

Wireless Sensor Network: At a Glance

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1. Introduction

Wireless Sensor Network is a technology which has capability to change many of the Information Communication aspects in the upcoming era. From the last decade Wireless Sensor Networks (WSNs) is gaining magnetic attention by the researchers, academicians, industry, military and other ones due to large scope of research, technical growth and nature of applications etc. Wireless Sensor Networks (WSNs) employ a large number of miniature disposable autonomous devices known as sensor nodes to form the network without the aid of any established infrastructure. In a Wireless Sensor Network, the individual nodes are capable of sensing the environments, processing the information locally, or sending it to one or more collection points through a wireless link. Day to day applications of WSNs is increasing from domestic use to military use and from ground to space.

The objective of this book chapter is to explore all aspects of WSNs under different modules including these as well in a systematic flow: Sensor nodes, Existing hardware, Sensor node's operating systems, node deployment options, topologies used for WSN, architectures, WSN lifecycle, Resource constraint nature, Applications, Existing experimental tools, Usability & reliability of experimental tools, Routing challenges and Protocol design issues, Major existing protocols, Protocol classifications, Protocols evaluation factors, Theoretical aspects of major Energy Efficient protocols, Security issues, etc.

This chapter contains from very basic to high level technical issues obtained from highly cited research contribution in a concluding manner but presenting whole aspects related to this field.

2. Wireless sensor nodes and existing hardware

Wireless sensor nodes are tiny, light weight sensing devices consists of a constrained processing unit, little memory, EEPROM or Flash memory for tiny operating systems and other desired programs, one or more sensors, a limited range transceiver, battery or solar based power unit and optionally a mobility subsystem for mobile sensor nodes (Dwivedi & Vyas, 2010).

Tatiana Bokareva presented a mini hardware survey related to wireless sensor nodes (Tatiana), except this a comprehensive listing of existing wireless sensor nodes is presented

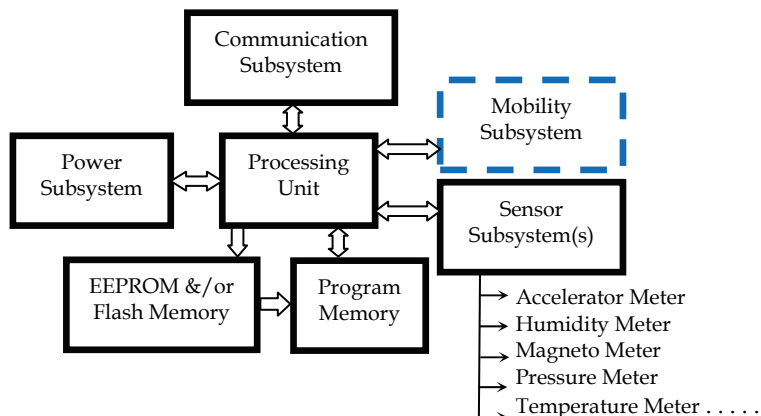


Fig. 1. Block diagram of wireless sensor node

and maintained by Imperial College London (ICL, 2007), Embedded WiSeNts Platform Survey (Embedded WiSeNts, 2006) presents an in-depth survey of five popular wireless sensor nodes (ESB/2, BTnode, uNode, Tmote Sky, and EYES IFXv2), another pretty listing is presented by University of California's Sensor Network Systems Laboratory (Senses, 2005). As well as Sensor Network Museum (SNM, 2010) maintained by TIK computer Engineering and Networks Laboratory, ETH Zurich presents a collection of reference data and links for commonly used wireless sensor nodes and related links. In a research contribution (Manjunath, 2007), technical specifications of some well known wireless sensor nodes are presented in tabular format, as here in its original (Table 1).

Resource footprint (Tatiana; ICL, 2007; Embedded WiSeNts, 2006; Senses, 2005; SNM, 2010; Manjunath, 2007) for various currently available Wireless Sensor nodes provides us a summary that most of the Nodes belongs to within the following configuration:

- 4-bit to 8-bit processor
- 512 Byte to 512 KB RAM (Program and Data Memory)
- 4 KB to 4 MB Flash/External Memory
- 250 Kbps 2.4 GHz IEEE 802.15.4 or Bluetooth 2.0 or 10 Kbps etc. as radio transceiver

On the basis of above mentioned resource footprint it can be concluded that each and every currently available sensor nodes face limited resource problems such as narrow address space and slow clock cycle of micro controller, small program and data memory as well as external memory, low bandwidth and low range of transceivers.

Table 2 presents a wider look on technical aspects of some hardware systems for WSNs, because hardware designing requires a holistic approach for WSNs, looking at all areas of the design space. Expanding the uses of WSNs for various applications, expect more performance for less power out of the hardware platforms. Envision a future of WSNs made up of ultra low power nodes that provide high power computation and can be deployed for decades is possible only with more research effort (Hempstead et al., 2008).

3. Operating systems for wireless sensor nodes

WSNs are composed of large numbers of tiny-networked devices that communicate untethered. Operating systems are at the heart of the sensor node architecture. In terms of

Table 1. A summarized list of some popular wireless sensor node (Manjunath, 2007)

S.N.	Platform	MCU	RAM	Code Memory	RF Transceiver	
1.	Mica	Atmel ATmega128L	4KB	128KB	TR1000	
2.	Mica2	Atmel ATmega128L	4KB	128KB	CC1000	3
3.	Mica2Dot	Atmel ATmega128L	4KB	128KB	CC1000	3
4.	MicaZ	Atmel ATmega128L	4KB	128KB	CC2420	
5.	Cricket	Atmel ATmega128L	4KB	128KB	CC1000	
6.	TelosA	TIMSP430	2KB	60KB	CC2420	
7.	TelosB	TIMSP430	10KB	48KB	CC2420	
8.	BNode3	Atmel ATmega128L	64KB	128KB	Zeevo-BT/CC1000	2
9.	EYES	TIMSP430	4KB	60KB	TR1001	
10.	Intel mote	ARM7TDMI (Core)	64KB	512KB	Zeevo-BT	
11.	Intel mote2	PXA27x (Core)	256KB	32MB	CC2420	
12.	MANTIS nymph	Atmel ATmega128L	4KB	128KB	CC1000	315
13.	XYZ mote	ARM7TDMI (Core)	32KB	256KB	CC2420	
14.	ECR	TIMSP430	2KB	60KB	TR1001	
15.	ESB	TIMSP430	2KB	60KB	TR1001	
16.	Smart-Its mote	Atmel ATmega103L	4KB	128KB	Ericsson-BT/TR1001	2.
17.	Tmote Sky	TIMSP430	10KB	48KB	CC2420	
18.	TinyNode 584	TIMSP430	10KB	48KB	Xemics XE1205	
19.	ZebraNet H/W	TIMSP430	2KB	60KB	9XStream	

SN	System	Arch Style	Data path width	Event driven (Y/N)	Circuit Techniques	Accelerators	Memory (KB)	Process
1.	Atmel ATmega128L	GP Off-the-shelf	8	N	N	N	132KB	350nm
2.	TI MSP430	GP Off-the-shelf	16	N	N	N	10KB	NA
3.	SNAP/LE	GP RISC	16	Y	Asynchronous	Timer, message interface	8KB	180nm
4.	BitSNAP	GP RISC Bit-serial datapath	16	Y	Asynchronous	Timer, message interface	8KB	180nm
5.	Smart Dust	GP RISC	8	N	Synchronous - 2 clock	None	3.125KB	250nm
6.	Charm	Protocol processor	NA	N	Two power domains	Custom radio stack	68KB	130nm
7.	Michigan 1	GP	8	Y	Sub-threshold	None	0.25KB	130nm
8.	Michigan 2	GP	8	Y	Sub-threshold	None	0.3125KB	130nm
9.	Harvard	Event driven accelerator	8	Y	VDD-gating	Timer, filter, message proc	4KB	130nm

Table 2. Technical specification for some hardware systems for Wireless Sensor Network (Hempstead et al., 2008)

Wireless Sensor Networks we need these things in operating system architectures: Extremely small footprint, extremely low system overhead and extremely low power consumption. When designing or selecting operating systems for tiny-networked sensors, our goal is to strip down memory size and system overhead because typical wireless sensor nodes are equipped with a constrained processing unit, little memory, EEPROM or Flash memory, battery or solar based power unit. In a research contribution (Hempstead et al., 2008) and in a technical report (Fröhlich & Wanner, 2008) three classifications of O. S. architectures are described for wireless sensor nodes: Monolithic, Modular/Micro and Virtual Machine.

After evaluating various research contributions specifically devoted to operating systems used for wireless sensor nodes (Fröhlich & Wanner, 2008, Reddy et al., 2007; Dwivedi et al., 2009a; Manjunath, 2007) total 39 operating systems are identified:

1.	TinyOS	2.	Contiki	3.	Mantis OS
4.	Microsoft .NET Micro	5.	YATOS (Yet Another Tiny OS)	6.	BTnutOS or NutOS
7.	PeerOS	8.	Embedded Linux	9.	NanoRK
10.	µCOS	11.	Squawk VM	12.	SensorOS
13.	MagnetOS	14.	CORMOS	15.	Bertha
16.	kOS	17.	VMSTAR	18.	Maté
19.	CVM	20.	EYES	21.	SenOS
22.	DCOS	23.	t-Kernel	24.	Nano-QPlus
25.	SmartOS	26.	AVRX	27.	Pixie
28.	LiteOS	29.	T2	30.	OSSTAR
31.	Jallad	32.	CustomOS	33.	GenOS
34.	MoteWorks	35.	NanoVM	36.	ParticleVM
37.	KVM	38.	AmbiCompVM	39.	SOS

Table 3. List of operating systems available for Wireless Sensor Nodes

D. Manjunath presents a review of current operating systems for WSNs (Manjunath, 2007) whose aims were to explicate “why sensor operating systems are designed the way they are”. This technical report questions every design decision, and provide a detail reasoning for why these decisions.

4. Node deployment options in wireless sensor networks

As we know that WSN is deployed to measure environment parameters in Region of Interest (ROI) and to send it to a controller node or base station. In WSNs how nodes will deployed is basically application specific and totally dependent on environment. The node deployment option affects the performance of routing protocol basically in terms of energy consumptions. Basically there are three ways in which tiny sensor nodes can be deployed in a wireless sensor network environment:

- **Regular Deployment** - Sensor nodes can be deployed in a well planned, fixed manner; not necessarily geometric structure, but that is often a convenient assumption. In this type of deployment data is routed through a predefined path.

Area of Use: Medical and health, Industrial sector, Home networks, etc.

- **Random Deployment** - Sensor nodes are scattered over finite area. When the deployment of nodes is not predefined optimal positioning of cluster head becomes a critical issue to enable energy efficient network operation. Random deployment is generally used in rescue operations.
Area of Use: Environmental and Habitual monitoring, etc.
- **Sensor Nodes with Mobility** - Can move to compensate for deployment shortcomings; can be passively moved around by some external force (wind, water, vehicle); can actively seek out "interesting" areas.
Area of Use: Battle field surveillances, Emergency situations (Fire, Volcano, Tsunami), etc.

5. Topologies used for wireless sensor networks

Wireless sensor nodes are typically organized in one of three types of network topologies:

- In a **star topology**, each node connects directly to a gateway.
- In a **cluster tree topology**, each node connects to a node higher in the tree and then to the gateway, and data is routed from the lowest node on the tree to the gateway.
- Finally, to offer increased reliability, **mesh networks** feature nodes that can connect to multiple nodes in the system and pass data through the most reliable path available.

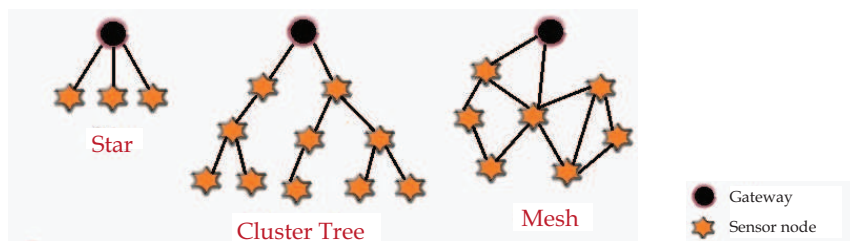


Fig. 2. Topologies used for Wireless Sensor Networks

Three phases related to topology maintenance and changes has been presented in a research contribution (Akyildiz et al., 2002a):

- Pre-deployment and Deployment phase
- Post-deployment phase
- Redeployment of additional nodes phase

6. Architectures for wireless sensor networks

In a technical report (Karl & Willig, 2003) Holger Karl and Andreas Willig present views on WSN architectures in the light of principle differences in application scenarios and underlying communication technology. The architecture of WSNs will be drastically different both concerning a single node and the network as a whole. Wide range of sensor node architectures has been presented till today but as a general design principle all of them have targeted the following objectives: energy efficiency, small size and low cost. The architecture for network as a whole is a set of principles that guide where functionality should be implemented along with a set of interfaces, functional units, protocols, and physical hardware that follows those guidelines.

In another research paper (Dulman & Havinga, 2005) the characteristics of wireless sensor networks from an architectural point of view is presented. Since WSNs are designed for specific applications so there is no precise architecture to fit them all but rather a common set of characteristics that can be taken as a starting point. In same paper a data-centric architecture is also presented.

A research paper (NeTS-NOSS, 2007) presents six aspects of architecture for WSN: Design Principles, Functional Architecture, Programming Architecture, Protocol Architecture, System Support Architecture and Physical Architecture. This paper also states that “The situation today in sensor networks is that none of these six levels of network system architecture are ‘solved’ or even clearly established. The vast majority of the studies fall in the category of protocol architecture”.

In a research paper (Vazquez et al., 2009), an architecture for integrating Wireless Sensor Networks into the Internet of Things called “Flexeo” is presented. In another research paper (Schott et al., 2007) a flexible protocol architecture “e-SENSE” for WSNs has been introduced, which is well-suited for capturing the context surrounding service users in order to enable a variety of advanced context-aware applications in beyond 3G mobile communication systems.

7. Wireless sensor networks lifecycle

Characteristically, there are four phases in the lifecycle of a wireless sensor network (the implementation phase is omitted because the sensor code is frequently reused). Researchers are usually involved in the planning and deployment phase, while the final customers are more interested in monitoring and control the WSN.

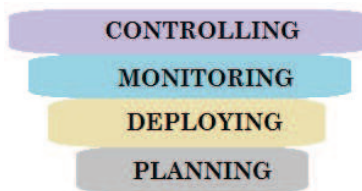


Fig. 3. Wireless sensor network lifecycle

- Planning WSNs** Planning phase usually involves the inspection of the deployment area and the selection of the correct locations to position the sensors in a way that accomplishes the intended goal.
- Deploying WSNs** In the deployment phase, sensor nodes continually send their wireless connection quality and route to the base.
- Monitoring WSNs** In this phase, the user interest is mainly focuses on the values read by network sensors.
- Controlling WSNs** The application can also be used to control WSNs by sending commands to the network. These commands can tell the network devices to stop sending messages, increase the time between messages or even reset the network (restart the Multi-Hop algorithm). In future, WSNs could be controlled via a web interface or a handheld device, being easier to stop and restart the network as needed.

8. Resource constraint nature of wireless sensor networks

Wireless Sensor Networks (WSNs) employ a large number of miniature disposable autonomous devices known as sensor nodes to form the network without the aid of any established infrastructure. In a Wireless Sensor Network, the individual nodes are capable of sensing their environments, processing the information locally, or sending it to one or more collection points through a wireless link. Sensor node may fail due to lack of energy, physical damage, communications problem, inactivity (a node becomes suspended), or environmental interference. Resource footprint for various currently available Wireless Sensor nodes is presented in section 2, obtained from (Tatiana; ICL, 2007; Embedded WiSeNts, 2006; Senses, 2005; SNM, 2010; Manjunath, 2007). Here is a table focuses on resource constraint nature of Wireless Sensor Nodes and obviously WSNs:

Node	CPU	Memory	Radio
Rene 1999	ATMEL 8535	512 Byte RAM 8 KB Flash	10 Kbps
Mica-2 2001	ATMEGA 128	4 KB RAM 128 KB Flash	76 Kbps
Telos 2004	Motorola HC 508	4 KB RAM	250 Kbps
Mica-Z 2004	ATMEGA 128	4 KB RAM 128 KB Flash	250 Kbps
BT Node 2001	ATMEL Mega 128L	128 KB Flash 4 KB EEPROM 4 KB SRAM	Bluetooth
Imote 1.0 2003	ARM 7TDMI	64 KB SRAM 512 KB Flash	Bluetooth
Stargate 2003	Intel PXA 255	64 KB SRAM	Serial Connection to Sensor Network
Insynsnc Cerfoube 2003	Intel PXA 255	32 KB Flash 64 KB SRAM	
PC 104	X86 Processor	32 KB Flash 64 KB SRAM	

Table 4. Presenting resource constraint nature of some popular wireless sensor nodes

9. Applications of wireless sensor networks

WSNs can be applied in a wide range of areas, such as: habitat monitoring and tracking, disaster relief, emergency rescue operation, home networks, detecting chemical/biological/radiological/nuclear/explosive material, monitoring patents and elderly people, asset and warehouse management, building monitoring and control, fleet monitoring, military battlefield awareness and surveillance, security and surveillance, environmental monitoring, pipeline corrosion monitoring, homeland security, monitoring conditions of buildings and bridges, industrial process monitoring and control, machine health monitoring, healthcare applications, home automation, traffic control, etc.

With the help of research contributions (Biradar et al., 2009; Katiyar et al., 2010) a table is presented here, which systematically summarized some applications for different areas:

Area	Applications
Military	<ul style="list-style-type: none"> • Military situation awareness. • Sensing intruders on basis. • Detection of enemy unit movements on land and sea. • Battle field surveillances
Emergency situations	<ul style="list-style-type: none"> • Disaster management. • Fire/water detectors. • Hazardous chemical level and fires.
Physical world	<ul style="list-style-type: none"> • Environmental monitoring of water and soil. • Habitual monitoring. • Observation of biological and artificial systems. • Marginal Farming.
Medical and health	<ul style="list-style-type: none"> • Sensors for blood flow, respiratory rate, ECG (electrocardiogram), pulse oxymeter, blood pressure and oxygen measurement. • Monitoring people's location and health condition.
Industry	<ul style="list-style-type: none"> • Factory process control and industrial automation. • Monitoring and control of industrial equipment. • Machine health monitoring.
Home networks	<ul style="list-style-type: none"> • Home appliances, location awareness (blue tooth). • Person locator.
Automotive	<ul style="list-style-type: none"> • Tire pressure monitoring. • Active mobility. • Coordinated vehicle tracking.
Area monitoring	<ul style="list-style-type: none"> • Detecting enemy intrusion • Geo-fencing of gas or oil pipelines. • Detecting the presence of vehicles.
Environmental monitoring	<ul style="list-style-type: none"> • Air pollution monitoring. • Forest fires detection. • Greenhouse monitoring. • Landslide detection. • Volcano monitoring. • Flood detection.
Water/Wastewater monitoring	<ul style="list-style-type: none"> • Landfill ground well level monitoring and pump counter. • Groundwater arsenic contamination assessment. • Measuring water quality.
Cognitive sensing	<ul style="list-style-type: none"> • Bio-inspired sensing. • Swarm intelligence. • Quorum sensing.
Underwater acoustic sensor systems	<ul style="list-style-type: none"> • Oceanographic data collection. • Pollution monitoring. • Disaster prevention. • Assisted navigation. • Tactical surveillance.
Traffic Management & Monitoring	<ul style="list-style-type: none"> • Traffic congestion control. • Road Surface Condition Monitoring (BusNet in Sri Lanka).

Table 5. Some applications of WSNs in different areas

Deploying nodes in an unattended environment will provide more possibilities for the exploration of new applications. WSNs will be ubiquitous in the near future, due to new opportunities for the interaction between humans and their physical world also WSNs are expected to contribute significantly to pervasive computing.

10. Existing standards for wireless sensor networks

WSNs fascinate a number of standardization bodies to develop standards, due to a smaller amount of standards exists for WSNs in comparison to other wireless networks. A number of standards are currently under development or ratified for WSNs. Some standardization bodies working in the specific field of WSNs to setup standards, such as:

Standardization body	Specific work area for WSN
Institute of Electrical and Electronics Engineers	Physical layer and MAC sub layer of Data link layer.
Internet Engineering Task Force	Data link layer and all above layers of WSN protocol stack.
International Society of Automation	All layers of WSN protocol stack
DASH7 Alliance	Promotes the use of the ISO 18000-7 standard for wireless sensor networks.

Table 6. Some main Standardization bodies and their specific work area

Apart from these several non-standard, proprietary mechanisms and specifications also exist. The most commonly used predominant standards in WSNs include:

IEEE 802.15.4	Standard for low-rate, wireless personal area networks, defines the "physical layer" and the "medium access layer".
Zigbee	ZigBee builds upon the 802.15.4 standard to define application profiles that can be shared among different manufacturers.
IEEE 802.11	Standards efforts for low-power Wi-Fi.
IEEE 1451	The objective of this standard is to make it easier for different manufacturers to develop smart sensors and to interface those devices to networks.
ISA100	Addresses wireless manufacturing and control systems in the areas of the: Environment, Technology and life cycle, and Application of Wireless technology.
6LoWPAN	IPv6 over low-power wireless networks, defines an adaptation layer for sending IPv6 packets over IEEE 802.15.4.
uIPv6	uIPv6 is the world's smallest certified open source IPv6 stack provides TCP/IP connectivity to tiny embedded 8-bit micro controllers for low-cost networked device such as sensors and actuators with maintained interoperability and RFC standards compliance.

Table 7. Predominant standards in field of WSNs

11. Existing experimental tools for wireless sensor networks

Research activities in the area of Wireless Sensor Networks (WSNs) need expositive performance statistics about scenario, systems, protocols, gathered data, applications and many more. There are various experimental tools for fulfilling these requirements, someone are in practical use while other one are in literatures. In this part of chapter a glance on currently available simulation tools/frameworks, emulators, visualization tools, testbeds, debuggers, code-updaters and network monitoring tools used for wireless sensor networks is presented (Dwivedi & Vyas, 2011).

11.1 Simulator/simulation framework

A simulator is a software that imitates selected parts of the behavior of the real world. Depending on the intended usage of the simulator, different parts of the real-world system are modeled and imitated. The parts that are modeled can also be of varying abstraction level. A wireless sensor network simulator imitates the wireless media and the constraints nodes in the network. Some sensor network simulators have a detailed model of the wireless media including effects of obstacles between nodes, while other simulators have a more abstract model.

Type of simulation

Simulators either run as in an asynchronous mode, event triggered mode, or in synchronous mode, where events happen in parallel in fixed time slots (DCG's Sinalgo, 2009):

- *Synchronous simulation*
The synchronous simulation is purely based on rounds.
- *Asynchronous Simulation*
The asynchronous simulation is purely event based.

Categorization of simulators

A large number of sensor network simulators have been proposed by researchers. In a research contribution WSN Simulators are categorized (Eriksson, 2009) as:

- *Generic Network Simulators*
- *Code Level Simulators*
- *Firmware Level Simulators*

In another research contribution (Shu et al., 2009), simulators have been classified into the following three major categories based on complexity:

- *Algorithm Level Simulators*
- *Packet Level Simulators*
- *Instruction Level Simulators*

Several simulators exist that are either adjusted or developed specifically for wireless sensor networks. Here is a table presenting 63 simulators/simulation frameworks (Table 8).

11.2 Emulator or emulation environment

As a networked embedded system, a WSN application involves sensor node hardware, its drivers, operating systems, and networking protocols. As a result, the performance of the WSN application depends on all of these factors in addition to its implementation. An emulator is a special type of simulator whose aims is to enable realistic performance evaluation for WSN applications. Emulation environment or emulators are good choice, in

1.	Network Simulator (NS)	2.	Mannasim (NS-2 Extension for WSNs)	3.	DiSenS (Distributed SENSor network Simulation)
4.	(J) Prowler	5.	LecsSim	6.	WISDOM
7.	TOSSIM	8.	OPNET	9.	Sinalgo
10.	TOSSF	11.	SENS	12.	SENSORIA
13.	PowerTOSSIMz	14.	EmStar/Em*	15.	Capricorn
16.	ATEMU	17.	EmTOS	18.	SIDnet-SWANS
19.	COOJA	20.	SenQ	21.	Stargate Simulator (starsim)
22.	GloMoSim (Global Mobile Information Systems Simulation)	23.	H-MAS (Heterogeneous Mobile Ad-hoc Sensor-Network Simulation Environment)	24.	JiST/SWANS (Java in Simulation Time/ Scalable Wireless Ad hoc Network Simulator)
25.	QualNet	26.	SensorSim	27.	SNSim
28.	SENSE	29.	Shawn	30.	SNIPER-WSNSim
31.	VisualSENSE	32.	NetTopo	33.	SNAP
34.	AlgoSenSim	35.	Atarraya	36.	SimPy
37.	Georgia Tech Network Simulator (GTNetS)	38.	SSFNet (Scalable Simulation Framework)	39.	Mule
40.	OMNet++	41.	WiseNet	42.	CaVi
43.	Castalia	44.	SimGate	45.	Ptolemy
46.	J-Sim (formerly JavaSim)	47.	SimSync	48.	Maple
49.	Mote simulator (motesim)	50.	SNetSim	51.	WISENES (Wireless Sensor Network Simulator)
52.	JiST/SWANS++	53.	SensorMaker	54.	WSNet-Worldsens and WSim
55.	Avrora	56.	TRMSim-WSN	57.	LSU SensorSimulator
58.	Sidh	59.	PAWiS	60.	WSNGE
61.	Prowler	62.	OLIMPO	63.	TikTak

Table 8. Simulator/simulation frameworks specifically designed for WSNs

which WSN applications can be directly run for testing, debugging, and performance evaluation. Additionally, studies on the lower layers (e.g., hardware drivers, OS, and networking) as well as cross-layer techniques can also be done in this environment by plugging the target modules into the emulator. Here is a table which presents 14 emulators:

1.	VMNET	2.	Freemote	3.	UbiSec&Sens
4.	ATEMU	5.	EmPro	6.	Emuli
7.	Emstar	8.	NetTopo	9.	MSPSim
10.	TOSSIM	11.	OCTAVEX	12.	MEADOWS
13.	AvroraZ/Avrora	14.	SENSE		

Table 9. Emulators specifically designed for WSNs

11.3 WSN data visualization tools

With the increase in applications for sensor networks, data manipulation and representation have become a crucial component of sensor networks. The data gathered from WSNs is usually saved in the form of numerical form in a central base station. There are many programs that facilitate the viewing of these large amounts of data. These special programs are called data visualization tool for WSNs. Visualization tools can support different data types, and visualize the information using a flexible multi-layer mechanism that renders the information on a visual canvas. Here is a table presenting 19 data visualization tools (Parbat et al., 2010) that are especially designed and developed for WSNs applications:

1. SpyGlass	2. TOSGUI	3. <i>Oscilloscope</i>
4. MoteView	5. MSR Sense	6. GSN
7. TinyViz	8. Trawler	9. WiseObserver
10. XbowNet	11. SNAMP	12. SenseView
13. MonSense	14. Surge Network Viewer	15. <i>MeshNetics WSN Monitor</i>
16. NetTopo	17. Mica Graph Viewer	18. MARWIS
19. Octopus		

Table 10. Data visualization tools specifically designed for WSNs

1. Motelab	2. NetEye	3. Sharesense
4. NESC-Testbed	5. INDRIYA	6. Trio
7. WUSTL	8. CLARITY	9. sMote
10. CitySense	11. GNOMES	12. CTI-WSN Testbed
13. Kansei	14. WSNTB	15. FEEIT WSN Testbed
16. MISTLAB	17. TWIST	18. Roulette
19. Orbitlab	20. X-sensor	21. BigNet
22. Emulab	23. ENL Sensor Network Testbed	24. UCR Wireless Networking Research Testbed
25. WISEBED (Wireless Sensor Network Testbeds)	26. Imote2 Sensor Network Testbed	27. SWOON (Secure Wireless Overlay Observation Network)
28. REALnet	29. PICESNSE	30. WHYNET
31. KonTest	32. SOWNet	33. CENS-Testbed
34. SANDbed	35. IP-WSN Testbed	36. SCADDS WSN Testbeds
37. BANAIID	38. SenseNet	39. Crossbow WSN Testbed
40. Motescope	41. Omega	42. GaTech Testbed
43. TutorNet: A Tiered Wireless Sensor Network Testbed	44. CENSE (A Century of Sensor nodes)	45. Intel Research Berkeley's 150-mote SensorNet Testbed
46. WINTeR (Wireless Industrial Sensor Network Testbed for Radio-Harsh Environments)	47. FireSenseTB: A wireless sensor networks testbed for forest fire detection (Kosucu et al., 2009)	

Table 11. Testbeds used for experimental usage specifically for WSNs

11.4 Testbeds for WSN

To achieve high-fidelity in WSN experiments use of testbed is very productive. Testbeds are an environment that provides support to measure number of physical parameters in controlled and reliable environment. This environment contains the hardware, instrumentations, simulators, various software and other support elements needed to conduct a test. Generally, testbeds allow for rigorous, transparent and replicable testing. By providing the realistic environments for testing the experiments, the testbeds bridge the gap between the simulation and deployment of real devices. The testbeds thus deployed can improve the speed of innovation and productive research. Here is a table presenting 47 testbeds, used for experimental purposes in various universities, colleges, research institutions or by individuals (Table 11).

11.5 Debugging tools/services/concepts

Due to extreme resource constraints nature, deployment in harsh and unattended environments, lack of run-time support tools and limited visibility into the root causes of system and application level faults make WSNs notoriously difficult to debug. Currently, most debugging systems in WSNs are aimed at diagnosing specific faults, such as detection of crashed nodes, sensor faults, or identifying faulty behavior in nodes. There are few debugging solutions for WSNs available, with a fairly wide range of goals and feature sets. Debuggers for WSNs have been categorized (Tavakoli, 2007) into three distinct categories: source-level debuggers, query-oriented debuggers, and decision-tree debuggers. Here is a table presenting 26 debuggers/debugging concepts/debugging concepts:

1. Clairvoyant	2. S ₂ DB	3. ActorNet
4. Dustminer	5. Envirolog	6. ANDES
7. Sympathy	8. NodeMD	9. EvAnT
10. FIND	11. StackGaurd	12. KleeNet
13. Passive Distributed Assertions (PDA)	14. Storage-centric method for Debugging	15. Model-based diagnosis for WSNs
16. Chowkidar	17. Marionette	18. Post-Deployment Performance Debugging (PD2)
19. Nucleus-NMS	20. REDFLAG	21. Declarative Tracepoints
22. Debugging WSNs Using Mobile Actors	23. Monitored External Global State (MEGS)	24. SNTS: Sensor Network Troubleshooting Suite
25. Wringer	26. MDB	

Table 12. Debugging tools/services/concepts specifically useful for WSNs

11.6 Code-updation/reprogramming tool

Large scale WSNs may be deployed for long periods of time during which the requirements from the network or the environment in which the nodes are deployed may change. This may necessitate modifying the executing application or re-tasking the existing application with different sets of parameters, which will collectively refer to as code-updation/reprogramming. The relevant forms of code-updation/reprogramming are (Panta et al., 2009):

- *Remote Multi-hop Reprogramming*
- *Incremental Reprogramming*

Incremental Reprogramming poses several challenges. A class of operating systems, including the widely used TinyOS, does not support dynamic linking of software components on a node. SOS and Contiki, do support dynamic linking, however, their reprogramming support also does not handle changes to the kernel modules. Here is a table presenting 10 code-updaters/reprogramming (Table 13).

1.	Trickle	2.	Deluge	3.	Hermes
4.	FlexCup	5.	Stream	6.	FIGARO
7.	Zephyr	8.	MNP (Multi-hop network reprogramming)	9.	Multihop Over-the-Air Programming (MOAP)
10.	MARWIS (Management ARchitecture for WIreless Sensor Networks)				

Table 13. Code-updaters/Reprogramming tools specifically designed for WSNs

11.7 Network monitoring tools

WSNs are typically composed of low cost tiny hardware devices and tend to be unreliable, with failures a common phenomenon. Accurate knowledge of network health status, including nodes and links of each type, is critical for correctly configuring applications on really deployed WSN and/or WSN testbeds and for interpreting the data collected from them. Here is a table presenting 8 networks monitoring:

1.	Memento	2.	Sympathy	3.	LiveNet
4.	NUCLEUS	5.	HERMES	6.	Chowkidar
7.	DiMo	8.	MARWIS (Management Architecture for heterogeneous Wireless Sensor Networks)		

Table 14. Network monitoring tools specifically designed for WSNs

12. Usability & reliability of experimental tools

The statistics gathered from experimental tools can be realistic and convenient, but due to cost of large number of sensors most researches in wireless sensor networks area is performed by using these experimental tools in various universities, institutes, and research centers before implementing real one. These experimental tools provide the better option for studying the behavior of WSNs before and after implementing the physical one.

Simulators are commonly used for rapid prototyping and also used for the evaluation of new network protocols and algorithms as well as enable repeatability because they are independent of the physical world and its impact on the objects. Moreover, simulations enable nonintrusive debugging at the desired level of detail. In a research contribution various factors have been presented that influences simulation results (Dwivedi et al., 2010). For successful WSN development cooperation not only between test-beds and simulators but also between simulators is required, however, simulators are usually not designed with cooperation in mind (Li et al., 2010).

13. Routing challenges & protocol design issues in WSNs

Routing in WSNs is very challenging due to unique inherent characteristics (energy efficiency and awareness, connection maintenance, minimum resource usage limitation, low

Table 15. Protocol classifications and sub-classifications for WSNs

SN	Main Category	Sub Categories
1.	Classification based on Network Structure (Al-Karaki & Kamal, 2004)	<ul style="list-style-type: none"> • <i>Flat-based or Data Centric routing</i>: In flat-based routing algorithm, all nodes play mainly apply flood based data transferring. • <i>Hierarchical-based or Cluster based routing</i>: Hierarchical protocols aim at clustering. Cluster heads can do some aggregation and reduction of data in order to save energy. Routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used to route data to the destination. • <i>Location-based routing</i>: Location-based protocols utilize the position information of nodes to route data to the desired regions rather than the whole network.
2.	Classification based on Protocol Operation (Al-Karaki & Kamal, 2004)	<ul style="list-style-type: none"> • <i>Multipath-based routing</i>: This type of routing protocols uses multiple paths in order to enhance network performance. • <i>Query-based routing</i>: In this type of routing protocol destination nodes propagate a query (sensing task) from a node through the network, and a node with this data sends the query back to the node that initiated the query. • <i>Negotiation-based routing</i>: These protocols use high-level data descriptors in order to reduce redundant data transmissions through negotiation. Communication decisions are based on the resources available to them. • <i>QoS-based routing</i>: In QoS-based routing protocols, the network has to balance energy consumption and data quality. In particular, the network has to satisfy certain QoS requirements (e.g., energy, bandwidth, etc.) when delivering data to the base station. • <i>Non-coherent & Coherent data-processing based routing</i>: In non-coherent data processing, nodes will locally process the raw data before it is sent to other nodes for further processing.
3.	Classification based on Packet Destination (Karl & Willig, 2006)	<ul style="list-style-type: none"> • <i>Gossiping and agent-based unicast forwarding</i>: These schemas are an attempt of using routing tables in order to minimize the overflow needed to build the tables, as much as possible in stages in which the tables were not built yet. • <i>Energy-efficient unicast</i>: These techniques analyze the network nodes distribution and route data transmitting over the link between two nodes and select an algorithm to calculate the energy cost. • <i>Broadcast and multicast</i>: Many nodes must collect or distribute the information in the network (broadcast). In a similar way, sometimes it is necessary to distribute data to a set of previously known nodes. This process is called multicast. • <i>Geographic routing</i>: This kind of routing appeared due to two main motivations: (1) the destination is specified geographically or relatively (with a location service); (2) the destination is specified randomly to every node in a given region is called geo-casting. • <i>Mobile nodes</i>: These aspects with motion ability should be considered for wireless networks. Mobile sensor nodes, mobile base station, mobile sensed phenomenon or communication are examples.
4.	Crossbow (Xbow) classification (Olivares et al., 2007)	<ul style="list-style-type: none"> • <i>Basic routing (with normal or improved variants)</i> • <i>Reliable routing</i> • <i>Low Power routing</i> • <i>XMesh routing</i>

Table 15. (continues) Protocol classifications and sub-classifications for WSNs

SN	Main Category	Sub Categories
5.	Classification based on State (Eriksson, 2009)	<ul style="list-style-type: none"> • <i>Stateful Ad Hoc routing</i>: Stateful ad hoc routing protocols require node to maintain information that is collected using the routing protocol (e.g., through route reversing paths taken by the query). • <i>Stateless Geometric Ad Hoc routing</i>: These kinds of protocols only track the position and select among them a neighbor that is likely to be closer to the destination.
6.	Classification based on Epidemic behavior (Akdere et al., 2006)	<ul style="list-style-type: none"> • <i>Pull based epidemic algorithm</i>: A node asks a selected neighbor for new information, and requests new information only if the neighbor has new information. • <i>Push based epidemic algorithm</i>: A node with new information sends the information to its neighbor. • <i>Pull-push based epidemic algorithm</i>: This algorithm is a combination of two modes.
7.	Classification based on Sensor Node Architecture (Al-Karaki & Kamal, 2004)	<ul style="list-style-type: none"> • <i>Protocols operating on flat topology (WSN consisting Homogeneous nodes)</i> • <i>Protocols operating on hierarchical topology (WSN consisting Heterogeneous nodes).</i>
8.	Classification based on Protocol's initialization point (Biradar et al., 2009)	<ul style="list-style-type: none"> • <i>Source-initiated (Src-initiated)</i>: A source-initiated protocol sets up the routing paths from the source node, and starting from the source node. Here source advertises the destination and initiates the data delivery. • <i>Destination-initiated (Dst-initiated)</i>: A destination initiated protocol, on the other hand, sets up the routing paths from a destination node.
9.	Classification based on how the source finds the destination (Biradar et al., 2009)	<ul style="list-style-type: none"> • <i>Proactive</i>: A proactive protocol sets up routing paths and states before there is any traffic. Paths are maintained even there is no traffic flow at that time. This approach is best suited for applications having fixed nodes • <i>Reactive</i>: In reactive routing protocol, routing actions are triggered when there is traffic. Paths are disseminated to other nodes. Here paths are setup on demand when queries are received. This approach is best suited for applications mobile nodes • <i>Hybrid</i>: This approach combines both techniques.
10.	Classification based on the basis of how to reduce useful energy consumption (Younis & Fahmy, 2004)	<ul style="list-style-type: none"> • Protocols that control the transmission power level at each node by increasing or decreasing the power level, keeping the network connected. • Protocols that make routing decisions based on power optimization goals. • Protocols that control the network topology by determining which nodes should be active during network operation (be awake) and which should not (remain asleep).
11.	Cooperative routing (Castillo et al., 2007)	<ul style="list-style-type: none"> • In this approach, sensor nodes send data to a central node that join the data to the destination, reducing the energy consumption.

to WSNs these design challenges are identified (Dwivedi et al., 2009a; Eriksson, 2009; Al-Karaki & Kamal, 2004; Karl & Willig, 2006; Akyildiz et al., 2002b; Akkaya & Younis, 2005; Wachs et al., 2007).

- Due to the relatively large number of sensor nodes, it is not possible to build a global addressing scheme for the deployment of a large number of sensor nodes as the overhead of ID maintenance is high. Thus, traditional IP based protocols may not be applied to WSNs.
- In contrast to typical communication networks, almost all applications of sensor networks require the flow of sensed data from multiple sources to a particular Base Station.
- Sensor nodes are tightly constrained in terms of energy, processing, and storage capacities. Thus, they require careful resource management.
- In most application scenarios, nodes in WSNs are generally stationary after deployment except for, may be, a few mobile nodes.
- Sensor networks are application specific, i.e., design requirements of a sensor network change with application.
- Position awareness of sensor nodes is important since data collection is normally based on the location.
- Finally, data collected by various sensors in WSNs is typically based on common phenomena; hence there is a high probability that this data has some redundancy.

Visibility (Wachs et al., 2007) is a new metric for WSNs protocol design. The objective of this visibility metric is that "Minimize the energy cost of diagnosing the cause of a failure or behavior".

14. Major existing protocols for wireless sensor networks

A lot of protocols has been proposed in various research contributions, some of them are as follows: Rumor, DSR, SER (Stream Enabled Routing), AODV, SPIN (Sensor Protocols for Information via Negotiation) (SPIN-PP, SPIN-EC, SPIN-BC, SPIN-RL), GRAB, Direct Diffusion, GAF, SEER (Simple Energy-Efficient Routing), GBR, ARPEES, TIDD, TEEN, CADR, APTEEN, ACQUIRE, CEDAR, COUGAR, SAR, TinyAODV, PEQ (Periodic Event-driven and Query-based), GEAR, HPEQ (Hierarchical PEQ), MECN, CPEQ (Cluster PEQ), SMFCN, HEAP (Hierarchical Energy Aware Protocol for Routing & Aggregation in Sensor Networks), GF, PEGASIS (Power Efficient Gathering in Sensor Information System), GF-RSST, HPEGASIS (Hierarchical PEGASIS), LEACH, etc.

Some good research contributions (Al-Karaki & Kamal, 2004; Wachs et al., 2007) presents survey on existing WSN Protocols, whereas some other good one are dedicated to comparison, classification and other aspects of WSN Protocols (Dwivedi & Vyas, 2010; Biradar et al., 2009; Al-Karaki & Kamal, 2004; Wachs et al., 2007; Castillo et al., 2007).

15. Existing protocol classifications for wireless sensor networks

A careful attention is needed while selecting or proposing a new routing protocols for wireless sensor networks because WSNs are challenging due to the inherent characteristics such as energy efficiency and awareness, connection maintenance, minimum resource usage limitation, low latency, load balancing in terms of energy used by sensor nodes, etc. Various classifications for WSNs are presented in different literatures, at a glance these are (Table 15).

16. Protocol evaluation factors

These are the some parameters on which routing protocols must be evaluated during designing new one:

Evaluation Parameter	Description
Power Usage	Sensor node's lifetime is clearly dependent on its power source, thus useful power usage must be which involves: transmitting/receiving data, processing query requests, forwarding queries/ data to neighboring nodes.
Data Aggregation	Substantial energy savings and traffic optimization can be obtained through data aggregation.
Scalability	The possibility to enlarge and reduce the network.
Reliability or Fault Tolerance	Fault tolerance is the ability to sustain WSN functionalities without any interruption due to node failures.
Latency (delay) and Overhead	Multi-hop relays and data aggregation cause data latency, these important factors influences routing protocol design.
Data Delivery Model	Data delivery model (Continuous, Event-driven, Query-driven , Hybrid) (Ahvar & Fathy, 2010) determines when the data collected by the sensor node has to be delivered.
Quality of Service (QoS)	Quality service required by the application, involves: length of life time, data reliability, energy efficiency, location-awareness, collaborative-processing, etc. QoS factors will affect the selection of routing protocols for a particular application.
Security	Security concerns needs special attention in current era where data stealing and data diddling becomes major issue.
Node Deployment option	Node deployment option affects the performance of routing protocol basically in terms of energy consumptions.
Topology	Topology of a WSN affects many of its characteristics like; latency, capacity, and robustness. As well as, the complexity of data routing and processing depends on the network topology.
Sensor Density and Network Size	Sensor density of nodes affects the degree of coverage area of interest whereas networks size affects reliability, accuracy, and data processing algorithms.
Environment or Scenario	A critical parameter, because node and network lifetime is directly dependent on it.
Byte Overhead (Saaranen & Pomalaza-Ráez, 2004)	Byte overhead means the total number of bytes in the routing control messages needed to find a route to the sink. For flooding, byte overhead means the total number of bytes in the extra messages flooded throughout the network. In both cases the bytes in the data packets transmitted by nodes along the route from the originating node to the sink node are not counted as overhead.

Table 16. WSN Protocol evaluation factors

Except these there are exist some common performance metrics, including latency, throughput, success rates, energy consumption and energy load, that must be calculated for the evaluation of routing algorithms.

17. Theoretical aspects of major energy efficient protocols

A classification on energy efficient/aware routing protocols is available in a research contribution (Ahvar & Fathy, 2010) which classified this type of protocols into: Energy Saver and Energy Manager. Energy saver protocols decrease energy consumption totally because most of them try to find the shortest path between source and destination to reduce energy consumption. The objective of energy manager protocols is to balance energy consumption in networks to avoid network partitioning. In first approach finding best route is totally based on energy balancing consideration, it may lead to long path with high delay and decreases network lifetime whereas in later approach finding best route only with the shortest distance consideration may lead to network partitioning. A lot of researches were conducted on the energy efficiency/awareness issue, some are presented here (Table 17)

18. Security issues in wireless sensor networks

In a survey paper (Dwivedi et al., 2009b) different classes of adversaries, and considers security goals in each scenario (indoor and outdoor) of WSNs, including: sensor nodes, networks of sensor nodes, operating systems, applications, middleware, and internet, are presented. This paper also presents valuable, in-depth recommendations of how to design and implement a security strategy for WSN. A procedure for protecting systems makes sure that the facility is physically secure, provides a recovery/restart capability, and has access to backup files establishing a priority sequence, one would probably want to start from within the firm and work out. Threats and their usual defenses are illustrated in (Figure 4)

Most WSN routing protocols are quite simple thus sometimes even more susceptible to attacks. Most network layer attacks against sensor networks falls under one of the following categories: Selective forwarding, Sinkhole attacks, Sybil attacks, Wormholes, HELLO flood attacks, Spoofed/Altered/Replayed routing information, Acknowledgement spoofing.

Some security issues that must need attention in wireless sensor networks, are as follows: Secure routing, Secure discovery and verification of location, Key establishment and trust setup, Attacks against sensor nodes, Secure group management, and Secure data aggregation.

In the ideal world, a secure routing protocol should guarantee the integrity, authenticity, and availability of messages in the presence of adversaries of arbitrary power. Every eligible receiver should receive all messages intended for it and be able to verify the integrity of every message as well as the identity of the sender. Several countermeasures and design considerations are also proposed in a research contribution (Karlof & Wagner, 2003).

Some mechanisms for authentication and security are based on public key cryptography. Public key cryptography is too expensive for sensor nodes. Security protocols for sensors networks must rely exclusively on efficient symmetric key cryptography. These protocols are too expensive in terms of node state and packet overhead and are designed to find and establish routes between any pair of nodes - a mode of communication not prevalent in sensor networks. Tackling with natural and manmade disasters is only possible with proper planning.

Table 17. Major theoretical aspects of some major energy efficient protocols for WSNs

S.N.	Energy Efficient Protocol	Major Theoretical Aspects
1.	TEEN (Threshold sensitive Energy Efficient sensor Network protocol) (Manjeshwar & Agarwal, 2001)	<ul style="list-style-type: none"> - First protocol for reactive networks with enhanced efficiency. - Time critical data reaches the user almost instantaneously. Eminently well suited for sensing applications. - Message transmission consumes much more energy than data sensing. If data is sensed continuously, the energy consumption in this scheme can potentially be reduced in the network, because data transmission is done less frequently. - The soft threshold can be varied, depending on the criticality of the sensed data in the application. - A smaller value of the soft threshold gives a more accurate picture of the network, but at the cost of increased energy consumption. Thus, the user can control the trade-off between accuracy and energy. - At every cluster change time, the attributes are broadcast afresh and so, the energy consumption is required. - The main drawback of this scheme is that, if the thresholds are not reached, the nodes do not communicate; the user will not get any data from the network at all and eventually all the nodes die. Thus, this scheme is not well suited for applications where data is required on a regular basis. - Another possible problem with this scheme is that a practical implementation of this scheme may have some collisions in the cluster.
2.	APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient Network Sensor Protocol) (Manjeshwar & Agarwal, 2002)	<ul style="list-style-type: none"> - A Protocol for Hybrid network (inherit best characteristics of both proactive and reactive networks). - To provide periodic data collection as well as near real-time warnings about network conditions. - By sending periodic data, it gives the user a complete picture of the network and reacts immediately to drastic changes, thus making it responsive to time critical events. - It offers a flexibility of allowing the user to set the time interval (TC) and the threshold values. - Energy consumption can be controlled by the count time and the threshold values. - The hybrid network can emulate a proactive network or a reactive network by adjusting the count time and the threshold values. - The main drawback of this scheme is the additional complexity required for the periodic data collection functions and the count time. However, this is a reasonable trade-off between accuracy and versatility.
3.	HEED (Hybrid Energy-Efficient Distributed clustering) (Younis & Fahmy, 2004)	<ul style="list-style-type: none"> - An energy-efficient clustering protocol, using residual energy as primary and network topology features (e.g. node degree, distances to neighbors) as secondary. - Here all nodes are assumed to be homogenous nodes (with same initial energy). - It extends the basic scheme of LEACH. - The clustering process is divided into a number of iterations, as well as nodes not covered by any cluster head doubles their probability of becoming a cluster head. - Since it enable every node to independently and probabilistically decide whether to become a cluster head, thus cannot guaranteed optimal elected set of cluster heads.

Table 17. (continues) Major theoretical aspects of some major energy efficient protocols for WSNs

S.N.	Energy Efficient Protocol	Major Theoretical Aspects
4.	H-HEED (Heterogeneous - HEED) (Kour & Sharma, 2010)	<ul style="list-style-type: none"> - A protocol for heterogeneous WSN. - Cluster head selection is primarily based on the residual energy of each consumed per bit for sensing, processing, and communication is typical energy can be estimated. - Intra cluster communication cost is considered as the secondary parameter that a node might fall within the range of more than one cluster head. - Different level of heterogeneity is introduced: 2-level, 3-level and multi-level energy. - In 2-level H-HEED, two types of sensor nodes, i.e., the advanced nodes and the normal nodes are used. - In 3-level H-HEED, three types of sensor nodes, i.e. the super nodes, advanced nodes and normal nodes are used. - In this heterogeneous approach all the sensor nodes are having different energy levels and they die randomly. - Multi-level H-HEED prolongs lifetime and shows better performance than the HEED protocol.
5.	Reactive Energy Decision Routing Protocol (REDRP) (Ying-Hong et al., 2006)	<ul style="list-style-type: none"> - To solve the problem of limited energy, the loading of nodes have to be balanced. - If the energy consumption can be shared averagely by most nodes, then the network lifetime will be enlarged. - This protocol will create the routes in reactive routing method to transmit data. - It uses the residual energy of nodes as the routing decision for energy-aware routing.
6.	PEGASIS (Power-Efficient Gathering in Sensor Information Systems) (Lindsey & Raghavendra, 2002)	<ul style="list-style-type: none"> - A near optimal chain-based protocol and an enhanced descendant of LEACH. - It has two main objectives: increases the lifetime of each node by using local coordination between nodes that are close together so that the energy consumption and communication is reduced. - Nodes route data destined ultimately for the base station through intermediate nodes. - In determining the routes only consider the energy of the transmitter and the receiver. - It assumes that each sensor node can be able to communicate with the base station. - It maintains a complete database about the location of all other nodes in the network. - The method of which the node locations are obtained is not outlined. - It also assumes that all sensor nodes have the same level of energy and they die at the same time.
7.	Hierarchical-PEGASIS (Savvides et al., 2001)	<ul style="list-style-type: none"> - Its objective is to decrease the delay incurred for packets during transmission. - In its concept only spatially separated nodes are allowed to transmit at the same time. - This chain-based protocol with CDMA capable nodes, constructs a chain-based hierarchy, and each selected node in a particular level transmits data to the next level in the hierarchy, that ensures data transmitting in parallel and reduces the delay. - Results shows that this hierarchical extension of PEGASIS performs better than the PEGASIS scheme by a factor of about 60.
8.	SHPER (Scaling Hierarchical Power Efficient Routing) (Kandris et al., 2009)	<ul style="list-style-type: none"> - Enhanced integration of a hierarchical reactive routing protocol. - It supposes the coexistence of a base station and a set of homogeneous sensor nodes distributed within a delimited area of interest. - Consists of two phases: the initialization phase and the steady state phase. - Hard and soft thresholds are utilized in the SHPER protocol as with TECLA. - Best suited in real life applications where imbalance in energy distribution exists. - Network scalability is retained because it adopts both multi-hop routing and

Table 17. (continues) Major theoretical aspects of some major energy efficient protocols for WSNs

S.N.	Energy Efficient Protocol	Major Theoretical Aspects
9.	TREnD (Timely, Reliable, Energy-efficient and Dynamic) (Marco et al., 2010)	<ul style="list-style-type: none"> - A novel cross-layer WSN protocol for control applications. - The routing algorithm of TREnD is hierarchically subdivided into two p clusters level and a dynamical routing algorithm at node level. This is s hybrid TDMA/CSMA solution. - The protocol parameters are adapted by an optimization problem, whos network energy consumption, and the constraints are the reliability and - It uses a simple algorithm that allows the network to meet the reliability for energy consumption. - It is best fit for industrial environments.
10.	LEACH (Low Energy Adaptive Clustering Hierarchy) (Heinzelman et al., 2000)	<ul style="list-style-type: none"> - A most popular cluster-based protocol, which includes distributed clust - The idea is to form clusters of the sensor nodes based on the received sig - cluster heads as routers to the sink. - It randomly selects a few sensor nodes as cluster-heads and rotates this energy load among the sensors in the network. - Its operation is separated into two phases: setup phase where clusters a - selected and steady state phase where the actual data transfer to the bas - It uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster c - Optimal number of cluster heads is estimated to be 5% of the total num - This protocol is most appropriate for the applications when there is a ne
11.	SEER (Simple Energy Efficient Routing) (Hancke & Leuschner, 2007)	<ul style="list-style-type: none"> - A protocol that considers energy saving and balancing, with poor idea a - Once the network has been deployed in the area where it is to operate, t - packet. - Each node in the network is assumed to have a unique address within th - When a node observes new data, it initiates the process of routing. Two - sent: normal data and critical data. - When nodes receive a data message they update the remaining energy v - the neighbor that sent the message. Nodes that forward data messages f - for minor differences. - If node's remaining energy falls below a certain threshold, it transmits a - neighbors to inform them of its energy level. - The sink node periodically sends a broadcast message through the netw - neighbors that joined the network to neighbor tables and remove neigh - neighbor tables. - Nodes also update remaining energy values stored in the neighbor tabl
12.	BEAR (Balanced Energy-Aware Routing) (Ahvar & Fathy, 2010)	<ul style="list-style-type: none"> - An extended version of SEER protocol with some visible difference spec - procedure that saves and balance energy consumption in WSNs. - Finds optimal route in energy level and hop count both. - Routing decisions in BEAR are based on the distance to the base-station - energy level of nodes on the path towards the base station. - BEAR is better than the SEER protocol in energy managing, due to the f - along a balanced path.

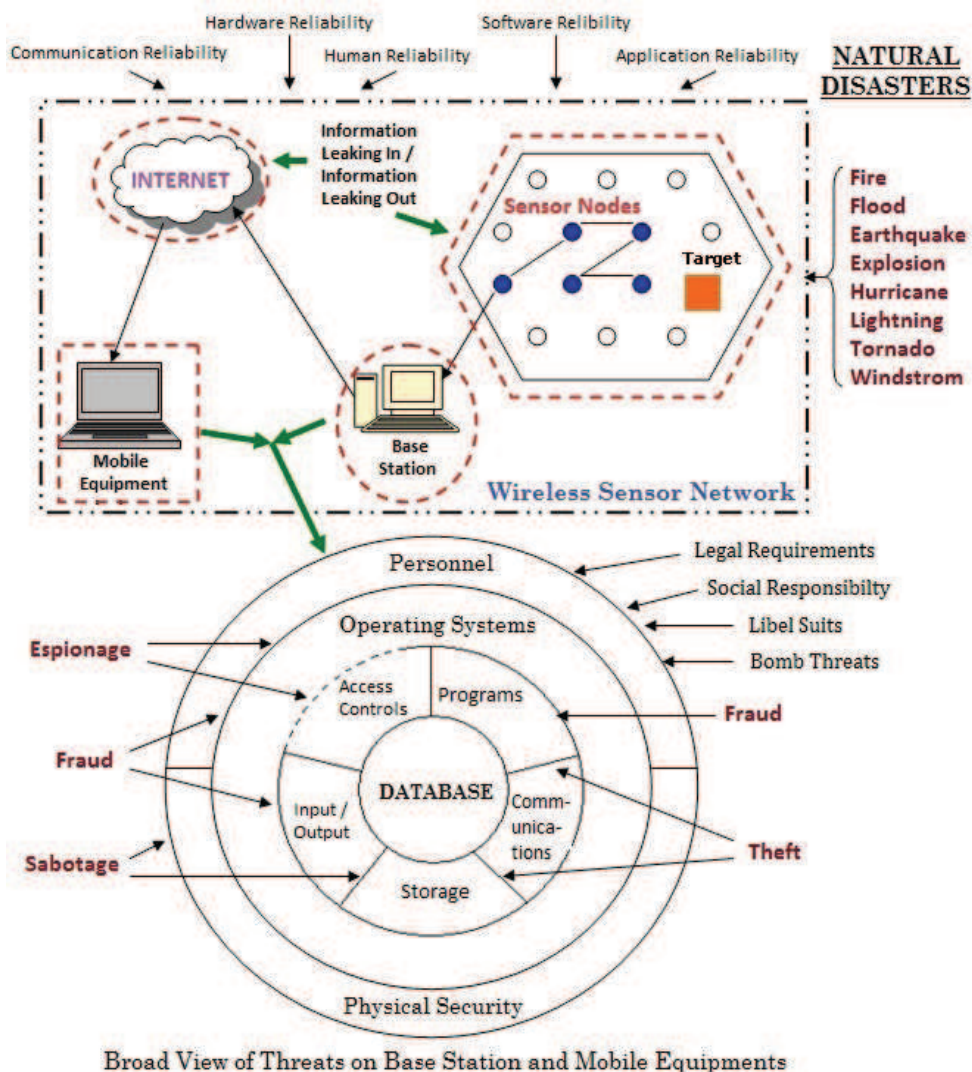


Fig. 4. Security threats and their usual defenses in Wireless Sensor Networks (Dwivedi et al., 2009b)

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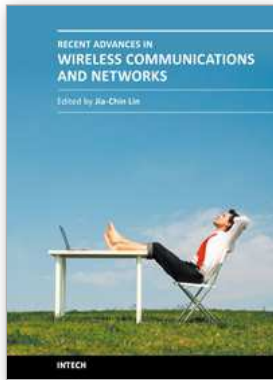
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