A Survey on Wireless Sensor Network Applications, Design Influencing Factors & Types of Sensor Network

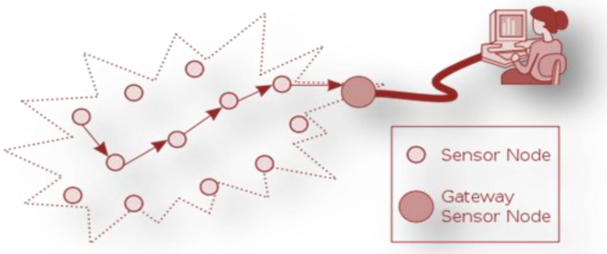
Richa Verma

Abstract*- Modern advancement in wireless communications and electronics has facilitated the development of low-cost sensor networks. These sensor networks can be used for various application areas (e.g., health, military, home). For different application areas, there are various technical issues that researchers are presently resolving. Wireless sensor networks are interesting to researchers due to their broad range of application in areas such as target detection and tracking, environmental monitoring, industrial process monitoring, and tactical systems. A wireless sensor network (WSN) has significant applications such as remote environmental monitoring and target tracking. These sensors are prepared with wireless interfaces with which they can communicate with one another to form a network. WSN term can be usually sensed as devices range from laptops, PDAs or mobile phones to very tiny sensing devices. In this paper we give an overview of several new applications, factors influencing sensor network design and about different network topologies.

***Index Terms*—: Wireless sensor network, Sensor network services, Applications, factors, Ad hoc networks**

I. INTRODUCTION

The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one or several sensors. Each such sensor network node has typically several parts: an antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery. A sensor node varies in size. The cost of sensor nodes is equally changeable, ranging from a few to hundreds of dollars. Size and cost limitation on sensor nodes affects other constraints on resources such as energy, memory, computational speed and communications bandwidth. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding.



Manuscript received on October 2013.
Richa Verma, M.E Student, Department of Electronics and Communication NITTTR, Chandigarh, India.

A sensor network is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be engineered or predetermined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an on board processor. Instead of sending the raw data to the nodes responsible for the fusion, they use their processing. Abilities to carry out simple computations locally, and transmit only the required and partially processed data. [1]

Recent advances in micro-electro mechanical systems (MEMS) technology, wireless, and digital electronics have allowed the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short distances. Sensor networks represent an important improvement over conventional sensors, which are organized in the following two ways:

- Sensors can be located far from the actual phenomenon, i.e., something known by sense view. In this approach, large sensors that use some difficult techniques to distinguish the targets from environmental noise are required.
- Several sensors that perform only sensing can be installed. The location of the sensors and communications topology is carefully engineered. They pass on time series of the sensed phenomenon to the central nodes where computations are performed and data are fused.

A sensor network is composed of a huge number of sensor nodes, which are closely organized either inside the phenomenon or very close to it. The sensor nodes position need not be engineered or pre-determined. This allows random use in unreachable terrains or disaster relief operations. This also means that sensor network protocols and algorithms must have self-organizing capabilities. Another unique feature of sensor networks is the supportive endeavor of sensor nodes. Sensor nodes are fixed with an on-board processor. In place of sending the raw data to the nodes responsible for the fusion, sensor nodes use their handing out abilities to locally carry out simple computations and transmit only the necessary and partially processed data.

Understanding sensor network applications need wireless ad hoc networking techniques. Though many protocols and algorithms have been proposed for traditional wireless ad hoc networks, they are not fine suited for the unique features and application requirements of sensor networks. To illustrate this point, the differences between sensor networks and ad hoc networks [2] are outlined below:

- The nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network.
- Sensor nodes are efficiently deployed.
- Nodes in sensor network are prone to failures.
- The topology of a sensor network changes regularly.
- Broadcast communication models are used by sensor nodes whereas most ad hoc networks are based on point-to-point communications.
- Sensor nodes are inadequate in power, computational capacities, and memory.
- Large amount of overhead and large number of sensors are the reason for sensor nodes, not having global identification. [3]

As great numbers of sensor nodes are closely organized, neighbor nodes appear very close to each other. Multi-hop communication in sensor networks is expected to use less power than the traditional single hop communication. Furthermore, the transmission power levels can be kept low, which is extremely preferred in hidden operations.

Expansion in hardware technology has effect on low-cost sensor nodes, which are composed of a single chip embedded with memory, a processor, and a transceiver. In comparison to other mobile devices low-power capability leads to limited coverage and communication range for sensor nodes. In order to cover the target area effectively sensor networks must include a great number of nodes. Unlike other wireless networks, it is usually difficult or impractical to charge/replace tired batteries. That is why the primary purpose in wireless sensor networks design is benefit from on node/network lifetime, leaving the other performance metrics as secondary objectives. While the communication of sensor nodes will be more energy consuming than their computation, it is a primary worry to minimize communication while achieving the desired network operation.

The remainder of the paper is organized as follows: In Section 2, we present some potential sensor network applications which show the usefulness of sensor networks. In Section 3, we discuss the factors that influence the sensor network design. We provide detailed investigation about the types of sensor networks in Section 4 and we conclude our paper in Section 5.

II. SENSOR NETWORK APPLICATIONS

Sensor networks may consist of many diverse types of sensors such as seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic and radar, which are capable to observe a wide variety of ambient conditions that include the following [4]:

- Temperature,
- Humidity,
- Vehicular movement,
- Lightning condition,
- Pressure,
- Soil makeup,
- Noise levels,
- The presence or absence of certain kinds of objects,
- Mechanical stress levels on attached objects, and
- The current characteristics such as speed, direction, and size of an object [5].

Sensor nodes can be used for continuous sensing, event detection, event ID, location sensing, and local control of actuators. The conceptions of micro-sensing and wireless connection of these nodes assure many new application areas. The applications are classified into military, environment, health, home and other commercial areas. It is feasible to increase this classification with more categories such as space exploration, chemical processing and disaster relief.

A. Military Application

Wireless sensor networks can be an essential part of military command, control, communications, computing, intelligence, surveillance, reconnaissance and targeting (C4ISRT) systems. The quick deployment, self-organization and fault tolerance uniqueness of sensor networks make them a very promising sensing technique for military C4ISRT. Since sensor networks are based on the intense deployment of disposable and low-cost sensor nodes, demolition of some nodes by hostile actions does not change a military operation as much as the destruction of a traditional sensor, which makes sensor networks concept a better approach for battlefields. A few of the military applications of sensor networks are monitoring friendly forces, equipment and ammunition; battlefield surveillance; investigation of opposing forces and terrain; targeting; battle damage assessment; and nuclear, biological and chemical (NBC) attack detection and reconnaissance.

1) In monitoring friendly forces, equipment and ammunition: Leaders and commanders can continuously monitor the status of friendly troops, the condition and the accessibility of the equipment and the ammunition in a battlefield by the use of sensor networks. Each troop, vehicle, equipment and critical ammunition can be attached with small sensors that report the status. These reports are collected in sink nodes and sent to the troop leaders. The data can also be forwarded to the upper levels of the command hierarchy as being combined with the data from other units at each level.
2) Battlefield Surveillance: Critical terrains, approach routes, paths and straits can be quickly covered with sensor networks and closely looked at for the activities of the opposing forces. Since the operations develop and new operational plans are prepared, new sensor networks can be deployed anytime for battlefield surveillance.
3) Investigation of opposing forces and terrain: Sensor networks can be arranged in critical terrains, and some valuable, detailed, and timely intelligence about the opposing forces and terrain can be gathered within minutes before the opposing forces can catch them.
4) Targeting: Sensor networks can be built-into guidance systems of the intelligent ammunition.

Battle damage assessment: Immediately before or after attacks, sensor networks can be deployed in the target area to gather the battle damage assessment data.

B. Environmental Applications

Some environmental applications of sensor networks comprise of tracking the movements of birds, small animals, and insects; observe environmental conditions that influence crops and livestock; irrigation; macro instruments for large-scale. Earth monitoring and planetary exploration; chemical/biological detection; precision agriculture; biological, Earth, and environmental observation in marine, soil, and atmospheric contexts; forest fire detection; meteorological or geophysical research; flood detection; bio-complexity mapping of the environment; and pollution learning[6,7,10,11–13,14,15,16,17,18,19-21]

1) Forest fire detection: As sensor nodes may be strategically, randomly, and densely arranged in a forest, sensor nodes can transmit the exact origin of the fire to the end users before the fire is spread uncontrollable. Millions of sensor nodes can be installed and integrated using radio frequencies/optical systems. They are also equipped with effective power searching methods [6], such as solar cells, because the sensors may be left unattended for months and even years. The sensor nodes will team up with each other to perform distributed sensing and overcome obstacles, such as trees and rocks that block wired sensors' line of sight.
2) Bio-complexity mapping of the environment [9]: A Bio-complexity mapping of the environment requires complicated approaches to fit in information across temporal and spatial scales [22,23]. The advances of technology in the remote sensing and automated data collection have facilitated higher spatial, spectral, and temporal resolution at a geometrically declining cost per unit area [24]. Beside these advances, the sensor nodes have the capability to attach with the Internet, which allow remote users to control, monitor and observe the bio complexity of the environment [25,26].
3) Flood Detection [12]: An example of flood detection is the ALERT system [27] planned in the US. Several types of sensors installed in the ALERT system are rainfall, water level and weather sensors. They supply information to the centralized database system in a pre-defined way.
4) Precision Agriculture: It is the ability to observe the pesticides level in the drinking water, the level of soil erosion, and the level of air pollution.

C. Health Application

Sensor networks are offering interfaces for the disabled; integrated patient monitoring; diagnostics; drug administration in hospitals; monitoring the movements and internal processes of insects or other small animals; [6, 21, 28, 29, 30].

1) Telemonitoring of human physiological data: The physiological data composed by the sensor networks can be gathered for a long period of time [20], and can be used for medical exploration [31]. The installed sensor networks can also watch and detect elderly people's behavior, e.g., a fall [7,32].
2) Tracking and monitoring doctors and patients inside a hospital: Every patient has small and light weight sensor nodes attached to them. Each sensor node has its particular task. For example, one may be detecting the heart rate while another is detecting the blood pressure. Doctors may also hold a sensor node, which allows other doctors to locate them within the hospital.
3) Drug administration in hospitals: if sensor nodes can be attached to medications, the possibility of getting and recommending the wrong medication to patients can minimize. Patients will have sensor nodes that identify their allergies and required medications.

D. Home Applications

1) Home Automation: Since with the advancement in technology, smart sensor nodes and actuators can be buried in appliances, such as vacuum cleaners, micro-wave ovens, refrigerators, and VCRs [33]. These sensor nodes contained by the domestic devices can interact with each other and with the external network via the Internet or Satellite. They allow end users to control home devices locally and remotely more easily.
2) Smart Environment: The design of smart environment can have two different point of views, i.e., human-centered and technology-centered [1]. For human-centered, a smart environment has to adjust to the needs of the end users in terms of input/output capabilities. For technology-centered, new hardware technologies, networking solutions, and middleware services have to be developed. The sensor nodes can be fixed into furniture and appliances, and they can communicate with each other and the room server. The room server can also converse with other room servers to learn about the services they offered, e.g., printing, scanning, and faxing. These room servers and sensor nodes can be incorporated with existing embedded devices to become self-organizing, self regulated and adaptive systems based on control theory models as described in[34].

E. Other Commercial Applications

Commercial applications are observing material fatigue; building virtual keyboards; managing inventory; monitoring product quality; constructing smart office spaces; environmental control in office buildings; robot control and guidance in automatic manufacturing environments; interactive toys; interactive museums; factory process control and automation; monitoring disaster area; smart structures with sensor nodes embedded inside; machine diagnosis; transportation; factory instrumentation; local control of actuators; detecting and monitoring car thefts; vehicle tracking and detection; and instrumentation of semiconductor processing chambers, rotating machinery, wind tunnels, and anechoic chambers . [6,15, 35 ,36 37].

1) Environmental control in office buildings: The air conditioning and heat of nearly all buildings are centrally controlled. Therefore, the temperature within a room can differ by few degrees; one side may be warmer than the other because there is only one control in the room and the air flow from the central system. A distributed wireless sensor network system can be put in to control the air flow and temperature in different parts of the room.[35]
2) Interactive Museums: In the upcoming time, children will be capable to interact with objects in museums to learn more about them. These objects will be able to reply to their touch and speech. Children can also participate in real time cause-and-effect experiments, which can teach them about science and environment. Wireless sensor networks can offer paging and localization inside the museum. [36]
3) Detecting and monitoring car thefts: Sensor nodes are being organized to detect and identify threats within a geographic region and inform about these threats to remote end users by the Internet for analysis [37].

4) Managing inventory control: Every item in a warehouse may have a sensor node attached. The end users can find out the exact location of the item and mark the number of items in the same category. If the end users want to put in new inventories, all the users need to do, is to connect the appropriate sensor nodes to the inventories. The end users can follow and locate where the inventories are at all times.
5) Vehicle tracking and detection: There are two approaches as described in [36] to follow and detect the vehicle: first, the line of bearing of the vehicle is firmed locally within the clusters and then it is forwarded to the base station, and second, the raw data gathered by the sensor nodes are forwarded to the base station to determine the location of the vehicle.

III. FACTORS INFLUENCING SENSOR NETWORK DESIGN

A sensor network design is controlled by many factors, which include fault tolerance; scalability; production costs; operating environment; sensor network topology; hardware constraints; transmission media; and power consumption. These factors are surveyed by many researchers because they serve as a guideline to design a protocol or an algorithm for sensor networks. In addition, these influencing factors can be used to contrast different schemes.

A. Fault Tolerance

Some sensor nodes may be unsuccessful or be blocked due to lack of power, have physical damage or environmental interference. The failure of sensor nodes should not change the overall assignment of the sensor network. This is the dependability or fault tolerance issue. Fault tolerance is the ability to maintain sensor network functionalities without any break due to sensor node failures [38,39,40]. Protocols and algorithms may be measured to address the level of fault tolerance required by the sensor networks. If the environment where the sensor nodes put in order little interference, then the protocols can be more relaxed. On the other hand, if sensor nodes are being deployed in a battlefield for surveillance and detection, then the fault tolerance has to be high because the sensed data are serious and sensor nodes can be destroyed by hostile actions.

B. Scalability

The number of sensor nodes situated in studying a phenomenon may be in the order of hundreds or thousands. Depending on the application, the number may attain an extreme value of millions. They must also use the high density character of the sensor networks. The density can vary from few sensor nodes to few hundred sensor nodes in a area, which can be less than 10 m in diameter [15]. The density can be calculated according to [6] as $\mu(R) = (N\pi r^2)/A$, Where N is the number of scattered sensor nodes in region A; and R, the radio transmission range. Basically, μ(R) gives the number of nodes within the transmission radius of each node in region A. The number of nodes in a section can be used to identify the node density. The node density depends on the application in which the sensor nodes are fixed. For machine analysis application, the node density is around 300 sensor nodes in a 5 *5 m2 region, and the density for the vehicle tracking application is approximately 10 sensor nodes per region [36]. In general, the density can be as high as 20 sensor nodes/m3 [36]. A home may have around two dozens of home appliances containing sensor nodes [33], but this number will produce if sensor nodes are embedded into furniture and other miscellaneous items. For surroundings monitoring application, the number of sensor nodes ranges from 25 to 100 per region [14]. The density will be tremendously high when a person usually containing hundreds of sensor nodes, which are embedded in eye glasses, clothing, shoes, watch, jewelry, and human body, is sitting in a stadium watching a basketball, football, or baseball game.

C. Production Costs

The cost of a single node is very important to justify the overall cost of the networks as the sensor networks consist of a large number of sensor nodes. If the cost of the network is extra expensive than installed traditional sensors, then the sensor network is not cost-justified. As a result, the cost of each one node has to be kept low. The state-of-the-art technologies permit a Bluetooth radio system to be less than 10$ [35]. Also, the price of a PicoNode is embattled to be less than 1$ [41]. The cost of a sensor node should be less than 1$ in order for the sensor network to be feasible [41]. The cost of a Bluetooth radio, which is known to be a low-cost device, is even 10 times more expensive than the embattled price for a sensor node. Note that a sensor node also has some extra units such as sensing and processing units. In addition, it might be prepared with a location finding system, mobilizer, or power generator depending on the applications of the sensor networks. As a result, the cost of a sensor node is a very demanding issue, known the amount of functionalities with a price of much less than a dollar.

D. Hardware Constraints

A sensor node is equipped up with four basic components as shown in Fig. 1: a sensing unit, a processing unit, a transceiver unit and a power unit. They may also have application reliant additional components such as a location finding system, a power generator and a mobilize. Sensing units are usually composed of two subunits: sensors and analog to digital converters (ADCs). The analog signals formed by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and afterward fed into the processing unit. The processing unit, which is usually associated with a small storage unit, handles the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks. A transceiver unit joins the node to the network. One of the most vital components of a sensor node is the power unit. Power units may be hold up by a power scavenging unit such as solar cells. There are also other application dependent subunits. All of these subunits may require fitting into a matchbox-sized module [42]. The necessary size may be smaller than even a cubic centimeter [37] which is light adequate to remain suspended in the air. Apart from the size, there are also some other rigorous constraints for sensor nodes. These nodes must [21]

- Consume tremendously low power,
- Activate in high volumetric densities,
- Have low production cost and is dispensable,
- Be independent and operate unattended,
- Be adaptive to the environment.

Since the sensor nodes are regularly unreachable, the lifetime of a sensor network depends on the lifetime of the power possessions of the nodes. Power is also a limited resource due to the size limitations. For example, the total stored energy in a smart dust mote is on the order of 1 J [37]. Most of the sensing responsibilities require the knowledge of location. Since sensor nodes are generally deployed aimlessly and run unattended, they need to share with a location finding system. Location finding systems are also required by many of the proposed sensor network routing protocols as explained in Section 4. It is often assumed that each sensor node will have a global positioning system (GPS) unit that has at least 5 m accuracy.

E. Sensor Network Topology

Numbers of inaccessible and unattended sensor nodes, which are prone to regular failures, make topology maintenance a challenging task. Hundreds to several thousands of nodes are deployed all over the sensor field. They are deployed within tens of feet of each other [42]. The node densities may be as high as 20 nodes/m3[36]. Deploying high number of nodes densely requires cautious handling of topology maintenance. The issues related to topology maintenance and changes are in three phases:

1) Pre-deployment and deployment phase: The sensor nodes can be either thrown in mass or placed one by one in the sensor field. They can be deployed by
   • sinking from a plane,
   • delivering in an artillery shell, rocket or missile,
   • placing one by one either by a human or a robot.
   • placing in factory, and
2) Post-deployment phase: After use, topology changes are due to change in sensor nodes [42,43]
   • Position,
   • Task details
   • Reachability (due to jamming, noise, moving obstacles, etc.),
   • malfunctioning, and
   • Available energy
3) Re-deployment of additional nodes phase: Extra sensor nodes can be re-deployed at any time to substitute the malfunctioning nodes or due to changes in task dynamics. Addition of new nodes creates a need to re-organize the network. Coping with regular topology changes in an ad hoc network that has numerous of nodes and very rigid power consumption constraints require special routing protocols.

F. Environment

Sensor nodes are heavily deployed either very close or directly inside the phenomenon to be observed. They generally work unattended in remote geographic areas. They may be functioning

• In the core of a large machinery,
• In demanding intersections,
• At the underneath of an ocean,
• On the surface of an ocean through a tornado,
• In a biologically or chemically polluted field,
• In a battlefield outside the enemy lines,
• In a home or a huge building,
• In a huge warehouse,
• In the internal of twister
• Close to animals,
• Attached to speedy moving vehicles, and
• In a drain or river moving with current.

This list gives us an idea regarding the conditions in which sensor nodes are expected to work.

IV.TYPES OF SENSOR NETWORKS

Existing WSNs are organized on land, underground, and underwater. Depending on the environment, a sensor network features diverse challenges and constraints. There are following kinds of WSNs: terrestrial WSN, underground WSN, multi-media WSN, and mobile WSN

A. Terrestrial WSNs

Typically consist of hundreds to thousands of low-priced wireless sensor nodes deployed in a given area, either in an ad hoc or in a pre planned manner. In ad hoc operation, sensor nodes can be dropped from a plane and aimlessly placed into the target area. In pre-planned deployment, grid placement is there, optimal placement [46], 2-d and 3-d placement [44,45] models. In a terrestrial WSN, consistent communication in a intense environment is very important. Terrestrial sensor nodes must be capable to communicate successfully data back to the base station. While battery power is restricted and may not be rechargeable, terrestrial sensor nodes still can be equipped with a secondary power source such as solar cells. For a terrestrial WSN, energy can be preserved with multi-hop optimal routing, short transmission range, in-network data aggregation, eliminating data redundancy, minimizing delays, and using low duty-cycle operations.

B. Underground WSNs

It consist of a quantity of sensor nodes buried underground or in a cave or mine which are used to monitor underground conditions. Extra sink nodes are located above ground to extend information from the sensor nodes to the base station. An underground WSN is more expensive than a terrestrial WSN in terms of equipment, deployment, and maintenance. Underground sensor nodes are costly because appropriate equipment parts must be selected to guarantee reliable communication through soil, rocks, water, and other mineral contents. The underground environment makes wireless communication a challenge due to signal losses and high levels of attenuation. Unlike terrestrial WSNs, the process of an underground WSN requires cautious planning and energy and cost considerations. Energy is an important worry in underground WSNs. Like terrestrial WSN, underground sensor nodes are prepared with a limited battery power and organized into the ground, it is difficult to recharge or replace a sensor node's battery. A key objective is to watch energy in order to increase the lifetime of network which can be achieved by executing efficient communication protocol.

C. Multi-Media WSNs

[49] It has been proposed to facilitate monitoring and tracking of events in the form of multimedia such as video, audio, and imaging. Multi-media WSNs consist of a number of low cost sensor nodes prepared with cameras and microphones. These sensor nodes interrelate with each other over a wireless connection for data recovery, process, correlation, and compression. Multi-media sensor nodes are organized in a pre-planned manner into the environment to assure coverage. Challenges in multi-media WSN comprise high bandwidth demand, high energy consumption, quality of service (QoS) provisioning, data processing and compressing techniques, and cross-layer design. Multi-media content such

as a video stream needs elevated bandwidth in order for the content to be delivered. As a consequence, high data rate leads to high energy consumption. Transmission techniques that seize high bandwidth and low energy consumption have to be developed. QoS provisioning is a demanding task in a multi-media WSN due to the variable delay and variable channel capacity. It is significant that a certain level of QoS must be achieved for consistent content delivery. In-network processing, filtering, and compression can considerably develop network performance in terms of filtering and extracting redundant information and merging contents. Similarly, cross-layer interaction between the layers can improve the processing and the delivery process.

D. Mobile WSNs

It consists of a set of sensor nodes that can move on their own and interact with the physical environment. Mobile nodes contain the ability to sense, compute, and communicate like static nodes only the key difference is that the mobile nodes have the ability to move and organize itself in the network. A mobile WSN can start with some initial deployment and nodes can then increase out to collect information. Information gathered by a mobile node can be converse to another mobile node when they are within range of each other. One more key difference is data distribution. In a static WSN, data can be distributed by fixed routing or flooding while dynamic routing is used in a mobile WSN. Challenges in mobile WSN comprise deployment, localization, self-organization, navigation and control, coverage, energy, maintenance, and data process. In military surveillance and tracking, mobile sensor nodes can work together and make decisions based on the target. Mobile sensor nodes can attain a higher degree of coverage and connectivity compared to static sensor nodes. In the presence of obstacles in the field, mobile sensor nodes can plan ahead and move properly to obstructed regions to increase target exposure.

V.CONCLUSION

The flexibility, fault tolerance, high sensing fidelity, low-cost and rapid deployment uniqueness of sensor networks make many new and exciting application areas for remote sensing. In the future, this broad range of application areas will make sensor networks an integral part of our lives. However, recognition of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, hardware, topology change, environment and power consumption. Since these constraints are highly severe and specific for sensor networks, new wireless ad hoc networking techniques are required. Many researchers are currently engaged in developing the technologies needed for this purpose.

Unlike other networks, WSNs are designed for specific applications and each application differs in features and requirements. To support this diversity of applications, the development of new communication protocols, algorithms, designs, and services are needed. We have surveyed about different wireless sensor network applications, factors influencing sensor network design, also discussed different types of sensor networks. There are still many issues to be resolved around WSN applications such as communication architectures, security, and management.

REFERENCES

[1] H. Kim, J. Song, and S. Lee "Energy-Efficient Traffic Scheduling in IEEE 802.15.4 for Home Automation Networks," IEEE Transaction on Consumer Electronics, vol. 53, issue. 2, pp. 369-374, May 2007.

[2] C. Perkins, Ad Hoc Networks, Addison-Wesley, Reading, MA, 2000.

[3] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, A survey on sensor networks, IEEE Communications Magazine 40 (8) (2002) 104–112.

[4] D. Estrin, R. Govindan, J. Heidemann, S. Kumar, Next century challenges: scalable coordination in sensor networks, ACM MobiCom'99, Washingtion, USA, 1999, pp. 263–270.

[5] I.A. Essa, Ubiquitous sensing for smart and aware environments, IEEE Personal Communications (October 2000) 47–49.

[6] A. Cerpa, D. Estrin, ASCENT: adaptive self-configuring sensor networks topologies, UCLA Computer Science Department Technical Report UCLA/CSDTR-01-0009, May 2001.

[7] R. Colwell, Testimony of Dr. Rita Colwell, Director, National Science Foundation, Before the Basic Research Subcommitte, House Science Committe, Hearing on Remote Sensing as Research and Management Tool, September 1998.

[8] A. Cerpa, J. Elson, M. Hamilton, J. Zhao, Habitat monitoring: application driver for wireless communications technology, ACM SIGCOMM'2000, Costa Rica, April 2001.

[9] J. Agre, L. Clare, An integrated architecture for cooperative sensing networks, IEEE Computer Magazine (May 2000) 106–108.

[10] J. Agre, L. Clare, An integrated architecture for cooperative sensing networks, IEEE Computer Magazine (May 2000) 106–108.

[11] M. Bhardwaj, T. Garnett, A.P. Chandrakasan, Upper bounds on the lifetime of sensor networks, IEEE International Conference on Communications ICC'01, Helsinki, Finland, June 2001.

[12] P. Bonnet, J. Gehrke, P. Seshadri, Querying the physical world, IEEE Personal Communications (October 2000) 10–15.

[13] N. Bulusu, D. Estrin, L. Girod, J. Heidemann, Scalable coordination for wireless sensor networks: self-configuring localization systems, International Symposium on Communication Theory and Applications (ISCTA 2001), Ambleside, UK, July 2001.

[14] A. Cerpa, J. Elson, M. Hamilton, J. Zhao, Habitat monitoring: application driver for wireless communications technology, ACM SIGCOMM'2000, Costa Rica, April 2001.

[15] S. Cho, A. Chandrakasan, Energy-efficient protocols for low duty cycle wireless microsensor, Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI Vol. 2 (2000), p. 10.

[16] B. Halweil, Study finds modern farming is costly, World Watch 14 (1) (2001) 9–10.

[17] W.R. Heinzelman, J. Kulik, H. Balakrishnan, Adaptive protocols for information dissemination in wireless sensor networks, Proceedings of the ACM MobiCom'99, Seattle, Washington, 1999, pp. 174–185.

[18] C. Intanagonwiwat, R. Govindan, D. Estrin, Directed diffusion: a scalable and robust communication paradigm for sensor networks, Proceedings of the ACM Mobi- Com'00, Boston, MA, 2000, pp. 56–67.

[19] C. Jaikaeo, C. Srisathapornphat, C. Shen, Diagnosis of sensor networks, IEEE International Conference on Communications ICC'01, Helsinki, Finland, June 2001.

[20] P. Johnson et al., Remote continuous physiological monitoring in the home, Journal of Telemed Telecare 2 (2) (1996) 107–113. 420 I.F. Akyildiz et al. / Computer Networks 38 (2002) 393–422

[21] J.M. Kahn, R.H. Katz, K.S.J. Pister, Next century challenges: mobile networking for smart dust, Proceedings of the ACM MobiCom'99, Washington, USA, 1999, pp. 271–278.

[22] B. Walker, W. Steffen, An overview of the implications of global change of natural and managed terrestrial ecosystems, Conservation Ecology 1 (2) (1997). Available from <http://www.consecol.org/vol1/iss2/art2>.

[23] R. Colwell, Testimony of Dr. Rita Colwell, Director, National Science Foundation, Before the Basic Research Subcommitte, House Science Committe, Hearing on Remote Sensing as a Research and Management Tool, September 1998.

[24] M.P. Hamilton, M. Flaxman, Scientific data visualization and biological diversity: new tools for spatializing multimedia observations of species and ecosystems, Landscape and Urban Planning 21 (1992) 285–297.

[25] M.P. Hamilton, Hummercams, robots, and the virtual reserve, Directors Notebook, February 6, 2000, available from http://www.jamesreserve.edu/news.html.

[26] N. Noury, T. Herve, V. Rialle, G. Virone, E. Mercier, G. Morey, A.

Moro, T. Porcheron, Monitoring behavior in home using a smart fall sensor, IEEE-EMBS Special Topic Conference on Microtechnologies in Medicine and Biology, October 2000, pp. 607–610.

[27] J.M. Rabaey, M.J. Ammer, J.L. da Silva Jr., D. Patel, S. Roundy, PicoRadio supports ad hoc ultra-low power I.F. Akyildiz et al. / Computer Networks 38 (2002) 393–422 421 wireless networking, IEEE Computer Magazine (2000) 42–48.

[28] S. Vardhan, M. Wilczynski, G. Pottie, W.J. Kaiser, Wireless integrated network sensors (WINS): distributed in situ sensing for mission and flight systems, IEEE Aerospace Conference, Vol. 7, 2000, pp. 459–463.

[29] M. Ogawa et al., Fully automated biosignal acquisition in daily routine through 1 month, International Conference on IEEE-EMBS, Hong Kong, 1998, pp. 1947–1950.

[30] G. Coyle et al., Home Telecare for the elderly, Journal of Telemedicine and Telecare 1 (1995) 183–184.

[31] E.M. Petriu, N.D. Georganas, D.C. Petriu, D. Makrakis, V.Z. Groza, Sensor-based information appliances, IEEE Instrumentation and Measurement Magazine (December 2000) 31–35.

[32] M.P. Hamilton, Hummercams, robots, and the virtual reserve, Directors Notebook, February 6, 2000, available from http://www.jamesreserve.edu/news.html.

[33] J.M. Rabaey, M.J. Ammer, J.L. da Silva Jr., D. Patel, S. Roundy, PicoRadio supports ad hoc ultra-low power wireless networking, IEEE Computer Magazine (2000) 42–48.

[34] E. Shih, S. Cho, N. Ickes, R. Min, A. Sinha, A. Wang, A. Chandrakasan, Physical layer driven protocol and algorithm design for energy-efficient wireless sensor networks, Proceedings of ACM MobiCom'01, Rome, Italy, July 2001, pp. 272–286.

[35] G.J. Pottie, W.J. Kaiser, Wireless integrated network sensors, Communications of the ACM 43 (5) (2000) 551– 558.

[36] G. Hoblos, M. Staroswiecki, A. Aitouche, Optimal design of fault tolerant sensor networks, IEEE International Conference on Control Applications, Anchorage, AK, September 2000, pp. 467–472.

[37] D. Nadig, S.S. Iyengar, A new architecture for distributed sensor integration, Proceedings of IEEE Southeastcon'93, Charlotte, NC, April 1993.

[38] C. Shen, C. Srisathapornphat, C. Jaikaeo, Sensor information networking architecture and applications, IEEE Personal Communications, August 2001, pp. 52–59.

[39] J. Rabaey, J. Ammer, J.L. da Silva Jr., D. Patel, Pico- Radio: ad-hoc wireless networking of ubiquitous lowenergy sensor/monitor nodes, Proceedings of the IEEE Computer Society Annual Workshop on VLSI (WVLSI'00), Orlanda, Florida, April 2000, pp. 9–12.

[40] C. Intanagonwiwat, R. Govindan, D. Estrin, Directed diffusion: a scalable and robust communication paradigm for sensor networks, Proceedings of the ACM Mobi- Com'00, Boston, MA, 2000, pp. 56–67

[41] S. Meguerdichian, F. Koushanfar, G. Qu, M. Potkonjak, Exposure in wireless ad-hoc sensor networks, Proceedings of ACM MobiCom'01, Rome, Italy, 2001, pp. 139– 150.

[42] J. Yick, G. Pasternack, B. Mukherjee, D. Ghosal, Placement of network services in sensor networks, Self-Organization Routing and Information, Integration in Wireless Sensor Networks (Special Issue) in International Journal of Wireless and Mobile Computing (IJWMC) 1 (2006) 101–112

[43] D. Pompili, T. Melodia, I.F. Akyildiz, Deployment analysis in underwater acoustic wireless sensor networks, in: WUWNet, Los Angeles, CA, 2006.

[44] S. Toumpis, T. Tassiulas, Optimal deployment of large wireless sensor networks, IEEE Transactions on Information Theory 52 (2006) 2935–2953.

[45] I.F. Akyildiz, E.P. Stuntebeck, Wireless underground sensor networks: research challenges, Ad-Hoc Networks 4 (2006) 669–686.

[46] I.F. Akyildiz, E.P. Stuntebeck, Wireless underground sensor networks: research challenges, Ad-Hoc Networks 4 (2006) 669–686.

[47] I.F. Akyildiz, T. Melodia, K.R. Chowdhury, A survey on wireless multimedia sensor networks, Computer Networks Elsevier 51 (2007) 921–960.