1-20-2013

Exploring Broadband Enabled Smart eEnvironment: Wireless Sensor (Mesh) Network

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Abstract
This paper explored the emergent importance of the use sensors as complementary or as alternative to environmental sensing and monitoring, industrial monitoring, and surface explorations. Advances in wireless broadband technology have enabled the use Wireless Sensor (Mesh) Network (WSN), a type mobile ad hoc network (MANET), in all facet of human endeavor. As a next-generation wireless communication, which centered on energy savings, communication reliability, and security, WSN has increased our processing, sensing, and communications capabilities. Hence, this paper is an exploration of recent reliance on sensors as result of broadband enabled smart environment for activities, such as environmental and habitat monitory, military surveillance, target tracking, search and rescue, and logistical tracking and supply-chain management.

Keywords: Wireless Network, Mesh, WSN, WSMN, Broadband, RFID, ad hoc network,Next Generation Wireless Communication (NGWC), environmental and habitat monitory, military surveillance, target tracking, search and rescue, logistical tracking and supply-chain management.

Permanent URL: http://sprouts.aisnet.org/13-3

Reference: Offor, P. I. (2013). "Exploring Broadband Enabled Smart eEnvironment: Wireless Sensor (Mesh) Network," . *Sprouts: Working Papers on Information Systems*, 13(3). http://sprouts.aisnet.org/13-3

Introduction

Wireless broadband has revolutionized the world and has ushered in a new world full of smart environment in our industries, homes, exploration, maintenance, supply-chain, distribution management, and transportation (Lewis, 2004). Wireless Sensor (Mesh) Network (WSN) is a network that combines processes, sensors, and communications capabilities into an embedded system or device and routes data from the device and among nodes in a mesh topology through a designated gateway to a designated database or server (Hill, Horton, Kling, & Krishnamurthy, 2004). The network automatically establishes *ad hoc* network and maintains connectivity through dynamic self-organization and self-configuration (Akyildiz, 2005). Wireless Sensor Network is scalable to any number of nodes, in hundreds or thousands, and it does not require additional or external infrastructure, i.e., it operates within available and existing network. WSN is also a low energy communication network and has the capacity to collect and transfer real-time data through its designated gateway that is connected to either LAN (local area network), WLAN (wireless local area network), WAN (wide area network, MAN (metropolitan area network) and the like. The network architecture or topology could have a planned or unplanned node placement, directional or omni-directional antennas, or single-hop base stations or multi-hop routing (Bicket, Aguayo, Biswas, & Morris, 2005).

Yick, Mukherjee, and Ghosal (2008) classified wireless sensor network platforms into terrestrial (sensor nodes deployed on land); underground (sensor nodes deployed in caves, mines, or underground); underwater (sensor nodes deployed into the ocean environment); multimedia (sensor nodes devices capable of storing, processing, and retrieving multimedia data—video, audio, and images); and mobile (sensor nodes that are mobile capable). In addition, Yick et al. (2008) described WSN application based on the aforementioned taxonomy: Terrestrial WSN activities deal with environmental sensing and monitoring, industrial monitoring, and surface explorations. Underground WSN activities deal with agricultural monitoring; landscape management; underground structural monitoring; underground environmental monitoring of soil, water, or mineral; and military border monitoring. Underwater WSN activities deal with pollution monitoring, undersea surveillance and exploration, disaster prevention monitoring, seismic and equipment, and underwater robotics. Multimedia WSN activities deal with enhancement to existing WSN applications. Mobile WSN activities deal with environmental and habitat monitory, military surveillance, target tracking, search and rescue, and logistical tracking and supply-chain management.

The network offers the same control services as wired infrastructure, yet with low installation and maintenance cost (Alcaraz & Lopez, 2011). As a next-generation wireless communication, which is centered on energy savings, communication reliability, security, and coexistence with other communication systems, it has helped in the development of new industrial communication standards: ZigBee standards (ZigBee Website, 2012); WirelessHART communication protocol standard (Hart Communication Website, 2012); and ISA automation and wireless standards (ISA Website, 2012) according to Alcaraz and Lopez (2011).

Background

Early development of WSN started from a need to fulfill military application in the areas of battlefield surveillance (Callaway, 2005); today, industries and practitioners use the network in variety of ways to monitor, control, and assess environmental conditions and as a tracking system anywhere, anytime. Callaway (2003) described how the U.S. Signal Corps received authorization in 1921 for the establishment of War Department Radio Net, and by 1925 had created 164 radiotelegraphic stations. Impressively, by 1933, the stations were sending over 26 million words of messages annually. Furthermore, early characterization of wireless communication network showed that wireless sensor network systems require hierarchy of nodes, from low-level sensors to a high-level data aggregation, analysis, and storage (Hill et al., 2004). The data flow could best be described with tree network according Callaway (2005):

> Messages generated at the lower levels were passed up the tree to a station that had the destination below it in the tree; at that point, the message was routed back down the tree to its destination. With the exception of the leaves of the tree, each member of the tree acted as a Net Control Station (NCS) of a first “tactical net” consisting of itself and stations immediately below it in the hierarchy, and as a member of a second tactical net controlled by the station directly above it (p. 22).

With the Internet of Things (uniquely identifiable objects and their virtual representations in the internet-like structure) and with the ubiquitous of networks capable systems today, the potential is growing and unlimited for systems that could sensor and track people and things using wireless sensor network. The point is that “if we had computers that knew everything there was to know about things (using data they gathered without any help from us) we would be able to track and count everything, and greatly reduce waste, loss and cost. We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best,” according to Ashton (2009). Therefore, with the downturn in the world economy, the need to find efficiencies in all facets of our human activities is growing and seems to be the extraneous event necessary to engineer research and novel development of wireless sensor network systems.

Advances in WSN development is on increase today, in part, because of recent developments in area of micro-sensor devices (Bhattacharyya, Kim, & Pal, 2010). Government, academia, and practitioners are now investing enormous resources into wireless sensor network capability development for industrial control and monitoring, environmental monitoring, home automation and consumer electronics, security and military sensing, asset tracking and management, inventory management, supply-chain management, intelligent agriculture, and health and health services monitoring (Callaway, 2005). However, wireless sensor network are constrained by its limited energy, storage capacity, or computing power (Bhattacharyya et al., 2010). In underwater monitoring, acoustic communication rather radio frequencies or optical alternatives is preferred because it allows for better range in distance or when submerged; it is self-powered and mitigates against difficulty of battery replacements; and it allows for extension of energy life in years rather than months (Sánchez et al., 2012).

Literature Review

Review of literatures have shown the importance and viability of wireless sensor networks and had revealed that application and employment of WSN enable systems and devices are valuable and could be a game-changer in how researcher and practitioners monitor and track things across discipline, industry, and across countries. Researcher in the Life Science could use WSN instead of human in monitoring plants and animals in field conditions in order to minimize human disturbances, which could distort results by changing behavioral patterns and distribution and in areas where repeated field study is unsafe or unwise (Mainwaring, Polastre, Szewczyk, Culler, & Anderson, 2004). For example, Anderson (1995) found in Maine that in a given breeding year, a 15-minute visit to cormorant habitant could result to about 20% mortality among egg and chicks. In his article in GEANT3, Krmicek (2011) described how honeypots and sensors scattered throughout the internet are able to report attacks on internet. Werner-Allen (2006) illustrated how WSN is helping the Geophysics community. For example, collaboration among scholars from Harvard University, University of New Hampshire, and University of North Carolina resulted in an effective study of active volcanoes in Volcan Revenator, northern Ecuador and in Volcan Tungurahua, central Ecuador that required "high data rate, high data fidelity, and sparse arrays with high spatial separation between nodes."

Arora et al. (2004) explored the design space of sensors, signal processing algorithms, communications, networking, and middleware in order to study the application of sensor networks for intrusion detection. In Australia, wireless sensor network was deployed to study the impact of irrigation practices on the environment in the Burdekin area of Queensland. The deployment was to monitor water quality by assessing the salinity and water table of the underground water in northern Australia (Tuan Le et al., 2007). In the healthcare industry, WSN was used to monitor and detect early deterioration of patients in a hospital setting; improve first responders' capability, provide smart environments for the elderly, and enhance large-scale human behavior and chronic disease field studies (Ko et al., 2010).

The U.S. Army Logistics Innovation Agency (LIA) sponsored WSN, also known as Next Generation Wireless Communication (NGWC) for logistics operations is currently being used to track and monitor supply and equipment within the Department of Defense (DoD) areas of operations overseas. The DoD's goals and objectives are to leverage current active radio frequency identification (aRFID) investment, connect distribution nodes with conveyances, in process, in route, and storage from manufacturing to consumers; improve life cycle management and asset visibility; and ensure accurate and timely up-date-movement and condition of assets to avoid environmental compromise or loss (U.S. LIA Website, 2012). University of South Carolina (2007) developed a wireless sensor network for machine condition-based maintenance (CBM) that uses a signle hop sensor network to facilitate real-time monitoring and extensive data processing for machine monotoring. Similarly, the U.S. Army avaition maintenace community has implemented CBM (performance of maintenace when the need exists) within its fleets in order to predict replacement time for repair parts or components, minimize early or late repair parts replace, save costs, and maintain readiness (Bayoumi et al., 2008) using funtional layers, including condition monitoring, diagnosis, prognostics, and health managemnt systems (Blechertas et al., 2009).

Network Architecture and Topology

Mesh network topology, a type of *ad hoc* network, is an ideal network topology for wireless sensor network, however, for situations in which mobility of the nodes are involved, mobile ad hoc networks (MANET) may be preferred or used, perhaps in conjunction. Mesh is a type of network in which each node on the network captures and propagates its own data and act as a relay for other nodes in the network. The network may be a full mesh, where all the nodes are connected or partial mesh, where some node connects to all devices nodes and others to select devices. The advantage of the topology in wireless sensor network is that the instantaneous and simultaneous data transmission capability from the entire nodes that encourages and sustains high data traffic and high data throughput. In addition, the topology allows for modification and continuous data transmission even when some nodes in the network fail.

The objective of wireless sensor network is to use an efficient energy routing protocol and transmit data directly to a designated wireless or wired gateway or base station or among nodes and increase the lifetime of the network (Bhattacharyya et al., 2010). WSN basic architecture requires hardware, an operating system, a processor, and memory. The hardware enclosure is designed to minimize environment effects, such as wind, rain, temperature, and terrain (Arora et al., 2004). TinyOS operating system is a very popular WSN operating system (Levis et al., 2004). Mica motes (sensor board—sensing magnetic fields, power board and radar board—motion sensor) serve as the network nodes with radio frequency (RF) communication, secondary storage, and processors—Atmel: 900MHz of wireless radio and analog sensor interface; ARM: BT wireless radio and digital sensor interface (Levis et al., 2004). The architecture has flash program memories; external universal asynchronous receiver transmitter (UART), and serial peripheral interface (SPI) port as well (Arora et al., 2004; Hill, 2003). Levis et al. (2004) stated, "Networking issues are at the core of the design of embedded sensor networks because radio communication—listening, receiving, and transmitting—dominates the energy budget, defining the lifetime of a deployed system."

TinyOS overarching development in wireless sensor network architecture is based on three high-level goals; account for current and future designs of the networks and its nodes; allow for hardware and software mixes in the implementation of operating system services and applications. In addition, the goal is to address specific sensor network challenges, including limited resources, concurrency-intensive operation, robustness, and application specific requirements (Hill et al., 2000; Levis et al., 2004). Another challenge for Tiny OS was writing a new programming language, nesC (an extension to C programming language for TinyOS), for the operating system. The main problem is not necessary in writing the language itself, but in incorporating nesC with C language (Levis, 2009). Hill et al. (2000) identified concurrence-intensity and efficient modularity as the major issues with TinyOS operating system. The concurrent-intensive difficulty deals with passage of data simultaneously; efficient modularity deals with the capacity of the hardware and application software to handle such flow in an efficient manner and with limited overhead (Hill et al. 2000). The four major components in the software platform (TinyOS) as articulated in Hill et al. (2000) are command handlers, event handlers, encapsulated fixed-size frame, and bundle of simple tasks.

Wireless sensor networks hardware requirements has gone through many developments; from commercial of the dust prototypes to weC mote, Rene mote, and Dot mote to MICA mote and the like. However, they are not divorced from some shortcomings. Rene has insufficient memory due to code size limitation; slow and erratic radio performance; unpredictability of operation due to inability to determine battery levels; no unique identification; and instability of the power supply. These shortcomings coupled with the need for more storage capacity, communication throughput, communication flexibility, and longer and more stable energy has led to the production of the fourth generation mote, MICA (Hill, 2002). In Table 1 and in Figure 1, we showed some of the present WSN hardware according to Memsic Solution website:

Table 1. Wireless Sensor Network Hardware Comparison.

Specifications	MICA2	MICAz	LOTUS	IRIS
Wireless Measurement System	IEEE 868/916 MHz multi-channel transceiver	2.4 GHz IEEE 802.15.4	M3 32-bit processor at 10-100 MHz 802.15.4 on board antenna	2.4 GHz IEEE 802.15.4
Network	Mesh network sensor nodes	Deeply embedded sensor network	64kB SRAM, 512kB, 64MB serial Flash	Deeply embedded sensor network
Data Rate	38.4 kbps,	250 kbps,	250 kbps,	250 kbps,
Wireless Communication	Mesh networking protocols	Every node has router capability	USB client with on-board mini-B connector	Every node has router capability
Expansion/Integration	Analog and digital I/O interface for easy sensor integration	Connector for light, temperature, barometric pressure, magnetic and sensor boards	Connector for light, temperature, barometric pressure, magnetic and sensor boards	Connector for light, temperature, barometric pressure, magnetic and sensor boards

Figure 1. Wireless Sensor Network Hardware Samples.

Wireless sensor network processor is evolving, however, we will bring the basic configuration, MCU (ATMEL 90LS8535) popularly referred as Berkeley Motes, to the limelight. ATMEL major components are processing unit, transceiver unit, power unit, and sensing unit. The processing unit is an 8-bit architecture with 16-bit addresses provides 32-8 bit general registers that runs at 4 MHz and on 3.0 volts. It has 8 kb flash program memory and 512 bytes data memory. The processor integrates a set of timers and counters to generate interrupts at regular time intervals (Hill et al., 2000). The sensing unit has two sub-components: photo and temperature sensors. The photo sensor is an analog input device that eliminates power drain and the temperature sensor uses internal convertor to interface over a chip-to-chip protocol (Hill et al., 2000). The transceiver unit is a 916 MHz antenna that collects physical characteristic, such as signal strength and sensitivity, control signal configuration, and propagates transmission signals according to Hill et al. (2000).

Network Applications

Monitoring is a critical and valuable element of wireless sensor network application, whether you are talking about the aviation industry, environmental, automobile, academia, transportation, underwater, Department of Defense, or electronic appliances. In the case of an aircraft, where you have very delicate and expensive systems and components, the need for predictability in the product life cycle is ever more important. The mean-time-between-failures (MTBF) provide users with information about the system or component reliability. However, operation under server or extreme condition may results in a delta between the product's expected and actual useful life. In a condition-based maintenance (CBM) situation—a goal-driven process of efficiently and effectively diagnose component conditions through continuous-monitoring technology for proactive rather than reactive maintenance practices—WSN improves efficiency by allowing the user to predict with some level of certainty when the product will fail (USC University Website, 2012). Consequently, deployment of WSN helps in preventing unnecessary early product replacement, allows for just-in-time procurement of replacement parts or component, and minimizes aircraft downtime due to maintenance. In addition, WSN is more economical (Mainwaring et al., 2008); has less bias in longitudinal research monitoring over a long period; and could be deployed to detect enemy intrusions instead of landmine over a battlefield (Bhattacharyya et al., 2010).

Tracking using wireless sensor network is a capability of immense proportion. In supply-chain management and transportation (air, land, sea, and rail), organizations, including the U.S. military, Wal-Mart, DHL, or FedEx use global equipment tracking system to track personnel, packages, and equipment around the world (Narsing, 2005). Currently, most of the tracking is done with active and passive radio-frequency identification (RFID) technology. However, RFID is infrastructure intensive, high maintenance, energy inefficient, and is not low-cost. Wireless Sensor (Mesh) Network could be the answer to RFID inefficiency and ubiquitous challenges because it is low-cost, would be available worldwide, secure, low maintenance, self-organized, more mobile and has small physical size (Bhattacharyya et al., 2010).

Controlling is another application of wireless sensor network, popularly used to control temperature and humidity in commercial greenhouses and nuclear reactors (Bhattacharyya et al., 2010). WSN is also used to control transmission power level for each fixed or no-mobile wireless sensor network (Kubisch, Karl, Wolisz, Zhong, & Rabaey, 2003). In addition, distributed wireless sensor network is used to control irrigation systems (Yunseop, Evans, & Iversen, 2008).

Network Design and Issues

The essence of WSN design is the potential effect it may have on the timeliness of data collection, the expenditure of limited available energy, the data transfer rate, the storage capacity, and the devices computing power according to Bhattacharyya, Kim, and Pal (2010). The paper elaborated and argued that a successful wireless sensor network requires assessment of the network's node distribution, network dynamicity, energy efficiency, network scalability, data transmission, and data fusion. Romer and Mattern (2004) had demonstrated earlier that specific existing applications occupy different points in design space when they studied problematic multi-disciplinary wireless sensor network research among users, application-domain experts, hardware designers, and software developers for collaboration and implementation efficiencies. The design of WSN requires some specificity; for example, in the healthcare services, unique WSN has metamorphosed into Wearable Wireless Body/Personal Area Network (WWBAN), which includes inexpensive, lightweight, and miniature sensor nodes meant for real-time unobstructive and ambulatory health monitoring (Milenković, Otto, & Jovanov, 2006). Researcher and practitioners are looking at low-level to high-level design issue recently in order to facilitate the creation of component-based and efficient mobile agent that will enhance WSN effectiveness (Min, Gonzalez, & Leung, 2007). Therefore, the rest of the paragraph looked more closely at the taxonomy of the issue Bhattacharyya et al. (2010) described.

Node Distribution. Bhattacharyya et al. (2010) stated, "Node distribution in WSN is either deterministic or self-organizing and application dependent." They argued that the performance of the routing protocol is determined by the uniformity of the node distribution. Deterministic distribution meant systematic placement of sensor nodes that ensure data gathering via predetermined paths. On the other hand, self-organizing meant random placement of sensor nodes, which boost *ad hoc* modus data transmission. Another look at other literatures showed that the node distribution premise in Bhattacharyya et al. (2010) is supported. Xiaobing, Guihai, and Das (2008) found that "in a circular multihop sensor network (modeled as concentric coronas) with nonuniform node distribution and constant data reporting, the unbalanced energy depletion among all the nodes in the network is unavoidable." Yet, node clustering is an effective way to organize networks into a connected hierarchy (Younis, Krunz, & Ramasubramanian, 2006).

Network dynamicity. Wireless sensor network node is either static or dynamic, as such poses a challenge. Early assumption was that network nodes and base stations were going to be static. However, as the WSN need expands beyond and across industries, the need for more dynamic network nodes arises. Bhattacharyya et al. (2010) note that whether or not a network node is static or dynamic depends largely on the application and on whether the events work is in reactive or in proactive mode. For example, supply-chain management event, detection event, and tracking event require dynamic network, whereas most monitoring events would require static network. Network dynamicity in WSN is challenged by the state of our aging network infrastructure (Whelan & Janoyan, 2009). Whelan and Janoyan (2009) presented wireless sensing system designed that measures both static and dynamic structural response using strain transducers, accelerometers, and temperature sensors. The structural responses help in addressing the issue of signal conditioning, span-lengths, throughput, and power consumption.

Energy efficiency. Energy conservation is an issue in all facet of human endeavor and wireless sensor network is not immune or different despite its low energy consumption design concept. WSN uses energy for computation, communication and sensing, and transmission of power is proportional to distance squared, whether it is multi-hop routing or direct communication (Bhattacharyya et al., 2010). One way to enhance WSN data collection optimal time is by organizing sensor into a maximal number of disjointed sets, where only sets that monitors the objective and transmits data remain active at all times and other sets remain in low-energy sleep mode and activates as needed (Cardei & Du, 2005). To be effective, the how, when, and which characteristics of nodes would be in sleep mode should be spelled out in design mechanism: the length of time a node would be on sleep mode, when a node should enter sleep mode or activates, and which rule determines when a node enters sleep mode (Cardei & Wu, 2006).

Data Transmission. Bhattacharyya et al. (2010) stated that "data transmission is WSNs is application specific…may be continuous or event driven or query-based or hybrid." Continuous transmission deals with periodical transfer of data from nodes to other nodes, or to the base station; event and query transmission deal with data transfer when a specific event occur or when a user queries the system; and the hybrid is a combination of both (Bhattacharyya et al., 2010). Data transmission design is still a problem. For example, current supported transmission bandwidth is unable to support very high bandwidth demand, such as video streams despite MICAz mote and others' 250 kbps transfer rate (Akyildiz, Melodia, & Chowdhury, 2007). However, ultra-wide-band (UWB) transmission technique is promising for high demand Wireless (Multimedia) Sensor Network, especially when dealing with automated assistance for the elderly or intelligence surveillance, and the like (Akyildiz et al., 2007).

Scalability and Data Fusion. Scalability deals with the difficulty of the network's ability to accommodate hundreds, if not thousands of nodes that may be necessary for a give monitoring, tracking, or sensing activity. Routing protocol must be able handle both small- and large-scale node deployment over and extend period of time (Bhattacharyya et al., 2010). Akyildiz et al. (2007) stressed the need for improved WSN network architecture that would filter and extract relevant information in order to reduce transmission redundancies during collaboration and data distribution. Data fusion according to (Bhattacharyya et al. (2010) on the other hand, is a process that ensures fusion of data from similar packets, and multiple nodes in order to minimize transfer of redundant data and increase energy efficiency. The challenge remains in data fusion and data aggregation.

Conclusion

Although wireless sensor network data transmission can be routed through a wired gateway, it would have been unthinkable to imagine the expansion of the WSN and the proliferation of the technology without the ubiquitous of wireless broadband. This paper looked at WSN early stage, how far we have come, and to the challenges that still exist. We looked at the network architecture and at various application of the wireless sensor network: monitoring, sensing, and controlling with a sensed that we are just scratching the surface. WSN is an efficiency enabler in a variety of ways, whether the platform is for terrestrial, underwater, underground, mobile, or multimedia wireless sensor. There a plenty of opportunities for practitioners and researcher in this area, primarily because the world will continue to look at various ways to achieve efficiency in order to maintain viability within the commercial world and in academia respectively.

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Working Papers on Information Systems | ISSN 1535-6078