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Design and Topology issues for Wireless Sensor Networks

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Abstract— **Wireless Sensor Networks (WSN) are highly distributed self organized systems. WSN have been deployed in various fields. This paper focuses on various issues such as routing challenges and design issues, topology issues and Quality of Service support issues associated with WSN. Topology issues include geographic routing, sensor hole problems and sensor coverage issues. Quality of Service aims at providing better networking services over current technologies.**

Keywords— **Design issues, Latency, reliability, Geographic routing sensor holes, Sensor coverage topology, sensor connective topology, Quality of Service, Jitter, routing.**

1. Introduction

In recent years, advances in miniaturization; low-power circuit design; simple, low power, yet reasonably efficient wireless communication equipment; and improved small-scale energy supplies have combined with reduced manufacturing costs to make a new technological vision possible: Wireless Sensor Networks (WSN). These Wireless Sensor Networks are highly distributed self-organized systems. WSNs provide a new paradigm for sensing and disseminating information from various environments, with the potential to serve many and diverse applications. With recent developments in the wireless networks field, new and innovative medical applications based on this technology are being developed in the research as well as commercial sectors. This paper discusses the various issues of WSN. The paper is organized as follows. Section II gives some related works with WSN. Section III describes the routing challenges and the design issues in WSN. Section IV discusses the various topology issues associated with WSN. Section V focuses on the quality of service Support (QoS) in WSN.

2. Related Works

An A work titled “Rumor routing algorithm for sensor networks” explains the method for routing queries to nodes based on the event observed; not based on a unique id or geographic location of a node so that the data is allowed to be retrieved from the network keyed on the event and not on the underlying network addressing scheme or geography. [1]Another worker of WSN had worked for providing support for secure transient association between a master and a slave device or between peers in a Wireless ad-hoc network [2]. Many workers have worked on the security issues of WSN and one such work is “Talking to strangers: Authentication in adhoc wireless networks”. It provides support for secure communication and authentication in wireless ad-hoc networks without any public key infrastructure. [3] Many researchers recognize the need for methods that deal with conflicting performance demands and set up a sensor network properly. Some authors suggest using a knowledge base to make a match between task-level demands and network protocols to use [8, 9]. A work on “Energy-efficient communication protocol for wireless micro sensor networks” presents a 2-level hierarchical routing protocol which attempts to minimize global energy dissipation and distribute energy consumption evenly across all nodes. [11]. A worker of WSN has worked on the need for robustness and Scalability, which leads to the design of localized algorithms, where sensors only interact with other sensors in a restricted vicinity and have at best an indirect global view.[13]. The research community generally ignores mobility in sensor-nets because sensor-nets were originally assumed to consist of static nodes. However, recent efforts such as RoboMote [15] and Parasitic-Mobility [16] have enabled mobility in sensor-nets.

3. Routing Challenges and Design Issues in WSNs

Despite the innumerable applications of WSNs, these networks have several restrictions, e.g., limited energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs. In the following, we summarize some of the routing challenges and design issues that affect routing process in WSNs.

A. Node deployment:

Node deployment in WSNs is application dependent and affects the performance of the routing protocol. The deployment can be either deterministic or randomized. In deterministic deployment, the sensors are manually placed and data is routed through pre-determined paths. However, in random node deployment, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner. If the resultant distribution of nodes is not uniform, optimal clustering becomes necessary to allow connectivity and enable energy efficient network operation. Inter-sensor communication is normally within short transmission ranges due to energy and bandwidth limitations. Therefore, it is most likely that a route will consist of multiple wireless hops.

B. Energy consumption without losing accuracy:

Sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime [1]. In a multihop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

C. Data Reporting Model:

Data sensing and reporting in WSNs is dependent on the application and the time criticality of the data reporting. Data reporting can be categorized as either time-driven (continuous), event-driven, query-driven, and hybrid [13]. The time-driven delivery model is suitable for applications that require periodic data monitoring. As such, sensor nodes will periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest at constant periodic time intervals. In event-driven and query-driven models, sensor nodes react immediately to sudden and drastic changes in the value of a sensed attribute due to the occurrence of a certain event or a query is generated by the BS. As such, these are well suited for time critical applications. A combination of the previous models is also possible. The routing protocol is highly influenced by the data reporting model with regard to energy consumption and route stability.

D. Node/Link Heterogeneity:

In many studies, all sensor nodes were assumed to be homogeneous, i.e., having equal capacity in terms of computation, communication, and power. However, depending on the application a sensor node can have different role or capability. The existence of heterogeneous set of sensors raises many technical issues related to data routing. For example, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures, and capturing the image or video tracking of moving objects.

E. Fault Tolerance:

Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. If many nodes fail, MAC and routing protocols must accommodate formation of new links and routes to the data collection base stations. This may require actively adjusting transmit powers and signalling rates on the existing links to reduce energy consumption, or rerouting packets through regions of the network where more energy is available. Therefore, multiple levels of redundancy may be needed in a fault-tolerant sensor network.

F. Scalability:

The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands, or more. Any routing scheme must be able to work with this huge number of sensor nodes. In addition, sensor network routing protocols should be scalable enough to respond to events in the environment. Until an event occurs, most of the sensors can remain in the sleep state, with data from the few remaining sensors providing a coarse quality.

G. Network Dynamics:

Most of the network architectures assume that sensor nodes are stationary. However, mobility of both BS's or sensor nodes is sometimes necessary in many applications [19]. Routing messages from or to moving nodes is more challenging since route stability becomes an important issue, in addition to energy, bandwidth etc. Moreover, the sensed phenomenon can be either dynamic or static depending on the application, e.g., it is dynamic in a target detection/tracking application, while it is static in forest monitoring for early ¯re prevention. Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the BS.

H. Transmission Media:

In a multi-hop sensor network, communicating nodes are linked by a wireless medium. The traditional problems associated with a wireless channel (e.g., fading, high error rate) may also affect the operation of the sensor network. In general, the required bandwidth of sensor data will be low, on the order of 1-100 kb/s. One approach of MAC design for sensor networks is to use TDMA based protocols that conserve more energy compared to contention based protocols like CSMA (e.g., IEEE 802.11). Bluetooth technology [32] can also be used.

I. Connectivity:

High node density in sensor networks precludes them from being completely isolated from each other. Therefore, sensor nodes are expected to be highly connected. This, however, may not prevent the network topology from being variable and the network size from being shrinking due to sensor node failures. In addition, connectivity depends on the, possibly random, distribution of nodes.

J. Coverage:

In WSNs, each sensor node obtains a certain view of the environment. A given sensor's view of the environment is limited both in range and in accuracy; it can only cover a limited physical area of the environment. Hence, area coverage is also an important design parameter in WSNs.

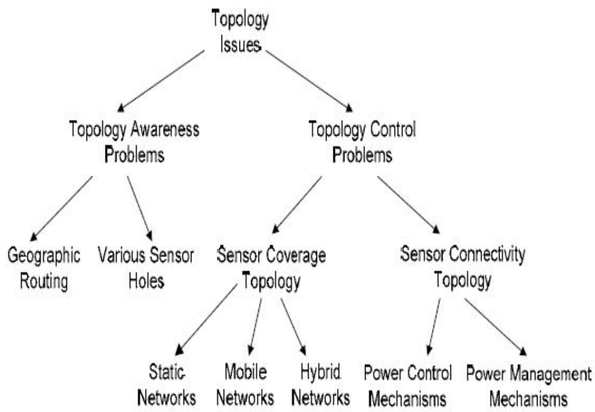
K. Data Aggregation:

Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced. Data aggregation is the combination of data from different sources according to a certain aggregation function, e.g., duplicate suppression, minima, maxima and average. Signal processing methods can also be used for data aggregation. In this case, it is referred to as data fusion where a node is capable of producing a more accurate output signal by using some techniques such as beam forming to combine the incoming signals and reducing the noise in these signals.

L. Quality of Service:

In some applications, data should be delivered within a certain period of time from the moment it is sensed, otherwise the data will be useless. However, in many applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent. As the energy gets depleted, the network may be required to reduce the quality of the results in order to reduce the energy dissipation in the nodes and hence lengthen the total network lifetime. Hence, energy-aware routing protocols are required to capture this requirement.

4. A TAXONOMY OF TOPOLOGY ISSUES IN WSNS



4.1 Various Issues

Various topology issues such as geographic routing, sensor holes problems, Sensor Coverage Topology, Sensor Connectify Topology are discussed in this section.

4.1.1 Geographic Routing

Geographic routing is a routing principle that relies on geographic position information. It is mainly proposed for wireless networks and based on the idea that the source sends a message to the geographic location of the destination instead of using the network address.[6] Geographic routing uses geographic and topological information of the network to achieve optimal routing schemes with high routing efficiency and low power consumption.

4.1.2 Sensor Holes

A routing hole consists of a region in the sensor network, where either nodes are not available or the available nodes cannot participate in the actual routing of the data due to various possible reasons.[7] If given a set of sensors and a target area, no coverage hole exists in the target area, if every point in the target area is covered by at least k sensors, where k is the required degree of coverage for a particular application. The identification of holes in a wireless sensor network is of primary interest since the breakdown of sensor nodes in a larger area often indicates one of the special events to be monitored by the network in the first place This task of identifying holes is especially challenging since typical wireless sensor networks consist of lightweight, low-capability nodes that are unaware of their geographic location.

4.1.3 Sensor Coverage Topology

We break this family of problems into small categories: Static Network, Mobile Network and Hybrid Network.

4.1.3.1 Static Network

For a static sensor network, proposed approaches have different coverage objectives. We introduce these approaches separately.

Partial Coverage:

In [47], Ye et al. propose PEAS, which extends WSN system functioning time by keeping only a necessary set of sensors working in case the node deployment density is much higher than necessary. PEAS protocol consists of two algorithms: Probing Environment and Adaptive Sleeping. In PEAS protocol, the node location information is not required as a pre-knowledge. Cao et al. [7] develop a near optimal deterministically rotating sensory coverage for WSN surveillance system. Their scheme aims to partially cover the sensing area with each point eventually sensed within a finite delay bound. Their assumption is that the neighbouring nodes have approximately synchronized clocks and know sensing ranges of each other.

Single coverage:

For single coverage requirement, Zhang et al. [51] have proposed the Optimal Geographical Density Control (OGDC) protocol. This protocol tries to minimize the overlap of sensing areas of all sensor nodes for cases when $Rc \geq 2Rs$ where Rc is the node communication range and Rs is the node sensing range. OGDC is a fully localized algorithm but the node location is needed as a pre-knowledge.

Multiple coverage:

Wang et al. [41] present the Coverage Configuration Protocol (CCP) that can provide flexibility in configuring sensor network with different degrees of coverage. The CCP protocol needs node location information as assistance. The authors suggest a central controller entity that can collect the details of insufficiently covered segments and dispatch new nodes to supplement. However, this centralized approach lacks scalability [45]. Yan et al. [46] propose a distributed density control algorithm based on time synchronization among the neighbours. A node can decide its on-duty time such that the whole grid still gets the required degree of coverage.

4.1.3.2 Mobile Network:

Wang et al. [40] study the deployment schemes for movable sensors. Given an area to be monitored, the proposed distributed self-deployment protocols first discover the existence of coverage holes in the target area then calculate the target positions and move sensors to diminish the coverage holes. Voronoi diagrams [1, 11]are used to discover the coverage holes and three movement-assisted sensor deployment protocols VEC, VOR and Minimax are designed. Howard et al. [15] and Heo et al. [14] study the sensor network in the viewpoint of virtual forces. In [15], nodes only use their sensed information to make moving decisions. They start moving based on partial forces exerted by the neighbours. The forces exerted on each node by its neighbours depend on the local density of deployment and on the distance between the node and the neighbour.

4.1.3.3 Hybrid Network

The coverage scenario with only some of the sensors are capable of moving has been under active research, especially in the field of robotics for exploration purpose. The movement capable sensors can help in deployment and network repair by moving to appropriate locations within the field to achieve desired level of coverage. The coverage problem is solved with the help of a constantly moving robot in a given target area. The algorithm does not consider the communications between the deployed nodes. All decisions are made by the robot by directly communicating with a neighbour sensor node. Wang et al. [39] address the single coverage problem by moving the available mobile sensors in a hybrid network to heal coverage holes. A comparison of different sensor coverage approaches are listed in Table 2. As you can see from the table, most of the proposed approaches need node location information as assistance and the unit-disk model is widely adopted as a simplification of the node transmitting model. .

Category	*Approach*	*Proposed Solution*	*Main Assumptions*	*Characteristics*
Static Network	Partial Coverage	PEAS [47]	Power dynamic adjustment	Distributed sleeping schedule
		Rotating coverage[7]	synchronized clocks, sensing range	Distributed sleeping schedule, guarantee finite delay bound
	Single Coverage	OGDC[51]	Location info, uniform sensing disk	Residual energy consideration
		Sponsored Area[36]	Location info.	Sector based coverage calculations
		Extended-Sponsored Area[18]	Location info, synchronized clock	Uniform disk sensing model
	Multiple Coverage	CCP[41]	Location info	Configurable degree of coverage.
		k-UC, k-NC[17]	Location info	Non-unit disk model supported
		Differentiated [46]	Location info, synchronized clock	Grid based differentiated degree of coverage
Mobile Networks	Computational Geometry	VEC, VOR, Minmax [40]	Location info	Localized, Scalable, Distributed.
		Co-Fi [13]	Location info, Nodes predict its death	Single coverage based. Residual ener considerations.
	Virtual Forces	Potential Fields[15]	Range and bearing	Scalable, Distributed. No local communication required.
		DSS[14]	Location info	Scalable, Distributed. Residual energ based.
Hybrid Networks	Single Mobile sensor	Single Robot[2]	Location info	Distributed. No multi-hop communications.
	Multiple Mobile Sensor	Bidding Protocol[39]	Location info	Voronoi diagram is used for single coverage requirement.

4.1.4 Sensor Connectivity Topology

4.1.4.1 Power Control Mechanisms

The goal of power control mechanisms is to dynamically change the nodes' transmitting range in order to maintain some property of the communication graph, while reducing the energy consumed by node transceivers because they are one of the primary sources of energy consumption in WSNs. Power control mechanisms are fundamental to achieving a good network energy efficiency. Power control is studied in homogeneous and non-homogeneous scenarios which can be distinguished by examine if the nodes have the same transmitting range or not. For homogeneous network, the CTR (Critical Transmitting Range) problem has been investigated in theoretical ways as well as practical viewpoints. Narayanaswamy et al. [31] present a distributed protocol, called COMPOW that attempts to determine the minimum common transmitting range needed to ensure network connectivity. They show that setting the transmitting range to this value has the beneficial effects of maximizing network capacity, reducing the contention to access the wireless channel, and minimizing energy consumption. Santi and Blough [34] investigate through simulation the tradeoffs between the transmitting range and the size of the largest connected component in the communication graph. The experimental results presented show that, in sparse two and three-dimensional networks, the transmitting range can be reduced significantly if weaker requirements on connectivity are acceptable: halving the critical transmitting range, the largest connected component has an average size of approximately $0.9n$. This means that a considerable amount of energy is spent to connect relatively few nodes. Non-homogeneous networks are more challenging because nodes are allowed to have different transmitting ranges. The problem of assigning a transmitting range to nodes in such a way that the resulting communication graph is strongly connected and the energy cost is minimum is called the Rang Assignment (RA) problem, and it was first studied in [21]. The computational complexity of RA has also been analysed in [21]. It is shown to be NP-hard in the case of 2D and 3D networks. However the optimal solution can be approximated within a factor of 2 using the range assignment generated in [21]. An important variant of RA has been recently studied is based on the concept of symmetry of the communication graph. Due to the high overhead needed to handle unidirectional links in routing protocols or MAC protocols which are naturally designed to work under the symmetric assumption, Symmetric Range Assignment (SRA) shows more practical significance. However, Blough et al. [3] show that SRA remains NP-hard in 2D and 3D networks, and it even incurs a considerable additional energy cost over RA. We can refine SRA to WSRA (Weakly Symmetric Range Assignment) which weakens the requirement that the communication graph contains only bidirectional links by allowing the existence of the unidirectional links but requiring the symmetric sub graph of the communication graph resulting from RA connected. In the released WSRA problem, only marginal effect on the energy cost has been induced while the desired symmetry property has been kept. Two polynomial approximation algorithms for WSRA have been introduced by Calinesc et al. [6]. A lot of power control approaches have been proposed which try to design simple and practical protocols that build and maintain a reasonably good topology. Rodoplu and Meng [33] present a distributed power control algorithm that leverages on location information to build a topology that is proven to minimize the energy required to communicate with a given master node. Pan et al. [32] consider a two-tired Wireless Sensor Network (WSN) consisting of sensor clusters deployed around strategic locations and base-stations (BSs) whose locations are relatively flexible.

4.1.4.2 Power Management Mechanisms

Power management is concerned of which set of nodes should be turned on/off and when, for the purpose of constructing energy saving topology to prolong the network lifetime. It can utilize information available from all the layers in the protocol stack. In GAF approach [44] proposed by Xu et al., nodes use location information to divide the field into fixed square grids. The size of each grid stays constant, regardless of node density. Nodes within a grid switch between sleeping and listening mode, with the guarantee that one node in each grid stays up so that a dynamic routing backbone is maintained to forward packets. Chen et al. [8] propose Span, a power saving topology maintenance algorithm for multi-hop ad hoc wireless networks which adaptively elects coordinators from all nodes to form a routing backbone and turn off other nodes' radio receivers most of the time to conserve power. Schurgers et al. [35] proposed STEM approach, which exploits the time dimension rather than the node density dimension to control a power saving topology of active nodes. They switch nodes between two states, "transfer state" and "monitoring state". Data are only forwarded in the transfer state. In the monitoring state, nodes remain their radio off and will switch into transfer state to be an initiator node on event detected. The extended study on combining STEM and GAF shows the potential of further power saving by exploiting both time dimension and node density dimension.

4.2 Available Topologies

We can use several network topologies to coordinate the WSN gateway. This topology is simple but restricts the overall distance that the network can achieve. [5]

To increase the distance a network can cover, we can implement a cluster, or tree, topology. In this more complex architecture, each node still maintains a single communication path to the gateway but can use other nodes to route its data along that path. This topology suffers from a problem, however. If a router node goes down, all the nodes that depend on that router node also lose their communication paths to the gateway.

The mesh network topology remedies this issue by using redundant communication paths to increase system reliability. In a mesh network, nodes maintain multiple communication paths back to the gateway, so that if one router node goes down, the network automatically reroutes the data through a different path. The mesh topology, while very reliable, does suffer from an increase in network latency because data must make multiple hops before arriving at the gateway.

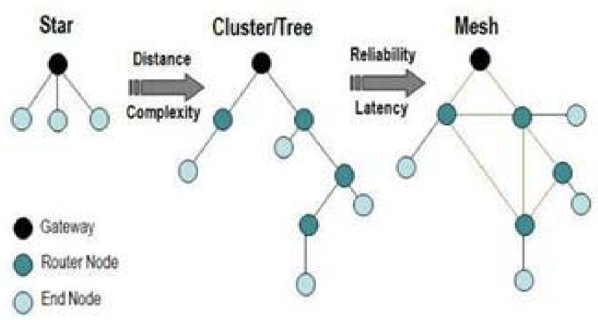


Figure 1. WSN Topologies

5. QUALITY OF SERVICE (QOS) SUPPORT IN WSN

Quality of Service (QoS) aims at providing better networking services over current technologies such as ATM, Ethernet and others. The main three parameters for QoS are latency (delay), jitter and loss. Other QoS parameters include reliability, responsiveness, mobility, power efficiency network availability and bandwidth.

5.1 Delay, Jitter and Loss

Delay is the total amount of time a network spends to deliver a frame of data from source to destination. Jitter in turn is the delay between two consecutive packets in that frame. While loss determines the maximum amount of packets loss the stream can tolerate to provide good quality. Each parameter has been investigated thoroughly and many solutions are proposed such as forward error correction and interleaving.

5.2 Reliability and Scalability

In wireless sensor networks (or infrastructure less networks), reliability and scalability are always inversely coupled. In other words, it becomes more difficult to build a reliable ad hoc network as the number of nodes increases. This is due to the network overhead that comes with the increased size of the network. In ad hoc networks, the network is formed without any predetermined topology or shape. Therefore, any node wishing to communicate with other nodes should generate more packets than its data packets. These extra packets are generally called "control packets" or "network overhead." Route discovery packets and route response packets in typical ad hoc network routing protocols are a few examples of the overhead. As the size of the network grows, more control packets will be needed to find and keep the routing paths.

5.3 Responsiveness

Responsiveness is the ability of the network to quickly adapt itself to changes in topology. To achieve high responsiveness, an ad hoc network should issue and exchange more control packets, which will naturally result in less scalability and less reliability.

5.4 Power Efficiency

Power efficiency also plays another important role in this complex equation. A typical method for designing a low-power wireless sensor network is to reduce the duty cycle of each node. The drawback is that as the wireless sensor node stays longer in sleep mode to save power, there is less chance that the node can communicate with its neighbours. In addition to creating scalability challenges due to the need for a more complicated synchronization technique to keep more nodes in low duty cycle, this will decrease the network responsiveness and may also lower reliability due to the lack of the exchange of control packets and delays in packet delivery.

5.5 Mobility

Mobility in sensor networks is highly essential for allowing communication between different connected components of the network. This also allows the operation of the sparse networks. When there is mobility in the sensor networks energy consumption is greatly reduced, so that the life time of the nodes are increased. Sensor mobility also allows better coverage.

5.6 Bandwidth

Bandwidth is defined as the total distance or range between the highest and lowest signals on the communication channel. [14] Bandwidth represents the capacity of the connection. The greater the capacity, the more likely that greater performance will follow, though overall performance also depends on other factors, such as latency. Sensor networks need to be supplied with the required amount of bandwidth so that it is able to achieve a minimal required QoS. Limited bandwidth results in congestion which impacts normal data exchange and may also lead to packet loss.

CONCLUSION

Wireless sensor networks are more than just a specific form of ad hoc networks. Recent advanced hardware technologies result in more powerful sensors as small as a few millimetres volume. The main drawback is still energy constraints. Additional strategies aiming at extending sensor lifetimes have also been studied along with pre-processing or data aggregation prior to transmission, and the optimal positions to place sensors. The stringent miniaturization and cost requirements make economic usage of energy and computational power a significantly bigger issue than in normal ad hoc networks. As wireless sensor networks are still a young research field, much activity is still on-going to solve many open issues. As some of the underlying hardware problems, especially with respect to the energy supply and miniaturization, are not yet completely solved, wireless sensor networks are having certain short comings, which are to be solved. WSN is emerging as a very important tool for making human life comfortable and safe. Yet, there is enormous scope for improving this WSN technology.

REFERENCES

[1]D. Braginsky, D. Estrin 2002. Rumor routing algorithm for sensor networks. International Workshop on Wireless Sensor Networks and Applications, WSNA

[2] F.Stajano and R. Anderson. 1999. The Resurrecting Duckling: Security Issues for Ad-hoc Wireless Networks wireless networks. 7th International Workshop on Security Protocols.

[3] D.Balfanz and D. Smetters and P. Stewart and H. Wong, 2002Talking to strangers: Authentication in adhoc wireless networks, Symposium on Network and Distributed Systems Security.

[4]Kurose, J. F., and Ross, K. Computer Networking: A Top-Down Approach Featuring the Internet. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA,.

[5]W.R.Heinzelman, A.Chandrakasan, H.Balakrishnan,"2000 Energy-efficient communication protocol for wireless micro sensor networks",IEEE Hawaii International Conference on System Sciences.

[6]C.Intanagonwiwat and R. Goninan and D. Estrin "Directed Diffusion: A Scalable and Robust Communication" MOBICOM 2000

[7]M. Laibowitz and J. A. Paradiso, "Parasitic mobility for pervasive sensor networks," in Third International Conference on Pervasive Computing (PERVASIVE 2005), Munich, Germany, May 2005.

[8] C. Guestrin et al. Near-optimal sensor placements in Gaussian processes. In ICML, pages 265–272, 2005.

[9] C.-C. Han et al. A dynamic operating system for sensor nodes. In MobiSys, 2005.

[10]W.Heinzelman, .ChandrakasanandH.Balakrishnan,"Energy-E±cient Communication Protocol for Wireless Micro sensor Networks," Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS '00), January2000.

[11] Y. Yao and J. Gehrke, \The cougar approach to in-network query processing in sensor networks", in SIGMOD Record, September 2002.

[12] F. Ye, H. Luo, J. Cheng, S. Lu, L. Zhang, \A Two-tier data dissemination model for large-scale wireless sensor networks", proceedings of ACM/IEEE MOBICOM, 2002.

[13] http://www.ieee802.org/15/

[14] F. Aurenhammer, "Voronoi Diagrams - A Survey of a Fundamental Geometric Data Structure," *ACM Computing Surveys*, 1991.

[15] M. A. Batalin and G. S. Sukhtame, "Coverage, Exploration and Deployment by a Mobile Robot and Communication Network," *Telecommunication Systems Journal, Special Issue on Wireless Sensor Networks*, vol. 26(2), pp. 181 -196, 2004.