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Issues in Wireless Sensor Networks

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***Abstract*—In recent years there has been a growing interest in Wireless Sensor Networks (WSN). Recent advancements in the field of sensing, computing and communications have attracted research efforts and huge investments from various quarters in the field of WSN. Also sensing networks will reveal previously unobserved phenomena. The various areas where major research activities going on in the field of WSN are deployment, localization, synchronization, data aggregation, dissemination, database querying, architecture, middleware, security, designing less power consuming devices, abstractions and higher level algorithms for sensor specific issues. This paper provides an overview of ongoing research activities, various design issues involved and possible solutions incorporating these issues. This paper provides a cursory look at each and every topic in WSN and our main aim is to introduce a newbie to the field of WSN and make him understand the various topics of interest available for research.**

***Index Terms*—Sensor networks, issues, challenges, research areas, sensor problems.**

I. INTRODUCTION

Mobile communications and wireless networking technology has seen a thriving development in recent years. Driven by technological advancements as well as application demands various classes of communication networks have emerged such as Cellular networks, Ad hoc Networks, Sensor Networks and Mesh Networks.

Cellular Networks are the infrastructure dependent networks. Ad hoc networks are defined as the category of wireless networks that utilize multi hop radio relaying since the nodes are dynamically and arbitrarily located. Ad hoc networks are infrastructure independent networks. [1]

So what's a Wireless Sensor Network (WSN)? We have different view points for this question. According to Akylidiz et al., WSN consists of large number of nodes that are deployed in such a way that they can sense the phenomena [2]. Akkaya and Younis define WSN as a network that consists of small nodes with sensing, computation and communication capabilities [3].We shall generalize the above view points and define WSN as a special class of ad hoc wireless network that are used to provide a wireless communication infrastructure that allows us to instrument, observe and respond to phenomena in the natural environment and in our physical and cyber infrastructure.

Even though sensor networks are a special type of ad hoc networks, the protocols designed for ad hoc networks cannot be used as it is for sensor networks due to the following reasons:

1) The number of nodes in sensor networks is very large and has to scale to several orders of magnitude more than the ad hoc networks and thus require different and more scalable solutions.
2) The data rate is expected to be very low in WSN and is of statistical in nature. But mobile ad hoc network (MANET) is designed to carry rich multimedia data and is mainly deployed for distributed computing.
3) A sensor network is usually deployed by a single owner but MANET is usually run by several unrelated entities. [4]
4) Sensor networks are data centric i.e. the queries in sensor network are addressed to nodes which have data satisfying some conditions and unique addressing is not possible as they do not have global identifiers. But MANET is node centric, with queries addressed to particular nodes specified by their unique addresses.
5) Sensor nodes are usually deployed once in their life time and those nodes are generally stationary except a few mobile nodes, while nodes in MANET move in an ad hoc manner.
6) Like MANET sensor nodes are also designed for self configuration, but the difference in traffic and energy consumption require separate solutions. In comparison to ad hoc networks, sensor nodes have limited power supply and recharge of power is impractical considering the large number of nodes and the environment in which they are deployed. Therefore energy consumption in WSN is an important metric to be considered.
7) Sensor networks are application specific. One can't have a solution that fits for all the problems.
8) Simplicity is the rule in the WSN. Since sensor nodes are small and there is restriction on energy consumption; the communicating and computing software in the nodes should be of less size and computation efficient than the traditional software used for the same purpose.

Sensor networks have been proposed for a variety of application [2, 5, 6] like Intrusion detection and tracking for

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military purpose, habitat monitoring, motion detection for understanding earthquake patterns and to prevent theft, health application by monitoring the drug administered to the patients and for traffic analysis.

The remainder of this paper is organized as follows. We have identified various issues for sensor networks in the next section and a detailed explanation is given for each issue in the proceeding sections. The last section concludes the paper.

II. Various issues

The major issues that affect the design and performance of a wireless sensor network are as follows:

1) Hardware and Operating System for WSN
2) Wireless Radio Communication Characteristics
3) Medium Access Schemes
4) Deployment
5) Localization
6) Synchronization
7) Calibration
8) Network Layer
9) Transport Layer
10) Data Aggregation and Data Dissemination
11) Database Centric and Querying
12) Architecture
13) Programming Models for Sensor Networks
14) Middleware
15) Quality of Service
16) Security

III. Hardware and Operating system for WSN

Wireless sensor networks are composed of hundreds of thousands of tiny devices called nodes. A sensor node is often abbreviated as a node. What is a Sensor Node? A Sensor is a device which senses the information and passes the same on to a mote. Sensors are used to measure the changes to physical environment like pressure, humidity, sound, vibration and changes to the health of person like blood pressure, stress and heartbeat. A Mote consists of processor, memory, battery, A/D converter for connecting to a sensor and a radio transmitter for forming an ad hoc network. A Mote and Sensor together form a Sensor Node. The structure of the sensor node is as shown in fig 1. There can be different Sensors for different purposes mounted on a Mote. Motes are also sometimes referred to as Smart Dust. A Sensor Node forms a basic unit of the sensor network [14, 15].

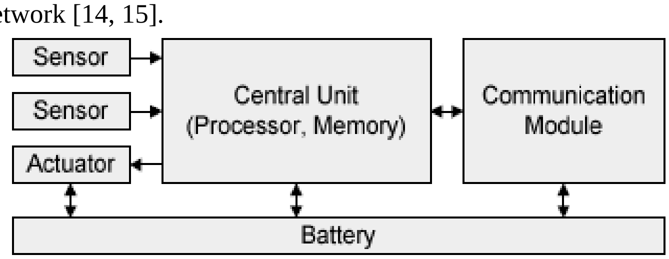

Fig 1. Structure of Sensor node

The nodes used in sensor networks are small and have significant energy constraints. The hardware design issues of sensor nodes are quite different from other applications and they are [16]:

1) Radio Range of nodes should be high (1-5 kilometers). Radio range is critical for ensuring network connectivity and data collection in a network as the environment being monitored may not have an installed infrastructure for communication. In many networks the nodes may not establish connection for many days or may go out of range after establishing connection.
2) Use of Memory Chips like flash memory is recommended for sensor networks as they are non-volatile, inexpensive and volatile.
3) Energy/Power Consumption of the sensing device should be minimized and sensor nodes should be energy efficient since their limited energy resource determines their lifetime. To conserve power the node should shut off the radio power supply when not in use. Battery type is important since it can affect the design of sensor nodes. Battery Protection Circuit to avoid overcharge or discharge problem can be added to the sensor nodes.
4) Sensor Networks consists of hundreds of thousands of nodes. It is preferred only if the node is cheap.

There are various platforms that are developed considering the above discussed design issues like Mica2, MicaZ, Telos, BT Node and Imotes and MIT μAMPS (μ-Adaptive Multi-domain Power-aware Sensors) [22, 23]. Among them the Berkeley Motes, which is commercially made available by Crossbow Technologies is very much popular and is used by various research organizations.

Berkeley Motes consists of an embedded microcontroller, low-power radio, flash memory and they are powered by two AA batteries. MICA and MICA2 are the most successful families of Berkeley motes. The MICA2 platform is equipped with an Atmel ATmega128L and has a CC1000 transceiver. A 51-pin expansion connector is available to interface sensors. Microcontrollers are used to handle medium access and baseband processing. An event driven real time operating system like TinyOS has been implemented to specifically address the concurrency and resource management needs of sensor nodes [18, 19]. Fig 2 shows the Mica2 node.

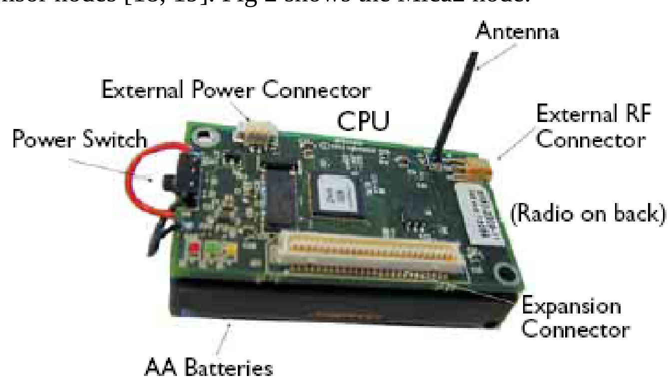

Fig 2. The Mica2 Sensor Node.

Active Research Areas

The research issues that can be considered are different strategies to improve signal reception, design of low power, less cost sensors and processing units.

Various schemes to conserve node power consumption and node optimization and simple modulation schemes may also be considered for sensor nodes.

Operating System

An operating system framework for a sensor node should be able to provide memory management and resource management in a constrained environment. The various issues in designing an Operating System (OS) for sensor networks are:

1) In sensor network a sensor node is mainly responsible for computation of the extracted data from the local environment. It processes the extracted data and manipulates the data as per the requirement of an application. All these activities require real time response, processing and routing of the data. So concurrency management is needed in sensor nodes.
2) An OS for sensor nodes should be hardware independent and application specific. It should support multihop routing and simple user level networking abstractions.
3) The OS should have inbuilt features to reduce the consumption of battery energy. Motes cannot be recharged as and when wished due to small size and low cost requirement of motes and it should be in a position to enforce limitation on the amount of resources used by each application [13]. The OS should be priority based and it should give precedence for higher priority events.
4) The OS should have an easy programming paradigm. Application developers should be able to concentrate on their application logic instead of being concerned with the low level hardware issues like scheduling, preempting and networking.

Various Operating Systems for Sensor nodes like TinyOS, Mantis Operating System [9] and Nano-Qplus [10] have been designed keeping in mind the above design issues.

TinyOS is an open source and far by the most popular OS adapted by both the researchers and industry alike for embedded sensor networks. It has been ported on to many platforms and sensor devices. According to the information available on the TinyOS website [7] TinyOS has a component-based architecture enabling rapid innovation and implementation while minimizing the code size as required by the severe memory constraints which is inherent in sensor networks [8]. TinyOS's component library includes network protocols, distributed services, sensor drivers and data acquisition tools. The execution model of TinyOS supports complex yet safe concurrent operations. TinyOS has been implemented in NesC language [12], which supports the TinyOS component and concurrency model.

IV. Wireless Radio Communication Characteristics

Performance of wireless sensor networks depends on the quality of wireless communication. But wireless communication in sensor networks is known for its unpredictable nature.

Main design issues for communication in WSNs are:

1) Low power consumption in sensor networks is needed to enable long operating lifetime by facilitating low duty cycle operation, local signal processing.
2) Distributed Sensing effectively acts against various environmental obstacles and care should be taken that the signal strength, consequently the effective radio range is not reduced by various factors like reflection, scattering and dispersions.
3) Multihop networking may be adapted among sensor nodes to reduce communication link range and also density of sensor nodes should be high.
4) Long range communication is typically point to point and requires high transmission power, with the danger of being eavesdropped. So we should consider short range transmission to minimize the possibility of being eavesdropped.
5) Communication systems should include error control subsystems to detect errors and to correct them.

Active Research Areas

Research areas include designing low power consuming communication systems and complementary metal oxide semiconductor (CMOS) circuit technique specifically optimized for sensor networks, designing new architecture for integrated wireless sensor systems and modulation method and data rate selection.

V. Medium Access Schemes

Communication is a major source of energy consumption in WSNs and MAC protocols directly control the radio of the nodes in the network. MAC protocols should be designed for regulating energy consumption, which in turn influences the lifetime of the network [24].

The various design issues of the MAC protocols suitable for sensor network environment are: [25, 26, 27, 28, 29]

1) The MAC layer provides fine-grained control of the transceiver and allows on and off switching of the radio. The design of the MAC protocol should have this switching mechanism to decide when and how frequently the on and off mechanism should be done. This helps in conserving energy.
2) A MAC protocol should avoid collisions from interfering nodes, overemitting, overhearing, control packet overhead and idle listening. When a receiver node receives more than one packet at the same time, these packets are called "collided packets", which need to be sent again thereby increasing energy consumption. When a destination node is not ready to receive messages then it is called overemitting. Overhearing occurs if a node picks up packets that were destined for some other node. Sending and receiving of less useful packets results in control overhead. Idle listening is an important factor as the nodes

often hear the channel for possible reception of the data which is not sent.

3) Scalability, Adaptability and decentralization is another important criterion in designing a MAC protocol. The sensor network should adapt to the changes in the network size, node density and topology. Also some nodes may die overtime, some may join and some nodes may move to different locations. A good MAC protocol should accommodate these changes to the network.
4) A MAC protocol should have minimum latency and high throughput when the sensor networks are deployed in critical applications.
5) A MAC protocol should include Message Passing. Message passing means dividing a long message into small fragments and transmit them in burst. Thus, a node which has more data gets more time to access the medium.
6) There should be uniformity in reporting the events by a MAC protocol. Since the nodes are deployed randomly, nodes from highly dense area may face high contention among themselves when reporting events resulting in high packet loss. Consequently the sink detects fewer events from such areas. Also the nodes which are nearer to the sink transmit more packets at the cost of nodes which are away from the sink.
7) The MAC protocols should take care of the well know problem of Information Asymmetry, which arises if a node is not aware of packet transmissions two hops away.
8) MAC Protocols should satisfy the Real-time requirements. Mac being the base of the communication stack; timely detection, processing and delivery of the information from the deployed environment is an indispensable requirement in a WSN application.

Some popular MAC Protocols are S-Mac (Sensor MAC), B-Mac, ZMAC, Time-MAC and WiseMac.

Active Research Areas

Conserving energy at MAC layer is a very important research area by reducing the potential energy wastes which are discussed in the previous section. Lot of research has to be done for fine tuning the radio parameters which is the main source of energy consumption.

MAC protocols should be more susceptible to the movement of nodes. The research community generally ignores mobility at the MAC layer because sensor networks were originally assumed to compromise of static nodes. But recent works like RoboMote [31] have enabled mobility in sensor nodes and there is much room for research in this area.

Optimization criteria such as latency, compliance with real time constraints or reliable data delivery for MAC protocols have not gained importance in research.

The cross layer designs in sensor networks have lead to monolithic, vertically integrated solutions which might work for a research group but may not be useful for other research groups. So developing standard sensor network architecture is a continuous process.

VI. DEPLOYMENT

Deployment means setting up an operational sensor network in a real world environment [41]. Deployment of sensor network is a labor intensive and cumbersome activity as we do not have influence over the quality of wireless communication and also the real world puts strains on sensor nodes by interfering during communications. Sensor nodes can be deployed either by placing one after another in a sensor field or by dropping it from a plane. Various deployment issues which need to be taken care are [42, 43]:

1) When sensor nodes are deployed in real world, Node death due to energy depletion either caused by normal battery discharge or due to short circuits is a common problem which may lead to wrong sensor readings. Also sink nodes acts as gateways and they store and forward the data collected. Hence, problems affecting sink nodes should be detected to minimize data loss.
2) Deployment of sensor networks results in network congestion due to many concurrent transmission attempts made by several sensor nodes. Concurrent transmission attempts occur due to inappropriate design of the MAC layer or by repeated network floods. Another issue is the physical length of a link. Two nodes may be very close to each other but still they may not be able to communicate due to physical interference in the real world while nodes which are far away may communicate with each other.
3) Low data yield is another common problem in real world deployment of sensor nodes. Low data yield means a network delivers insufficient amount of information.
4) Self Configuration of sensor networks without human intervention is needed due to random deployment of sensor nodes.

A framework is proposed in [43] considering the above deployment issues. POWER is a software environment for planning and deploying wireless sensor network applications into actual environment.

Active Research Areas

Research issues include improving the range and visibility of the radio antennas when deployed in various physical phenomenon, detecting wrong sensor readings at the earliest, to reduce latency and reduce congestion.

VII. LOCALIZATION

Sensor localization is a fundamental and crucial issue for network management and operation. In many of the real world scenarios, the sensors are deployed without knowing their positions in advance and also there is no supporting infrastructure available to locate and manage them once they are deployed [44, 47, 48].

Determining the physical location of the sensors after they have been deployed is known as the problem of localization. Location discovery or localization algorithm for a sensor network should satisfy the following requirements [45]:

1) The localization algorithm should be distributed since a centralized approach requires high computation at

selective nodes to estimate the position of nodes in the whole environment. This increases signaling bandwidth and also puts extra load on nodes close to center node.

2) Knowledge of the node location can be used to implement energy efficient message routing protocols in sensor networks.
3) Localization algorithms should be robust enough to localize the failures and loss of nodes. It should be tolerant to error in physical measurements.
4) It is shown in [46] that the precision of the localization increases with the number of beacons. A beacon is a node which is aware of its location. But the main problem with increased beacons is that they are more expensive than other sensor nodes and once the unknown stationary nodes have been localized using beacon nodes then the beacons become useless.
5) Techniques that depend on measuring the ranging information from signal strength and time of arrival require specialized hardware that is typically not available on sensor nodes.
6) Localization algorithm should be accurate, scalable and support mobility of nodes.

Active Research Areas

The research on mobile nodes localization and motion analysis in real time will continue to grow as sensor networks are deployed in large numbers and as applications become varied. Scientists in numerous disciplines are interested in methods for tracking the movements and population counts of animals in their habitat i.e. passive habitat monitoring. Another important application is to design a system to track the location of valuable assets in an indoor environment. We need to improve the maximum likelihood estimation in a distributed environment like sensor networks. Developing mobile assisted localization is another important research area. One needs to improve the localization accuracy which depends on ToA or TDoA

VIII. SYNCHRONIZATION

Clock synchronization is an important service in sensor networks. Time Synchronization in a sensor network aims to provide a common timescale for local clocks of nodes in the network. A global clock in a sensor system will help process and analyze the data correctly and predict future system behavior. Some applications that require global clock synchronization are environment monitoring, navigation guidance, vehicle tracking etc. A clock synchronization service for a sensor network has to meet challenges that are substantially different from those in infrastructure based networks [49, 50, 51].

1) Energy utilization in some synchronization schemes is more due to energy hungry equipments like GPS (Global Positioning System) receivers or NTP (Network Time Protocol).
2) The lifetime or the duration for the nodes which are spread over a large geographical area needs to be taken into account. Sensor nodes have higher degree of failures. Thus the synchronization protocol needs to be more robust to failures and to communication delay.
3) Sensor nodes need to coordinate and collaborate to achieve a complex sensing task like data fusion. In data fusion the data collected from different nodes are aggregated into a meaningful result. If the sensor nodes lack synchronization among themselves then the data estimation will be inaccurate.
4) Traditional synchronization protocols try to achieve the highest degree of accuracy. The higher the accuracy, then there will be more requirement for resources. Therefore we need to have trade off between synchronization accuracy and resource requirements based on the application.
5) Sensor networks span multi hops with higher jitter. So, the algorithm for sensor network clock synchronization needs to achieve multihop synchronization even in the presence of high jitter.

Various synchronization protocols which can be found in the literature are Reference Broadcast Synchronization (RBS) and Delay Measurement Time Synchronization protocol.

Active Research Areas

Various research issues include building analytical model for multihop synchronization, improving the radio communication in the existing synchronization protocols like RBS (Reference Broadcast Synchronization) and LTS (LightWeight Tree Based Synchronization).

IX. CALIBRATION

Calibration is the process of adjusting the raw sensor readings obtained from the sensors into corrected values by comparing it with some standard values. Manual calibration of sensors in a sensor network is a time consuming and difficult task due to failure of sensor nodes and random noise which makes manual calibration of sensors too expensive.

Various Calibration issues in sensor networks are [52, 53 54]:

1) A sensor network consists of large number of sensors typically with no calibration interface.
2) Access to individual sensors in the field can be limited.
3) Reference values might not be readily available.
4) Different applications require different calibration.
5) Requires calibration in a complex dynamic environment with many observables like aging, decaying, damage etc.
6) Other objectives of calibration include accuracy, resiliency against random errors, ability to be applied in various scenarios and to address a variety of error models.

Research includes designing various calibration techniques involving the various issues which we have discussed previously.

X. NETWORK LAYER ISSUES

Over the past few years sensor networks are being built for specific applications and routing is important for sending the data from sensor nodes to Base Station (BS). As discussed in the introduction part, routing in sensor networks is a very challenging issue. Various issues at the network layer are [36, 3, 37, 39]:

1) Energy efficiency is a very important criterion. We need to discover different techniques to eliminate energy inefficiencies that may shorten the lifetime of the network. At the network layer, we need to find various methods for discovering energy efficient routes and for relaying the data from the sensor nodes to the BS so that the lifetime of a network can be optimized.
2) Routing Protocols should incorporate multi-path design technique. Multi-path is referred to those protocols which set up multiple paths so that a path among them can be used when the primary path fails.
3) Path repair is desired in routing protocols when ever a path break is detected. Fault tolerance is another desirable property for routing protocols. Routing protocols should be able to find a new path at the network layer even if some nodes fail or blocked due to some environmental interference.
4) Sensor networks collect information from the physical environment and are highly data centric. In the network layer in order to maximize energy savings we need to provide a flexible platform for performing routing and data management.
5) The data traffic that is generated will have significant redundancy among individual sensor nodes since multiple sensors may generate same data within the vicinity of a phenomenon. The routing protocol should exploit such redundancy to improve energy and bandwidth utilization.
6) As the nodes are scattered randomly resulting in an ad hoc routing infrastructure, a routing protocol should have the property of multiple wireless hops.
7) Routing Protocols should take care of heterogeneous nature of the nodes i.e. each node will be different in terms of computation, communication and power.

Various type of routing Protocols for WSNs are Sensor Protocols for Information via negotiation (SPIN), Rumor Routing, Direct Diffusion, Low Energy Adaptive Cluster Hierarchy (LEACH), Threshold sensitive Energy Efficient sensor Network protocol (TEEN), Geographic and Energy Aware Routing (GEAR), Sequential Assignment Routing (SAR) and others

Active Research Areas

Sensor networks are still at an early stage in terms of technology as it is still not widely deployed in real world and this opens many doors for research. The current routing protocols need to be improved as they have their own set of problems. Much work is not reported on contention issues or high network traffic. Very little analytical work is done.

XI. TRANSPORT LAYER ISSUES

End to End reliable communication is provided at Transport layer. The various design issues for Transport layer protocols are [32, 33]:

1) In transport layer the messages are fragmented into several segments at the transmitter and reassembled at the receiver. Therefore a transport protocol should ensure orderly transmission of the fragmented segments.
2) Limited bandwidth results in congestion which impacts normal data exchange and may also lead to packet loss.
3) Bit error rate also results in packet loss and also wastes energy. A transport protocol should be reliable for delivering data to potentially large group of sensors under extreme conditions.
4) End to End communication may suffer due to various reasons: The placement of nodes is not predetermined and external obstacles may cause poor communication performance between two nodes. If this type of problem is encountered then end to end communication will suffer. Another problem is failure of nodes due to battery depletion.
5) In sensor networks the loss of data, when it flows from source to sink is generally tolerable. But the data that flows from sink to source is sensitive to message loss. (A sensor obtains information from the surrounding environment and passes it on to the sink which in turn queries the sensor node for information)

Traditional transport protocols such as UDP and TCP cannot be directly implemented in sensor networks for the following reasons:

1. If a sensor node is far away from the sink then the flow and congestion control mechanism cannot be applied for those nodes.
2. Successful end to end transmissions of packets are guaranteed in TCP but it's not necessary in an event driven applications of sensor networks.
3. Overhead in a TCP connection does not work well for an event driven application of sensor networks.
4. UDP on the other hand has a reputation of not providing reliable data delivery and has no congestion or flow control mechanisms which are needed for sensor networks.

Pump Slowly, Fetch Quickly (PSFQ) proposed in [34] one of the popular transport layer protocol.

Active Research Areas

Developing transport protocols for sensor networks is itself a difficult task due to the previously discussed issues and not much work is reported.

Existing transport layer protocols for WSNs assume that the network layer uses a single path routing and multi path routing is not considered; which opens many doors for research in this direction.

Many of the transport protocols do not consider priority when routing. Since sensor nodes are placed in various types of environment, the data from different locations will have different priorities.

XII. DATA AGGREGATION AND DATA DISSEMINATION

Data gathering is the main objective of sensor nodes. The

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sensors periodically sense the data from the surrounding environment, process it and transmit it to the base station or sink. The frequency of reporting the data and the number of sensors which report the data depends on the particular application. Data gathering involves systematically collecting the sensed data from multiple sensors and transmitting the data to the base station for further processing. But the data generated from sensors is often redundant and also the amount of data generated may be very huge for the base station to process it.

Hence we need a method for combining the sensed data into high quality information and this is accomplished through Data Aggregation [58]. Data Aggregation is defined as the process of aggregating the data from multiple sensors to eliminate redundant transmission and estimating the desired answer about the sensed environment, then providing fused information to the base station.

Some design issues in data aggregation are [58, 59]:

1) Sensor networks are inherently unreliable and certain information may be unavailable or expensive to obtain; like the number of nodes present in the network and the number of nodes that are responding and also it is difficult to obtain complete and up-to date information of the neighboring sensor nodes to gather information.
2) Making some of the nodes to transmit the data directly to the base station or to have less transmission of data to the base station to reduce energy.
3) Eliminate transmission of redundant data using meta- data negotiations as in SPIN protocol.
4) Improving clustering techniques for data aggregation to conserve energy of the sensors.
5) Improving In-Network aggregation techniques to improve energy efficiency. In-Network aggregation means sending partially aggregated values rather than raw values, thereby reducing power consumption.

Data dissemination is a process by which data and the queries for the data are routed in the sensor network [81]. Data dissemination is a two step process. In the first step, if a node is interested in some events, like temperature or humidity, then it broadcasts its interests to its neighbors periodically and then through the whole sensor network. In the second step, the nodes that have the requested data will send the data back to the source node after receiving the request. . The main difference between data aggregation and data dissemination is, in data dissemination all the nodes including the base station can request for the data while in data aggregation all al the aggregated data is periodically transmitted to the base station. In addition, data aggregation data can be transmitted periodically, while in data dissemination data is always transmitted on demand. Flooding is one important protocol which includes data dissemination approach.

Active Research Areas

Main research focus in data aggregation is geared towards conserving energy. Other research issues include improving security in data transmission and aggregation, handling tradeoffs in data aggregation i.e. tradeoffs between different objectives such as energy consumption, latency and data accuracy, improving quality of service of the data aggregation protocols in terms of bandwidth and end to end delay.

XIII. DATABASE CENTRIC AND QUERYING

Wireless sensor networks have the potential to span and monitor a large geographical area producing massive amount of data. So sensor networks should be able to accept the queries for data and respond with the results.

The data flow in a sensor database is very different from the data flow of the traditional database due to the following design issues and requirements of a sensor network [62, 63, 65, 66]:

1) The nodes are volatile since the nodes may get depleted and links between various nodes may go down at any point of time but data collection should be interrupted as little as possible.
2) Sensor data is exposed more errors than in a traditional database due to interference of signals and device noise.
3) Sensor networks produce data continuously in real time and on a large scale from the sensed phenomenon resulting in need of updating the data frequently; whereas a traditional database is mostly of static and centralized in nature.
4) Limited storage and scarce of energy is another important constraint that needs to be taken care of in a sensor network database but a traditional database usually consists of plenty of resources and disk space is not an issue.
5) The low level communication primitives in the sensor networks are designed in terms of named data rather than the node identifiers which are used in the traditional networks.

Active Research Areas

Some research areas in sensor database include providing spatio-temporal querying, multiquery optimization, storage placement, designing a distributed long term networked data storage, should have low energy communication overhead, various ways of representing the sensor data, processing and distributing query fragments, dealing with communication failures and designing various models for deploying and managing a sensor database systems.

XIV. ARCHITECTURE

According to the authors of [76] lack of an overall sensor network architecture is the main factor for currently limiting the progress in sensor networks. Architecture can be considered as a set of rules and regulation for implementing some functionalities along with a set of interfaces, functional components, protocols and physical hardware. Software architecture is needed to bridge the gap between raw hardware capabilities and a complete system.

The key issues that must be addressed by the sensor architecture are [77, 78, 79]:

1) Several operations like continuous monitoring of the channel, encoding of data and transferring of bits to the

radio need to be performed in parallel. Also sensor events and data calculations must continue to proceed while communication is in progress.

2) A durable and scalable architecture would allow dynamic changes to be made for the topology with minimum update messages being transmitted.
3) The system must be flexible to meet the wide range of target application scenarios since the wireless sensor networks to not have a fixed set of communication protocols that they must adhere to.
4) The architecture must provide precise control over radio transmission timing. This requirement is driven by the need for ultra-low power communication for data collection application scenarios.
5) The architecture must decouple the data path speed and the radio transmission rate because direct coupling between processing speed and communication bit rates can lead to sub-optimal energy performance.

The authors of [80] design a novel SP abstraction which promotes cooperation across the link and network layers to utilize limited resources efficiently. A unifying abstraction in SP leads to supporting a variety of link-layer technologies and network protocols while taking care that doing so will not lead to a significant loss of efficiency.

XV. PROGRAMMING MODELS FOR SENSOR NETWORKS

Currently, programmers are too much concerned with low level details like sensing and node to node communication raising a need for programming abstractions. There is considerable research activity for designing programming models for sensor networks due to following issues [82]:

1) Since the data collected from the surrounding phenomenon is not for general purpose computing we need a reactive, event driven programming model.
2) Resources in a sensor network are very scarce, where even a typical embedded OS consuming hundreds of KB of considered too much. So programming models should help programmers in writing energy efficient applications.
3) We need to reduce the run time errors and complexity since the applications in a sensor network need to run for a long duration without human intervention.
4) Programming models should help programmers to write bandwidth efficient programs and should be accompanied by runtime mechanisms that achieve bandwidth efficiency whenever possible.

TinyOS with Nesc [12] and TinyGALS [83] are examples for this category. Improving programming ease in languages such as Nesc and galsC [84] itself provides tremendous opportunities for research.

XVI. MIDDLEWARE

A middleware for wireless sensor network should facilitate development, maintenance, deployment and execution of sensing-based applications. WSN middleware can be considered as a software infrastructure that glues together the network hardware, operating systems, network stacks and applications [86]. Various issues in designing a middleware for wireless sensor networks are [87, 88, 89, 90, 91, 92]:

1) Middleware should provide an interface to the various types of hardware and networks supported by primitive operating system abstractions. Middleware should provide new programming paradigm to provide application specific API's rather than dealing with low level specifications.
2) Efficient middleware solutions should hide the complexity involved in configuring individual nodes based on their capabilities and hardware architecture.
3) Middleware should include mechanisms to provide real time services by dynamically adapting to the changes in the environment and providing consistent data. Middleware should be adaptable to the devices being programmed depending on the hardware capabilities and application needs.
4) There should be transparency in the middleware design. Middleware is designed for providing a general framework whereas sensor networks are themselves designed to be application specific. Therefore we need to have some tradeoff between generality and specificity.
5) Sensor network middleware should support mobility, scalability and dynamic network organization. Middleware design should incorporate real time priorities. Priority of a message should be assigned at runtime by the middleware and should be based on the context.
6) Middleware should support quality of service considering many constraints which are unique to sensor networks like energy, data, mobility and aggregation.
7) Security has become of paramount importance with sensor networks being deployed in mission critical areas like military, aviation and in medical field.

Several middleware systems have been designed to deal with the aforementioned issues. Mate [94] is a middleware architecture for constructing application specific virtual machines that executes on top of TinyOS.

Active Research Areas

The design and implementation of a middleware layer for fully realizing the potential of wireless sensor network is an open research area which still needs to be investigated further. One needs to design developer friendly middleware architecture which is not only generic but also should take care of all the underlying hardware intricacies while helping to reduce the energy consumption and also provide adequate quality of support.

XVII. QUALITY OF SERVICE

Quality of service is the level of service provided by the sensor networks to its users. The authors of [100] define Quality of Service (QoS) for sensor networks as the optimum number of sensors sending information towards information-collecting sinks or a base station. Since sensor networks are getting implemented in more and more number of applications which includes mission critical applications such as military applications and nuclear plant monitoring applications; QoS is being given considerable review as the events occurring in these situations are of utmost importance.

The QoS routing algorithms for wired networks cannot be directly applied to wireless sensor networks due to the following reasons:

The performance of the most wired routing algorithms relies on the availability of the precise state information while the dynamic nature of sensor networks make availability of precise state information next to impossible.

Nodes in the sensor network may join, leave and rejoin and links may be broken at any time. Hence maintaining and re-establishing the paths dynamically which is a problem in WSN is not a big issue in wired networks.

Various Quality of Service issues in sensor networks are [95, 96, 97, 98, 99]:

1) The QoS in WSN is difficult because the network topology may change constantly and the available state information for routing is inherently imprecise.
2) Sensor networks need to be supplied with the required amount of bandwidth so that it is able to achieve a minimal required QoS.
3) Traffic is unbalanced in sensor network since the data is aggregated from many nodes to a sink node. QoS mechanisms should be designed for an unbalanced QoS constrained traffic.
4) Many a time routing in sensor networks need to sacrifice energy efficiency to meet delivery requirements. Even though multihops reduce the amount of energy consumed for data collection the overhead associated with it may slow down the packet delivery. Also, redundant data makes routing a complex task for data aggregation affecting thus affecting Quality of Service in WSN.
5) Buffering in routing is advantageous as it helps to receive many packets before forwarding them. But multihop routing requires buffering of huge amount of data. This limitation in buffer size will increase the delay variation that packets incur while traveling on different routes and even on the same route making it difficult to meet QoS requirements.
6) QoS designed for WSN should be able to support scalability. Adding or removing of the nodes should not affect the QoS of the WSN.

One of the very first protocol which had QoS support was the Sequential Assignment Routing (SAR) [101].

Active Research Areas

The area of sensor network QoS largely remains an unexplored research area. Designing an appropriate QoS model, deciding how many layers need to be integrated, support for heterogeneous nodes, designing QoS model for specific applications, designing QoS based protocols to integrate them with other network like cellular, LANs and IP, and designing QoS via middleware layer.

XVIII. Security

Security in sensor networks is as much an important factor as performance and low energy consumption in many applications. Security in a sensor network is very challenging as WSN is not only being deployed in battlefield applications but also for surveillance, building monitoring, burglar alarms and in critical systems such as airports and hospitals.

Since sensor networks are still a developing technology, researchers and developers agree that their efforts should be concentrated in developing and integrating security from the initial phases of sensor applications development; by doing so, they hope to provide a stronger and complete protection against illegal activities and maintain stability of the systems at the same time.

Following are the basic security requirements to which every WSN application should adhere to [102, 103, 104, 105, 106, 107, 108].

1) Confidentiality is needed to ensure sensitive information is well protected and not revealed to unauthorized third parties. Confidentiality is required in sensor networks to protect information traveling between the sensor nodes of the network or between the sensors and the base station; otherwise it may result in eavesdropping on the communication.
2) Authentication techniques verify the identity of the participants in a communication. In sensor networks it is essential for each sensor node and the base station to have the ability to verify that the data received was really sent by a trusted sender and not by an adversary that tricked legitimate nodes into accepting false data. A false data can change the way a network could be predicted.
3) Lack of integrity may result in inaccurate information. Many sensor applications such as pollution and healthcare monitoring rely on the integrity of the information to function; for e.g., it is unacceptable to have improper information regarding the magnitude of the pollution that has occurred.
4) One of the many attacks launched against sensor networks is the message reply attack where an adversary may capture messages exchanged between nodes and reply them later to cause confusion to the network. So sensor network should be designed for freshness; meaning that the packets are not reused thus preventing potential mix-up.
5) In sensor networks secure management is needed at the base station level, since communication in sensor network ends up at the base station. Issues like Key distribution to sensor nodes in order to establish encryption and routing information need secure management. Also, clustering techniques require secure management as well, since each group of nodes may include a large number of nodes that need to be authenticated with each other and exchange data in a secure manner.
6) Security and QoS are two opposite poles in sensor networks. Security mechanisms like encryption should be

lightweight so that the overhead is minimized and should not affect the performance of the network.

Different types of threats in sensor networks are Spoofing and altering the routing information, passive information gathering, node subversion , sinkhole attacks, sybil attacks, Denial of service attack and jamming.

Active Research Areas

The security issues posed by sensor networks are a rich field for research problems. Designing routing protocols having built in security features, a new symmetric key cryptography for sensor networks, designing secure data aggregation protocols, designing intrusion detection systems and security systems for multimedia sensors.

XIX. Conclusion

Wireless Sensor Networks have created wide range of challenges that still needs to be addressed. In this paper we have identified a comprehensive list of issues associated with Wireless Sensor Networks. We have also discussed some popular protocols implementing these issues in part or as a whole. The impact of wireless sensor networks on our day to day life can be preferably compared to what Internet has done to us. This field is surely going to give us tremendous opportunity to change the way we perceive the world today.

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