

Energy Conservation Challenges in Wireless Sensor Networks: A Comprehensive Study

Suraiya Tarannum

Department of Telecommunication Engineering AMC Engineering College, Bangalore, India

E-mail: ssuraiya@gmail.com

Received December 31, 2009; revised February 5, 2010; accepted February 10, 2010

Abstract

A Wireless Sensor Network (WSN) consists of a large number of randomly deployed sensor nodes. These sensor nodes organize themselves into a cooperative network and perform the three basic functions of sensing, computations and communications. Research in WSNs has become an extensive explorative area during the last few years, especially due to the challenges offered, energy constraints of the sensors being one of them. In this paper, a thorough comprehensive study of the energy conservation challenges in wireless sensor networks is carried out. The need for effective utilization of limited power resources is also emphasized, which becomes pre-eminent to the Wireless Sensor Networks.

Keywords: Wireless Sensor Network, Sensor Node, Communication Protocols Architecture, Energy Consumption of Sensor Node, Energy Conservation, Communication Protocols

1. Introduction

Wireless Sensor Networks (WSNs) are a spatially distributed autonomous system which is a collection of power-conscious wireless sensors without the support of pre-existing infrastructure. A co-operative system is created, formed by a group of specialized transducers with communication infrastructure intended to monitor and record conditions at diverse locations. A WSN is used for information gathering, performing data-intensive tasks such as habitat monitoring, seismic monitoring, terrain, surveillance etc. Sensor Networks are a giant leap toward “Proactive Computing”, a paradigm where computers anticipate human needs and if necessary, act on their behalf. Sensor Networks and proactive computing has the potential to improve our productivity and enhance safety, awareness and efficiency at the societal scale [1].

Building sensors has been made possible by the recent advances in Micro-Electro-Mechanical System (MEMS) technology and wireless communications technology making it a pragmatic vision to deploy a large-scale, low power, inexpensive wireless sensor network [2]. Such an approach promises advantages over the traditional sensing methods in many ways: large-scale, dense deployment not only extends the spatial coverage and achieves higher resolution, but also increases the fault-tolerance and robustness of the system.

The recent advances in MEMS (Micro Electro Me-

chanical Systems) [3], Digital Signal Processing and Wireless Communications have led to the production of new class of wireless, battery operated smart sensor nodes [4]. These nodes organize themselves to form active, full-fledged processing elements, capable of measuring the real world phenomena, filtering, sharing and combining these measurements. In such networks, the devices identify themselves and each other, to route data without possessing any prior knowledge of or assumptions of the network topology, which may change, run out of power or experience shifting waves of interference.

A network formed by a web of such sensors is deployed in remote areas or hostile terrains, without the infrastructure support from the outside world. This exerts serious physical constraints on the application of single sensor, and thus, all the sensor nodes can form an autonomous and robust data computing and communication distributed system for automated information gathering and distributed sensing. Sensor networks are highly distributed networks of small, lightweight nodes termed motes, deployed in large numbers to monitor the environment or a system by measuring physical parameters such as temperature, pressure or relative humidity.

Each sensor node consists of three subsystems: the sensor subsystem which senses the environment, the processing subsystem which performs local computations on the sensed data, and the communication subsystem which is responsible for message exchange with neighbouring sensor nodes. While individual sensors have

limited sensing region, processing power and energy, networking a large number of sensors gives rise to a robust, reliable and accurate sensor network covering a wider region.

The network so formed is fault-tolerant since many nodes participate in sensing the same events. Furthermore, the nodes cooperate and collaborate on their data, which leads to accurate sensing of events in the environment. The two most important operations in a sensor network are data dissemination, which is the propagation of data/queries throughout the network, and data gathering where the collection of observed data takes place from each of the sensor nodes. Finally, the aggregated data is sent to the sink/basestation. A typical scenario of the WSN is depicted in **Figure 1**.

Efficient management of energy deserves much of the attention in the WSNs. Routing protocols designed for WSNs must therefore effectively tackle these issues in order to enhance the lifetime of the network. Hierarchical routing techniques are preferable in this direction. The arrangement of the nodes in the form of a load balanced hierarchy proves beneficial.

In this paper, a state-of-art study of the energy conservation challenges in wireless sensor networks is described. The rest of the paper is organized as follows. In section 2, the sensor node is described. The applications and the issues and challenges are described in sections 3 and 4 respectively. Section 5 throws light on the energy consumption details and the communication protocol architecture is described in section 6. Section 7 enlightens the energy conservation challenges in communication protocols and related design issues in wireless sensor networks. The usual performance evaluation metrics employed in WSNs are described in sections 8 and 9 contains the conclusions.

2. The Sensor Node

The sensor node is an atomic element of the wireless

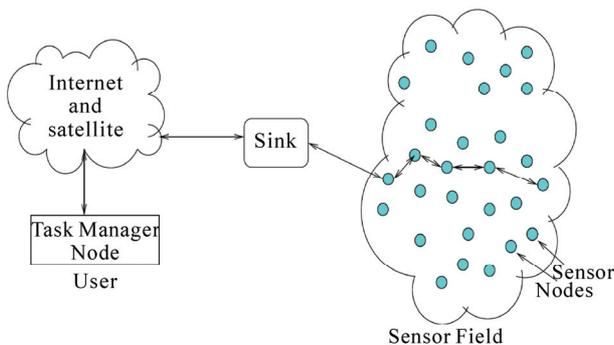


Figure 1. A typical scenario of a Wireless Sensor Network (WSN).

sensor network, which gathers data from its surroundings, and transmits them to the *base station/sink* enroute the radio transmission medium. Every node is provided with a unique ID number and has an input queue as a buffer. At any point of time, a sensor can behave as a transmitter node, relay node, and sink node or all them. In many application scenarios, a myriad of sensor nodes are spread across a large geographical area, which collaborate and organize themselves in order to carry out the desired task. This implies that a sensor node forms an integral and the most important unit of the wireless sensor network and deserves understanding of its internal architecture.

A sensor node is typically made up of four basic components as shown in **Figure 2**: A sensing/actuating unit, a processing unit, transceiver section and power supply unit. In addition to this, the sensor node may also be equipped with location detection unit such as a Global Positioning System (GPS), a mobilizer etc. The sensor networks consist of different types of sensors such as seismic, thermal, visual, and infrared and are used to monitor a variety of ambient conditions such as temperature, humidity, pressure and characteristics of objects and their motion. The sensors give these nodes their eyes and ears. Sensor nodes can be used in military, health, chemical processing and disaster relief scenarios. The sensor node architecture is described in **Figures 2** and **3**.

2.1. Sensing Unit

The sensing unit is usually made up of two subunits, the sensors themselves and analog-to-digital converters (ADCs). The signals generated by the sensors, based on the phenomenon to be sensed, are analog in nature and hence need to be converted to a digital to aid further processing. These signals are then fed to the processing unit.

2.2. Processing Unit

The processing unit forms the core of the sensor node.

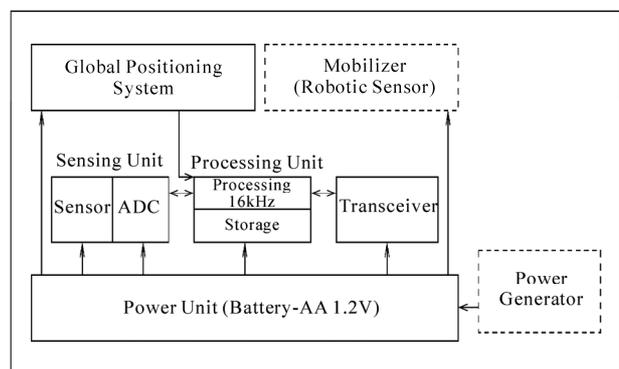


Figure 2. Sensor node architecture.

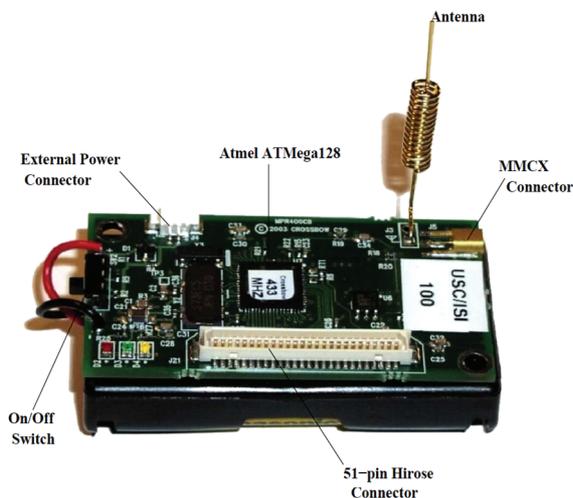


Figure 3. A typical sensor node.

This unit in association with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to carry the sensing tasks. The processors employed in the sensor nodes include, the *Atmel AtMega Microcontroller, MSP430, Intel Strong ARM* [5], to name a few.

2.3. Communication Unit

The transceiver unit connects wirelessly through the RF channel and is linked to an omni-directional antenna that allows for communications in all directions. The main task of a transceiver is to convert a bit stream arriving from the processing unit into electromagnetic radio waves. Some of commonly used transceivers in sensor nodes are *RFM TR family, Chipcoa CC10000 family, The Infineon TDA 525x family* etc.

The transceiver unit may be passive or an active optical device or a RF device. RF communications require modulation, band pass filtering, demodulation and multiplexing circuitry, which make them more complex and expensive. Moreover, the path loss of the transmitted signal between two sensor nodes may be as high as the fourth order exponent of the distance between them, because the antennas of the sensor nodes are close to the ground. Nevertheless, RF communications is preferred in most of the ongoing sensor network research, because the packets conveyed in sensor networks are small, data rates are low and frequency reuse is high due to short communication distances. These characteristics also make it possible to use low duty cycle radio electronics for sensor networks.

Of the three domains, a sensor node expends maximum energy in data communications. This involves both data transmission and reception. It is found that for short-range communications with low radiation power, the transmission and reception energy costs are nearly

the same. Mixers, frequency synthesizers, voltage controlled oscillators, phase locked loops (PLLs) and power amplifiers, all consume valuable power in the transceiver circuitry.

2.4. Power Supply Unit

The sensor nodes can be powered from energy storage devices or by energy scavenging. The former technique employs a variety of tiny batteries made up of thin films of vanadium oxide and molybdenum oxide [6]. These are fabricated using micro-machined cavities containing an electrolyte, in addition to chemical energy storage. The latter technique employs energy scavenging from the environment in order that the sensor node can operate uninterrupted. The most widely used energy scavenging technique is the solar radiation. There is a possibility of energy-harnessing from body heat in bio-medical applications.

The battery forms the heart of the sensor system as it decides the lifetime of the system. The battery lifetime needs to be prolonged to maximize the network lifetime. Network Lifetime is defined as the maximum number of times a certain data collection function or task can be carried out without any node running out of energy. It is also defined as the time elapsed until the first node in the network is completely depleted of its energy and is determined by the ability to conserve energy in the network. The requirement is that the size of the battery should be as small as possible, the same time being energy efficient. Batteries with energy scavenging capabilities are being designed to increase the lifetime of the sensor system. Two AA sized batteries of 1.2 V each are employed in the battery subsection [1].

Most of the sensor network routing techniques require the knowledge of precise location of nodes that are deployed in the sensor field. This requires a Global Positioning System (GPS) to carry out the tasks. A *mobilizer* may sometimes be needed, especially in Heterogeneous Wireless Sensor Networks (HWSNs) to move the sensor nodes, when circumstances demand. All of these subunits may need to fit into a matchbox-sized module [1]. The required size may be smaller than even a cubic-centimeter [4], which is light enough to be suspended in air.

The Heterogeneous Wireless Sensor Networks (HWSN), a class of WSNs are distributed networks consisting of large number of tiny, typically the size of 35 mm film canister [7,8], static, low power sensor nodes along with a few mobile, high power nodes. These sensor nodes just like their WSN counterparts, have sensing, processing, co-ordinating and communicating abilities. They are used to monitor changes in unattended regions and relay information to the respective control center where necessary action would be taken. In order to complete a

given task, all sensor nodes have to collaborate by exchanging and forwarding measurement data.

3. Applications

The Wireless Sensor Network technology has the potential to change the way we live, work and do business, with applications in entertainment, travel, retail industry, disaster and emergency management. It forms an increasingly attractive means of monitoring environmental conditions and to bridge the gap between the physical and the virtual world. Application areas for WSNs include geophysical monitoring (seismic activity), precision agriculture (soil management), habitat monitoring (tracking of animal herds), transportation (traffic monitoring), military systems, business process (supply chain management) [9,10] etc.

With continued advances in Micro-Electro-Mechanical Systems (MEMS), Wireless Sensor Networks (WSNs) have and will play a vital role in our daily lives. Humans have relied on wired sensors for years, for simple tasks such as temperature monitoring, to complex tasks such as monitoring life-signs in hospital patients. Wireless Sensor Networks provide unforeseen applications in this new field of design [1]. From military applications such as battlefield mapping and target surveillance, to creating context-aware homes [11] where sensors can monitor safety and provide automated services tailored to the individual user; the number of applications are endless. Smart Dust is an example of one such application [12,13]. However this new technology poses many design goals, [1] that up until recently, have not been considered feasible for these applications.

1) The sensor networks are used in a variety of applications which require constant monitoring and detection of specific events. The military applications include battle field surveillance and monitoring, guidance systems of intelligent missiles and detection of attack by weapons of mass destruction, such as chemical, biological or nuclear [14].

2) The WSNs are employed in environmental applications [15] such as forest-fire and flood detection and habitat exploration of animals [16-19].

3) Sensors are extremely useful in patient diagnosis and monitoring. Bio-sensors are implanted in the human body to monitor the patient's physiological parameters such as heart beat or blood pressure. The data so collected is sent regularly to alert the concerned doctor on detection of an anomaly. Such an arrangement provides patients a greater freedom of movement instead of being constantly confined to the hospital bed. Rapid advancements in MEMS technology has made bio-sensors so sophisticated as to enable correct identification of allergies and associated diagnosis [1,20].

4. Issues and Challenges

The WSN is subjected to various resource constraints. The constraints are energy, bandwidth, memory and processing ability. Among them, energy is of prime concern, since it is severely constrained at sensor nodes and it is not feasible to either replace or recharge the batteries of sensor nodes that are often deployed in hostile environment. As a result, these constraints impose an important requirement on any QoS support mechanism in WSNs. Energy efficiency is a critical design issue in WSNs, where each sensor node relies on its limited battery power for data acquisition, processing, transmission and reception.

As the sensor nodes are typically very small and powered by irreplaceable battery, energy control becomes primary and also the most challenging problem in designing sensor networks [21]. In WSNs, each sensor node has different energy consumption rate due to inequality in event sensing and distance from Base Station. This leads to energy disparity among sensor nodes in the network which in turn shortens the lifetime of the network.

Another important issue in WSN is satisfying the QoS parameters. QoS parameters are used for evaluating the performance of networks. The various QoS parameters under considerations are latency, throughput and reliability. Security is a major concern in wireless communications. Sensor network is susceptible to a variety of attacks, including node capture, physical tampering and denial of service while prompting a range of fundamental research challenges. The QoS parameters and energy conservation are the prime factors affecting the lifespan of sensor network. Energy efficient routing mechanisms are inculcated to boost the performance of the sensor network. Wireless sensor networks pose certain design challenges due to the following reasons,

1) The sensor nodes are randomly deployed and hence do not fit into any regular topology. Once deployed, they usually do not require human intervention. This implies that setup and maintenance need to be autonomous.

2) Sensor networks are infrastructureless. Therefore, all routing and maintenance algorithms need to be distributed.

3) An important bottleneck in the operation of sensor nodes is the available energy. Sensors usually rely on their battery for power, which in many cases should be considered as a major constraint while designing protocols. The wireless sensor node, being a micro-electronic device, can only be equipped with a limited power source. In most application scenarios, replenishment of power resources might become impossible. The sensor node lifetime, therefore, shows a strong dependence on battery lifetime.

4) Hardware design for sensor nodes should also consider energy efficiency as a primary requirement. The

micro-controller, operating system, and application software should be designed to conserve power.

5) Sensor nodes should be able to synchronize with each other in a completely distributed manner, so that TDMA schedules can be imposed and temporal ordering of detected events can be performed without ambiguity.

6) A sensor network should also be capable of adapting to changing connectivity due to the failure of nodes, or new nodes powering up. The routing protocols should also be able to dynamically include or avoid sensor nodes in their paths.

7) Real-time communication over sensor networks must be supported through provision of guarantees on maximum delay, minimum bandwidth, or other QoS parameters.

5. Energy Consumption of Sensor Node

The sensor nodes operate in the three modes of sensing, computing and communications, and all of which consume energy. Of the three modes, maximum energy is expended for the communications process. The sensing unit is entrusted with the responsibility to detect the physical characteristics of the environment and has an energy consumption that varies with the hardware nature and applications. However, sensing energy represents a meagre percentage of the entire energy consumption within the entire WSN. In comparison, computations energy is much more. The communication unit consists of a short-range RF circuit which performs the transmission and reception tasks.

Communication energy contributes to data forwarding and it is determined with the transmission range that increases with the signal propagation in an exponential way. The energy consumption model includes the five states: *Acquisition, Transmission, Reception, Listen and Sleep* [22]. These states are described in **Table 1**.

Since the sensor nodes can be in any of three main operations of sensing, computations and communications, each of them could be in different states depending on the component nature. Accordingly different levels of energy are expended in each of them.

Table 1. States of the energy consumption model.

(i) Acquisition: The acquisition state includes sensing, A/D conversion, preprocessing and eventually storage of these data.

(ii) Transmission: The transmission state includes processing, packet forming, encoding, framing, queuing and base band adapting to RF circuits.

(iii) Reception: This state is responsible for low noise amplification, down converter oscillator, filtering, detection, decoding, error detection, address checking and random reception.

(iv) Listen: The listen state is similar to reception and involves the processes of low noise amplification, down convertor oscillator, filtering and terminates at detection.

Sleep: The sleep state expends least energy as compared to the other states.

6. Wireless Sensor Networks Communication Protocols Architecture

Figure 4 depicts the communication protocol stack architecture of the WSN. The energy consumed in one sensor node is influenced by protocol layers structure and the way each layer manages the sensing data.

The protocol layers stack used by the sink and nodes within the network includes the *application layer, transport layer, network layer, data link layer, physical layer, power management plane, mobility management plane and task management plane* and described in **Table 2**.

7. Energy Conservation Challenges in Communication Protocols and Design Issues in WSNs

Despite the innumerable applications of WSNs, these networks have several restrictions, e.g., limited energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques.

The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved. In

Table 2. Protocol layer stack.

(i) Application Layer: This supports different softwares for applications depending on the sensing tasks. There are three types of protocols defined for this layer:

(a) SMP - Sensor Management Protocol

(b) TADAP - Task Assignment and Data Advertisement Protocol
SQDDP - Sensor Query and Data Dissemination Protocol

(ii) Transport Layer: This layer helps to maintain the data flow when the application layer is in need. The protocol development on this layer is a real challenge because sensors are influenced by many factors and constraints such as limited power and memory.

(iii) Network Layer: The network layer allows routing of data through the wireless communication channel. There are several methods and strategies to route data such as routing power cost with available energy based on the energy metric and data-centric routing based on interest dissemination and attribute based naming [1,23].

(iv) Data Link Layer: This layer is responsible for the multiplexing of data streams, data frame detection, medium access control (MAC) and error detection and correction. The design issues of the MAC layer protocol must take into account the different constraints such as power conservation, mobility management and recovery failure strategies.

(v) Physical Layer: This is the lower-most layer and is responsible for frequency selection, carrier frequency generation, signal detection, modulation and data encryption.

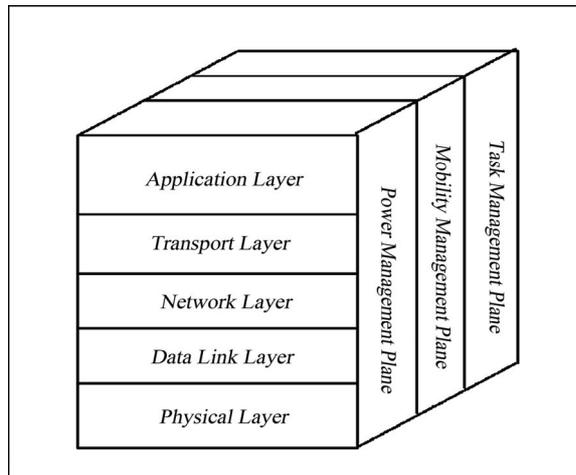


Figure 4. Wireless Sensor Network protocol stack.

the following subsections, some of the routing challenges and design issues that affect routing process in WSNs, are summarized [1,24,25,26].

1) Node Deployment

Node deployment in WSNs is application dependent and affects the performance of the routing protocol. The deployment can be either deterministic or randomized. In deterministic deployment, the sensors are manually placed and data is routed through pre-determined paths. However, in random node deployment, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner.

If the resultant distribution of nodes is not uniform, optimal clustering becomes necessary to allow connectivity and enable energy efficient network operation. Inter-sensor communication is normally within short transmission ranges due to energy and bandwidth limitations. Therefore, it is most likely that a route will consist of multiple wireless hops.

2) Energy Consumption without Losing Accuracy

The sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy-conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime [1].

In a multihop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require re-routing of packets and reorganization of the network.

3) Data Reporting Model

Data sensing and reporting in WSNs is dependent on the application and the time criticality of the data reporting. Data reporting can be categorized as either time-driven (continuous), event-driven, query-driven, and hybrid [27]. The time-driven delivery model is suitable for

applications that require periodic data monitoring. As such, sensor nodes will periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest at constant periodic time intervals.

In event-driven and query-driven models, sensor nodes react immediately to sudden and drastic changes in the value of a sensed attribute due to the occurrence of a certain event or a query is generated by the BS. As such, these are well suited for time critical applications. A combination of the previous models is also possible. The routing protocol is highly influenced by the data reporting model with regard to energy consumption and route stability.

4) Node/Link Heterogeneity

In many studies, all sensor nodes are assumed to be homogeneous, *i.e.*, having equal capacity in terms of computation, communication, and power. However, depending on the application a sensor node can have different role or capability. The existence of heterogeneous set of sensors raises many technical issues related to data routing. For example, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures, and capturing the image or video tracking of moving objects.

These special sensors can be either deployed independently or the different functionalities can be included in the same sensor nodes. Even data reading and reporting can be generated from these sensors at different rates, subject to diverse quality of service constraints, and can follow multiple data reporting models. For example, hierarchical protocols designate a cluster-head node different from the normal sensors. These cluster-heads can be chosen from the deployed sensors or can be more powerful than other sensor nodes in terms of energy, bandwidth, and memory. Hence, the burden of transmission to the BS is handled by the set of cluster-heads [28].

5) Fault-Tolerance

Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. If many nodes fail, MAC and routing protocols must accommodate formation of new links and routes to the data collection base stations. This may require actively adjusting transmit powers and signalling rates on the existing links to reduce energy consumption, or rerouting packets through regions of the network where more energy is available [29]. Therefore, multiple levels of redundancy may be needed in a fault-tolerant sensor network.

6) Scalability

The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands, or more. Any routing scheme must be able to work with this huge number of sensor nodes. In addition, sensor network routing protocols should be scalable enough to re-

spond to events in the environment. Until an event occurs, most of the sensors can remain in the sleep state, with data from the few remaining sensors providing a coarse quality.

7) *Network Dynamics*

Most of the network architectures assume that sensor nodes are stationary. However, mobility of both BSs and sensor nodes is sometimes necessary in many applications [19]. Routing messages from or to moving nodes is more challenging since route stability becomes an important issue, in addition to energy, bandwidth etc.

Moreover, the sensed phenomenon can be either dynamic or static depending on the application, e.g., it is dynamic in a target detection/tracking application, while it is static in forest monitoring for early fire prevention. Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the BS.

8) *Transmission Media*

In a multi-hop sensor network, communicating nodes are linked by a wireless medium. The traditional problems associated with a wireless channel (e.g., fading, high error rate) may also affect the operation of the sensor network. In general, the required bandwidth of sensor data will be low, on the order of 1-100 kbps. Related to the transmission media is the design of medium access control (MAC). One approach of MAC design for sensor networks is to use TDMA based protocols that conserve more energy compared to contention based protocols like CSMA (e.g., IEEE 802.11).

9) *Connectivity*

High node density in sensor networks precludes them from being completely isolated from each other. Therefore, sensor nodes are expected to be highly connected. This, however, may not prevent the network topology from being variable and the network size from being shrinking due to sensor node failures. In addition, connectivity depends on the possibly random distribution of nodes.

10) *Coverage*

In WSNs, each sensor node obtains a certain view of the environment. A given sensors view of the environment is limited both in range and in accuracy; it can only cover a limited physical area of the environment. Hence, area coverage is also an important design parameter in WSNs.

11) *Data Aggregation/Fusion*

Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced. Data aggregation is the combination of data from different sources according to a certain aggregation function, e.g., duplicate suppression, minima, maxima and average.

This technique has been used to achieve energy effi-

ciency and data transfer optimization in a number of routing protocols. Signal processing methods can also be used for data aggregation. In this case, it is referred to as data fusion where a node is capable of producing a more accurate output signal by using some techniques such as beamforming to combine the incoming signals and reducing the noise in these signals.

12) *Quality of Service*

In some applications, data should be delivered within a certain period of time from the moment it is sensed; otherwise the data will be useless. Therefore bounded latency for data delivery is another condition for time-constrained applications. However, in many applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent.

As the energy gets depleted, the network may be required to reduce the quality of the results in order to reduce the energy dissipation in the nodes and hence lengthen the total network lifetime. Hence, energy-aware routing protocols are required to capture this requirement.

8. Performance Evaluation Metrics

In order to study the challenges offered by the energy constrained wireless sensor nodes and to evaluate the performance and the QoS offered by the network, the performance metrics under consideration are discussed in **Table 3**.

The previous sections threw light on the WSNs, their characteristics, issues, challenges and applications. In order to understand their performance and behavior, the OMNET++ (Objective Modular Network Test-bed in C++) simulator may be employed. OMNET++ is a discrete-

Table 3. Performance metrics.

(i) Energy Consumption per successful data report This gives a good measure of the network lifetime. A routing algorithm which maximizes the lifetime of network, is desirable. This metric also shows how efficient the algorithm is, in energy consumption. This metric is an indication of the energy cost incurred to realize the achieved performance.

(ii) Network Lifetime

Network Lifetime is defined as the time elapsed until the first node in the network is completely drained of its energy (dies).

(iii) Network Throughput

This is defined as the total number of packets received at the sink divided by the simulation time.

(iv) Latency

Latency is defined as the average time that a packet moves on the network.

(v) Delivery Ratio

Delivery ratio of the network is specified in terms of the number of packets received at the sink divided by the number of packets generated at the source.

event simulator for WSNs [30]. It is a public-source, component-based, modular simulation frame work and used to simulate communication networks and other distributed systems.

Discrete-event simulation is a trusted platform for modelling and simulating a variety of systems. The design of WSNs requires the simultaneous consideration of the effects of several factors such as energy efficiency, fault-tolerance, Quality of Service (QoS) demands, synchronization, scheduling strategies, system topology, communications and coordination protocols.

9. Conclusions

A WSN is composed of tens to thousands of sensor nodes which communicate through a wireless channel for information sharing and processing. The sensors are deployed on a large scale for environmental monitoring and habitat study, for military surveillance, in emergent environments for search and rescue, in buildings for infrastructure health monitoring, in homes to realize a smart environment. WSNs have been made viable by the convergence of micro-electro-mechanical systems technology, wireless communications and digital electronics. The energy conservation challenges and related issues emphasize the need for energy saving and optimizing protocols to increase the lifetime of sensor networks.

10. References

- [1] I. F. Akyildiz, W. L. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless Sensor Networks: A Survey on Sensor Networks," *IEEE Communications Magazine*, Vol. 40, No. 8, 2002, pp. 102-114.
- [2] D. Estrin, R. Govindan, J. Heidemann and S. Kumar, "Next Century Challenges: Scalable Coordination in Sensor Networks," *Proceedings of the ACM/IEEE International Conference on Mobile Computing and Networking*, Seattle, Washington, USA, August 1999, pp. 263-270.
- [3] P. B. Chun, N. R. Lo, E. Berg and K. S. J. Pister, "Optical Communication Using Micro-Corner Cube Reflectors," *Proceedings of the 10th IEEE International Micro Electro Mechanical Systems Conference (MEMS'97)*, Vol. 40, No. 8, 1997, pp. 350-355.
- [4] G. Pottie and W. Kaiser, "Wireless Integrated Network Sensors," *Communications of the ACM*, Vol. 43, No. 5, 2000, pp. 51-58.
- [5] H. Hashemi, "The Indoor Radio Propagation Channel," *Proceedings of IEEE*, Vol. 81, No. 7, 1993, pp. 943-968.
- [6] H. Baltes *et al.*, "Micromachined Thermally Based CMOS Microsensors," *Proceedings of IEEE*, Vol. 86, No. 8, 1998, pp. 1660-1678.
- [7] D. Culler, D. Estrin and M. Srivastava, "Overview of Sensor Networks," *IEEE Computer*, Vol. 37, No. 8, 2004, pp. 41-49.
- [8] S. Tarannum, D. Prakash, S. George, B. V. Tara, S. Ushe, L. Nalini, K. R. Venugopal and L. M. Patnaik, "Consolidate and Advance: An Efficient QoS Management in Heterogeneous Wireless Sensor Networks," *IEEE ICSCN 2008*, Chennai, January 2008, pp. 93-98.
- [9] B. Akan, Y. Sankarasubramaniam and I. F. Akyildiz, "ESRT: Event-to-Sink Reliable Transport in Wireless Sensor Networks," *Proceedings of the 4th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, Annapolis, Maryland, USA, 2003, pp. 177-188.
- [10] M. Kuorilehto, M. Hännikäinen and T. D. Hämäläinen, "A Survey of Application Distribution in Wireless Sensor Networks," *EURASIP Journal on Wireless Communications and Networking*, Vol. 2005, No. 5, 2005, pp. 774-788.
- [11] S. Meyer and A. Rakotonirainy, "A Survey of Research on Context-Aware Homes," *Workshop on Wearable, Invisible, Context-Aware, Ambient, Pervasive and Ubiquitous Computing*, Adelaide, 2003, pp. 159-168.
- [12] B. Warneke, M. Last, B. Liebowitz and K. S. J. Pister, "Smart Dust: Communicating with a Cubic-Millimeter Computer," *Computer Magazine*, Vol. 34, No. 1, 2002, pp. 44-51.
- [13] V. Hsu, M. Kahn and K. Pister, "Wireless Communication for Smart Dust," *Electronic Research Laboratory Technical Memorandum*, February 1998.
- [14] A. G. Ruzzelli, R. Tynan, M. J. O'Grady and G. M. P. O'Hare, "Advances in Wireless Sensor Networks," *Encyclopaedia of Mobile Computing and Commerce (EMCC)*, Vol. 1, 2006, pp. 1-12.
- [15] D. C. Steere, A. Baptista, D. McNamee, C. Pu and J. Walpole, "Research Challenges in Environmental Observation and Forecasting Systems," *Proceedings of the 6th Annual International Conference on Mobile Computing and Networking*, Boston, Massachusetts, United States, 2000, pp. 292-299.
- [16] E. Biagioni and K. Bridges, "The Application of Remote Sensor Technology to Assist the Recovery of Rare and Endangered Species," *In Special Issue on Distributed Sensor Networks for the International Journal of High Performance Computing Applications*, Vol. 16, No. 3, 2002, pp. 315-324.
- [17] A. Cerpa, J. Elson, D. Estrin, L. Girod, M. Hamilton and J. Zhao, "Habitat Monitoring: Application Driver for Wireless Communications Technology," *Proceedings of the 2001 ACM SIGCOMM Workshop on Data Communications in Latin America and the Caribbean*, San Jose, Costa Rica, April 2001, pp. 20-41.
- [18] A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler and J. Anderson, "Wireless Sensor Networks for Habitat Monitoring," *In ACM International Workshop on Wireless Sensor Networks and Applications (WSNA'02)*, Atlanta, September 2002, pp. 88-97.
- [19] H. Wang, J. Elson, L. Girod, D. Estrin and K. Yao, "Target Classification and Localization in Habitat Monitoring," *Proceedings of the IEEE ICASSP'03*, Hong Kong, April 2003, pp. 597-600.

- [20] L. Schwiebert, S. K. S. Gupta and J. Weinmann, "Research Challenges in Wireless Networks of Biomedical Sensors," *Mobile Computing and Networking*, Rome, Italy, 2001, pp. 151-165.
- [21] M. Eltoweissy, M. Younis, K. Akkaya and A. Wadaa, "On Handling QoS Traffic in Wireless Sensor Networks," *Proceedings of the 37th Annual Hawaii International Conference on System Science*, Hawaii, 2004, pp. 5-8.
- [22] M. Ilyas and I. Mahgoub, "Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems," CRC Press, Boca Raton, 2005.
- [23] S. Tarannum, S. Aravinda, L. Nalini, K. R. Venugopal and L. M. Patnaik, "Routing Protocol for Lifetime Maximization of Wireless Sensor Networks," *International Journal on Information Processing*, Vol. 1, No. 2, 2007, pp. 58-67.
- [24] T. Nieberg, S. Dulman, P. Havinga, L. Hoesel and J. Wu, "Collaborative Algorithms for Communication in Wireless Sensor Networks," University of Twente, Netherlands, 2003.
- [25] J. N. A. Karaki and A. E. Kamal, "Routing Techniques in Wireless Sensor Networks: A Survey," *IEEE on Wireless Communications*, Vol. 11, No. 6, 2004, pp. 6-28.
- [26] M. Yebari, T. Addali, A. Z. Sadouq and M. Essaaidi, "Energy Conservation Challenges in Wireless Sensor Networks: A State-of-The-Art Study," *International Journal on Information and Communication Technologies*, Vol. 1, No. 2, 2008, pp. 29-35.
- [27] Y. Yao and J. Gehrke, "The Cougar Approach to In-Network Query Processing in Sensor Networks," SIGMOD Record, September 2002.
- [28] S. Tarannum, S. Srividya, D. S. Asha and K. R. Venugopal, "Dynamic Hierarchical Communication Paradigm for Wireless Sensor Networks: A Centralized, Energy Efficient Approach," *Wireless Sensor Networks*, Vol. 1, No. 4, 2009, pp. 340-349.
- [29] S. Tarannum, V. Anitha, A. Priya, K. R. Venugopal and L. M. Patnaik, "Self-Healing AntChain for Increasing Lifespan in Wireless Sensor Networks," *International Engineering and Technology (IETECH) Journal of Communication Techniques*, Vol. 2, No. 4, 2008, pp. 239-246.
- [30] A. Vargas, "OMNET ++ Discrete Event Simulator System," Version 2.3 Edition, 2003.