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Wireless Sensor Network: Characteristics and Architecture

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Abstract - Wireless sensor network (WSN) as an emerging technology has eased life via its numerous applications. Research interests and attention have been drawn to WSN in the last decades. Exploring and finding better ways of improving the existing technology has been a continuous process. This paper presents a review on wireless sensor networks, covering WSN architecture to characteristics, advantages, several challenging issues of WSN, network topology and IEEE standards for physical layer of WSN.

Keywords: *WSN Architecture, Sensor Node, WSN Topology, Wireless Standard.*

1. Introduction

A wireless sensor network (WSN) is a network consisting distributed autonomous sensor nodes for monitoring physical and environmental conditions such as temperature, pressure, sound, speed and direction, chemical concentrations, vibrations, pollutant levels etc which is either communicated directly to base station or to neighbour nodes after being sensed by the sensor. Figure 1 shows components of sensor nodes grouped under the following sub units: communicating subunit containing radio transceiver antenna, sensing subunit, computing subunit - microprocessor with memory and power unit containing the battery [1]. The sensor which is a transducer senses and measures natural occurring events in analog form (including physical and environmental conditions), changing it to electrical signal using ADC. The physical condition to be measured determines the sensor to incorporate during design such as light sensor, thermal sensor, magnetic sensor, vibration sensor, chemical sensor, seismic sensor, acoustic sensor, bio-sensor. The converted electrical signal goes into the microprocessor (controller) which executes rightful algorithmic operation on the digital signal via thorough signal processing. The transmitting antenna sends the signal to neighboring nodes or to a base station (BS) which finds the best route for the delivery. This however depends on the network topology type. The battery as a critical component sustains the operation of sensor nodes by providing continuous power supply to the sensor nodes. This is because a sensor without a power is as good as dead. The capacity and size of the battery determines the life span of the sensor especially for sensors in remote areas with limited power supply, underwater sensors and underground sensors. The issue of using sensor batteries is still a challenge to effective operation and sustainability of sensors. As a result of undoubted benefits of WSN, research in this area is still on the rise for improvement. Nevertheless, WSN technology offers numerous advantages over conventional networking solutions, such as, lower costs, scalability, reliability, accuracy, flexibility and ease of deployment that enable their use in a wide range of applications [2, 3]. With advancement in technology, sensors are becoming smaller, smarter and cheaper as billions of wireless sensors are deployed in strategic places for numerous applications.

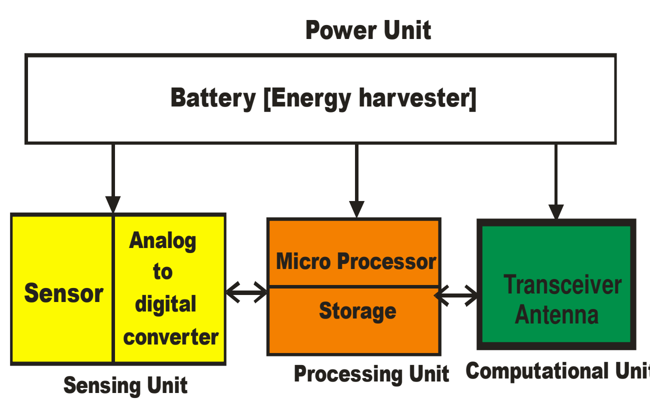

Figure 1: Components of a Sensor Node

2. WSN Architecture

WSN architecture constitutes the WSN protocol stack and the three management planes (layers) as shown in figure 2 [6, 7]. The protocol stack follows the structure of Open System Interconnect (OSI) model. Out of the seven layers proposed by International Standard Organization (ISO) which are Application, Presentation, Session, Transport, Network, Data link and Physical layer. WSN architecture has only five (5) layers which include Application, Network, Transport, Data link and Physical layer with additional three management planes viz: task management, mobility management and power management [4, 6, 12].

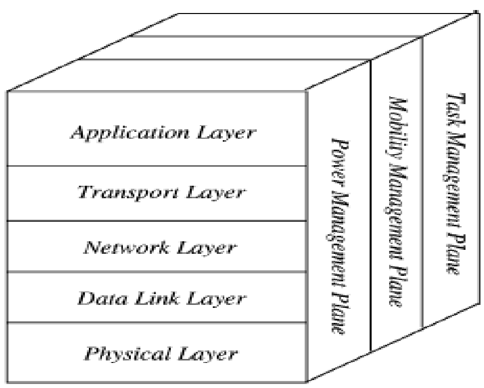

Figure 2: WSN Architecture [12]

Application layer: This layer is responsible for traffic management. It also offers software for numerous applications which convert data from machine language to human language. The program takes care of formatting of data, encryption and data storage.

Transport layer: This layer delivers congestion avoidance and reliability. Various transport layer protocol such as Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) use dissimilar mechanisms in providing loss recognition and loss recovery. While TCP provides reliable communication service with extensive error handling, transmission control and flow rate, UDP provides unreliable transport layer protocol service but with minimal error handling, transmission and flow control.

Network layer: The major responsibility of this layer is routing of packets. There are lots of routing protocols which can be categorized into flat routing and hierarchal routing.

Data Link layer: Functions include multiplexing of data, data frame detection, MAC and error control. It confirms the reliability of point – point or point – multipoint connections.

Physical layer: This layer functions as (i) providing a medium for transmission of streams of bits; (ii) Defines and manages connections between nodes and their communication medium; (iii) Takes care of frequency selection, carrier frequency generation, signal detection, modulation and data encryption; (iv) Determines the type of cable connectors and cables that will be compatible with the communication medium.

2.1 Three management plane

Power management: This manages the power level of sensors nodes, sensing and communication of nodes. It also minimizes the consumption and turns off some functions to preserve energy.

Mobility management: This layer is responsible for keeping track of nodes movement in the network.

Task management: This distributes tasks among sensor nodes to prolong network life time and improve energy efficiency.

According to [5] the management planes are rather power management plane, connection and task plane, the connection plane configures or reconfigures sensor nodes in attempt to establishing connection.

3.0 Characteristics of WSN

i. Limited battery power.
ii. Capacity to handle node failures.
iii. Scalability to large scale of distribution.
iv. Simplicity in usage.
v. Node heterogeneity (ability to accommodate different devices such as peripheral devices)
vi. Robust to failure in terms of harsh environmental condition.
vii. Mobility of nodes (this ensures better coverage).
viii. Vulnerable to attacks.

3.1 Advantages of WSN

i. Network arrangements can be carried out without fixed infrastructure.
ii. WSN installation is very cheap.
iii. Use of wireless transmission medium.
iv. Suitable for inaccessible places like mountains, sea, rural areas and thick forests.
v. Ability to accommodate new devices in the network at any time.

vi. Centralized monitoring.

4.0 Challenges of WSN

Energy constraint: This is the major challenge of sensor nodes as the life span of sensor nodes depend on the battery. Most sensors are in inaccessible places, some in remote places where there is epileptic power supply. This limits the operation of the sensors as they are expected to operate 24/7. This makes charging of sensors after discharge almost impossible.

Transmission media: Since WSN are linked with wireless medium they are vulnerable to fading, attenuation, interference and high error rate.

Computational capability: Sensor nodes have limited computing power, therefore they may not be able to run sophisticated network protocols.

Limited bandwidth: The bandwidth of communicating sensor nodes is often limited.

Fault tolerance: Sensors deployed at strategic places may encounter hardware or software problem or rather fail due to lack of power or environmental interference. The routing protocol must locate these nodes and be able to accommodate formation of new links.

Scalability: Wireless sensor network must be able to accommodate new nodes as the network expands.

Network topology: The dynamic nature of topology especially in ad hoc network makes localization of nodes difficult.

Cost of deployment: The cost of purchasing a sensor node is very dear. Therefore, deploying hundreds or thousands of nodes will have a multiplying cost effect not only on purchase but also on maintenance.

Time synchronization: For a node to receive information from another node, it ought to have the same timing with the transmitting node. Otherwise packet sent will experience delay or loss due to differences in timing.

5.0 Applications of WSN

- **Military application:** Used in battle field for monitoring advancement of enemies during war and in detecting all forms of chemicals, nuclear and human attacks.
- **Health monitoring:** In gathering of patient's bio-data and in monitoring patient's progress such as breathing rate, blood level and pressure, heart conditions. For medical doctors, it helps in diagnosing patients and determining patient's progress. Some of these sensors are wearable while some are embedded.
- **Home monitoring:** Sensors can be attached to buildings for monitoring human movement and as well as in home appliances to have a remote control.
- **Vehicle monitoring:** To have a check over car parking, intra car security and in car tracking.
- **Environmental application:** Sensors are deployed to monitor animal movement, human movement and in studying animal behavior. Others include: check on the events such as flood, landslide and earthquake detection, forest fire detection and natural disasters, etc.
- **Area surveillance/monitoring: s**ensors are deployed for effective monitoring of a given mapped out area such as to monitor traffic defaulters, crime scene, fire disaster, mineral deposit detection and oil deposit detection, amongst others.
- **Environmental/Earth Sensing:** For monitoring mother earth against earthquake, volcanoes, air pollution monitoring, glaciers and other likely disasters.
- **Industrial monitoring:** Here, sensors are used to monitor industrial facilities, structures and machines. In Oil companies, WSNs are used in monitoring Oil pipelines for leakages and vandalism**.**
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6.0 WSN Topology

Common types of wireless sensor network topology include:

a. Point–point network topology
b. Star network topology
c. Tree network topology
d. Mesh network topology

6.1Point-point Topology:

Point**-**point topology communicates message to nodes directly through one communicating channel (see figure 3). It has no central hub. Therefore, each node acts as a node and as a client at the same time.

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Figure 3: Point-Point network topology

6.2 Star topology:

Here each node connects directly to a gateway. For nodes to communicate, data must pass through the sink (gateway) which routes the data to the desired node. This allows for low latency communication between remote nodes and the gateway. Due to its dependency on a single node for management of a network, the gateway must be within the communication range. Advantage: It consumes minimal node power. The size of the network depends on the number of node connections to the hub as shown in Figure 4.

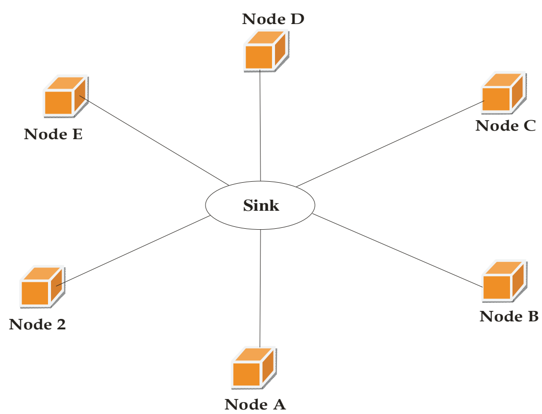

Figure 4: Star Network Topology

6.3 Tree Topology

Each node connects to a node that is placed higher in the tree called the parent node and then to a gateway. The advantage of this topology is that the expansion of the network is easy and error detection is possible (figure 5).

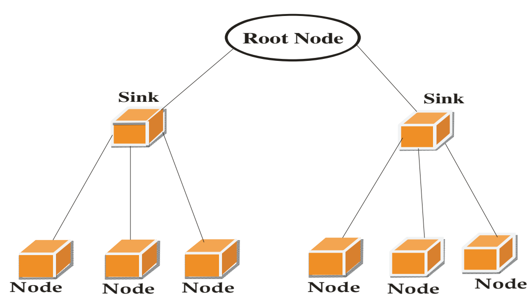

Figure 5: Tree Network Topology

6.4 Mesh Topology

This topology allows client to transmit datato another client and can take several routes to get to their destination. Nodes must be within radio communication range. If a node is not within the communication range, data will pass through an intermediate route to the desired node (figure 6). Advantage: Since fault detection is easy, it makes the topology most reliable. Disadvantage: Due to its complex nature it requires huge investment. Other topologies include: Bus topology, Circular topology, Ring topology and Grid topology [8].

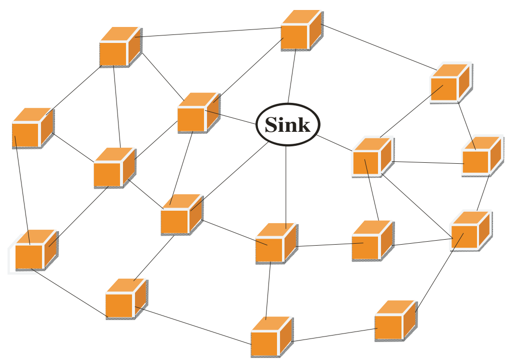

Figure 6: Mesh Network Topology

7.0 Types of WSN

Below are the detailed types of WSNs based on place of deployment.

7.1 Terrestrial WSN

Here, sensor nodes are randomly distributed in their large numbers within the targeted area, usually on land in an infrastructure less or Ad hoc manner. They are equipped with solar cells as alternative power source since battery depletes. Energy can be conserved with multi-hop optimal routing, short distance transmission range, in-network data aggregation and using low-duty cycle operation [15]. Application: Environmental sensing and monitoring, industrial condition monitoring, agricultural monitoring and military application.

7.2 Underground WSN

These WSNs are deployed under the ground, caves and mines to monitor various underground conditions. These sensors are more expensive than the terrestrial WSN in terms of deployment, maintenance and cost of equipment and require careful planning. Challenges: Sensor batteries are very difficult to recharge or replace. As a result, it requires high cost of maintenance. Again, signals are faced with intense attenuation and signal loss. Application: Earth sensing and monitoring, mineral deposit and water quality monitoring.

7.3 Underwater WSN:

These sensors are deployed under water unlike underground types. They are faced with challenges of long propagation delay, limited bandwidth, high latency, signal fading and sensor failures, and limited energy of the battery. Application: Aquatic life study and monitoring, mineral and oil deposit monitoring, undersea surveillance, water pollution monitoring, disaster management monitoring, Seismic monitoring.

7.4 Multimedia WSN

This enables tracking and monitoring of events in the form of videos, images and audio. The network constitutes sensor nodes equipped with cameras and microphone. Nodes are interconnected with each other over a wireless connection for data compression. Challenges: High energy consumption, high bandwidth requirement, data processing and compressing technique are needed. Application: Home monitoring, Structural health monitoring, Health/medical condition monitoring

7.5 Mobile WSN

Wireless sensor nodes can be mobile in nature. Typical deployment is in Mobile Ad hoc Network (MANET). Dynamic routing protocol is usually deployed due to dynamic network topology. It provides better coverage and connectivity compared to Static WSN. Challenges: Faced with problem of node localization, limited bandwidth, constant network connectivity and energy constraint of the battery. Application: Deployment in VANET & FANET in vehicle and flying Airplane tracking, Military, search and rescue operation, animal and human movement monitoring.

8.0 Wireless Standards in WSN

Table 1 below shows different wireless standards in WSN, their data rate, topology, communication range and transmission/modulation technique.
Other families of IEEE802.15.4 not included in the table are:

1) **ISA100.11a** provides reliable and secure wireless operation for non critical monitoring, alerting, supervising control, open loop control and closed – loop control application. The architecture supports wireless systems that span the physical range from a single, small and isolated network [18]. Operating frequency: 2.4GHz. Topology: star and Mesh. Application: Industrial automation and control.
2) **WirelessHART:** WirelessHART is a mesh networking technology operating in the 2.4GHz ISM radio band. It utilizes IEEE 802.15.4 compatible DSSS radios with channel hopping on a packet by packet basis. WirelessHART operates in the 2.4 GHz ISM band and to prevent interference from other applications. It uses frequency hopping with black-listing of bad channels and has high reliability in challenging environments. Key features are reliability, security, energy efficiency, compatibility with existing devices.

Table 1: Comparison of Wireless Standards [18,19]

Wireless standard	Frequency (ISM Band)	Max Data rate	Range	Topology	Transmision technique
WLAN/Wi-Fi (IEEE 802.11a)	**5GHz**	**54Mbps**	**120m**		**OFDM**
IEEE 802.11b	**2.4GHz**	**11Mbps**	**140m**		**DSSS**
IEEE 802.11g	**2.4GHz**	**54Mbps**	**140m**		**OFDM or DSSS**
IEEE 802.11n	**2.4/5GHz**	**248Mbps**	**250m**		**OFDM**
Bluetooth (1EEE802.15.1)	**2.4GHz**	**3Mbps**	**10 to 100m**	**Point-to-point**	**FHSS**
UWB (IEEE802.15.3a)	**3.1-10.6 GHz**	**110Mbps**	**10m**		**Ds-UWB, multi-band OFDM**
Bluetooth low energy (BLE)	**2.4GHz**	**1Mbps**	**200m**	**Star**	**FHSS**
Zigbee (IEEE802.15.4)	**868/915-MHz, 2.4GHz**	**250Mbps**	**100m**	**Mesh, Star, Cluster, Tree**	**DSS**
WiMax (IEEE 802.16	**10- 66GHz**	**32- 134 Mbps**	**2-5km**		

9. Conclusion

WSNs in addition to being an emerging technology are becoming very relevant in the communication industry. Irrespective of the challenges and short falls, they are providing services that are essential in most common and everyday applications. Key features of reliability, security, energy efficiency, compatibility, etc. are always going to be faced but with research and advance in technology, the challenges can be met.

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