Chapter 1

Introduction

There is a lot of research work going on in the field of Wireless Network.A wireless ad hoc network is special type of network which is decentralized in nature. The network is called ad hoc because it does not depend upon a pre-existing infrastructure, such as routers and base stations in wired networks or like access points in the managed wireless networks. Instead, each node themselves participates in the routing by forwarding data to other nodes, so the determination of route and which node will forward data to which node is made dynamically on the basis of the network connectivity. In addition to the classic routing methods, ad hoc networks can also use flooding for forwarding data.

Wireless ad hoc network have many uses and are seldom characterized on the basis of one single performance metric, yet the current work lacks a flexible framework which assist in characterizing the design and the trade-offs in such networks. In this work, we will address this problem. We are proposing a new modelling framework which can be used for routing in ad hoc network; it is used in conjunction with the meta-heuristic multi-objective search algorithms. It will result in the better understanding of the network performance and behaviour when multiple criteria are relevant.

In our approach we will consider a holistic view of the network which captures the cross-interactions among the various interference management techniques which are implemented at different layers of the protocol stack. The result will be a framework which is a complex multi-objective optimization problem which can be solved efficiently through existing multi-objective search techniques. In this work we will consider three parameters namely delay, robustness and energy as the performance metric. These parameters are very critical from performance point of view.

Our main contribution through this work is two-fold:

- Propose a general and cross-layer framework network model, which is capable of capturing the impact of interaction of a wide range of the interference and resource management approaches for various channel conditions.

- Formulate a multi-objective routing optimization problem. It is done by defining an appropriate evaluation functions for various criteria such as: end-to-end delay, robustness of information transfer and energy consumption.

1.1 Motivation

A wireless ad hoc network or sensor network often operates in difficult environment and tough conditions. Irrespective of the circumstance it is expected from the network that it satisfy several performance criteria. It is expected to be reliable, secure and economical in time. To ensure the successful information transfer across a wireless network, one of the key elements is the selected routing algorithm whose design poses many significant challenges.

In such ad hoc networks, cooperation among all the layers of the protocol stack is must and should be enlisted so as to deal with the problem of channel impairments. To further add to the long list of the design challenges of routing protocols, it is seldom possible to equally optimize all the desirable performance criteria, as many of them can be antagonistic in nature. From the myriad of the possible operating points, it is hard to say which one is more optimal.

Understanding the trade-offs involved and the pros and cons with respect to several performance metrics will not only helps in making a better design, but also will help us in the selection of better and possible operating points (which are characterized by various trade-offs) to enable an optimal and graceful degradation of the whole network performance as the condition of channels worsen. While a lot of significant work has been done in the field of routing in wireless ad hoc network or sensor networks, we lack in this area as yet no integrated design framework is there to address many facets of the problem described just above.With the motivation of these approaches, a new hybrid technique is presented in this thesis.

1.2 Related Work

There is a lot of work done in the field of wireless network and significant effort has been put to characterize and optimize the theoretical performance of sensor wireless networks. But most of it is focused on their theoretical capacity, it can be clearly seen in several landmark papers which are proposed under various assumptions [1]–[4]. However, sadly none of these works directly focused on practical implementation of any routing algorithm, and they generally lack a general view of multiple objective trade-offs although some of them do considered the impact of end-to-end delay on the capacity.

On the other hand, there is lot of work dedicated to designing of routing protocols which are optimized for some of the specific criteria and applied on specific network instances (e.g. [5], [6] and the references within). It is very difficult to compare the quality of solutions provided by these works as no benchmarks for multi objective multiple criteria performance routing exist. Very limited work exists on the multi-objective (MO) routing [7], and again the constrained network scenarios used for the optimization are very much application specific.

Understanding the intricacies of trade-offs involved within various routing solutions will enable us to design an adaptive resource management scheme across layers and nodes, leading to a optimized and more accurate performance mapping for practical routing protocol design.

Face recognition is mainly used in security system. In today's world, automatic face recognition is one of the utmost requirements. In face recognition process, our first step is to extract features; this is one of the fundamental steps. Researchers are looking for the most efficient face recognition techniques

1.3 Problem Statement

There is a lot of research work going on in the field of Wireless ad hoc network. The performance of any wireless networks can be expressed with respect to various criteria such as capacity or throughput, overall energy consumption, end-to-end transmission delay or transmission robustness. The main purpose of the multi-objective framework proposed in this work is to determine and evaluate, given a communication pattern and a network, what kind of trade-offs arises between various performance metrics while varying the routing strategies.

We will first determine the various characteristics of a given network. We will derive robustness, delay and energy consumption in the given network. Then we will try to do multi-objective optimization we will try to optimize the value of energy given to a node. Our aim will be to maximize robustness and minimize delay and energy consumption.

Our problem statement can be given as follows:

"**To develop a Multi-Objective Framework for routing protocols in wireless ad hoc network and implement it to optimize the value of average initial energy of nodes in the network**".

1.4 Scope Of The Work

In this thesis we proposed a multi-objective framework for wireless ad hoc network. We are trying to develop a model which will help to understand the trade-offs between various performance parameters. In this work we will try to understand the tradeoff between three very crucial performance metric namely robustness, time delay and energy consumption.

The three parameters are as described below:

Robustness criterion

Robustness can be defined as the probability that a message emitted from some node S will successfully arrives at a destination node D.

Time Delay criterion

Time delay can be defined as sum of time spent at each of the intermediate node in the path during the transmission of packet from source to destination.

Energy criterion

Energy criterion is given by the total forwarding energy needed for a packet sent by a source to reach destination.

The scope of the work is described as:

1) To propose a framework for Multi-Objective Optimization in wireless ad hoc network.
2) To study the impact of three crucial parameters namely robustness, time delay and energy consumption on overall transmission of message from source node to destination node.
3) To optimize the value of average initial value of nodes in the network while minimizing the time delay and energy consumption and maximizing robustness of network.

1.5 Organization of the Dissertation

Rest of work is organized as follows:

Chapter 2: Ad hoc Wireless Network
This chapter introduces the concept of Ad hoc wireless network. It also briefly explains some of the key concepts of wireless sensor networks. Also in this chapter we discuss various routing protocols used these days.

Chapter 3: Performance Criterion
In this chapter we will discuss various performance metric which are used to describe the characteristic of a network. We will also discuss how these parameters affect the efficiency of the network.

Chapter 4: A Cross Layer Framework for Network Modeling

In this chapter we define a framework which will describe the networking model of our wireless ad hoc network. This framework will be independent of layers and can be applied across various layers of our network.

Chapter 5: A Multi-objective Optimization problem

In this chapter we will describe our proposed multi objective optimization framework for wireless ad hoc network. We will also discuss how to use this framework to optimize the value of some parameter.

Chapter 6: Experiments and Results

This chapter tells us about the experimental setup. We will implement our multi objective framework. In this we will optimize the value of average initial energy of nodes in the network while maximizing the robustness and minimizing the time delay and energy consumption.

Chapter 7: Conclusion

This chapter concludes the thesis as well as gives the future scope of the work presented.

References: This section gives the reference details of the thesis.

Chapter 2

Wireless Ad hoc Network

What is an ad hoc Network?

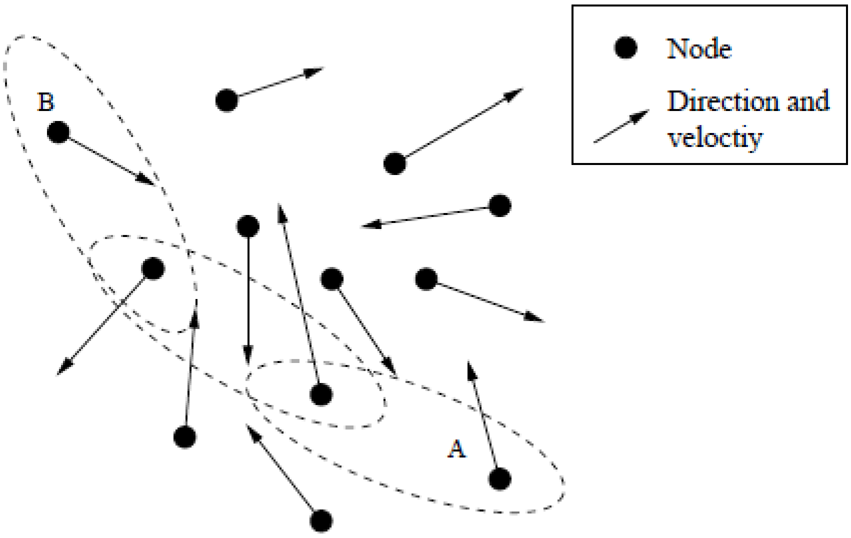

Figure 1An ad hoc network. In this network nodes are mobile they can move arbitrarily in any direction with any speed. Here node A is communicating with node B via other nodes.

An ad hoc network is a kind of wireless network without centralized control where every node can act as a router, forwarding packets for other nodes as necessary. This makes it possible for this kind of network to emerge wherever there is a need for it. As soon as two nodes are within range, a network connection can be established. This type of network has many advantages over traditional wired networks, for example that it is possible to use very small and common devices as nodes Example are PDAs (Personal Digital Assistants), laptops and cellular phones. But the greatest is that there is no need for existing infrastructure in order for a network to form. Setting up a mobile network is very fast, efficient and can be done practically anywhere. This type of network is preferable in many situations when people wish to share information quickly, such as search-and-rescue operations, meetings or conferences, various military operations and police matters.

2.1 MANET

There is an IETF working group called MANET (Mobile Ad hoc Networks) that is assigned the task of developing routing protocol specifications for ad hoc networks.A mobile ad hoc network (MANET) is a continuously self-configuring, infrastructure-less network of mobile devices connected without wiresWe will shortly describe some the currently used wireless protocols such as DSDV, DSR, AODV and TORA in greater detail. A few of the other protocols are also mentioned briefly. It was decided not to put that much weight in explaining the functionality of the protocols here since they are already well documented in a number of articles prior to this work.

2.2 Desired protocol properties

In a wired network, topology changes are rather infrequent. Most hosts and other nodes in the network have their given position. This is the natural behavior that we expect from a wired network. Link breakages will only occur when there is a physical disruption, such as a failing host or a cable was physically damaged. For this type of wired infrastructure a classic routing protocol functions very well. In order to maintain updated routing tables, routers exchange information by periodically sending update messages to each other. In case of a link failure, the routes have to be recalculated and once again propagated through the network. This process may take a couple of minutes, and this is the normal behavior in a wired network.

Obviously this approach will not work well in an ad hoc network. In an ad hoc network, rather frequent link changes are expected since the nodes are constantly moving. Consider, for example, the case where two nodes are communicating while moving away from each other. As long as they are both within transmitter range, communication can take place. When the distance between the nodes grows too large the communication will fail. When more and more nodes become involved in such a scenario, more links will form and new routes to the destinations may have to be computed.

These differences between wired and wireless networks make it quite obvious that an ad hoc routing protocol need to address some additional problems not present in a wired network. Below is a list of things that a routing protocol should take into account. The more of these properties the protocol can provide the better. Some of these properties are more important than others though. In the initial stages, power conservativeness was less important than functionality. However, these days, when functionality is already achieved, conserving the power in order to make batteries last longer is becoming increasingly important. The reason for this is that mobile units are constantly decreasing in size and hence battery sizes also decreases. Even though the size/power/efficiency ratio for batteries is constantly improved, the energy source for mobile units is still a limiting factor. A routing protocol should not add up more to the total energy consumption than necessary.

The goal of routing protocol design in general is to make the protocol;

- Scale as the network topology grows
- Respond quickly to topology changes
- Provide loop free routes
- Minimize delay (short routes)
- Present multiple routes to avoid congestion

In an ad hoc network, the routing protocol design should also strive to make the protocol:

- Have decentralized execution
- Be bandwidth efficient (minimize routing overhead)
- Utilize both unidirectional and bidirectional links
- Act power conservative

2.3 Routing protocol strategies

There are two basic ad hoc routing strategies. One is derived from the old and well known routing protocols that have been used for wired networks for a long time. These protocols are called table-driven or proactive. The other routing strategy is called source-initiated, on-demand-driven or reactive. These terms will be used inter-changeably in the text from now on. The differences between the two strategies are explained in the next few sections. In addition to these two basic methods there is also a hybrid approach that utilizes some of the functionality from both the proactive and reactive strategies.

This report focuses on four different protocols belonging to different protocol groups. These four will be given a deeper explanation while other protocols are just briefly mentioned.

2.3.1 Proactive strategy

The classic routing strategies for wired networks — link state, distance vector and source routing are all well documented and thoroughly tested. Why not use them in wireless networks as well?

As mentioned earlier there is one significant difference between wired and wireless networks the nodes are moving! In a wireless scenario where the mobility is negligible a conventional protocol would probably function very well. However, as soon as nodes start moving to any greater extent these protocols would fail to stabilize due to the frequently occurring route changes. The algorithms are simply not fast and efficient enough to handle the many events that will occur. In addition to this, conventional protocols also assume that all links are bidirectional; this may not always be the case in a wireless scenario since two nodes may have different transmitter ranges. Proactive protocols for wireless networks are therefore modified to address these problems.

In short, distance vector routing means that nodes keep track of the cost for its outgoing links. With constant intervals the expected values of the node's shortest distance to every other node in the network is broadcasted to all neighboring nodes who update their routing tables accordingly.

2.3.2 Reactive strategy

The reactive approach to the problem works differently because routes are requested when needed, and it is the sender that initiates this route request (hence the name source-initiated on-demand). If a source wants to send a packet to the receiver, but does not have a route to the destination it will need to acquire this route from other nodes in the network. The source sends out a route request packet to its neighbors, asking for a route to the destination. This route request is then propagated through the network until it reaches a node that either has a route to the destination or is the destination itself. A route reply packet is then sent back over the same path as the request came from and a connection between the two nodes can be established. In case of a link failure, a route reconstruction phase is deployed in order to suggest an alternative route for the packet stream. The outdated route will be purged from the routing structure if it does not become valid again within a certain time. This scheme provides high connectivity in a dynamic scenario. As node mobility increases, so will the number of link changes, as well as the amount of overhead routing traffic.

2.3.3 Hybrid strategy

There are some protocols that combine the two different strategies. These protocols divide the network into zones (clusters) and run a proactive protocol within the zone and a reactive approach in order to perform routing between the different zones. This approach is better suited for large networks where clustering and partitioning of the network often occur

2.4 Routing protocols

The first protocol described, DSDV, is the only proactive protocol. The other three are reactive.

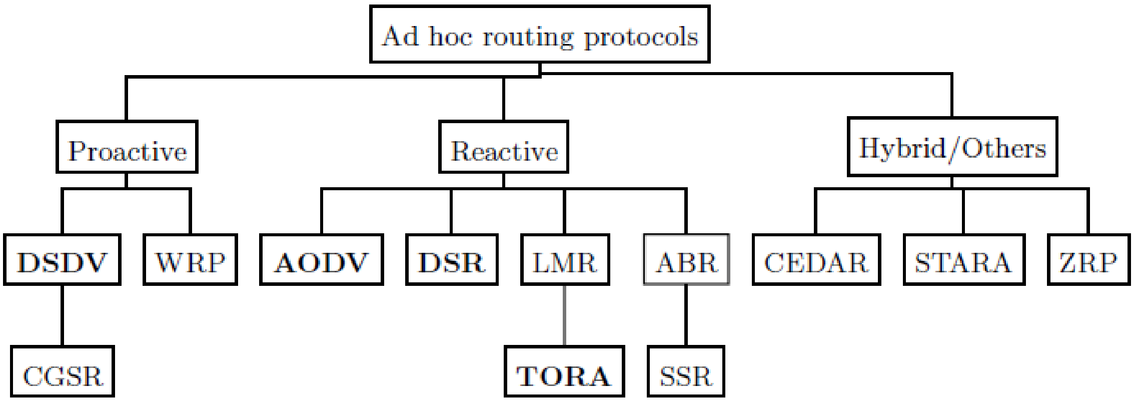

Figure 2 Categorization of ad hoc routing protocols

2.4.1 Destination Sequenced Distance Vector — DSDV

DSDV is an entirely proactive protocol, i.e., DSDV does not attempt to find a route for a packet if none is available in the node's routing table when the packet arrives. The advantage of this approach is that a packet can be forwarded immediately if there is an entry for its destination in the routing table. However, if the period between successive update messages is too long compared to the time between topology changes, DSDV will not be able to converge.

Since there is no mechanism in DSDV to explicitly query the network for a particular route when needed, all nodes keep a routing table which holds the routes for all reachable nodes. A node broadcasts updates of its routing table regularly to its neighbors, which set their routing tables accordingly.

DSDV avoids loops by using a quite simple technique. Each route is labeled with a sequence number, which determines its age. Newer routes have higher sequence numbers, and if a node receives an update which contains a route with a higher sequence number than the corresponding one in its routing table, or if the routes have equal sequence numbers but the new one is shorter, it updates its routing table with the new route.

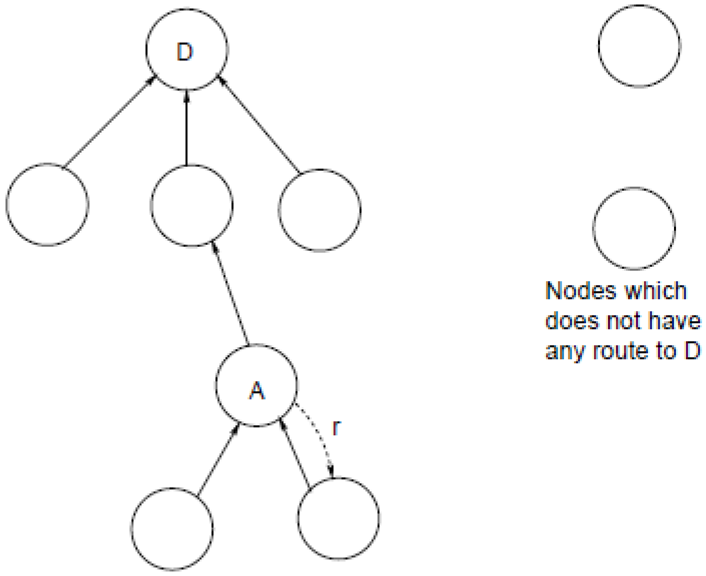

Figure 3 Network with stable routes. When A selects a new route, it bases its decision on the sequence number and the metric of the route. r must either have lower sequence number or higher hop-count. Thus, A will not select r as a route to D avoiding the routing loop

Note that the routes will eventually stabilize if there is no movement in the network. Consider each node as a destination. For each destination D, the network can be modeled as a set of trees with the routes to D as edges. These trees either has D or a node without a route to D as root. Hence, it contains no loops. To form a loop, a node A needs to select a route which goes through a node in one of its sub-trees. However, routing updates propagate through the network starting at D. Thus all nodes on the path between A and the destination contain routes to D with higher or equal sequence number (higher if an update has not yet reached A). Conversely, all nodes below A in the tree, contain routes with lower or equal sequence numbers. Obviously, nodes below A is also further away from D. Consequently, if A doses a loop when selecting a new route, it must either have a lower sequence number or a higher hop count. Thus, if all nodes always pick routes with higher sequence numbers, or equal sequence numbers and lower hop counts, loops can never be formed. See figure 3.

There are two weaknesses with DSDV that can be identified. First, there is some redundant routing overhead. Many routes which are discovered will never be used and the bandwidth consumed for announcing them is therefore wasted. Second, the delay from the time a new connection is established to the time a new route is known is relatively long. Consequently, there can be substantial difficulties to find a route when mobility is high.

These two factors can be compromised to tune performance. Frequent routing updates find routes faster but increase the overhead.

2.4.2 Dynamic Source Routing - DSR

DSR was designed by Broth at Carnegie Mellon University [CMU] and is a strictly reactive protocol. It does not make queries for routes until they are needed. The protocol is based on source routing, which allows intermediate nodes to forward packets without having a fresh route in the cache. However, since every packet carries the complete route, there will be some extra overhead in each packet. The packet size depends on the distance between the communicating nodes.

When node A wants to send a packet to node B, it searches its cache for a route to B. If a route is found, it is inserted into the header and sent. If somewhere along the way a link is broken, possibly due to two nodes which have moved out of range of each other, an error message will be returned to A. A then searches its cache for additional routes.

If A does not have a route to B, it broadcasts a query to its neighbors. Each neighbor records its address in the query message and forwards it in a controlled manner to its neighbor. This process is repeated until B is reached. B then sends a reply along the reversed recorded route. It is also possible to create asymmetrical routes where B replies by sending out a query for a route to A, piggy-backing the recorded route to the query.

A possible optimization is that each node receiving the query, searches its cache for a path to B, and if found, the intermediate node replies with the cached route appended to the recorded one. Hence, the route discovery is shortened and routing overhead is reduced.

A DSR node must provide hop-by-hop reliability. Each node attempts to verify that the packet is received at the next hop. If it is unable to do so within a certain amount of time, an error message is sent back to the originator and the link is assumed to be broken. Consequently, the route will be considered invalid and deleted from the cache.

DSR provides limited support for multi-casting. By piggy-backing data to the route query for a multicast address, it will propagate through the network to all nodes interested in the multicast group. This scheme does not scale well and does not provide all of the qualities a multicast routing protocol should have.

2.4.3 Ad hoc On demand Distance Vector - AODV

AODV is as DSDV (chapter 2.4.1, using a sequence number to avoid routing loops, and periodic updates to keep routing tables at each node. However, it has been altered to provide routes on demand for better performance in ad hoc networks.

The sequence numbering is similar to the one used in DSDV. It states when the route was created. A higher sequence number indicates a fresher route, which should be used in favor of older ones. For this purpose, each node keeps the sequence number of the last generated route. This will be increased for each new route.

Route queries are done as follows; An arbitrary node A, wants a route to B. A then broadcasts a route request to its neighbors. Then it waits for a reply. The request may be re-broadcasted a limited number of times if no reply is received. It propagates through the network until it reaches a node which has a valid route to B

A list of neighbors that are actively forwarding packets is also kept at each node. It contains all neighbors that have been positively acknowledged forwarding packets within a certain time limit. The link layer may indicate that links are down and stale routes could then be removed. Hence, a link breakage will be detected relatively fast.

Unlike the other routing protocols described in this report, AODV supports multicasting. There are no technical limitations in the design which makes multicasting awkward, and support for it has been developed. This is probably the main issue that favors the usage of AODV.

2.4.4 Temporally Ordered Routing Algorithm – TORA

TORA is a distributed routing protocol, i.e., each node need only maintain information about its closest neighbors (on a one hop basis). Furthermore it provides multi-path, loop-free routing and is designed to minimize reaction to topological changes. The route establishment procedure may be done either proactively or reactively. It maintains per-destination states in a manner similar to the other distance-vector routing protocols. The design also allows it to find routes on-demand since it might not be desirable to maintain information about all possible routes at all times. Selected destinations may initiate proactive operation, similar to the traditional table-driven protocols. Invalid routes that might result from a network partition are discovered and erased.

By assigning upstream or downstream directions to the links between routers, TORA creates a directed, multi-path routing structure where the destination is down-stream from the source. This structure can be described as a directed acyclic graph (see figure 4). Each router keeps a value that can be thought of as the router's height in the routing structure. Routers may only forward packets to a downstream destination.

It should also be pointed out that TORA only performs routing and rely on Internet MANET Encapsulation Protocol (IMEP) to perform the underlying functionality. This introduces some overhead to the routing scheme.

2.4.5 Internet MANET Encapsulation Protocol – IMEP

The idea with IMEP2 is to have a common general protocol that other routing protocols can make use of. It incorporates many common mechanisms that other protocols may need. These include:

- Link status sensing
- Control message aggregation and encapsulation
- Broadcast reliability
- Network layer address resolution
- Hooks for inter-router security authentication procedures

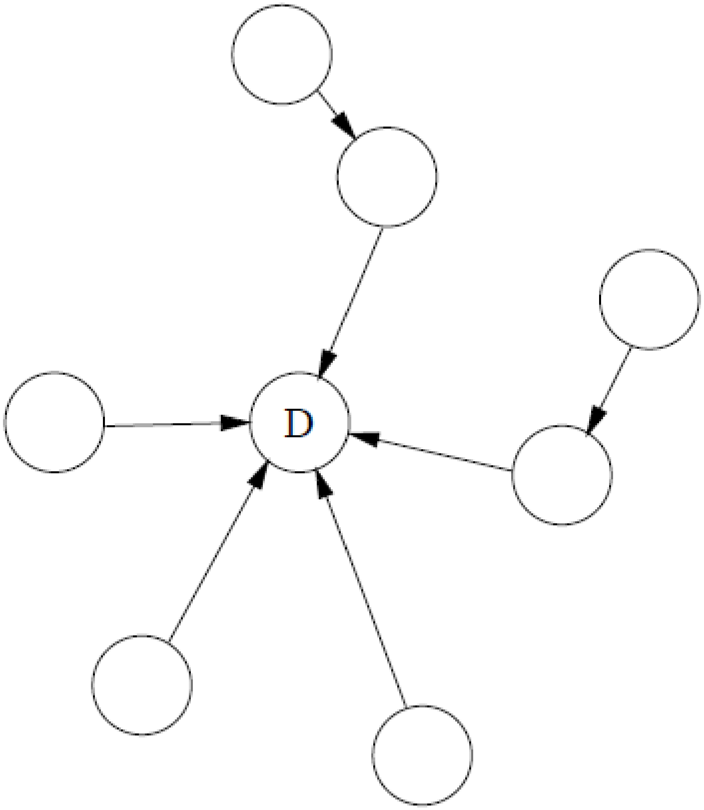

Figure 4 A Directed Acyclic Graph rooted at the destination

IMEP also provides architecture for MANET router identification, interface identification and addressing. IMEP's purpose is to improve overall performance by reducing the number of control messages and to put common functionality into one unified, generic protocol useful to all upper-level routing protocols.

IMEP was designed to support many ad hoc routing protocols, however of the proposed protocols only TORA and one other protocol (OLSR - Optimized Link State Routing Protocol) use it. It can be used by other protocols to provide some security and authentication. It should also be pointed out that both IMEP and TORA were designed by the same author.

The basic idea is good, but from a performance point of view it is not such a good idea. The work performed by the CMU monarch project [CMU] has shown that IMEP produces a lot of overhead, mainly because of IMEP's neighbor discovery mechanism that generates at least one hello message per second, but also because of the reliable in-order delivery of the packets that IMEP provides.

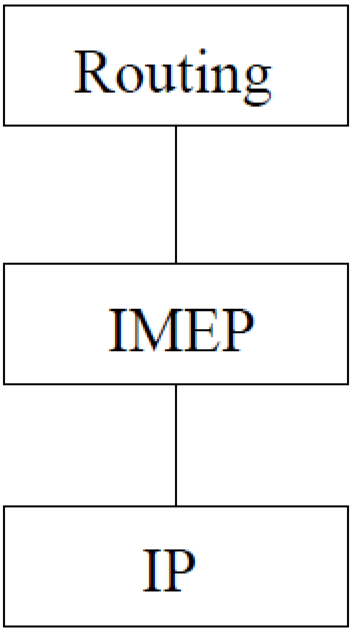

Figure 5 IMEP in the protocol stack

2.4.6 Other routing protocols

DSDV is a proactive protocol, other proactive protocols worth mentioning is Wireless Routing Protocol, WRP and Cluster head Gateway Switch Routing, CGSR [C+97]. Examples of hybrid protocols are Zone Routing Protocol, ZRP Cluster Based Routing Protocol, CBRP.

Core Extraction Distributed Ad hoc Routing algorithm, CEDAR ISSB991 and Associativity Based Routing, ABR are both demand-driven protocols but their functionality is slightly modified as described below. Both CEDAR and ABR are protocols designed for smaller networks of tens or possibly hundreds of nodes making them appropriate for conferences and similar scenarios.

The main contribution of CEDAR is the addition of QoS into ad hoc routing. However, the route computations are performed by the network core nodes on behalf of all the other nodes in the core node's domain. The core node also keeps track of its domain topology. The different core nodes communicate with each other and via local state and local computations the core is kept intact and reacts quickly to link changes. Still, robustness rather than optimal performance is the primary concern of CEDAR.

C-K Toh introduces ABR and the concept of associativity in [Toh97]. The asso-ciativity property describes the amount of time that a mobile node stays dormant before it starts moving again. Routes are demanded by the source, but all route decisions are made by the destination that can choose from the different routes found. The associativity property is supposed to allow the routing protocol to choose long-lived routes,as op-posed to shortest-path routes, resulting in fewer route reconstructions than for other protocols.

2.5 Protocol testing

Before employing a routing protocol in a real network, it has to be thoroughly simulated in order to find bugs etc. There seem to be a few different simulators in use The Network Simulator from Berkeley [UCB], is used in a couple of the protocol suggestions and comparisons made. Some designers have their own simulators.

2.5.1 Scenarios

The most common approach for an ad hoc scenario is a randomized movement pattern within a constantly sized area. As far as the author knows, only two-dimensional simulations have been made, even though a three dimensional approach would be better since it would correspond better to the reality (radio signals do propagate through walls and floors to some extent).

The two-dimensional scenarios are typically based on a couple of input variables. Pause time and velocity are the two most significant variables for the movement model. Nodes are initially randomly distributed inside a rectangular area. When the simulation commences each node pauses at its current position for pause time seconds. The next step is to pick a new arbitrary location and start moving towards it. As with the pause time the velocity with which the node will start moving is randomly chosen from an interval of max and min velocity. When the node reaches its new position it will pause once again for pause time seconds and then the process will repeat itself until the end of the simulation is reached. All nodes behave in the same way.

Realistic scenarios

Even though random movement may be well suited for some simulations there is also a need for realistic scenarios. It turns out that humans are not as randomly distributed as we might think. This idea was foreseen in where a couple of realistic scenarios were presented. It is a very interesting approach and will therefore be a bit further explained.

Conference —This is a model of a conference or something similar. Few nodes are moving and there is one "speaker" which moves back and forth in the front of the room and transmits data. All movement in this scenario is fairly slow. Figure 6 shows the conference scenario. In the picture, the upper part is referred to as the front.

Event coverage — In this scenario there is more movement. The idea is that two temporary clusters are forming in the network and communication within these clusters take place. However information cannot be exchanged between the clusters. Figure 7 shows the event coverage scenario.

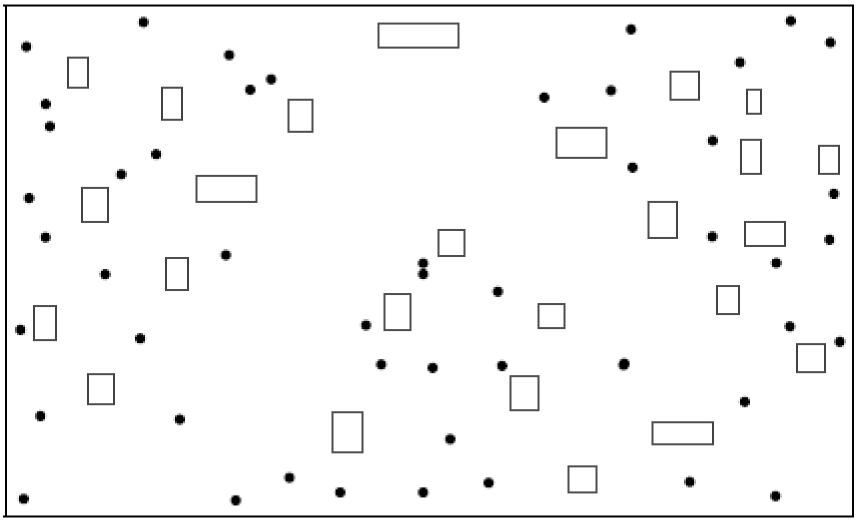

Figure 6 Conference scenario

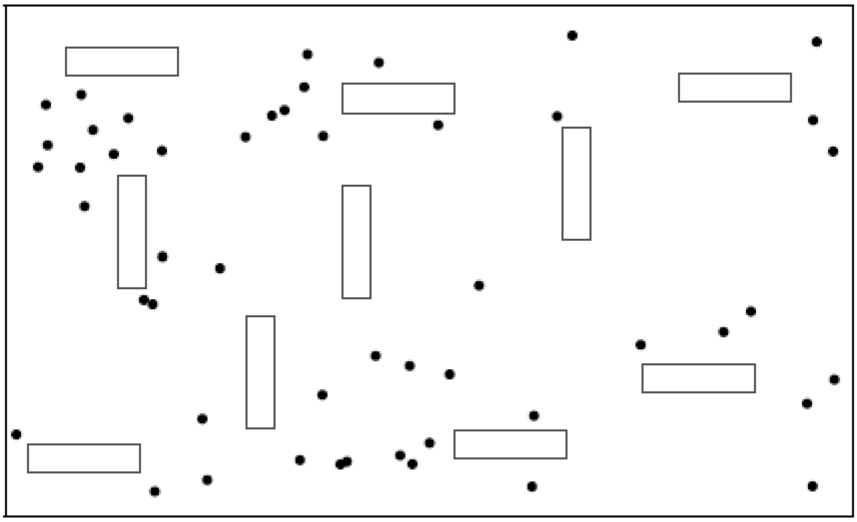

Figure 7 Event coverage scenario

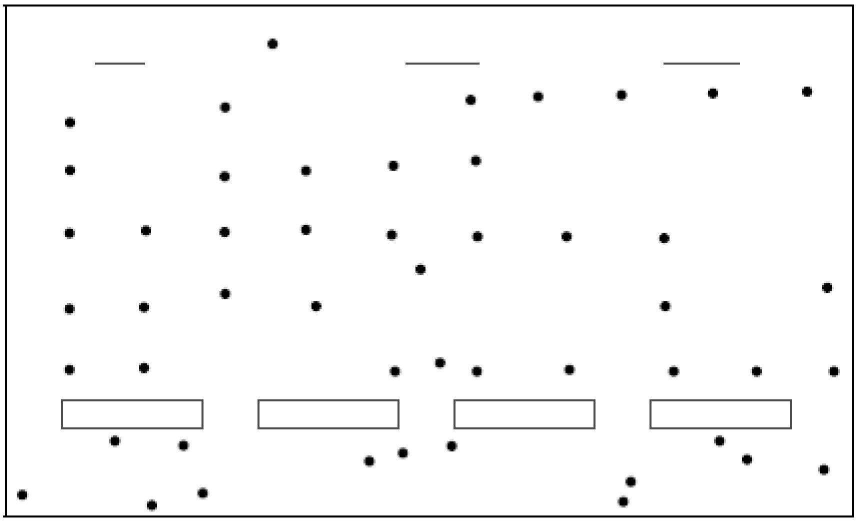

Figure 8 Disaster scenario

Disaster area —The third scenario models a disaster area where a couple of partitioned networks are characterized by high mobility. The three clusters are sometimes bound together by vehicles moving back and forth between different locations. It is the authors opinion that this scenario might not be as realistic as Larsson and Hedman suggests since in a situation like this, it would be more realistic to use a few base stations enabling the different networks to communicate. The point is that it is not very realistic to only rely on two moving vehicles to temporarily form a link between the clusters in a disaster scenario since in-formation would most likely have to be exchanged all the time. Figure 8 show the disaster scenario. The two vehicles are moving diagonally over the scenario.

This work is the only work done on realistic scenarios so far. It is an interesting approach since these scenarios better model a realistic movement pattern of humans compared to the randomly created scenarios.

2.5.2 Communication patterns

In addition to the movement patterns, communication patterns are also used in a simulation. These communication models could be generated in a random fashion or if the communication is known, exact communication specifications can be set up. In the random case connections are set up between a predetermined number of node pairs.. When creating these patterns some input variables can be altered, such as sending data rate, packet size, traffic type and the number of sending nodes.

Chapter 3

Existing Routing Metrics

As mentioned in chapter 2, a number of ad hoc routing protocols have been suggested. These all try to solve the problems and different aspects that a wireless environment presents. But how is it decided which one is the best? This depends on the structure and properties of the network. The nodes might be moving fast or slow, they might be highly concentrated into a small area or widely spread out over a large area. There are undoubtedly many questions that a designer of a protocol have to take into account and most likely a single protocol will not be able to have all suggested properties.

There are a few comparative studies written on the subject, the comparisons performed show that there are major performance differences between the protocols. In general, since weaknesses of earlier protocols are known, new protocol designs try to address those problems as well. Then it has to be proved that the new protocol is actually better than the older ones. In order to quantify the differences, some kind of performance metrics have to be used The following sections will mention most of the metrics that have been used up until now. Where appropriate, their strengths and weaknesses will also be discussed.

There are two main categories of routing metrics, the first category, performance metrics, describes the outcome of a simulation, or a set of simulations. Scenario metrics is the other class of metrics. These describe the simulation input parameters.

3.1 Performance metrics

These metrics are interesting because they can be used to point out what really happened during the simulation and provide valuable information about the routing protocol. In the following sections some metrics of this type are described.

3.1.1 Packet delivery ratio

The packet delivery ratio presents the ratio between the number of packets sent from the application layer and the number of packets actually received at the destination nodes. It is desirable that a routing protocol keep this rate at a high level since efficient bandwidth utilization is important in wireless networks where available bandwidth is a limiting factor.

This is an important metric because it reveals the loss rate seen by the transport protocols and also characterizes the completeness and correctness of the routing protocol.

3.1.2 Routing overhead

Routing overhead is of course an interesting metric. In some way it reveals how bandwidth efficient the routing protocol is. The routing overhead metric simply shows how much of the bandwidth (which often is one of the limiting factors in a wireless system) that is consumed by the routing messages, i.e., the amount of bandwidth available to the data packets.

An interesting observation is that for all protocols there is a theoretical limit where some properties of the scenario force the data rate down to zero because all the bandwidth is used for routing messages. The ideal case is naturally no overhead at all i.e., only data packets traverse the network. An ideal routing protocol can be implemented in a simulator but a routing protocol without routing messages is a contradiction and cannot be implemented in a real network.

The routing overhead is typically much larger for a proactive protocol since it periodically floods the network with update messages. As mobility in the network increases reactive protocols will of course have to send more routing messages too. This is where the real strength or weaknesses of the routing protocol can be revealed. On the other hand

In DSR another type of overhead presents itself even though it is easily overlooked in the previously described packet delivery ratio metric. DSR works by finding source routes to the destination on-demand. By storing information about all intermediate nodes in the packet header as the route discovery packet traverses the network it knows the full route once the route discovery packet returns. These source routes cause the packet headers to grow and hence produce more routing overhead. Considering this, the traditional metric, packets sent versus packets delivered, might give the impression that DSR is able to deliver more packets than other protocols. Looking at the ratio payload bytes sent versus payload bytes received instead could result in a different performance for DSR. This would be most obvious in a network with long routes (many hops).

3.1.3 End-to-end delay

The term end-to-end is used to an average measure of performance between nodes in a network. It is the sources and the receivers that are involved. The end-to-end delay is therefore the total delay that a data packet experiences as it is traveling through a network. This delay is built up by several smaller delays in the network that adds together. These delays might be time spent in packet queues, forwarding delays, propagation delay (the time it takes for the packet to travel through the medium) and time needed to make retransmissions if a packet got lost etc.

Typically, in a packet based radio network without QoS (Quality of Service) the delay could vary much depending on the routing protocol. One parameter that is critical is the time a packet is kept in a buffer before it is dropped if there is no route for its destination. This buffering time is controlled by a timer in each node. If this timer is set to a high value it could imply that packets are delayed in a network for this rather long period of time. A high value would probably decrease the number of dropped packets but it would also result in a somewhat higher average delay. Of course this is a question of what is important in a particular network, low delay or few dropped packets. It is a tradeoff that the system designer need to do, and as stated earlier, this will have an impact on the end-to-end delay.

3.1.4 End-to-end throughput

Since the available bandwidth in a network is fairly well known, it is interesting to see what the actual throughput achieved in a simulation is. If a good estimation of this value can be extracted it would be possible to see how efficient the routing protocol is. The higher the average throughput, the less is the routing overhead consuming the bandwidth.

3.1.5 Path optimality

Traditionally this measurement compares the optimal path usually defined as the shortest path between two nodes in the simulator at the sending moment with the length of the path that the packet actually travelled. If the average actual path length is close to the shortest path, the protocol is said to be good. However, it is hard to know what the actual optimal path is (consider figure 9). Just settling with the shortest path does not address queuing and congestion in the network, or high latency links.

STARA (System and Traffic Dependent Adaptive Routing Algorithm) as presented by Gupta and Kumar is one of the few protocol suggestions that consider other optimal paths than the shortest path. STARA uses the mean delay as distance measure instead. ABR (discussed in chapter 2.3.6) use the expected longevity of a route when it makes the routing decisions.

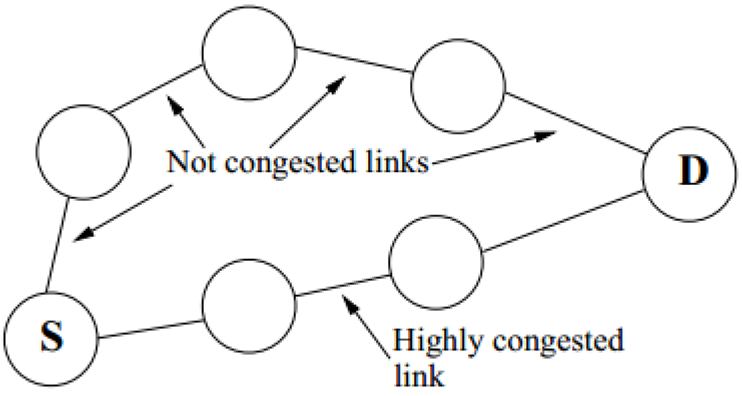

Figure 9The shortest path from S to D is congested and is therefore not the optimal path, instead the optimal case here would be the longer but uncongested route.

3.2 Scenario metrics

A scenario metric is calculated from the input data to the simulation, or might even be an input variable (such as the pause time described in chapter 3.2.2). These metrics are interesting since their value will not be dependent of the routing protocol or the simulation process, as the performance metrics (described in chapter 3.1) might be. It is crucial that non-biased metrics exists in order to provide a truthful comparison between the different routing protocols.

3.2.1 Mobility

The mobility metric was introduced by Larsson, Hedman. It is an attempt to measure the mobility in the network by calculating the relative node movement between all pairs of nodes in the network. The mobility metric is proportional to the number of link changes in a model where nodes move in a random fashion as described in chapter 2.4.

In some sense the associativity property as described tries to catch the same property as this mobility metric with the difference that it incorporates it in the routing decisions.

3.2.2 Pause time

As described in chapter 2.5, pause time is also a simulation input variable. When used as a metric, the mean pause time of all the nodes throughout the simulation is used as a measure similar to the mobility metric (chapter 3.2.1). The longer the average pause time is, the less node movement within the network. However measuring mobility in this way may be very misleading since the relative movement between the nodes is left out. Even though nodes are pausing for extended periods at one spot they could be moving very rapidly in the next moment, causing many link breakages.

Still, pause time is a realistic description of human behavior *as* described in where an experiment was conducted by letting employees wear badges from the Active Badge System that reported the bearers location at constant intervals and hence giving a rather truthful images of the movement behavior of humans in an office environment. It turned out that the pause time was indeed a realistic measure, because it showed that the average human, in an office environment tend to move periodically, pausing in between movements. The results achieved are presented in table1.

Table 1Dormant time distribution of 52 badge wearers 'n a week at the Cambridge Computer Laboratory

Dormant time (m mites)					
Distributions	Day of the week				
	Mon	The	Wed	Thu	Fri
Minimum	5.08	5.06	5.10	5.01	5.02
Maximum	299.15	277.00	281.68	223.06	297.64
Mean	35.79	36.26	41.08	40.84	47.99
Standard deviation	46.63	50.88	50.55	55.40	62.81

Chapter 4

A Cross Layer Framework for Network Modelling

4.1. Probabilistic network model

Our proposed model considers a probabilistic network which is characterized by two probability measures: link and node probability. These two parameters completely characterize the network and capture cross-layer interactions.

The node probability (χ_i) captures the availability of node *i* for routing purposes, i.e. the probability that node *i* re-broadcasts a received packet. The node probability has two components ($\chi_i = \xi_i . x_i$), one that is determined by the environment and protocol implementations at adjacent layers, (e.g. congestion models, node failures, security risks, energy levels), and one component x_i that corresponds to network routing choices, which we aim to optimize in the multi-objective routing framework.

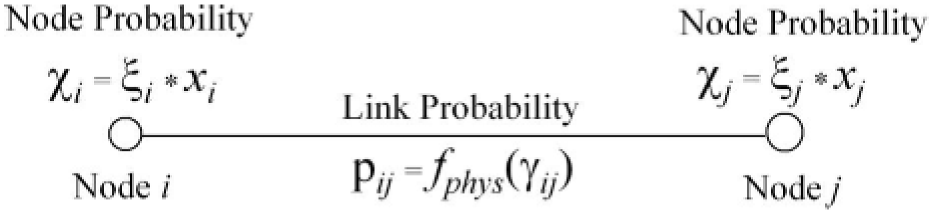

Figure 10 Link probability shows the availablity of a link between two nodes

The link probability (p_{ij}) captures the link availability, i.e., the probability of a successful transmission over a link *(i, j)*. Characterization of the link probability is impacted by impairments and enhancements at various layers of the protocol stack such as fading at the physical layer or congestion at the MAC layer. Both node and link probabilities are illustrated in Fig. 10.

Both node and link probability measures are strongly related due to the nature of the wireless channel. Hence, once the node probabilities x_i are set, the activity of every node of the network is fixed and the interference distribution can be completely determined given the nodes activity on the wireless channel. As a consequence, the link probabilities can be computed as a function of the signal to noise and interference ratio (SINR). Once link and node probabilities are available, various performance metrics such as delay, robustness or energy consumption can be calculated for various transmission schemes (unicast, multicast, broadcast, anycast, etc...).

In the following, we consider the set of node probabilities as the variables of the network optimization problem. Finding the best possible routing with respect to one particular criterion reduces to the problem of selecting the set of node probabilities that optimizes one particular objective of the network. Within a multi-objective perspective, solving the network optimization problem requires finding the set of Pareto-optimal solutions that concurrently optimizes several performance metrics of the network.

To illustrate our framework, we consider here a network where the nodes are independent and randomly distributed according to a random point process of density p over a disk D. The communication between any two nodes is performed in a half-duplex mode over a single to multi-hop path. The bandwidth of the channel is divided into R resources (time slots, frequencies or codes). For clarity purposes, we present this model in the context of time-multiplexing.

Our work concentrates on a single flow but our framework can be extended to multiple flows since the proposed interference model accurately accounts for all the nodes transmitting in the network. Hence, one source transmits a constant traffic in one of the R time slots. A relay does not keep track of the packets already transmitted and consequently may forward the same packet several times. However, a node relays the packets in the order they are received in one of its available resources. If several packets are received in the same frame it can only transmit the proportion of packets its global transmission probability x_i allows. The packets that the node cannot forward are dropped. The maximum number of hops *HM* a packet can travel in the network is also fixed.

4.2. Link probabilities

A realistic link (i, j) in time slot r is characterized by its transmission probability $p_{ij}(r)$, which is a function of the statistical distribution of the SINR at the location of the destination node j. Such a computation captures the cross-layer impact of the routing decision on the physical layer performance since the activity of all the nodes of the network are accounted for statistically in the model. The following are some preliminary definitions and notations that are needed to define the link probability:

Pathloss attenuation factor: a_{ij} reflects the attenuation due to propagation effects between node i and j. In our simulations, the simple isotropic propagation model is considered.

Interference: Since we consider time-multiplexed channels, interference only occurs between transmissions using the same channel at the same time. Hence, the power of interference $h_i(r)$on a link (i, j) using resource r and computed at node j is defined by:

$$I_{ij}(r) = \sum_{k=1}^{K} P_k a_{kj} \text{ for} k \neq i \quad (1)$$

where$K$ is the number of interfering signals in resource r. **SINR:** The SINR between any two nodes i and j in resource r is given by:

$$\overline{\gamma_{ij}}(r) = \frac{P_{ij}}{N_o + I_{ij}(r)} \quad (2)$$

Where $P_{ij}$is the power received in j, $I_{ij}(r)$ is the interferencepower on the link and N_o the noise power density. We have $P_{ij} = P_i P_{ij}$ for a fixed nominal transmission power $P_i$and a pathloss attenuation factor

Packet error rate (PER): For a specific value of SINR , the packet error rate PER can be computed according to:

$$PER(\gamma) = 1 - [1 - BER(\gamma)]^{N_b} \quad (3)$$

where$N_b$is the number of bits of a data packet and $BER(\gamma)$ is the bit error rate for the specified SINR per bit γwhich depends on the physical layer technology and the statistics of the channel. Results are given for an AWGN channel and a BPSK modulation without coding where

$$BER(\gamma) = Q\sqrt{2\gamma} = 0.5 * erfc(\sqrt{\gamma})$$

Transmission rate: The activity of a network node in a channel r $\in [1,..,R]$is given by its transmission rate $\tau_i(r) \in [0,1]$ in that particular channel. This rate is defined as the percentage of time a node i transmits using resource r.

Additional Notations: A node *i* is said to be active in the network if $\sum_r \tau_i(r) > 0$, and

- M gives the number of active nodes of the network,

- An interfering set on a link (i, *j)* is a set of $K < M — 1$ active nodes,

- C_i refers to the set of all possible interfering sets and has a cardinality of

$$L = \sum_{k=1}^{M-1} \binom{M-1}{k} + 1$$

The link probability: p_{ij} (r) depends on the distribution of the SINR, and consequently on the distribution of the corresponding packet error rates. It is defined by the equation:

$$p_{ij}(r) = \sum_{l=1}^{L} [1 - PER_l(r)] . P_l(r) \tag{4}$$

where the index *1* represents one of the L interfering sets. Consequently, γ_l(r) is the SINR experienced because of the interfering set *1* on the link (i, *j)* for the resource r and *PERi(r)* is the corresponding PER. The SINR can be computed according to Eq. (2) considering the *K* interfering links of *1* and the PER according to Eq. (3).

P1 (r) is the probability for the link (i, *j)* to experience the interference distribution *1* in resource r, i.e. the probability that the nodes of the interfering set *I* are transmitting concurrently and the others are not. Hence, this probability for a link (i, *j)* is given by:

$$P_l(r) = \prod_{k=1}^{K} \tau_k(r) . \prod_{m=1}^{M-K-1} (1 - \tau_m(r)) \tag{5}$$

In Eq. (5) $\prod_{k=1}^{K} \tau_k(r)$ gives the probability that the Kactive nodes of the interfering set l are transmitting and $\prod_{m=1}^{M-K-1} (1 - \tau_k(r))$ the probability that the $M — K — 1$ other active nodes are not.

4.3. Node probabilities and transmission rate

The variables of our model are the probability $\chi_i = \xi_i . x_i$for each node *i* to re-transmit a received message. In the following, we consider that $i = 1$ to simplify our model. Hence, the main variable is the 'forwarding probability' x_i. There is no notion of routing paths herein and a packet sent by a source may use one or more paths in parallel to reach the destination. For $x_i = 1$ each received packet by node i is forwarded. For

$x_i < 1$ node i drops the packets with probability $1 - x_i$. Values of $x_i \in]1, R]$ are not allowed yet as they imply that node i transmits several copies of the same packet.

As stated earlier, the transmission rate $\tau_i(r)$ in resource r is a function of the node probability x_i but also depends on the amount of traffic coming into node i, which is a function of the activity of the other nodes of the network. As a consequence, computing the values of $\tau_i(r)$ knowing the x_i values is intractable since determining the $\tau_i(r)$ requires the knowledge of the link probabilities which are themselves a function of the $\tau_i(r)$ values.

However, the reverse approach where the variables x are expressed as a function of the $\tau_i(r)$ can be easily derived as stated below. Hence, such a reverse approach leads to the use of the transmission rates as the variables of our multi-objective optimization problem instead of the forwarding probabilities. This reverse approach represents an important contribution of our cross-layer model since it captures an exact picture of the interference distribution at the physical layer and determines the corresponding node forwarding probability x_i at the routing level.

Relationship between x_i and the $\tau_i(r)$: Given the values of $\tau_i(r), \forall r \in [1..R], i \in [1..N]$, we can define the quantity of information coming from all the neighbors of node i (except from the destination) by:

$$q_i = \sum_{k \neq \{i,D\}} \sum_r p_{ki}(r).\tau_k(r).v_{ki} \qquad (6)$$

where $p_{ki}(r)\tau_k(r)v_{ki}$ is the probability that a packet arrives in node i from node k in resource r.

The variable v_{ki} is introduced to represent the usefulness of the link (k,i) with respect to the maximum number of hops constraint. Hence, if no data can arrive from neighbor k because the hop count h for all the packets k received is already equal to H_M, we have $v_{ki} = 0$. On the contrary, we have $v_{ki} = 1$ if k only receives packets with a number of hops $h < H_M$. If k receives packets with both $h < H_M$ and $h = H_M$,, v_{ki} represents the proportion of packets being retransmitted.

The quantity of information going out of i is given by the sum of the $\tau_i(r)$ over all the time slots. Hence, we can determine the global forwarding probability of i to be:

$$x_i = \frac{\sum_r \tau_i(r)}{\sum_{k \neq \{i,D\}} \sum_r p_{ki}(r).\tau_k(r).v_{ki}} \qquad (7)$$

Chapter 5

A Multi-Objective Optimization Problem

The performance of most wireless networks can be assessed with regards to various criteria such as throughput or capacity, end-to-end transmission delay, overall energy consumption or transmission robustness. The purpose of the multi-objective framework presented in this work is to determine, given a network and a communication pattern, what kind of tradeoffs arise between chosen performance metrics when varying the routing strategies. It relies on the cross-layer probabilistic network model presented in chapter 4.

5.1. Variables of the Multi-objective (MO) Framework

The routing strategies are the variables of our multi-objective optimization problem and a solution is defined by:

Definition 1 A solution *S* of the MO framework is defined by the set of transmission rates $\tau_i(r) \in [0, 1]$ used by each node i on each resource r:

$$S = \{\tau_i(r)\}_{i\epsilon[1...N],r\epsilon[1..R]} \tag{8}$$

The set of node probabilities $x_{i,i\in[1..N]}$ is derived according to Eq.(7) and represents the routing strategy of the network. Each variable τ_i (r) takes its values in a discrete set F of size $T = |F|$. As a consequence, the solution space is derived as:

$$|s| = \sum_{m=0}^{N} \binom{N-2}{m} T^{R.m} \tag{9}$$

In order to reduce the size of this very big search space, we only consider solutions where at least one cumulative time slot per node is available in the frame, i.e. $s.t. \forall i \in , \sum_{t=1}^{R} \tau_i(r) \leq R - 1$. The solutions that do not meet this constraint are usually very bad solutions since at least one of the nodes of the solution is transmitting in all its time slots preventing a failure free packet reception.

Using this definition of a routing strategy, a solution may reflect various features: it can be single-hop or multi-hop, single path or multi-path, probabilistic or deterministic. The aim of our MO framework is to obtain the set of Pareto-optimal routing strategies of the MO problem. A Pareto-optimal set is composed of all the non-dominated solutions of the MO problem with respect to the performance metrics considered. A solution *A* dominates a solution *B* for a*n—objective* MO problem if A is at least as good as *B* for all the objectives and A is strictly better than *B* for at least one objective.

We propose in the following to assess the performance of a wireless sensor network (WSN) by capturing the tradeoffs that arise between end-to-end robustness, overall energy consumption and end-to-end delay. These criteria are prevalent since providing a maximal network throughput is usually not the main task of a WSN. The criteria are defined for a single source-destination pair *(S, D).*

5.2. Robustness criterion

Robustness is defined as the probability that a message emitted at *S* successfully arrives at *D* in at most H_M hops. The robustness criterion is given by:

$$f_R = P(T_{SD}^{H_M}) \tag{10}$$

For any two nodes i and *j* of the network, T_ZH represents the event that a message transmitted by i successfully arrives in *j* in at most *H* hops. Our aim is to maximize $P(T_{SD}^{H_M})$.

Definition 2: Global link probability.

For a link (i, *j),* the global link probability p_{ii} is the probability that a message arrives with success at node *j.* It is given by:

$$p_{ij} = \sum_{r=1;\,\tau_i(r)\neq 0}^{R} p_{ij}\,(r)\,\frac{\tau_i(r)}{\sum_r \tau_i(r)} \tag{11}$$

where$p_{ij}\,(r)$ is the link probability between i and j for resource r and $\tau_i(r)/\sum_r \tau_i(r)$ the probability for the packet to be sent using r.

Definition 3: Robustness probability.

$P(T_{SD}^{H_M})$.is the probability that the message arrives successfully in D in at most H_M hops and is given by:

$$P\left(T_{SD}^{H_M}\right) = 1 - \prod_{h=1}^{H_M}(1 - P(T_{SD}|H = h)) \tag{12}$$

where $P(T_{SD}|H = h)$ is the probability for a packet to arrive in h hops at D. For $h = 1$, $P(T_{SD}|H = 1) = p_{SD}$, the successful transmission probability on the link *(S, D)* following Eq. (11). For $h > 1$, we have:

$$P(T_{SD}|H = h) = 1 - \prod_{j=1}^{N_S}[1 - p_{Sj}\, x_j\, P\left(T_{jD}\,|H = h - 1\right)] \tag{13}$$

withNs the number of possible first hop relays of S; p_{sj} the link probability between S and its neighbor j; $P(T_{jD}|\ H = h\text{-}1)$ the probability to reach D in $(h — 1)$ hops and x_j the forwarding probability of j. The set of Ns relays is given by all the nodes different from S that are active in at least one of the time slots in the current solution (i.e. having $\sum_{t=1}^{R}(x_i^t)$> 0, i ≠ $\{j, S\}$).

To reduce the computation complexity of the robustness probability, a restricted set Ns of first hop relays may be considered but the loss in terms of accuracy is hard to quantify. Therefore, we rather introduce a *link threshold value Pth*computed for each path made of h hops. While recursively calculating $P(T_{SD}|\ H = h)$, if the probability of a path gets lower than P_{th}, the recursion is stopped for that particular path and its contribution to $P(T_{SD}|\ H = h)$is set to zero.

5.3. Delay criterion

The end-to-end delay is the sum of the times spent at each relay on a multi-hop path where each relay introduces a delay of 1. The criterion $f_D$is defined by:

$$f_D = R.\sqrt{\sum_{h=1}^{H_M}(h - 1)^2.R_h} \tag{14}$$

The quantity $(h —1)$ is the delay needed by a packet to arrive in h hops using $(h — 1)$ relay nodes. The scaling factor R represents the delay induced by the R resources. Rh is the probability that the packet arrived in exactly h hops and did not arrive in 1, or 2 or $(h — 1)$ hops. For $h = 1$, we have $R_h = P(T_{SD}|\ H = 1)$ and for $h > 1$:

$$R_h = P(T_{SD}|H = h).\prod_{i=1}^{h-1}(1 - P(T_{SD}|H = i)) \tag{15}$$

If no route exists between S and D then $fp = +\infty$. *C. Energy criterion*

The energy criterion $f_E$is given by the total forwarding energyneeded for a packet sent by S to reach D. We do not account for the energy spent by the initial transmission in S. The reception (resp. transmission) of a packet at node j in resource r consumes $e_j^R(r)$ (resp. $e_j^T(r)$). Hence, the energy criterion is defined as:

$$f_E = \sum_{h=1}^{H_M} \varepsilon(T_{SD}|H = h) \quad (17)$$

where$\varepsilon(T_{SD}|H = h)$is the total energy needed by the h-hop communications between S and D defined by:

$$\varepsilon(T_{SD}|H = h) = \sum_{j=1}^{N_s}(p_{Sj}\, e_j^R + p_{Sj}\, x_j \left[e_j^T + \varepsilon\left(T_{jD}\,|H = h-1\right)\right]) \quad (18)$$

In Eq. (17), $p_{Sj}\, e_j^R$ is the energy consumed for a packet reception by the neighbor j of S; $p_{Sj}\, x_j\, e_j^T$ is the energy consumed for the packet transmitted by neighbor j and $p_{Sj}\, x_j\, \varepsilon(T_{jD}\,|H = h-1)$is the total energy consumed by the following possible paths made of *(h — 1)* hops between neighbor j and the destination. For $h = 1$, $\varepsilon(T_{SD}|H = 1) = 0$since the energy in S is not accounted for.

Chapter 6

Implementation and Results

This chapter tells us about the experimental setup. Our simulation is divided into two steps. In First step we calculate the robustness, time delay and energy consumption of our network. In Second step we use the results calculated to optimize the value of initial energy we derive the equation of robustness, time delay and energy consumption with respect to initial energy.

Then we use these non-linear equations and optimize the value of initial energy by using multi objective genetic algorithm function of Matlab. The result thus obtained is the optimal value of initial energy with respect to robustness, time delay and energy consumption.

Experimental Setup

In first step we simulate our network. We create a network with 100 Nodes. The position of nodes is selected randomly. A source node (S) and a destination node (D) are selected among them. Now our aim is to send packet from source node to destination node. Every node has a set of neighbors. Neighbors are decided on the basis of distance from the respective node.

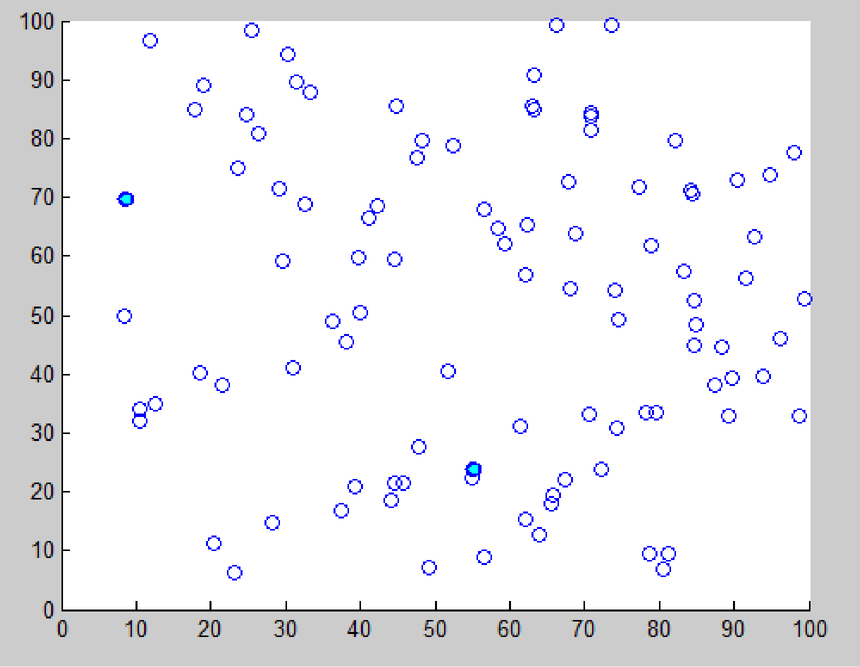

Figure 11A plot showing distribution of nodes in a 100 X100 unit area

We have a taken an area of 100 units wide and 100 units long. So our node can have x and y coordinate ranging from 1 to 100. We have considered two nodes to be neighbor of each other if distance between them is less than 20 units.

In every simulation, we assign initial energy randomly to every node and calculate the average initial energy of each round. Then we simulate our network by sending a packet from source node to destination node and in result we get robustness, time delay and energy consumption of the network in that round.

In second step we form non linear equation representing relation between the robustness, time delay and energy consumption of network with respect to initial energy. These equation now act as input of our multi-objective genetic algorithm function.

Through our multi-objective function our aim is to maximize robustness and minimize time delay and energy consumption. The results thus obtained are a set of optimal values of initial energy. We can plot various values obtained on graph depicting performance of network with respect to initial energy.

The following graphs show the performance of network with respect to initial energy for different simulations.

Simulation I Results:

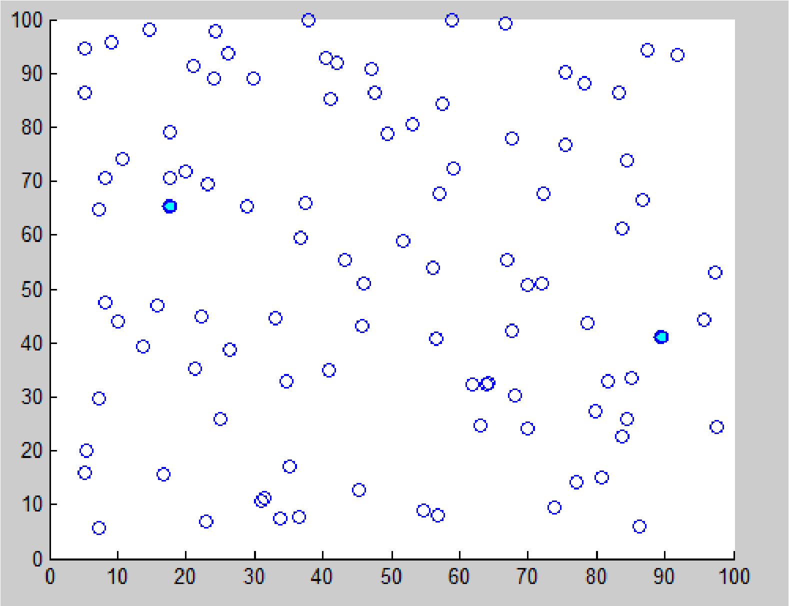

Figure 12 Simulation I distribution of nodes

Round	Average Energy in Joules
Round 1	0.5524
Round 2	1.0569
Round 3	1.5507
Round 4	2.0544
Round 5	2.5545

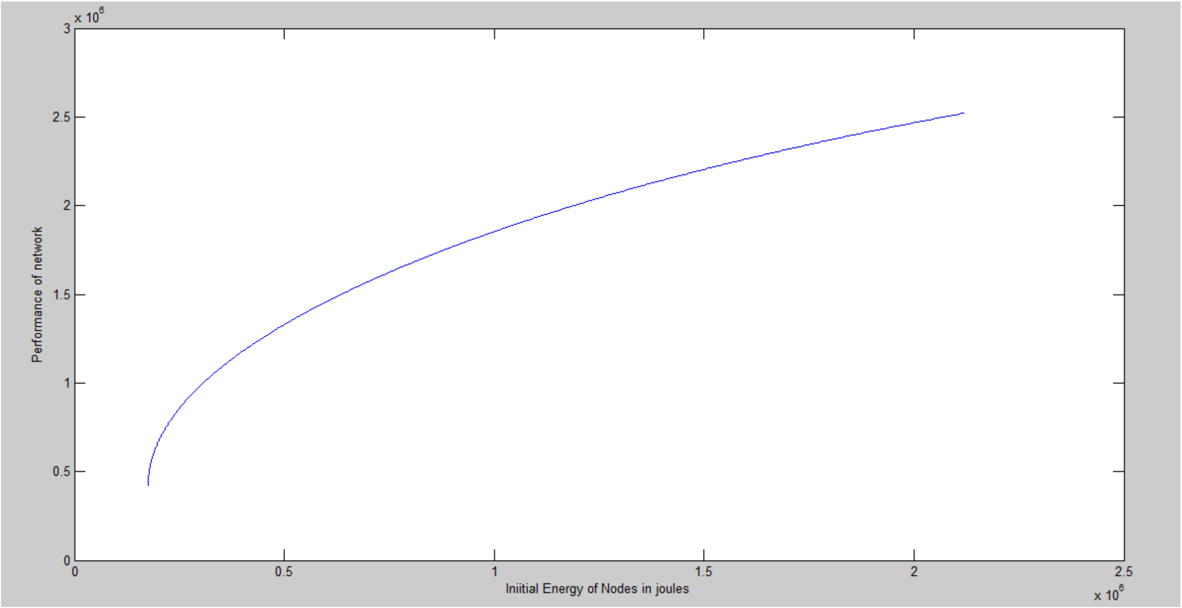

Figure 13 Simulation I Optimal Value of Initial Energy of Nodes

Simulation II Results:

Round	Average Energy in Joules
Round 1	0.5505
Round 2	1.0576
Round 3	1.5510
Round 4	2.0612
Round 5	2.5425

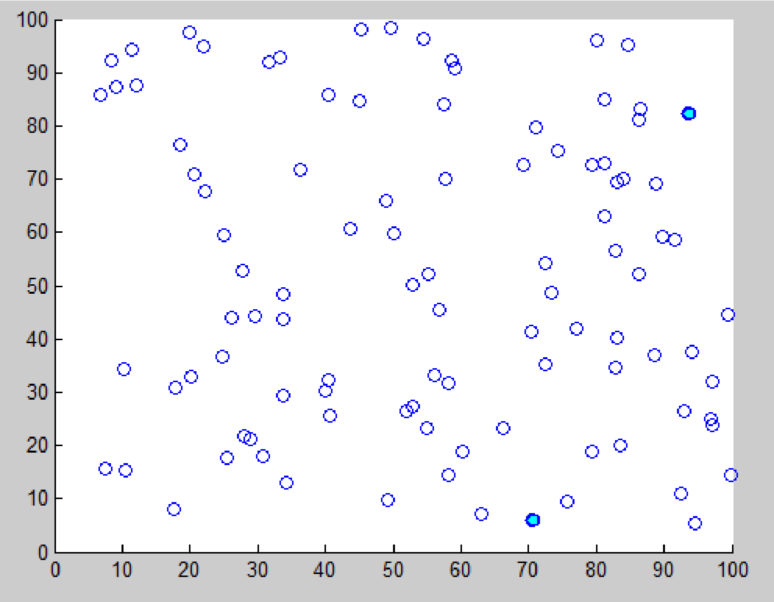

Figure 14 Simulation I distribution of nodes

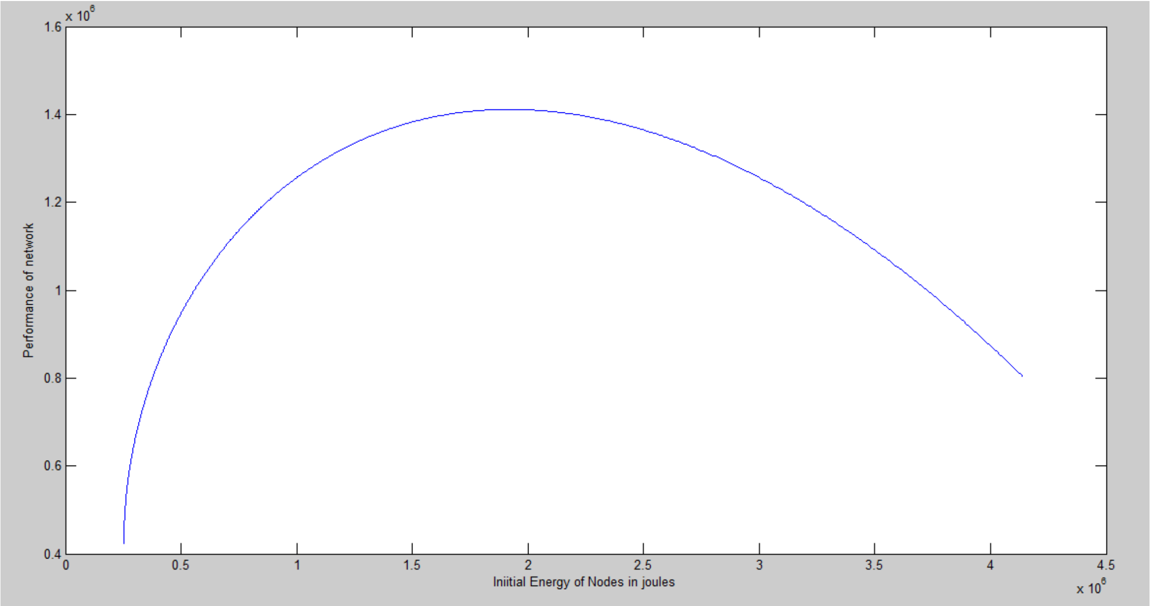

Figure 15 Simulation II Optimal Value of Initial Energy of Nodes

It can be easily observed performance of network increases with increase in initial energy, but energy is a very crucial resource we have to choose a optimal value otherwise we will just end up wasting our resources.

Chapter 7

Conclusion

In this thesis we proposed a multi-objective framework for wireless ad hoc network. We are trying to develop a model which will help to understand the trade-offs between various performance parameters. Through this work we tried to understand the tradeoff between three very crucial performance metric namely robustness, time delay and energy consumption.

All the three parameters are very crucial for the optimal performance of any ad hoc network. We first derived various mathematical formulas useful to calculate the robustness, time delay and energy consumption of any network. Then we simulated the behavior of ad hoc wireless network and calculated robustness, time delay and energy consumption of network at different initial energy.

Then we applied multiobjective optimization on our observation. In Multiobjective optimization our aim was to maximize robustness and minimize time delay and energy consumption of our network.

We used multi-objective genetic algorithm function which gave us the optimal value of initial energy based on the different configuration of our wireless network.

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