Integrating Route Optimization into Data transmission for Reliable Routing in Wireless Sensor Network

A dissertation submitted in the partial fulfillment for the award of Degree of

MASTER OF TECHNOLOGY
IN
SOFTWARE ENGINEERING

By

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DECLARATION

I hereby want to declare that the dissertation entitled "**Integrating route optimization into Data transmission for reliable routing in wireless sensor network"** which is being submitted to the **Delhi Technological University**, in partial fulfillment of the requirements for the award of degree in **Master of Technology in Software Engineering** is an authentic work carried out by me. The material contained in this dissertation has not been submitted to any institution or university for the award of any degree or Diploma to the best of my knowledge.

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This is to certify that the dissertation entitled **“Integrating route optimization into Data transmission for reliable routing in wireless sensor network”** submitted by **Sushil Kumar (Roll Number: 2K13/SWT/17),** in partial fulfillment of the requirements for the award of degree of **Master of Technology** in Software Engineering at **Delhi Technological University**, is an authentic work carried out by him under my guidance. The content embodied in this dissertation has not been submitted by him earlier to any institution or organization for any degree or diploma to the best of my knowledge and belief.

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ABSTRACT

In this report, Aiming at reliable data delivery in wireless sensor network a novel routing protocol. This protocol differs from the traditional protocol as it integrates path quality information collection into the data transmission and achieves route optimization dynamically and adaptively.

Integrating route optimization works in a “monitor and adjust” way means every route is selected for every data packet independently according to the route selection probability vector (RSPV). Real time quality information is gathered in the course of packets transmission and fed back by the sink periodically. Using the interval estimation, Source node identifies and filters out the paths of low quality and adjusts the route selection probability vector according to that. A simulation result in semi-static and dynamic environment show integrated route optimization is competent to deal with the adverse, dynamic, bandwidth constrained wireless sensor network and outperform typical reliable routing protocol in both energy efficiency and reliability.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter-1

INTRODUCTION

This Chapter provides overview of dissertation and explains need for enhanced and energy efficient routing protocol. Along with this, it will explain various challenges and research issues that are currently being faced.

1.1 Motivation

Due to recent technological advances, the manufacturing of small and low cost sensors became technically and economically feasible. The sensing electronics measure ambient conditions related to the environment surrounding the sensor and transform them into an electric signal. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. A large number of these disposable sensors can be networked in many applications that require unattended operations. A Wireless Sensor Network contains hundreds or thousands of these sensor nodes. These sensors have the ability to communicate either among each other or directly to an external base-station. A greater number of sensors allows for sensing over larger geographical regions with greater accuracy. Figure 1 shows the schematic diagram of sensor node components. Basically, each sensor node comprises sensing, processing, transmission, mobilize, positioning system, and power units (some of these components are optional like the mobilize). The same figure shows the communication architecture of a Wireless Sensor Network. Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment. Each sensor node bases its decisions on its mission, the information it currently has, and its knowledge of its

As an advanced method of information gathering, Wireless Sensor Networks find wide range of applications including environment monitoring, precision agriculture, health care, battle field situation assessment etc. Recently, experimental studies have demonstrated that there exist large amounts of unreliable and asymmetric wireless links in low-power Wireless Sensor Networks which makes it a challenging problem for routing protocols to deliver data reliably. A direct solution is to design link metrics reflecting link’s reliability and choose the most reliable path from candidate ones. Use per-link signal strength as link reliability metric and apply a threshold to avoid links with high loss ratio. One drawback of this mechanism is that “threshold” may eliminate links necessary for connectivity. What’s more, signal strength measurement at sensor node may fail to distinguish accurately between links. DeCouto et al. Propose ETX to characterize link reliability and find path with the fewest expected number of transmissions (including retransmissions) required to deliver a packet to sink. Hereafter, without confusion we use quality and reliability interchangeably. In order to collect link quality information, in all nodes send “HELLO” continually during network setup phase in its one hop neighborhood and link quality is obtained by measuring the loss probabilities of broadcast packets. Abtin et al point out that due to densely deployment of WSN, “HELLO” messages should be scheduled so as to avoid collision. Methods are off-line in nature. Different from it, on-line method is discussed in where Probe messages are sent during network operation phase to gather real-time link quality information. Traditional methods treat reliable route setup and data transmission as two separated processes: dedicated Probe messages are sent to collect link quality information and reliable routing is transformed to classical minimum cost path problem under reliability metrics; then data packets are transmitted along the selected optimal path. Large amounts of energy are exerted in sending Probes but the effect is not satisfactory: as for off-line method, information collected in network setup phase doesn’t reflect the Real-time situation when data packets are to be transmitted while as for on-line methods; Probes compete with data transmissions for rare bandwidth resource and may interfere normal data transmission. In fact, when data packets are transmitted along a path, route quality is reflected naturally. If this information is used, route optimization can be achieved at very low overhead.

Based on these observations, Integrating Routing Optimization into data transmissions is presented in this paper. The defining aspect it differs from typical existing mechanisms is it integrates route quality information collection into data transmission and achieves route optimization in a dynamic and adaptive way. Before we describe integrating routing optimization into data transmission in detail, we state the assumptions of this work: sensor nodes are randomly distributed and node density is high; the main traffic is data gathering from sensor nodes to sink and the data packets are of the same length; event driven data report mode is used where sensor nodes only react to sudden and drastic changes in the value of a sensed attribute.

In this project, we proposed sensor nodes are randomly distributed and node density is high; the main traffic is data gathering from sensor nodes to sink and the data packets are of the same length; event driven data report mode is used where sensor nodes only react to sudden and drastic changes in the value of a sensed attribute.

1.2 Integrating Routing Optimization into data transmission

In layered protocol stack, network layer has two main functions: route setup and repair (RSR), packet for-warding (PF). Traditional protocols treat them as independent modules: Route setup and repair collects topology information (for example, link reliability), finds optimal route under certain object and provides it to Packet forwarding; PF sends data packets along the selected route; there’s little interaction between Route setup and repair and packet forwarding except when link failure occurs. We refer to the design as “separated mode”. Lack of information sharing between Route setup and repair and packet forwarding, separated mode is not efficient in energy and bandwidth usage. In order to setup reliable route, a mass of probe messages are sent which imposes heavy tax on energy constrained sensor nodes. Moreover, as for densely deployed and bandwidth constrained WSN, probe messages consume large amounts of bandwidth resource so that route setup might be interfered and normal data transmissions might be jammed.

1.3 Related Work

Most routing protocols for ad hoc wireless networks such as AODV/DSR/DSDV use flooding to find optimal routes and hence are not very scalable for use in large networks such as sensor networks. Geographic routing protocols mitigate this route discovery overhead by routing on the basis of the geographic positions of nodes and are much more scalable. But the deployment of geographic routing protocols in real networks has proved to be unexpectedly difficult because of the presence of unreliable links in the network. Reliability of a radio link is characterized by the delivery ratio p, which we define as the probability that a packet transmitted over the link will be received correctly at the other end. The standard link model that geographic routing protocols such as GPSR assume is known as the unit disk model. In the unit disk model, any two nodes are assumed to be connected by a 100% reliable link if they are within radio range.

1.4 Problem Formulation

The defining aspect it differs from typical existing mechanisms is it integrates route quality information collection into data transmission and achieves route optimization in a dynamic and adaptive way. Sensor nodes are randomly distributed and node density is high; the main traffic is data gathering from sensor nodes to sink and the data packets are of the same length; event driven data report mode is used where sensor nodes only react to sudden and drastic changes in the value of a sensed attribute

1.5 Methodology

This section provides overview of the approach adopted to provide solution of the problems mentioned above. There are basically two modules that work to achieve the required target. The output from one module is fed as input to another module and the result is our target goal to provide the proposed methodology.

1.6 Thesis Outline

The scope of this thesis is to study existing routing protocol and propose enhanced routing Algorithm. Thesis is organized into 6 chapters. Brief description of each chapter is given below.

- **Chapter 2- Literature Survey**. In this chapter brief introduction of Wireless Sensor Network has been explained.
- **Chapter 3-Routing Protocol.** In this chapter, different Routing techniques are presented.
- **Chapter 4- Proposed Algorithm.** This chapter presents detailed description of proposed details of proposed methods, implementation and Simulation Environment parameters.
- **Chapter 5- Simulation Result.** In this chapter implementation and results of experiment are presented and compared with existing work.
- **Chapter 6- Conclusion and Future Work.** This chapter briefly explains scope of future work and summarizes work done in thesis.

Chapter-2

LITERATURE SURVEY

2.1Wireless Sensor Network

Sensor networks are widely used in both civil and military applications such as security management, surveillance, automation, and environmental monitoring. So far, most commercially deployed systems utilize wire based communication. However, in recent years there has been tremendous interesting both industry and academia in self-configuring wireless networks. Main motivations are to reduce installation cost. Gain flexibility, allow for unobtrusive installation, and enable entirely new applications such as tracking and wireless interrogation. The recent developments have been fuelled by advances in low cost and low power RF communication. as most envisioned systems are battery operated and expected to the successful only if low cost. A wireless sensor network may he generalized as a distributed system consisting of hundreds of sensor nodes each equipped with a wireless radio transceiver along with application-specific sensors and signal processing hardware. There may or may not be a central control unit, i.e., a base station. Due to the typically short range of low-power RF transceivers, communication takes place via multi-hop through neighboring nodes. The information flow may be from the sensor nodes to a network access point e.g., the base station, or from the network access point to sensor nodes. or among sensors themselves. In order to fully utilize the benefits of a multi-hop RF network, the system should also be self-configuring and able to adapt to environmental changes by reconfiguration. The nodes are typically small and battery operated and is expected to live for at least couple of years. Therefore energy efficiency is a crucial factor for all tasks performed throughout the lifetime of the system. Energy can he saved by communicating over reliable links and by avoiding collision of packets, which eliminates the necessity of re-transmission. Wireless sensor networks are still in the development stage with some industrial interest. e.gEmber, Intel_ ABB, Sensicast, ParcBosch. Most industrial applications for wireless sensor networks are low cost and deal with stationary scenarios. In spite of the low cost of these wireless sensor nodes (typically less than $5) it is still not low enough to allow the use of redundant sensors as proposed in current academic research. This implies that there is still a need to gather information from every available sensor, requiring a reliable path to every sensor in the network. During the implementation of a protocol targeting industrial applications of stationary wireless sensor networks, it was found that it is advantageous to acquire accurate information about the availability and quality of the RF communication links prior to the network topology formation. This task is accomplished by the “link assessment process”. The link assessment process includes discovery of all nodes and the available links between them, and grading the quality of these links. The latter can be achieved by estimating parameters such as packet success rate or signal strength, which may he determined by assessing a sufficient number of packets exchanged between neighboring nodes. This information can then be used to make routing decisions and form a reliable multi-hop network topology. The paper is organized as follows: In the following section the network scenario and link assessment requirements.

2.2 Topology in Wireless Sensor Network

The network structure of wireless network is not limited to one design. While designing the network, the developer has several choices of topologies for configuring the network. Following are the different topologies:

Single Hop star topology: Single hop star topology is the simplest WSN topology. In this topology, every node communicates directly with the gateway or the data collector. Due to minimum networking concerns, this topology simplifies the network wherever it is realizable. However, due to its design only, the biggest limitation it possesses is the problem of scalability. The nodes that are at a large distance from the gateway will have poor quality connections with the gateway. Thus, this topology is good to be used only when the number of nodes in the network is very small and the coverage area does not extend beyond the radio transmission range of around 30 meters in a building. However, in most cases, it is important that an initialization vector is never reused under the same key

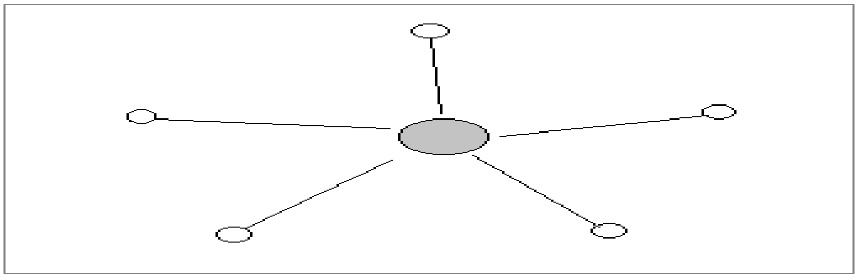


Figure 2.1: Single Hop Star Topology

Multi Hop mesh & grid topology: For covering large are, multi hop network is necessary. In this topology, the signal goes from one sensor to the other until it reaches the gateway. Here, the route of the signal is determined by a particular routing protocol. Depending upon whether the network is random or structured, it can look like the below figures:

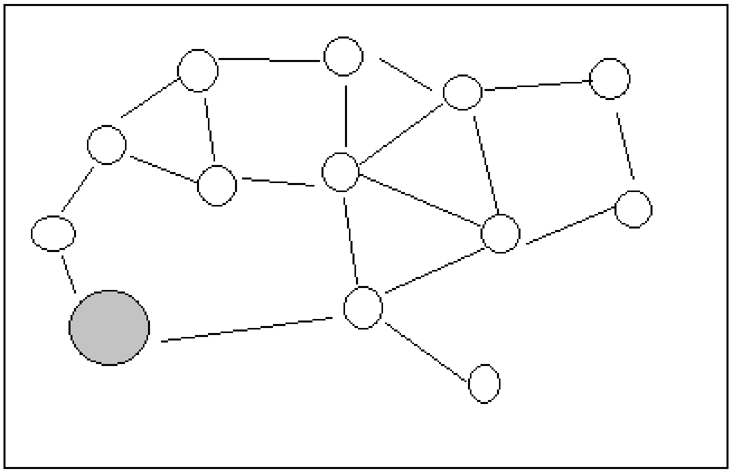


Figure 2.2: Multi Hop mesh Topology

Two Tier hierarchical cluster topology: This is the most common architecture for larger WSNs. In this topology, nodes within a specific region send their data to a local cluster head. In turn all such cluster heads from different regions send their collected data to the gateway. This network can be interlaced further also i.e. the cluster head of tier 2 can send the data to the cluster head of another network which can further send the data to the gateway. The biggest advantage of this topology is that it divides the whole network into a number of small zones within which routing of signals can be done locally. The cluster heads can be designed to be more powerful in terms of computation/communication. In addition to it, the nodes can also be connected through a wire, which increases the transmission speed as well as reliability of the network.

2.3Wireless Sensor Networks Applications

Wireless Sensor Networks are used in many applications such as:

- Health care monitoring
- Air pollution monitoring

- Landslide detection
- Natural disaster prevention
- Machine health monitoring
- Civilian environments
- Law enforcement activities
- Commercial projects

2.4 Challenges in Wireless Sensor Networks

Node Deployment: Node deployment in WSNs is application dependent and aspects 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.

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. In a multi-hop Wireless Sensor Networks, 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.

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. 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.

Security and Reliability: 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.

Quality of Service (QoS): Data should be delivered within a certain period of time from the moment it is sensed otherwise the data will be useless. Therefore bounded latency for data delivery is another condition for time-constrained applications. 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 .hops.

Chapter-3

ROUTING PROTOCOLS

Routing in WSNs can be divided into network-based routing, hierarchical-based routing, and location-based routing depending on the network structure. In flat-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, however, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. A routing protocol is considered adaptive if certain system parameters can be controlled in order to adapt to the current network conditions and available energy levels. Furthermore, these protocols can be classified into multipath-based, query-based, negotiation-based, QoS-based, or coherent-based routing techniques depending on the protocol operation. In addition to the above, routing protocols can be classified into three categories, namely, proactive, reactive, and hybrid protocols depending on how the source finds a route to the destination. In proactive protocols, all routes are computed before they are really needed, while in reactive protocols, routes are computed on demand. Hybrid protocols use a combination of these two ideas. When sensor nodes are static, it is preferable to have table driven routing protocols rather than using reactive protocols. A significant amount of energy is used in route discovery and setup of reactive protocols. Another class of routing protocols is called the cooperative routing protocols. In cooperative routing, nodes send data to a central node where data can be aggregated and may be subject to further processing, hence reducing route cost in terms of energy use.

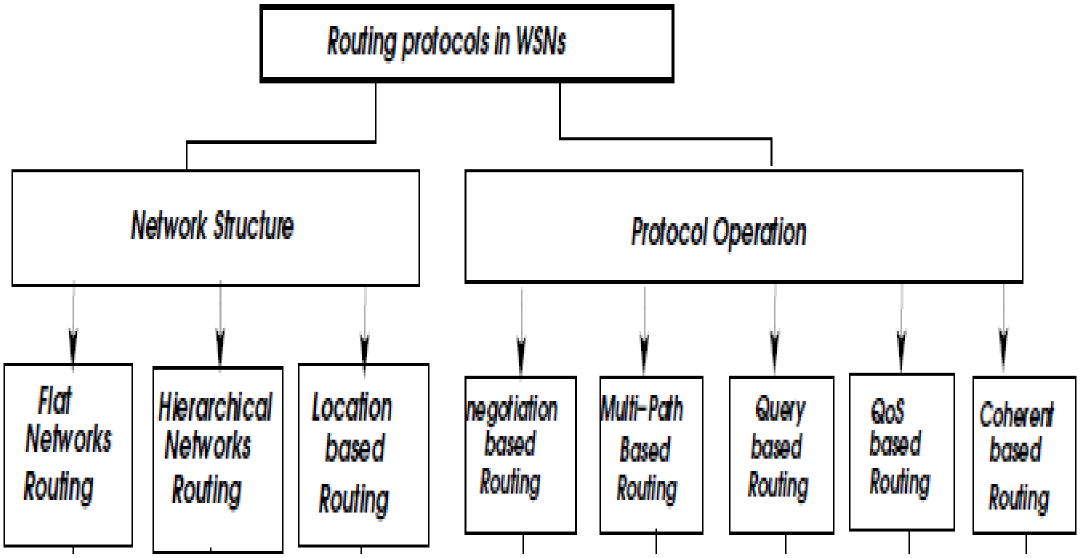


Figure 3.1: Routing Protocols in WSN

3.1 Network Structure Based Protocols

The underlying network structure can play significant role in the operation of the routing protocol in Wireless Sensor Networks.

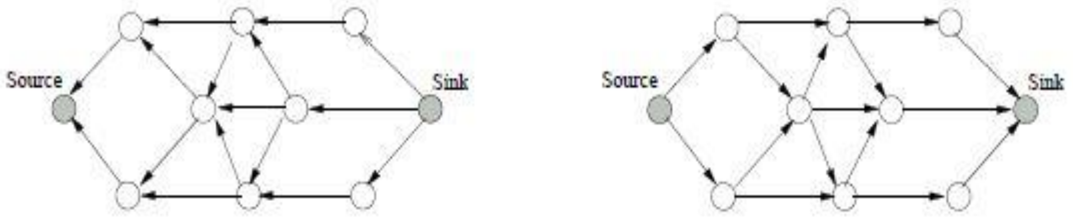
Flat Routing: The first category of routing protocols is the multi-hop flat routing protocols. In flat networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data centric routing, where the BS sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. Early works on data centric routing, e.g., SPIN and directed diffusion was shown to save energy through data negotiation and elimination of redundant data. These two protocols motivated the design of many other protocols which follow a similar concept

Sensor Protocol for Information via Negotiation (SPIN): It disseminates all the information at each node to every node in the network assuming that all nodes in the network are potential base-stations. This enables a user to query any node and get the required information immediately. These protocols make use of the property that nodes in close proximity have similar data, and hence there is a need to only distribute the data that other nodes do not posses. The SPIN family of protocols uses data negotiation and resource-adaptive algorithms. As running SPIN assign a high-level name to completely describe their collected data (called meta-data) and perform meta-data negotiations before any data is transmitted. This assures that there is no redundant data sent throughout the network. The semantics of the meta-data format is application-specific and is not specified in SPIN. For example, sensors might use their unique IDs to report meta-data if they cover a certain known region. In addition, SPIN has access to the current energy level of the node and adapts the protocol it is running based on how much energy is remaining. These protocols work in a time-driven fashion and distribute the information all over the network, even when a user does not request any data. The SPIN family is designed to address the deficiencies of classic flooding by negotiation and resource adaptation. The SPIN family of protocols is designed based on two basic ideas:

1. Sensor nodes operate more efficiently and conserve energy by sending data that describe the sensor data instead of sending all the data; for example, image and sensor nodes must monitor the changes in their energy resources
2. Conventional protocols like flooding or gossiping based routing protocols waste energy and bandwidth when sending extra and un-necessary copies of data by sensors covering overlapping areas. The drawbacks of flooding include implosion, which is caused by duplicate messages sent to the same node, overlap when two nodes sensing the same region will send similar packets to the same neighbor and resource blindness by consuming large amounts of energy without consideration for the energy constraints. Gossiping avoids the problem of implosion by just selecting a random node to send the packet to rather than broadcasting the packet blindly. However, this causes delays in propagation of data through the nodes.

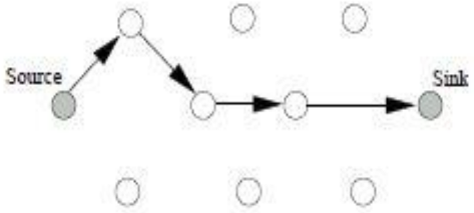
SPIN's meta-data negotiation solves the classic problems of flooding, and thus achieving a lot of energy efficiency. SPIN is a 3-stage protocol as sensor nodes use three types of messages ADV, REQ and DATA to communicate. ADV is used to advertise new data, REQ to request data, and DATA is the actual message itself. The protocol starts when a SPIN node obtains new data that it is willing to share. It does so by broadcasting an ADV message containing meta-data. If a neighbor is interested in the data, it sends a REQ message for the DATA and the DATA is sent to this neighbor node. The neighbor sensor node then repeats this process with its neighbors. As a result, the entire sensor area will receive a copy of the data.

Directed Diffusion: Intanagonwiwatet. al. proposed a popular data aggregation paradigm for WSNs, called directed diffusion. Directed diffusion is a data-centric (DC) and application aware paradigm in the sense that all data generated by sensor nodes is named by attribute-value pairs. The main idea of the DC paradigm is to combine the data coming from different sources en route (in-network aggregation) by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime. Unlike traditional end-to-end routing, DC routing nodes routes from multiple sources to a single destination that allows in-network consolidation of redundant data. In directed diffusion, sensors measure events and create gradients of information in their respective neighborhoods. The base station requests data by broadcasting interests. Interest describes a task required to be done by the network. Interest diffuses through the network hop-by-hop, and is broad-cast by each node to its neighbors. As the interest is propagated throughout the network, gradients are set-up to draw data satisfying the query towards the requesting node, i.e., a BS may query for data by disseminating interests and intermediate nodes propagate these interests. This process continues until gradients are set-up from the sources back to the BS. More generally, a gradient specifies an attribute value and a direction. The strength of the gradient may be different towards different neighbors resulting in different amounts of information flow. At this stage, loops are not checked, but are removed at a later stage. Figure 3 shows an example of the working of directed discussion ((a) sending interests, (b) building gradients, and (c) data dissemination). When interests gradients, paths of information flow are formed from multiple paths and then the best paths are reinforced so as to prevent further flooding according to a local rule. In order to reduce communication costs, data is aggregated on the way. The goal is to find a good aggregation tree which gets the data from source nodes to the BS. The BS periodically refreshes and re-sends the interest when it starts to receive data from the source(s). This is necessary because interests are not reliably transmitted throughout the network.



(a) Propagate Interest

(b) Set up Gradients

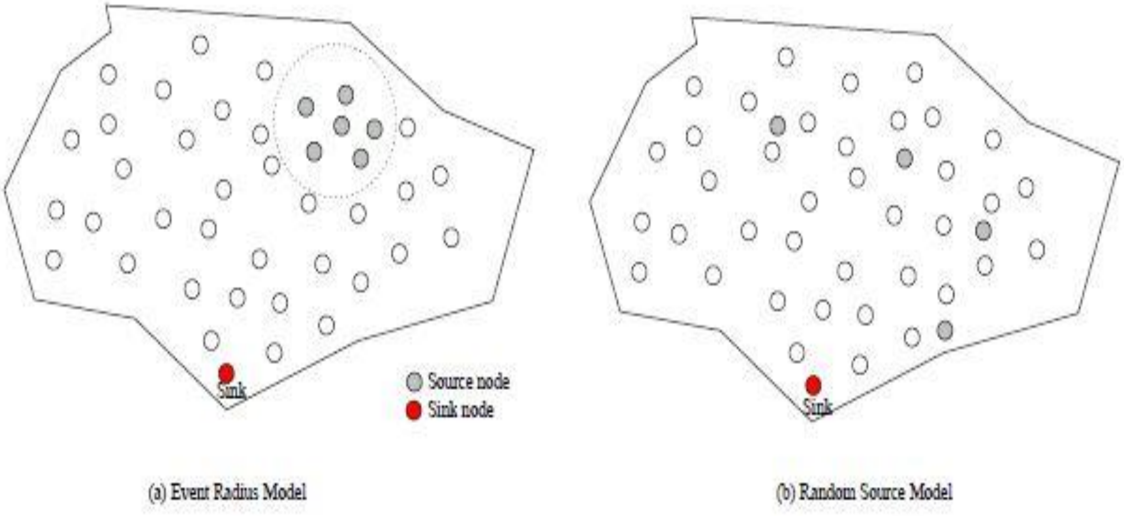


(c) Send data and path Reinforcement

Figure 3.2: Example of Interest Diffusion in sensor Network

All sensor nodes in a directed diffusion-based network are application-aware, which enables diffusion to achieve energy savings by selecting empirically good paths and by caching and processing data in the network. Caching can increase the efficiency, robustness and scalability of coordination between sensor nodes which is the essence of the data diffusion paradigm. Other usage of directed diffusion is to spontaneously propagate an important event to some sections of the sensor network. Such type of information retrieval is well suited only for persistent queries where requesting nodes are not expecting data that satisfy a query for duration of time. This makes it unsuitable for one-time queries, as it is not worth setting up gradients for queries, which use the path only once.

The performance of data aggregation methods, used in the directed diffusion paradigm, are affected by a number of factors which includes the positions of the source nodes in the network, the number of sources, and the communication network topology. In order to investigate these factors, two models of source placement. These models are called the event radius (ER) model, and the random sources (RS) model. In ER model, a single point in the network area is defined as the location of an event. This may correspond to a vehicle or some other phenomenon being tracked by the sensor nodes. All nodes within a distance S (called the sensing range) of this event that are not BSs are considered to be data sources. The average number of sources is approximately ¼S2n in a unit area network with n sensor nodes. In RS model, k of the nodes that are not BSs is randomly selected to be sources. Unlike the ER model, the sources are not necessarily clustered near each other. In both models of source placement, and for a given energy budget, a greater number of sources can be connected to the BS. However, each one performs better in terms of energy consumption depending on the application. In conclusion, the energy savings with aggregation used in the directed diffusion can be transformed to provide a greater degree of robustness with respect to dynamics in the sensed phenomena.



(a) Event Radius Model

(b) Random Source Model

Figure 3.3: Directed Diffusion Protocol Model

Directed diffusion differs from SPIN in two aspects. First, directed diffusion issues on demand data queries as the BS send queries to the sensor nodes by flooding some tasks. In SPIN, however, sensors advertise the availability of data allowing interested nodes to query that data. Second, all communication in directed diffusion is neighbor-to-neighbor with each node having the capability of performing data aggregation and caching. Unlike SPIN, there is no need to maintain global network topology in directed diffusion. However, directed diffusion may not be applied to applications (e.g. environmental monitoring) that require continuous data delivery to the BS. This is because the query-driven on demand data model may not help in this regard. Moreover, matching data to queries might require some extra overhead at the sensor nodes

Rumor Routing: It is a variation of directed diffusion and is mainly intended for applications where geographic routing is not feasible. In general, directed diffusion uses flooding to inject the query to the entire network when there is no geographic criterion to diffuse tasks. However, in some cases there is only a little amount of data requested from the nodes and thus the use of flooding is unnecessary. An alternative approach is to flood the events if the number of events is small and the number of queries is large. The key idea is to route the queries to the nodes that have observed a particular event rather than flooding the entire network to retrieve information about the occurring events. In order to flood events through the network, the rumor routing algorithm employs long-lived packets, called agents. When a node detects an event, it adds such event to its local table, called events table, and generates an agent. Agents travel the network in order to propagate information about local events to distant nodes. When a node generates a query for an event, the nodes that know the route, may respond to the query by inspecting its event table. Hence, there is no need to flood the whole network, which reduces the communication cost. On the other hand, rumor routing maintains only one path between source and destination as opposed to directed diffusion where data can be routed through multiple paths at low rates. Simulation results showed that rumor routing can achieve significant energy savings when compared to event flooding and can also handle node's failure. However, rumor routing performs well only when the number of events is small. For a large number of events, the cost of maintaining agents and event-tables in each node becomes infeasible if there is not enough interest in these events from the BS. Moreover, the overhead associated with rumor routing is controlled by different parameters used in the algorithm such as time-to-live (TTL) pertaining to queries and agents. Since the nodes become aware of events through the event agents, the heuristic for defining the route of an event agent highly affects the performance of next hop selection in rumor routing.

Minimum Cost Forwarding Algorithm (MCFA): The Minimum Cost Forwarding Algorithm exploits the fact that the direction of routing is always known, that is, towards the fixed external base-station. Hence, a sensor node need not have a unique ID nor maintain a routing table. Instead, each node maintains the least cost estimate from itself to the base-station. Each message to be forwarded by the sensor node is broadcast to its neighbor’s. When a node receives the message, it checks if it is on the least cost path between the source sensor node and the base-station. If this is the case, it re-broadcasts the message to its neighbor’s. This process repeats until the base-station is reached. In Minimum Cost Forwarding Algorithm, each node should know the least cost path estimate from itself to the base-station. This is obtained as follows. The base-station broadcasts a message with the cost set to zero while every node initially set its least cost to the base-station to infinity. Each node, upon receiving the broadcast message originated at the base-station, checks to see if the estimate in the message plus the link on which it is received is less than the current estimate. If yes, the current estimate and the estimate in the broadcast message are updated. If the received broadcast message is updated, then it is re-sent; otherwise, it is purged and nothing further is done. However, the previous procedure may result in some nodes having multiple updates and those nodes far away from the base-station will get more updates from those closer to the base-station. To avoid this, the Minimum Cost Forwarding Algorithm was modified to run a back off algorithm at the setup phase. The back off algorithm dictates that a node will not send the updated message until a*lc time units have elapsed from the time at which the message is updated, where a is a constant and lc is the link cost from which the message was received.

Gradient Based Routing: Schurgersetal.proposed another variant of directed diffusion, called Gradient-Based Routing. The key idea in Gradient Based Routing is to memorize the number of hops when the interest is diffused through the whole network. As such, each node can calculate a parameter called the height of the node, which is the minimum number of hops to reach the BS. The difference between a node's height and that of its neighbor is considered the gradient on that link. A packet is forwarded on a link with the largest gradient. Gradient Based Routing uses some auxiliary techniques such as data aggregation and traffic spreading in order to uniformly divide the traffic over the network. When multiple paths pass through a node, which acts as a relay node, that relay node may combine data according to a certain function. In Gradient Based Routing, three different data dissemination techniques have been discussed (1) Stochastic Scheme, where a node picks one gradient at random when there are two or more next hops that have the same gradient, (2) Energy-based scheme, where a node increases its height when its energy drops below a certain threshold, so that other sensors are discouraged from sending data to that node, and (3) Stream-based scheme, where new streams are not routed through nodes that are currently part of the path of other streams. The main objective of these schemes is to obtain a balanced distribution of the traffic in the network, thus increasing the network lifetime. Simulation results of Gradient Based Routing showed that Gradient Based Routing outperforms directed diffusion in terms of total communication energy.

Information-driven sensor querying (IDSQ) and Constrained anisotropic diffusion routing (CADR): The key idea is to query sensors and route data in the network such that the information gain is maximized while latency and bandwidth are minimized. Constrained anisotropic diffusion routing diffuses queries by using a set of information criteria to select which sensors can get the data. This is achieved by activating only the sensors that are close to a particular event and dynamically adjusting data routes. The main difference from directed diffusion is the consideration of information gain in addition to the communication cost. In

Constrained anisotropic diffusion routing, each node evaluates an information/cost objective and routes data based on the local information/cost gradient and end-user requirements. Estimation theory was used to model information utility measure. In Information-driven sensor querying, the querying node can determine which node can provide the most useful information with the additional advantage of balancing the energy cost. However, Information-driven sensor querying does not specifically define how the query and the information are routed between sensors and the BS. Therefore, Information-driven sensor querying can be seen as a complementary optimization procedure. Simulation results showed that these approaches are more energy-efficient than directed diffusion where queries are diffused in an isotropic fashion and reaching nearest neighbors first.

COUGAR: Another data-centric protocol called COUGAR views the network as a huge distributed database system. The key idea is to use declarative queries in order to abstract query processing from the network layer functions such as selection of relevant sensors and so on. Cougar utilizes in-network data aggregation to obtain more energy savings. The abstraction is supported through an additional query layer that lies between the network and application layers. Cougar incorporates architecture for the sensor database system where sensor nodes select a leader node to perform aggregation and transmit the data to the BS. The BS is responsible for generating a query plan, which specifies the necessary information about the data flow and in-network computation for the incoming query and send it to the relevant nodes. The query plan also describes how to select a leader for the query. The architecture provides in-network computation ability that can provide energy efficiency in situations when the generated data is huge. Cougar provided network-layer independent methods for data query. However, Cougar has some drawbacks. First, the addition of query layer on each sensor node may add an extra overhead in terms of energy consumption and memory storage. Second, to obtain successful in-network data computation, synchronization among nodes is required (not all data are received at the same time from incoming sources) before sending the data to the leader node. Third, the leader nodes should be dynamically maintained to prevent them from being hot-spots (failure prone).

ACQUIRE: Sadagopan et al. proposed a technique for querying sensor networks called Active Query forwarding in sensor networks (ACQUIRE). Similar to COUGAR, ACQUIRE views the network as a distributed database where complex queries can be further divided into several sub queries. The operation of Active Query forwarding can be described as follows. The BS node sends a query, which is then forwarded by each node receiving the query. During this, each node tries to respond to the query partially by using its pre-cached information and then forward it to another sensor node. If the pre-cached information is not up-to-date, the nodes gather information from their neighbors within a look-ahead of d hops. Once the query is being resolved completely, it is sent back through either the reverse or shortest-path to the BS. Hence, Active Query forwarding can deal with complex queries by allowing many nodes to send responses. Note that directed diffusion may not be used for complex queries due to energy considerations as directed diffusion also uses flooding-based query mechanism for continuous and aggregate queries. On the other hand, Active Query forwarding can provide efficient querying by adjusting the value of the look-ahead parameter d. When d is equal to network diameter, Active Query forwarding mechanism behaves similar to flooding. However, the query has to travel more hops if d is too small. A mathematical modeling was used to find an optimal value of the parameter d for a grid of sensors where each node has 4 immediate neighbors. However, there is no validation of results through simulation. To select the next node for forwarding the query, Active Query forwarding either picks it randomly or the selection is based on maximum potential of query satisfaction. Recall that selection of next node is based on either information gain (CADR and IDSQ) or query is forwarded to a node, which knows the path to the searched event (rumor routing).

Energy Aware Routing: The objective of energy-aware routing protocol, a destination initiated reactive protocol, is to increase the network lifetime. Although this protocol is similar to directed diffusion, it differs in the sense that it maintains a set of paths instead of maintaining or enforcing one optimal path at higher rates. These paths are maintained and chosen by means of a certain probability. The value of this probability depends on how low the energy consumption of each path can be achieved. By having paths chosen at different times, the energy of any single path will not deplete quickly. This can achieve longer network lifetime as energy is dissipated more equally among all nodes. Network survivability is the main metric of this protocol. The protocol assumes that each node is addressable through a class-based addressing which includes the location and types of the nodes. The protocol initiates a connection through localized flooding, which is used to discover all routes between source/destination pair and their costs; thus building up the routing tables. The high-cost paths are discarded and a forwarding table is built by choosing neighboring nodes in a manner that is proportional to their cost. Then, forwarding tables are used to send data to the destination with a probability that is inversely proportional to the node cost. Localized flooding is performed by the destination node to keep the paths alive. When compared to directed diffusion, this protocol provides an overall improvement of 21.5% energy saving and a 44% increase in network lifetime. However, the approach requires gathering the location information and setting up the addressing mechanism for the nodes, which complicate route setup compared to the directed diffusion.

Routing Protocols with Random Walks: The objective of random walks based routing technique is to achieve load balancing in a statistical sense and by making use of multi-path routing in Wireless Sensor Networks . This technique considers only large scale networks where nodes have very limited mobility. In this protocol, it is assumed that sensor nodes can be turned on or off at random times. Further, each node has a unique identifier but no location information is needed. Nodes were arranged such that each node falls exactly on one crossing point of a regular grid on a plane, but the topology can be irregular. To find a route from a source to its destination, the location information or lattice coordination is obtained by computing distances between nodes using the distributed asynchronous version of the well-known Bellman-Ford algorithm. An intermediate node would select as the next hop the neighboring node that is closer to the destination according to a computed probability. By carefully manipulating this probability, some kind of load balancing can be obtained in the network. The routing algorithm is simple as nodes are required to maintain little state information. Moreover, different routes are chosen at different times even for the same pair of source and destination nodes. However, the main concern about this protocol is that the topology of the network may not be practical.

Information from this leakage reveals nothing about the plaintext and is, effectively, garbage data.

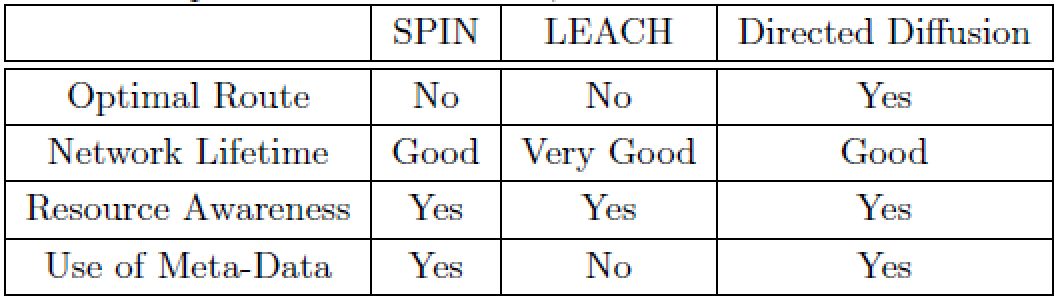
3.2 Hierarchical Routing Protocols

Hierarchical or cluster-based routing, originally proposed in wire line networks, are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing. However, most techniques in this category are not about routing, rather on "who and when to send or process/aggregate" the information, channel allocation etc., which can be orthogonal to the multi-hop routing function.

Low Energy Adaptive Clustering Hierarchy (LEACH): Heinemann, introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy. Low Energy Adaptive Clustering Hierarchy is a cluster-based protocol, which includes distributed cluster formation. Low Energy Adaptive Clustering Hierarchy randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network. In Low Energy Adaptive Clustering Hierarchy, the cluster head (CH) nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the base station in order to reduce the amount of information that must be transmitted to the base station. LEACH uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions. However, data collection is centralized and is performed periodically. Therefore, this protocol is most appropriate when there is a need for constant monitoring by the sensor network. A user may not need all the data immediately. Hence, periodic data transmissions are unnecessary which may drain the limited energy of the sensor nodes. After a given interval of time, a randomized rotation of the role of the CH is conducted so that uniform energy dissipation in the sensor network is obtained. The authors found, based on their simulation model that only 5% of the nodes need to act as cluster heads. The operation of LEACH is separated into two phases, the setup phase and the steady state phase. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the base station takes place. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead. During the setup phase, a predetermined fraction of nodes, p, elect themselves as CHs as follows. A sensor node chooses a random number, r, between 0 and 1. If this random number is less than a threshold value, T(n), the node becomes a cluster-head for the current round. The threshold value is calculated based on an equation that incorporates the desired percentage to become a cluster-head, the current round, and the set of nodes that have not been selected as a cluster-head in the last (1/P) rounds, denoted by G. It is given by:

$$T(n) = \frac{p}{1 - p(r \bmod (1/p))} \quad if\ n \in G$$

Where G is the set of nodes that are involved in the CH election. Each elected CH broadcast an advertisement message to the rest of the nodes in the network that they are the new cluster-heads. All the non-cluster head nodes, after receiving this advertisement, decide on the cluster to which they want to belong to. This decision is based on the signal strength of the advertisement. The non cluster-head nodes inform the appropriate cluster-heads that they will be a member of the cluster. After receiving all the messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule and assigns each node a time slot when it can transmit. This schedule is broadcast to all the nodes in the cluster. During the steady state phase, the sensor nodes can begin sensing and transmitting data to the cluster-heads. The cluster-head node, after receiving all the data, aggregates it before sending it to the base-station. After a certain time, which is determined a priori, the network goes back into the setup phase again and enters another round of selecting new CH. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters. Although LEACH is able to increase the network lifetime, there are still a number of issues about the assumptions used in this protocol. LEACH assumes that all nodes can transmit with enough power to reach the BS if needed and that each node has computational power to support different MAC protocols. Therefore, it is not applicable to networks deployed in large regions. It also assumes that nodes always have data to send, and nodes located close to each other have correlated data. It is not obvious how the number of the predetermined CHs (p) is going to be uniformly distributed through the network. Therefore, there is the possibility that the elected CHs will be concentrated in one part of the network. Hence, some nodes will not have any CHs in their vicinity. Furthermore, the idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may diminish the gain in energy consumption. Finally, the protocol assumes that all nodes begin with the same amount of energy capacity in each election round, assuming that being a CH consumes approximately the same amount of energy for each node. The protocol should be extended to account for non-uniform energy nodes, i.e., use energy-based threshold. An extension to LEACH, LEACH with negotiation, was proposed. The main theme of the proposed extension is to precede data transfers with high-level negotiation using meta-data descriptors as in the SPIN protocol discussed in the previous section. This ensures that only data that provides new information is transmitted to the cluster-heads before being transmitted to the base stations.



	SPIN	LEACH	Directed Diffusion
Optimal Route	No	No	Yes
Network Lifetime	Good	Very Good	Good
Resource Awareness	Yes	Yes	Yes
Use of Meta-Data	Yes	No	Yes

Figure 3.4: Comparison between SPIN, LEACH and Directed Diffusion

Above mentioned table compares SPIN, LEACH, and the Directed Diffusion routing techniques according to different parameters. It is noted from the table that Directed Diffusion shows a promising approach for energy-efficient routing in WSNs due to the use of in-network processing.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS): An enhancement over LEACH protocol was proposed. The protocol, called Power-efficient Gathering in Sensor Information System, is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need only communicate with their closest neighbors and they take turns in communicating with the base-station. When the round of all nodes communicating with the base-station ends, a new round will start and so on. This reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes. Hence, PEGASIS has two main objectives. First, increase the lifetime of each node by using collaborative techniques and as a result the network lifetime will be increased. Second, allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS instead of using multiple nodes. To locate the closest neighbor node in PEGASIS, each node uses the signal strength to measure the distance to all neighboring nodes and then adjusts the signal strength so that only one node can be heard. The chain in PEGASIS will consist of those nodes that are closest to each other and form a path to the base-station. The aggregated form of the data will be sent to the base-station by any node in the chain and the nodes in the chain will take turns in sending to the base-station. The chain construction is performed in a greedy fashion. Simulation results showed that PEGASIS is able to increase the lifetime of the network twice as much the lifetime of the network under the LEACH protocol. Such performance gain is achieved through the elimination of the overhead caused by dynamic cluster formation in LEACH and through decreasing the number of transmissions and reception by using data aggregation. Although the clustering overhead is avoided, PEGASIS still requires dynamic topology adjustment since a sensor node needs to know about energy status of its neighbors in order to know where to route its data. Such topology adjustment can introduce significant overhead especially for highly utilized networks. Moreover, PEGASIS assumes that each sensor node can be able to communicate with the BS directly. In practical cases, sensor nodes use multi-hop communication to reach the base-station. Also, PEGASIS assumes that all nodes maintain 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. In addition, PEGASIS assumes that all sensor nodes have the same level of energy and they are likely to die at the same time. Note also that PEGASIS introduces excessive delay for distant node on the chain. In addition, the single leader can become a bottleneck. Finally, although in most scenarios, sensors will be fixed or immobile as assumed in PEGASIS, some sensors may be allowed to move and hence affect the protocol functionality. An extension to PEGASIS, called Hierarchical-PEGASIS was introduced with the objective of decreasing the delay incurred for packets during transmission to the BS. For this purpose, simultaneous transmissions of data are studied in order to avoid collisions through approaches that incorporate signal coding and spatial transmissions. In the later, only spatially separated nodes are allowed to transmit at the same time. The chain-based protocol with CDMA capable nodes, constructs a chain of nodes, that forms a tree like hierarchy, and each selected node in a particular level transmits data to the node in the upper level of the hierarchy. This method ensures data transmitting in parallel and reduces the delay significantly. Such hierarchical extension has been shown to perform better than the regular PEGASIS scheme by a factor of about 60.

Self-Organizing Protocol (SOP): Self-Organizing protocol and an application taxonomy that was used to build architecture used to support heterogeneous sensors. Furthermore, these sensors can be mobile or stationary. Some sensors probe the environment and forward the data to a designated set of nodes that act as routers. Router nodes are stationary and form the backbone for communication. Collected data are forwarded through the routers to the more powerful BS nodes. Each sensing node should be able to reach a router in order to be part of the network. A routing architecture that requires addressing of each sensor node has been proposed. Sensing nodes are identifiable through the address of the router node they are connected to. The routing architecture is hierarchical where groups of nodes are formed and merge when needed. Local Markov Loops (LML) algorithm, which performs a random walk on spanning trees of a graph, was used to support fault tolerance and as a means of broadcasting. Such approach is similar to the idea of virtual grid used in some other protocols that will be discussed later under location-based routing protocols. In this approach, sensor nodes can be addressed individually in the routing architecture, and hence it is suitable for applications where communication to a particular node is required. Furthermore, this algorithm incurs a small cost for maintaining routing tables and keeping a balanced routing hierarchy. It was also found that the energy consumed for broadcasting a message is less than that consumed in the SPIN protocol. This protocol, however, is not an on-demand protocol especially in the organization phase of algorithm. Therefore introducing extra overhead. Another issue is related to the formation of hierarchy. It could happen that there are many cuts in the network, and hence the probability of applying reorganization phase increases, which will be an expensive operation.

Sensor Aggregate Routing: A set of algorithms for constructing and maintaining sensor aggregates were proposed. The objective is to collectively monitor target activity in a certain environment (target tracking applications). A sensor aggregate comprises those nodes in a network that satisfy a grouping predicate for a collaborative processing task. The parameters of the predicate depend on the task and its resource requirements. The formation of appropriate sensor aggregates was discussed in terms of allocating resources to sensing and communication tasks. Sensors in a sensor field are divided into clusters according to their sensed signal strength, so that there is only one peak per cluster. Then, local cluster leaders are elected. One peak may represent one target, multiple targets, or no target in case the peak is generated by noise sources. To elect a leader, information exchanges between neighboring sensors are necessary. If a sensor, after exchanging packets with all its one-hop neighbors, finds that it is higher than all its one-hop neighbors on the signal field landscape, it declares itself a leader. This leader-based tracking algorithm assumes the unique leader knows the geographical region of the collaboration. Three algorithms were proposed. First, a lightweight protocol, Distributed Aggregate Management (DAM), for forming sensor aggregates for a target monitoring task. The protocol comprises a decision predicate P for each node to decide if it should participate in an aggregate and a message exchange scheme M about how the grouping predicate is applied to nodes. A node determines if it belongs to an aggregate based on the result of applying the predicate to the data of the node as well as information from other nodes. Aggregates are formed when the process eventually converges. Second, Energy-Based Activity Monitoring (EBAM) algorithm estimate the energy level at each node by computing the signal impact area, combining a weighted form of the detected target energy at each impacted sensor assuming that each target sensor has equal or constant energy level. The third algorithm, Expectation-Maximization like Activity Monitoring (EMLAM), removes the constant and equal target energy level assumption. EMLAM estimates the target positions and signal energy using received signals, and uses the resulting estimates to predict how signals from the targets may be mixed at each sensor. This process is iterated, until the estimate is sufficiently good. The distributed track initiation management scheme, combined with the leader-based tracking algorithm described, forms a scalable system. The system works well in tracking multiple targets when the targets are not interfering, and it can recover from inter-target interference once the targets move apart.

3.3 Location Based Routing Protocols

In this kind of routing, sensor nodes are addressed by means of their locations. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors. Alternatively, the location of nodes may be available directly by communicating with a satellite, using GPS (Global Positioning System), if nodes are equipped with a small low power GPS receiver. To save energy, some location based schemes demand that nodes should go to sleep if there is no activity. More energy savings can be obtained by having as many sleeping nodes in the network as possible. In the rest of this section, we review most of the location or geographic based routing protocols.

Routing Protocol based on Protocol Operation:

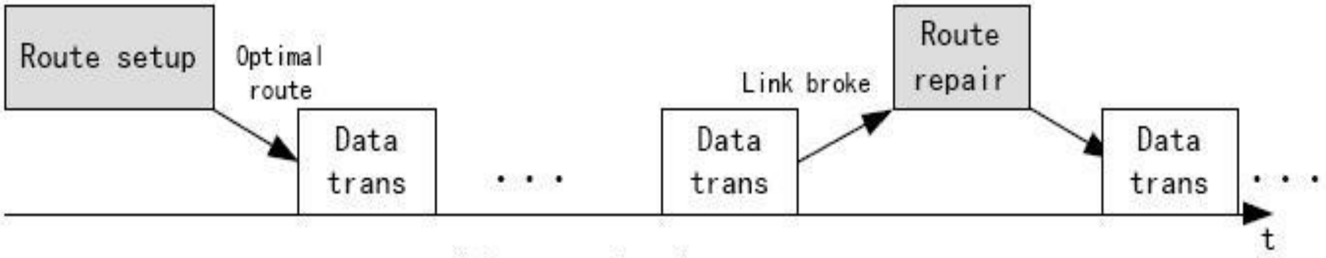
Multipath Routing Protocol: Multipath routing was used to enhance the reliability of Wireless Sensor Networks. The proposed scheme is useful for delivering data in unreliable environments. It is known that network reliability can be increased by providing several paths from source to destination and by sending the same packet on each path. However, using this technique, traffic will increase significantly. Hence, there is a tradeoff between the amount of traffic and the reliability of the network. This tradeoff is studied using a redundancy function that is dependent on the multipath degree and on failing probabilities of the available paths. The idea is to split the original data packet into sub packets and then send each sub packet through one of the available multipath. It has been found that even if some of these sub packets were lost, the original message can still be reconstructed. According to their algorithm, it has also been found that for a given maximum node failure probability, using higher multipath degree than a certain optimal value will increase the total probability of failure.

Query Based Routing: In this kind of routing, the destination nodes propagate a query for data (sensing task) from a node through the network and a node having this data sends the data which matches the query back to the node, which initiates the query. Usually these queries are described in natural language, or in high-level query languages. For example, client C1 may submit a query to node N1 and ask: Are there moving vehicles in battle space region? All the nodes have tables consisting of the sensing tasks queries that they receive and send data which matches these tasks when they receive it. In directed diffusion, the BS node sends out interest messages to sensors. As the interest is propagated throughout the sensor network, the gradients from the source back to the BS are set up. When the source has data for the interest, the source sends the data along the interest's gradient path. To lower energy consumption, data aggregation (e.g., duplicate suppression) is performed en route.

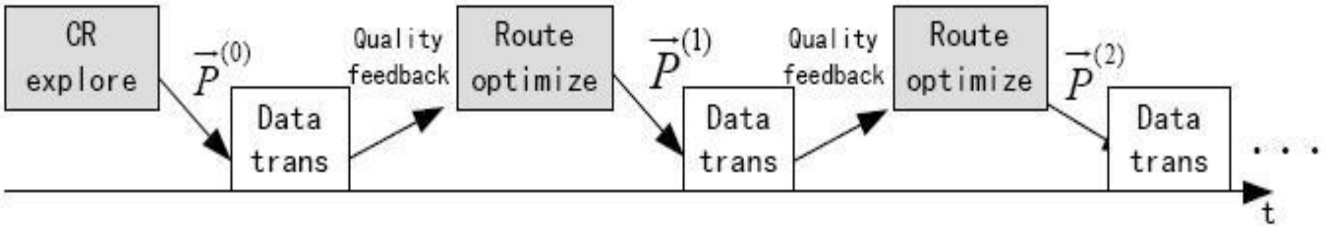
Chapter-4

PROPOSED ALGORITHM

In layered protocol stack, network layer has two main functions: route setup and repair (RSR), packet for-warding (PF). Traditional protocols treat them as independent modules: RSR collects topology information (for example, link reliability), finds optimal route under certain object and provides it to PF; PF sends data packets along the selected route; there's little interaction between RSR and PF except when link failure occurs. We refer to the design as "separated mode". Lack of information sharing between Route setup and repair and Packet forwarding, separated mode is not efficient in energy and bandwidth usage. In order to setup reliable route, a mass of probe messages are sent which imposes heavy tax on energy constrained sensor nodes. Moreover, as for densely deployed and bandwidth constrained Wireless Sensor Network, probe messages consume large. Amounts of bandwidth resource so that route setup might be interfered and normal data transmissions might be jammed. Different from separated mode, integrates route optimization into data transmission. In integrates route optimization into data transmission, candidate routes from a sensor node to sink are explored with restricted flooding first. The set of candidate routes is referred to as CR {r_i, i=1,..., m}. Route optimization is achieved in a "monitor-and-adjust" way. When source node has data packet to sent, route selection probability vector P, instead of the optimal next hop, is provided. P contains the probability to select each path in CR. At first, source has no information about route quality so P (0) = {1/m, 1/m,..} .One route is selected for a packet according to P(0) . In the course of data transmission, route quality information is gathered and pigged back in data packet. Sink extracts route quality information from data packets and feeds it back periodically to source node. Considering that ARQ mechanism is widely used in multi-hop networks, we take the accumulated transmission times (ATT) of a packet from the source to sink as route quality metric. ATT of a route is a random variable because wireless transmission is easily influenced by random factors. The ultimate goal of Integrating Routing Optimization into data transmissions is to select route with smallest ATT expectation.



a) Seperated mode



b) Integrated mode

Figure 4.1: Data transmission modes

4.1 Implementation

Route Optimization via bad path filtering: How to make the algorithm converge fast to optimal route and at the same time be adaptive to network dynamics are key points of Integrating Routing Optimization into data transmissions. Window Integrating Routing Optimization into data transmissions collects samples of route's Accumulated Transmission Times and infers route quality. This is a statistical inference problem. When there exist several high quality routes (referred to as "good route") and the quality of them are very close, it is difficult to identify the best one based on a small number of samples. From another perspective, if there exists some route with significant low quality comparing with others (referred to as "bad route"), it is much easier to filter out bad route from good ones; after that source node can concentrate data packets on a relatively small number of paths which in turn accelerates convergence of the algorithm. So, filtering out the routes of significant low quality is cost-effective for route optimization. How can one judge which route is of significant low quality? Let X_i and μ_i be the mean value of ATT samples of route r_i and the expectation of ATT_i. When the number of packet sent over r_i is small (that means the number of ATT samples is small), X_i may have a large deviation from μ_i. It's likely to make misjudgment if we compare X_i directly. Here, interval estimation is introduced. Suppose that sink receives n_i packets from r_i, let X_{ij} be the ATT sample carried by the jth packets, then the mean and deviation of sample is

$$\overline{X}_i = \frac{\sum_{j=1}^{n_i} X_{ij}}{n_i}, \qquad S_i^2 = \frac{\sum_{j=1}^{n_i}\left(X_{ij} - \overline{X}_i\right)^2}{n_i - 1}, \qquad \frac{\overline{X}_i - \mu_i}{S_i / \sqrt{n_i}}$$

Obeys T distribution with parameter $n_i - 1$, that is

$$\frac{\overline{X}_i - \mu_i}{S_i / \sqrt{n_i}} \sim t(n_i - 1) \qquad (1)$$

$T(n_i - 1)$ is independent of other parameter, so for any α (0 ≤α ≤1), the following equation exists:

$$P\{-t_{\alpha/2}(n_i - 1) < \frac{X_i - \mu_i}{S_i / \sqrt{n_i}} < t_{\alpha/2}(n_i - 1)\} = 1 - \alpha \quad (2)$$

Then the confidence interval for μi with confidence level 1−α is as the following:

$$\left(\overline{X}_i - t_{\alpha/2}(n_i - 1) S_i / \sqrt{n_i}, \overline{X}_i + t_{\alpha/2}(n_i - 1) S_i / \sqrt{n_i}\right) \qquad (3)$$

We refer to the upper and lower limit of μ_i's confidence interval as u_i and d_i, respectively. Based on interval evaluation result, "significantly low quality route" is defined.

Definition: significantly low quality route: Given route a and b, the confidence interval of μ_a, μ_b with confidence level 1− α are (d_a, u_a) and (d_b, u_b), respectively. If $d_b \geq u_a$ (or $d_a \geq u_b$), then b (or a) is termed as significantly low quality path comparing with route a (or b). If the confidence interval of μ_a, μ_b is overlapped, then there is no significant difference between the two routes. Based on the definition, it is easy to get the following rule.

Bad Path filtering rule: $\forall r_i (r_i \in CR)$, if there exists r_j that satisfies $d_i > u_j$, then the state of r_i is set to "hang up"; else the state of r_i is "active"; the selection probability of active route is equal while that of hang up route is zero. Considering that link quality may change after system run for some time because of environment changes etc., a soft state timer of T_hangup seconds is triggered as a route is set to “hang up”. We call this timer “hang up timer”. Route in “hang up” state is prevented from data transmission until hang up timer is timeout. “Route hang up” mechanism allows low quality route to re-join data transmission after some time if network dynamics change it to a better one.

Re-Route: Source node monitors route quality based on information periodically fed back by sink. Let $d^{(r)}$ be the data delivery ratio within recent seconds.

$$d^{(r)} = \frac{\sum_{i=1}^{m} n_i}{R * t\_window} \qquad (4)$$

Where n_i is the number of packets sink received from r within the recent t _ window seconds, R is source’s packet generation rate. Let δ be the relative delivery ratio change comparing to the previous round. If the following formula exists, source node infers that great changes have taken place in network so that it clears records in CR and explores candidate route set again. TH is a predetermined parameter which reflects how sensitive Integrating Routing Optimization into data transmissions is to network dynamics.

$$\delta = \frac{d^{(r-1)} - d^{(r)}}{d^{(r-1)}} > TH \qquad (5)$$

4.2 Simulation Environment

Designed In this section, we evaluate the effectiveness of Integrating Routing Optimization into data transmissions through extensive simulations on NS2 platform. The environment parameters are set as the following: 800 nodes are randomly deployed in a 150m*150m rectangular area; the source node and sink node is set at the two ends of diagonal of the rectangular; lognormal path loss model is adopted to simulate signal attenuation over wireless links; constant bit rate (CBR) traffic is adopted to simulate data transmission and data packet generation rate is 1 packet/s, packet length is 20 byte or 40 byte; wireless bandwidth is 40kbps; we use the same radio model, in which a radio dissipates 50 nJ/bit to run the transmitter or receiver circuitry and 100 pJ/bit/m^2 for the transmitter amplifier; the wireless communication range is 20m and node wireless transmission power is fixed. We choose two metrics to investigate the performance of Integrating

Routing Optimization into data transmissions: packet delivery ratio (PDR) and average energy consumption per packet delivery (ECPP). PDR is defined as the ratio of the number of data packets successfully received by sink node to the total number of data packets sent by source node. ECPP is the ratio of total energy dissipation to total number of successfully delivered data packets. AODV_ETX, a typical reliable routing protocol designed with “separated mode”, is also simulated. In AODV_ETX, link quality information, ETX, is collected through periodically Probe message exchanges between neighbors as described, when the source node has data to send but doesn’t know the route, route setup is triggered to find path with minimum ETX of total links along the path, when link breaks, route repair is triggered. In simulation, the Probe period is set to 5s.

Chapter-5

IMPLEMENTATION AND RESULTS

5.1 Simulation Result

Simulation in semi static environment: Simulation is done in semi-static environment. “Semi-static” means link quality changes very slow so that it can be treated as static during one data transmission. BER is set to $5*10^{-3}$. Fig. 2 is the statistical result of PDR and ECPP every 50 seconds. It can be seen that from the beginning to 200s, PDR of 20byte and 40byte packet increase from 0.94 and 0.76 to 1 while ECPP decreases 13.6% and 41.6% comparing to that at the beginning; after 200s PDR and ECPP don’t have evident changes. Fig. 2 shows IRON optimizes route selection in the course of data transmission and at around 200s it converges to optimal route of current environment, long packet is more vulnerable to link unreliability and the route optimization effect is more evident than that for short packet. Performance of Integrating Routing Optimization into data transmissions under different BERs is explored. As illustrated in Fig 3, when BER increase from 10^{-4} to 10^{-2}, ECPP of 20byte and 40byte packet increase to 1.64 and 2.1 times respectively. This is because the ATT increases as link quality decrease. Note that PDR in both cases are above 90%. Integrating Routing Optimization into data transmissions is competent to deal with unreliable links in Wireless Sensor Network.

1. Below mentioned figure show the Performance variation with time

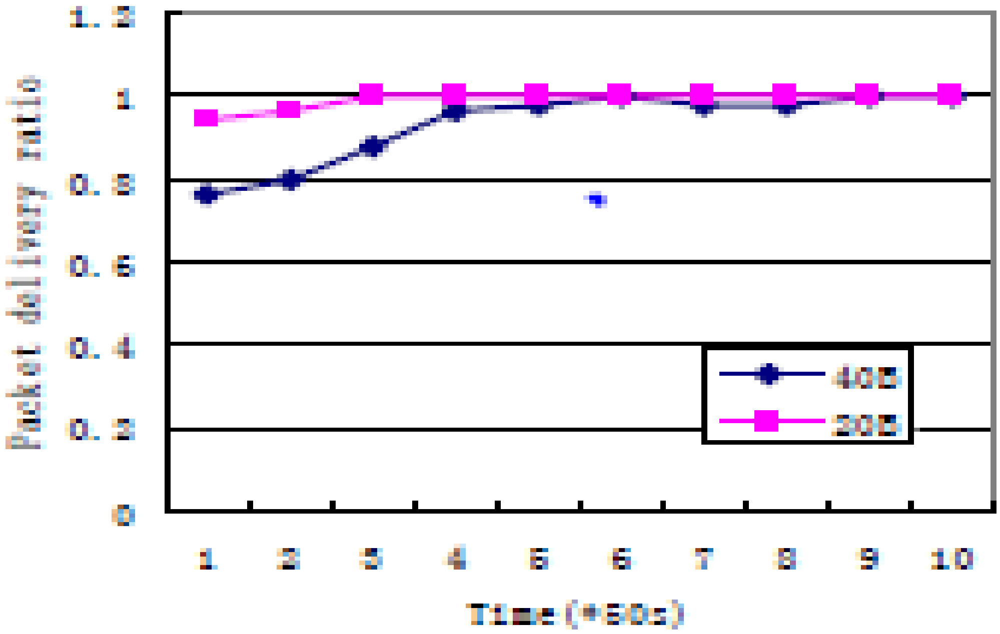


Figure 5.1: Packet Delivery Ratio vs. Time Plot

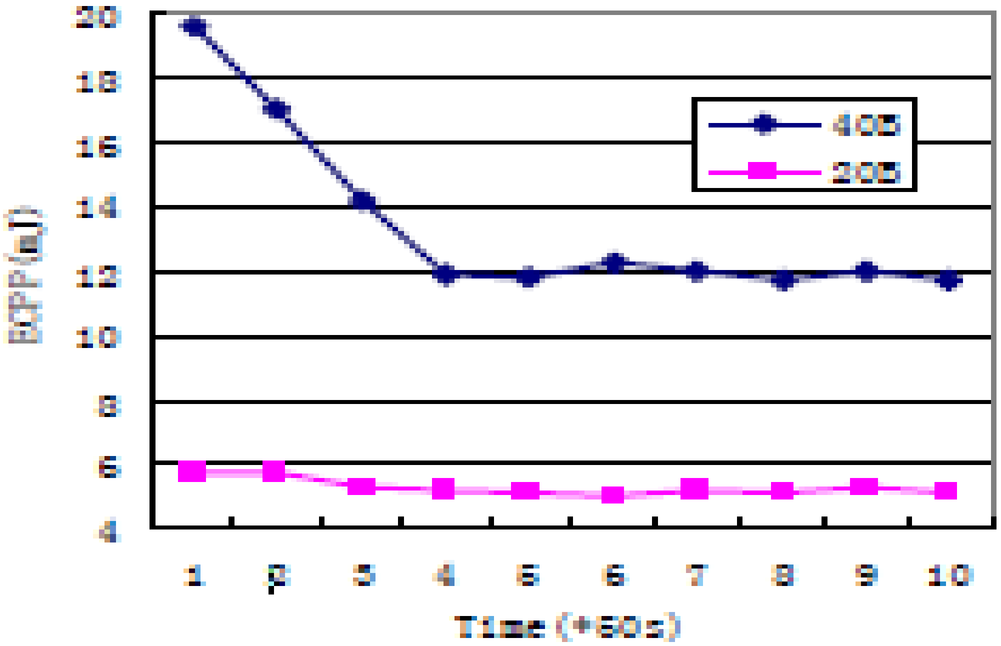


Figure 5.2: Energy consumption per packet (ECPP) vs. Time Plot

2. Below mentioned figure show the Performance under different BER

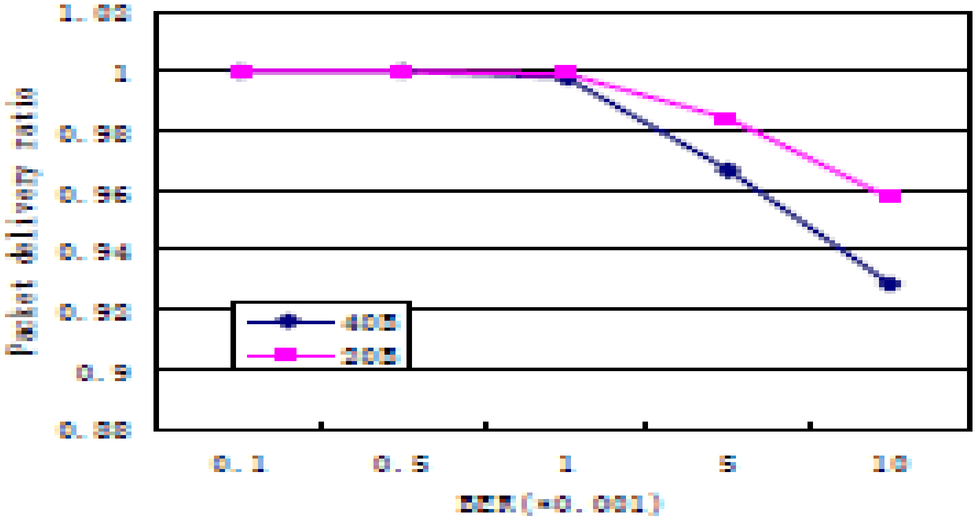


Figure 5.3: Packet Delivery Ratio vs. BER plot

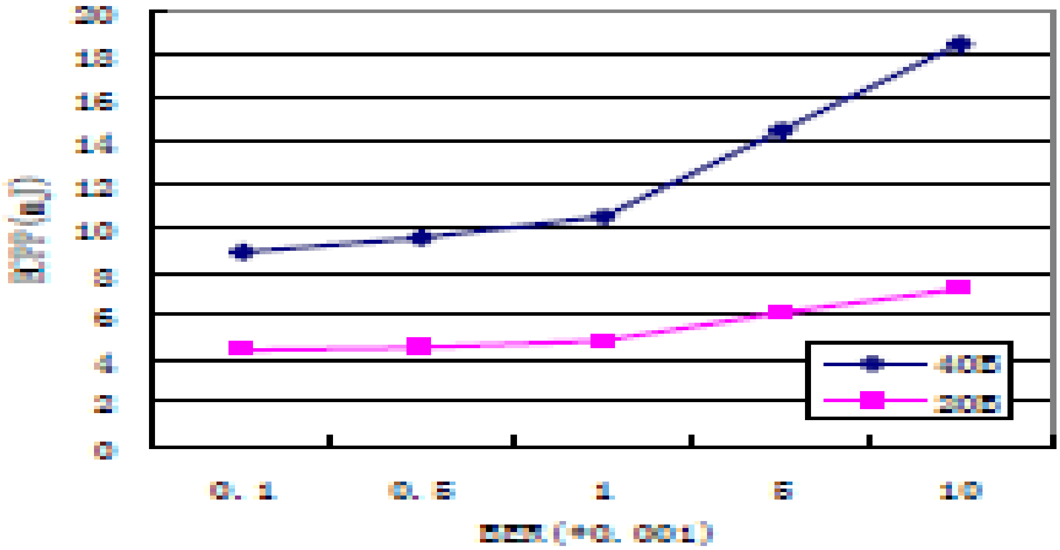


Figure 5.4: Energy Consumption per Packet (ECPP) vs. BER plot

Simulation of AODV_ETX is done in the same environment. Probe messages consume a high percentage of wireless bandwidth. Route setup messages (such as RREQ and RREP) and data packets experience severe collisions; the packet delivery ratio is very low. We increase bandwidth and get the results. It can be seen that AODV_ETX is sensitive to bandwidth changes; as the bandwidth decreases, the performance of AODV_ETX deteriorates dramatically while Integrating Routing Optimization into data transmissions appears not be affected. This is because AODV_ETX use dedicated Probe messages to monitor link quality so that it has a high demand on wireless link bandwidth; when the bandwidths is lower than its demand, collision is unavoidable. Integrating Routing Optimization into data transmissions integrates route quality information collection into data transmission and only needs a small bandwidth quota. Another finding is that when the bandwidth is abundant (for example 2M bandwidth is available, the performance), AODV_ETX can find optimal route quickly and the convergence time is almost no noticeable. As for Integrating Routing Optimization into data transmissions, a period time is necessary before converge to the optimal route (or routes). It is because AODV_ETX calculates optimal route upon link quality information already collected. Integrating Routing Optimization into data transmissions sends packets to learn the route quality and select the best from multiple candidate ones step by step. It can be seen that AODV_ETX is expensive for bandwidth constrained Wireless Sensor Networks.

Simulation in dynamic environment: Preliminary simulation has been done in dynamic environment. Network dynamics is caused by many reasons such as node malfunction, environment changes, sudden emergence of obstacles etc. It is believed to be a complicated task to describe the network dynamics systematically. As our goal is to test whether Integrating Routing Optimization into data transmissions is adaptive to link quality changes and how quick its reaction is, a simple environment is set: supposing that link quality change is caused by a certain obstacle appears at the point (75m, 75m) at T seconds after the beginning of simulation, the PDR of any link within the radius of R of point (75m, 75m) drops to PDR* (1−β) , where β is a random variable uniformly distributed between 0 and 0 β . In simulation, T=1000s, R=50m and 0 β = 0.3.

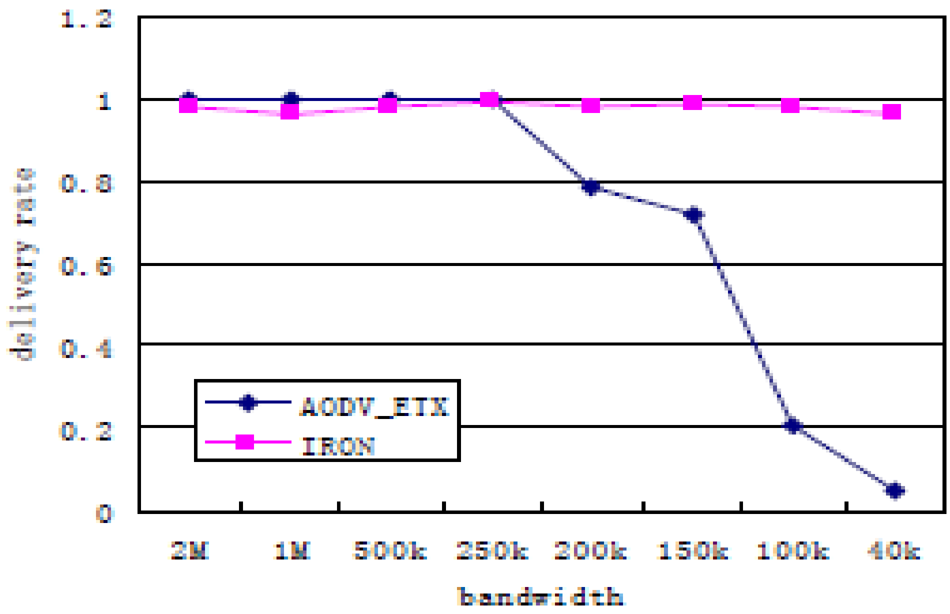


Figure 5.5: Performance comparison with different bandwidth

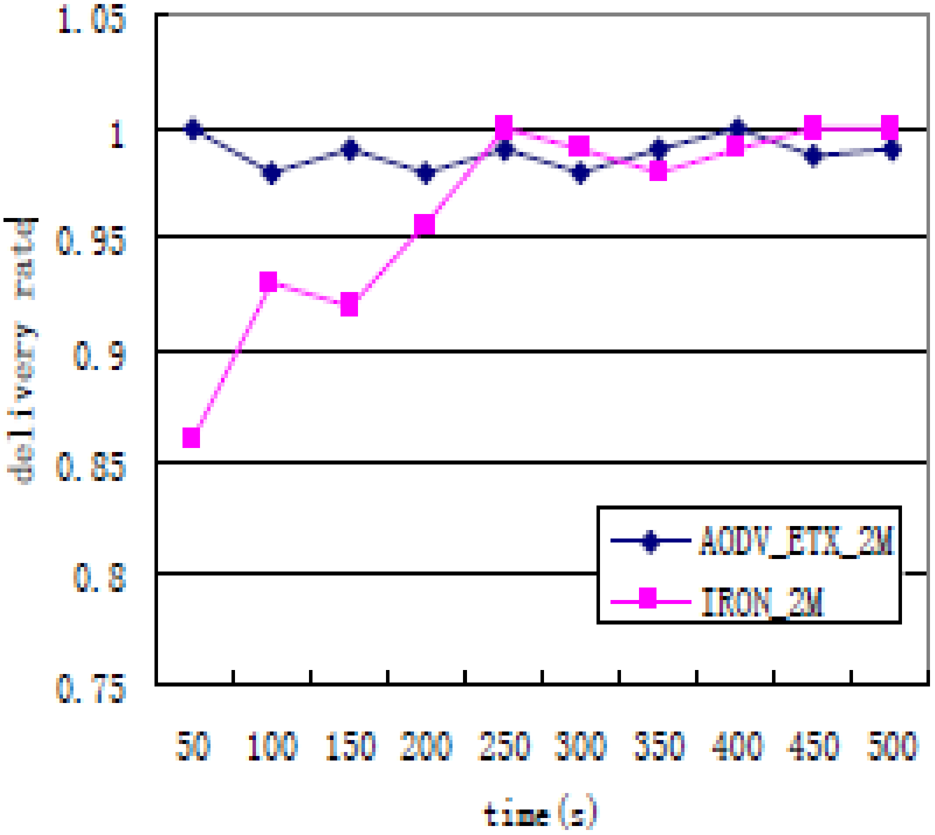


Figure 5.6: Performance comparison with 2M bandwidth

Dijkstra algorithm is adopted to calculate the optimal route before and after link quality changes and the performance of data transmission along optimal route is used as the benchmark. Integrating Routing Optimization into data transmissions with TH=0.5, T_hangup=1000s and TH=0.2, T_hangup=1000s are simulated. In Figure the PDR and ECPP from 800s to 2000s. It is seen that link quality changes results in delivery ratio decline from 99% to 83% if optimal route is used; IRON is able to adapt to link quality changes; parameter settings have significant impact on performance. When TH is set to 0.2, re-route is triggered at 20s after link changes; PDR drops to around 56% and then accents step by step; at around 1700s, delivery ratio is close to that of optimal route. When TH is set to 0.5, PDR drops as link quality changes but re-route isn't triggered; after that the PDR fluctuates in a period of time and the fluctuation amplitude is much small than that when TH is 0.2. Fig shows different countermeasures "re-route" and "route hang up" towards link quality changes. When TH is set to a relatively small value (for example, 0.2), re-route is easy to be triggered. Re-route works as system reset, new CR is explored and optimal route will be selected out but during the course of convergence, performance fluctuates greatly. When TH is set to a relatively large value, “route hang up” mechanism works. Route hang up reacts to link quality changes in a more moderate way: some “hangup” routes become active and take part in data transmission; the new active route may become better and route optimization may be achieved little by little in a long time. Although there is still much to be explored about how to set parameters properly, we believe that a relatively higher TH is beneficial to keep the system steady and T_hangup is to be set according to the frequency of link quality changes

Chapter-6

CONCLUSION AND FUTURE WORK

6.1 CONCLUSION

As Wireless Sensor Network steps into commercial implementation, the problem of reliable information delivery attracts the attention of researchers. Traditional reliable routing protocols treat route optimization and data transmission separately which is not appropriate for Wireless Sensor Network because of large amounts of bandwidth and energy consumption. Aiming at this problem, Integrating Routing Optimization into data transmissions is proposed which integrates route optimization and data transmission together: route quality information is gathered through data transmission, based on which route selection probability is adjusted and route optimization is achieved dynamically and adaptively. Simulations on NS2 platform show that Integrating Routing Optimization into data transmissions is able to deal with adverse and dynamic network environment, the packet delivery ratio and energy efficiency is better than typical reliable routing protocol AODV_ETX.

6.2 FUTURE WORK

I will also like to further explore ways to optimize the algorithm in terms of energy efficiency, performance and scalability.

I am currently investigating the impact certain steps of the algorithm play in the performance and resource use of procedure, as well as what role they play in strengthening the reliability of the algorithm.

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