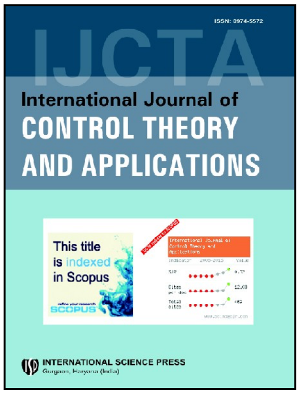

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Challenges in Wireless Sensor Networks – A signal Processing Perspective

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Abstract: Recent advances in sensing, computing and communication technologies coupled with the need to continuously monitor physical phenomena have led to the development of Wireless Sensor Networks. Wireless sensor networks consists of tiny, low energy and multi-functional sensors. These sensor nodes are deployed with high density to monitor environments, to control industrial operations with precision or to track different objects. They are responsible for sensing, processing and monitoring environmental data. In this paper, the general organization of the wireless networks are studied and analyzed based on our basic system implementation, to understand the various signal processing activities in the networks. Along with this, the various challenges and constraints in the design and implementation of the networks are identified and listed out.

Keywords: sensors, wireless network, signal processing, controller etc.

1. INTRODUCTION

The sensor network is formed by densely deployed sensor nodes in an application area. These nodes will measure ambient conditions in the surrounding environment and then convert these measurements into signals that can be processed to reveal some characteristics about the phenomena in the environment. The sensors normally monitor parameters like pressure, temperature, motion, position, power-line voltage, humidity, force, vibration, flow, wind direction and speed, sound intensity, vibration intensity, illumination intensity, vital body functions, chemical concentrations, pollutant levels etc. The sensor nodes will be deployed with self-organizing capabilities, to form an appropriate structure for performing a particular task collaboratively. They also possess ability of collaborating and exchanging information with its neighboring nodes, and intelligently analyze this data. The data delivered by these sensors can be huge and very rich with information. This immense amount of data can be processed to detect, evaluate and forecast various physical phenomena. Most of the sensor networks are bi-directional which helps us to control the sensor activity. The sensors have huge potential to sense, process, and monitor the signals from various applications where it would have been impossible or too expensive before. These smart sensors have found their roles in almost all aspects of our normal life.

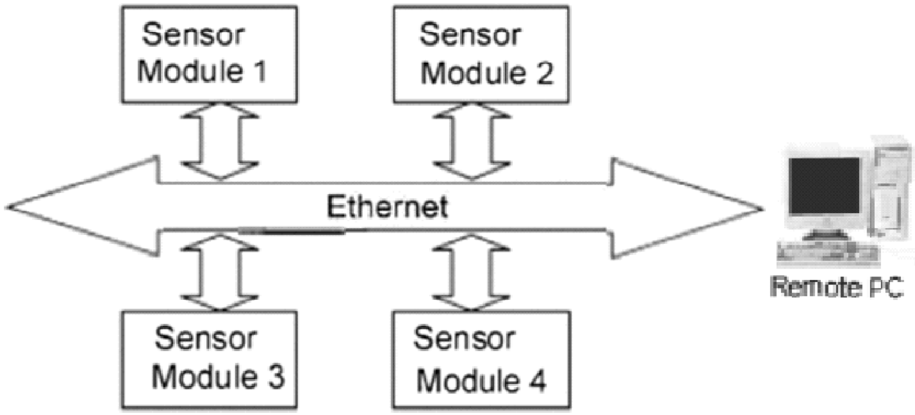

Figure 1: A Basic Sensor Network System

A basic sensor network with 4 sensor modules and one monitoring station has been shown in figure 1. The major components in the network are senor nodes and sink node. The sensor nodes are multiple detection terminals inside a sensor network which are having the capabilities of sensing, processing and communicating data to the specified destination. The basic elements in the sensor nodes are sensing unit, processing unit, communication unit, memory unit and power unit. Sometimes the nodes may contain additional units like GPS for providing location information. The sink node or base station is an interface between the external world and the sensor network. Sink node collects the data from normal sensor nodes and send it for further processing to the management terminal. It is typically a resourceful node which is having enormous computational capabilities, communication resources and energy supply. There can be single or multiple sink nodes in a network.

2. THE SYSTEM

We have implemented a basic wireless sensor network system to study about the general organization and signal processing activities and associated problems in the system. Besides explaining the working of traditional sensing systems, the study tries to explore the practical difficulties in design, implementation and troubleshooting of sensor networks. The System Consists of microcontroller integrated sensor modules distributed over a vast area. The microcontroller modules sense the signals, process the signals, communicate with the network and can control the system remotely. The system can be connected to the Internet. Different types of sensors collect environmental data which are networked and integrated into a globally accessible distributed database**.**

In our system, there are two data acquisition sensor modules. Each module consists of sensor unit, control unit, microcontroller (PIC), max 232 interfaces, serial to Ethernet converter and the necessary circuits. These 2 modules are connected to the wireless router, which sends out the encrypted UDP data through the wireless network. A remote pc connected to the network can access the encrypted datagrams. The PC contains a GUI which shows the decrypted data and can initiate the control action if necessary. The block diagram of our system is given as figure 2.

Sensor Unit - The sensor unit consists of temperature sensor, light sensor and voltage sensor. This part is doing the data acquisition. Measurement of these three quantities can provide enough information of the field. The analog input will be given to the onboard analog to digital converters of the PIC. We are using the LM35 series precision integrated-circuit temperature sensors, for which the output voltage is proportional to the Celsius temperature. The light intensity is sensed with an LDR. The voltage variation is measured by using a potentiometer.

Control Unit - Control unit consists of controlling circuitry for the three measuring parameters. If the parameter value exceeds or falls below the threshold values, there will be an alert signal at the remote pc and we can switch the systems accordingly to control the parameter to be in safe range. The control signals from the PC

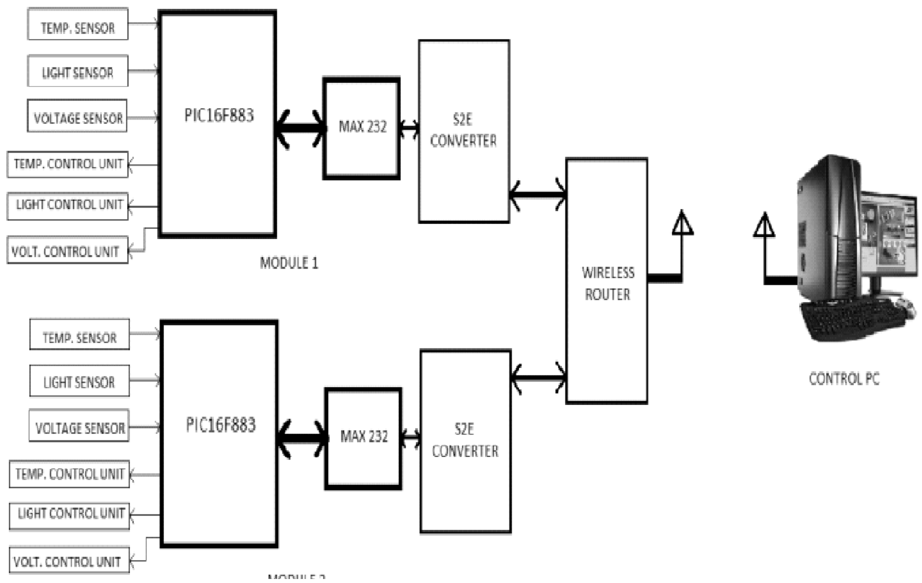

Figure 2: Block Diagram of the system

are encrypted and send through the network. This will be reached at the PIC and the decryption is done there and PIC will initiate the control switching.

Microcontroller -The microcontroller - PIC 16F883 is the heart of the system. The microcontroller can communicate with serial data acquisition equipment at the terminal through SPI interface and can transmit data to remote host computer through Ethernet interface. The microcontroller will do the data encryption before transmission and data decryption after receiving the control data.

The MAX232 Interface - This IC converts signals from an RS-232 serial port to signals compatible to TTL voltage levels.

Serial to Ethernet Converter - The S2E module is intended as a simple add-on product to existing systems to provide network connectivity. Data acquired by all the sensors are transferring to the monitoring server via Ethernet. IPv4 protocol stack has been ported to this equipment. UDP datagrams are used to communicate with servers.

Control PC - A graphical user interface (GUI) hosted on a personal computer allow the user to interact with the microcontroller. We are using Internet-based, platform independent graphics tool-Java to develop interactive GUIs for process monitoring and control. The software architecture is based on C/S model. Software on the PC will act as the "server" and will poll all the terminals, which are working as the clients. As soon as the terminal will receive the request from PC, it will send all the data acquired before. When the data arrived at PC, the server program will analyze the datagrams and display the data acquired from each terminals.

3. OPERATION OF THE SYSTEM

The microcontroller has been programmed with Embedded C. The LDR is sensing the light intensity, LM 35 is sensing the temperature and the Pot is detecting the voltage variation. These analog values, which are given to the ADC will be converted in to digital value. The microcontroller is doing a simple encryption on the values. This will be given to the S2E module. The S2E module is converting this serial data in to UDP packets. These UDP packets are sending to the PC by the wireless Router. The modules and the router are configured by connecting directly to the PC and we have allotted IP addresses for them to form a LAN. Here the PC will be acting as the server and the modules will be the clients. A LAN is established with the router, two modules and the controlling PC. The PC is communicating to the modules wirelessly. The PC is pinged successfully with the modules and data transfer was successful.

The Data is decrypted and presented in the GUI. The GUI consists of the application software done in JAVA. The window is divided in to 2.One part for module 1 and other part for module 2. Each part consists of the current readings from the respective modules. Figure 3 shows a sample of the the GUI window in the monitoring PC, when we run the application program. The window shows the details of two sensor modules – client 1 and client 2 with their respective IP addresses. This is showing the values for temperature, Light intensity and the voltage respectively for all the modules. There is alert buttons with Red indication, if the value exceeds the upper threshold value and falls below the lower threshold. We are having two buttons- ON and OFF for each of the parameters, which helps to control the respective systems from the PC if required, on the occurrence of an alert. There is a search window which helps to see the previous values of the parameters in the chronological order.

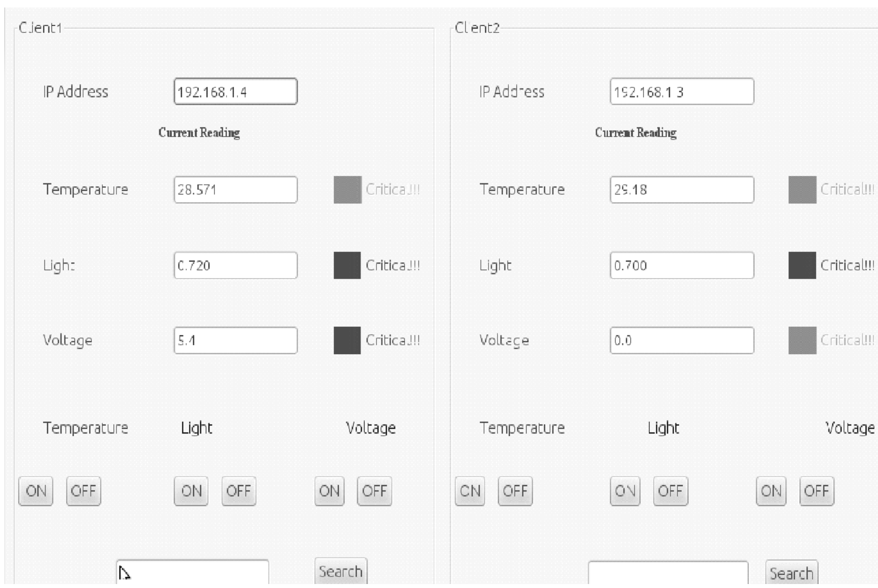

Figure 3: GUI Window

This system is very suitable for acquiring data or signals form a large scale industrial environment. Thousands of such terminals can be grouped within an intranet. One PC is enough for monitoring so many terminals. Link from terminals to the internet can be also established to realize remote monitoring

4. RESULTS AND ANALYSIS

We have developed a basic wireless sensor network which is capable of acquiring data from various sensors and transmitting the data to the remote server or PC for further processing. We are able to control the field parameters also from the remote PC by exploiting the possibilities of computer networking. The signal processing activities which are involved in a generalized sensor networks are identified based on the study and analysis of this basic system. Also we got a general idea about the challenges involved in the design, implementation, trouble shooting and maintenance of the system from this pilot study. The inferences obtained from the study and the analysis of the system is compared with such similar systems for a better reference and reached at generalized inferences and conclusions, which are listed here. So the system analysis can be broadly interpreted in two different ways.

The first is the identification of the various the signal processing activities that is happening inside a sensor network. The second is concerned with the various challenges involved in the design, implementation and maintenance of a sensor network.

(A) Signal Processing Activities in a Sensor Network

If we closely analyze the different types of sensors systems, we see that only the input signal chain is unique to the type of sensor element. Most of the cases, the remaining elements of the signal processing system are very similar. The first stage of the signal processing after the sensor element is an amplifier. Besides amplification, the amplifier may perform attenuation, filtering, buffering, offset adjustment, or level shifting. The conditioned output signal from this stage will be fed to an Analog-to-Digital Converter (ADC). The ADC converts the analog signal to a digital form that can be given directly into the processor. The processor process the collected information by performing various system routines, compensation algorithms and other processing tools. Finally, the processed data are transmitted through a proper channel. The channel can be a digital bus or traditional analog lines or wireless interface. This data can be used for further processing or to take decisions for continuous monitoring, or can be stored for reference. There are different activities in the sensor networks which are coming under signal processing are listed here.

Source localization in space and time – Here the target's location is estimated with respect to the sensor nodes. This also deals with estimating the minimum number of sensor nodes needed to accomplish a given amount of precision in the location of the target and the arrangement of sensors to have an adequate coverage of the sensing area. The major techniques in this involve measurement of the direction of arrival (DOA), time of arrival (TOA), and received signal strength indices (RSSI).

Distributed detection, signal estimation and classification - Distributed methods are more robust, need less communication bandwidth and computational load than centralized algorithms. But these methods require the development of specialized multi-sensor fusion techniques to achieve an optimal performance. Finding the suitable decision-fusion rules in these uncertain environments is a challenging problem.

Collaborative signal processing – Sensor nodes will be densely deployed in a noisy environment to gather extensive information of an event. In such dense networks, collaboration of sensor activities for the efficient utilization of resources is a real challenge. The spatially sampled raw data from the sensors about the phenomena of interest should be properly combined to achieve the maximum benefits. This process greatly depends on the nodes, the leader nodes and the sensor network architecture.

Distributed calibration in sensor networks– This includes the calibration of various signals like time synchronization.

Multi-sensor data fusion – To attain improved accuracy and reduced uncertainty about the events of interest, the processing and synergistic arrangement of data from multiple sensor nodes are necessary. This fusion of data from different sensor nodes will improve the reliability and robustness of the system.

Application specific processing - The sensor networks can be made suitable for various applications like military, commercial, health, etc., by customized and typical processing of the concerned signals.

Encryption and compression of data- The data obtained from the nodes should be compressed to reduce the bandwidth requirements and encrypted for security purpose. This is essential before sending the data to the remote location. So the networks must incorporate an optimum level of data security to avoid intrusion and passive monitoring of data. There should be compression algorithms to compress the data to minimum size, to reduce the communication bandwidth and the processing power.

(B) Challenges in the Sensor Networks

The fusion of data from different nodes and the constraints like power, bandwidth, computational needs etc. impose so many challenges in sensing, signal processing and communication in the sensor networks. These challenges should be considered at the design stage and must be avoided to the maximum extent well before the deployment of sensor networks. More technical issues and challenges are coming up with the increasing popularity of sensor networks in different fields. Some of the major challenges in the field, based on our analysis and observation are being enumerated here. They can be broadly classified in to seven categories.

1. Deployment

Dense deployment of sensors - Due to this, maximum amount of wide range of information will be obtained from the sensors. This huge information will create congestion in networks. Another major issue is to collect necessary informative data from the enormous data flow.

High scalability - Depending on the application, the number of sensors deployed in an area may range from the order of hundreds to millions. This large scale sensor systems helps to cover a wide area compared with small scale systems. These systems are more robust to node failures. But due to the large number of nodes, the traditional or manual methods of deployment and configuration are not practical and too costly in the case of sensor networks. So in this case nodes which are self-configurable after the deployment are preferred.

Topology maintenance of sensor networks – The topology of sensor networks are depending on their environment and it is highly dynamic. The network must support the changes in the topology due to change in the position of sensor nodes, malfunctioning of nodes, addition of nodes, replacing the malfunctioning nodes, changes in communication ranges, changes in tasks, shortage of energy, software errors, difficulty in reachability to the nodes due to obstacles, noise, jamming, etc., and task details. The proper maintenance of topology can reduce the installation cost and can increase the flexibility of arrangement and fault tolerance. But it is really a challenging task for such dense networks

Time varying environments - The sensors are normally deployed in rapidly changing environments. The sensors should be capable to adapt with these changes.

2. Hardware

Size – The sensor nodes should be tiny, but should include a sensor, processor, transceiver and a power unit. Sometimes it contains additional components like location finding system, a mobilizer and a power generator as per the specific application requirement.

Limitations of computational and memory resources - Sensors are limited in computation, communication and storage. So the protocols and algorithms for the sensor networks are to be designed in view with these constraints.

Position finding - As the sensor nodes are randomly deployed, a location finding system like GPS should be incorporated with them to attain the knowledge of the position. As equipping all sensor nodes with GPS units are not feasible, a bunch of nodes will share a GPS with a little compromise in accuracy.

Sensors with different modalities - The same phenomenon will be normally sensed with sensors of different modalities. The raw data output from these sensors corresponds to different aspects of the same phenomenon. Obtaining a synergy on the data from these varied information to accomplish maximum performance is really challenging.

Failure of sensor node - The sensor nodes may often fail due to physical, power shortage or any interferences as they are set up in intimidating environments. The network should be fault tolerant or reliable to perform the overall functionality of the sensor network without any disturbance due to such failures. As these types of issues are more common to the networks, the sensors should have self-healing and self-learning ability to adapt and reconfigure themselves in such situations. This robustness to sensor device failures will help to perform the tasks without any interruptions.

Environment conditions - Sensor nodes are usually working unattended in remote geographic areas, where the environment is harsh, extreme and noisy. So the sensor network should be designed with an idea of the application and environment conditions.

3. *Software*

Simulation of WSNs - Network simulators are needed to model and simulate a wireless sensor network. This helps to understand the complex behavior of wireless sensors in the environments.

Operating systems - As sensor nodes contains low power microcontrollers, sensor networks need real-time embedded operating systems than complex general-purpose operating systems

Protocols and algorithms - The protocols and algorithms used in the sensor networks should be capable enough to deal with the issues of energy optimization, maximum lifetime, fault tolerance, robustness, self-healing and self-configuration. This should ensure simple and flexible programming abstraction

Online collaborative sensor data management platforms - These are on-line database services which allow sensor networks to connect the network devices to provide data into an online database for storage. These services simplify the online collaboration between users with different data sets. These platforms allow the developers to connect to the online database, to build applications based on that data, to analyze and process historical data from the database, to embed real-time graphs, to send real-time alerts to control devices and environments etc.

4. *Data Processing*

Sensing - Depending on the nature of applications, detection complexity and environment, the sensing power will vary. Periodic sensing will consume lesser power compared with constant event monitoring. If the ambient noise levels are high, the senor signal may be more corrupted. This will increase the complexity of detection.

Local data processing - As the data communication consumes more power, the amount of data for communication must be reduced to minimum. So local data processing in the nodes is required and it is essential to minimize energy expenditure in a sensor network.

Data redundancy - To minimize the communication overhead, the redundant sensor information from the nodes should be removed and such data should not be forwarded. This type of redundancy of data aroused due to the spatial correlation between the sensor inputs will be utilized properly while doing in-network data aggregation and mining. The algorithms and protocols must be capable of doing this.

Data integration - The heterogeneous data generated from various sensors must be integrated in real time and must be saved in numerical form in a central data base. This needs specific standards for metadata encodings and interoperability interfaces. This data should be also integrated with internet and must be accessible through a web browser to monitor and control the sensor networks remotely.

5. *Communication*

Communication paradigm - Sensor nodes normally will not use point-to-point communication, but use broadcast communication paradigm. Considering the large number of sensors and the large amount of overhead involved in providing the identifier for each node, typically sensor nodes will not be given global identification.

Throughput - It is very crucial in the design of the sensor network to estimate the volume of data traffic that the sensor node can handle at any moment. This should be always within the limits for all the nodes, especially for the relay nodes. Even though the average traffic is low, the data flow through these nodes will be high, as these nodes relay data from different sensor nodes to the Base station.

Connectivity - When the connectivity is lost, the application of the network will be failed to accomplish. So maintaining the connectivity is very important to prevent the formation of not-connected partitions within the network.

Security - The sensor networks should be provided with enough security to prevent different types of attacks, to detect the intrusion and to avoid loss of data due to stealing.

Transmission media - The transmission media for the network can be optical, radio, infrared etc. The selected medium must be available globally to ensure worldwide operation of the networks. For radio links, normally the license free ISM band is preferred as they have huge spectrum allocation, global availability, more freedom for the implementation and power saving schemes. Even though, these unregulated frequencies are susceptible for interference from prevailing applications, most of the present networks are working with hardware to support Radio frequency. Another mode is infrared communication, as it is license-free, robust to the interference and have cheaper transceivers. But this have the constraint of line of sight communication. Optical medium is comparatively a new mode. This can be passive type using retro reflectors or active type with an onboard source and steerable reflectors. As per specific and particular application needs, the transmission media can be of other customized types. Whatever medium is used, it should support the channel characteristics, the modulation schemes and coding methods specific to the application.

Transceiver efficiency - A cheap, tiny, ultralow power transceiver is preferred for the sensor networks. Normally the sensor antenna will not have much height and radiation power. But there exists a trade-off between the antenna efficiency and the power consumption. This will also put constraints on the carrier frequency range for the antenna.

Sleep mode - As communication consumes a momentous amount of power, the communication unit will communicate data only when it is required and it will be in sleep mode at all other times. This to minimize the power consumption

6. Power

Limitations in energy resources - A sensor node is normally powered with a battery. Changing the battery or charging it is very expensive or not possible due to unfriendly environments of the nodes. So the power consumption in the nodes should be minimized and the sensor nodes should be made energy efficient to maximize the lifetime of a sensor node, while keeping an acceptable performance level.

Alternate energy sources – The sensor nodes are with limited power supply. So it will be more effective to search for the usage of any alternative energy sources like piezo, solar, thermal etc. to cater these hungry circuit elements.

Rechargeable power units - The sensor nodes can be equipped with rechargeable batteries, capacitors, solid state/thin film devices etc., which can be recharged with energy recurrently and continuously. This will enable greater flexibility and functionality for the nodes. The recharge cycle can be scheduled, continuous, passive or on-demand depending on the specific application

Low power methodology - Comparing with radio waves and infrared, optical medium will consume less energy. So optimize the medium, which support less power consumption. Putting the power supply in sleep mode and reducing current from the supply by using a low sampling rate procedure will eventually lead to low power expenditure by reducing the supply current to the nodes. Also the sensors should be of inherently latent type with zero stand-by power. Power must be transferred to the sensors whenever a sensor reading is required. This transfer should last until the sensors complete the sending of the data after their activation.

Reduced computational requirements - One of the main reason for the high power consumption at a node is due to computational requirement for the data processing. Reducing this to the maximum possible limits will help in energy scavenging.

Communication requirements -The communication of a node with its neighboring nodes and Base Station consumes maximum power among its complete functional domains. This involves filtering, modulation, band pass, demodulation and multiplexing circuits. Mixers, voltage control oscillators, frequency synthesizers, power amplifiers, phase locked loops etc. are consuming considerable energy in the transceiver circuitry. The effective idea to reduce the power consumption in communication is to communicate information only when it is required and be in sleep mode for all other times. This is effective if the start-up time is of the order of micro-seconds. If the startup time is high, the power required for the start-up is not negligible. This will again dominate the active power consumption, if the transmission packet size is reduced. In this case, it is inefficient to put the transceiver in to off mode, as a substantial amount of power is depleted in turning on the transceiver each time. The other factors need to be optimize to reduce the power consumption include transmission and reception power, communication rate, medium of communication, type of modulation etc.

Power aware protocols and algorithms – The main functions of the sensor nodes are sensing, data processing and communication. The design of application specific protocols should take the consideration of obtaining high level for performance parameters, maintaining power efficiency. Also these protocols and algorithms should support the anticipated topological changes, re-routing of packets, re-organization of the network etc. originated as a consequence of malfunctioning of nodes in the network

7. Cost

The total cost involved includes the implementation cost and the maintenance cost.

The implementation cost – This includes the expenses for sensor nodes and network infrastructure.

Sensor Node: The overall cost of the networks depends on the cost of a single node. So the cost of the single node should be made as low as possible. Manufacturing low cost sensor nodes is a very big challenge. A sensor node contains sensor, transceiver, processor, power unit, GPS, mobilizer etc. All of these subunits should be made in a cost effective way to reduce the total cost.

Network Infrastructure: The design and implementation of the total network structure including base stations, communication interfaces, web interfaces should be cost effective to minimize the overall cost.

Maintenance cost - The total maintenance cost consist of mainly three parts – Infrastructure maintenance, replacement of faulty nodes and battery replacement. The network infrastructure maintenance involves the activities involved in maintaining the network structure, communication interfaces, base stations etc. Many of the nodes deployed can become worthless due to hardware problems or environmental factors. These nodes must be repaired or replaced. Maintaining these nodes, especially at hard to service locations will add considerable overhead to the maintenance cost.

The major part of the maintenance requirement is the replacement of batteries. The power source for wireless sensors are mainly disposable, primary batteries. However, there are two main challenges involved, while using the disposable batteries for wireless sensors - maintaining sensors in hard to service locations, and scaling a sensor network to hundreds or thousands of nodes. Hard to service locations can add significant cost to the already high replacement cost of batteries for wireless sensors and can even limit the sensor locations. This will potentially reduce the effectiveness of the overall deployment. So scaling the sensor networks with power supplies that have limited life is a big challenge. Traditional energy harvesting methods such as solar, piezo, and thermal, share a common limitation of being reliant on ambient sources generally beyond their control. Solar requires light, vibration requires motion, and thermal requires a heat source.

Another option is to ensure proper performance and to reduce risk, batteries must be replaced on a regular schedule, without waiting for a low voltage output to reach. This also result in wasted battery life. As the network becomes large, the replacement of batteries for thousands of nodes will become a continuous and costly maintenance process.

8. CONCLUSION

The flexibility, fault tolerance, high sensing fidelity, low-cost and rapid deployment characteristics of sensor networks create many new and exciting application areas for them. Sensor networks are becoming an inevitable part of the day to day process in almost all the fields. As the usage and application areas are becoming wider, the issues involved in the design and implementation of the networks faces variety of challenges. In this, a sensor network system with two sensor nodes with each having three basic sensors have been designed and implemented. Here an overview of the sensor networks has been given, emphasizing the challenges involved in the effective implementation and the signal processing activities in the system. This area needs a lot of contributions to cover up the issues to have properly oriented and well-functioning networks. Sensor networks made of multiple sensors must be designed properly with the intention to overcome these constraints by taking advantage of the synergy between distributed nodes. This can be served as a preliminary work for the advanced research to the sensor networks.

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