Chapter 2
Applications of Sensor Networks

2.1 Introduction

A wireless sensor network (WSN) consisting of a large number of randomly deployed sensor nodes (SNs) was initially introduced for intrusion detection for tactical applications [1], and a scheme determining type and number of talks in a battlefield is shown in Fig. 2.1. Since then, the use of WSNs has increased dramatically in many diverse disciplines and the list is growing every moment. SNs have become a central focus of daily routine, and as indicated in Fig. 2.1, sensing bridges the gap between an embedded system and networked collaborative activities. Thus, sensors are finding applications in areas people never thought about and multitude of benefits offered by sensors in different disciplines are summarized in Table 2.1 [2]. As is clear from the table, all aspects of daily life are being directly or indirectly affected by sensor devices and the influence is anticipated to grow in the near future.

Each SN consists of many different functional units, and main constituent components are illustrated in Fig. 2.2 (same as Fig. 1.48a). Transducer basically converts energy from one form to electrical voltage and current and is primarily responsible for measuring and representing physical parameter in the surrounding area. Thus, the type of transducer needed depends on the application as input signal type to a transducer could vary. The output of a transducer is in analog voltage or current form and needs to be converted by A/D converter in digital format. This signal is fed and processed by an embedded processor that could temporarily store the result in a local memory. The size of processor is kept small in order to keep the cost and power consumption to acceptable level. The heart of a SN is a wireless transmitter/receiver which can either transmit or receive data wireless at any desired time. It is interesting to note that all these units get power from batteries. A commercial version of a SN is called mote [3] and it has 4 different built-in transducers to measure sound, light, humidity, and temperature level in the surrounding area. Different amount of energy is consumed in different functional units and is shown in Table 2.2, and a lot more energy is consumed in transmission/

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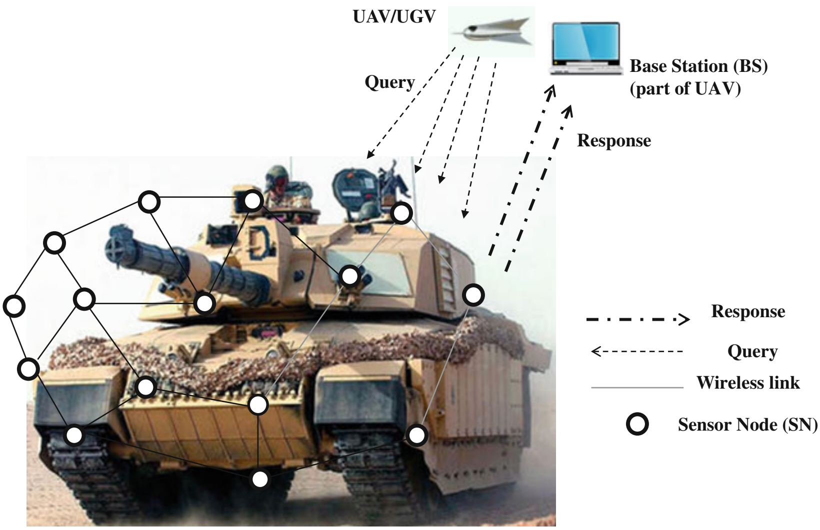


Fig. 2.1 A WSN using a large number of SNs

Table 2.1 WSNs bring multitude of benefits to our daily lives [2, 4]

Application	Benefit
Measure microclimates on farms	Increase crop yield per square km
Monitor traffic on road systems	Steer traffic away from jams, accidents, and construction zones; alert emergency services
Detect human presence in homes and offices	Reduce wasted power in HVAC and lighting
Electrical/gas/water metering	Optimize utility distribution systems and reduce inefficiencies

Fig. 2.2 Functional components of a SN device (Fig. 1.48a)

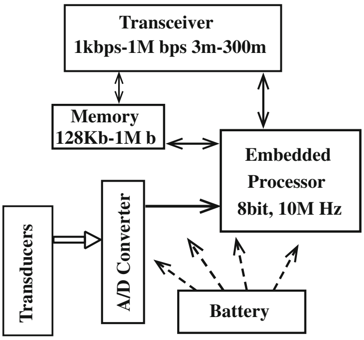


Table 2.2 Energy consumption in MICA2 motes' SN

Component	Current	Power
Nothing test	7.5 µA	0.02325 µW
Radio off	4 µA	0.0124 µW
Radio idle	16 mA	0.0496 mW
Radio receiver	16 mA	0.0496 mW
Radio transmit	21 mA	0.0651 mW
Computation only	10 µA	0.0310 µW
Transmit cost	–	1 µJ/bit

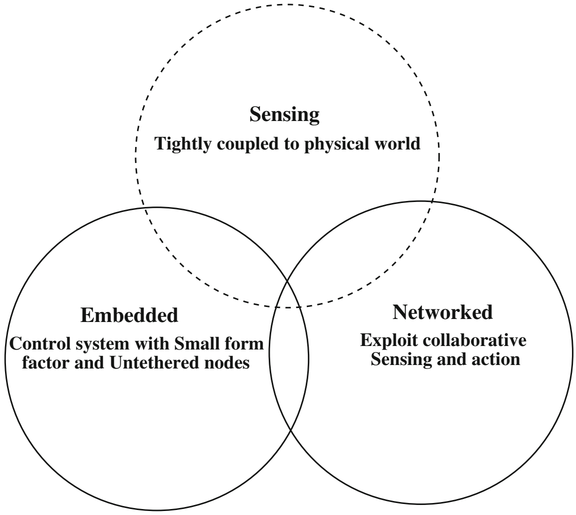


Fig. 2.3 Intersection of sensing, network, and embedded system

reception as compared to processing within a SN. It is also important to keep SNs in sleep mode in order to conserve energy consumption. As massive amount of SNs are to be deployed for a given application, many different aspects have become critical to usefulness and correct functioning. In some areas, digital cameras are used as sensing devices, utilizing them as SNs (Fig. 2.3).

2.2 Applications of WSNs

Numerous applications of WSNs have emerged, and a broad classification has been given in Table 2.1. It is rather hard to organize them in a systematic way, and some overlap is unavoidable. Figure 2.4 shows many areas of applications. However, they do not represent any chronological progression of development nor a complete list but a comprehensive classification of different areas. From functional point of view, WSNs can be divided into two complimentary steps: one is for collection of data from SNs (Fig. 2.5) and another is for dissemination of data to selected

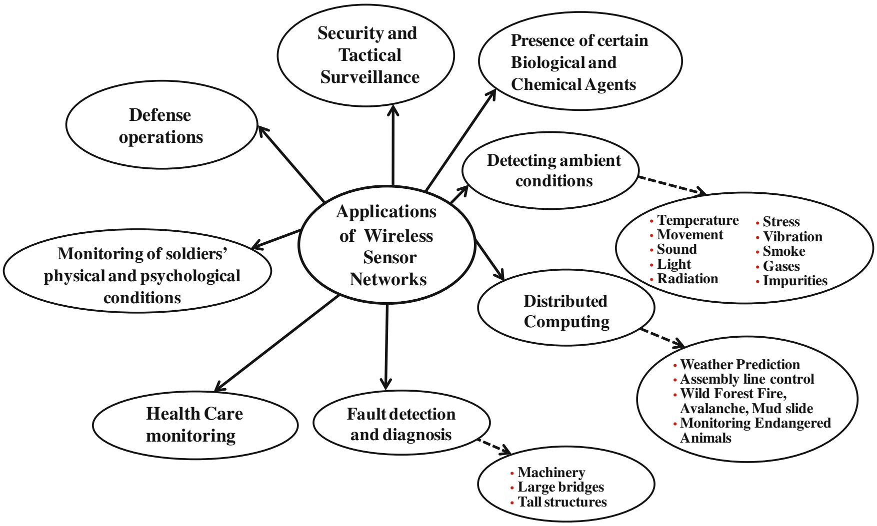


Fig. 2.4 Applications of WSNs

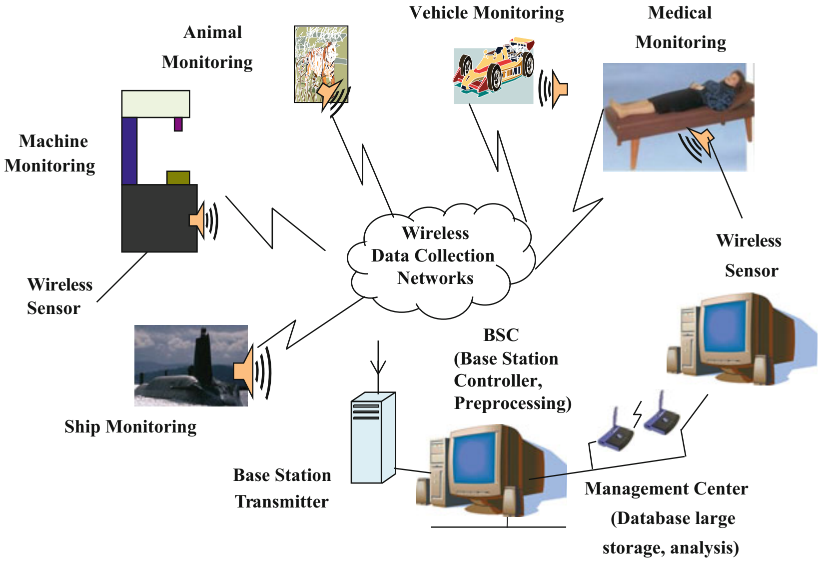


Fig. 2.5 Data acquisition using a WSN [5]

systems for appropriate action, primarily useful as an actuator (Fig. 2.6). The first step requires appropriate location of SNs, selection of appropriate and adequate data rate, harmonization between them for data transfer including SN clock synchronization, coordinated sleep–awake cycle sequence, aggregation of voluminous

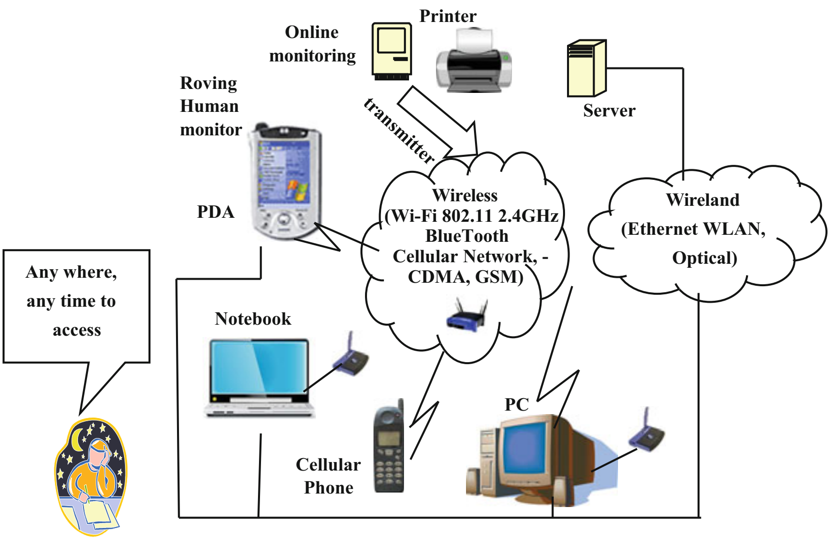


Fig. 2.6 Data distribution for a WSN

collected data, and delivery of data through storage for BS. The second step involves delivering desired collected data to appropriate devices and systems, including associated actuators.

2.2.1 Defense Applications of WSNs

WSNs were introduced for defense purpose, and we start with those types of applications. The idea here is to deploy SNs from low-flying airplanes or drones, and when SNs land on surface of land, they collect information from the surrounding area of war zone and send data to a powerful base station (BS) or sink node located inside the plane. Data are gathered and analyzed by the BS and determine strategic information such as type and number of tanks in the battlefield, number of soldiers, elevation of terrain, and types of hiding places such as bunkers. Such information is useful purely from defense perspectives and is shown in Fig. 2.7.

A more complex tactical system involves wireless communication between tanks and fighter planes and is shown in Fig. 2.8. WSN is also useful in detecting potential intrusion in a given area and is given in Fig. 2.9. A soldier in a battlefield is equipped with many different types of sensors and some of them are illustrated in Fig. 2.10. A closer look at night vision sensor is shown in Fig. 2.11. SNs are needed to protect soldier's face and thermal imaging, and night vision schemes are used to detect activities in dark (Figs. 2.12 and 2.13). Soldiers also have to face biological and chemical fighting, and SNs to detect and protect from such warfares are shown in

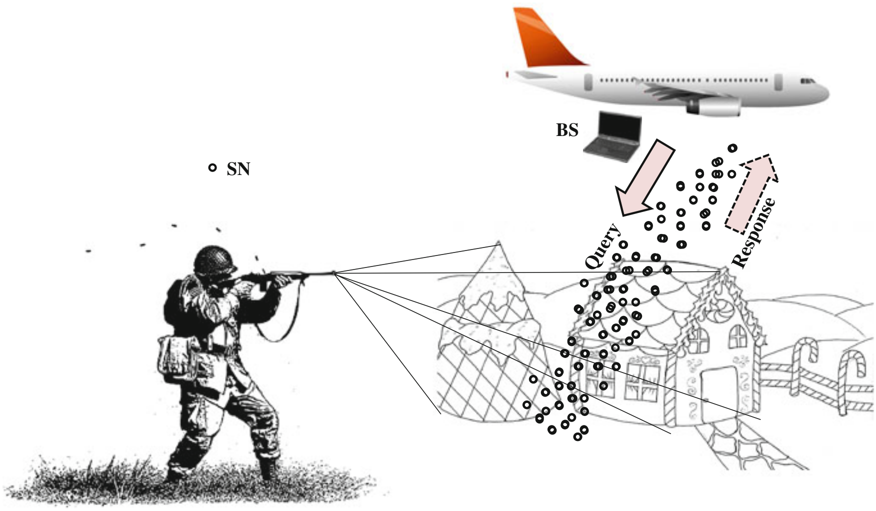


Fig. 2.7 Use of a WSN for defense application

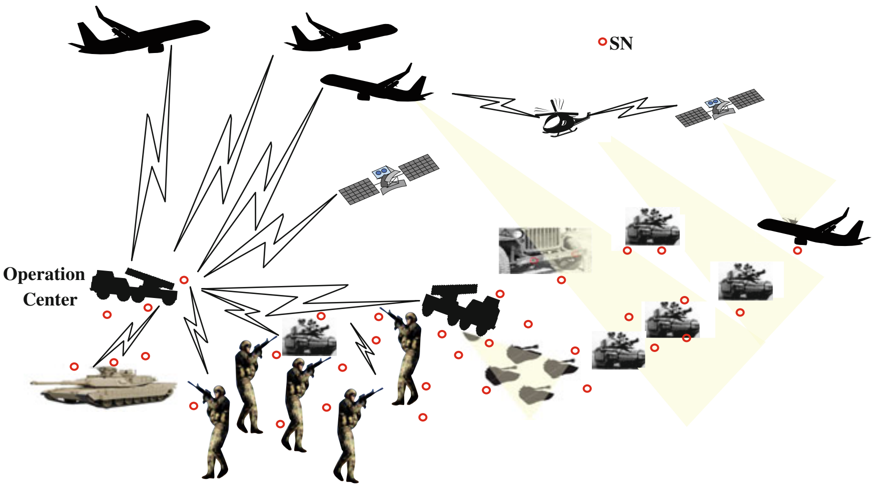


Fig. 2.8 Another defense application of WSN

Fig. 2.13. Another defense-oriented application that attracted a lot of attention is unmanned securing of a building by placing SNs on robots that move around the area and monitoring associated activities as shown in Figs. 2.14 and 2.15.

Another defense-based application involves detecting land mines (Fig. 2.16) which is now performed in a total manual way. Land mines are responsible for 73,576 casualties in 119 countries/areas in the past 10 years from 1999 to 2009 [11, 12]. Another peripheral area of interest to defense is to monitor national boarder for

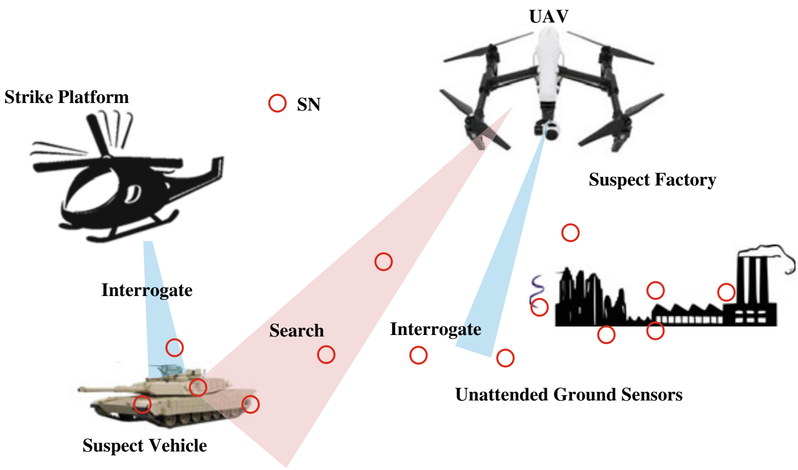


Fig. 2.9 Application of WSNs for defense against invasion

Fig. 2.10 **a** A soldier equipped with different SNs [6] and **b** closer look at a soldier with different SNs [7]

illegal trespassers that cross the countrywide border illegally [13] as indicated in Fig. 2.17. The idea is to deploy SNs around US–Mexico border that could detect illegal crossing of people by using heat and motion SNs that can send these parameters. Based on collected data, the BS can determine if there is substantial change in the measured temperature or increased mobilityin a short span of area.

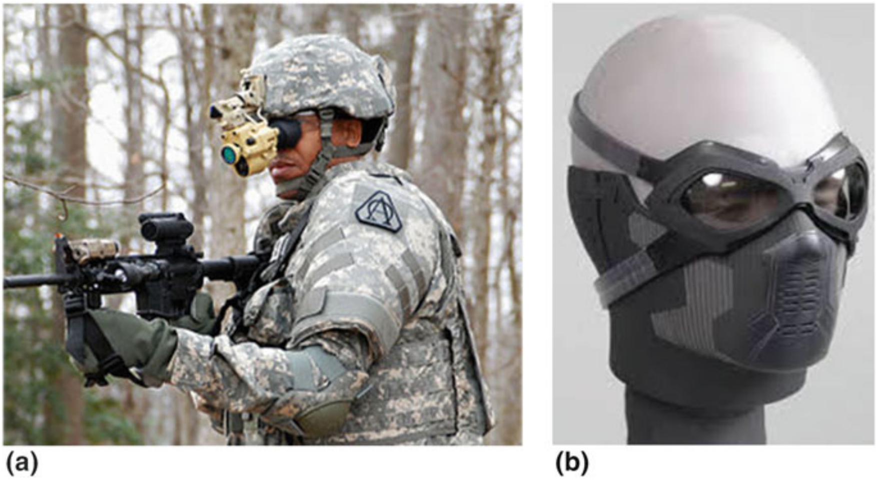


Fig. 2.11 **a** SNs used to protect soldier's face and **b** a soldier equipped with night vision SNs

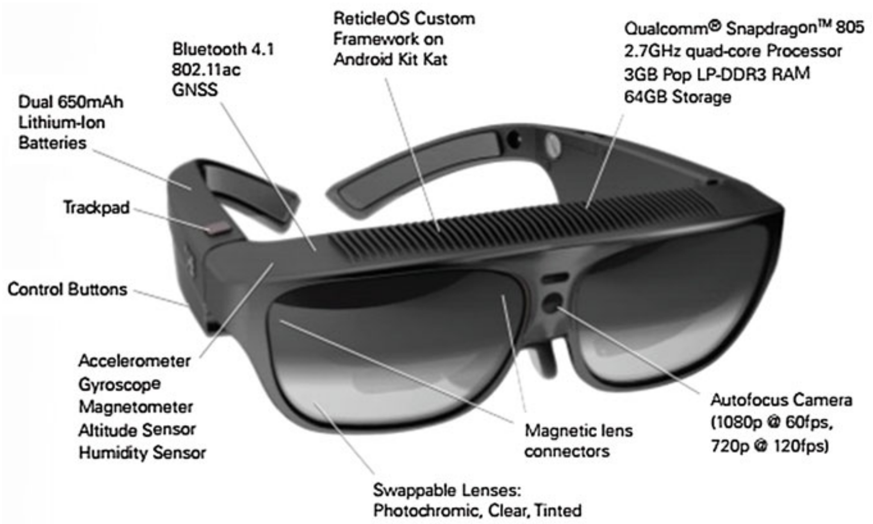


Fig. 2.12 **a** Night vision goggle [8] and **b** SNs used for night vision

That is how SNs help in determining unwanted activities as SNs do not have eyes and can only measure physical parameters from the surrounding area. But, human beings are much smarter, and as long as people do not come within sensing range of SNs, they can easily cross the border without being noticed by SNs. To keep undetected by SNs, many possible alternatives are possible such as digging tunnel under earth surface and following a path that cannot be detected by SNs.

Fig. 2.13 **a** SNs for thermal image and **b** SNs for another thermal image [9]

Another area of peripheral interest to defense department is the identification of accurate area in wild forest fires that occur frequently in USA and other parts of the world. Images taken from a satellite and an airplane provide an estimate aerial photograph of the territory as the space is commonly masked and occluded by smoke and fire waste. It is important to determine the location of fire initiation by measuring temperature distribution of the fire area. This is feasible by deploying SNs using low-flying airplanes or drones in the fire area, and once SNs land in the fire area, they send the temperature value to BS located at the plane or drone. Once data are collected at the BS from SNs, temperature distribution can indicate values and hence the origin of fire area can initiate the rescue operation from that area. This is illustrated in Fig. 2.18, with adequate number of SNs deployed as each SN has coverage area limited by its sensing range.

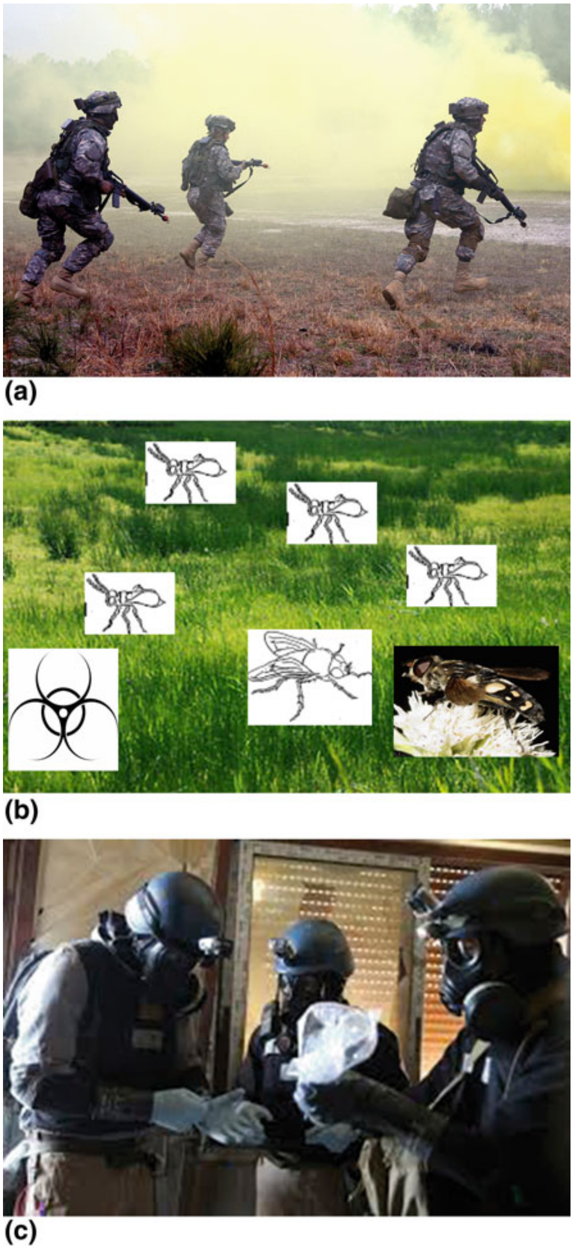


Fig. 2.14 **a** SNs for biological agents, **b** SNs for detecting biological agents and **c** SNs for chemical agents [10]

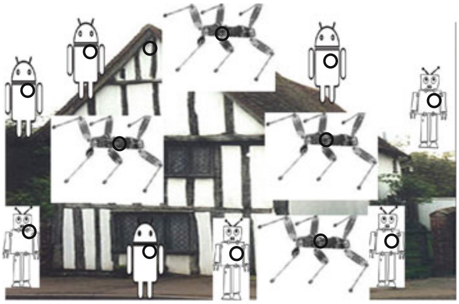


Fig. 2.15 Securing a building with SNs on robots

Fig. 2.16 SNs for detecting land mines

Fig. 2.17 SNs to detect illegal crossing

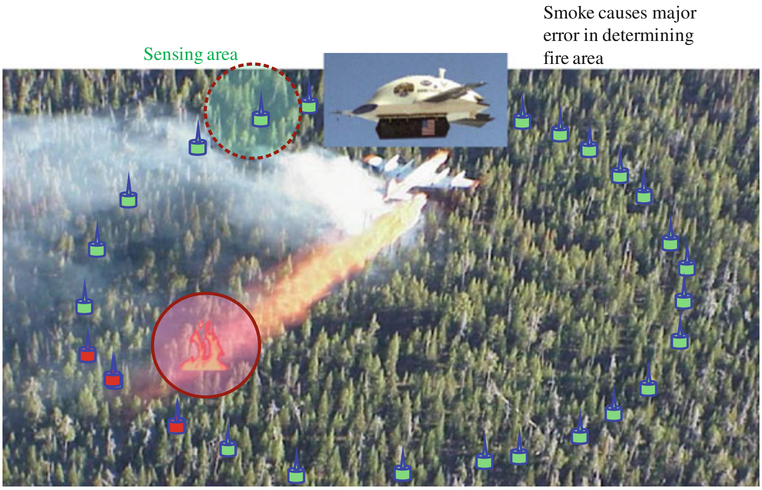


Fig. 2.18 Wild forest fire accurate area mapping

2.3 Civilian Applications

Many civilian applications have been suggested for WSNs. These can be divided into four main categories as shown in Fig. 2.19. These are discussed in the following paragraphs.

2.3.1 Weather Monitoring Applications

Weather monitoring is an important area of interest for our daily life and can be predicted by detecting numerous atmospheric weather-related parameters such as temperature, amount of rainwater, wind velocity, air pressure, wind velocity, natural disaster monitoring, and on land snow coverage and urban heat effects. One of the important considerations is collecting data related to the forests and their health can predict future falling of leaves and update harvesting information. High-density pixel intensities are collected to determine this phenomenon and are illustrated in Fig. 2.20. The assessment of forest structure is used to determine the forest conditions, and density and volume of pixels indicate past and future health in terms of falling of leaves. The color code of images could very well indicate such surrounding situations. Further analysis of forests is needed to monitor living animals, and activities of habitats are checked by determining landscape characteristics and structure. The landscape pattern such as structural components, patch geometry (e.g., patch size and amount of edge versus core), and spatial context of adjacency to other habitats are used to indicate living area for a given animal [15]. A patch is a closed area that differs from adjacent areas in terms of at least one attribute. Any

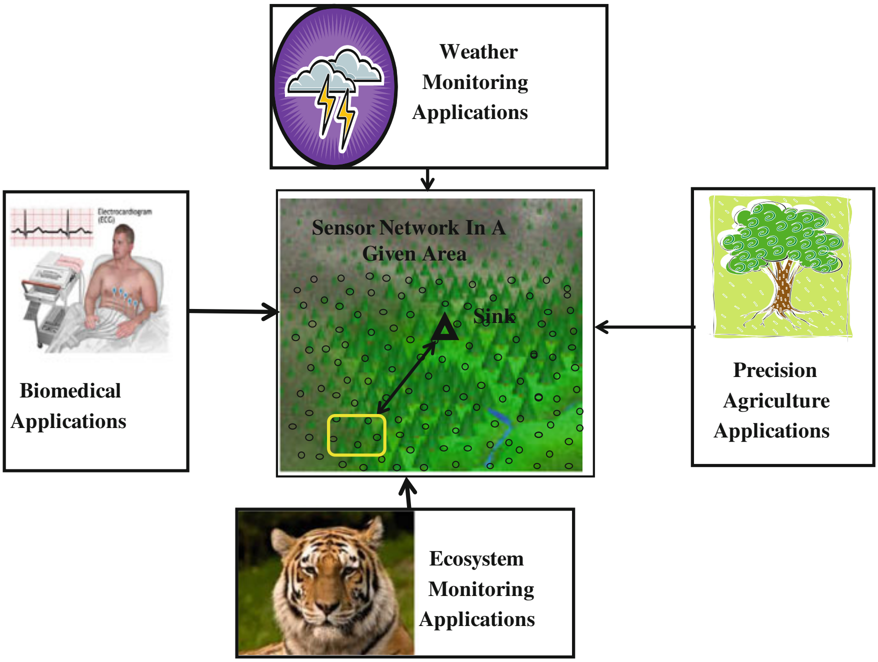


Fig. 2.19 Categorization of WSNs' civilian applications

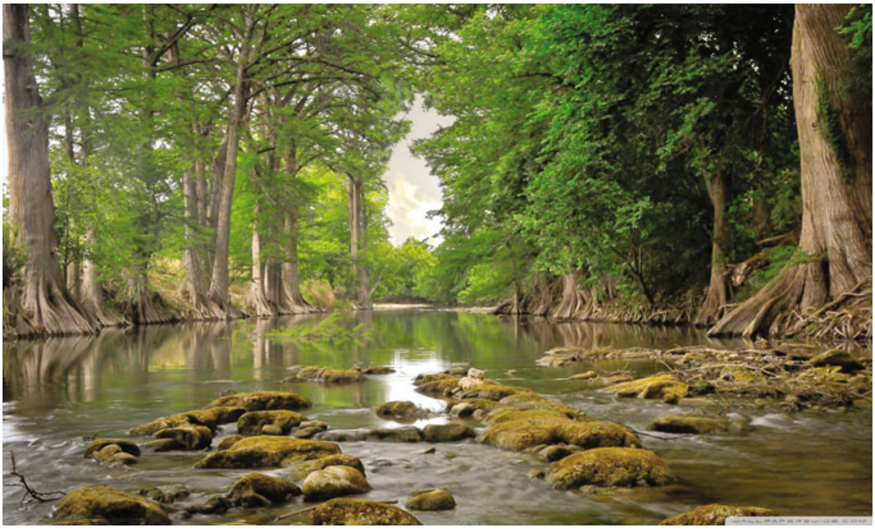


Fig. 2.20 River in a forest area [14]

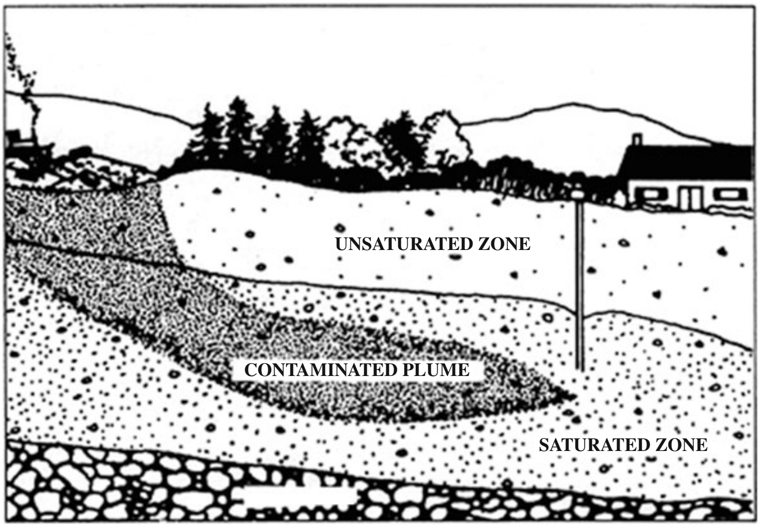
heterogeneity within a patch is usually neglected. The main attributes of a landscape are the presence of each class, the number of different patch types, membership concentration of different patch types, patch size distribution density, patch shape complexity, relative difference among patch types, spatial aggregation of patch types, etc. In this way, scaling is important in defining a landscape as it is directly related to how it is used by a species.

A qualified assessment can be made about water in the rivers and drainage basin in the surrounding areas. That also indicates the quality of life that indirectly controls the atmospheric conditions. In addition, microsensors can analyze data corresponding to air, water, and soil mixture on real-time basis and determine pollution level from collected data.

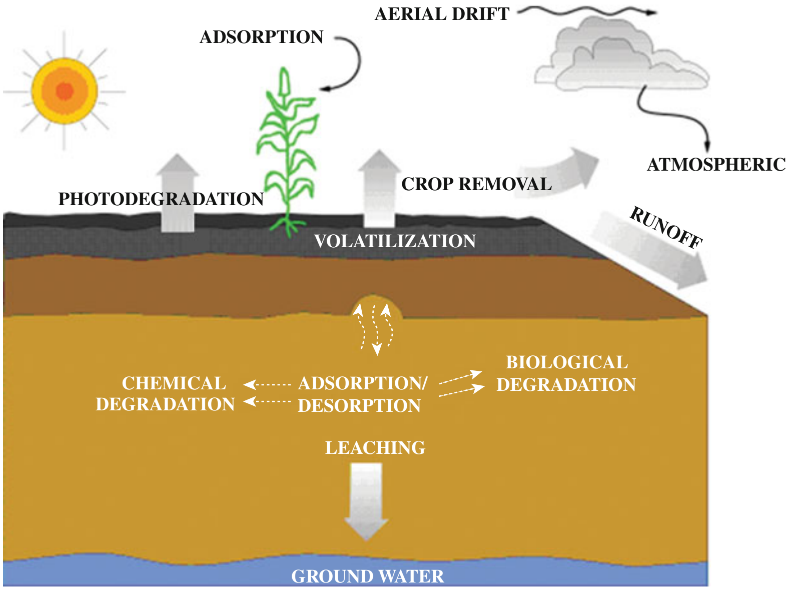
The quality of groundwater depends on how it moves through the unsaturated soil and finally to water area. Water is drawn by roots of plants, and many dissolved ingredients enter the plants in this way. SNs are designed to withstand harsh environment for a long period of time and are capable of performing real-time analysis of signals. Environmental hydrodynamics is illustrated in Fig. 2.21 and largely depends on sediments from the rivers and does affect the quality of rainwater [15]. Phosphorus content in rainwater also comes from contamination, and the environment is accordingly affected. Pesticides are also transported by the plants through their roots. Accurate boundary between forests and habitat living area can be easily determined using quality images. The ecological process is influenced by fertilization and draught. Archeological findings (Fig. 2.22) are also performed by satellite images, and exposed structures are analyzed for fault lines, identifying rocks, texture, pattern, and tone determination, fortitude of obscured structures, and the detection of hydrocarbons and oils and gases.

Monitoring of volcanos [16, 17] is also an important function that can be effectively achieved using multiple SNs and is illustrated in Fig. 2.23. The application is such that continuous transfer of data is not needed while it has to be triggered based on occurring events. This is also critical as a large area needs to be covered for monitoring the areas. Because of large area, a large number of sensors are needed and they need to be tightly synchronized.

National Science Foundation has been supporting highways research [18] to minimize delays in highways. The main idea is to explore the use of highway sensors networks for safety so that a warning signal can be generated to alert the driver of a possible danger in the forward direction. This is done by placing sensors at fixed locations on the highway for data collection from the cars. By measuring the distance between adjacent cars, the event information is forwarded about any accident or seriousness of an event such as traffic jam, occurrence of fog intensity, and duration. Another set of sensors are placed on each auto for receiving signals from the highway sensors and providing location information through GPS capability. A similar arrangement can be used to detect congested parts of a city, especially downtown or main shopping areas.



(a)



(b)

Fig. 2.21 **a** River in a forest area and **b** river in a forest area: another view

Fig. 2.22 **a** Archaeological images and **b** archaeological images: another view

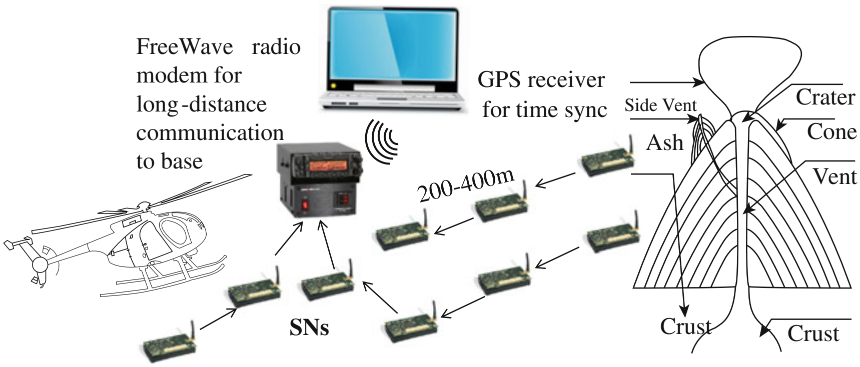


Fig. 2.23 Monitoring of volcanic activity using SNs

2.3.2 Precision Agriculture Applications

Precision agriculture has been a very hot topic and has been used for growing good-quality grains. A crop type is identified using spectral characteristics, image texture, and the knowledge of crop development over time. The crop condition is indicated by the health and vigor of the crop, detection of drought, pests, flooding, and disease. The most common remote sensing tool is a normalized difference vegetation index (NDVI). DARPA was the first to support assisting recovery of rare and endangered plant species by a comprehensive environmental measurement using a WSN. Each SN unit contains a computer and a wireless transceiver, with environmental sensors such as thermostat for temperature and photoresistor for light sensing while flexible piezoelectric strips are also employed for sensing the wind, relative humidity sensors, and some units with a high-resolution digital camera. Rechargeable batteries are employed in conjunction with thermoelectric unit for auto-charging. The weather data are collected and stored every ten minutes while high-resolution images are taken once an hour. Some of the SNs are also linked to the Internet to make it very useful in space exploration.

One noted example is that precision agriculture is growing grapes by measuring humidity and temperature at the root of grape trees (Fig. 2.24) and accordingly controlling amount and frequency of water irrigation. This is illustrated in Fig. 2.24b, c by placing SNs at the root of one tree selected every 4 blocks. Each SN senses three parameters such as light illumination, soil temperature, and soil moisture at different depths from 6″ and 14′. The soil moisture is obtained by capacitance sensors and is not affected in extreme dry conditions. The data collected also include the exact location of the SNs, and critical vineyard and wine grape information. The vineyard operations manager can view the data on any

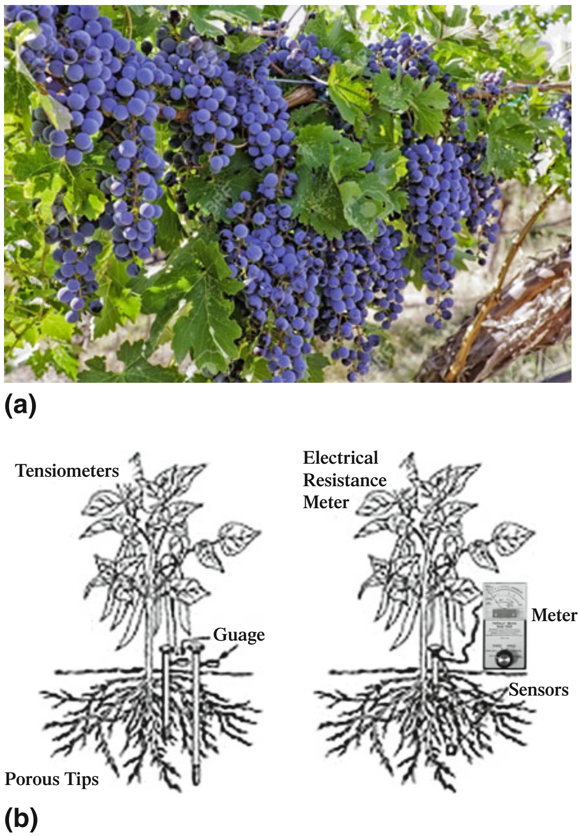


Fig. 2.24 **a** Grape trees field, **b** monitoring of grape trees using SNs and **c** placement of SN to monitor grape tree

Fig. 2.25 Monitoring of impurities in excessive drainage using SNs

Web-enabled cellular phone or PC and can also set the threshold values over Internet or via e-mail or SMS. These parameters are used to control pressure SNs at irrigation manifold, prefilter, and postfilter so as to control of water to be supplied to grape trees to grow better quality grapes. The grape project has been adopted not only in Napa Valley, CA, but also in Australia and many parts of the world.

It is interesting to note that when it rains heavily, the drainage system is commonly inadequate to handle a large volume of water, and overflow is diverted to lakes used for drinking water. In this way, unprocessed and dirty water is mixed in the creek from where drinking water is supplied after appropriate treatment. This may be hazardous to human health, and impurities can be checked if appropriate SNs are deployed to check impurity level as shown in Fig. 2.25. This could be very helpful in maintaining quality of drinking water supply.

2.3.3 Echo System Monitoring Applications

Echo system has become an ideal application for monitoring endangered animals and birds. The SN size can vary from small to large size and can be placed close to each other (1 cm) or far away from each other (up to 100 m). Data from SNs can be collected every ms or once in few days. If you deploy too many SNs, the amount of data collected at BS also grows with SNs and it may be desirable to process and compress data from SNs using signal processing algorithms. Data from SNs to BS are propagated through open airspace, and signal attenuation depends on the terrain and vegetation also affects the signal quality. Therefore, it is desirable to achieve reliable transfer of information in a dynamic WSN unattended for a long time in a harsh environment. To achieve these, high-resolution SNs could be deployed as scare resources.

As illustrated in Fig. 2.26, the idea is to place SNs in the neighborhood of species or embed inside their body to monitor their activities. Here, SNs are placed

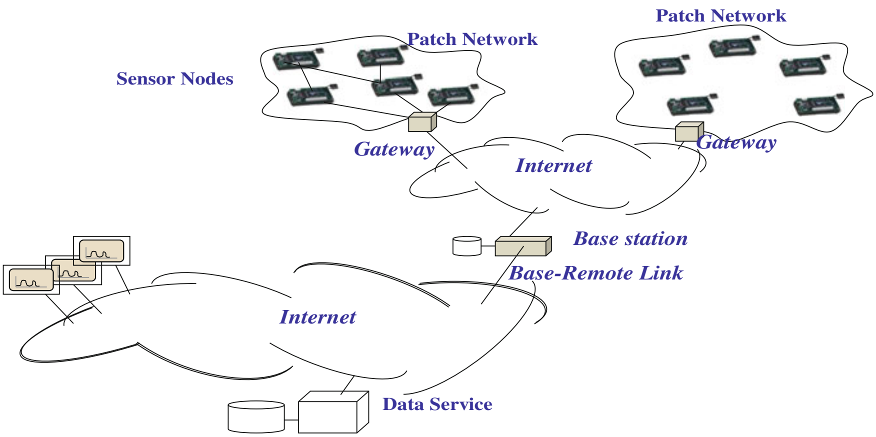


Fig. 2.26 Monitoring the behavior of storm petrel in Grand Duck Island

in the area to be sensed grouped into sensor patches to transmit sensed data to a gateway which is responsible for forwarding the information from the SNs patch to a remote BS through a local transit network. The BS logs the data and replicates the data every 15 min to a database located in Berkeley using a satellite link. Remote users can access the replicated database server in Berkeley, while local users make use of a small PDA-sized device to perform local interactions such as adjusting the sampling rates and power management parameters. Preprocessing is done to minimize data for habitat monitoring applications. A 2-tier network architecture is suggested that consists of micro-nodes and macro-nodes, wherein the micro-nodes perform local filtering and data to significantly reduce the amount of data transmitted to macro-nodes. In August 2002, researchers from the University of California at Berkeley (UCB) and Intel Research Laboratory deployed a mote-based tiered WSN in Great Duck Island (GDI), Maine, to monitor the behavior of storm petrel and similar schemes can be adopted for monitoring other animals in a given area of interest.

A similar approach has been utilized in UMass for monitoring activities of turtles by placing SNs on top of turtles and monitoring temperature and wetness over period of days as given in Fig. 2.27. Another project using SNs in monitoring behavior of animals under different environments by placing sensors at the collar of the zebra. This ecology project [19] investigates the migration of animals (Fig. 2.28) on the long-range basis, noting their interspecies interactions and determining their nightly behavior. There are many projects dealing with other animals.

A project at University of Hawaii at Manoa [20] looked at the issue of why endangered species of plants will grow in one area but not in neighboring areas. Inconspicuous SNs, each consisting of a computer, radio transceiver, and environmental sensors, sometimes including a high-resolution digital camera, were deployed in the Hawaii Volcanoes National Park. The sensed data were relayed back to the Internet with Bluetooth and 802.11b for delivering data packets through

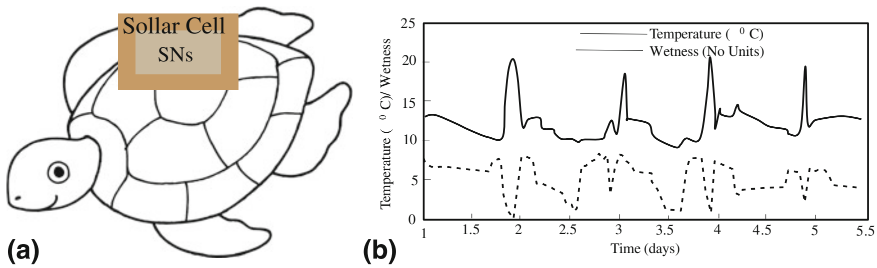


Fig. 2.27 **a** TurtleNet with SNs and **b** parameters of TurtleNet with SNs

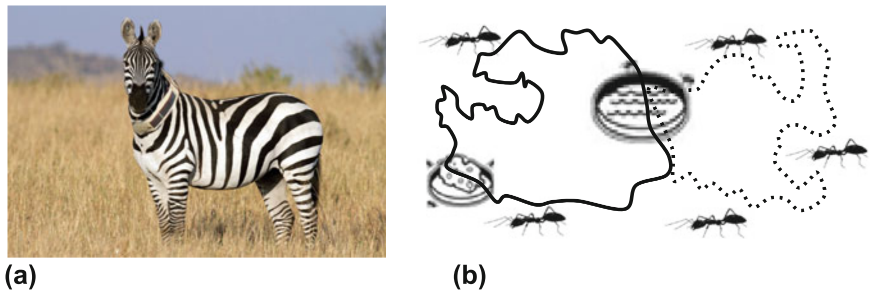


Fig. 2.28 **a** ZebraNet with SNs at Princeton University and **b** simulation of ants' food search process forming two trails

the IP. The placement strategy for the sensor nodes is then investigated, and various topologies of 1-dimensional and 2-dimensional regions such as triangle tile, square tile, hexagon tile, ring, star, and linear are explored. The sensor placement strategy evaluation is based on three goals: resilience to single point of failure, the area of interest to be covered by at least one sensor, and minimum number of nodes. Finally, the choice of placement of SNs depends on sensing and communication ranges and data are being interpreted in the near future.

Detecting structural faults in high-rise buildings in downtown area is a challenging question as interaction between ground motions and structure/foundation response is not well understood [20]. Current seismic network is not spatially dense enough to monitor structure deformation in response to ground motion. In understanding response of buildings and underlying soil to ground shaking, models are developed to predict structure response for earthquake scenarios. It is critical to identify seismic events that cause significant structure shaking, and processing of waveforms is to be done locally that requires a dense structure monitoring system. This work provides field data at sufficient densities to develop predictive models of structure, foundation, soil response, etc. A 17-story steel frame building has been instrumented with 100-node grid of seismometers at 100 m spacing across the UCLA campus and surrounding the building. Projects have explored the use of sensors in monitoring the health of buildings, bridges, and highways [21].

A Bluetooth-based scatternet has been proposed to monitor stress, vibration, temperature, humidity etc., in civil infrastructures. Simulation results are given to justify the effectiveness of their solution by having a set of rectangular Bluetooth-equipped sensor grids to model a portion of bridge span. Fiber optic-based sensors have been proposed for monitoring crack openings in concrete bridge decks of strain and corrosion of the reinforcement in concrete structures. Corrosion of steel bars is measured by using special super glue and angular strain sensors.

Smart small size SNs, equipped with a wireless communication interface, some sensors and an autonomous power supply constitute an embedded WSN has been proposed [22] that can be envisioned in the context of a smart house. The devices interact with other devices inside the house. It is observed that temporal and spatial validity intervals of sensed data are dependent on the validity interval of the data used in the application. The data from various SNs need to be conditioned to get metadata to be used for an event understanding. Another important project dealing with the use of WSNs is smart transportation [23] where poor signal-to-noise ratio is influenced by the traffic, construction, and explosions. Usually, insufficient data are available for large earthquakes, and structure response must be extrapolated from small and moderate size earthquakes.

2.3.4 Biomedical Applications

These are the areas that directly affects human life and for new applications are growing at an unprecedented rate. An initial application appeared in the first edition of the book back in 2000 [24] that suggested use of wireless technology when a patient is being transported to a close-by hospital. The idea is to support the medical personnel with ambulance with needed advice on the treatment of the patient based on ECG and other vital signals besides body temperature and blood pressure by wireless communication. The SNs play a vital role in generating ECG and other signals, and since then, many other biomedical applications have appeared.

Wireless technology facilitates the mobility of doctors, practitioners, and caregivers, and WSN is an important constituent of a wireless system. WSN allows access to patient information at any moment, everywhere, and on real-time basis. Wireless technology improves automatic data gathering through barcode or RFID reading and allows an immediate sharing of patient information and thereby improves the internal communication within the caregiver team and the support staff. This also helps in reducing paper work. A generic health monitoring involves checking of glucose level in blood, heart rate, and the detection of potential cancer, checking for chronic diseases, and a need for artificial retina, and cochlear implants used to provides a sense of sound to a person who is profoundly deaf or severely hard of hearing. Sensors in a hospital involve monitoring of vital signs and record anomalies.

Tele-monitoring involves monitoring of human physiological data, tracking and monitoring of doctors and patients inside a hospital, drug administrator in hospitals.

Sensors for physiological conditions are designed for personal health and general environmental monitoring, and temperature, pressure, humidity, and vibration/position are measured. This can be packaged in a wrist strap to make it a wearable system. Many versions of micro-cluster have been used in variety of military, navy, and marine corporation applications. There are many transducers (sensors) available off-the-shelf such as inertial and gyro systems by companies such as HoneyWell Sensing and Control, Analog Devices, MicroStrain, Memsense, Crossbow, and Empfasis. The structural monitoring systems include vibration sensors supplied by Columbia Research labs, Colibrys, Electro-sensors Inc., and Instrumented Sensor Technology. The accelerometers can be obtained from Tronics Microsystems and STMicroelectronics.

The first application of WSN is a project at USC [25] that utilizes a group of SNs to collect information about skin pigment that is used to determine oxygen intake and white cell count in the blood. This is useful during golden hour of a newborn baby when no one is allowed to insert any needle in baby's body (Fig. 2.29).

Another important invention is the creation of camera pill shown in Fig. 2.30a that could travel through body taking pictures for 6 h, helping diagnose a problem which doctor previously would have found only through surgery. The pill takes images as it is propelled forward by peristalsis. A wireless recorder, worn on a belt, receives the images transmitted by the pill. Movement of the capsule through digestive system is shown in Fig. 2.30b. Through the picture obtained, it is possible to detect Crohn's disease, malabsorption disorders, tumors of the small intestine, vascular disorders, and ulcerative colitis. The main advantage [26] of the camera pill is that it does not require trained staff and the process is relatively quick as no sedation is needed. On a similar line, a capsule has been developed by Philips [27] that could measure body temperature accurately and transmit live data. The pill is small enough to be swallowed with a glass of water, takes 6 h to pass through the body, and transmits temperature to a close by smart phone attached to the belt. This has extensively been used by astronauts and fire fighters.

Fig. 2.29 White cell count and oxygen level determination using SNs

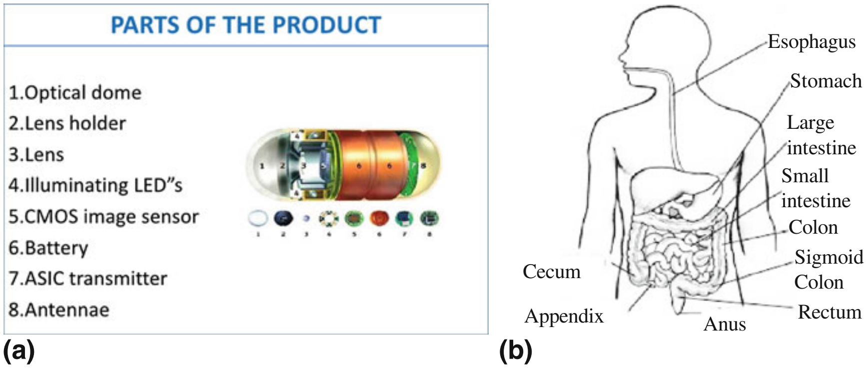


Fig. 2.30 **a** Camera pill or capsule and **b** movement of capsule through the digestive system

In this respect, body area networks (BAN) or wireless body area sensor networks (WBASN) [28] are enabling use of WSNs in many areas of monitoring human health. As a wearable computing, a WBASN has also been suggested to remotely monitor the progress of a physical therapy done at home and an initial prototype has been developed using electroluminescent strips indicating the range of human body's motion [29]. An indoor/outdoor wearable navigation system has been suggested for blind and visually impaired people through vocal interfaces about surrounding environment and changing the mode from indoor to outdoor and vice versa using simple vocal command [30]. A differential GPS receiver has been used to provide accurate location information outdoor while ultrasound position devices are used for indoor coverage. A wearable sensor network that finds environmental information and controls home electric appliances is by a Bluetooth-based network or a large scatternet network. The data throughput and communication delay have also been measured, and battery life is also observed. A thin multi-resolution flat SNs that adopt resolution based on the regions of interest or the information contents have been proposed which placed at a soldier's helmet provides entire scene simultaneously. A recent work allows the development of new vests that could optimally distribute soldiers' load, thereby alleviating discomfort and reducing the fatigue [31]. A recent US patent describes a cortisol sensor to detect level of hormone, indicating stress and fatigue levels of soldiers.

A generic personal BAN server shown in Fig. 2.31 can be implemented on an Internet-enabled PDA or a 3G mobile phone, or a regular laptop or desktop computer. It can communicate with remote upper-level services in hierarchical type architecture. It performs initialization, configuration, and synchronization of WBAN nodes, controls and monitors operation of WBAN nodes, collects readings from physiological SNs, processes and integrates data from the SNs, and securely communicates with remote healthcare provider. Specialized transducers and SNs are being developed to measure human body characterizing parameters in a non-invasive way to predict efficiently and accurately. Numerous proposals have recently been introduced in biomedical area, and the use of a micro-SNs array has

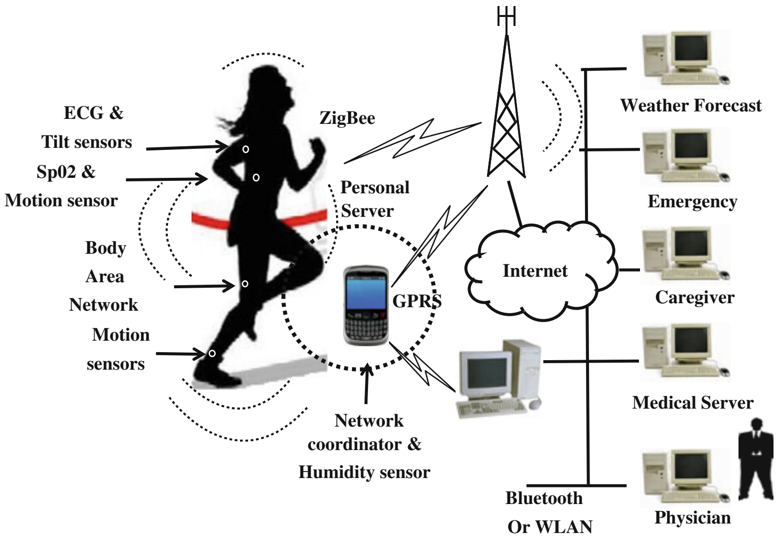
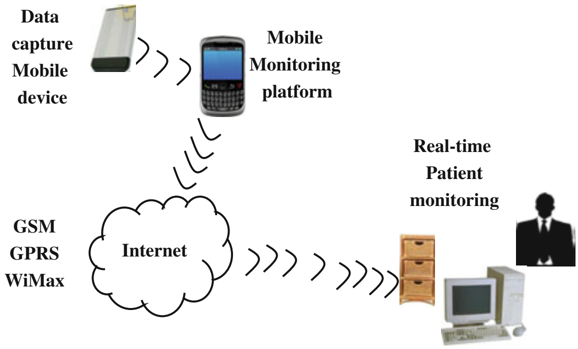


Fig. 2.31 A generic BAN or WBASN illustrated

Fig. 2.32 A generic remote monitoring



been suggested for artificial retina, glucose level monitoring, organ monitors, cancer detectors, and general health monitoring. Such remote monitoring of patients (Fig. 2.32) reduces the number of patients transferred to urban hospitals, allows tele-consultation and tele-diagnosis including the option of obtaining opinions of distant experts, facilitates the patient remote monitoring with instantaneous data transmission for analyses and follow-ups, allows remote handling of medical equipment (tele-surgery) and direct action of the expert on the patient, and improves coordination of first-responders workers during in the event of catastrophes or emergency cases. A detailed design of a wearable sensor vest has been introduced that measures, records, and transmits physical characteristics such as heart rate, temperature, and movement. This could also be very useful in assisted living of elderly and handicapped people or keeping track of endangered species.

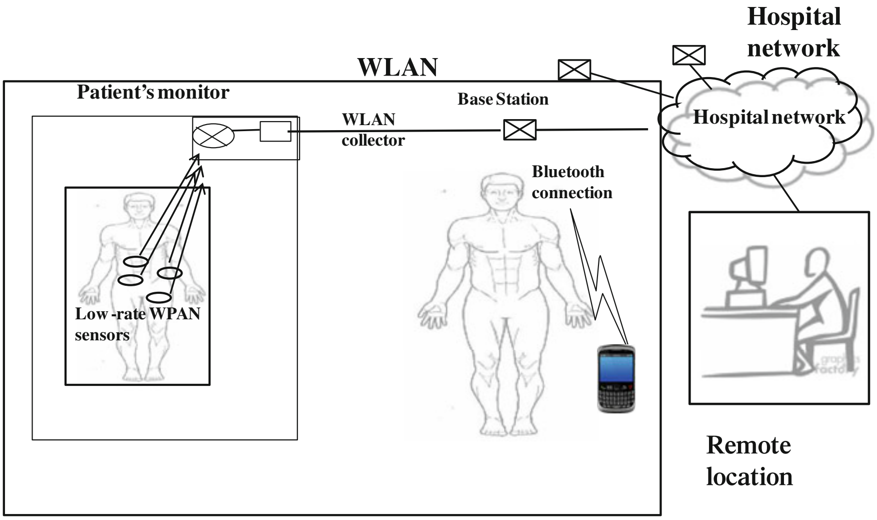


Fig. 2.33 Patient's room monitoring

The remote medical image repositories communicate through different types of network connections with the central computing site that coordinates the distributed analysis. Efforts have also been made to detect human daily life pattern by measuring physiological, behavioral, and environmental parameters using SNs such as accelerometers, audio sensors, and electrical signals and gathering data from SNs. Refining them by segmentation and integrating and finally interpreting the result as occurrence of an event detection could be useful in monitoring a given area without any human intervention.

Another example of use of WSN is to display medical information collected by SNs on the patient's body (WPAN) on a bedside monitor (Fig. 2.33) [32]. Such information is also transmitted to another location for remote monitoring, e.g., a nurses' station. In case of emergency, when the patient is moved from his/her room to the intensive care unit, these communications need to be maintained.

There is need for intercommunication among medical devices and clinical information systems. This has been accomplished with a number of medical products. Infusion pumps and ventilators commonly have RS-232 ports, and these devices can communicate with many physiological monitoring instruments. Products to link medical equipment and personal communication devices exist as well. However, virtually all of these are specialized applications—custom interfaces unique to the two devices being linked. To address the medical device plug-and-play interoperability problem, a single communication standard is needed.

Digital Imaging and Communications in Medicine (DICOM) standard [33] is created by the National Electrical Manufacturers Association (NEMA) to aid the distribution and viewing of medical images. DICOM is the most common standard for receiving scans from a hospital. A single DICOM file contains both a header (which stores information about the patient's name, the type of scan, image dimensions, etc.), and all of the image data. DICOM images can be compressed both by the common lossy JPEG compression scheme and by a lossless JPEG scheme. A single 500-slice MRI can produce a 68 MB image file and is useful in monitoring patients undergoing physical rehabilitation such as after a stroke.

The *Pluto* custom wearable designed at Harvard [34] incorporates the TI MSP430 microprocessor and ChipCon CC 2420 radio. Pluto can run continuously for almost 5 h on a rechargeable 120 mAh lithium battery. It has a Mini-B USB connector for programming and to recharge the battery. The software runs under TinyOS. Pulse oximeter [35] employs a noninvasive technology used to measure the heart rate (HR) and blood oxygen saturation (SpO_2). The technology projects infrared and near-infrared light through blood vessels near the skin. By detecting the amount of light absorbed by hemoglobin in the blood at two different wavelengths, the level of oxygen can be measured. The heart rate can also be measured since blood vessels contract and expand with the patient's pulse which affects the pattern of light absorbed over time. Computation of HR and SpO_2 from the light transmission waveforms can be performed using standard DSP algorithms.

The most common type of ECG involves the connection of several leads to a patient's chest, arms, and leg via adhesive foam pads (Fig. 2.34a). The device records a short sampling, e.g., 30s, of the heart's electric activity between different pairs of electrodes. When there is need to detect intermittent cardiac conditions, a continuous ECG measurement is used. This involves the use of a two- or three-electrode ECG to evaluate the patient's cardiac activity for an extended period. The ECG signal shown in Fig. 2.34b is small (~ 1 mV peak to peak). Before the signal is digitized, it has to be amplified (gain >1000) using low-noise amplifiers and filtered to remove noise. The P wave is associated with the contractions of the atria (the two chambers in the heart that receive blood from outside). The QRS is a series of waves associated with ventricular contractions (the ventricles are the two major pumping chambers in the heart). The T and U waves follow the ventricular contractions.

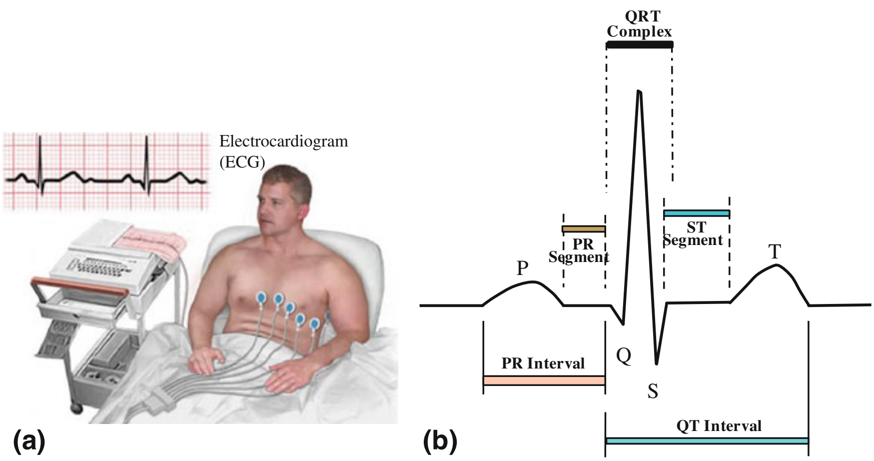


Fig. 2.34 **a** ECG test of a patient and **b** ECG pattern

IMEC [36] has recently developed a wireless, flexible, stretchable ECG patch for continuous cardiac monitoring. Placed on the arm or on the leg, the same system can be used to monitor muscle activity (EMG). The patch includes a microprocessor, a 2.4 GHz radio link, and a miniaturized rechargeable lithium-ion battery. The total size is 60×20 mm^2, and data are sampled between 250 and 1000 Hz and continuously transmitted. The battery has a capacity of 175 mAh which provides for continuous monitoring from one day to several days.

2.3.5 Other Applications

Societal-scale sensor networks can greatly improve the efficiency of energy provision chain, which consists of three components: the energy generation, distribution, and consumption infrastructure. It has been reported that 1% load reduction due to demand response can lead to a 10% reduction in wholesale prices, while a 5% load response can cut the wholesale price in half. Many other applications of WSNs are possible, and the list keeps growing. SNs are used extensively in various assembly line plants, and architecture depends on the application. Nowadays, we witness more and more electronic appliances in an average household. Therefore, great commercial opportunities exist for home automation and smart home/office environment cooling, heating, and humidity control. An example application is described where a "Smart Kindergarten" consisting of a sensor-based wireless network for early childhood education is discussed. It is envisioned that this interaction-based instruction method will soon replace the traditional stimulus-responses-based methods. In addition, emission of CO_2 from coal power plant can be minimized if efficient ways of distributing energy can be devised.

A project was undertaken at the University of Cincinnati to monitor emission of CO from vehicles around the campus [37]. The sensor boards were placed at 20′ height for protection purpose, and solar cells were used to charge the batteries. In another project, reflective markers are used to monitor human activities. Multiple cameras are employed that digitize different views of performance. An unusual application of SNs at University of Cincinnati has been to measure dancers' movements and accordingly generate music. A total of 23 SNs were used to measure movements of dancers having SNs attached to their hands [38]. Four different shows were conducted at the UC campus.

Another device that can be used as a SN is RFID and RF reader pair as they facilitate management of associated assets (wheel chairs, scanners, ambulatory equipment, etc.), improves patient localization and helps caregivers to provide services without delays, enhances the process of drug administration (identification, distribution, localization, returns and disposal), and facilitates the automatic data capture and the follow-up of blood and biological samples. Low-power mobile SNs are being developed that can move around to provide mobilityto SNs, and their future is yet to be established.

2.4 Conclusions

The WSN has been observed to be very useful in unattended monitoring of surrounding area 24 × 7 and is expected to grow at an unprecedented rate. There is no need to wait for any such confirmation as it has now become obvious. The challenge for the readers and researchers is to come up with unique applications that could prove to be overwhelming for the mankind.

2.5 Questions

Q.2.1. What are the differences and similarities between sensors and transducers?
Q.2.2. How do you select transducers for a given application?
Q.2.3. How do you determine the frequency of data to be collected by a sensor?
Q.2.4. How long you can keep the sensors in sleep mode?
Q.2.5. Can you use SNs for two different applications? Explain clearly.
Q.2.6. Can you think of two new applications of WSNs?
Q.2.7. Why are SNs appropriate for unusual applications?
Q.2.8. Why do you need synchronization among SNs?
Q.2.9. SNs can be hardwired together. Then, what is the need for having wireless connectivity among SNs?
Q.2.10. Multiple communication paths are available between SNs and BS. How do you select a path?
Q.2.11. A SN contains many functional components. Can you compare their cost?
Q.2.12. Do you include beacon signals with transceiver of each SN? Explain.

References

1. https://www.en.wikipedia.org/wiki/Wireless_sensor_network.
2. http://www.silabs.com/Support%20Documents/TechnicalDocs/evolution-of-wireless-sensor-networks.pdf.
3. http://www.xbow.com/Products.
4. https://en.wikipedia.org/wiki/Crossbow_Technology.
5. https://www.s-media-cache-ak0.pinimg.com/736x/f8/c6/9a/f8c69abf3018f5534997ec209a1c5b90.jpg.
6. https://www.pinterest.com/jmachaas/military-gear/.
7. https://www.google.co.in/imgres?imgurl=http://www.x20.org/wp-content/uploads/2014/04/thermal1-1.jpg&imgrefurl=http://www.x20.org/product/x27-clip-on-thermal-rifle-scope/&h=200&w=299&tbnid=IfZusWRzpHWOQM:&docid=1RKlWBCU7VSMiM&ei=f3CLVoiJOpCouwTv9Z_4Cw&tbm=isch&ved=0ahUKEwjIxPHqkpLKAhUQ1I4KHe_6B784ZBAzCAgoBTAF.

8. Pengda Cheng, Hongwei Zhu, Baochang Zhong, and Daozeng Wang ," Transport mechanisms of contaminants released from fine sediment in rivers," Acta Mechanica Sinica, vol. 31, no. 6, pp. 791–798, Dec. 2015.
9. http://www2.hawaii.edu/~esb/prof/pub/ijhpca02.html.
10. http://richardsonblog.dallasnews.com/2015/11/richardson-reports-two-major-wastewater-overflows.html/.
11. http://www.strategicstudiesinstitute.army.mil/pdffiles/ksil499.pdf.
12. http://www.ducks.org/hunting?id=2262&poe=RRGPPCAD&utm_source=google&utm_medium=cpc&utm_term=duck&utm_campaign=paid.
13. http://www.bobdillon33blog.com.
14. http://www.calit2.net/newsroom/article.php?id=214.
15. Mary M. Rowland Christina D. Vojta (editors), "A Technical Guide for Monitoring Wildlife Habitat," United States Department of Agriculture Forest Service Gen. Tech. Report WO-89 October 2013.
16. http://www.x20.org/product/l3-lwts-thermal-rifle-scope/.
17. http://www.slideshare.net/nidhin999/pill-camera-13267328.
18. http://www.x20.org/product/x27-clip-on-thermal-rifle-scope/.
19. http://www.princeton.edu/~equids/images/zebranet.pdf.
20. http://www2.hawaii.edu/~esb/pods/overview.html.
21. http://www.telfor.rs/telfor2002/radovi/4-19.pdf.
22. http://www.ee.ktu.lt/journal/2009/6/04__ISSN_1392-1215_Smart%20Dust%20Motes%20in%20Ubiquitous%20Computing%20Scenarios.pdf.
23. http://disalw3.epfl.ch/teaching/swarm_intelligence/ay_2006-07/exercises/SI_06-07_labhwk09_tutorial.pdf.
24. Dharma P. Agrawal and Q. A. Zeng, Introduction to Wireless and Mobile Systems, 4th edition, Cengage Learning, 650 pages, 2016.
25. https://www.marwadieducation.edu.in/UploadPdf/News/635836948227633617_TECHANZIA_ACADEMIC_YEAR_2014-2015.pdf.
26. http://www.nhs.uk/news/2013/01January/Pages/Pill-size-camera-may-make-cancer-diagnosis-easier.aspx.
27. http://www.bmedical.com.au/shop/activity-heat-research/core-body-temperature.htm.
28. https://www.en.wikipedia.org/wiki/Body_area_network.
29. http://www.instructables.com/id/PIR-Motion-Sensor-Tutorial/.
30. Nadia Kanwal, Erkan Bostanci, Keith Currie, and Adrian F. Clark, "A Navigation System for the Visually Impaired: A Fusion of Vision and Depth Sensor," Applied Bionics and Biomechanics, vol. 2015, pp. 1–16, 2015.
31. http://www.qualitydigest.com/inside/twitter-ed/pressure-mapping-body-armor-takes-load-soldiers.html.
32. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4208221/.
33. http://www.medicalconnections.co.uk/DicomObjects.
34. http://www.eecs.harvard.edu/~mdw/talks/ucsd-codeblue.pdf.
35. http://www.nxp.com/files/32bit/doc/app_note/AN4327.pdf?tid=AMdlDR.
36. http://www2.imec.be/be_en/research/wearable-health-monitoring.html.
37. Demin Wang, Dharma P. Agrawal, Wassana Toruksa, Chaichana Chaiwatpongsakorn, Mingming Lu and Tim C. Keener, "Monitoring Ambient Air Quality with Carbon Monoxide Sensor based Wireless Network," Communications of the ACM, vol. 53, no. 5, May 2010, pp. 138–141.
38. Mara Helmuth, Jung Hyun Jun, Talmai Oliveira, Vaibhav Pandit and Dharma Agrawal, "Wireless Sensor Networks and Percussion Tracking for Ocean Drum Processing," International Computer Music Conference (ICMC) 2012, Ljubljana Slovenia, September 9–15, 2012.