nodes associated with the network.
- **Anywhere, anytime:** Wireless ad hoc networks could be deployed anywhere, anytime especially in the hostile or geographically harsh areas where fixed network deployment is difficult.

4 Proposed Framework

The enormous promise, benefits and attractive features of the wireless sensor and wireless ad hoc networks persuade us to utilize them to design a framework [19] to develop a smart environment which not only would act smartly but also would work in co-operation with some other practical smart systems. In this paper, we considered the combination of some of the smart technologies and their usages as parts of our smart environment. We focused basically on the rural areas of Bangladesh as smartening the rural areas along with other rich and developed areas could effectively develop a large-scale smart environment.

Timely and accurate data are very necessary for many applications as well as for good governance. In most of the developing countries, often the governments cannot get the actual information about many of the rural areas. On the other hand, as most of the rural areas are either hard-to-reach or technologically lagging, they cannot get most of the benefits offered by the government. In some cases, some rural areas are deprived of good education facilities, health care, food and nutrition, disaster management systems, disaster relief etc. So, acquiring exact and timely data from these rural areas is a crucial task which could assist the government to extend their development activities as well as to provide the rural areas with the facilities to fulfill the basic needs for living. Keeping this point in mind, we designed our framework for a smart environment which not only uses sensory data but also data from other sources and as a whole we term this a smart environment. We also discuss how the collected data could effectively be used for providing various types of smart services even to the rural areas in a developing country like Bangladesh.

4.1 Framework – Phase One

In our proposed system, wireless sensor networks underpin the phase one, which are used for collecting various types of data from the environment. The sensors are deployed over the crucial parts of rural areas, river banks, geographically challenging areas (for example; hilly areas) and other areas of interest. The sensor networks could collect various critical data (e.g., level of water in the rivers which could help for flood warning, earthquakes etc.) and send them to the kiosks. Each of the villages or areas of interest has at least a kiosk (acts as a sink) which is equipped with computers for storing acquired data. In addition to the sensory data collected by the wireless sensor networks, other necessary data like demographic data, health care information (for example, arsenic problem in the rural areas of Bangladesh), agricultural information, educational information etc. could be manually entered into the kiosks. Various kiosks, K_1, K_2, K_3,……,K_n established in different areas are shown in the Figure 3. All of these kiosks are capable of wireless communications.

4.2 Framework – Phase Two

In phase two, Mobile Access Points (MAPs) play the major role. A MAP is a vehicle mounted wireless access point which uses low-cost Wi-Fi (Wireless Fidelity) technology [20], [21]. In Figure 3 we have shown MAP_i where $i=1,2,3,4 \ldots\ldots n$ and $i \geq n$ (n is the number of kiosks). These MAPs move around the kiosks in different areas and collect data from the kiosks. When a MAP comes near to a kiosk, a wireless ad hoc network is automatically formed and all the raw data are downloaded into the MAP. The 802.11b Wi-Fi technology operates in the 2.4 GHz range offering data speeds up to 11 megabits per second [22]. There are two other specifications that offer up to five times the raw data rate, or 54 Mbps. One is 802.11g which operates on the same 2.4 GHz frequency band as 802.11b. The other alternative 802.11a, occupies frequencies in the 5 GHz band. If offers less range of coverage than either 802.11b and 802.11g but offers up to 12 non-overlapping channels, compared to three for 802.11b or 802.11g, so it can handle more traffic than it's 2.4 GHz counterpart [23]. Based on the need or particular situation, any of these specifications is chosen for a particular area for transmitting stored data from the kiosks to the MAPs. These data are then taken and delivered to the DPCs (Data Processing Center) located at nearby towns by the MAPs. So, a Wi-Fi enabled MAP operates in two ways:

1) Forms wireless ad hoc network automatically when comes close to the kiosks and collects data from the rural kiosks using Wi-Fi radio transceivers.

2) Again, forms wireless ad hoc network when comes close to the DPCs and delivers raw data to the DPCs using Wi-Fi radio transceivers.

The major task of the MAPs is to ensure quick acquisition and delivery of various types of sensory and human inputted data which could be helpful to bridge the gaps between rural areas and developed town areas.

4.3 Framework – Phase Three

DPCs are capable of wireless communications. All the incoming data from the MAPs are stored temporarily and processed in the DPCs. For data integrity and authenticity, all the DPCs are networked either using wireless or wired connections. In Figure 3, we have shown the DPC_1, DPC_2, $DPC_3 \ldots DPC_m$ where, $m \leq n \leq i$ those are set up throughout the town areas. A functional diagram of a DPC is shown in Figure 2. In the data processing phase, related data from other DPCs are collected using wired or wireless transmission and after processing the data, confidence threshold is checked. Error detection is defined by the predetermined threshold and if necessary sent back to processing mechanism. Once processed data is ready, they are transmitted to the CDC (Central Data Center) for the next phase. Wireless or wired transmission could be used for this data transfer.

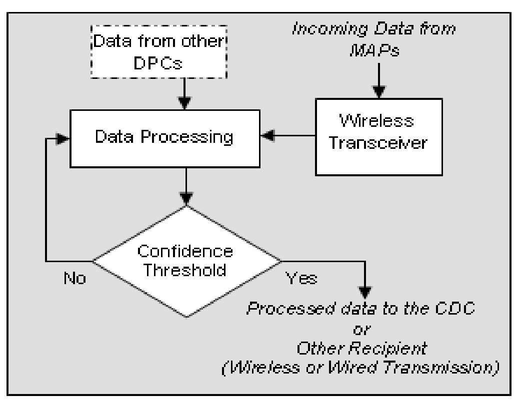

Fig. 2. Functional diagram of a DPC aided with wireless communications

4.4 Framework - Phase Four

In this phase, the processed data from the DPCs are gathered in the CDC. Now, the CDC could combine this data with the past records for a particular rural area and supply the data to the DCC (Decision and Command Center). In this way, the government gets the timely and processed data from the rural and other areas of interest and could take immediate actions accordingly. This data not only helps the government to provide various services to the rural areas but also helps in the emergency situations. Depending upon the gravity of the data, (for example, emergency situations like, cyclones, flash floods etc.), the MAPs or the DPCs could use the wireless communications to directly call the emergency or other services bypassing the CDC and DCC. Figure 3 shows the optional wireless connectivity using dashed lines.

5 Application View of the Proposed Framework

The major theme of the proposed framework is to gather timely and accurate data and information which would definitely facilitate various kinds of smart systems. This section talks about various possible applications and systems which could operate in parallel with the implementation of the proposed framework.

5.1 Flood and Water Level Monitoring System

By the geographical location in the globe, a country like Bangladesh is very susceptible to many environmental calamities like, flood, cyclone, tsunami etc. Good warning systems could effectively help to mitigate the damages caused by these natural disasters. Hence, the development of wireless sensor networks to assist meteorologists has a great deal of national importance in such countries. Sensor networks provide the ability to gather accurate and reliable information, to enable early warnings and rapid coordinated responses to potential threats. This encompasses the ability to save lives through environmental monitoring of natural disasters. Definitely proper infrastructure could make a huge difference in such a country. There is a great deal of potential for sensor networks to be deployed for the flood and water level monitoring system especially in a tropical region like Bangladesh. As sensor networks are deployed in the phase one of our proposed system, they could be utilized for this purpose. Here we discuss how this phase would assist for the development of a smart flood and water level monitoring system.

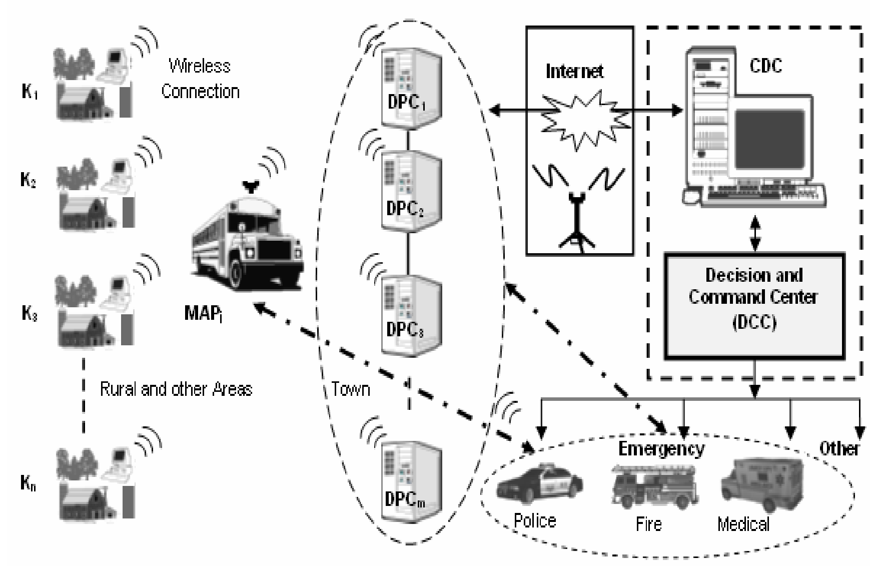

Fig. 3. Proposed Framework aided with wireless technologies

At the very first stage, physically dispersed sensor nodes along the riverbanks and crucial parts of the areas of interest monitor and collect the water flow level in the rivers. The changes of water level are eventually sent to the kiosks which in turn send the raw data to the DPCs. As shown in the Figure 2, DPCs check the correctness of the data and after a proper analysis delivers the data to other phases of the framework. If a considerable change is detected, the smart disaster management system starts working as DPCs are also capable of initiating the emergency response system by-passing CDC and DCC.

5.2 Providing E-Services to the Rural Areas

The smart environment promised by the proposed framework also promises the delivery of several e-services to the hard-to-reach rural areas. Here we discuss how various smart e-services could be benefited with the utilization of this framework.

E-Medicine and E-Health care

Computer-supported medical diagnosis or e-medicine [24] and e-health care [25], [26] could significantly be benefited by the use of our framework. For improving the health scenario of the rural areas, at least a paramedical doctor should be associated with each of the kiosks or in the village dispensaries. The doctors could use the computers for keeping records about the symptoms of the diseases of the incoming patients. The MAPs could automatically download these medical solution requests from the kiosks and deliver those to the town hospitals. The hospitals could have DPCs or nearby DPC could supply the requests to the hospital. In the reverse way, the medical solutions from the hospitals could be sent to the village dispensaries using wireless technologies. Again the government could be well-informed about some critical health information like arsenic problem, diarrhoea breakout etc. in the rural areas. This framework certainly reduces the cost of sending medical teams. Based on the information received, in severe situations, the government could take this decision but otherwise, the solutions related to these health issues could be sent to the village paramedical doctors who will in turn work accordingly. Thus, it ensures low cost e-medicine and e-health care service for the rural areas.

E-Learning

E-Learning refers to the utilization of information systems and information technology in educational services [27]. Various applications and processes that could be delivered in synchronous or asynchronous format, like web-based learning, computer-based learning, virtual classrooms, digital collaboration etc. are the examples of E-Learning methodologies. The ultimate goal of E-Learning is to bring the learning to the learners, not to bring the learners to learning. Many rural areas do not have proper educational facilities; hence, the proposed framework could be used for delivering quality learning materials to the students as well as to bring quality learning to the learners. This could definitely facilitate the improvement of the education sector in the developing countries. As mentioned earlier, depending upon the requirement particular Wi-Fi technology could be chosen and the MAPs could be used for delivering e-learning materials even in audio-visual format.

E-Commerce and E-Business

Some of the rural areas have small cottage industries which produce traditional handicrafts which often have a great demand in the other areas or sometimes in other countries. In our framework, the MAPs could be used for delivering the demands from outside and also the information about exporting these traditional goods. At the same time, information about other goods and products could be supplied to the rural areas. So, it could be a means of expanding e-commerce even in the rural areas.

As a whole the framework could significantly contribute to the development of a large-scale smart environment and could make life easier.

6 Concluding Remarks

While our proposed framework seems to be promising for developing a large-scale smart environment as well as the development of rural areas, there could arise some operational and technical challenges for implementing such a framework:

- Primary installation costs might be a bit high for the developing countries to bear. So, the MIS specialists should come up with proper cost analysis of such a system
- Further practical work and detailed planning is required to decide which areas should have kiosks, which areas should be chosen for deploying wireless sensors etc
- Computer literate people are required at each village kiosk. So, some of the people should be trained for this
- Some rural areas might not have good communication facilities. Roads are often not suitable for the movement of heavy vehicles like the wireless access point carrier buses or MAPs
- In disastrous situations like, storm, heavy rainfall etc. the wireless technology might not come as useful

Any new system is often expensive and has some preliminary installation costs. But, once it is set up, it could run smoothly and serve for the greater benefits. As wireless technologies are growing rapidly to replace wired systems in many sectors and to make life easier, we believe that, our proposed framework could play a key role for the development of a large-scale smart environment as well as to provide various e-services to the village inhabitants. In comparison with other existing systems, we believe that, this framework would be helpful to provide cost-effective telemedicine facilities to the people in the rural areas. It could also be very useful to face pre and post-disaster situations.

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