Wireless Sensor Networks and Applications: a Survey

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Summary

In this research work, a survey on Wireless Sensor Networks (WSN) and their technologies, standards and applications was carried out. Wireless sensor networks consist of small nodes with sensing, computation, and wireless communications capabilities. Many routing, power management, and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue. Routing protocols in WSNs might differ depending on the application and network architecture. A multidisciplinary research area such as wireless sensor networks, where close collaboration between users, application domain experts, hardware designers, and software developers is needed to implement efficient systems. The flexibility, fault tolerance, high sensing fidelity, low cost, and rapid deployment characteristics of sensor networks create many new and exciting application areas for remote sensing. In the future, this wide range of application areas will make sensor networks an integral part of our lives. However, realization of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, hardware, topology change, environment, and power consumption.

Key words:
Application, Middleware, wireless sensor network survey and protocol

1. Introduction

WIRELESS ad-hoc sensor networks have recently emerged as a premier research topic. They have great longterm economic potential, ability to transform our lives, and pose many new system-building challenges. Sensor networks also pose a number of new conceptual and optimization problems. Some, such as location, deployment, and tracking, are fundamental issues, in that many applications rely on them for needed information. Coverage in general, answers the questions about quality of service (surveillance) that can be provided by a particular sensor network. The integration of multiple types of sensors such as seismic, acoustic, optical, etc. in one network platform and the study of the overall coverage of the system also presents several interesting challenges.

With the refinement of energy harvesting techniques that can gather useful energy from vibrations, blasts of radio energy, and the like, self-powered circuitry is a very real possibility, with networks of millions of nodes, deployed

through paintbrushes, injections, and aircraft. Also, the introduction of an additional type of sensor nodes allowing the network to self-organize and "learn", by embedding smart and adaptive algorithms. On the other hand, The use of adaptive power control in IP networks that utilize reactive routing protocols and sleep-mode operation, more powerful mobile agents, QoS (Quality of Service) to guarantee delivery, security mechanisms, robustness and fault-tolerance.

Wireless sensors have become an excellent tool for military applications involving intrusion detection, perimeter monitoring, information gathering and smart logistics support in an unknown deployed area. Some other applications: sensor-based personal health monitor, location detection with sensor networks and movement detection.

2. Standards

From [2], while most ongoing work in IEEE 802 wireless working groups is geared to increase data rates, throughput, and QoS, the 802.15.4 LR-WPAN (Low rate-Wireless Personal Area Network) task group is aiming for other goals. The focus of 802.15.4 is on very low power consumption, very low cost, and low data rate to connect devices that previously have not been networked, and to allow applications that cannot use current wireless specifications. Working within a standards organization to develop a wireless solution has the advantage of bringing developers and users of such a technology together in order to define a better solution.

The work also fosters high-level connectivity to other types of networks and enables low-volume products that do not justify a proprietary solution to be wirelessly connected.

Two physical layer specifications were chosen to cover the 2.4 GHz worldwide band and the combination of the 868 MHz band in Europe, the 902 MHz band in Australia, and the 915 MHz band in the United States. Both physical layers are direct sequence spread spectrum (DSSS)

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solutions. For further information, the selected proposals can be downloaded from the 802.15 Web site. The efforts of the IEEE 802.15.4 task group will bring us one step closer to the goal of a wirelessly connected world [2].

From [1], one of the IEEE 802.15.4 physical layers operates in the 2.4 GHz industrial, scientific and medical band with nearly worldwide availability; this band is also used by other IEEE 802 wireless standards. Coexistence among diverse collocated devices in the 2.4 GHz band is an important issue in order to ensure that each wireless service maintains its desired performance requirements.

On the other hand, from [4], the IEEE 1451**,** a family of Smart Transducer Interface Standards, describes a set of open, common, network-independent communication interfaces for connecting transducers (sensors or actuators) to microprocessors, instrumentation systems, and control/field networks. The key feature of these standards is the definition of a TEDS (Transducer Electronic Data Sheet). The TEDS is a memory device attached to the transducer, which stores transducer identification, calibration, correction data, and manufacture-related information. The goal of 1451 is to allow the access of transducer data through a common set of interfaces whether the transducers are connected to systems or networks via a wired or wireless means. The family of IEEE 1451 standards are sponsored by the IEEE Instrumentation and Measurement Society's Sensor Technology Technical Committee.

IEEE P1451.5 defines a transducer-to-NCAP (Network Capable Application Processor) interface and TEDS for wireless transducers. Wireless standards such as 802.11 (WiFi), 802.15.1 (Bluetooth), 802.15.4 (ZigBee) are being considered as some of the physical interfaces [4].

3. Protocols

There are several protocols proposed for WSNs (Wireless Sensor Network). From [5], the MAC (Medium Access Control) layer reacts to this probabilistic reception information by adjusting the number of acknowledgments and/or retransmissions. It is observed that an optimal route discovery protocol cannot be based on a single retransmission by each node, because such a search may fail to reach the destination or find the optimal path. Next, It is discussed that gaining neighbor knowledge information with "hello" packets is not a trivial protocol. It is described the localized position-based routing protocols that aim to minimize the expected hop count (in case of hop-by-hop acknowledgments and fixed bit rate) or maximize the probability of delivery (when acknowledgments are not sent).

An interesting open problem for future research is to consider physical-layer-based routing and broadcasting where nodes may adjust their transmission radii. Expected power consumption may then be considered a primary optimality measure. Further research should address other problems in the design of network layer protocols. For instance, if we consider a more dynamic and realistic channel model, such as multi-path fading, the estimated number of packets may suffer from large variance, and the described protocols may need some adjustments. More realistic interference models can be added, and transport layer protocols also need to be adjusted [5].

From [6], a survey of state-of-the-art routing techniques in WSNs is presented. First, it is outlined the design challenges for routing protocols in WSNs followed by a comprehensive survey of routing techniques. Overall, the routing techniques were classified into three categories based on the underlying network structure: flit, hierarchical, and location-based routing.

Furthermore, these protocols could be classified into multipath-based, query-based, negotiation-based, QoS-based, and coherent-based depending on the protocol operation. Design trade-offs between energy and communication overhead savings in every routing paradigm were studied. Advantages and performance issues of each routing technique were highlighted [6].

From [7], when compared with now classical MANETs (Mobile Ad hoc Networks) [28], sensor networks have different characteristics, and present different design and engineering challenges. One of the main aspects of sensor networks is that the solutions tend to be very application-specific. For this reason, a layered view like the one used in OSI imposes a large penalty, and implementations more geared toward the particular are desirable.

Communication, which is the most energy-costly aspect of the network, can be organized in three fundamentally different ways: node-centric, data-centric, and position-centric. Node-centric communication is the most popular and well understood paradigm, being currently used in the Internet. The other two, data-centric and position-centric, are more scalable, better adaptable to applications, and conceptually more appropriate in many cases, and therefore may successfully challenge the node-centric way of looking at the sensor networks.

Data-centric approaches, on the other hand, tend to provide a top-to-bottom solution, as is the case with directed diffusion. In fact, directed diffusion solves only one problem, but solves it right. A new IEEE standard, 802.15.4, is aimed at low-power low-distance communication devices that may allow years of battery life. The standard allows for both hierarchical and flat peer-to-peer topologies, and provisions for one hop reliability and real-time guarantees. At the lower layers, there may be a choice between RF and optical communication, but it is still unclear what the logical and address organization of future sensor networks will be. It can be flat with identical nodes, or hierarchical with cluster heads that are more powerful in terms of storage, computation, and communication.

Solutions here are either awkward (triangle routing in mobile Internet) or wasteful (rediscovery of paths in ad hoc node-centric networks). Here position-centric approaches have the advantage because they do not require particular nodes to be involved in forwarding, but use whichever ones provide connectivity.

Some of the projects exploring the possibility of installing arbitrary code on sensors are SensorWare and Maté. The use of Tcl (Tool Command Language) scripts and bytecode allows installation of complex distributed algorithms that can access all the communication and sensing capabilities of each node. Finally, if sensor networks are to be deployed in large sizes, scalability with respect to the number of nodes becomes a deciding factor in choosing a communication paradigm.

It is likely that position-centric, data-centric, or maybe a combination of them is the best bet for future sensor networks [7].

From [30], IS-MAC protocol based flooding protocol (ISF) for wireless sensor networks was introduced. Existing flooding protocols are based on IEEE 802.11 MAC layer that gives ideal listing problem for the sensor networks. Ideal listening is the most prominent cause for energy waste in sensor networks. It was proposed ISF routing protocol that gives energy efficient data delivery mechanism for wireless sensor networks. Special features of IS-MAC protocol makes the ISF protocol most promising candidate for the routing protocols for wireless sensor networks. ISF protocol uses hop count/location information to achieve energy efficiency for the data delivery mechanism. Performance evaluation showed the superiority of ISF protocol over the direct and directional flooding protocols.

4. Coverage

From [8], for the context of coverage, negotiation and resolution strategies are needed to integrate information from this stage to be used in related contexts such as tracking mobile objects in the network and handling obstacles.

Although the algorithm was developed for a wireless adhoc sensor network, a centralized control server, where nodes are connected using a gateway was assumed. Other control strategies such as distributed control systems are also feasible. It is possible to compare the centralized coverage algorithm to distributed ones in terms of power consumption, cost, and performance.

In practice, other factors influence coverage such as obstacles, environmental conditions, and noise. In addition to nonhomogeneous sensors, other possible sensor models can deal with non-isotropic sensor sensitivities, where sensors have different sensitivities in different directions. The integration of multiple types of sensors such as seismic, acoustic, optical, etc. in one network platform and the study of the overall coverage of the system also presented several interesting challenges [8].

From [9], two algorithms for the efficient placement of sensors in a sensor field are presented. The proposed approach is aimed at optimizing the number of sensors and determining their placement to support distributed sensor networks. The optimization framework is inherently probabilistic due to the uncertainty associated with sensor detections.

It was formulated an optimization problem on sensor placement, wherein a minimum number of sensors are deployed to provide sufficient coverage of the sensor field. This approach offers a unique “minimalistic” view of distributed sensor networks in which a minimum number of sensors are deployed and sensors transmit/report a minimum amount of sensed data [9].

From [10], the basic topology desired in data-gathering wireless sensor networks is a spanning tree, since the traffic is mainly in the form of many-to-one flows. Nodes in the network can selfconfigure themselves into such a topology by a two-phase process: a flood initiated by the root node, followed by parent selection by all nodes. Four localized topology generation mechanisms are presented – earliest-first, randomized, nearest-first, and weighted-randomized parent selection. Network performance of these mechanisms on the basis of the following metrics: node degree, robustness, channel quality, data aggregation and latency are compared; this study shows how localized selfconfiguration mechanisms can impact the global network behavior: earliest-first and nearest-first schemes produce a data-gathering tree with low network reliability, high data aggregation ability, and long response time to an event.

Randomized and weighted-randomized schemes, on the other hand, construct a balanced data-gathering tree with high network reliability, low data aggregation ability, and short response time to an event. In addition, nearest-first scheme outperforms other three schemes in channel quality [10].

From [24], some sensor nodes may be equipped with special hardware such as a Global Positioning System

(GPS) receiver to act as beacons for other nodes to infer their location; some nodes may act as gateways to long-range data communication networks (e.g., GSM (Global System for Mobile) networks, satellite networks, or the Internet).

5. Energy

From [11], a microsensor network that can gather and transmit data for years demands nodes that operate at energy efficiencies unheard of in today's wireless systems. Sensor nodes must take advantage of operational diversity, such as the long periods of idle time between interesting events, by gracefully scaling back energy consumption. The user must precisely define the network's performance requirements using metrics ranging from latency to accuracy to reliability so that the network performs just enough computation to meet the user's specific demands, and no more.

The network must consider itself as a single entity, where collaborative communication protocols remove redundancies in computation and communication, and maintain an even spatial distribution of energy. Only with such careful attention to the details of energy consumption at every point in the design process we can expect to see a 1000-node microsensor network that can deliver years of continuous service. In [11], a discussion on the hardware and algorithmic enablers for energy-efficient microsensor networks is carried out.

One possible next step is a node with infinite lifetime. Since nodes are essentially sensing energy in the environment, why not harvest it for operation as well? A "sensor" that efficiently transduces environmental energy into useful electrical energy is an energy harvester. With the refinement of energy harvesting techniques that can gather useful energy from vibrations, blasts of radio energy, and the like, self-powered circuitry is a very real possibility. Energy harvesting schemes developed in the laboratory have generated 10 μW of power from mechanical vibrations, already enough for low-frequency DSP (Digital Signal Processor). With continuing advances in energy harvesting and improvements in node integration, a batteryless infinite-lifetime sensor network is possible.

It is inevitable that wireless microsensor networks will mature from laboratory curiosities to networks of millions of nodes, deployed through paintbrushes, injections, and aircraft. So perhaps it is not far-fetched to envision that the wireless microsensor network will be the true enabler for ubiquitous computing: the availability of computational power that is taken for granted anywhere, at any time. To be truly imperceptible, technology must be omnipresent. And in Ranger Smith's forest preserve, teeming with many millions of nano-nodes, it is [11].

From [12], an energy-efficient distributed clustering approach for ad-hoc sensor networks was presented. This approach is hybrid: cluster heads are randomly selected based on their residual energy, and nodes join clusters such that communication cost is minimized.

From [13], the focus is on improving the energy consumption of sensor nodes in large networks. A sensor's durability and reliability depend on its battery's capacity and on the energy consuming tasks it performs in order to fulfill its functions. To achieve this goal. A new "biomorphic" paradigm that imports solutions to existing engineering problems from the biological world is proposed.

It is shown that this paradigm offers better solutions through the introduction of an additional type of sensor nodes and allowing the network to self-organize and "learn". This allows the network to perform better in a dynamical environment in accordance to its acquired knowledge [13].

From [14], wireless sensor networks must minimize overall power consumption in order to maximize operational lifetime. The primary focus is on networks that use a mixture of higher-powered IP-speaking nodes and lower-powered non-IP nodes. Graph-theoretic techniques are used to investigate heuristics for guaranteeing full network connectivity in networks consisting of sensors with differing transmission ranges.

Simulation results were provided for the use of adaptive power control in IP networks that utilize reactive routing protocols and sleep-mode operation. First, clustering is useful in "hand-emplaced" networks, but may be less so in "random lay-downs" that contain both high-powered and low-power radios. Second, reactive routing-protocols with topology-based Adaptive Power Control improve energy-usage in sensor networks. Third, reactive-routing was compatible with sleep-mode operation and Adaptive Power Control (APC) [14].

From [15], an architecture for large scale low power sensor network is proposed. Referred to as sensor networks with mobile agents (SENMA), SENMA exploits node redundancies by introducing mobile agents that communicate opportunistically with a large field of sensors. The addition of mobile agents shifts computationally intensive tasks away from primitive sensors to more powerful mobile agents, which enables energy efficient operations under severely limited power constraints.

Mobile agents in SENMA are powerful hardware units, both in their communication and processing capability and in their ability to traverse the sensor network. Examples of mobile agents are manned/unmanned aerial vehicles, ground vehicles equipped with sophisticated terminals and power generators, or specially designed light nodes that can hop around in the network [15].

6. Security

From [17, 29], sensor networks are expected to play an essential role in the upcoming age of pervasive computing. Due to their constraints in computation, memory, and power resources, their susceptibility to physical capture, and use of wireless communications, security is a challenge in these networks. The scale of deployments of wireless sensor networks require careful decisions and trade-offs among various security measures.

Mechanisms to achieve secure communication in these networks are considered. Widespread deployment of sensor networks is on the horizon. Given their versatility, sensor networks will soon play an important role in critical military applications as well as pervade our daily life. However, security concerns constitute a potential stumbling block to the impending wide deployment of sensor networks. Current research on sensor networks is mostly built on a trusted environment. Several exciting research challenges remain before we can trust sensor networks to take over important missions [17, 29].

Depending on the application, a sensor network must support certain QoS (guaranteed delivery [16]) aspects such as real-time constraints (e.g., a physical event must be reported within a certain period of time), robustness (i.e., the network should remain operational even if certain well defined failures occur), tamper-resistance (i.e., the network should remain operational even when subject to deliberate attacks), eavesdropping resistance (i.e., external entities cannot eavesdrop on data traffic), and unobtrusiveness or stealth (i.e., the presence of the network must be hard to detect). These requirements may impact other dimensions of the design space such as coverage and resources [24].

From [18], current security mechanisms in ad-hoc sensor networks do not guarantee reliable and robust network functionality. Even with these mechanisms, the sensor nodes could be made non-operational by malicious attackers or physical break-down of the infrastructure. Measurement of the network characteristics in a ’threat’ of network failure is essential to understand the behavior of these networks.

Two main contributions of this research work are the analysis of performance variation and measuring the after-effects of the threats to a sensor network i.e. threat of node failures, attack on nodes etc. Two metrics: connectivity cost and dis-connectivity co-efficient; the former studies the variation in performance when a network topology is subject to different threats, while the latter measures the impact of the threat(s) on the sensor network.

Simulations [18] were performed on dynamic network models vulnerable to adversarial and non-adversarial threats as in any practical deployment scenario. Results show that robustness and fault-tolerance (also in [20]) of the sensor network topologies comes as a tradeoff with the vulnerability of the network topologies to various threats. It was performed a detailed measurement study of the clustered and unclustered network topology under models of threat like node failures, malicious attackers and mix attack.

Results show that the clustered topology display high degree of tolerance to perform efficiently in case of random attacks, unlike the unclustered topologies. But, this sustained efficient performance comes at the cost of the high losses incurred in case of intentional attacks on the network. Clustered networks are affected significantly in case of an attack on the network, whereas the unclustered topologies perform resiliently in such a situation. The distribution of connectivity in sensor networks plays a significant role in the behavior of the topology in threatening situations [18].

From [19], in a constant search for efficient security control and intrusion detection systems (IDS) [28], the ultimate goal in designing protocols remains less resource consumption while possessing broad coverage and wider applicability. Wireless sensors have become an excellent tool for military applications involving intrusion detection, perimeter monitoring, information gathering and smart logistics support in an unknown deployed area. Since sensor networks are resource-constrained devices, their design needs to minimize efforts without compromising the task’s integrity.

For this purpose, in [19] a novel approach for an intrusion detection based on the structure of naturally occurring events is proposed. With the acquired knowledge distilled from the self-organized criticality aspect of the deployment region, a hidden Markov model was applied. In other words, the sensor network adapted to the norm of the dynamics in its natural surroundings so that any unusual activities could be singled out. This IDS is simple to employ, requires minimal processing and data storage.

Other advantages of this model are: Energy efficient algorithm for detecting intrusions incurring minimum calculations, robustness with low false-alarm rate as it adapts well to the surrounding phenomena and flexible to modified task requirements, hard to fool because the data used for detection is unique to its location [19].

From [3], the IEEE 802.15.4 draft standard provides for three levels of security: no security of any type (e.g., for advertising kiosk applications); access control lists (non-cryptographic security); and symmetric key security, employing AES-128 (Advanced Encryption Standard).

7. Middleware

From [21], current trends in computing include increases in both distribution and wireless connectivity, leading to highly dynamic, complex environments on top of which applications must be built. The task of designing and ensuring the correctness of applications in these environments is becoming more complex. The unified goal of much of the research in distributed wireless systems is to provide higher level abstractions of complex low-level concepts to application programmers, easing the design and implementation of applications.

A new and growing class of applications for wireless sensor networks require similar complexity encapsulation. However, sensor networks have some unique characteristics, including dynamic availability of data sources and application quality of service requirements, that are not common to other types of applications. These unique features, combined with the inherent distribution of sensors, and limited energy and bandwidth resources, dictate the need for network functionality and the individual sensors to be controlled to best serve the application requirements.

In [21], different types of sensor network applications were described and existing techniques for managing these types of networks are discussed. A variety of related middleware is overviewed and that no existing approach provides all the management tools required by sensor network applications is also argued. To meet this need, A new middleware called MiLAN was developed. MiLAN allows applications to specify a policy for managing the network and sensors, but the actual implementation of this policy is effected within MiLAN. MiLAN is described and its effectiveness through the design of a sensor-based personal health monitor is shown.

From [22], a sensor information networking architecture, called SINA, is introduced that facilitates querying, monitoring, and tasking of sensor networks. SINA serves the role of middleware that abstracts a network of sensor nodes as a collection of massively distributed objects.

SINA’s execution environment provides a set of configuration and communication primitives that enable scalable and energy-efficient organization of and interactions among sensor objects. On top the execution environment is a programmable substrate that provides mechanisms to create associations and coordinate activities among sensor nodes. Users then access information within a sensor network using declarative queries, or perform tasks using programming scripts [22].

From [31], integration of sensor networks with mobile devices can provide additional flexibility and functionality for a variety of applications and can have a significant practical potential by designing a middleware architecture for integration of sensornets with mobile devices. As a result of initial research it was designed a distributed index that adapts to local event and lookup query rates to minimize the amount of communication overhead.

8. Applications

From [24], in the recent past, wireless sensor networks have found their way into a wide variety of applications and systems with vastly varying requirements and characteristics. As a consequence, it is becoming increasingly difficult to discuss typical requirements regarding hardware issues and software support. This is particularly problematic in a multidisciplinary research area such as wireless sensor networks, where close collaboration between users, application domain experts, hardware designers, and software developers is needed to implement efficient systems (see figure 1).

A classification of sample applications according to the design space is presented, considering deployment, mobility, resources, cost, energy, heterogeneity, modality, infrastructure, topology, coverage, connectivity, size, lifetime and QoS. These sample applications are: Great Duck (bird observation on Great Duck island), ZebraNet, Glacier (glacier monitoring), Herding (cattle herding), Bathymetry, Ocean (ocean water monitoring), Grape (grape monitoring), Cold Chain (cold chain management), Avalanche (rescue of avalanche victims), Vital Sign (vital sign monitoring), Power (power monitoring), Assembly (parts assembly), Tracking (tracking military vehicles), Mines (self-healing mine field) and sniper (sniper localization) [24].

Many researchers are currently engaged in developing the technologies needed for different layers of the sensor networks protocol stack. A list of current sensor network research projects is given. Along with the current research projects, we encourage more insight into the problems and intend to motivate a search for solutions to the open research issues described. These current research projects are (Project name): SensorNet, WINS, SPINS, SINA, mAMPS, LEACH, SmartDust, SCADDS, PicoRadio, PACMAN, Dynamic Sensor Networks, Aware Home, COUGAR and Device Database Project DataSpace [26]. Some applications for different areas are shown in table I.

TABLE I - Some applications for different areas

Area	Applications
Industrial	Monitoring and control of industrial equipment (LR-WPAN [2]). Factory process control and industrial automation [22]. Manufacturing monitoring [17].
Military	Military situation awareness [22]. Sensing intruders on bases, detection of enemy units movements on land/sea, chemical/biological threats and offering logistics in urban warfare [13]. Battlefield surveillance [17]. Command, control, communications, computing, intelligence, surveillance, reconnaissance, and targeting systems [26].
Location	Location awareness (LR-WPAN and Bluetooth [2]). Person locator [17].
Mobile wireless low-rate networks for precision location	Tracking of assets, people, or anything that can move in various environments, including industrial, retail, hospital, residential, and office environments, while maintaining low-rate data communications for monitoring, messaging, and control [2].
Physical world	Monitor and control the physical world: deployment of densely distributed sensor/actuator networks for a wide range of biological and environmental monitoring applications, from marine to soil and atmospheric contexts; observation of biological, environmental, and artificial systems; environmental monitoring of water and soil, tagging small animals unobtrusively, and tagging small and lightweight objects in a factory or hospital setting [23].
Public safety	Sensing and location determination at disaster sites [2,3].
Automotive	Tire pressure monitoring [2,3]. Active mobility [24]. Coordinated vehicle tracking [22].
Airports	Smart badges and tags [2,3]. Wireless luggage tags [2]. Passive mobility (e.g., attached to a moving object not under the control of the sensor node) [24].
Agriculture	Sensing of soil moisture, pesticide, herbicide, pH levels [2,3].
Emergency situations	Hazardous chemical levels and fires (petroleum sector) [2]. Fire/water detectors [13]. Monitoring disaster areas [26].
Rotating machinery	Monitoring and maintenance (electric sector) [2].
Seismic	Warning systems [13].
Commercial	Managing inventory, monitoring product quality [17,26].
Medical/ Health	Monitoring people’s locations and health conditions [17]. Sensors for: blood flow, respiratory rate, ECG (Electrocardiogram), pulse oxymeter, blood pressure, and oxygen measurement [21]. Monitor patients and assist disabled patients [26].
Ocean	Monitoring fish [17].

9. Manufacturers

Technological progress in wireless networks, low-power circuit design, and micro electro-mechanical systems (MEMS) has led to the production of tiny sensor devices about a cubic inch in size, bringing us closer to connecting the physical world with pervasive networks. These sensor devices do not only have the ability to communicate information across the sensor network, but also to cooperate in performing more complex tasks, like signal processing, data aggregation and compression [25].

Motes developed at UC Berkeley and manufactured by Crossbow Inc. [27] are one example of these tiny sensor devices. With their small physical size, sensing and computing capabilities, motes are highly practical and currently used for various purposes ranging from habitat and environmental monitoring to different data collection applications [25].

Some applications with Motes, Smart Dust Sensors and Wireless Sensor Networks are shown in table II.

TABLE II - Some applications with Motes, Smart Dust Sensors and Wireless Sensor Networks

Applications	Motes, Smart Dust Sensors and Wireless Sensor Networks
In general	Indoor/Outdoor Environmental Monitoring, Security and Tracking, Health and Wellness Monitoring, Power Monitoring, Inventory Location Awareness, Factory and Process Automation and Seismic and Structural Monitoring.
For Industrial and Vibration Monitoring	Plant-wide telemetry, Compliance and quality measurements, Overlay monitoring, SCADA systems, Machine health diagnostics, Waste water and tank monitoring, Utility power-line monitoring and Automotive performance monitoring.
For Test and Measurement	Vibration and Machine Health Measurement, product test/qualification, and scientific research. There are several major product categories of sensors: Accelerometers, Vibration Sensors, Inertial Sensors, Tilt/Angle Sensors, Magnetic Sensors, data acquisition accessories and distributed and wireless data acquisition.
For advanced wireless	Small size, low cost, unobtrusive, unattended, wireless, onboard processing and communications, dynamic reprogramming, development of dense wireless sensor networks and message hopping.
Available sensor boards	Light and Temperature, Acceleration/Vibration (2-Axis), Acoustic, Magnetometer, Weather Monitoring and GPS.

Customers benefit by: Reducing the costs of hard-wiring and maintaining sensor deployments, Clearing safety and regulatory obstacles to running cables in constricted or dangerous areas, and Improving operational visibility thereby catching problems before they occur and before they create millions of dollars in down-time losses.

Some Electric Sector applications based mainly in monitoring subsystems and power devices are shown in table III.

TABLE III - Electric Sector applications (monitoring subsystems and power devices)

Electric Sector Applications
Power transmission line monitoring
Gas-insulated power transmission line monitoring
Power transmission tower monitoring
Underground cable monitoring
In-pipe underground cable monitoring
Thermoelectric power plant monitoring (water vapor generador, water vapor turbine, condenser)
Electric power generator monitoring
Turbogas unit monitoring
Power plant dam monitoring
Power transformer monitoring
Power switch monitoring
Current transformer and power transformer monitoring
Power circuit-braker monitoring
Battery bank monitoring
Lightning (Surge) Arrester monitoring

Some MEMS-based sensors solutions for the Electric Sector applications are shown in table IV (some sensors available and some other to be developed).

TABLE IV - MEMS-based sensors solutions for the Electric Sector applications

MEMS-based sensors
Nanoscale strength
Mechanical bearing
“smart splice” (for high-voltage transmission lines transmitting data to engineers)
Ultrasound micromotors (high frequency vibrations to rotor or ruler movement through a controller)
Local position
Vibration to electrical energy
Damage detection (structural elements condition)
Acelerometer (seismic)
Wind pressure
Strain gages
Gas leakage
Intra-pipe inspection (inside the pipe) and between pipes [already applied to nuclear power plants using a MEMS-based mini-robot]
Chemical, gas, relative humidity and chemical reaction infrared sensor.
Force sensing
Vibration for geophysical applications
Underground cable displacements (sensors alert engineers)
Temperature
Viscosity
Pressure
Flow
Oxygen concentration in gases
Gases for nitrogen oxides, sulphur oxides, oxygen, carbon monoxide and carbon bioxide.
Boiler escaping gases
Magnetic field
Voltage
Electric field
Vibrations
Oil composition
Gases
Oil level
Microdisplacement
Strain
Concrete structure vibrations
Oil humidity
Event counter
Temperature in the joint

10. Conclusion

In this research work, a survey on Wireless Sensor Networks (WSN) and their technologies, standards and applications was carried out. Wireless sensor networks consist of small nodes with sensing, computation, and wireless communications capabilities. Many routing, power management, and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue. Routing protocols in WSNs might differ depending on the application and network architecture.

When compared with now classical MANETs (Mobile Ad hoc Network), sensor networks have different characteristics, and present different design and engineering challenges. One of the main aspects of sensor networks is that the solutions tend to be very application-specific.

Wireless ad-hoc sensor networks have great longterm economic potential, ability to transform our lives, and pose many new system-building challenges. Sensor networks also pose a number of new conceptual and optimization problems. Some, such as location, deployment, and tracking, are fundamental issues, in that many applications rely on them for needed information. Coverage in general, answers the questions about quality of service (surveillance) that can be provided by a particular sensor network. The integration of multiple types of sensors such as seismic, acoustic, optical, etc. in one network platform and the study of the overall coverage of the system also presents several interesting challenges. Also, an integrated framework for sensor placement that incorporates power management and fault tolerance.

The basic topology desired in data-gathering wireless sensor networks is a spanning tree, since the traffic is mainly in the form of many-to-one flows.

A sensor that efficiently transduces environmental energy into useful electrical energy is an energy harvester. With the refinement of energy harvesting techniques that can gather useful energy from vibrations, blasts of radio energy, and the like, self-powered circuitry is a very real possibility.

Current security mechanisms in ad-hoc sensor networks do not guarantee reliable and robust network functionality. Even with these mechanisms, the sensor nodes could be made non-operational by malicious attackers or physical break-down of the infrastructure. Robustness and fault-tolerance of the sensor network topologies comes as a tradeoff with the vulnerability of the network topologies to various threats.

In a constant search for efficient security control and intrusion detection systems (IDS), the ultimate goal in designing protocols remains less resource consumption while possessing broad coverage and wider applicability. Wireless sensors have become an excellent tool for military applications involving intrusion detection, perimeter monitoring, information gathering and smart logistics support in an unknown deployed area. Some other applications are: the design of a sensor-based personal health monitor, location detection with sensor networks, and using wireless sensor networks to perform movement detection.

The flexibility, fault tolerance, high sensing fidelity, low cost, and rapid deployment characteristics of sensor networks create many new and exciting application areas for remote sensing. In the future, this wide range of application areas will make sensor networks an integral part of our lives. However, realization of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, hardware, topology change, environment, and power consumption.

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