APPLICATIONS AND CHALLENGES OF WIRELESS SENSOR NETWORK (WSN) IN REMOTE SENSING AND MONITORING

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ABSTRACT
A wireless sensor network (WSN) is a group of spatially distributed, independent device that collects data by measuring physical or environmental conditions. Some of the conditions being measured are: temperature, pressure, moisture, position, usage information, lighting, and sound. These readings, in the form of data, are passed through the network, are collated and organized; and then delivered to the end user. WSNs are already in use for many applications like industrial process monitoring and control, electricity system controls, and human health monitoring. Traditionally, these WSNs tend to need a lot of power to function, but decreasing the power needs of the system increases the lifetime of the sensor devices, and creates space for battery-powered applications. Battery-powered devices allow for wide-ranging use cases and opens opportunities for lower-ROI applications. In this paper, some applications and challenges of wireless sensor network (WSN) in remote sensing and monitoring were x-rayed. It was observed that irrespective of some of challenges being faced by this sensor network, its applications are very useful and find wide coverage in modern day remote sensing.

KEYWORDS/PHRASES: Wireless Sensor Network, microcontroller, computer, telecommunication.

I. INTRODUCTION

1.1 Background of Study

A wireless sensor network (WSN) (sometimes called a wireless sensor and actor network (WSAN)) are spatially distributed autonomous sensor to monitor physical or environmental conditions, such as temperature, sound, Kasimoglu, 2021). The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding 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 (Dargie and Doellabauer, 2019).

In computer science and telecommunications, wireless sensor network is an active research area with numerous workshops and conferences arranged each year. Figure 1.1 shows a typical wireless sensor network arrangement.

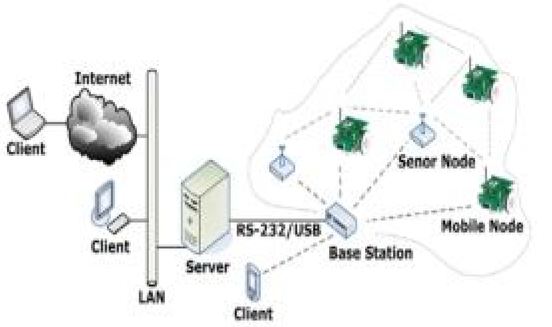

Figure 1.1: A typical wireless sensor network arrangement

1.2 Low Power Wireless Sensor Networks

The key to achieving a longer lifetime for WSN is to design wireless sensor networks that minimize power consumption of wireless sensor devices, hence the name "low power." To cut down on overall power consumption, low power wireless sensor networks control the active time or "awake time" of the devices (such as a radio or microcontroller) and limit the current draw when they are "sleeping". These networks accomplish this by varying the power setting modes of the devices, such as "always on", "standby", or "hibernation" modes.

For example, think about a basic remote temperature sensor that collects data over a long period of time. In "active" mode, the device uses power to take temperature readings and to manipulate data using a sophisticated noise-filtering algorithm, but the device does not have to do this constantly. When not in active mode, the microcontroller can return to sleep mode until more sample measurements are taken. Then, at regular intervals, the Real-Time Clock and Calendar (RTCC) will wake up from sleep mode to see if there is another task to perform. If not, it will go back to sleep, conserving power usage. When the amount of time the microcontroller spends running is smartly managed and controlled, the overall amount of power consumption is drastically reduced (Sohraby et al., 2018).

One ideal use case for low power wireless sensor networks is in "smart city" applications. Low-power network technology is optimal for monitoring the condition of things such as parking, streetlights, traffic control, municipal transportation systems (buses), snow plowing, trash collection, and public safety. Data is collected from these devices, then interpreted into meaningful information in a format that allows city employees to make informed decisions about allocating resources and delivering services. In many cases, responses to changing conditions can be made ahead of time and automated, resulting in a "smart city."

1.3 Characteristics of a Wireless Sensor Network

The main characteristics of a WSN include:

- Power consumption constraints for nodes using batteries or energy harvesting
- Ability to cope with node failures (resilience)
- Mobility of nodes
- Heterogeneity of nodes
- Scalability to large scale of deployment
- Ability to withstand harsh environmental conditions
- Ease of use
- Cross-layer design

Cross-layer is becoming an important studying area for wireless sensor network. In addition, the traditional layered approach presents three main problems:

1. Traditional layered approach cannot share different information among different layers , which leads to each layer not having complete information. The traditional layered approach cannot guarantee the optimization of the entire network.

2. The traditional layered approach does not have the ability to adapt to the environmental change.
3. Because of the interference between the different users, access conflicts, fading, and the change of environment in the wireless sensor networks, traditional layered approach for wired networks is not applicable to wireless networks.

So the cross-layer can be used to make the optimal modulation to improve the transmission performance, such as data rate, energy efficiency, QoS (Quality of Service), etc. Sensor nodes can be imagined as small computers which are extremely basic in terms of their interfaces and their components (Peiris, 2018). They usually consist of a processing unit with limited computational power and limited memory, sensors or MEMS (including specific conditioning circuitry), a communication device (usually radio transceivers or alternatively optical), and a power source usually in the form of a battery. Other possible inclusions are energy harvesting modules, secondary ASICs, and possibly secondary communication interface (e.g. RS-232 or USB).

The base stations are one or main components of the WSN with much more computational, energy and communication resources. They act as a gateway between sensor nodes and the end user as they typically forward data from the WSN on to a server. Other special components in routing based networks are routers, designed to compute, calculate and distribute the routing tables. Figure 1.2 shows a wireless sensor network arrangement with application server.

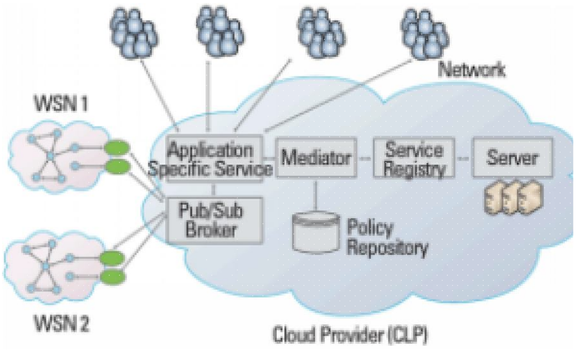

Figure 1.2: A wireless sensor network arrangement with application server

II. LITTERATURE REVIEW

Although wireless sensor nodes have existed for decades and used for applications as diverse as earthquake measurements to warfare, the modern development of small sensor nodes dates back to the 1998 Smartdust project and the NASA Sensor Webs Project (Hart and Martinez, 2016). One of the objectives of the Smartdust project was to create autonomous sensing and communication within a cubic millimeter of space. Though this project ended early on, it led to many more research projects. They include major research centres in Berkeley NEST and CENS. The researchers involved in these projects coined the term *mote* to refer to a sensor node.

The equivalent term in the NASA Sensor Webs Project for a physical sensor node is *pod*, although the sensor node in a Sensor Web can be another Sensor Web itself. Physical sensor nodes have been able to increase their capability in conjunction with Moore's Law. The chip footprint contains more complex and lower powered microcontrollers. Thus, for the same node footprint, more silicon capability can be packed into it. Nowadays, motes focus on providing the longest wireless range (dozens of km), the lowest energy consumption (a few uA) and the easiest development process for the user (Magno et al., 2017).

To illustrate the impact of the physical limits of sensor networks on the design of a wireless networking algorithms, we briefly discuss related wireless network models, namely mobile ad hoc networks, cellular networks, and a number of short range wireless local area networks.

A Mobile Ad-hoc NETwork (MANET) is a peer-to-peer network which is usually comprised of tens to hundreds of communicating nodes which are able to cover ranges of up to hundreds of meters. Each node is envisioned as a personal information appliance such as a Personal Digital Assistant (PDA) outfitted with a fairly sophisticated radio transceiver. The nodes are fully mobile. The MANET aims to form and maintain a connected multi-hop network capable of transporting multi-media traffic between the nodes.

In order to provide QoS in the face of mobility a MANET must do the following:
a) Organize the nodes in such a way that they are able to access the shared communications medium efficiently. This is called forming an infrastructure in some cases, and includes the function of providing a means of channel access for the nodes as well.
b) Performing routing in the network
c) Maintain the network organization and routing in the face of mobility

In a MANET, the three-pronged tasks of Organization-Routing-Mobility-management (ORM) are done to optimize for QoS. That is, the network is designed to provide good throughput/delay characteristics in the face of high node mobility. Although the nodes are portable battery powered devices, energy consumption
in this system is of secondary importance, since each device is always attached to a person, and presumably the depleted battery will be replaced when needed (the same way batteries are changed on Laptops).

A cellular network is a vast network consisting of both stationary and mobile nodes. The stationary nodes or base stations are connected among them in a sub-network with a wired backbone, forming a fixed infrastructure (Peiris 2019). The mobile nodes greatly outnumber the stationary nodes (tens to hundreds of mobiles per base station) which are usually situated quite sparsely. The base stations are usually placed to cover a large region with little overlap. The issue of organization is only encountered in terms of cell-to-cell handoffs as the mobile navigates the region.
Each mobile node will be only one hop away from any base station. The primary goal here is of providing a high QoS, along with high bandwidth efficiency. The base stations themselves effectively have an unlimited power supply, while the mobiles are battery operated.

Bluetooth is a short-range wireless networking system which is intended to replace the cable between electronic consumer devices and provide RF connection between them. The Bluetooth topology is a star network where a *master* node is able to have up to seven *slave* nodes attached to it to form a *piconet*. Each *piconet* uses a centrally assigned TDMA schedule and frequency-hopping pattern. The raw signaling rate in this system is 1 Mb/s. All nodes are synchronized to the *master*. There are mechanisms in place for multiple *piconets* to interconnect and form a multihop topology. Typical transmission power is about 1 mW. It is expected to achieve a 10 m range. Another short-range commercial system under development is the HomeRF. The goals of this system are very similar to those of Bluetooth (Muaz and Amir, 2019).

However the networking model is based on the IEEE 802.11 standard. The system is able to handle single hop ad-hoc networks. The radio is a frequency-hopping module. Channel access is possible under TDMA and CSMA modes. Raw data rates of up to 2 Mb/s are possible. Transmission power levels are at 100 mW. Typical ranges are distances encountered in the house and the yard.

The overall theoretical work on WSNs works with passive, omnidirectional sensors. Each sensor node has a certain area of coverage for which it can reliably and accurately report the particular quantity that it is observing (Margno et al., 2017). Several sources of power consumption in sensors are: signal sampling and conversion of physical signals to electrical ones, signal conditioning, and analog-to-digital conversion. Spatial density of sensor nodes in the field may be as high as 20 nodes per cubic meter.

2.1 Some Important Literatures

A sensor node, also known as a mote (chiefly in North America), is a node in a sensor network that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. A mote is a node but a node is not always a mote. Typical wireless sensor nodes are shown in figure 2.1.

Figure 2.1: Wireless sensor nodes

The main components of a sensor node as shown in figure 2.2 are a microcontroller, transceiver, external memory, power source and one or more sensors.

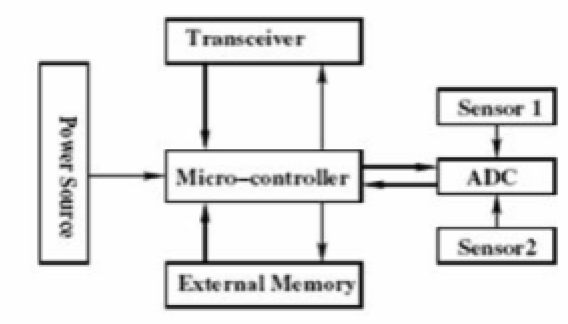

Figure 2.2: Main components of a sensor node

2.1.1 Microcontroller

The controller performs tasks, processes data and controls the functionality of other components in the sensor node. While the most common controller is a microcontroller, other alternatives that can be used as a controller are: a general purpose desktop microprocessor, digital signal processors, FPGAs and ASICs. A microcontroller is often used in many embedded systems such as sensor nodes because of its low cost, flexibility to connect to other devices, ease of programming, and low power consumption. A general purpose microprocessor generally has a higher power consumption than a microcontroller, therefore it is often not considered a suitable choice for a sensor node.

Digital Signal Processors may be chosen for broadband wireless communication applications, but in Wireless Sensor Networks the wireless communication is often modest: i.e., simpler, easier to process modulation and the signal processing tasks of actual sensing of data is less complicated. Therefore, the advantages of DSPs are not usually of much importance to wireless sensor nodes. FPGAs can be reprogrammed and reconfigured according to requirements, but this takes more time and energy than desired.

2.1.2 Transceiver

Sensor nodes often make use of ISM band, which gives free radio, spectrum allocation and global availability. The possible choices of wireless transmission media are radio frequency (RF), optical communication (laser) and infrared. Lasers require less energy, but need line-of-sight for communication and are sensitive to atmospheric conditions. Infrared, like lasers, needs no antenna but it is limited in its broadcasting capacity. Radio frequency-based communication is the most relevant that fits most of the WSN applications. WSNs tend to use license-free communication frequencies: 173, 433, 868, and 915 MHz; and 2.4 GHz.

The functionality of both transmitter and receiver are combined into a single device known as a transceiver. Transceivers often lack unique identifiers. The operational states are transmit, receive, idle, and sleep. Current generation transceivers have built-in state machines that perform some operations automatically.

2.1.3 External memory

From an energy perspective, the most relevant kinds of memory are the on-chip memory of a microcontroller and Flash memory—off-chip RAM is rarely, if ever, used. Flash memories are used due to their cost and storage capacity. Memory requirements are very much application dependent. Two categories of memory based on the purpose of storage are: user memory used for storing application related or personal data, and program memory used for programming the device. Program memory also contains identification data of the device if present.

2.1.4 Power source

A wireless sensor node is a popular solution when it is difficult or impossible to run a mains supply to the sensor node. However, since the wireless sensor node is often placed in a hard-to-reach location, changing the battery regularly can be costly and inconvenient. An important aspect in the development of a wireless sensor node is ensuring that there is always adequate energy available to power the system. The sensor node consumes power for sensing, communicating and data processing. More energy is required for data communication than any other process. The energy cost of transmitting 1 Kb a distance of 100 metres (330 ft) is approximately the same as that used for the execution of 3 million instructions by a 100 million instructions per second/W processor. Power is stored either in batteries or capacitors.

Batteries, both rechargeable and non-rechargeable, are the main source of power supply for sensor nodes. They are also classified according to electrochemical material used for the electrodes such as NiCd (nickel-cadmium), NiZn (nickel-zinc), NiMH (nickel-metal hydride), and lithium-ion. Current sensors are able to renew their energy from solar sources, temperature differences, or vibration. Two power saving policies used are Dynamic Power Management (DPM) and Dynamic Voltage Scaling (DVS). DPM conserves power by shutting down parts of the sensor node which are not currently used or active. A DVS scheme varies the power levels within the sensor node depending on the non-deterministic workload. By varying the voltage along with the frequency, it is possible to obtain quadratic reduction in power consumption.

2.1.5 Sensors

Sensors are hardware devices that produce a measurable response to a change in a physical condition like temperature or pressure. Sensors measure physical data of the parameter to be monitored. The continual analog signal produced by the sensors is digitized by an analog-to-digital converter and sent to controllers for further processing. A sensor node should be small in size, consume extremely low energy, operate in high volumetric densities, be autonomous and operate unattended, and be adaptive to the environment. As wireless sensor nodes are typically very small electronic devices, they can only be equipped with a limited power source of less than 0.5-2 ampere-hour and 1.2-3.7 volts.

Sensors are classified into three categories: passive, omnidirectional sensors; passive, narrow-beam sensors; and active sensors. Passive sensors sense the data without actually manipulating the environment by active probing. They are self-powered; that is, energy is needed only to amplify their analog signal. Active sensors actively probe the environment, for example, a sonar or radar sensor, and they require continuous energy from a power source. Narrow-beam sensors have a well-defined notion of direction of measurement, similar to a camera. Omnidirectional sensors have no notion of direction involved in their measurements.

III. APPLICATIONS OF WIRELESS SENSOR NETWORK

3.1 Area monitoring

Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors to detect enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines. Wireless sensor network deployed in remote monitoring area is shown in figure 3.1.

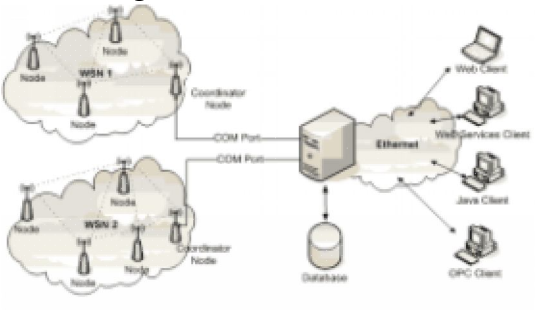

Figure 3.1: Wireless sensor network deployed in area monitoring

3.2 Health care monitoring

The medical applications can be of two types: wearable and implanted. Wearable devices are used on the body surface of a human or just at close proximity of the user. The implantable medical devices are those that are inserted inside human body. There are many other applications too e.g. body position measurement and location of the person, overall monitoring of ill patients in hospitals and at homes. Body-area networks can collect information about an individual's health, fitness, and energy expenditure.

3.3 Environmental/Earth sensing

There are many applications in monitoring environmental parameters. They share the extra challenges of harsh environments and reduced power supply. Figure 3.2 shows how wireless sensors are positioned for environmental monitoring.

3.4 Air pollution monitoring

Wireless sensor networks have been deployed in several cities to monitor the concentration of dangerous gases for citizens. These can take advantage of the ad hoc wireless links rather than wired installations, which also make them more mobile for testing readings in different areas.

3.5 Forest fire detection

A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; thanks to Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading.

3.6 Landslide detection

A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the occurrence of landslides long before it actually happens.

3.7 Water quality monitoring

Water quality monitoring involves analyzing water properties in dams, rivers, lakes & oceans, as well as underground water reserves. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status, and allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval.

3.8 Natural disaster prevention

Wireless sensor networks can effectively act to prevent the consequences of natural disasters, like floods. Wireless nodes have successfully been deployed in rivers where changes of the water levels have to be monitored in real time.

3.9 Industrial monitoring

Machine health monitoring: Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionality.[9]

Wireless sensors can be placed in locations difficult or impossible to reach with a wired system, such as rotating machinery and untethered vehicles.

3.10 Data logging

Wireless sensor networks are also used for the collection of data for monitoring of environmental information. This can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants. The statistical information can then be used to show how systems have been working. The advantage of WSNs over conventional loggers is the "live" data feed that is possible.

3.11 Structural Health Monitoring

Wireless sensor networks can be used to monitor the condition of civil infrastructure and related geo-physical processes close to real time, and over long periods through data logging, using appropriately interfaced sensors.

IV. CHALLENGES AND IMPROVEMENTS IN WSN APPLICATION

4.1 Hardware

One major challenge in a WSN is to produce low cost and tiny sensor nodes. There are an increasing number of small companies producing WSN hardware and the commercial situation can be compared to home computing in the 1970s. Many of the nodes are still in the research and development stage, particularly their software. Also inherent to sensor network adoption is the use of very low power methods for radio communication and data acquisition.

In many applications, a WSN communicates with a Local Area Network or Wide Area Network through a gateway. The Gateway acts as a bridge between the WSN and the other network. This enables data to be stored and processed by devices with more resources, for example, in a remotely located server.

4.2 Software

Energy is the scarcest resource of WSN nodes, and it determines the lifetime of WSNs. WSNs may be deployed in large numbers in various environments, including remote and hostile regions, where ad hoc communications are a key component. For this reason, algorithms and protocols need to address the following issues:

- Increased lifespan
- Robustness and fault tolerance
- Self-configuration

Lifetime maximization: Energy/Power Consumption of the sensing device should be minimized and sensor nodes should be energy efficient since their limited energy resource determines their lifetime. To conserve power, wireless sensor nodes normally power off both the radio transmitter and the radio receiver when not in use.

4.3 Operating systems

Operating systems for wireless sensor network nodes are typically less complex than general-purpose operating systems. They more strongly resemble embedded systems, for two reasons. First, wireless sensor networks are typically deployed with a particular application in mind, rather than as a general platform. Second, a need for low costs and low power leads most wireless sensor nodes to have low-power microcontrollers ensuring that mechanisms such as virtual memory are either unnecessary or too expensive to implement.

It is therefore possible to use embedded operating systems such as eCos or uC/OS for sensor networks. However, such operating systems are often designed with real-time properties.

TinyOS is perhaps the first operating system specifically designed for wireless sensor networks. TinyOS is based on an event-driven programming model instead of multithreading. TinyOS programs are composed of *event handlers* and *tasks* with run-to-completion semantics. When an external event occurs, such as an incoming data packet or a sensor reading, TinyOS signals the appropriate event handler to handle the event. Event handlers can post tasks that are scheduled by the TinyOS kernel sometime later.

LiteOS is a newly developed OS for wireless sensor networks, which provides UNIX-like abstraction and support for the C programming language.

Contiki is an OS which uses a simpler programming style in C while providing advances such as 6LoWPAN and Protothreads.

4.4 Online collaborative sensor data management platforms

Online collaborative sensor data management platforms are on-line database services that allow sensor owners to register and connect their devices to feed data into an online database for storage and also allow developers to connect to the database and build their own applications based on that data. Examples include Xively and the Wikisensing platform.

4.5 Simulation of WSNs

At present, agent-based modeling and simulation is the only paradigm which allows the simulation of complex behavior in the environments of wireless sensors (such as flocking). Agent-based simulation of wireless sensor and ad hoc networks is a relatively new paradigm. Agent-based modelling was originally based on social simulation.

Network simulators like OPNET, NetSim and NS2 can be used to simulate a wireless sensor network.

4.6 Distributed sensor network

If a centralised architecture is used in a sensor network and the central node fails, then the entire network will collapse, however the reliability of the sensor network can be increased by using a distributed control architecture. Distributed control is used in WSNs for the following reasons:

1. Sensor nodes are prone to failure,
2. For better collection of data,
3. To provide nodes with backup in case of failure of the central node.

There is also no centralised body to allocate the resources and they have to be self-organized. A distributed wireless sensor network is shown in figure 4.1.

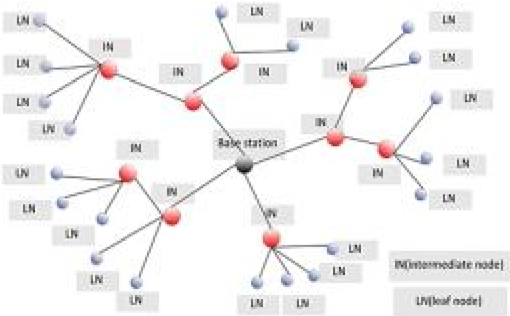

Figure 4.1: A distributed wireless sensor network

4.7 Data integration and Sensor Web

The data gathered from wireless sensor networks is usually saved in the form of numerical data in a central base station. Additionally, the Open Geospatial Consortium (OGC) is specifying standards for interoperability interfaces and metadata encodings that enable real time integration of heterogeneous sensor webs into the Internet, allowing any individual to monitor or control Wireless Sensor Networks through a Web Browser.

4.8 In-network processing

To reduce communication costs, some algorithms remove or reduce nodes' redundant sensor information and avoid forwarding data that is of no use. As nodes can inspect the data they forward, they can measure averages or directionality for example of readings from other nodes. For example, in sensing and monitoring applications, it is generally the case that neighboring sensor nodes monitoring an environmental feature typically register similar values. This kind of data redundancy due to the spatial correlation between sensor observations inspires techniques for in-network data aggregation and mining

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