Technology transitions in WSN, Network Components and WSN Attributes for Ubiquitous Computing

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Abstract: *WSN is supposed to operate in an unattended mode and collect data of interest from its coverage area. Adoption of new fabrication technologies has improved operating efficiencies of these nodes. Besides the research in hardware improvements, research community is more inclined towards research at software level as it has many possibilities and great potential to yield significant results. The paper gives an overview of WSN, building blocks, its architecture, characteristics and applications.*

Keywords: *WSN, MEMS, Sensor node, Base Station, IEEE 802.15.4, Sun SPOT*

I. INTRODUCTION

Wireless Sensor Network (WSN) is a distributed network of a large number of randomly deployed tiny devices called nodes which have inbuilt computational, storage and communication capabilities. WSN is supposed to operate in an unattended mode and collect data of interest from its coverage area. The nodes are low cost devices also prone to failures due to harsh and uncertain environment in which these operate. Though the nodes are self configuring and network reconfigures itself on failure of nodes however high failure rate may affect the network badly. In addition to failure due to environmental conditions, exhaustion of limited battery also renders a node useless. As the life of a WSN depends upon life of its constituent nodes, so the main objective in a sensor network is to extend life of a node. Endeavour to use limited battery power of a node efficiently has led to many hardware and software advances in WSN area. Adoption of new fabrication technologies has improved operating efficiencies of these nodes. Besides the research in hardware improvements, research community is more inclined towards research at software level as it has many possibilities and great potential to yield significant results. Data collected by sensors is extracted by various applications which set up data flow or communication of data in the network. Various strategies such as application specific MAC and routing protocols are employed to minimize communication. Query is the most popular and convenient method of data extractions. Optimization of the queries at the Base Station (BS) is another tool to reduce communication load. Modern WSN are so versatile that they can serve simultaneously multiple users having varying informational interests.

The paper gives an overview of WSN, building blocks, its architecture, characteristics and applications and information extraction from WSN through various means. Queries – the most popular means of information extraction and their processing has also been discussed. Various performance evaluation metrics for WSN and sensor nodes have also been defined.

History of Wireless Sensor Networks

Though rapid interest and research in WSN fields have taken place only recently but, use of sensors for specialized services is not new. During the Cold War, quiet Soviet submarines were detected by deploying the Sound Surveillance System (SOSUS), which employed acoustic sensors. These systems are now adopted by National Oceanographic and Atmospheric Administration (NOAA) for sensing the events in the oceans. Simultaneously, Air defense radar networks were developed employing aerostats as sensors. The predecessor to the internet, Advanced Research Project Agency (ARPANET) formed by US DARPA in 1969, served as a test bed for new networking technologies connecting various universities and research centers. A sensor network can be assumed to have many spatially distributed autonomous sensing devices which route the information to a node which can make the best use of the acquired information. The actual WSN may be traced back to the Distributed Sensor Networks (DSN) program which started in 1980 at Defense Advanced Research Projects Agency (DARPA).

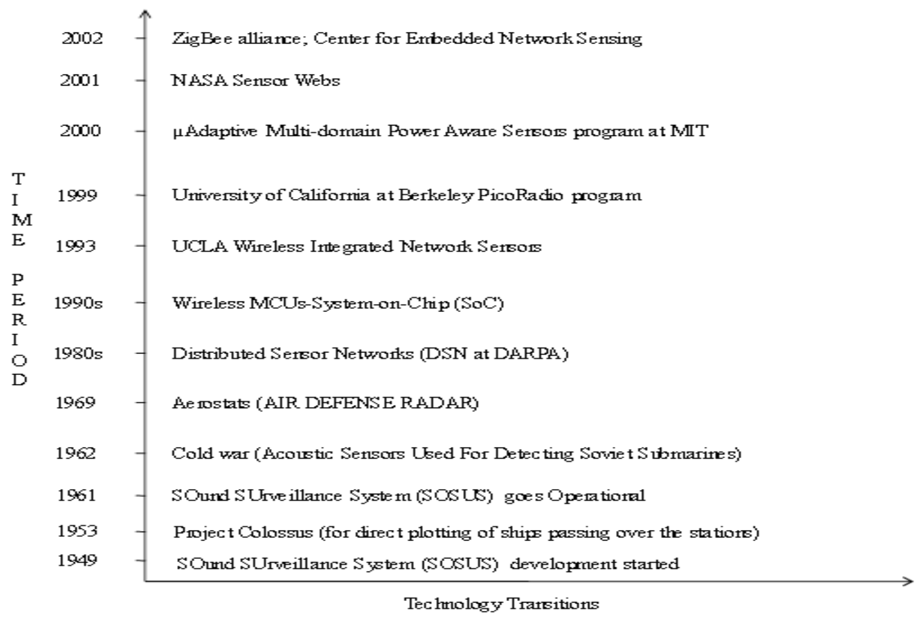

Figure 1.1: Technology transitions in WSN

Recent advances in micro fabrication technologies have made it possible to produce tiny nodes which can house multiple sensors and have reasonable processing and communication capabilities. In addition to this, development of wireless networking standards having security, stability and minimum end to end delays have led to proliferation of WSN in to the field of control and monitoring the area which was unheard of earlier. The usage of WSN is increasing exponentially due to the features such as: Scalability, Adaptability, Convenience, Mobility, Accessibility, low cost etc.

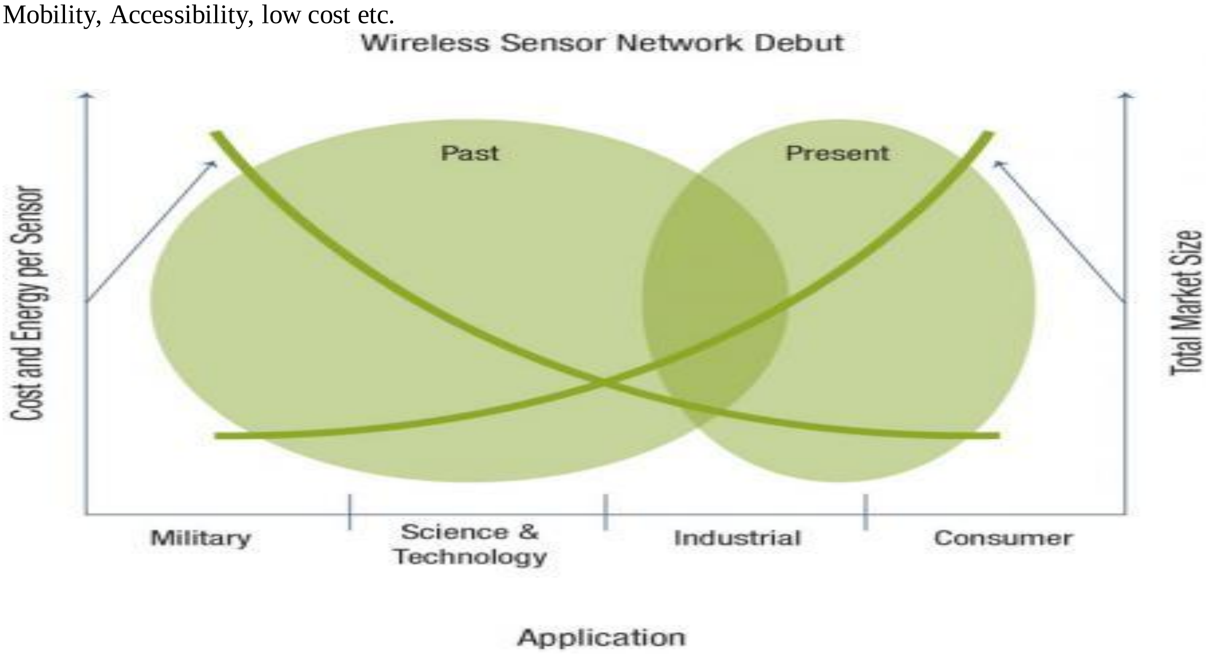

Figure1.2: WSN gain market traction with decrease in sensor costs [10]

Features of WSN

The striking features in WSN are as follows:

i) *Scalability:* WSN can be extended to any extent by adding more and more devices in random to serve more geographical area and applications. Strength of a WSN lies in numbers. As nodes are added WSN interconnections become stronger which is contrary to other wireless networks such as - cell phone network, where increasing number of active cell phones in a small area hamper the service. Nodes are self configuring; therefore they build themselves up into a meaningful collaborative network.

ii) *Adaptability:* These networks are able to adapt dynamically to changing environment or needs. Inbuilt easy adaptation mechanisms are quick to respond to changes in network topologies or failure of nodes. Network can shift to vastly diverse modes of operations.

iii) *Low cost networks:* Besides low cost of nodes, no cable laying/ routing or pre-existing infrastructure is required to setup these networks. Each individual node when added to the network becomes part of the overall infrastructure called wireless sensor network.

iv) *Convenience*: The use of wireless communication technologies has become ubiquitous due to the freedom, distributed capabilities and cost savings they offer. These are capable of providing information that is precisely localized in time/ space according to the needs/ demands of the users.

II. WIRELESS SENSOR NETWORKS

Randomly deployed innumerous self configuring nodes having sensing, computation and communication abilities make a WSN. Individual capabilities of these nodes may be minimal but their build up in a network opens up vast areas of diverse application possibilities which may range from real-time tracking, to monitoring environmental conditions to in-situ monitoring of health of structures, equipment or humans. Development of WSN was originally motivated by military applications like battlefield surveillance which gradually grew into the areas like healthcare applications, home automation, traffic control etc. Advances in wireless networking, micro-fabrication & integration using Micro Electro Mechanical System (MEMS) technology and embedded chips called, micro-processors have led to the evolution of a new generation of WSN, which are capable of performing numerous applications which hitherto have been unbelievable. Applications of WSN are going to revolutionize the way we live [1-3]. It is not a distant possibility when these sensors would be sprayed on the roads, walls, machines etc. for monitoring vehicular traffic, track job flows and supply chains in smart factories etc. Each node in a sensor network is equipped with various sensors, a radio transceiver, a microcontroller and an energy source (usually battery). Size and cost constraints on sensor nodes force the manufacturer to introduce corresponding constraints on available resources like energy, memory, computational speed and bandwidth in a node.

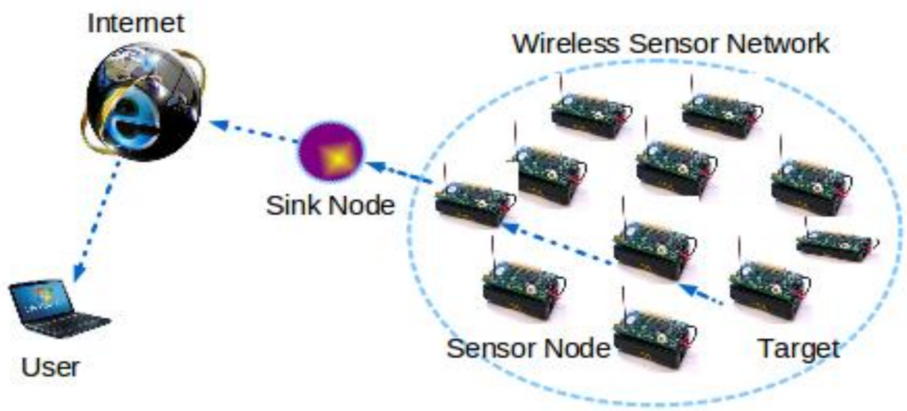

Figure1.3: A Wireless Sensor Network [11] comprising of Sensor nodes and Base Station

A sensor network is usually made up of a wireless ad-hoc network i.e., each sensor supports a multi-hop routing algorithm. WSN can also operate actuators controlling various processes thus extending their control to physical world also.

Sensor Node Architecture

Dynamic random topology of WSN and collaborative processing by nodes in a distributed setup makes classical network organization concepts irrelevant. Separate programming techniques and technologies are required to cater to special characteristics of WSN which make their software architecture special and vibrant. Software architecture is unique so as to solve inherent difficulties [4] of these networks. Special characteristics influencing the software architecture are:

i) *Self-Organization*: Due to large number of nodes in a WSN network organization [5] by manual means of users is very cumbersome. The nodes are capable of organizing themselves in a meaningful configuration and partition for efficient operation. The nodes of a sensor network are robust [6] and the aggregate formed by the nodes is required to tolerate any device failure and change in topology. It requires complex software routines to be implemented for fault tolerance.

ii) *Concurrency, Cooperative Processing*: The nodes in a network control the information flow through the network. Each sensor node possesses a limited amount of memory, so buffering of data is impractical [6]. A node performs a number of operations: capturing, processing and transmitting sensor data and forwarding data from other nodes as well. WSN relies on cooperative processing. Cooperative processing reduces network traffic through data aggregation and processing [5].

iii) *Energy Efficiency*: WSN generally operate in hostile or remote environments [5]. Therefore, energy efficiency dictates the need for minimization of communications which leads to the development of protocols and network configuration. Further power savings can be given by operating system for the nodes by supporting advanced power management and task scheduling [5].

iv) *Modularity*: In case of special networks sensor nodes tend to be specific and contain only the hardware needed for that special application only. The range of possible applications creates a large variance in hardware required for sensor nodes. Therefore, the software for the nodes should show high degree of modularity [6].

Network Layer Stack of WSN

Architecture used in WSN follows generally five layers of OSI Model. In it also worth mentioning that because of multi-hop communication, the Transmission Control Protocol (TCP) is not suitable for WSN.

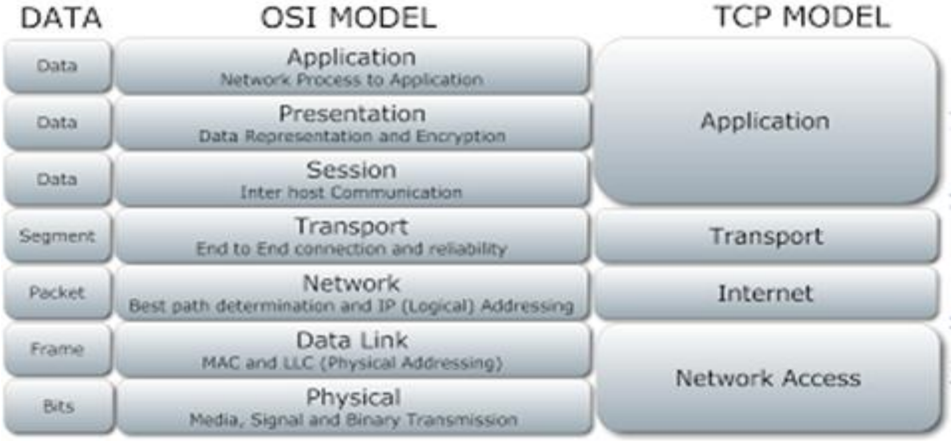

Figure1.4: Comparison between the OSI Model and the TCP Model [12]

Different layers used in it are: application, transport, network, data link and physical. In addition to these, the special tasks of a WSN such as power management, mobility management and task scheduling to increase the efficiency of the network are controlled by three cross layers.

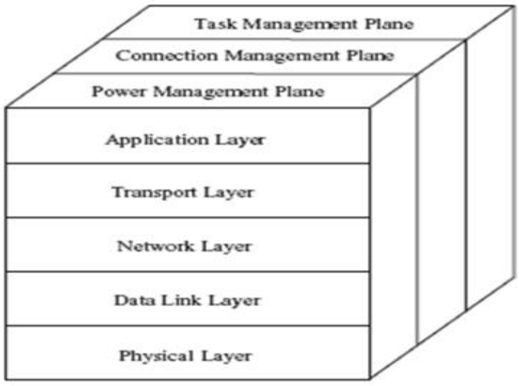

Figure 1.5: Network layer Stack of WSN [13]

a) *Application layer*: It manages traffic and provides software for various applications which send queries to obtain information.

b) *Transport layer*: This layer is required in case of internetwork communication. Many protocols have been designed to provide reliability and congestion avoidance. Because of multi hop communication TCP is not suitable for WSN.

c) *Network Layer*: This layer serves the function of routing which is a challenging task in WSN. Due to low power, limited memory, routing protocol has to provide reliable and redundant paths, for which many protocols are available according to the desired metric. This layer protocols may either be divided into flat routing or hierarchical routing or can be divided into Time driven, Query driven or Event driven. To ensure reliability in case of node failure, redundant nodes are deployed which result in production of a lot of redundant data. This data can be processed as processing consumes less power as compared to communication. It is achieved through Data Aggregation and Data Fusion. Data Aggregation is combining the data from many sensor nodes into meaningful information and eliminates redundancy. It is used in flat routing [7]. Data Fusion is further processing of aggregated data such as reduction of noise from aggregated data [7]. Some Data centric Routing Protocols are SPIN, Directed Diffusion etc.

d) *Data link layer*: It ensures reliability from point-to-point or point-to-multipoint. Error control and multiplexing of data streams is also done by this layer. In WSN, Medium Access Control (MAC) has an important role to play. It provides higher efficiency, reliability, low delay and higher rates of communication [8].

e) *Physical layer*: It provides an interface to transmit streams of data over a physical medium. Selection of frequency, generation of carrier frequency for modulation, signal detection and security etc. are done in this layer. IEEE 802.15.4 is one such protocol.

III. NETWORK COMPONENTS

WSN is composed of devices (nodes/ motes) capable of sensing the environment of the area under study. The data sensed by the nodes is transmitted to the sink (Base-Station (BS)) either through single hop or through multi hops. As multi-hop saves energy so it is preferred and most widely used method of communication. These nodes may be stationary or moving, homogeneous or heterogeneous and be aware of their location or not. The diagram below shows a typical node. Main components of a wireless sensor node are various sensors, a micro controller, memory, transceiver, and analog-to-digital convertor.

i) *Micro controller*: The micro controller operates at low frequency compared to traditional processing units. It performs tasks, processes data and controls the functionality of other components in the sensor node.

ii) *Transceiver:* Sensor nodes use Industry, Scientific and Medical (ISM) Band, which gives a free radio spectrum allocation and global availability. Radio frequency-based communication is the most relevant that fits most of the WSN applications. WSNs tend to use license-free communication frequencies: 173 MHz, 433 MHz, 868 MHz and 915 MHz and 2.4 GHz. The functionality of both transmitter and receiver are combined into a simple device called transceiver. The operational states of the transceiver are transmitter, receiver, idle and sleep.

iii) *Memory:* The most relevant kind of memory is the on-chip memory of a micro-controller. Memory requirements are usually application dependent. They are employed for storing the application related data and for programming the device. Memory storage is only a few kilobytes (kB).

iv) *Battery/Power Source*: A critical aspect in the development of a wireless sensor node is ensuring that there is always sufficient energy available to power the system. Power is consumed by a node in sensing, communicating and data processing. The energy required in data transmission is very large as compared to any other process. Power source is generally a low power between 1.2 to 3.7 volts battery.

v) *Sensor:* This is a hardware device which responds to a change in a physical condition like temperature, pressure etc. and converts it into a measurable analog signal. It measures the physical parameter to be monitored. The analog signal generated by the sensors is digitized by an Analog-to-Digital Convertor (ADC) and sent to controller for further processing. Sensor may be categorized as passive omni-directional, passive narrow-beam sensors and active sensors. Passive omni-directional sensors sense the data without manipulating the environment. They are self powered and require energy to amplify analog signals and have no notion of direction in measurement. Passive narrow-beam sensors have well defined notion of direction of measurement (like a camera) and active sensors actively probe the environment e.g. SONAR or RADAR sensors.

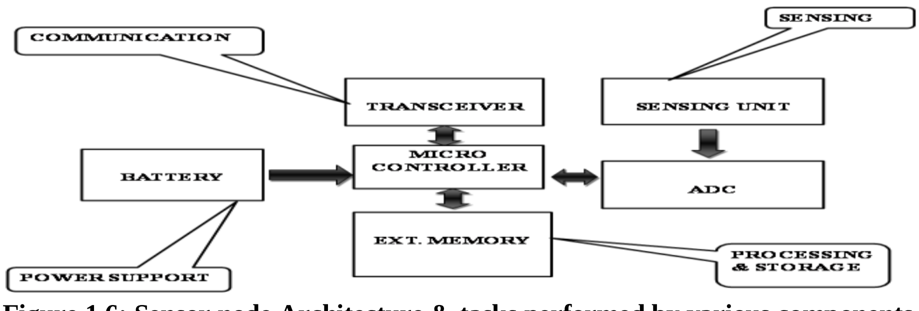

Figure 1.6: Sensor node Architecture & tasks performed by various components

Sun Small Programmable Object Technology (Sun SPOT) mote, a WSN mote developed by Sun Microsystems [9] that we have used for our experimental verification has: 180 MHz 32 bit ARM920T core processor– 512K RAM – 4MB Flash, 2.4 GHz IEEE 802.15.4 radio with integrated antenna, AT91 timer chip and a USB interface. The sensor board is equipped with 2G/6G three-axis accelerator, temperature and light sensor, 8 tri-color LEDs, 6 analog inputs, 2 momentary switches and 5 general purpose I/O pins and 4 high current output pins. It is equipped with 3.7V rechargeable 750 mAh lithium-ion battery. It has 30µA deep sleep mode power requirement. Unlike other available mote systems, the Sun SPOT does not use TinyOS it is built on the Squawk Java Virtual Machine.

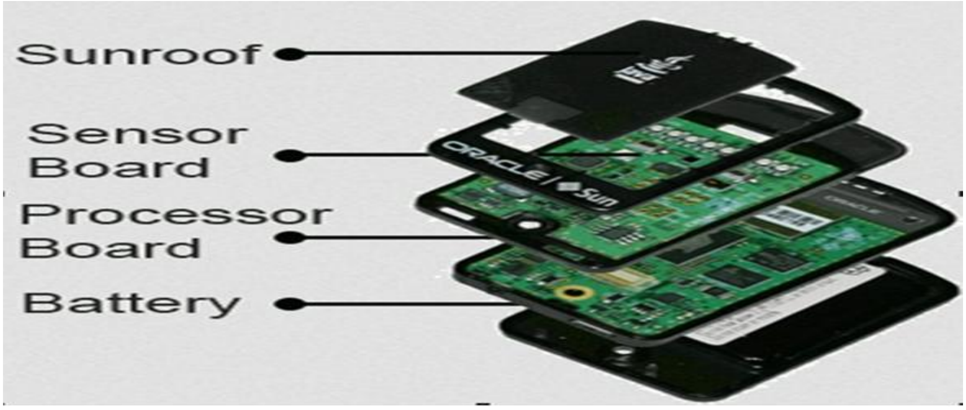

Figure 1.7: Anatomy of a SunSpot [9]

Attributes of WSN

WSN does not require any infrastructure, it itself is an infrastructure which grows according to the needs and serve the objective of ubiquitous computing. WSN infrastructure has some basic characteristics which are enumerated as below:

i. WSN may consist of thousands of nodes which are far big in number than traditional networks.
ii. Limited amount of data is stored in these nodes due to small size of the nodes.
iii. WSN are required to withstand harsh environmental conditions therefore are programmed and equipped to cope with node failures.
iv. WSN are able to change topology dynamically and hence are suitable for mobile applications also.
v. Communication in a WSN is data centric and very short packets are communicated due to low bandwidth and power. Therefore network layer overheads should be very small. This makes protocol design for a WSN a challenging task.
vi. Communication failures are frequent due to failure of intermediate nodes from the source to the sink (BS) or due to battery exhaustion. Redundant links or nodes are deployed to maintain communication.
vii. In order to gather information like the temperature, pressure, light etc. from the environment it is essential that the nodes are deployed in large quantity at random.
viii. Node location is important in these networks as they are deployed for monitoring of physical environment. Therefore, various localization techniques are used in WSN.
ix. In these networks nodes do not compete with each other for resources rather nodes work in a cooperative and collaborative manner to accomplish same goal of providing desired Quality of Service (QoS) for the designed application. As size of traditional wireless networks increases problem of spectrum congestion is faced and efficient division multiplexing techniques are required. Sarma et al. in [14] has proposed application of Artificial Neural Network (ANN) in wireless communication where as in case of WSN no such problem is faced as sensors co-operate with each other moreover multihop transmission make re use of channel in the network possible so limited bandwidth can be put to optimum use.

IV. CONCLUSION

All these characteristic unique features of a WSN make it imperative that network protocols are designed by keeping these requirements in mind and which can use constrained resources efficiently. However, packing all these features in a single protocol is not feasible in multi-hop small packet communication. Therefore a number of applications specific protocols from data link layer to transport layer have been devised which suits best to the requirements of the application.

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