

show that LKE requires low storage overhead in worker nodes and provides resilience against attacks.

TinySec: TinySec uses link-layer security architecture to guarantee message authenticity, integrity, and confidentiality. Message authenticity is the ability to detect false messages and reject them. Similar to message authenticity is message integrity, the detection of a tampered message. TinySec provides message authenticity and integrity by including a message authentication code (MAC) with each packet. The MAC is a cryptographically secure checksum of a message. The MAC is computed using a share secret key between the sender and the receiver. The sender computes the MAC of a packet using its secret key. The packet and the MAC are sent to the receiver. The receiver sharing the same secret key recomputes the MAC value of the message and compares it against the MAC received. If they are the same, the packet is accepted, else it is dropped. If an adversary alters the message during transit, he/she would not be able to recompute the MAC value. Hence, the receiver will reject the message. Message confidentiality keeps information safe from unauthorized members. In this case, the encryption mechanism should achieve semantic security. Semantic security implies that adversaries cannot learn any property of the message even if they have obtained the message. TinySec achieves semantic security by using a unique initialization vector (IV) as a side input to the encryption algorithm. The purpose of IV is to add variation to the encryption process when there is little variation in the message set. The receiver must use IV to decrypt messages. Using IV, adversaries will not be able to determine the contents of messages simply by looking at its encryption.

TinySec supports authentication encryption (TinySecAE) and authentication only (TinySec-Auth) modes of operation. With TinySec-AE, the data payload is encrypted and the packet is authenticated using the MAC. With TinySecAuth, only authentication is performed on the packet with a MAC. TinySec utilizes cipher block chaining (CBC) for data encryption. CBC is used together with non-repeating IV to provide strong confidentiality guarantees.

4. Open Research Issues

Provisioning, management, and control services are needed to sustain network connectivity and maintain operations. Provisioning services such as localization and coverage can improve network performance. Efficient algorithms can reduce the cost of localization while sensor nodes are able to self-organize and identify themselves in some spatially coordinated system. Localization has been studied extensively to minimize energy, cost, and localization errors. The problem of energy conservation while maintaining a desired coverage has also been studied. Coverage efficiency depends on the number of active nodes. The more active nodes there are in the network, the higher is the degree of coverage. Coverage protocols should meet different levels of coverage requirements and be energy efficient. Existing solutions have investigated different degrees of coverage along with network connectivity. Future research and development should

continue to focus on optimizing coverage for better energy conservation.

Management and control services include synchronization, data aggregation and compression, security, and cross-layer optimization. In a dense WSN, there is a need for network-wide time synchronization. Time synchronization eliminates event collision, energy wastage, and non-uniform updates. Proposed time synchronization protocols aim to synchronize local node clocks in the network and reduce energy overhead. Continuing research should focus on minimizing uncertainty errors over long periods of time and dealing with precision.

With large amounts of data generated over time, the cost of transferring all of the sensed data to the base station is expensive. Data compression and aggregation techniques aid in reducing the amount of data to be transferred. The development of various compression and aggregation scheme for event-based or continuous data collection network is a challenging research topic. For security monitoring in a WSN, secure protocols have to monitor, detect, and respond to attacks with uninterrupted service. Many proposed secure protocols are for the network layer and data-link layer. Malicious attacks can occur at any layer in the protocol stack. Secure monitoring for different layers of the protocol stack need to be explored. Cross-layer secure monitoring is another challenging area for research.

5. Sensor Networks Applications

Sensor networks may consist of many different types of sensors such as seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic and radar, which are able to monitor a wide variety of ambient conditions that include the following [3]:

- Temperature,
- Humidity,
- Vehicular movement,
- Lightning condition,
- Pressure,
- Soil makeup,
- Noise levels,
- The presence or absence of certain kinds of objects,
- Mechanical stress levels on attached objects, and
- The current characteristics such as speed, direction, and size of an object.

Sensor nodes can be used for continuous sensing, event detection, event ID, location sensing, and local control of actuators. The concepts of micro-sensing and wireless connection of these nodes promise many new application areas. We categorize the applications into military, environment, health, home and other commercial areas. It is possible to expand this classification with more categories such as space exploration, chemical processing and disaster relief.

A. Military Applications

Wireless sensor networks can be an integral part of military command, control, communications, computing, intelligence, surveillance, reconnaissance and targeting (C4ISRT) systems. The rapid deployment, self-organization and fault tolerance characteristics of sensor networks make them a very promising sensing technique for military C4ISRT. Since sensor networks are based on the dense deployment of disposable and low-cost sensor nodes, destruction of some nodes by hostile actions does not affect a military operation as much as the destruction of a traditional sensor, which makes sensor networks concept a better approach for battlefields. Some of the military applications of sensor networks are monitoring friendly forces, equipment and ammunition; battlefield surveillance; reconnaissance of opposing forces and terrain; targeting; battle damage assessment; and nuclear, biological and chemical (NBC) attack detection and reconnaissance.

Monitoring friendly forces, equipment and ammunition: Leaders and commanders can constantly monitor the status of friendly troops, the condition and the availability of the equipment and the ammunition in a battlefield by the use of sensor networks. Every troop, vehicle, equipment and critical ammunition can be attached with small sensors that report the status. These reports are gathered in sink nodes and sent to the troop leaders. The data can also be forwarded to the upper levels of the command hierarchy while being aggregated with the data from other units at each level.

Battlefield surveillance: Critical terrains, approach routes, paths and straits can be rapidly covered with sensor networks and closely watched for the activities of the opposing forces. As the operations evolve and new operational plans are prepared, new sensor networks can be deployed anytime for battlefield surveillance.

Reconnaissance of opposing forces and terrain: Sensor networks can be deployed in critical terrains, and some valuable, detailed, and timely intelligence about the opposing forces and terrain can be gathered within minutes before the opposing forces can intercept them.

Targeting: Sensor networks can be incorporated into guidance systems of the intelligent ammunition. **Battle damage assessment:** Just before or after attacks, sensor networks can be deployed in the target area to gather the battle damage assessment data.

Nuclear, biological and chemical attack detection and reconnaissance: In chemical and biological warfare, being close to ground zero is important for timely and accurate detection of the agents. Sensor networks deployed in the friendly region and used as a chemical or biological warning system can provide the friendly forces with critical reaction time, which drops casualties drastically. We can also use sensor networks for detailed reconnaissance after an NBC attack is detected. For instance, we can make a nuclear reconnaissance without exposing a recon team to nuclear radiation.

B. Environmental Applications

Some environmental applications of sensor networks include tracking the movements of birds, small animals, and insects; monitoring environmental conditions that affect crops and livestock; irrigation; macro instruments for large-scale Earth monitoring and planetary exploration; chemical/biological detection; precision agriculture; biological, Earth, and environmental monitoring in marine, soil, and atmospheric contexts; forest fire detection; meteorological or geophysical research; flood detection; bio-complexity mapping of the environment; and pollution study [1].

Forest fire detection: Since sensor nodes may be strategically, randomly, and densely deployed in a forest, sensor nodes can relay the exact origin of the fire to the end users before the fire is spread uncontrollable. Millions of sensor nodes can be deployed and integrated using radio frequencies/ optical systems. Also, they may be equipped with effective power scavenging methods, such as solar cells, because the sensors may be left unattended for months and even years. The sensor nodes will collaborate with each other to perform distributed sensing and overcome obstacles, such as trees and rocks that block wired sensors' line of sight.

Bio complexity mapping of the environment: A bio complexity mapping of the environment requires sophisticated approaches to integrate information across temporal and spatial scales. The advances of technology in the remote sensing and automated data collection have enabled higher spatial, spectral, and temporal resolution at a geometrically declining cost per unit area. Along with these advances, the sensor nodes also have the ability to connect with the Internet, which allows remote users to control, monitor and observe the bio complexity of the environment.

Although satellite and airborne sensors are useful in observing large biodiversity, e.g., spatial complexity of dominant plant species, they are not fine grain enough to observe small size biodiversity, which makes up most of the biodiversity in an ecosystem. As a result, there is a need for ground level deployment of wireless sensor nodes to observe the bio complexity [17]. One example of bio complexity mapping of the environment is done at the James Reserve in Southern California. Three monitoring grids with each having 25– 100 sensor nodes will be implemented for fixed view multimedia and environmental sensor data loggers.

Flood detection [6]: An example of flood detection is the ALERT system [2] deployed in the US. Several types of sensors deployed in the ALERT system are rainfall, water level and weather sensors. These sensors supply information to the centralized database system in a pre-defined way. Research projects, such as the COUGAR Device Database Project at Cornell University [6] and the Data Space project at Rutgers, are investigating distributed approaches in interacting with sensor nodes in the sensor field to provide snapshot and long-running queries.

Precision Agriculture: Some of the benefits is the ability to monitor the pesticides level in the drinking water, the level of soil erosion, and the level of air pollution in real time.

C. Health Applications

Some of the health applications for sensor networks are providing interfaces for the disabled; integrated patient monitoring; diagnostics; drug administration in hospitals; monitoring the movements and internal processes of insects or other small animals; Telemonitoring of human physiological data; and tracking and monitoring doctors and patients inside a hospital [19].

Telemonitoring of human physiological data: The physiological data collected by the sensor networks can be stored for a long period of time, and can be used for medical exploration. The installed sensor networks can also monitor and detect elderly people's behaviour, e.g., a fall. These small sensor nodes allow the subject a greater freedom of movement and allow doctors to identify pre-defined symptoms earlier. Also, they facilitate a higher quality of life for the subjects compared to the treatment centers. A "Health Smart Home" is designed in the Faculty of Medicine in Grenoble—France to validate the feasibility of such system.

Tracking and monitoring doctors and patients inside a hospital: Each patient has small and light weight sensor nodes attached to them. Each sensor node has its specific task. For example, one sensor node may be detecting the heart rate while another is detecting the blood pressure. Doctors may also carry a sensor node, which allows other doctors to locate them within the hospital. Drug administration in hospitals: If sensor nodes can be attached to medications, the chance of getting and prescribing the wrong medication to patients can be minimized. Because, patients will have sensor nodes that identify their allergies and required medications.

D. Home Applications

Home automation: As technology advances, smart sensor nodes and actuators can be buried in appliances, such as vacuum cleaners, micro-wave ovens, refrigerators, and VCRs [4]. These sensor nodes inside the domestic devices can interact with each other and with the external network via the Internet or Satellite. They allow end users to manage home devices locally and remotely more easily. Smart environment: The design of smart environment can have two different perspectives, i.e., human-centered and technology-centered. For human-centered, a smart environment has to adapt to the needs of the end users in terms of input/output capabilities. For technology-centered, new hardware technologies, networking solutions, and middleware services have to be developed. A scenario of how sensor nodes can be used to create a smart environment. The sensor nodes can be embedded into furniture and appliances, and they can communicate with each other and the room server. The room server can also communicate with other room servers to learn about the services they offered, e.g., printing, scanning, and faxing. These room servers and sensor nodes can be integrated with

existing embedded devices to become self-organizing, self-regulated, and adaptive systems based on control theory models. Another example of smart environment is the "Residential Laboratory" at Georgia Institute of Technology. The computing and sensing in this environment has to be reliable, persistent, and transparent.

E. Other Commercial Applications

Some of the commercial applications are monitoring material fatigue; building virtual keyboards; managing inventory; monitoring product quality; constructing smart office spaces; environmental control in office buildings; robot control and guidance in automatic manufacturing environments; interactive toys; interactive museums; factory process control and automation; monitoring disaster area; smart structures with sensor nodes embedded inside; machine diagnosis; transportation; factory instrumentation; local control of actuators; detecting and monitoring car thefts; vehicle tracking and detection; and instrumentation of semiconductor processing chambers, rotating machinery, wind tunnels, and anechoic chambers.

Environmental control in office buildings: The air conditioning and heat of most buildings are centrally controlled. Therefore, the temperature inside a room can vary by few degrees; one side might be warmer than the other because there is only one control in the room and the air flow from the central system is not evenly distributed. A distributed wireless sensor network system can be installed to control the air flow and temperature in different parts of the room. It is estimated that such distributed technology can reduce energy consumption by two quadrillion British Thermal Units (BTUs) in the US, which amounts to saving of \$55 billion per year and reducing 35 million metric tons of carbon emissions [12].

Interactive museums: In the future, children will be able to interact with objects in museums to learn more about them. These objects will be able to respond to their touch and speech. Also, children can participate in real time cause-and-effect experiments, which can teach them about science and environment. In addition, the wireless sensor networks can provide paging and localization inside the museum. An example of such museums is the San Francisco Exploratorium that features a combination of data measurements and cause and-effect experiments.

Detecting and monitoring car thefts: Sensor nodes are being deployed to detect and identify threats within a geographic region and report these threats to remote end users by the Internet for analysis. Managing inventory control: Each item in a warehouse may have a sensor node attached. The end users can find out the exact location of the item and tally the number of items in the same category. If the end users want to insert new inventories, all the users need to do is to attach the appropriate sensor nodes to the inventories. The end users can track and locate where the inventories are at all times.

Vehicle tracking and detection: There are two approaches to track and detect the vehicle: first, the line of bearing of the vehicle is determined locally within the clusters and then it

is forwarded to the base station, and second, the raw data collected by the sensor nodes are forwarded to the base station to determine the location of the vehicle.

6. Conclusion

In this paper, we have surveyed issues on Wireless Sensor Network and its five different categories: (1) internal platform and underlying operating system, (2) communication protocol stack, and (3) network security, security issues. We have studied and compared different application on WSN. The security issues are analysed. Moreover, we have highlighted possible improvements and research in each area. There are still many issues to be resolved around WSN applications such as communication architectures, security, and management. By resolving these issues, we can close the gap between technology and application

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