PREDICTION OF OPTIMUM PERFORMANCE IN SELF-ORGANIZING NETWORKS WITH DYNAMIC SOURCE ROUTING PROTOCOL

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TAJUK PROJEK : PREDICTION OF OPTIMUM PERFORMANCE IN SELF-ORGANIZING NETWORKS WITH DYNAMIC SOURCE ROUTING PROTOCOL

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Prediction of Optimum Performance in Self-Organizing Networks with Dynamic Source Routing Protocol

Dr. Muhammad Hisyam Lee

Abstract

An ad-hoc network is a special type of wireless mobile networks formed by a collection of mobile platforms in a self-organizing way without relying on any centralized administration. A good routing protocol for the ad hoc networks should be minimizing routing overhead and power conservative. Many different protocols have been proposed in solving routing problems in mobile ad hoc networks. As a result, a study of evaluating the performance of a protocol in the most systematic ways becomes significant. Such study is important in order to know about the actual performance of the protocol. Many performance evaluation studies have been reported, but most of which were conducted based solely on experimental studies with no formal statistical method applied. In this study, a statistical method is presented to evaluate the performance of dynamic source routing protocol in mobile ad hoc networks. The protocol is evaluated with respect to number of packets dropped and routing overhead. An experiment matrix is used to perform simulation, after which the selected methods of analysis are performed to simulation data.

Abstrak (Bahasa Malaysia)

Rangkaian Ad Hoc merupakan sejenis rangkaian mobil wireles terbentuk oleh sekumpulan platform mobil dalam suasana pengurusan sendiri tanpa bergantung kepada pengurusan berpusat. Laluan protokol yang baik untuk rangkaian ad hoc hendaklah memininumkan beban laluan dan mengurangkan penggunaan kuasa. Pelbagai protokol telah dicadangkan untuk menyelesaikan masalah laluan dalam rangkaian mobil ad hoc. Justeru itu, kajian tentang penilaian kecekapan protokol secara sistematik adalah bererti. Kajian sedemikian adalah penting untuk mengetahui kecekapan sebenar protokol. Pelbagai kajian penilaian kecekapan telah dilaporkan tetapi kebanyakkan telah dijalankan secara kajian ekperimen tanpa kaedah statistik digunakan. Kajian ini, kaedah statistik digunakan untuk penilaian kecekapan protokol laluan sumber dinamik dalam rangkaian ad hoc mobil. Protokol telah dinilai dengan bilangan bungkusan digugurkan dan beban laluan. Satu matrik ekperimen telah digunakan untuk melaksanakan simulasi, setelah itu kaedah yang dipilih bagi analisis dilaksanakan untuk data simulasi.

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Chapter 1

Introduction

1.1 Background

An ad hoc network is a special type of wireless mobile networks in which a collection of mobile platforms with wireless devices may form a temporary network, without the aid of any organized administration [6]. The mobile platforms could be PDAs, cell-phones, laptops, sensors which are also known as nodes [39]. This type of networks are basically peer-to-peer multihop mobile wireless networks where information packets are transmitted from source to destination, via intermediate nodes, as shown in Figure 1.1.

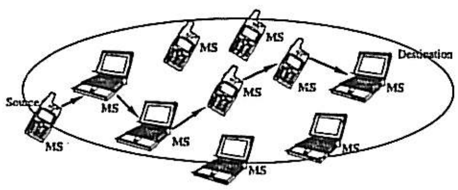


Figure 1.1: Illustration of an ad hoc network

Since some receiving nodes may be out of the direct range of a sending node, intermediate nodes have to act as routers to forward packets to the receiving nodes. The potential application for mobile ad hoc networks can be found in various fields such as virtual navigation, telemedicine, rescue operations, conferencing, and military networks [2]. Requiring no fixed infrastructure as well as the nodes in the networks are constantly moving give rise to several challenging issues for this type of networks, some of which are routing, energy conservation, security, node cooperation and quality of service (QoS) [1, 7]. In this research, the routing problem is of interest.

A good routing protocol used for mobile ad hoc networks should minimize the computing load on the nodes (i.e., hosts) as well as the traffic overhead on the network. A conventional routing protocol based on the link-state or distance vector is not suitable for ad hoc networks [3], which has lead to a number of problems (see Johnson [4]). As a result, a number of routing protocols have been proposed which can be divided into two basic strategies based on how and when the route discovery process is being used [5]: proactive and reactive.
In reactive routing protocols, consistent and up-to-date routing information is maintained at each node, where as in reactive routing protocols, the routes are discovered only they are needed. In addition to these two basic methods there is also a hybrid approach that is a combination of cooperative works between proactive and reactive strategies. Dynamic Source Routing (DSR) [6] and Ad Hoc On-Demand Distance Vector Routing (AODV) [7] are examples of a reactive routing protocols and Destination Sequenced Distance Vector (DSDV) [8] is an example of a proactive routing protocol, as shown in Figure 2.1.
Since many different routing protocols have been proposed in mobile ad hoc networks, a study of evaluating the performance the routing protocol become significant so as to know about the performance of these protocols. Many of the performance evaluation in mobile ad hoc networks have been reported such as in [6, 7, 19, 18, 20], but most of which were conducted based on experimental studies with no formal statistical method applied. These studies lead to a huge number of experimental run since each experimental run was repeated many times. Naturally, one would like to reduce the number of experimental runs to a practical point, but still provides the sufficient information about the performance of the protocols.
Therefore, the main concern of this research is to introduce statistical analysis into experimental studies that brings down the size of experiment to be minimum, in order to evaluate the performance of a routing protocols used for mobile ad hoc networks. Specifically, the research focuses on evaluating the performance of Dynamic Source Routing (DSR) [6]. A detailed description of this protocol is given in Chapter 2.

1.2 Statement of the Research Problem

Requiring no base station and nodes's constantly moving give rise to several challenges which include routing problem. Routing is the process of exchanging information between any pair of nodes. An efficient routing protocol is necessary for mobile ad hoc networks since two nodes that may wish to exchange information packets might not be able to communicate directly due to a limited transmission range of a node. Some receiving node may be out of the transmission range of a sending node. Therefore, intermediate nodes have to act as routers to forward packets to the receiving nodes.

Some traditional routing protocol are not suitable for mobile ad hoc networks, which has lead to a number of problems including many links between routers may be redundant, periodically sending route updates wastes network bandwidth, and periodically sending routing updates wastes battery power.

Many routing protocols have been proposed to solve routing problems in mobile ad hoc networks. A good routing protocol should be bandwidth efficient (minimize routing overhead), power conservative, responding quickly to topology changes, and scaled to as the network topology grows. A routing protocol is evaluated with respect to performance metrics which include number of packets dropped, packet delivery ratio, throughput, routing overhead and average end-to-end delay. These metrics play a very important role in evaluating the performance of a routing protocol used for mobile ad hoc networks.

The important of studying the performance of a routing protocol used for mobile ad hoc networks are two-folds: (1) to know about the actual performance of the protocol under different scenario such as network load, mobility, and network density, (2) to find the best protocol design under specified scenario.

Numerous performance studies about routing protocols have been reported, but most of which conducted based solely on the simulation data and graph method. As a results, introducing statistical analysis into performance study is highly beneficial in gaining more accurate information about the protocol performance in the most organized and efficient ways.

1.3 Objective of the Research

The main goal of this study is to evaluate the performance of dynamic source routing protocol used for mobile ad hoc networks. To achieve the target, the following objectives are specified:

1. To estimate the main as well as the interaction effect of the influential factors on the performance of mentioned protocol.

2. To determine factor-level combination contributed to optimum performance of the mentioned protocol.

3. To predict optimum performance of the mentioned protocol.

1.4 Scope of the Research

This study is carried out using computer simulation. The simulation setup which represents the mobile ad hoc network environments is bounded with respect to a small terrain size, a small number of nodes (i.e., small density), the mean speed of walking pedestrian, and the transmission range of 10 meters corresponding to the radio range of Bluetooth.

1.5 Contribution of the Research

The expected results are the estimation of the effect of the factors on the performance of dynamic source routing protocol, the best factor-level combination contributed to optimum performance, and the prediction of optimum performance of dynamic source routing protocol. The benefits of this research is to providing useful performance analysis in evaluating the proposed routing protocols for mobile ad hoc networks.

Chapter 2

Ad Hoc Network

2.1 Ad Hoc Networking

An ad hoc networking and communications is a research subject that has become ever more interesting over the last couple of years. The ad hoc networks abbreviated as MANET in literature is a wireless-multihop network formed by a group of mobile nodes in a self-organizing way without relying on centralized administration such as base station. According to D.B. Johnson and D.A Maltz [6], "an ad network is a collection of wireless mobile hosts forming a temporary network without the aid of any centralized administration or standard support services regularly available on the wide area network which the host may normally connected."

In this networks, each mobile node functions as hosts and routers. It means that networking function including discovering and maintaining routes to other nodes are performed by the nodes themselves. Since each mobile node has a limited wireless transmission range, in order to forward packets to destination, it may be necessary for one mobile nodes to enlist the aid of other mobile nodes. This resulted in multiple hops in network layer. Mobile nodes are free to move randomly and can be located arbitrarily. Due to these fashions, the network topology between nodes may change rapidly and unpredictably overtime.

2.1.1 Advantages

There are several advantages of mobile ad hoc networks over a fixed networks:

1. **Easy and rapid deployment:** Ad hoc networks can be easily and rapidly deployed because of the absence of fixed infrastructure [5]. Due

to little efforts needed to deployed them, these networks are the only possible options in which a quickly share information are most required. For instance, in the emergency services and rescue operation.

2. **Anywhere and at anytime communication come to reality:.** As user with their mobile host can set up networks more rapidly, and is free to roam about while communication to meet their particular purposes, establishing network communication in anywhere and at anytime is come into reality.

3. **Internet connection:.** Due to the rapid growing in the Internet, it becomes important issues to consider the integration between ad hoc nodes and Internet. A wireless nodes on the edge of the network cloud are typically connected and supported by a single wireless hop to wired Internet.

4. **Zero configuration:.** Zero configuration requirement is also an attractive point for mobile ad hoc networks. It is suitable for home networks or for users who either do not know how to configure a network, or do not have an inclination to do so.

5. **Economical investment:.** There are situation, where fixed network may not provide adequate services. Moreover, a large investment for installation such as central offices and radio towers is likely to be too expensive. In this case, setting up an ad hoc network is desirable.

2.1.2 Characteristics

The salient characteristics of ad hoc networks are as follows [1]:

1. **Dynamic topologies:** Nodes are free to move arbitrarily; thus, the network topology may change randomly and at unpredictable times and may consist of bidirectional links. In some cases, where the transmission power of two mobile nodes is different, a unidirectional link may exist.

2. **Bandwidth-constrained and variable capacity links:** Wireless links continue to have significantly lower capacity than infrastructures networks. In addition, the realized throughput of wireless communications, after accounting for the effects of multiple access, fading, noise, interference condition, and so on, is often much less than a radio's maximum transmission rate.

3. **Energy-constrained operation:** Some or all of the nodes in an ad hoc network may rely on batteries or other exhaustible means for their energy. For these nodes, the most important system design optimization criteria may be energy conservation.

4. **Limited physical security:** Mobile wireless networks are generally more prone to physical threats than wire line networks. The increased possibility of eavesdropping, spoofing, and minimization of denial-of-service type attacks should be carefully considered.

2.1.3 Applications

Potential application for ad hoc network can be found in various fields as given below [1].

1. **Virtual navigation:** A remote database contains the graphical representation of streets, buildings, and physical characteristics of a large metropolis. Blocks of this database are transmitted in rapid sequence to a vehicle, where a rendering program permits vehicle occupants to visualize the needed environment ahead of time. They may also "virtually" see the internal layout of buildings, including an emergency rescue plan, or find possible points of interest.

2. **Telemedicine:** The paramedic assisting the victim of a traffic accidents in a remote location must access medical records (e.g., X-rays) and may need video conference assistance from a surgeon for an emergency intervention. In fact, the paramedic may need to instantaneously relay back to the hospital the victim's X-rays and other diagnostic tests from the site of the accident.

3. **Tele-geoprocessing applications:** The combination of geographical information systems (GIS), GPS, and high-capacity wireless mobile systems enables a new type of application referred to as tele-geoprocessing. Queries dependent on location information of several users, in addition to temporal aspects, have a potential business applications.

4. **Crisis-management applications:** These arise, for example, as a result of natural disasters in which the entire communication infrastructure is in disarray. Restoring communications quickly is essential. With wide band wireless mobile communications, limited and even total communication capability, including Internet and video services, could be set up in hours instead of the days or even weeks required for restoration of wire line communications.

5. **Conferencing:** When mobile computer users gather outside their normal office environment, the business infrastructure is often missing. Sometimes, the need for collaborative computing is even more important than in the everyday office environment. In such situation, requiring to form temporally networks is likely to be the solution. For instance, a number of people in conferences, where by the need to set up ad hoc network seem most required.

6. **Military networks:** Military tactical operation are still the main application of ad hoc network today. For example military units such as soldiers, tanks or planes that are equipped with wireless communication units forming a temporary networks when rooming in a battlefields.

2.2 Desired routing properties

Requiring no fixed infrastructure and node's constantly moving give rise to several challenges for mobile ad hoc network, one of which is routing [1]. Routing is the process of exchanging information among a group of nodes. As long as connection among nodes is established. there must be a routing.

Some form of routing protocol is necessary for mobile ad hoc network, since two nodes that may wish to exchange packets might not be able to communicate directly [4]. In mobile ad hoc network, the routing protocol design should strive to make the protocol satisfied some characteristics [39] which include have decentralized execution, be bandwidth efficient (minimize routing overhead), utilize both unidirectional and bidirectional links, and act power conservative.

2.3 Routing protocol strategies

There are two basic ad hoc routing protocols. One is called table-driven or proactive. The other routing protocol is called on-demand-driven or reactive. 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.

2.3.1 Proactive strategy

In reactive routing protocol, each node maintains one or more tables containing routing information to every other node in the network. When network topology changes, the nodes propagate update massages throughout the network in order to maintain a consistent and up-to-date routing information about the whole network.

2.3.2 Reactive strategy

In reactive routing protocol, the routes are created only when required. When a source wants to send to a destination, it initiates the route discovery mechanisms to find the path to the destination within the network. The route remains valid till the destination is reachable, or until the route is no longer needed.

2.3.3 Hybrid strategy

Hybrid routing protocol is a combination of cooperative works between proactive and reactive routing protocols. These protocols divide the network into zones (clusters) and run a proactive routing 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

This section gives some overview of various routing protocol in mobile ad hoc networks. A number of routing protocol have been suggested for mobile ad hoc networks [5]. These proposed routing protocols can be divided into three categories which are proactive, reactive and hybrid routing protocols as shown in Figure 2.1.

2.4.1 Destination Sequenced Distance Vector

The Destination Sequenced Distance Vector (DSDV) routing protocol [8] is based on the classical Bellman-Ford Routing Algorithm with certain improvements.

Every node maintains routing table that list all destinations, the number of hops to reach destination, and the sequence number assigned by the destination node. The sequence number is used to distinguish stale routes

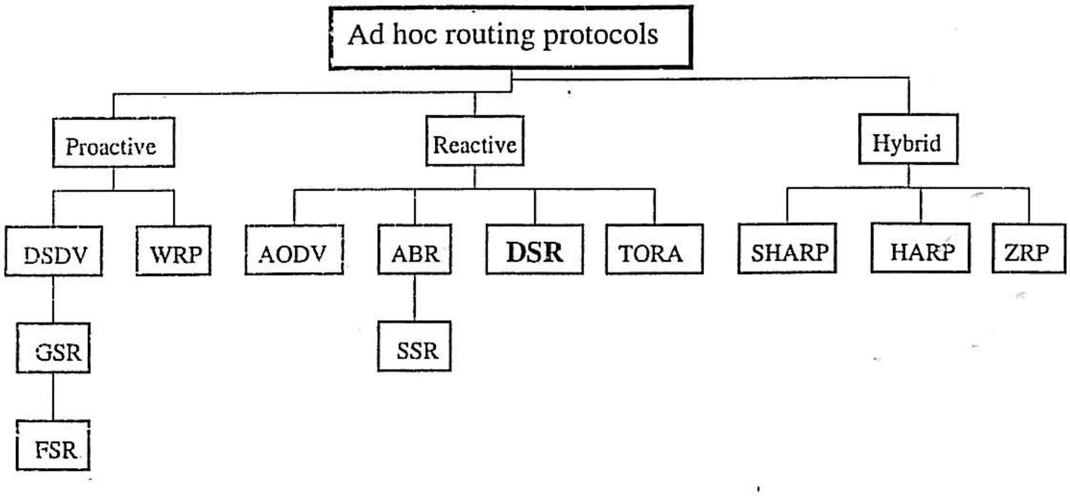


Figure 2.1: Categorization of ad hoc routing protocols

from new ones, and thus to avoid the formation of loops. The nodes periodically transmits their routing table to their intermediate neighbors. The nodes also transmits their routing table if a significant change has occurred in its table from the last update sent. The routing table updates can be sent in two ways: full dump and incremental packets. In a fast-changing network, incremental packets can grow big, and then full dumps will be more frequent. The transmission of route updates is delayed by settling time to eliminate those update that would occur if a better route were found very soon. The improvement was made here is preventing routing loops in a mobile network of routers. By this improvement routing, information can always available regardless of whether the source node requires or not.

2.4.2 Wireless Routing Protocol

The Wireless Routing Protocol (WRP) [10] is a table-based distance-vector routing protocol. Each node maintain four tables, namely Distance table, Routing table, Link-Cost table, and Massage Retransmission list. Each node exchanges routing table with their neighbors using update massages periodically as well as propagation of link changes. Hello massages are periodically exchanged between neighbors. This protocol avoids count-to-infinity problem by forcing each node to check predecessor information. A unique feature of this algorithm is that, it checks the consistency of all its neighbors every time once detecting a change in their link. This will help to eliminate looping situation in a better way and also has fast convergence.

This protocol, however, requires selection of periodic updates interval, maximum value of the settling time for a destination, and the number of update intervals which may be happen before a route is considered stale.

2.4.3 Global State Routing

The Global State Routing (GSR) [11] is similar to DSDV. It takes the idea of link state routing, but improves it by avoiding flooding of routing massages. Each node maintains a Neighbor list, a Topology table, a Next Hop table, and a Distance table. The routing message are generated on the link state vector, so that nodes maintain a global knowledge of the network topology, and optimize their routing decisions locally. This protocol provides a better solution than existing approaches in a truly mobile ad hoc network, where mobility is high and bandwidth is relatively low.

2.4.4 Fisheye State Routing

The Fisheye State Routing (FSR) [12] is an improvement of GSR. In GSR, the large size of update massages are contributed to wasting of a network bandwidth. The improvement are made in FSR is that, it reduces the sizes of tables to be exchanged in the network connectivity. Instead of each update massages containing information about all nodes, it exchanges information about closer nodes more frequently than about the nodes further away. As the bandwidth overhead can be controlled, FSR scales well to large networks.

2.4.5 Clusterhead Gateway Switch Routing

The Clusterhead Gateway Switch Routing Protocols (CGSR) [13] uses DSDV as the underlying routing algorithm. Under this protocol, mobile nodes are grouped into clusters and each cluster has a cluster head. The cluster head can control a group of ad hoc host, and clustering provides framework for separation among clusters, channel access, routing and also bandwidth allocation. In CGSR, the node such as cluster heads and gateway node have a higher computation and communication load than other nodes. Moreover, the network reliability may also be affected due to single points of failure of these critical nodes.

2.4.6 Ad Hoc On-Demand Distance Vector

The Ad Hoc On-Demand Distance Vector Routing (AODV) [7] protocol builds on DSDV protocol, and the improvement is on minimizing the number of required broadcast. It is made by creating routes on an-demand basis as opposed to DSDV protocol that maintains the list of all the routes. A path discovery is initiated when a route to destination does not exist. Broadcast is used for route request. The AODV protocol uses only symmetric link, and link failure notification is sent to the upstream neighbors. The advantage of the protocol is that, it uses bandwidth efficiently by minimizing the network load. Others are responsive to changes in topology, scalable and ensuring loop free routing. This protocol, however, are created significant overhead.

2.4.7 Dynamic Source Routing

The Dynamic Source Routing Protocol (DSR) [6], is based on the concept of source routing. Each node is required to maintain route caches containing the source routes that the node is aware of. The node continually updates entries in the route caches as new routes are learned. Two major phases of the protocol: route discovery and route maintainable. Route discovery employ route request and route reply packets, where as route maintainable employ route error packets and acknowledgements. Although the DSR protocol is better than the conventional routing protocols, this protocol is claimed to have a major scalability problem due to the nature of source routing. As the network becomes larger, the control packets and massage packets also become larger.

2.4.8 Temporally Ordered Routing Algorithm

The Temporally Ordered Routing Algorithm (TORA) [9] is a highly adaptive, loop-free, efficient, and scalable distributed routing algorithm, based on the concept of the link reversal. It is proposed to operate for highly dynamic mobile, multihop wireless environment. This protocol is a source initiated and provides multiple routes from a source node to a destination node. This algorithm requires the need for synchronized clocks. There are three basic functions of the protocol, namely route creation, route maintenance, and route erasure. Some advantages of this algorithm are providing multiple routes, establishing route quickly, and minimizing communication overhead. It also capable of detecting network partitions very quickly. However, since TORA uses internodal co-ordination, it poses instability behavior similar to count-to-infinity problem in distance routing protocols.

2.4.9 Associativity Based Routing

The Associativity Based Routing (ABR). [14] is a new approach in routing proposal. It is free from loops, deadlock, and packet duplicates. The ABR protocol is source initiated and route are selected based on associativity states of nodes. The associativity table of neighbor nodes are periodically updated upon receiving a beacon from another node. There are three phases of ABR protocol, namely route discovery, route reconstruction and Route deletion. The route discovery phase consists of a broadcast query and await-reply cycle. The route reconstruction phase consists of partial route discovery, invalid route erasure, and new route discovery. The route deletion are broadcasted by source node when a discovered node is no longer needed.

2.4.10 Signal Stability Routing

The Signal Stability Routing (SSR) [16] is on-demand routing protocol. In SSR protocol, the route are selected based on the signal strength between nodes and the location stability of a node. It is a source initiated routing protocol, and comprises of two cooperative protocols, Dynamic Routing Protocol (DRP) and Static Routing Protocol (SRP).

2.4.11 Zone Routing Protocol

The Zone Routing Protocol (ZRP) [15] takes the advantage of proactive discovery within a zone (Intrazone Routing Protocol), and uses a reactive protocol for communication between these zone (Interzone Routing Protocol). The ZRP divides its network in different zones. Each node has its own zone, and also each node may be within multiple overlapping zones. Every zone may be have a different size. The size of a zone is not determined by geographical measurement. It is given by a radius of length, where the number of hops is the parameter of the zone. The Broadcast Resolution Protocol, which is called BRP, is responsible for the forwarding of a route request. The advantage of this protocol is that, it is less control overhead as in the proactive protocols, but it seems to have short latency for finding new routes.

2.4.12 Sharp Hybrid Adaptive Routing

The Sharp Hybrid Adaptive Routing Protocol (SHARP) [17] automatically finds the balance point between proactive and reactive routing. This can be done by adjusting the degree to which route information is propagated proactively versus the degree to which it needs to be discovered reactively.

The zone sizes are determined by each node in isolation, solely based on local information. The SHARP only creates relatively large zones around popular destination and relatively small proactive zones around nodes that get little traffic. In contrast to ZRP, SHARP maintains proactive routing zones only around those nodes that have significant incoming data. This protocol are contributed at minimizing packet overhead, bounding loss rate, and controlling jitter.

Chapter 3

Dynamic Source Routing (DSR)

3.1 Introduction

Dynamic Source Routing (DSR) [6] is one of the more generally accepted protocols used for mobile ad hoc networks. In this protocol, each node maintains route caches containing the source routes that it is aware of. The node updates entries in the route cache as and when it learns about new routes. DSR has the advantage that no periodic routing advertisement must be maintained [19]. This, therefore, significantly reduces the number of control messages being sent, resulting in reducing network overhead. The DSR protocol is also able to adapt quickly to routing changes when node movement is frequent [4]. Two major phases of the protocol, namely route discovery and route maintenance.

3.1.1 Route discovery

When the source node wishes to send a packet to the destination, it looks up its route cache to determine if it already contains a route to the destination. If it finds that an unexpired route to the destination exists, then it uses this route to send the packet. But if the node does not have such a route, then it initiates the route discovery process by broadcasting a route request packet. The route request packet contains the address of the source and the destination, and a unique identification number. Each intermediate node (i.e router) checks whether it knows of a route to the destination. If it does not know the route to the destination, it appends its address to the route record of the packet and forwards the packet to its neighbors. To limit the number of route requests propagated, a node processes the route request packet only if it has not already seen the packets and its address is not present in the route record of the packet.

A route reply is generated when either the destination or an intermediate node with current information about the destination receives the route request packet. A route request packet reaching such a node already contains, in its route record, the sequence of hops taken from the source to this node. As the route request packet propagates through the network, the route record is formed as shown in Figure 3.1.

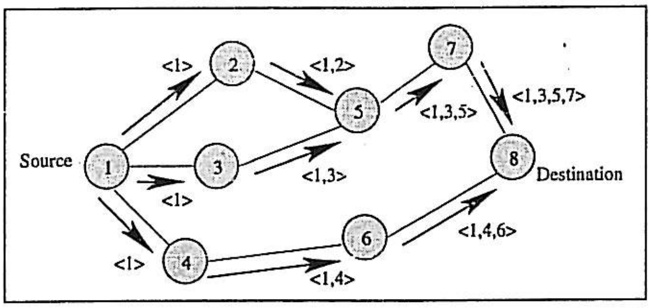


Figure 3.1: Building Record Route during Route Discovery

If the route reply is generated by destination, then it places the route record from the route request packet into the route reply packet. On the other hand, if the node generating the route reply is an intermediate node, then it appends its cached route to destination to the route record of the route request packet and, puts that into the route reply packet.

Figure 3.2 shows the route reply packet being sent by the destination itself. To send the route reply packet, the responding node must have a route to the source. If it has a route to the source in its route cache, it can use that route. The reverse of the route record can be used if symmetric links are supported. In case symmetric links are not supported, the node can initiate route discovery to source node and piggyback the route reply on this new route request.

3.1.2 Route maintenance

The Dynamic Source Routing protocol uses two types of packets for route maintenance, which are Route Error packet and Acknowledgements. When a node encounters a fatal transmission range problem at its data link layer, it

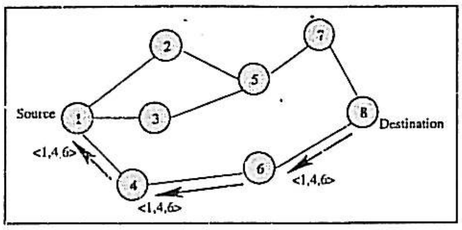


Figure 3.2: Propagation of Route Reply with the Route Record

generates a Route Error packet. When a node receives the route error packet, it removes the hop in error from its route cache. All routes that contain the hop in error are truncated at that point. Acknowledgement packets are used to verify the correct operation of the route links. This also includes passive acknowledgements in which a node hears the next hop forwarding the packet along the route.

3.2 Baseline evaluation of DSR protocol

The performance of DSR [6] protocol is evaluated with respect to performance metrics of the number of packets dropped and routing overhead. The number of packets dropped, x, is defined as

$$x = y - z \tag{3.1}$$

where y = number of packets sent by source
z = number of packets delivered to destination

A minimum number of packets dropped is desired. The routing overhead is the number of routing packets which consists of two parts: *route_request* and *route_reply*. A minimum number of routing overhead is also desired to conserve node's energy in the network. In general, several factors (i.e,. parameters) are suspected to influence these performance metrics [25], which include number of nodes, speeding node, pause time, and terrain size. The relationship between performance metrics (i.e dependent variable) and factors (i.e independent variable) are usually represented by plotting a graph, a factor in x-axis and a performance metric in y-axis, as have been done in one of the performance evaluation studies [6, 18, 19, 20].

3.3 Performance studies of DSR

3.3.1 Simulation

The performance of dynamic source routing (DSR) [6] protocol was initially evaluated by Johnson and Maltz [6], the authors of the protocol. The researchers conducted simulation to analyze the protocol performance. The basic simulation parameters included were a square medium-size terrain of 9 meter, speed between 0.3 and 0.7 meters per second, and a radio range of 3 meters. The performance of DSR protocol were observed under different number of mobile nodes and mobility of nodes (i.e., pause time). The simulation data then used to consult a graph. Upon inspecting the graph, the results showed that the DSR protocol performed well over a variety of environmental condition such as movement rates and nodes density.

In [6], the performance of DSR protocol was evaluated just in terms of metrics of interest to network users (e.g., packet delivery ratio and routing overhead), Maltz *et al.* [20], in contrast, studied and analyzed closely the effect of individual mechanisms in DSR protocol on the overall performance measured by metrics. These include the effect of on-demand behavior, caching mechanisms, and cache correctness on the routing protocol performance. The effect of these mechanisms were analyzed through simulation under an identical network with an identical workload. Maltz *et al.* [20] discovered that, the use on-demand behavior resulted in packet latency, although on-demand behavior could reduce routing overhead, the actual cost of performing *route_discovery* could be significant, and utilizing routing cache might degrade the performance of DSR protocol rather than improve it.

As caching strategies in DSR protocol can effect the protocol performance negatively by reporting invalid routes frequently, as observed in [20], Mahesh and Das [21], therefore, presented three techniques to improve cache correctness in DSR protocol: (a) wider error notification, (b) route expiry mechanisms with adaptive timeout selection, and (c) the use of negative caches. Upon observing simulation results, Mahesh and Das [21] found that the combination of the proposed techniques not only resulted in substantial improvement of cache performance but also reduced the overheads.

Extensive research has also been done in comparing the performance of DSR protocol to other proposed routing protocols used in mobile ad hoc networks under either the same or different strategies. Some of them were presented in [18] and [19]. In [18], DSR protocol was compared with AODV [7] routing protocol. These two routing protocols are reactive ones. Using detailed simulation model, the results demonstrated that, even though DSR and AODV routing protocol share similar on-demand behavior, their performance were significantly different under different network load, mobility and network size. In [19], DSR protocol was compared with three different routing protocols namely DSDV [8], TORA [9], and AODV [7]. The DSDV and TORA routing protocol share similar reactive strategies with DSR protocol, while AODV routing protocol is a proactive one. In terms of packet delivery ratio, the results showed that DSR protocol performed well than others in "stressful situation", where nodes are highly mobile.

3.3.2 Simulation with statistical analysis

All of the performance evaluation studies discussed in Section 3.3.1 (i.e., [6, 20, 21, 18, 19]) are conducted based solely on simulation and graph. Even though a simulation based on experimental or statistical analysis, that is design of experiment have been carried in one of the experimental studies, [26, 27, 28, 25], the interests are not particularly to study or evaluate the performance of certain routing protocol used for mobile ad hoc networks. But it is rather to study the main as well as the interaction effects of various factors in mobile ad hoc networks.

Recent study conducted by Boppana and Mathur [29] have been a first performance evaluation study, particularly evaluating the performance of DSR protocol, with formal statistical analysis applied. Since several mechanisms such as caching techniques in DSR protocol hurt the performance of DSR protocol, as presented in [21, 20], Boppana and Mathur [29] also proposed three simple techniques for improvement of the DSR protocol's performance: (a) limiting the replies sent by destinations in response to route request from sources, (b) sorting the routes based on freshness rather than hop count, and (c) limiting the number of routes kept per destination to one. To study the effect of these proposed techniques on the protocol performance, Boppana and Mathur [29] used 2^k factorial design with simulation data. Based on the statistical analysis, the results showed that limiting replies by destination is the most beneficial change to the improvement of the performance of DSR protocol.

Chapter 4

Introduction to Taguchi Method

4.1 A new experimental strategy

Taguchi method, invented by Dr. Genechi Taguchi in the early 1940s, is a new experimental strategy based on statistical design of experiment (DOE) [30]. The beauty of this method lies in the fact that it integrates statistical analysis into powerful engineering process [32]. The potential applications of this method in engineering industries had been presented by Hefin *et al.* [32]. Taguchi method offers a systematic approach to optimize the size of experiments, and therefore it makes the DOE become more effective and efficient in application [31]. This method also contributes to reducing the experimental time, which results in optimizing performance, quality and cost [33]. Two major tools in this technique are orthogonal array and signal-to-noise ratio. To know complete tutorial of this approach, refer to [30], [31], and [33].

4.2 Orthogonal array

In designing the experiment, Taguchi method offers orthogonal array which can be used to run multiple factors simultaneously. This matrix experiment is able not only to measure the effect of a factor but also to determine the variation from the average results [30]. Terminologically, the orthogonal array represents in the form of $L_A(B^C)$. Here, A represents the number of experimental run conducted in experiment. B denotes the number of level for each factor, and C represents the number of factors to be studied. For example, $L_9(3^4)$ means that 9 experiments are to be conducted in order to study 4 factors at 3 levels. A variety of orthogonal arrays can be found in [30]. Several examples of them are given in Table 4.1.

Table 4.1: Examples of orthogonal array

Orthogonal array	Factors number	Levels	Experiments number
$L_4(2^3)$	3	2	4
$L_9(3^4)$	4	3	9
$L_{16}(4^5)$	5	4	16
$L_{25}(5^6)$	6	5	25
$L_8(2^7)$	7	2	8

The primary advantage of the orthogonal array is that, a larger number of experiments can be studied with a small number of experiments. Compared to the full factorial design (e.g., 2^k factorial), there are definitely a greater saving in testing for a larger number of experiments. This can be observed in the Table 4.2 . For example, using $L_{16}(2^{15})$, 15 factors can be studied at 2 levels by running only 16 experiments instead of 32, 768, which is a result of applying 2^k factorial design.

Table 4.2: Taguchi and full factorial design

Taguchi design	Ex. number	Full factorial design	Ex. number
$L_4(2^3)$	4	2^3	8
$L_8(2^7)$	8	2^7	128
$L_{12}(2^{11})$	12	2^{11}	2,048
$L_{16}(2^{15})$	16	2^{15}	32,768
$L_9(3^4)$	9	3^4	81
$L_{18}(3^7)$	18	3^7	2,187

4.3 Signal-to-noise ratios analysis

In analyzing the data from orthogonal array, Taguchi method offers signal-to-noise ratios (S/N), method of analysis, as a performance measure in determining the design optimal solution. The S/N is useful for analysis of repeated results as it takes both mean and variability into account (see [31]). In engineering application, S/N analysis is used to determine the important factors which can produce the best performance (i.e., high signal) while minimizing the effect of those can not be controlled (i.e., low noise). A discussion on some advantages of S/N ratios has been presented by Genichi and Jugulum in [34]. Since the S/N ratios is the ratio of the mean (signal) to standard deviation (noise), a larger value of S/N ratio is always desired.

4.4 Equations for signal-to-noise ratios

Taguchi method treats optimization problems in two categories: (a) static problems and (b) dynamic problems.

4.4.1 Static problems

In static problems, generally, a process to be optimized has several control factors. The optimization then involves determining the best control factors levels so that output is at the target value. There are three signal-to-noise ratios of common interest for optimization of static problems: (a) smaller-the-better, (b) larger-the-better, and (c) nominal-the-best. These S/N ratios are expressed as a log transformation of mean square deviation. Transformation of results into a logarithmic scale before analysis is a common practice in experimental engineering [31]. Many scientific data are plotted in log versus log or log versus natural scale to make a wide-ranging data fit into a graph and to make the plot appear linear. The linear plot is desirable as it offers the ability to form conclusions by extrapolation and interpolation of results. Since these ratios are a logarithmic base 10 function, the resulting units are in decibels.

(a) Smaller-the-better

In smaller-the-better, the goal is to obtain a measure of zero. Let $t_1, t_2, .., t_n$ represent multiple data of one experimental trial observed in an experiment. Since our target value or ideal value is zero, that is defects zero defects, the mean square deviation is

$$\text{MSD (smaller)} = \frac{t_1^2 + t_2^2 + t_3^2 + \cdots + t_n^2}{n} \tag{4.1}$$

Taking a log transformation to the Equation (4.1) and multiplying it by -10, the signal-to-noise ratio for smaller-the-better is

$$
\begin{aligned}
S/N &= -10 \log \left(\frac{t_1^2 + t_2^2 + t_3^2 + \cdots + t_n^2}{n}\right) && (4.2) \\
&= -10 \log \frac{1}{n} \sum_{i=1}^{n} t_i^2 && (4.3)
\end{aligned}
$$

The multiplier 10 is a scale factor which has no effect on the conclusion derived from results. The negative sign is applied purposely to assure that signal-to-noise ratio increases for decreasing mean square deviation. Therefore, lower mean square deviation and higher signal-to-noise values is desired.

(b) Larger-the-better

Just the opposite of smaller-the-better, the goal in larger-the-better is to achieve the highest value possible. Let $t_1, t_2, .., t_n$ represent multiple data of one experimental trial observed in an experiment. The mean square deviation of reciprocal of data is

$$
\text{MSD (larger)} = \frac{\frac{1}{t_1^2} + \frac{1}{t_2^2} + \frac{1}{t_3^2} + \cdots + \frac{1}{t_n^2}}{n} \qquad (4.4)
$$

Taking a log transformation to the Equation (4.4) and multiplying it by -10, the signal-to-noise ratio for larger-the-better is

$$
\begin{aligned}
S/N &= -10 \log \left(\frac{\frac{1}{t_1^2} + \frac{1}{t_2^2} + \frac{1}{t_3^2} + \cdots + \frac{1}{t_n^2}}{n}\right) && (4.5) \\
&= -10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{t_i^2} && (4.6)
\end{aligned}
$$

(c) Nominal-the-best

In Equation (4.3) and (4.6), the mean square deviation can be viewed as deviation with respect to the origin, that is target at zero, but in nominal-the-best the target is not zero. Let $y_1, y_2, .., y_n$ be n data points. To obtain the signal-noise ratios equation for nominal type, several terms are necessary to define. The sum of the data, T, which is the sum of all the values associated with one experimental data, is

$$T = \sum_{i=1}^{n} y_i \tag{4.7}$$

The mean of the data, $\overline{y}$, and the sum of the square of all data, S_s are

$$\overline{y} = \frac{T}{n} \tag{4.8}$$

$$S_s = y_1^2 + y_2^2 + \cdots + y_n^2 \tag{4.9}$$

Sum of the squares of the mean, S_m, is

$$S_m = n(\overline{y})^2 \tag{4.10}$$

The easiest way of calculating S_m is by squaring Equation (4.7) and dividing by n (the number of data), as follows.

$$S_m = \frac{T^2}{n} \tag{4.11}$$

The experimental variance, V_e, is equal to the sum of the squares of the difference between each data and $\overline{y}$ (mean of the data) divided by $n-1$ (the number of data minus one).

$$V_e = \sum_{i=1}^{n} \frac{(y_i - \overline{y})^2}{n-1} \tag{4.12}$$

A simpler version is to take the difference between Equation (4.9) and Equation (4.11) and dividing it by $n-1$.

$$V_e = \frac{S_s - S_m}{n-1} \tag{4.13}$$

Using Equation (4.11) and Equation (4.12), the signal-to-noise ratios for nominal-the-best is

$$\text{S/N (nominal)} = 10\log(\frac{\text{S}_m - \text{V}_e}{n\text{V}_e}) \tag{4.14}$$

4.4.2 Dynamic problems

In dynamic problems, if the process to be optimized has a signal input that directly affects the output, the optimization involves determining the best control factor levels so that the input signal/ouput is closest to the desired relationship. To explore the computation of the signal-to-noise ratios for the dynamic system, refer to [30] and [34].

Chapter 5

Experimental Setup

5.1 The simulator

The simulator used for this simulation is the Network Simulator (version ns-2.28) [22]. The simulator was selected because of the range of features that it provides, and partly because it has an open source code that can be modified and extended. Ns is written in C++ and uses OTcl as a command and configuration interface [23]. This means that the simulator is implemented in C++ and that the simulation are set up by using tcl scripts.

A typical simulation run from ns produces a trace file containing packets traces for routing and data packets, current node location and etc. that can later be analyzed using statistical analysis. Network Animator [22] is a simulation tool for viewing network simulation from the trace file.

Originally, ns was developed by the VINT research group at University of California at Berkeley. It was then extended and modified by the Monarch project at Carnegie Mellon University. A couple of ad hoc routing protocols were implemented by ns so that the wireless network research such as performance evaluation could continue.

5.2 Simulation factors

In proactive, several factors are suspected to influence the performance of DSR through experimental studies. In this study, however, three factors were only considered, while holding all other factors constant. Table 5.2 shows the factors studied in this experiments. The factors considered here are also being used in the experimental such as in studies [6], [19] and [18]. For each factor, two levels are considered. To obtain a meaningful results of experiments, those levels with a good reason in representing a real life scenario were chosen. The justification of the factors and levels are given in the following subsection. In addition, some comments on several experimental studies in selecting the same factors considered here are also pointed out.

Table 5.1: Experimental factors

Label	Factor	Level 1	Level 2
A	Terrain size (meter × meter)	30×30	50×50
B	Pause time (seconds)	10	60
C	Node speed (meter per seconds)	0.72	1.34

5.2.1 Terrain size

Terrain is an area where nodes move freely around and communicate each other. The terrain size is usually measured in width times length, that is meter × meter.

Some studies such as one conducted by Maltz *et al.* [20] considered two different shape of terrain that would represent a real life scenario as desired. The first one is rectangular site whose size 1500m×300m. The other is square size whose size 670m×670m. Both terrain were chosen so as to examine DSR in different ways due to the fact that by varying the shape of terrain it will create a network with qualitatively different arrangement and pattern of mobile nodes. This is useful as different topologies could lead to different performance of a protocol in experiments. In [20], a bigger terrain size are selected as a number of 50 mobile nodes are being configured, which is considered a higher density of simulation scenarios.

Other studies such as [6, 18, 19, 21] proffered only one shape of terrain. Johnson and Maltz [6] considered a square terrain, which length and width are equal, whose size 9m×9m. Such dimension was selected as the researchers considered 3 meters of node's transmission range. If the terrain size consider higher regardless of number of nodes, some participating nodes would tend to be disconnected as the possibility that nodes are placed far away each other are higher and also some receiving nodes may be out of direct range of some sending nodes. When this happens, the performance of a protocol is expected to degrade. Broch *et al.* [19] and Marina and Das [21] proffered only rectangular terrain, which approximately equals to square terrain but length is much greater than its width, whose size 1500m×300m and 2200m×600m, respectively. In [19], 50 nodes are considered while in [21] 100 nodes are configured. Das *et al.* [18] considered two configuration of rectangular terrain, which are 1500m×300m with 50 nodes and 2200m×600m with 100 nodes.

Many performance studies tend to have a higher dimension of terrain size particularly when comparing the performance of several protocols as found in [20, 18, 19]. On other hand, a smaller terrain size is preferred when studying a specific routing protocol such as one carried out by Johnson and Maltz [6], evaluating the performance of DSR. Since the target of this study is to evaluate the performance of DSR and a small density which is below 30 nodes is considered, a small terrain size is selected, but higher than one in [6], due to each participating node has 10 meters of transmission range. Two levels of square terrain size are considered here: 30m×30m and 50m×50m. The square terrain is selected as there is a reasonable amount of path and spatial diversity available for a routing protocol to discover and use. Both terrain size could be a place like meeting room, lecture room, multipurpose room and so forth; the place where a group of people associated with their equipped-wireless devices such as cellular phones, PDAs, and laptops are either freely moving around or stationary, and communicate each other.

5.2.2 Pause time

Pause time is a temporary stop taken by node for its movement, measured in seconds. This parameter is set to reflect movement rate of mobile nodes which is essential to test how well a protocol performs when the nodes movement are higher. A higher pause time contributes to low mobility while a small pause time leads to higher mobility [18]. In simulation scenario, each node would stop within pause time amount before moving to another destination. Each node continues this behavior, alternatively pausing and moving to a new destination, for the duration of simulation.

Johnson and Maltz [6] evaluated the performance of DSR under different of movement rates and number of nodes. The different movement rates are determined by varying the pause time ranging from 0s to 4000 with 1000 increments. In this study, when the pause times are varied others parameters such as speed and terrain remain constant. Das *et al.* [18] have also done the same thing which ranges from 0s to 900s with 100s increments, to compare the performance of DSR and AODV [7]. The same amount of pause times were also used in [19] in comparing DSR with three different routing protocol namely DSDV [8], TORA [9], and AODV [7].

To change mobility node, most experimental studies such as ones discussed above varied pause time more than two amount, and moreover no reason of any pause time taken from real life are given. Instead, these pause time values are set and varied arbitrary without any reason in representing real life. Since the interest of this study is to bring statistical method to experimental studies, it is often useful to decide how many level of the pause time should be considered which best represents real life. As a result, in this experiment, two levels of pause time are considered whose values are 10s and 60s, respectively. A minimum of 10s is chosen so that all mobile nodes are in high motion. The 10s could represent a time when people who function as hosts take a temporary stop because of some purposes. For example hosts in a shopping complex stop by for temporary to have a talk to others, observe surroundings, and look to advertisements; signboards, banners and so on. Another example, hosts in an airport terminal take a temporary stop when approaching a gate of boarding areas, luggage claim and so on. As for the 60s, it could represent the same possible situation above but in a quicker manner.

5.2.3 Speed

Speed is the node mobility which will impact the frequency of topology changes measured in meter per seconds. Besides pause time, speed can also effect the movement rate of mobile nodes. In a simulator such as ns-2, the speed is uniformly distributed uniformly in interval [0, V_{max}]. Some simulators such as one used in [6], the speed is distributed uniformly in interval [V_{min}, V_{max}]. Johnson and Maltz [6] considered speed between 0.3 m/s (minimum speed) and 0.7 m/s (maximum speed). They claimed that such speed could be applied to somewhere between a slow walk and a quick stroll. The minimum speed of 0.3 m/s, however, in real fact basis, might be considered much lower as Lam dan Cheung [36], who have studied the relationship between walking speed and pedestrian flow for various pedestrian, found that the slowest mean of walking speed for pedestrian is 0.72 m/s in which people walks in shopping area. In addition, the minimum walking speed of the most majority people is 0.8 m/s as found in [38].

Das *et al.* [18] chosen speed between 0 m/s (minimum) and 20 m/s (maximum). They claimed such speed is a fairly speed for mobile ad hoc networks, comparable to traffic speed inside a city. The traffic speed they considered here must be referred to the combinations of the speed of pedestrian and vehicles in a road, as such speed could not be for walking pedestrian alone. Other studies such as in [20] and [21] considered the same speed, but unfortunately they given no reason as to why such speed values are selected. In this study, the selection of speed values are referred to [36] and [37], both studying about walking speeds for pedestrian in several places. Lam and Cheung [36], who studied the relationship between walking speed and pedestrian flow for various pedestrian, found the following findings which can be summarized in Table 5.2. On the other hand, Young [37] conducted a research on finding out walking speed for pedestrian in an airport terminal. He then compared his results with another research conducting the same purpose of study but at a transportation terminal. This findings is summarized as shown in Table 5.3.

Table 5.2: Mean walking speed for pedestrian, Source: Lam and Cheung, *Pedestrian speed/flow relationships for walking facilities in Hong Kong*, 2000.

Pedestrian facility	**Characteristics of walking facilities**	**Mean walking speed (m/s)**
Commercial area	Outdoor walking	1.23
	Indoor walking	1.02
Shopping area	Outdoor walking	0.91
	Indoor walking	0.72
Signalized crosswalk	With midblock	1.29
	Without midblock	1.36
LRT crosswalk	Signalized	1.44
	Nonsignalized	1.26

Table 5.3: Mean walking speed of pedestrian within transportation and airport terminals, Source: Young, *Evaluation of pedestrian walking speeds in airport terminals*, 1999.

Pedestrian facility	**Mean walking speed (m/s)**
Transportation terminal	1.345
Airport terminal (Young)	1.342

With referring to Table 5.2 and Table 5.3, two levels of the speed considered in this experiment are 0.72 m/s and 1.34 m/s, representing a minimum and maximum walking speed for pedestrian, respectively. The speed of 0.72 m/s is the slowest mean walking speed for pedestrian as shown in Table 5.2, while the speed of 1.34 m/s is the maximum of mean walking speed for pedestrian that normally found in an airport terminal as shown in Table 5.3. In real life, the differences can be explained by trip purposes of pedestrian and the places where they walk. For example, a pedestrian in a shopping complex tends to walk slower compared to a pedestrian in an airport terminal that tends to behave in a hurry.

5.3 Other simulation variables

While the selected factors were varied at two levels, the others remain constant with a specific value, as given in Table 5.4.

Table 5.4: Other simulation parameters

Parameter	Value
1. Transmission range	10 meter
2. Number of nodes	8
3. Maximum connection	2
4. Simulation time	200 s
5. Traffic type	constant bit rate (CBR)
6. Packet rate	4 packets/s
7. Packet size	512 bytes

5.4 Response variables

The performance of dynamic source routing protocol is evaluated with respect to performance metrics. These performance metrics are very useful to measure the actual performance of any proposed routing protocol used for mobile ad hoc networks. A couple of metrics used in performance study in mobile ad hoc networks can be found in [18] and [19]. As performance metrics play an important role in evaluating routing performance, some new metrics are also being proposed [39]. In this study, to evaluate the dynamic source routing protocol, the metrics of number of packets dropped and routing overhead are chosen.

5.4.1 Number of packet dropped

The number of packets dropped is defined as number of packets sent by source minus number of packets delivered to destination (see Equation 3.1). A minimum number of packets dropped is desired. This metrics is important to measure the ability of the routing protocols to react to network topology change while continuing to successfully deliver data packets to destinations.

5.4.2 Routing overhead

The routing overhead is the number of routing packets which consists of two parts: (a) *route_request* and (b) *route_reply*. A minimum number of routing overhead is also desired to conserve node's energy in the network. Routing overhead is an important metric, as it measures the scalability of a protocol, the degree to which it will function in low-bandwidth that is the process of broadcasting the routing update from one node to another, and its efficiency in terms of consuming battery power.

5.5 Experiment matrix

In applying Taguchi method, the ($L_4 2^3$) experiment matrix is used as shown in Figure 5.1. The matrix considers 3 factors with two distinct level. For computational purposes, it is often useful to code the factor levels as 1 and 2. Using the design, only four experiments were conducted. In fact, ($L_4 2^3$) experiment matrix is the fractional 2^3 factorial design. In 2^3 factorial design, there are 8 sets of factor-level combination, but in ($L_4 2^3$) experiment matrix only 4 sets of factor-level combination are taken into account. The selected of the sets factor-level combinations is shown in Figure 5.1.

Experiment number	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Figure 5.1: ($L_4 2^3$) design matrix

5.6 Factor assignment

The terrain size, pause time, and speed were assigned to the column 1, 2 and 3, respectively. The Table 5.5 shows the matrix design after assignment. Terrain size was assigned to column 1 as it considered "an expensive factor", referring to the fact that, when generating the factor in simulation, its changes from one level to another was considered difficult or time-consuming. Therefore, with such assignment, terrain was changed less frequent. On other hand, Both pause time and speed were assigned arbitrary to column 2 and 3, respectively.

Table 5.5: Factor assignment

Experiment	Terrain size	Pause time	Speed
1	30m×30m	10s	0.72m/s
2	30m×30m	60s	1.34m/s
3	50m×50m	10s	1.34m/s
4	50m×50m	60s	0.72m/s

5.7 Simulation environment

The simulation is carried out using ns-2. Note that the same simulation environment has also been used in several performance studies on mobile ad hoc networks [19, 20, 18]. The simulation scenarios consist of 8 nodes with two sources and two destinations. This means that two pairs of source-destination nodes were configured, which given randomly in simulation. Such settings are applied so as to have a small congestion in the network. In fact, the pairs of source-destinations are varied in order to test network congestion. When considering a higher number of mobile nodes, the pairs of source-destination nodes being considered are often high, as done in [20]. In this study, a total of 20 pairs of source-destinations nodes were used over 50 nodes. A high network congestion is always preferred to study performance comparison of several routing protocols as done in [18].

The packet type is constant bit rate (CBR) whose size 512 bytes. A smaller packets size is chosen as it still provides a good test of a routing protocol. This type of packets is widely used in the earlier experimental studies such as in [19, 20, 18, 21]. The packets sending rate is 4 packets per seconds.

The packet sending rate corresponds to a number of sources, which both are always varied to study the congestive effect on a routing protocol.

In this study, with regard to the number of mobile nodes considered, each node has a transmission range of 10 meters, corresponding to a radio range of Bluetooth. If the distance between two mobile nodes is larger than 10 m, then they can not communicate each other directly, but they have a forwarding node. Each simulation scenario was executed for 200 seconds. All simulations were performed on an Intel Pentium IV processor at 2.00 GHz, 256 MB of RAM running Linux Fedora Core 3.

5.8 Experimental data

Table 5.6 shows the experimental data. All combinations of factor levels are called design point (see Table 5.6). Each design point corresponds to a simulation scenario, which is replicated $r = 3$ times, in the experiment. Each of the four simulations was run three times, which results in a total of 12 simulation runs. The mean and the signal-to-noise ratios of the three runs for each design points was then computed. The equation signal-to-noise ratio used here is Equation (4.3), smaller-the-better, due to a minimum number of packet dropped and routing overhead are desired.

Table 5.6: Experimental data

Design point	Factors			Performance metrics			
	1	2	3	# of packet dropped		routing overhead	
	Terrain	P.time	Speed	Average	S/N	Average	S/N
1	30 × 30	10	0.72	300.00	-49.73	168.00	-44.62
2	30 × 30	60	1.34	680.67	-57.72	201.67	-46.29
3	50 × 50	10	1.34	985.67	-59.88	213.00	-48.51
4	50 × 50	60	0.72	1124.67	-61.06	99.00	-39.98

Chapter 6

Results and Analysis

6.1 Graphic evaluation

The graph is used to visualize performance changes as the factor levels are changed. Means results from the experimental data (see Table 5.6) were used. Each value along the x-axis corresponds to a simulation scenario (i.e., design point) as shown in Table 5.6. The y-axis is the means of response variables, and each point on the graph is the average of $r = 3$ runs for particular simulation scenario.

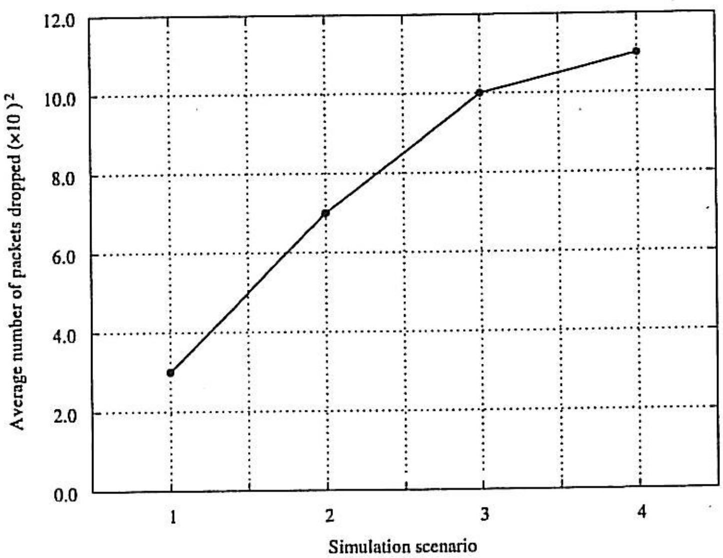


Figure 6.1: Graph of number of packets dropped

As shown in Figure 6.1, the average number of packets dropped increases almost linearly against the simulation scenarios. Specifically, from 1st to 2nd run, two factors were varied, pause time and speed, changing the their values from 10s (1 level) to 60s (2 level) and to 0.72m/s (1 level) to 1.34m/s (2 level), respectively (see Table 5.6). It is indicated that an increased number of packets dropped from 1st to 2nd were totally influenced by mobility of the nodes, due to the fact that both factors reflect the movement rate of nodes.

Next, from 2nd to 3rd run, terrain size and pause time were varied, switching from 30m × 30m (level 1) to 50m × 50m (level 2) and 60s (level 1) to 10s (level 2), respectively (see Table 5.6). The terrain size effects the length of the routes taken by packets from sender to destination. It is concluded that an increased number of packets dropped between 2nd and 3rd runs are likely to be influenced by both terrain size and pause time, resulting in a deduction that interaction effect between the two factors might be present.

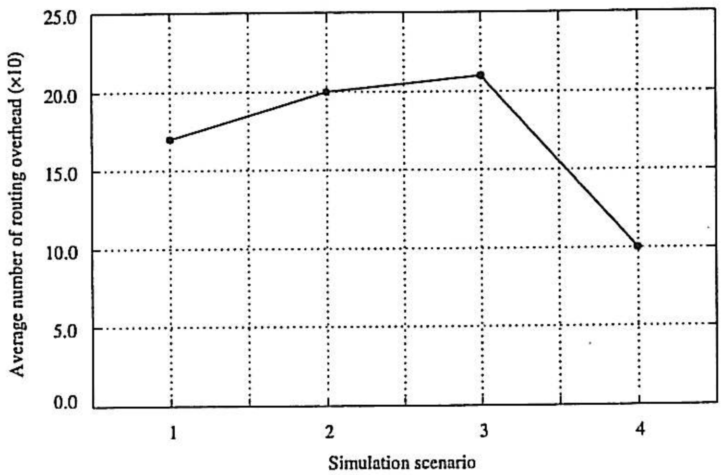


Figure 6.2: Graph of routing overhead

As Figure 6.1 shows, it is observed that the routing overhead seem increased from the 1st through 3rd experimental runs, but significantly went down from 3rd to 4th experimental runs. Upon inspecting Table 5.6, a decreased number of routing overhead from 3rd to 4th run reflects a change in pause time and node's speed from 10s (level 1) to 60s (level 2) and 1.34m/s (level 1) to 0.72m/s (level 2), respectively.

It is briefly commented on the graphs used in one of the earlier experimental studies in [6], [18] and [19], since the method (i.e., graph representation) the researcher used is nearly close to the one used here, but with some new addition. In [6], [18] and [19], the researcher usually evaluate the protocol performance (e.g., DSR and DSDV) by plotting a graph, a factor in x-axis and a performance metric in y-axis. A point in the graph represents a scenario. From one scenario to another, the researchers have only varied one factors (e.g., pause time) while the others remain constant (see [6], [18] and [19]). Interestingly, using ($L_4 2^3$) matrix design, at least two factors were varied from a scenario (i.e design point) to another (see Table 5.6). In other words, in this study, from one run to another, at least two factors were taken into account rather than one as done in [6], [18] and [19].

6.2 Effects estimation

The effect of the factors on specific response metrics were estimated using mean and signal-to-noise ratios analysis.

6.2.1 Formula

For clarity, how to quantify the effect of the factors from the matrix experiment is illustrated. Let consider the example of ($L_4 2^3$) design shown in Table 6.1.

Table 6.1: Example of ($L_4 2^3$) design

Experiment number	Factors A	Factors B	Factors C	Response (y_i)
1	1	1	1	y_1
2	1	2	2	y_2
3	2	1	2	y_3
4	2	2	1	y_4

Let A_1 and A_2 be the total of response values with factor A are set at level 1 and level 2, respectively (refer Table 6.1). Let N_{A1} and N_{A1} be the number of response values with factor A are set at level 1 and 2, respectively (refer Table 6.1). The average number of observation with factor A set at level 1, and 2, $\overline{A_1}$ and $\overline{A_2}$, respectively, are

$$\overline{A_1} = \frac{A_1}{N_{A1}} \tag{6.1}$$

$$= \frac{y_1 + y_2}{2} \tag{6.2}$$

$$\overline{A_2} = \frac{A_2}{N_{A1}} \tag{6.3}$$

$$= \frac{y_3 + y_4}{2} \tag{6.4}$$

Similarly, $\overline{B_1}$, $\overline{B_2}$, $\overline{C_1}$ and $\overline{C_2}$ can be defined using the following term.

$$\overline{B_1} = \frac{y_1 + y_3}{2} \tag{6.5}$$

$$\overline{B_2} = \frac{y_2 + y_4}{2} \tag{6.6}$$

$$\overline{C_1} = \frac{y_1 + y_4}{2} \tag{6.7}$$

$$\overline{C_2} = \frac{y_2 + y_3}{2} \tag{6.8}$$

From the simple Equation (6.2), (6.4), (6.6), (6.7), (6.8) and (6.8), the effect of the factor A,B and C are as follows.

$$A_{\text{effect}} = |\overline{A_1} - \overline{A_2}| \tag{6.9}$$

$$B_{\text{effect}} = |\overline{B_1} - \overline{B_2}| \tag{6.10}$$

$$C_{\text{effect}} = |\overline{C_1} - \overline{C_2}| \tag{6.11}$$

6.2.2 Means analysis

Using Equation (6.9), (6.10), and (6.11), means results from the experimental data (see Table 5.6) were used to identify the most important factors and determine the best combination of factors that affect response variables. Means response table for number of packets dropped and routing overhead were consulted.

Table 6.2 shows the effect estimate of factors on the number of packet dropped. As Table 6.2 shows, terrain size has greatest effect on the number of packet dropped, which followed by pause time. Speed has the least effect on the number of packet dropped. From this results, it is concluded that the

Table 6.2: Mean response table on the number of packet dropped

Factors	Column	Level 1 (L_1)	Level 2 (L_2)	Effect (—L_1-L_2—)
Terrain size	1	490.335	1055.170	564.835
Pause time	2	642.835	902.670	259.835
Speed	3	712.335	833.170	120.835

Table 6.3: Mean response table on the routing overhead

Factors	Column	Level 1 (L_1)	Level 2 (L_2)	Effect (—L_1-L_2—)
Terrain size	1	184.835	156.000	28.835
Pause time	2	190.500	150.335	40.165
Speed	3	133.500	207.335	73.835

number of packet dropped is influenced the most by terrain size.

Table 6.3 shows the effect estimate of factors on the routing overhead. As can be seen in Table 6.3, the results here are opposite with one found in Table 6.2 with regard to terrain size and speed factor. Instead, we found that speed has the greatest effect on the routing overhead. This followed by pause time. The terrain size has the least effect on the routing overhead. From this results, it is concluded that mobility node, which is measured as the average speed, is the most influence factor on the routing overhead.

6.2.3 Signal-to-noise ratios analysis

Using Equation (6.9), (6.10), and (6.11), signal-to-noise ratios results from the experimental data (see Table 5.6) were used to determine those factors that have strong effect on each response variables. S/N response table for the number of packets dropped and the routing packets were consulted.

Table 6.4 shows the response table for S/N ratios for the number of packets dropped. As shown in Table 6.4, terrain size has the strongest effect on the number of packets dropped, which followed by pause time, and the next is speed. In fact, the results found here is the same as the one used in means analysis. However, upon using S/N ratios analysis, it is discovered that the estimate effect of factor appeared to be smaller (see Table 6.2 and Table 6.4).

Table 6.5 shows the response table for S/N ratios for number of routing

Table 6.4: S/N response table for number of packets dropped

Factors	Column	Level 1 (L_1)	Level 2 (L_2)	Effect (—L_1-L_2—)
Terrain size (A)	1	-53.725	-60.470	6.745
Pause time (B)	2	-54.805	-59.390	4.585
Speed (C)	3	-55.395	-58.800	3.405

Table 6.5: S/N response table for routing overhead

Factors	Column	Level 1 (L_1)	Level 2 (L_2)	Effect (—L_1-L_2—)
Terrain size (A)	1	-45.455	-44.242	1.213
Pause time (B)	2	-46.565	-43.135	3.430
Speed (C)	3	-42.300	-47.400	5.100

packet. As shown in Table 6.5, speed has the strongest effect on the routing overhead followed by pause time, and the last was terrain size. The results here were also the same as the one used in means analysis, but using S/N analysis the estimate effect of factor appeared to be smaller (see Table 6.3 and Table 6.5).

The response variables that computed in terms of S/N ratios appeared to be smaller compared to the ones that computed using means. A small data are more useful when plotting a graph as the scales between data point are smaller.

6.3 Factor-level combination

In this section, the best combination of factor levels that yielded the minimum of response variables were determined. The signal-to-noise values in Table 6.4 and Table 6.5 were used to consult S/N ratio response graph for both response variable, number of packets dropped and routing overhead, respectively. The x-axis corresponds to level 1 or level 2 for particular factor as shown in Table 5.6. The y-axis is the response variables in terms of signal-to-noise ratios. Since higher signal-to-noise ratio is always preferred, the level of factor with the highest signal-to-noise values is desirable.

As shown in Figure 6.3, the best combination of factor levels that opti-

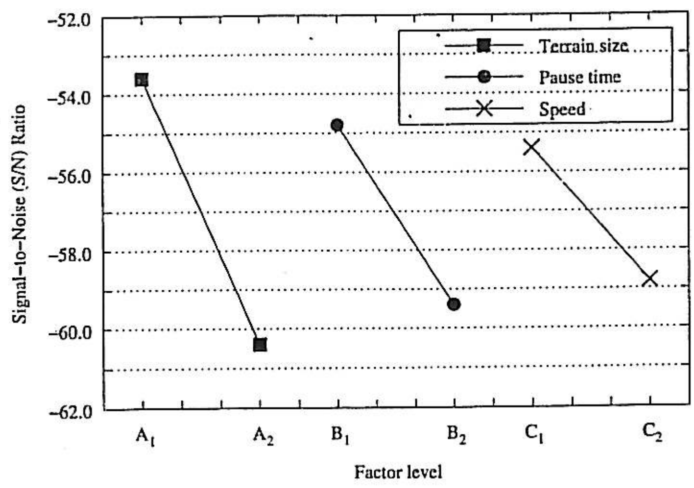


Figure 6.3: S/N ratios graph for number of packets dropped

mized the number of packets dropped are A_1, B_1 and C_1. That is 30 meter $\times$ 30 meter for terrain size, 10 seconds for pause time and 0.72 meter per seconds for speed.

An estimate of the predicted S/N ratios for the number of packets dropped based on the selected levels which are A_1, B_1 and C_1 is as follow.

$$\hat{\eta} = \overline{\mathrm{T}} + (\mathrm{A}_1 - \overline{\mathrm{T}}) + (\mathrm{B}_1 - \overline{\mathrm{T}}) + (\mathrm{C}_1 - \overline{\mathrm{T}}) \quad (6.12)$$
$$= \mathrm{A}_1 + \mathrm{B}_1 + \mathrm{C}_1 - 2\overline{\mathrm{T}} \quad (6.13)$$

where $\overline{\mathrm{T}} = \sum_{i=1}^{n} \frac{\eta_i}{n}$ with η_i is the value for the ith signal-to-noise ratio, and n is the number of signal-to-noise ratios. The $\overline{\mathrm{T}}$ is solved as follows.

$$\begin{aligned} \overline{\mathrm{T}} &= \sum_{i=1}^{n} \frac{\eta_i}{n} \\ &= \frac{-49.73 + (-57.72) + (-59.88) + (-61.06)}{4} \\ &= -57.0975 \end{aligned}$$

Substituting values from response table (Table 6.4), the estimate of the predicted S/N ratios for the number of packets dropped is

$$\begin{aligned} \hat{\eta} &= -53.725 + (-54.805) + (-55.395) - 2(-57.098) \\ &= -49.729 \end{aligned}$$

A confirmation run is conducted as shown in Table 6.6, and the results is compared to the predicted results. Since the actual results is considered close to the predicted value, the factor-level combination found here can be adopted in evaluating the performance of DSR with respect to number of packets dropped through experimental study [30].

Table 6.6: Confirmation run for number of packets dropped

Run	1	2	3	Average	S/N
Confirmation run	237	280	188	235.000	-47.530

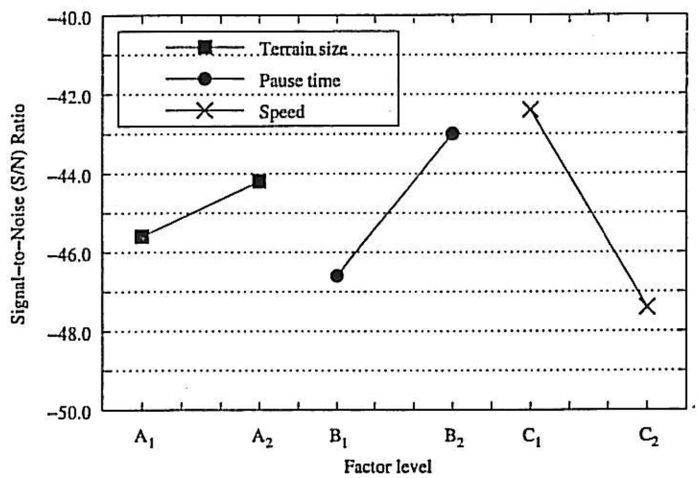


Figure 6.4: S/N ratios graph for routing overhead

As for the routing overhead, the best combination factors are A_2, B_2 and C_1, as shown in Figure 6.4. That is 50 meter $\times$ 50 meter for terrain size, 60 seconds for pause time and 0.72 meter per seconds for speed.

An estimate of the predicted S/N ratios for routing overhead on the selected levels which are A_2, B_2 and C_1 is as follow.

$$\hat{\eta} = \overline{T} + (A_2 - \overline{T}) + (B_2 - \overline{T}) + (C_1 - \overline{T}) \quad (6.14)$$

$$= A_2 + B_2 + C_1 - 2\overline{T} \quad (6.15)$$

where $\overline{T} = \sum_{i=1}^{n} \frac{\eta_i}{n}$ with η_i is the value for the ith signal-to-noise ratio, and

n is the number of signal-to-noise ratios. The $\overline{\text{T}}$ is solved as follows.

$$\begin{aligned}\overline{\text{T}} &= \sum_{i=1}^{n} \frac{\eta_i}{n} \\ &= \frac{-44.62 + (-46.29) + (-48.51) + (-39.98)}{4} \\ &= -44.850\end{aligned}$$

Substituting values from response table (Table 6.5), the estimate of the predicted S/N ratios for the number of packets dropped is

$$\begin{aligned}\hat{\eta} &= -44.242 + (-43.135) + (-42.300) - 2(-44.850) \\ &= -39.977\end{aligned}$$

A confirmation run is conducted as shown in Table 6.7, and the results is compared to the predicted results. Since the actual results is close to the predicted value, the factor-level combination found here can be adopted in evaluating the performance of DSR with respect to routing overhead through experimental study [30].

Table 6.7: Confirmation run for routing overhead

Run	1	2	3	Average	S/N
Confirmation run	109	79	101	96.33	-39.75

6.4 The performance under different node desity

In this section, using the ($L_4 2^3$) matrix design, the effect of the node density (i.e., number of nodes) was studied using graph. In each design point (i.e., scenario) in Table 5.6, the number of nodes were varied, ranging from 6 to 30 mobile nodes, with 2 increment nodes. This aims to observe the performance of DSR protocol on each scenario under different node density. A higher signal-to-noise ratio is desirable. In the signal-to-noise ratio equation of smaller the better characteristics as used in this analysis, the negative sign is applied to assure that signal-to-noise increases for the decreasing mean square deviation.

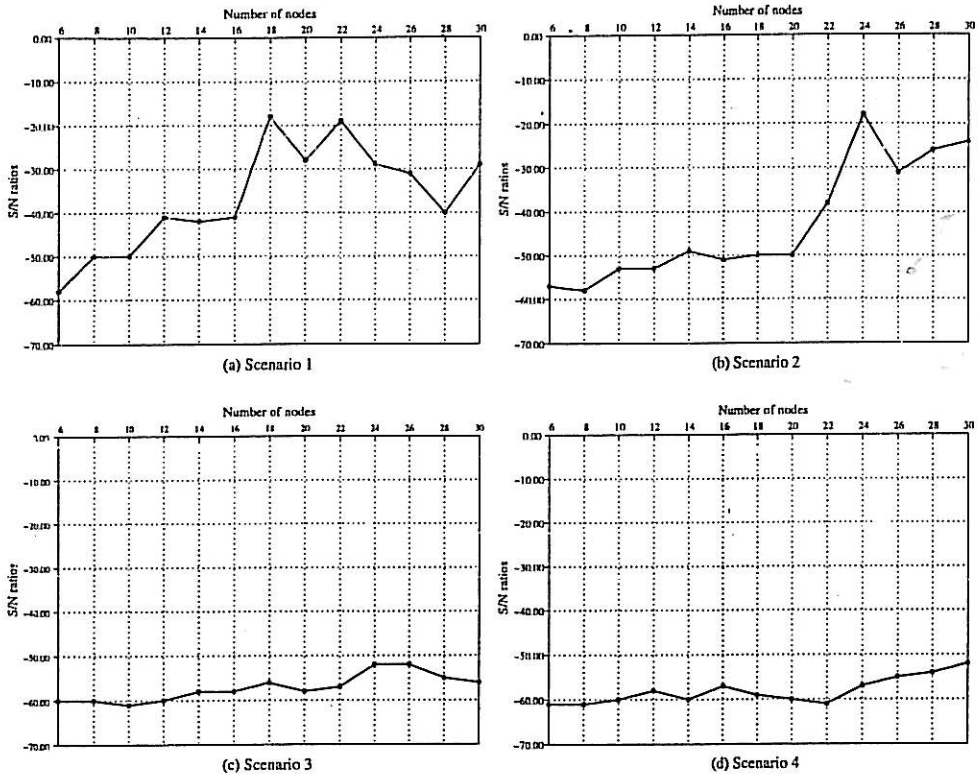
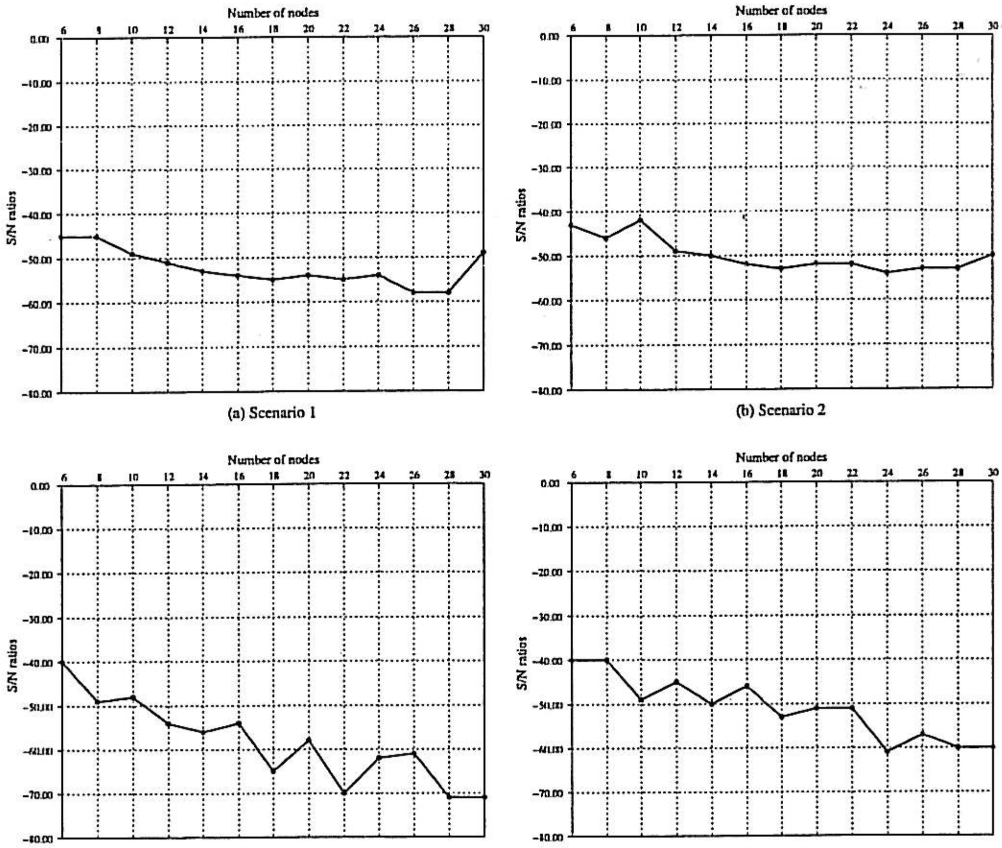


Figure 6.5: The effect of node density on the number of packets dropped

Figure 6.5 shows the effect of the node density on the number of packets dropped in each scenario. The x-axis is the number of mobile nodes. The minus y-axis corresponds to the number of packets dropped in terms of signal-to-noise ratios. The number of packets dropped were taken in terms of signal-to-noise values rather than average (means) as the signal-to-noise ratio gives a small values, although the exact data are larger. This results in a small scale when a point in a grap is plotted. Upon inspecting the four scenarios, the number of packets dropped in DSR protocol change over the number of mobile nodes. Here, the signal-to-noise values, in fact, are almost getting increased as the number of mobile node become increased. This is reasonable due to the fact that when the number of nodes in the network is high, the topology is dense, and therefore the connectivity is rich.

The best scenario that resulted in the highest signal-to-noise ratio (i.e.,-18.24) is given by scenario two. However, the DSR protocol is most likely to perform well in the scenario one as the number of packets dropped in terms of signal-to-noise values are relatively higher. The graph pattern for both scenario two and three are almost identical in shape. Here the performance of the DSR protocol degrades due to a larger terrain size compared to the scenario one and two (see Table 5.6). In fact, setting the terrain size considered larger regardless of the number of mobile nodes could lead to networks disconnected because of the node's limited transmission range. This, therefore, would probably reduce an attempt to making routes among nodes.

Figure 6.6 shows the effect of node density on the routing overhead. The x-axis is the number of mobile nodes. The minus y-axis corresponds to routing overhead in terms of signal-to-noise ratios. Upon observing the four scenarios, the routing overhead in DSR protocol changes over the number of mobile nodes. The number of routing overhead, in fact, are getting decreased as the number of mobile nodes become increased. It is clearly indicated that the number of routing overhead is related to size of the network (i.e node density), as found by Naserian *et al.* in [24]. This happens due to fact that when the number of nodes are increased the number of routing packets need to be maintained in the network are also increased. As a result, the bandwidth which is the process of broadcasting the routing update from one node to another become increased. In addition to this, when the number of routing overhead become large the probability of packets collisions and packets delays can also increase.



(a) Scenario 1

(b) Scenario 2

(c) Scenario 3

(d) Scenario 4

Figure 6.6: The effect of node density on routing overhead

Chapter 7

Discussion and Conclusion

7.1 Size of experiments

In evaluating the performance of dynamic source routing protocol and comparing it to other proposed routing protocols used for mobile ad hoc networks, researchers tend to have a huge number of experiments, as shown in [6, 20, 21, 18, 19]. In this study, using the Taguchi matrix design, the size of experiment particularly to study the performance of dynamic source routing protocol has been significantly minimized.

7.2 Effect of factors

Using the ($L_4 2^3$) matrix design, the effects of the factors (i.e., terrain size, pause time, and speed) on the performance of dynamic source routing protocol have been quantified. From the estimated values, the most influential factors affecting the selected response variables can be determined. The most influential factors affecting the number of packets dropped is the terrain size, while the speed has the greatest effect on routing overhead.

7.3 Ranked list of factors

Upon estimating the effect of factors, the ranked lists of factors in affecting the response variables are also determined. For the number of packets dropped, the ranked lists of factors are: terrain size, pause time, speed. For the number of routing packets, the ranked lists of factors are: speed, pause time, terrain size.

7.4 The best combination factor-level

Using the signal-to-noise ratios analysis, the best combination of factor levels that yielded the minimum of response variables are determined. The best combination of factor levels that optimized the number of packets dropped are A_1, B_1 and C_1. That is 30 meter × 30 meter for terrain size, 10 seconds for pause time and 0.72 meter per seconds for speed. As for the routing overhead, the best combination factors are A_2, B_2 and C_1. That is 50 meter × 50 meter for terrain size, 60 seconds for pause time and 0.72 meter per seconds for speed.

Consequently, the best factor-level combinations that yielded the response variables optimal found to be different, leading to a fact that the optimum parameters in the performance of DSR are significantly different with respect to a certain metrics used to evaluate the performance of a routing protocol for mobile ad hoc networks in general, and DSR protocol in specific.

7.5 Performance of DSR

The performance of dynamic source routing protocol is predicted using signal-to-noise ratios. In each scenario, the number of nodes were varied, ranging from 6 to 30 mobile nodes, after which the signal-to-noise ratios on the repeated results of one scenario with one set mobile nodes were calculated. The results showed that the signal-to-noise values of number of packets dropped are getting increased as the number of mobile node become increased. And, the signal-to-noise ratios of routing overhead are getting decreased as the number of mobile nodes become increased.

From this results, it is observed that in high node density the dynamic source routing protocol performs better. Conversely, the performance of dynamic source routing protocol found to be decreased with smaller number of mobile nodes.

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