Assessment of Impact on Wireless Sensor Networks

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Abstract

The advantages and risks of deploying wireless equipment in electricity substations are outlined, the resulting research motivation described and the research objectives defined. The character of the noise environment is considered and an estimate of likely antenna noise temperature at the frequencies used is made by extrapolation of ITU noise prediction models wireless sensor network is a group of smart sensors, each capable of sensing, processing and communicating, but when deployed in numbers, form a network which collectively monitor the state of the physical world. Wireless local area networks (LANs) are playing a major role in the information technology revolution. They are finding their way into a wide variety of markets including financial sectors, corporations, health care, and education. For example, wireless devices are used in New York stock exchange for trade reporting its applications and potential benefits are tremendous and seem only limited by imagination. As any technology at its infancy stage, there are plenty of challenges and obstacles lying ahead. One of the factors that could have had an adverse impact on the market for wireless devices is the interoperability issue between products developed by different vendors. However, the IEEE has developed the 802.11 standard, compliance with which should alleviate this issue. Other factors that will impact the long-term success of wireless LANs largely depend on improving the technology, reducing installation costs, and predicting the market and customer needs. While initial costs to install a wireless LAN infrastructure may be greater than its wired counter-part, in the long-term, benefits due to the wireless network can be significantly higher when the users are constantly mobile. The interdisciplinary nature makes the design challenges wide and deep, from network protocols, power provisioning, to programming models, just to name a few. This survey paper gives a brief overview on what wireless sensor network is, what the current design challenges are, and presents a variety of programming models that had been proposed.

Keywords: Wireless sensor, Technology, Power, Network protocols.

Introduction

Wireless sensor network is a network system comprised of many miniature sensor nodes, each has the ability to sense or to interact with the surrounding physical world, to process gathered data, and to communicate with each other and outside entities without wires. Thanks to the advance in semiconductor technology, network communications, embedded system and many others, sensor nodes with these abilities can now be integrated into an entity smaller than a penny coin, allowing what Kris Pister called smart dust to become a reality. The emergent MEMS technology has the potential to further scale down the form factor and enhance their performances.

Wireless sensor networks is a new breed of sensory system, although often with limited processing power and communication bandwidth, is nonetheless intelligent when compared to their more traditional relatives, hence often also referred to as smart sensors. Some networks are designed to utilize in-network processing, so decisions can be made on the spot or at least transformed to more abstract and aggregated high-level data before transmitted. The dramatically shrank form factor and the ability to communicate without wires means they can be deployed to remote areas and in higher density if desired. The combination of processing power, storage and wireless communications also means data can be assimilated and disseminated using smart algorithms. The vast number of sensor nodes planned for many applications also implies a major portion of these networks would have to acquire self-organization capability.
Two interesting observations have been offered, first one by Satyanarayanan (2003), he mentioned that wireless sensor network can be regarded as the nervous system of the physical world. These tiny self-organizing wireless sensors and actuators can bridge the gap between the digital and physical worlds, it offers the capability to observe the physical world continuously, and proactively transmit data of interest. In some implementations, sensory system can also analyze the data and react to it by sending commands to actuators, and this behavior is indeed a pretty good analogy to biological nervous system.

Wireless sensor networks also provide opportunities for close-up observations with much higher fidelity (Culler et al., 2004), yet extend the scope of monitoring beyond anything that was possible before. With the advantage in small form factor and wireless communication capability, sensors can be placed as closed and as dense as necessary to the phenomenon of interest. While the capabilities of self-organization, wireless communications and with power source attached, sensor nodes can be deployed to where previously wires or even humans had hard time to reach to. The rest of this paper starts with a brief overview of the building blocks of wireless sensor networks, followed by discussions on some of interesting applications proposed. A more extensive and comprehensive discussion on design issues and challenges ensue. Finally, it concludes with a presentation of various approaches and programming models in implementation of sensor networks, and a short summary.

Security issue

Security is a big concern in wireless networking, especially in m-commerce and e-commerce applications. Mobility of users increases the security concerns in a wireless network. Current wireless networks employ authentication and data encryption techniques on the air interface to provide security to its users. The IEEE 801.11 standard describes wired equivalent privacy (WEP) that defines a method to authenticate users and encrypt data between the PC card and the wireless LAN access point. In large enterprises, an IP network level security solution could ensure that the corporate network and proprietary data are safe. Virtual private network (VPN) is an option to make access to fixed access networks reliable. Since hackers are getting smarter, it is imperative that wireless security features must be updated constantly. In conclusion, wireless LAN technologies still have a long way to go. Both fundamental and practical problems still persist in this area. Therefore, it may be crucial to develop innovative and commercially viable solutions to some of the key issues and challenges discussed in this article to ensure the success of emerging wireless application.

Technology overview

The advance of wireless sensor network heavily depends on a wide range of technologies, such as aforementioned semiconductor and hardware, system software, network communications, but also others such as researches in programming methodology, security, privacy policy, battery and energy management (Culler et al., 2004). There are numerous potential applications for wireless sensor networks, as some of them would be discussed in this section. These applications place different requirements on the sensor nodes as well as the network as a whole. The coverage of the network varies widely from the order of square miles in the environmental monitoring to fractions of a square inch in industrial tool monitoring. The measurement of interest also differs from one application to another, as Lewis (2004) provides a summary of 20 different properties that can currently be measured by commercial sensors using electrical, photonic, seismic, chemical and other transduction principles. Not to mention various environments the sensors will be operated in, and the sensing fidelity in terms of accuracy and sampling rate, it is not easy to define generic requirements for sensor nodes and the network they formed. Lewis (2004) points out some of the desirable characteristics of wireless sensor networks, such as ease of installation, self-identification, self-diagnosis, reliability, time awareness, and locality awareness. In addition, Callaway (2003) further indicates other considerations such as small form factor, long maintenance cycle, scalability, fault tolerance, security and capable of operating in various hostile environments. Even with great diversity in operations and desirables, three requirements seem to stand out in importance in a wide variety of sensor networks, and all three have some association to lower total cost of ownership in one way or the other.

a. Low power: There are relatively few applications in which sensors are deployed to environments where main power is available. Even in those environments, the sensor nodes may not be able to plug into electric outlets due to difficulty of running power wires (such as industrial tool monitoring) or simply infeasible because of shear number of nodes deployed. The power requirement not only targets at low average power consumption, but also low peak power consumption as well. Except those connected to electric outlets, the majority of sensor nodes will have to be self-energy sufficient. Attaching battery cells is by far the most popular solution, while energy scavenging techniques have became a strong alternative in certain environments.

b. Low cost: When the targeted coverage area is broad and/or the fidelity and resolution requirement is high, the number of sensor nodes need to be deployed would be rather large. Coupling this with inherently limited power supply and dynamic hostile environment requiring redundancy to provide certain level of fault tolerance, in addition, many networks are established by spreading sensors over the area of interest without manual installation and adjustment, the natural conclusion to be inferred is that sensors have to be reasonably cheap for any viable realistic deployments. It is suggested that sensor nodes should be considered disposable, at least required as little and infrequent service as possible.

c. Self-organizing: The huge number of sensors deployed for a single applications, the possibly inaccessibility for humans, and the dynamic nature of sensor placement all suggest that sensors in the network has to be able to self-organize. This requirement can be further broken down to communication and position self-organization. The power consumption is proportional to the square of distance between transmitter and receiver. Therefore in order to reduce power consumption, ad-hoc network is the
predominant form of communication in wireless sensor networks. Neighboring sensors nodes therefore need to be able to self-organize into such networks, and route the data and messages accordingly. For properly interpreting collected sensor data, and sometimes for enabling location aware services, the sensor nodes need to be aware of their relative positions, and sometimes even absolute global positions. Many researches have also looked into self-organization at a higher, more abstract layer of functionality, such as data aggregation (Roedig et al., 2004). It is worth noting how advances in semiconductor technology following Moore’s Law have helped advance these goals. The shrinking distance between transistors on a single chip has greatly improved power efficiency (if no substantially more transistors are packed into the chip). The capability of implementing wireless communication circuitry on CMOS is the reason behind the cheaper and smaller wireless devices (Culler et al., 2004). MEMS technology has already been applied to implement sensory device in accelerator (Lewis, 2004), and currently being investigated for use on sensing other Measurement. Riding the improvement on semiconductor technology, all of the major components of sensor nodes are expected to be smaller, cheaper and more power efficient

**Critical challenges**

Since wireless devices need to be small and wireless networks is bandwidth limited, some of the key challenges in wireless networks are: data rate enhancements, minimizing size and cost, low power networking and user security.

**Application**

Since the availability of realistic miniature sensor units has only come into reality in the last decade, this new interdisciplinary research area has inspired many interesting novel proposals for a wide variety of applications. Culler et al (2004) classifies all these applications into three separate categories. The first category monitors space, with applications such as environmental monitoring, agricultural, climate control, surveillance and intelligent alarms. The second category monitors things, such as structural monitoring, condition-based equipment maintenance, asset tracking, and medical diagnostics. The third category monitors the interactions among things and the encompassing space, including wildlife habitat, disaster management, and ubiquitous computing environments, healthcare and manufacturing process flow. The following is a sample of some applications recently being proposed.

**Environmental monitoring**

Martinez et al (2004) create Glacsweb project to monitor glacial environment using embedded probe placed inside the glacier, with on-surface base station, gateway server and a web front end. They are able to automatically get daily readings of various sensors for an extended period of time, but have also discovered that designing a sensor network sustainable in harsh environment presents a tough challenge. On the other hand, Holman et al (2003) created Argus station using video camera as sensors, which allow automated multi-sensor sampling based on remote users’ high level tasking. The system use image processing technique to collect only appropriate data. In this project, the sensors are much more complex and powerful than most of other wireless sensor networks and the camera transmit collected video stream with wire. Although neither of these two applications use in network processing, they still show the feasibility and how very different approaches can be used for continuous remote monitoring of the environment over a large area and long period of time.

**Military applications**

Brennan et al (2004) designed a sensor array for radiation detection by using a multitude of much smaller portable sensors to form an array, and conclude that gamma counts received indicate the sensor network approach provides higher sensitivity than traditional portal sensor. It is also portable and much cheaper. Maroti et al (2004) investigated an urban shooter localization system in which by using acoustic model from multiple sensors around where shooting take place to pinpoint the location of shooter. This project provides an interesting simulation and prototype generating a pretty impressive accuracy of 1 meter using 60 sensors. As regarding to the practicality problem of how to deploy all the sensors before shooter shots is beyond the context of the discussion.

**Agricultural application**

Burrell et al (2004) experiment with applying sensor networks to a different context. Their vineyard computing project uses ethnographic research methods to extract knowledge about design factors in the context of a vineyard in an agricultural setting. The data mule system is composed of environmental sensors to record temperature, humidity and weather, and smart shovels record workers activity, and a nightly download with analysis performed in the shed. The data is then analyzed to provide suggestions on the production and optimization.

**Smart environment**

The Gator tech smart house applies sensor networks in the context of assistive living (Helal et al., 2005). With a wide array of sensors and actuators in a controlled environment, this house is aimed at integrating data collected from various sensors, and provides a programmable environment by offering more abstract concepts such as context and service composition as part of the middleware. In this project, the focus of interest is less on how long the sensor will last (they are plugged into the outlets) or if sensor
networks can form a self-organizing network (the environment is controlled and preset), but rather on smart handling of the collected data, and intelligence on reacting to various context and sensor inputs.

**Industrial control and monitoring**

Many mechanical failures are preceded by noticeable symptoms, such as squeaky bearing or shudder often indicate wearing of the bearing or imbalance of the shaft (Culler et al., 2004). The industrial monitoring often requires low maintenance, high reliability, inexpensive, and non-intrusive. It would be even better if it can self-maintained and self-healing. Wireless sensor networks provide a solution that is much closer to this goal than anything previously available.

**Design challenges**

To say designing a wireless sensor network is a complex task is a grossly understatement. Because of interdisciplinary nature of the related researches, designing such network requires a careful consideration due to many constraints and requirements described above. At current stage of research, there is still limited generic off-the-shelf smart sensor nodes, and close to none that can fulfill vastly diverse objectives of various planned applications. Therefore, in many cases, these pioneering or experimental projects require customized and mostly hand-made solutions to accomplish the planned task. The diversity and often conflicting challenges faced by system designers is clearly demonstrated by following a sensor node development project in Motorola (Callaway, 2003). The main objective of this project is to build a sensor node that has the ability to communicate using wireless channels, is self-organizing and has long battery life, with all these packed into a small form factor.

Callaway (2003) describes considerations methodically on various aspects of the design process, with discussions on existing candidate solutions, the reasoning involved in choosing final solution, and validation using simulation. The solutions mentioned below are by no mean the best answers to various problems, but only serve as a mean to convey the thought process and demonstrate difficulty behind such decisions. Other examples are also brought up to show the design objectives as well as the efforts to overcome these hurdles.

**Physical layer**

The decisions include which wireless band to use, modulation scheme to minimize duty cycle with low transmission power, the power signature of circuitry used for communications and signal processing, etc.

**Data link layer**

One of the primary objectives is to prolong the battery life for as long as possible under normal operations. Observing the power consumption at active transmission cycles is about 2 orders higher than in standby mode, and coupled with the fact that the density of data collected at each individual node is usually not very high, it is safe to assume the nodes and the network as a whole should operate in a mode with low duty cycle and burst high data rate. This approach, however, complicated the task at data link layer. Combining the ad-hoc nature and extremely low duty cycle presents great difficulty for nodes discovery and synchronization. If the system is assumed to operate without any special power nodes (which may have substantial more power store, processing power or communication bandwidth) in a totally distributed manner, then it is non-trivial to achieve efficient communications between neighboring nodes. Motorola team devises mediation device protocol (MD) in which nodes take stochastic turns to be MD, and tries to record the time differences between awaking time slots of nodes intending to communicate, and synchronize these nodes so they can be awake at the same time. Although this protocol usually results in long message latency and low system throughput, it seems to be quite suitable for many non-real times, low data density applications such as environmental monitoring.

**Routing**

For majority of applications, single hop transmission is either unrealistic (e.g. signal may have to traverse miles in the ecological monitoring applications), or energy inefficient (since transmission power is proportional to square of distance). The dynamic nature of nodes (node movements in the environment, low reliability due to power deprivation and hostile environment, etc) also prevents relatively static regular routing protocol from offering any reasonably reliable communications. It is widely agreed that multi-hop ad-hoc routing protocols are the reasonable solutions. Motorola team suggests the use of cluster tree architecture, which includes a power gateway as root of the tree, and the only node that can communicate with outside world using TCP/IP. All nodes are clustered into a hierarchical tree, and serve as the route to disseminate and aggregate messages from and forth to the gateway. Interesting discussion is also presented regarding how clusters were form initially and the techniques for load balancing and cluster adjustment.

**Power**

Power is probably the single most important considerations when designing wireless sensor networks. Comparing to the transistor density doubles every 18 months, the battery and power related technology advance only about an average of 7% on power density each year. Clearly, power provisioning and management is a major issue in terms of operation, form factor, reliability, maintenance, cost and almost every single aspect of any sensor network system. The basic approach to lengthen the battery life is
to switch sensor nodes into standby, or even sleep mode when not sensing or communicating. The choice of power source rely on many factors, some of the major ones include availability (in the intended application environment), cost, time between services, internal resistance, voltage matching with intended node operation, and ecological considerations. Battery is by all mean the most popular choice, which can be either high energy density primary cells or rechargeable secondary cells. They are relatively inexpensive, with many chemical compositions to choose from (hence with different characteristics to match against targeted application), and less relied on the environment.

The ultra-low average power consumption allows energy scavenging devices to be considered as alternative power source. These devices convert energy from light, vibration, temperature difference, etc into the electricity needed for operations. There will be no battery replacement maintenance needed, and they can probably have a longer lifespan as compared to their counterpart using batteries. But there are issues regarding whether scavenged energy can match peak voltage and current requirements in active cycle, or have necessary energy store for operation when the energy source is unavailable (e.g. solar cells at night time), and the power consumption needed at warm-up period of the scavenging circuitry itself. Power management allows low battery warning to be sent before the nodes is dead, and even switches different modes of behavior based on the available power left. Reliable power capacity detection maybe tricky for some kinds of battery, and hysteresis and different operations modes are all topics of ongoing researches.

Other software and architectural techniques proposed to extend battery life include local data processing to avoid communication, data compression to reduce power consumed during communication, data aggregation from multiple nodes, and use of low-power sensors to observe interesting event before triggering the activation of high-power sensors (Culler et al., 2004). Enz et al (2004) design a power efficient MAC protocol using preamble sampling with CSMA and a new transceiver that shuts down everything else except sampling block and optimized warm-up sequence among circuit blocks, and resulting in a 2-order reduction in power consumption. This demonstrates that reducing power consumption requires optimization across multiple layers (Enz et al., 2004).

**System software and sensor platforms**

Many research groups in both academia and industry are currently devoted to the development of sensor platforms. One of the first and probably most famous platforms is Berkeley motes and smart dust, and the progress and design reasoning is well documented in a series of published papers. However, with the wide range of Measurement, and broad spectrum of operating conditions, it is unlikely that any platform can become the de facto sensor network building block.

TinyOS is an open source project that was also originated from Berkeley, and the concept is by providing microkernels, these strip-down version of functional units in operating systems, can be selected to provide system support only when its functionality is needed. It is established that even with limited resources, sensor node can still achieve reasonable concurrency that are application-specific and event-driven. The bottom line is, due to severe restriction on various resources, the system should consist of only those functionalities needed, whether implemented in hardware or system software. But in reality, tradeoffs and conflicting requirements often make these decisions less than straightforward, as discussed in subsection h.

**Self-organization**

As mentioned in above section, self-organization is important to many wireless sensor networks. The self-organization protocols can be used to establish connectivity, relative topology and position, and allow data to be disseminated and aggregated. This capability is crucial to keep the system low-maintenance, fault tolerant and able to provide in-network processing more efficiently. Cluster (2003) tree architecture that Callaway and Motorola team devised is an example of self-organization in connectivity. Butler and Rus (2003) create simulation to examine how to reposition mobile sensors to where the phenomenon is, using history-free update rule or history-based algorithm. While Roedig et al (2004) proposed an intentional delay in nodes along the route message pass through to increase probably of message aggregation and therefore power efficiency.

**Privacy**

The amazing fidelity of wireless sensor network provides unprecedented opportunity for dense instrumentation, real-time access and automated analysis on various phenomenons (Culler et al., 2004). While there is less concern regarding environmental monitoring, intelligent agriculture or radiation detection and other focusing on natural or wide-range phenomenon, when similar setting is used to monitoring human activities, the concern about privacy and even safety becomes a major factor. Wireless sensor network in assistive living, or intelligent offices are valuable in terms of automation, remembering and remote assistance. But the same technology that allows doctors and relatives to monitor the health condition of an elderly can lead to breaching of privacy if data is processed in an improper manner or accessed by unauthorized persons. The capability of automated analysis and remote access make this new generation of sensing technology an even worst threat to individual’s privacy.

This issue can be addressed with a combination of technical measures and analytic framework from the perspective of law and psychology. Techniques such as tighter access control to the collected data, secure channel communications, options for user to voluntary opt out or control of data granularity can all mitigate privacy concern. As regarding to privacy issue from the perspective of law, Jacobs and Abowd (2003) have suggested an analytic framework based on fourth amendment and Supreme Court ruling, with audience of concern and the motivation of the reasoning process as two axis of the paradigm.
Other considerations

As a researcher in a project pursued by a wireless/semiconductor company, Callaway is able to point out some practical considerations that are often overlooked by academic researchers. For instance, should the design of the target sensor node be generic or specific. The volume of demand on the market plays a big part here, but this choice greatly affects technical decisions too, as it will decide the power consumption, and the need for different interfaces. Whether the node is to be a stand-alone device or attached to other equipment will decide the power and computation capability that can be borrowed from the host, but limiting its applications that require self-sufficient operations. Sensor integration is inherently difficult in practice, and variables such as flexibility and usability further complicated the decision on how much integration is optimal.

Programming models

As diverse as the potential fields of applications, and considering relative short time that related researches just burgeoned, it should not be hard to understand that just like the vast diversity in sensor nodes design and network organization, the programming models of wireless sensor networks is still in its early stage with models of hugely different philosophies and views being proposed.

Even without considering programs related to functionality of sensors and self-organization of the networks, and simply focus the discussion on how system developers can implement/instruct the wireless sensor network as a whole to perform the intended measurement, react to the stimulus, or communicate with other program or outside world, the number of models proposed is still enormous. As Gehrke and Madden (2004) suggested sensor networks provide a surprisingly challenging programming and computing environment: Partially due to the fact that devices are resource-poor and crash-prone, and the operating system provides no benefit to help mitigate these failures. Most of time there is no adequate debugging facilities, plus its highly distributed nature, with large number of information sharing and cooperative processing. The programming of wireless sensor networks is a huge undertaking indeed.

In this section, a sample of interesting models is discussed, while it is far from covering the entire spectrum of various programming models, it does show a flavor of some most predominant categories of approaches recently proposed. The first category, the query-based model is most intuitive for sensor systems. Just like any old dumb sensors, the first step before performing any action is to read the sensor. The query approach follows this philosophy, and makes efficient and intelligent query the top priority for successful operation. The second category is the distributed system programming model, where each node is regarded as a resource-poor embedded system and therefore various distributed algorithms, old and new, are tailored and applied to the specifics of various resource constraints.

A popular variation is to allow surrogates to represent resource-limited sensor nodes as proxies to interact with other entities. The third category is programs written in state or context-driven fashion. The reasoning behind is that the wireless sensor network as a whole does not really care about querying the value of the readings, or coordinate with neighboring systems, but in a more macro perspective, how such a system can react to the state of environment it currently resides.

Query based model

The model followed by Gehrke and Madden (2004) is a more traditional query-based approach. The code is split into two parts. The server side code deals with query parsing, query planning and optimization, while the sensor side code is responsible for routing, query aggregation, partial data aggregation, and lifetime specification, etc. The approach is a pretty straightforward extension of traditional queries, with sensor network specific modification to the query language, and to incorporate message routing and data aggregation. This model is applied to collect streaming numeric data. One of the more intriguing suggestions is cross-layer modification to achieve better efficiency. This approach is not popular in traditional layered network protocol model, but may merit considerations in this case due to limitation in resource and steady pursuit of light-weight implementation.

Hwang et al (2003) proposed a web based query and management programming model via a gateway. Basically all sensor readings go to gateway, a much more powerful node in the entire network, and the only one that has connection to outside world. Most of the data processing, aggregation, as well as query transformation and web front end to database module resides in the gateway. The system can be configured using web front end via the gateway.

IrisNet is a joint CMU and Intel Research project (Gibbons et al., 2003). The target system is a little bit different from typical wireless sensor networks. The project aimed at global distributed sensing system. In which sensors they are resourceful and capable of providing dense sensor data such as video stream. The project follows a more traditional two tier architecture, where sensor nodes are the leaves and servers in the core. The system is built upon global distributed database. The system behavior is programmable in the sense that sense lets are placed on sensor nodes, which can filter, store, process, analyze the collected data locally. Data are only transmitted when queried, and both queries and replied data are routed intelligently to the requesting user.

Distributed programming paradigm and centralized surrogates

Klavis and Murray (2004) make an analogy of robotic soccer games to the wireless sensor network system. The actuators in sensor networks need cooperative control to achieve the common goal. When implemented distributed, most of the close loop control using control algorithm and system dynamics are thrown out of window. They provide a formal language model to define how sensing and actuating units should specify the condition and reactions to follow, provided some initial condition is valid. They suggest
the use of Computation and Control Language (CCL) to program such a distributed system, and argue its simplicity gives great advantage in formal analysis and automated reasoning. Shaman is a service gateway based programming model, the basic idea is to use gateway as a surrogate to resource-poor sensors and actuators, and allows the various entities present in the system to be platform independent (Schramm et al., 2004). Shaman is a java-based service gateway, which provides wrapper as a proxy to the actual sensors or actuators regardless of in what platform or programming language they are implemented. It also provides a SWT based GUI for controlling every single entity that has a proxy resides on the gateway.

Gator Tech Smart House exploits a similar concept at lower layers, but utilizes OSGi platform instead of proprietary java extension (Helal et al., 2005). Building on top of similar idea that each entity has a surrogate service bundle exist in OSGi gateway, smart house further specifies a programming model for smart environment embodied in a middleware. In which the implementation of a smart environment is divided into four layers, physical (sensor), sensor platform (sensor surrogate), context and knowledge (system level services) and application layers. Another protocol with some similarity is Jini surrogate architecture, which is a Jini extension to the entities not running Java or resource deprived to participate in Jini coordination, by using a surrogate to represent the entity in the platform.

State centric programming

State-centric Programming from Palo Alto takes a quite different approach to the programming of wireless sensor network (Liu et al., 2003). To bridge the gap between node-centric programming and high-level processing, they propose that software artifacts should be divided based on the states they track. Since the number of nodes is typically quite large in sensor networks, the complexity resulted from the large number of participants along would deem that some higher level abstraction is a necessity. The sensors are divided into groups based on their locations or functionalities, which allow programmers to deal with nodes as a group rather than juggling with individual nodes. The concept of principle is used to keep and maintain the state associated with physical phenomenon, and each state has only one principle that store, update, and respond to the query as to the value of the state. The task of programming the system becomes the task of how to define interaction between principles without worrying about the low-level, per node operation and hurdles. This higher level of abstraction allows even domain experts not familiar with programming to define the system behavior using the terms they are familiar with, namely the various states.

An interesting work in progress in the context-driven programming model by Jansen et al (2005), the basic concept is that the current state of the observable universe can be defined by complex ontology diagram, where each current state can be expressed as a context node in the diagram, and the desired destination another. To program the system to allow the world to move toward target state is simply defining the path of context node transitions and the necessary actions needed to properly migrate from one context to the next on the path.

Conclusion

With the advance in semiconductor technology, network communication and embedded system design, smart sensors with small form factor capable of sensing physical world, performing preliminary processing and storage and communicating without tether has come into reality. The wireless communications industry generally, and WLAN/WPAN designers particularly, have an interest in the mechanisms by which impulsive noise degrades performance since such knowledge will suggest possible ways of mitigating these effects. If the technologies considered are found to be sufficiently resilient the economic benefit of their deployment will be substantial. If they are found to be insufficiently resilient then the programme will identify the mechanisms by which performance and reliability are degraded. The development of countermeasures to address these mechanisms can then follow. The emergence of wireless sensor networks can finally bridge the gap between physical and digital worlds, with the effect as if to establish nervous system for the physical world. It also allows measurement and monitoring in the way that is much closer to the phenomenon than ever before, resulting in continuous and high fidelity of data collected. These sensors also allow monitoring of previously inaccessible areas and phenomenon. With a vast diversity in the physical Measurement, the intended deployment environment, and intent of applications, the requirement for sensor nodes and the network they form are hugely different from one case to the other. But it is well perceived that low cost, low power and self-organizing are three desirable features for majority of applications.

Just as big as potential benefits and as diverse as candidate applications are, the design challenges are also remarkably huge and complex. There are issues to be resolved and decisions to be made on all layers of the network protocols, power issue, system software support, self-organization, reliability and scalability, privacy issues, not to mention practical tradeoffs before reaching mass production. There is no consensus yet as to what the best solutions to many of these issues are, but tremendous amount of efforts have already been spent on related researches. Numerous diverse programming models have been proposed. The vast number of sensors in the network, the terribly error-prone nature of nodes, plus strict restriction of resources, and lack of support from traditional operating system as available in desktop and server systems, make building a large-scale distributed wireless sensor networks a major challenge. Three popular models used by many system designers and developers are query-based model, distributed programming paradigm and state centric programming. Wireless sensor network has the potential to trigger the next revolution in computing. While its applications and potential benefits can spread far and beyond, and could finally break the barrier between physical and digital worlds to allow disappearance of computation as described in Weiser’ vision. There are huge obstacles
to overcome, not only in terms of technology, but also in sociology, security, and ecology, before the bright rosy future portrayed can become the reality.

References