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A Survey on Wireless Networks: Classifications, Applications and Research Challenges

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***Abstract:* A wireless sensor network is a group of specialized transducers with a communications infrastructure for monitoring and recoding conditions at diverse locations.Wireless technology over the wired technologies like network security, the increased amount of mobility, enables BYOD, the public WI-FI zones.Military application, industrial process monitoring, health care application, wireless SCADA, photo credits, WSN's for water quality**

***Keywords:* WLAN's; WPAN's; MIMO; AD HOC NETWORK; ISM;WSN;CR;CRN's; WRAN; SNR; WIRELESS SEADA; GPRS; SKE; MAC; PKC; DRS; CRISIS; SOA; DS's; HCI.**

I. Wireless Sensor Networks

A wireless network is a computer network that uses wireless data connection between networks nodes. Wireless networking is a method by which homes, telecommunication networks and business installations avoid the costly process of introducing cables into a building, or as a connection between various equipment locations. Wireless telecommunications networks are generally implemented and administered using radio communication. This implementation takes place at the physical level of the OSI model network structure.

Example of wireless networks includes cell phone networks, wireless local area networks (WLANs), wireless sensor networks, satellite communication networks, and terrestrial microwave networks.

A. Types of Wireless Connections

a) Wireless PAN

Wireless personal area networks (WPANs). Internet devices within a relatively small area, that is generally within a person's reach. For example, both Bluetooth radio and invisible infrared light provides a WPAN for interconnecting a headset to a laptop. Zig bee also supports WPAN applications. Wi -fi PANs are becoming commonplace as equipment designers start to integrate Wi -fi into a variety of consumer electronic devices. Intel" My Wi-Fi" and windows 7 "virtual Wi-Fi "capabilities have made Wi-Fi PANs simpler and easier to set up and configure.

b) Wireless LAN

A wireless local area network (WLAN) links two or more devices over a short distance using a wireless distribution method, usually providing a connection through an access point for internet access. The use of spread-spectrum or OFDM technologies may allow user to move around within a local coverage area, and still remain connected to the network.

Products using the IEEE802.11 WLAN standards are marketed under the Wi-Fi brand name. fixed wireless technology implements point-to-point links between computers or networks at two distant locations, often using dedicated microwave or modulated laser light beams over line of sight paths. It is often used in cities to connect networks in two or more buildings without installing a wired link.

c) Wireless AD HOC Network

A wireless ad hoc network, also known as a wireless mesh network or Mobile AD HOC network (manet)is a wireless network made up of radio nodes organized in a mesh Topology. Each node forwards messages on behalf of the other nodes and each node performs routing. AD HOC networks can "self – heal", automatically re - routing around a node that as lost power. Various network layer protocols are needed to realize AD HOC Mobile networks, such as distance sequenced distance vector routing, associativity-based routing, AD HOC on – demand distance vector routing, and dynamic source routing.

d) Wireless MAN

Wireless metropolitan area networks are a type of wireless network that connects several wireless LANs.

WIMAX wide area networks are wireless networks that typically cover large areas, such as between neighboring towns and cities, or city and suburb. These networks can be used to connect branch office of business or as a public internet accesssystem. The wireless connection between access points are usually point to point microwave links using parabolic dishes on the GHz band, rather than Omni direction antennas used with smaller networks. A typical system contains base station gate ways, access points and wireless.

II. Wireless Communications

In recent decades, the market for wireless devices and networks has boosted an unprecedented growth. This growth has led to numerous wireless services and applications. Consequently, regulatory agencies in different countries thus allocate (licensed) chunks of spectrum to different wireless services. For instance, the radio spectrum allocated for different applications is shown in Figure.1. These emerging and relentless growths of wireless networks have increased the demand for spectrum. To meet the rising demand, effective utilization of spectrum is the goal of the following technologies:

Multiple-input multiple-output(MIMO) communications: MIMO systems allow higher data throughput without additional spectrum usage by spreading the same total transmit power over the antennas, which improves spectral efficiency. For example, IEEE 802.11n (Wi-Fi) uses MIMO to achieve the maximum data rate up to 600Mbps at 2.4GHz (20)Different MIMO systems include single-user and multi-user MIMO. For a single-user MIMO network with n T. 1/ transmit and n R. 1/ receive antennas, the capacity of a single link increases linearly with min.n T ;n R/. This increase also motivates a multi-user MIMO network which achieves the similar capacity scaling when an access point with n T transmit antennas communicates with n R users [19]. Larger diversity gains can be achieved when each user has multiple antennas. Multi-user MIMO will be implemented in IEEE 802.11ac (in early 2014) which enables multi-station wireless local area network (WLAN) with throughput of at least 1 G bps [20]. In addition, massive MIMO using large-scale antenna arrays is capable of shrinking the cell size and reducing the transmit power and overhead for channel training (if channel reciprocity is exploited) [5]

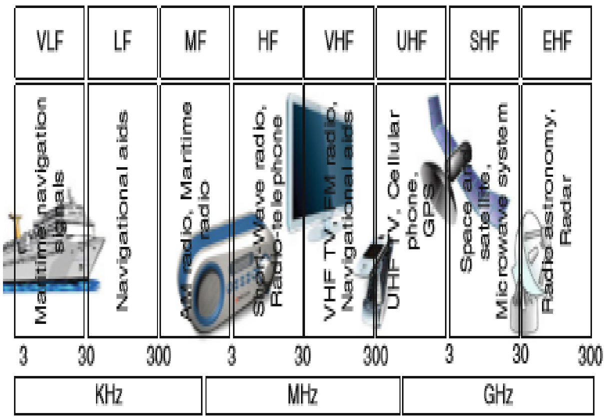

Fig 1. Radio spectrum allocated for wireless communication.

This successful application considerably promoted the development of early-phase WSN in the military area, and brought birth to the navy cooperative engagement system, remote battlefield sensor system and so on [7]. It also played a significant role in enhancing battlefield monitoring and the combating reaction capability. However, as the study on WSNs develops, researchers discover the huge commercial values of WSNs and gradually employ them into civil domains. Business Week listed WSN among the 21 most influential technologies in the twenty-first century in 1999, and the US journal Technology Review also rated WSN as the top 1 of ten emerging technologies to impose profound influences on future human life in 2003. Since then, countries across the world have increased their inputs in the research and industrial application of WSN, making it the hottest research area for academic and industry. In view of the characteristics of sensor nodes and user demands for WSN applications, the majority of commercial sensor nodes remain to develop for smaller size, lower cost and power consumption and so on. Short-range and low-power communication protocols like ZigBee operating in the unlicensed spectrum turn to be suitable communication technologies for sensor nodes. These protocols can effectivelyreducethecostofnetworkdeploymentandincreasetheenergyefficiency of sensor nodes, thus they are wildly adopted by most WSN applications. However, due to the explosion of wireless services and applications, the spectrum for wireless communication becomes a type of scarce resources. To avoid huge expense of using licensed spectrum, most newly-arisen wireless services, including Wi-Fi, Ad Hoc networks, Bluetooth, etc., all operate on the unlicensed spectrum, especially the Industrial, Scientific, and Medical, (ISM) spectrum bands. But, the problem is that the rapid growth of wireless services makes the unlicensed spectrum increasingly crowded, resulting in unavoidable interferences to WSN applications working on the same spectrum bands. Such inter-network interferences caused by spectrum scarcity are significantly uncontrollable to WSNs, greatly degrading the network performances of WSNs. Table 1 shows some working frequencies of typical sensor nodes as well as some overlapping wireless services.

Table 1. Frequency ranges

VLF	Maritime navigation signals
LF	Navigational aids
MF	AM radio, Maritime radio
HF	Short –wave radio, radio – telephone
VHF	VH TV,FM radio navigational aids
TV	cellular phone, GPS
SHF	Space and satellite, microwave system
EHF	KHz MHz 3 30 300 3 30 300 3 30

A. *Wireless Sensor Networks*

With the fast development of sensor, wireless communication and micro-electronics technologies, WSN that integrates sensing, computing and communicating technologies has emerged as a promising networking solution to revolutionize the field of information sensing and collection. Benefited by the features of self-organization, distributed operation, low cost, and low-power, e t c .WSN also attracts significant research attention from the academic during the past decade . A typical WSN consists of multiple sensor nodes deployed in an interested area for information sensing, converting, processing and transmission.

These distributed sensors no descan sense and collect the environmental data within certain in range(such as pictures, temperature, humidity, etc.) before sending it to the sink via multi hop data transmission. After simple data aggregation and processing, the sink will subsequently transmit the aggregated sensed information to the remote data center via an access point for specific applications. With the low-cost and self-organized WSNs, humans are enabled to transfer various information data from the physical world to thecyber world in an efficient manner and there by promote the great fusion of cyber physical systems. figure 2 For example, animalists have no need to personally track animals but know their living habits and health status through implanting sensor nodes into animals or deploying monitoring node in the grassland [5]. Another instance is that researchers can acquire real-time monitoring data without visiting mines and volcanoes by deploying sensor networks in these dangerous areas [6]. The promising advantages of WSNs have greatly driven its applications to penetrate into today's informative and technological society. The earliest research on WSN can be dated back to the tactics of US army during the Vietnam War.

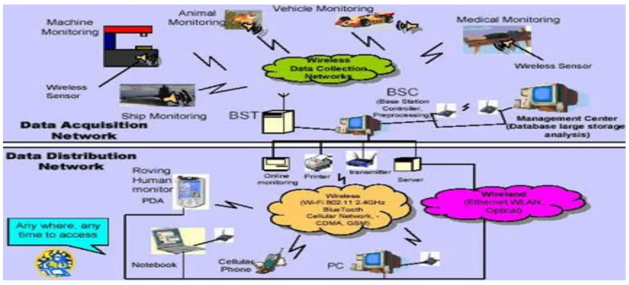

Fig 2. Wireless data connection networks.

III. Wireless Sensor Network Topologies

A. WSN Network Topology

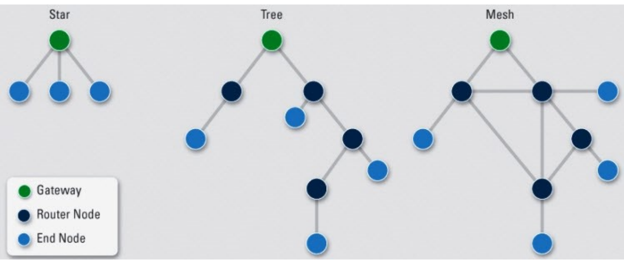

Fig 3. For the radio communication networks structure of a WSN includes various topologies like the ones given above.

B. Star Topologies

Star topology is a communication topology, where each node connects directly to a gateway. A single gateway can send or receive a message to a number of remote nodes. In star topologies, the nodes are not permitted to send messages to each other. This allows low-latency communications between the remote node and the gateway (base station).

Due to its dependency on a single node to manage the network, the gateway must be within the radio transmission range of all the individual nodes. The advantage includes the ability to keep the remote nodes' power consumption to a minimum and simply under control. The size of the network depends on the number of connections made to the hub.

C. Tree Topologies

Tree topology is also called as cascaded star topology. In tree topologies, each node connects to a node that is placed higher in the tree, and then to the gateway. The main advantage of the tree topology is that the expansion of a network can be easily possible, and also error detection becomes easy. The disadvantage with this network is that it relies heavily on the bus cable; if it breaks, all the network will collapse.

D. Mesh Topologies

The Mesh topologies allow transmission of data from one node to another, which is within its radio transmission range. If a node wants to send a message to another node, which is out of radio communication range, it needs an intermediate node to forward the message to the desired node. The advantage with this mesh topology includes easy isolation and detection of faults in the network. The disadvantage is that the network is large and requires huge investment.

IV. Types of WSNs (Wireless Sensor Networks)

Depending on the environment, the types of networks are decided so that those can be deployed underwater, underground, on land, and so on. Different types of WSNs include:

1. Terrestrial WSNs
2. Underground WSNs
3. Underwater WSNs
4. Multimedia WSNs
5. Mobile WSNs

A. Terrestrial WSNs

Terrestrial WSNs are capable of communicating base stations efficiently, and consist of hundreds to thousands of wireless sensor nodes deployed either in unstructured (ad hoc) or structured (Preplanned) manner. In an unstructured mode, the sensor nodes are randomly distributed within the target area that is dropped from a fixed plane. The preplanned or structured mode considers optimal placement, grid placement, and 2D, 3D placement models.

In this WSN, the battery power is limited; however, the battery is equipped with solar cells as a secondary power source. The Energy conservation of these WSNs is achieved by using low duty cycle operations, minimizing delays, and optimal routing, and so on.

B. Underground WSNs

The underground wireless sensor networks are more expensive than the terrestrial WSNs in terms of deployment, maintenance, and equipment cost considerations and careful planning. The WSNs networks consist of a number of sensor nodes that are hidden in the ground to monitor underground conditions. To relay information from the sensor nodes to the base station, additional sink nodes are located above the ground.

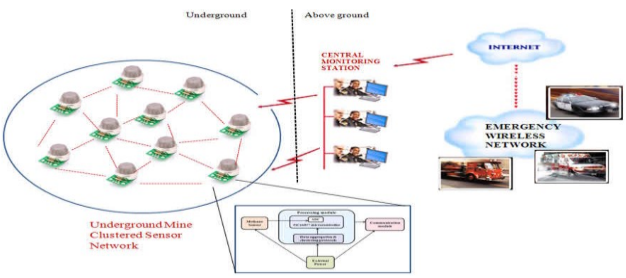

Fig 4. Underground WSNs

The underground wireless sensor networks deployed into the ground are difficult to recharge. The sensor battery nodes equipped with a limited battery power are difficult to recharge. In addition to this, the underground environment makes wireless communication a challenge due to high level of attenuation and signal loss.

C. Under Water WSNs

More than 70% of the earth is occupied with water. These networks consist of a number of sensor nodes and vehicles deployed under water. Autonomous underwater vehicles are used for gathering data from these sensor nodes. A challenge of underwater communication is a long propagation delay, and bandwidth and sensor failure.Under water WSNs are equipped with a limited battery that cannot be recharged or replaced. The issue of energy conservation for under water WSNs involves the development of underwater communication and networking techniques.

D. Multimedia WSNs

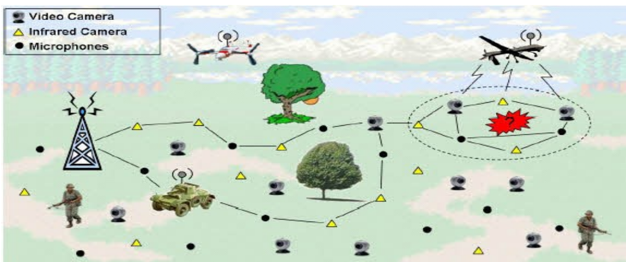

Fig 5. Multimedia WSNs

Multimedia wireless sensor networks have been proposed to enable tracking and monitoring of events in the form of multimedia, such as imaging, video, and audio. These networks consist of low-cost sensor nodes equipped with microphones and cameras. These nodes are interconnected with each other over a wireless connection for data compression, data retrieval and correlation.

The challenges with the multimedia WSN include high energy consumption, high bandwidth requirements, data processing and compressing techniques. In addition to this, multimedia contents require high bandwidth for the contents to be delivered properly and easily.

E. Mobile WSNs

These networks consist of a collection of sensor nodes that can be moved on their own and can be interacted with the physical environment. The mobile nodes have the ability to compute sense and communicate. The mobile wireless sensor networks are much more versatile than the static sensor networks. The advantages of MWSN over the static wireless sensor networks include better and improved coverage, better energy efficiency, superior channel capacity, and so on.

V. Cognitive Radio

Cognitive Radio (CR) is a form of wireless communication in which a radio can intelligently detect the radio environment and be programmed and configured dynamically to use the best vacant wireless channels in its vicinity [14]. It has been expected as a promising solution to address the spectrum scarcity problem. The concept of CR was first proposed by Joseph Mitola III in a seminar at KTH (the Royal Institute of Technology in Stockholm) in 1998 and published in an article by Mitola and Gerald Q. Maguire, Jr.in1999[15] In Mitola's work, CR was defined as an intelligent wireless communication system, which can sense the ambient radio environment and use artificial intelligence to analyze the sensing results. Based on the analysis results, CR can dynamically configure the radio-system parameters, including "waveform, protocol, operating frequency and networking", to make devices access different spectrum bands for communication at different times. CR enables communicating devices to timely detect and opportunistically access the "spectrum holes" for data transmission, significantly enhancing the spatiotemporal utilization of spectrum resources. During the past a few years, CR has been evolving in terms of both concept and implementation technologies. In December 2003, a formal definition of CR is announced by the Federal Communications Commission (FCC). "Aradirorsystem that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets." Based on this definition, FCC also aims to use the CR technology to create an open spectrum market, where Primary Users (PUs) have the priority to access the licensed spectrum, but Secondary Users (SUs) empowered by CR can opportunistically access the licensed spectrum for data transmission under the guarantee of no interference to PUs. Although there have been a number of different CR definitions [16], some common characteristic sand basic functionalities of CR can be summarized as follows.

A. Cognitive Radio Sensor Networks

By applying CR capabilities into WSN, Cognitive Radio Sensor Network (CRSN) emerges to be a promising solution for addressing the spectrum-scarcity problem in traditional WSNs. In general, a CRSN can be defined as a distributed network of wireless cognitive radio sensor nodes, which can sense event signals and leverage CR technology to communicate their readings dynamically over available spectrum bands in a multi hop manner ultimately satisfy the application specific requirements. In CRSN, sensor nodes act as SUs to sense the availability of licensed spectrum and opportunistically access the vacant ones for data transmission. In such a way, CRSN can significantly improve the network performance and the spectrum utilization efficiency. In this section, we briefly introduce a typical architecture of CRSN as well as its potential benefits.

B. A Typical Architecture Of CRSN

In 2009, the concept of CRSN was first proposed by Prof. Ozgur B. Akan and published on IEEE Network [17] ,with a detailed introduction to its architecture and associated challenges. Figure 1.1 shows the proposed architecture of CRSN, where a large number of distributed sensor nodes equipped with cognitive radio modules can opportunistically access vacant licensed channels to transmit their sensed data The architecture of CRSN to the sink node via a multi hop manner. The sink may also be equipped with CR capabilities to receive data via different channels. Besides, to efficiently manage the dynamic channel access in CRSN, there should be a default control channel for communicating the control information and coordinating the whole process. Figure 1.2 shows the hardware architecture of a cognitive radio sensor node. As shown in the figure, the main difference between the hardware structure of a classical sensornode and a CR sensor node is the cognitive radio transceiver. The cognitive radio unit enables the sensor nodes to dynamically adapt their communication parameters such as carrier frequency, transmission power, and modulation. Cognitiveradiosensornodesalsoinheritthelimitationsofcon ventional sensor no desinterm soft power, communication, processing, and memory resources, which consequently restricts the features of cognitive radio.

C. Benefits of CRSN

Compared to traditional WSNs with fixed spectrum allocation, CRSN can benefit from the following potential advantages. • Dynamic Spectrum Access. The existing WSN deployments assume fixed spectrum allocation over very crowded unlicensed bands that are also used by other devices. Nevertheless, a spectrum lease for a licensed band amplifies the overall deployment cost. Hence, to be able to cooperate efficiently with other types of users, opportunistic spectrum access may be utilized in WSNs.

a) Spectrum Sensing

Spectrum holes, i.e., available channels, must be sensed for opportunistic spectrum access. Their successful detection allows overlay user access (15)Since spectrum holes are due to idle state (i.e., no signal transmission) of primary users, to identify spectrum holes, the secondary users must detect the absence of primary signals in a given frequency slot. This task can be viewed as a binary hypothesis testing problem in which Hypothesis 0 (H0) and Hypothesis 1 (H1) are the primary signal absence and the primary signal presence, respectively [19].Spectrum holes are thus identified when H0 is true.

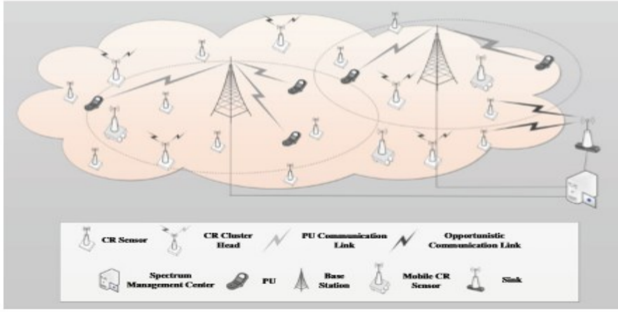

Fig 6. Spectrum sensing

While signal detection has been common in traditional networks, the following challenges arise with its use for cognitive radio spectrum sensing. • A much more reliable detector (than those in traditional networks) is required, since any missed-detection results in secondary transmissions which will interfere with the undetected active primary users. Thus, IEEE 802.22 standard specifies 90% accurate detection capability. • A much wider spectrum bandwidth needs to be sensed to identify as many as possible spectrum holes, e.g., one TV channel bandwidth (6–7MHz) is not sufficient for 4G mobile communications applications using up to 20MHz bandwidth. Further, since different frequency bands experience different signal propagation characteristics, design of detection algorithms and their performance analysis are challenging. • Over a large variety of transmission environments, signal transmission from multiple licensed wireless nodes must be detected. Different applications may have different populations of users, with different mobility patterns, which have a great impact on the signal detection.

b) Spectrum Sensing Techniques

Four major spectrum sensing techniques are energy detection, matched filter, cyclo stationary feature detection, and eigenvalue detection. • Energy detection: This measures the received signal energy within the pre-defined bandwidth and time period. The measured energy is then compared with a threshold to determine the status (presence/absence) of the transmitted signal. Not requiring channel gains and other parameter estimates, the energy detector has low implementation cost.

However, its performance degrades with high noise uncertainty and high background interference [22]. • Matched filter: This detector performs coherent operations, and thus requires perfect knowledge of the transmitted signal and the channel response. It is the optimal detector (in the Neyman-Pearson sense) that maximizes the signal to noise ratio (SNR) in the presence of additive noise. Since it requires perfect timing and synchronization at both physical and medium access control layers, computational complexity is high. Its performance decreases dramatically when channel response changes rapidly. In addition, when it is employed to sense spectrum holes, the presence of multiple primary user signals over the same bandwidth simultaneously an impact the accuracy of its decisions. This problem may be mitigated by having a dedicated matched filter structure for each primary signal. However, the resulting complexity issues may preclude the use of matched filter for dynamic and opportunistic spectrum sensing. • Cyclostationary feature detection: If periodicity properties are introduced intentionally to primary user signals, the statistical parameters of received signal such as mean and autocorrelation may vary periodically. Such statistical periodicity is exploited in cyclostationary detection. One possible way of extracting cyclostationary properties is by using the input-output spectral correlation density or cyclic spectrum. Since noise signal does not have any cyclostationary or periodicity property, this method allows the determination of signal presence/absence readily. While this detector is able to distinguish among the primary user signals, secondary user signals, or interference, it needs a higher sampling rate to get a sufficient number of samples, which increases the computational complexity. In addition, when there are frequency offset and sample timing error, the spectral correlation density may be weak, thus largely affecting detection performance.

VI. Spectrum Sensing Techniques

Eigenvalue detection: The ratio of the maximum (or the average) eigenvalue to the minimum eigen value of the covariance matrix of the received signal vector is compared with a threshold to detect the absence or the presence of the primary signal. However, if the correlation of the primary signal samples is zero (e.g., primary signal appears as white noise), eigenvalue detection may fail, a very rare event. This detector has the advantage of not requiring the knowledge of the primary signal parameters or the propagation channel conditions. The main drawback is computational complexity of covariance matrix computation and the eigenvalue decomposition. The threshold selection is challenging as well.using the similar concept, a sample autocorrelation-based spectrum sensing technique is also introduced in(20). Apart from these main spectrum sensing techniques, there are some alternatives: • The Anderson-Darling sensing is a non-parametric hypothesis testing problem (a goodness-of-fit testing problem) [33]. This technique tests whether or not the observed samples are drawn independently from the noise distribution. If the test does not satisfy the properties of the noise distribution, the detector decides on signal presence. Thus, any assumption/knowledge of the transmitted signal is unnecessary. • The Kolmogorov-Smirnov test [39] is also a non-parametric method to measure the goodness of fit. This technique computes the empirical cumulative distribution function, and compares it with the known empirical cumulative distribution function of the noise samples.

A. Adaptive Detection

Adaptive algorithms are employed when the conventional energy detector may fail due to insufficient signal strength. This happens when the signal bandwidth is narrow compared to the detector window, or when only a small fraction of the signal bandwidth is captured within the sensing window. In either case, signal energy does not meet pre-defined threshold level. Some possible ways to combat this problem are: • lower the threshold, which increases Pf significantly; • choose a window matching to the signal, which needs a priori knowledge of primary signal; • narrow the detector window, which increases the sensing time. Due to the drawbacks of performance and implementation complexity of the first two solutions, the third solution is developed as an adaptive energy detector. The window size is selected adaptively by sub dividing the original window size. In dynamic wireless communication networks, the primary signal can appear or disappear at any time instant within the sensing time.

B. Generalized Energy Detector

Channel sensing only when it is needed, and therefore, unnecessary sensing can be avoided. It makes each decision based on the previous sensing results, and thus, the sensing time is much shorter than that of the conventional energy detector. A shorter sensing period enhances the adaptability by increasing the frequency of decision intervals. For more reliability, multiple soft sensing results can be combined to generate reliable detection.

VII. Wireless Sensor Networks Applications

- These networks are used in environmental tracking, such as forest detection, animal tracking, flood detection, forecasting and weather prediction, and also in commercial applications like seismic activities prediction and monitoring.
- Military applications, such as tracking and environment monitoring surveillance applications use these networks. The sensor nodes from sensor networks are dropped to the field of interest and are remotely controlled by a user. Enemy tracking, security detections are also performed by using these networks.
- Health applications, such as Tracking and monitoring of patients and doctors use these networks.
- The most frequently used wireless sensor networks applications in the field of Transport systems such as monitoring of traffic, dynamic routing

management and monitoring of parking lots, etc., use these networks.

- Rapid emergency response, industrial process monitoring, automated building climate control, ecosystem and habitat monitoring, civil structural health monitoring, etc., use these networks.

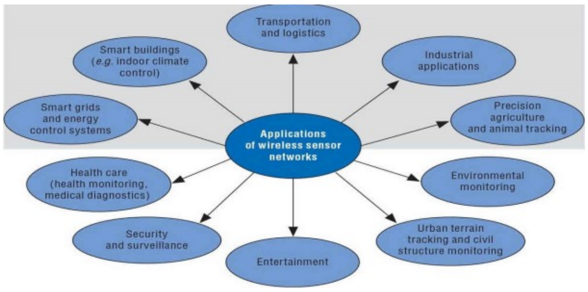

Fig 7. Applications of Wireless Sensor Networks

This is all about the wireless sensors networks and their applications. We believe that the information about all the different types of networks will help you to know them better for your practical requirements. Apart from this, for additional information about wireless SCADA, queries, and doubts regarding this topic or electrical and electronic projects, and for any suggestions, please comment or write to us in the comment section below.

A. *WSNs for Water Quality*

- Wireless sensor networks are made up of small computational devices connected to various sensors and wireless radios. The devices automatically and adaptively form ad-hoc networks (temporary point-to-point networks) over wireless radios to make decisions based on measurements of their environment. The hardware and software are designed to be extremely low power in order to enable long-term in-situ deployments, i.e. undisturbed

- Deployments that are left in the environment with minimal human intervention. Device sizes commonly range from that of a quarter to a PDA-like device. In general, resource availability and power consumption are commensurate with size. For example, while it largely depends on the power consumption of the sensors, the lower-power nodes (often called motes) can run for approximately one month on 2 AA batteries. Sensor networks provide dense spatial and temporal sampling even in remote and hard to reach locations. Thus, they are best applied to applications that need dense sampling in space and/or time. Soil applications are a good example, because the soil environment is heterogeneous across space, requiring dense spatial sampling. Abrupt changes can then be captured with a high temporal sampling rate. The fact that WSNs are low power and wireless makes them appealing as a technology for developing regions, but in addition the dense sampling is crucial for public health applications.

B. *Sensor Sharing Techniques*

- Sensor sharing will allow many people to benefit from sensor network data collection, even with minimal sensor resources. We believe the following three technical approaches are particularly suited for enabling sensor sharing for sustainable development: (1) moving a smaller number of sensors around in a deployment to emulate density, (2) gradually

- Removing redundant sensors from a deployment to go from dense to sparse deployments, and (3) leveraging shorter deployment cycles where possible. Here we describe each of these scenarios in greater detail, including a survey of our own and others' work in implementing related or supporting algorithms.

C. *Dense to Sparse Deployments*

Some sensor network applications require a dense mapping of the environment. Once sensors are densely deployed and details of the phenomenon are revealed, we may see it is possible to capture sufficient information with fewer sensors, freeing sensors for deployment elsewhere. Here we describe applicable work which is ongoing in the sensor network community. In [16], a technique called Back casting is described to identify unnecessary sensors. This work assumes that the field is densely deployed, and the algorithm turns off as many sensors as possible to maintain a certain level of fidelity of sensing. Their method uses measurements from the dense deployment to estimate the spatial nyquist frequency throughout the field. Where the frequency is low, sensors can be shut down to conserve energy. This can be adapted to direct a human user to remove these unnecessary sensors from the field. Another approach views the sensor network as a database query-response system: Model-based Data Acquisition [6]. A user issues a query to a densely deployed network. Using a Gaussian process (GP) model built from past data, the system chooses only a select number of sensors that must be queried to get the appropriate response. This can be extended to applications we have described where there is a single query for the duration of the deployment. Thus, the algorithm will find a particular subset of sensors that is useful to answer that query and can direct a human user to remove the other sensors. A third applicable work on optimizing sensor.

D. *Short Deployment Cycles*

Some applications only require short-duration deployments and therefore are ideal for sensor sharing. Our deployment in Bangladesh is an example of an application with a short deployment cycle. We wanted to collect data to validate a hypothesis about diurnal variations, and so we wanted several days of data for analysis. Another scenario in which short deployment cycles are appropriate is in a trigger-response sensor network usage model. Individuals own simple, inexpensive sensors for a particular contaminant, which communicate their measurements through a cellular network. Upon detection of unusual phenomena in an area, an NGO could bring a more sophisticated sensor network for a short-duration, detailed analysis of contamination transport. A trigger-based usage model such as this can build on systems like one which is being developed at Columbia University.

VIII. LIMITATIONS OF WIRELESS SENSOR NETWORKS

- Possess very little storage capacity – a few hundred kilobytes
- Possess modest processing power-8MHz
- Works in short communication range – consumes a lot of power
- Requires minimal energy – constrains protocols
- Have batteries with a finite life time
- Passive devices provide little energy

IX. RESEARCH ISSUES ON SENSOR NETWORKS

A. Sensor Network Development and Security

Since sensor networks is a young technology, there are many research problems that need to be solved, such as models and tools for designing better WSN architectures, standard protocols adapted to work robustly on certain scenarios, and so on. At present, the “de facto” standard Operative System for sensor nodes is an open source OS called Tiny OS, which provides limited support for network and protocol simulations. The preferred programming language for developing applications in this environment is a component-based C-dialect called nes C, but it is also possible to use other languages in other OS, such as C for the MSB nodes and Java for the Sun Spot nodes. Another concern in the development of sensor network applications is the lack of a standardized set of core protocols, which could be used for providing the services of the network in a certain context and application. These core protocols are routing, data aggregation, and time synchronization, and the service they provide are the ability to route a packet from a node to another node, to summarize many sensor readings into one single piece of data, and to synchronize the clocks of the network, respectively. The specific problem in this area is not the lack of protocols developed by the research community, but the lack of a set of tested solutions that could work robustly in a production environment. However, the biggest issue that a sensor network in a production environment has to face is security. Sensor nodes are highly constrained in terms of computational capabilities, memory, and battery power. In addition, the nodes can be physically accessible by anyone because they must be located near the physical source of the events, but they usually are not tamper-resistant due to cost issues.

B. Sensor Network Interoperability

It has been shown that sensor networks are useful elements in the global picture of protecting a critical information infrastructure, since they can provide the foundation of a robust and self-reactive intelligent distributed control system, be used for controlling and diagnosing any previously existent equipment, or used as an event feeder for Early Warning Systems or Dynamic Reconfiguration Systems (DRS). It is an open question, then, how to integrate these sensor networks with CII in order to provide all these protection services. This problem is actually being addressed by the CRISIS (CRitical Information Infrastructures Security based on Internetworking Sensors) project (Lopez et. al. (2006)). At a low level, it should be necessary to define and design the software components located in the sensor nodes needed to provide basic mechanisms for the creation of security services. These software components should allow the deployment of the control infrastructure, the efficient access to the information acquired by the sensors system and adjacent subsystems, and the secure access and control of the behavior of the network. On the other hand, at high level it should be obligatory to specify mechanisms for providing an appropriate interoperability of the elemental mechanisms, establishing the foundation of the sensor network as a Service-Oriented Architecture (SOA). This requires the correct specification of the associated middleware and the creation of security policiesand interfaces for the interchange of information.

X. CHALLENGES

Numerous technical challenges arise in order to be able to quickly deploy and move sensors, primarily because the work to date has largely focused on static, long-running deployments. Given that we have the goals to emulate density, reduce dense deployments to sparse ones, and leverage short deployments cycles, we find the following three challenges to be the mostpertinent. Algorithms must be interactive and robust to human error. Faults in the system must be quickly identified to maximize the amount of good data received. Finally, systems must be made to be rapidly deployable. In this section we discuss our research in these three areas.

A. Algorithm Issues

Sensor portability introduces challenges and new requirements in algorithm design.

Robust and Interactive Deployment Algorithms Using human-enabled mobility to move sensors in a deployment can be cheaper than robotics, depending on labor costs. Of course, human-enabled mobility is neither as accurate nor as sensitive to latency as robotic mobility, and deployment algorithms must take this fact into account.Thus, in order to guide a person to move sensors in a deployment, our algorithms must do two things. First, algorithms must employ some very basic audio or visual cues that provide feedback for a user. For instance, a green light might turn on when the node is in the correct location for deployment, or a red light might turn on once a sensor can be removed. Mechanical mechanisms could also be built into the hardware; a retractable measurement device could be attached to a pylon so that no two pylons are deployed within a certain distance of each other.Second, algorithms must be robust to human error and avoid frustrating the user. Requiring a user to place a sensor within a very small area or within a very small amount of time is unreasonable. In order to appropriately utilize human mobility, the algorithm must be able to tolerate placement errors and latency.

B. Detecting Data Disruption and Faults

The primary cause of faults and data disruption in a wireless sensor network is a failure in the communication or a failure in the sensor. Finding and fixing failures in a sensor network is a difficult problem because the devices are low-power and relatively cheap. Failures in the network can occur for a variety of reasons, including bad wiring, faulty hardware, uncalibrated sensors, buggy software, badly placed sensors, or bad communication between nodes due to physical obstructions or distance. Monitoring Network Health In order to aid users in finding and fixing network failures, we designed a tool called Sympathy [15]. Sympathy highlights anomalous network behavior based on the quantity of data expected at the base-station from each node in a network. For example, if the base station expects to receive a sensor measurement from every node in the network once every five minutes, Sympathy identifies nodes that are not transmitting these measurements. Detecting Sensor Faults Data integrity in short-term deployments is a critical issue. In our Bangladesh deployment, we saw faulty measurements for issues including broken sensors and shorted circuits. Often sensor measurements were indecipherable due to excessive faults in the data. We are working to develop a toolbox for detecting these problems real-time during deployment of our system. Our approach is to identify patterns in the data that indicate sensor failure. These fault patterns will be associated with particular causes for the user to fix. In this way, the user can address issues immediately in order to maximize usable data collected by the network.

C. Rapidly Deployable Systems

In order to frequently move sensors, they must be extremely easy to deploy and re-deploy. NIMS systems may be deployed rapidly in environments by simply attaching the NIMS cable system between two fixed points and attaching a WSN node control device for cable actuation. NIMS rapidly deployable systems have been developed for river and stream monitoring. For example, an investigation of the spatiotemporal distribution of nitrate concentration and other variables in an urban stream of Los Angeles, California is performed monthly. The current time for deployment is only two hours, and the system operates over 24 hours. In soil applications, a challenge is to minimize the disturbance due to placing sensors in the environment. Depending on soil type and moisture conditions, disturbed soil can require days to months to recover from intrusions made for the sake of sensor placement. In the pylon unit described in Section 2, sensors extend from the conduit to achieve intimate contact with the surrounding soil. Deployment strategies causing fewer disturbances would be highly desirable. We are developing conduits called javelins [8] for this purpose. For aquatic chemical sensors, the javelin requires water-saturated soil conditions, because the target chemicals must be transported through openings in the conduit to the sensor. Additionally, soil is a harsh environment for sensors, so such conduits would allow sensor withdrawal for cleaning and maintenance.

XI. CONCLUSION

Wireless sensor networks have the potential to be a useful tool for sustainable development. This can be facilitated by the technical community if we focus on issues with developing wireless sensor networks as a shared technology. In order to implement WSNs as a shared resource, we identified three promising technical approaches: emulating density, moving from dense to sparse deployments, and implementing short deployment cycles. We discussed our work on deployments that have demonstrated these techniques and described our past and ongoing work to address the major challenges which arise.

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This material is based upon work supported by the National Science Foundation under Grant No. CCF0120778 and 0331481.2. In order to protect the well-being of a nation and its citizens, it is essential to guarantee the security of Critical Infrastructures and its information infrastructures. One of the multiple technologies that are especially suitable for this purpose is the Wireless Sensor Networks. Thanks to their intelligent distributed control capabilities, alongside with their capacity to work under severe conditions, such networks are an excellent tool for detecting and reacting against problems in safety-critical information infrastructures. Both the scientific community and the governments around the world have recognized the importance of Wireless Sensor Networks for this very purpose, spanning multiple research efforts and prototypes. However, a sensor network does have its research issues of its own. There are few models and tools for designing WSN architectures, andmost protocols are reported to work in research testbeds but are untested in production environments. The state of the art on security in sensor networks is quite advanced, but it is also limited to research projects and prototypes. There have been no serious attempts to measure the actual security of a sensor network in a critical environment.

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