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Study of ad hoc networks with DSR algorithm and multi-hop transmissions

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Study of ad hoc networks with DSR algorithm and multi-hop transmissions

Dissertation presented to the Postgraduate Program in Computer Science, Department of Informatics, Technology Center of the State University of Maringa, as a partial requirement to obtain the Master Degree in Computer Science.

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DEDICATION

This study is totally dedicated to my wife, Mellina and my beloved parents, who have been my source of inspiration and gave me strength when I thought about giving up, who continually provided their moral, spiritual and emotional support. To my relatives, mentors, friends, and classmates who shared their words of advice and encouragement to finish this study. And lastly, I thank to the Almighty God for the guidance, strength and protection.

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Study of ad hoc networks with DSR algorithm and multi-hop transmissions

ABSTRACT

In recent years, a number of mobile technologies have emerged to provide access using IP (Internet Protocol) infrastructure for WLAN (Wireless Local Area Networks), enabling interconnection between devices such as mobile phones, PDAs (Personal Digital Assistants), computers and others. These technologies have the main advantages of ubiquitous communication, i.e., anytime, anywhere and without the need for wired connection. MANETs (Mobile ad hoc Wireless Networks) are network architectures that have attracted great interest because they are devoid of a central controller node. These networks are intrinsically more robust and can be deployed without a traditional physical infrastructure. Due to the low cost and wide availability of some devices, wireless networks can be built easily, affordable, and without the need of a physical infrastructure. One of the main challenges for MANETs is to define data routing and calculate the best route using heuristic criteria, for the data packets to flow through the network and arrive at their final destination consuming the minimum energy, with the smallest possible delay, in an environment that often has a high structural complexity. This dissertation focus is to study routing algorithms for wireless networks, in particular for ad hoc networks, considering the high mobility that the nodes may experience and identifying the minimum conditions for sending data. As an application of this study, a simulation of a wireless ad hoc network using DSR (Dynamic Source Routing) protocol is performed. This protocol was developed primarily for PANs (Personal Area Networks), to provide wireless connection to low-power mobile devices with low to medium traffic demands. In this work, simulations using different parameters are performed using two-ray ground, free-space and shadowing propagation models. In addition, the results presented here indicate that two-ray ground and free-space models perform similarly with need of radio adjustments. The study also highlights the in influence of shadowing in the system performance and shows the difficulties for the algorithm to maintain routes in severe fading environments.

Index terms: wireless network, routing algorithm, DSR.

Estudo das redes ad hoc com o algoritmo DSR e transmissões multi-hop

RESUMO

Nos últimos anos, várias tecnologias móveis surgiram para fornecer acesso usando a infraestrutura Internet Protocol (IP) para redes locais sem fio (WLAN), permitindo a interconexão entre dispositivos como telefones celulares, assistentes digitais pessoais (PDAs), computadores e outros. Essas tecnologias têm como principais vantagens a comunicação onipresente, ou seja, a qualquer momento, em qualquer lugar e sem a necessidade de conexão com fio. As redes móveis sem fio ad hoc (MANETs) são arquiteturas de rede que atraíram grande interesse porque são desprovidas de um nó controlador central. Essas redes são intrinsecamente mais robustas e podem ser implantadas sem uma infraestrutura física tradicional. Devido ao baixo custo e à ampla disponibilidade de alguns dispositivos de comunicação móvel, as redes sem fio podem ser construídas com facilidade, preço acessível e sem a necessidade de uma infraestrutura física. Um dos principais desafios das MANETs é definir o roteamento de dados e calcular a melhor rota usando critérios heurísticos, para que os pacotes de dados fluam pela rede e cheguem ao destino final consumindo o mínimo de energia, com o menor atraso possível, em um ambiente que geralmente tem uma alta complexidade estrutural. O foco desta dissertação é estudar algoritmos de roteamento para redes sem fio, em particular para redes ad hoc, considerando a alta mobilidade que os nós podem enfrentar e identificar as mínimas condições para o envio de dados. Como aplicação deste estudo, são realizadas simulações de redes ad hoc sem fio usando o protocolo Dynamic Source Routing (DSR). Esse protocolo foi desenvolvido principalmente para redes de área pessoal (PANs), para fornecer conexão sem fio a dispositivos móveis de baixo consumo de energia e com demandas de tráfego de baixo a médio. Neste trabalho, simulações usando diferentes parâmetros são realizadas usando os modelos de propagação de terra plana, espaço livre e sombreamento. Além disso, os resultados apresentados aqui indicam que os modelos terra plana e espaço livre funcionam de maneira semelhante com necessidade de ajustes no rádio (potência de transmissão, etc.). O estudo também destaca a influência do modelo de propagação sombreamento no desempenho do sistema e mostra as dificuldades do algoritmo em manter rotas em ambientes com desvanecimento grave.

Palavras-chave: Redes wireless, algoritmos de roteamento, DSR.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABR: Associativity-Based Routing

ACKs: Acknowledgment Messages

AODV: Ad-Hoc On-Demand Distance Vector Routing

AOMDV: Ad-Hoc On-Demand Multipath Distance Vector Routing

ARP: Address Resolution Protocol

CBR: Constant Bit Rate

CGSR: Clusterhead Gateway Switch Routing

CTS: Clear To Send

DARPA: Defense Advanced Research Projects Agency

DSDV: Destination-Sequenced Distance-Vector

DSR: Dynamic Source Routing

FSR: Fisheye State Routing

FTP: File Transfer Protocol

GloMo: Global Mobile Information System

GOD: General Operation Directory

GRP: Geographical Routing Protocol

HRP: Hybrid Routing Protocol

IoT: Internet of Things

IPv6: Internet Protocol version 6

MANET: Mobile ad hoc Wireless Networks

NAM: Network Animator

NS-2: Network Simulator

OBM: Object Block Message

OLSR: Optimized Link State Routing

OSI: Open System Interconnection

OTcl: Object-oriented Tcl

PANs: Personal Area Networks

PDAs: Personal Digital Assistants

QoS: Quality of Service

RERR: Request Error

RREP: Route Replay

RREQ: Route Request

RTS: Request To Send

RTT: Round-Trip Time

SSA: Stability-based Adaptive
SURAM: Survivable Adaptive Network
Tcl: Tool Command Language
Tclcl: Tool Command Language with Classes
Tcltk: Toolkit graphical user interface
TCP: Transmission Control Protocol
TORA: Temporally Ordered Routing Algorithm
UDP: User Datagram Protocol
VANETs: Vehicular Ad-Hoc Network
WLAN: Wireless Local Area Networks
WRP: Wireless Routing Protocol
WSN: Wireless Sensor Network
ZRP: Zone Routing Protocol

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1

Introduction

In wireless networks, the base station may perform the key roles of receiving data from a mobile node (device) and forward it to some other nodes (KUROSE and ROSS, 2012). A base station, in addition, may coordinate the transmission between nodes associated to the network. In MANETs (Mobile Ad Hoc Network), mobile nodes communicate with others using multi-hop wireless links. However, the central coordination node, i.e., the base station, is not available. In this case, it is attribution of the individual nodes to, cooperatively and in a distributed manner, coordinate the network operation without user involvement. The major concern of this topology is how to efficiently and reliably transmit data from the source node to the destination node (KAUR and MITTAL, 2014). Services such as address allocation, routing, and energy management must be controlled by the node itself, or by the various nodes cooperatively.

Algorithms, such as DSR (Dynamic Source Routing), allow the network to be completely self-organized and self-configured without the need for any centralized infrastructure or network administration (JOHNSON et al., 2001). The idea is that networks should be able to connect a number of nodes without having a predefined topology or infrastructure and, in particular, to allow the inclusion and exclusion of nodes to the network when required.

Understandably, route discovery and route maintenance are pivotal tasks for the successful operation of the network. In general, the goal is to find a route that generates the least bandwidth consumption and minimum overhead at the time of route construction. Thereby, unique challenges are imposed by a scenario of limited resources and lack of infrastructure.

Currently, wireless networks go through a period of exponential growth and usage. In particular, with the inclusion of “things” to the network, a situation termed as IoT (Internet of Things), and the idea that networks should be capable of connecting a mesh of nodes without a pre-defined infrastructure.

Several routing protocols related to this work have been proposed to be used in MANETs. The keys for successful routing protocols are: be adaptive to high mobility scenarios, avoid wastage of bandwidth, minimize the processing burden at the nodes, and generate little overhead and delay.

Given that there is a wide variety of possible scenarios and applications, investigation about the performance and operation of MANETs is still an active research topic. In particular, with regards to the routing algorithms for these networks, several interesting study topics remains unexplored or overlooked. Therefore, new insights on the operation of these networks by exploring usually overlooked scenarios are presented here.

1.1 Justification and motivation

With the increasing use of mobile nodes, such as laptops and smartphones, the use of wireless networks is booming, initially due of the mobile characteristics of the terminals served, but also because of the cost and difficulties of installing a traditional wired network. Considering the situation in which nodes move throughout the coverage area of the wireless network, several issues can be highlighted. How to perform data routing over the network? How best distribute nodes in different scenarios? What is the best approach to minimize the energy consumption in sensor nodes? Is it better to use direct transmissions to the desired destination or with multi-hops?

Although it is a promising technology to various scenarios, is not possible to deploy a mobile ad hoc network without the performance study of the protocols for MANETs. For this, increasingly, the ad hoc networks are studied and exploited due to their numerous possibilities of use in different environment.

Statistical propagation models[1], such as the shadowing model used in this work, try to mimic the influence that environment with buildings and others interfering obstacles, has on the propagation of radio waves. Therefore, the results offered here help filling this gap

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[1] The mobile radio channel is usually evaluated using statistical propagation models. Three propagation phenomena are usually considered: path loss, short term fading (or multipaht) and long term fading (or shadowing). The simulator used in this work also allows simulations of other propagation models, such as Nakagami-m and Rayleigh.

and intend to provide a better understanding of how the DSR routing algorithm works in such environments.

According to DAS and NAND (2016), routing is one way of providing connection between nodes. Two tasks are involved in the successful operation of a routing protocol: find the way to route packets and to maintain the discovered routes. The different types of existing routing algorithms have their own advantages and disadvantages, reason why none of them works well in all environments. For this, the lowest bandwidth consumption and minimum overhead are desirable attributes at the moment of route construction and during packets transmission.

VANETs have become a topic of intense study in the scientific community. The main motivation for studying VANETs in this work was to propose conditions to increase driver safety by improving conditions for sharing information such as traffic congestion and road condition detection.

With advances of new wireless networking technologies, it has become possible to establish communications even in an unstructured environment. Thus, the use of these networks, the development of route discovery, the maintenance mechanisms and the need to better understand these networks are the main motivations of this work.

An ad hoc network may have a serious restriction of energy consumption, since it nay not be recharged after being deployed in the environment. Protocols that use any type of periodic greeting messages can be inefficient in terms of energy. The main motivation to choose DSR is its reactive approach (FAN et al., 2017). It means that it does not send periodic messages to evaluate network conditions, resulting in low overhead. Therefore, the use of DSR produces good results in terms of throughput, packet delivery and overhead when compared of proactive algorithms (GRUPTA and KUMAR, 2015).

1.2 Formulation of the problem

One of the main disadvantages of ad hoc networks is the uncertainty of the packet reaching its destination due to constant link breaks, channel noises and signal fading. Therefore, a better understanding of how the network performs in diverse conditions becomes necessary. The survey of related works shows that in some cases there is discordance between authors and therefore, the need for a better understanding of DSR behavior.

Among the relevant issues that the analysis of wireless networks provides, this work focuses on the question of routing in MANETs. In these networks, sending a packet from a source node to a destination node depends on the choice of a route with some or all of the network nodes receiving or processing packets. Algorithms may periodically update their routing tables so as to keep nodes aware of available routes. Links or nodes may stop working, forcing nodes to search and establish new routes for packet forwarding due to the instability of these routes. Strategies such as these should be evaluated with criteria like lower bandwidth consumption and mainly, ability of the algorithm to find the solution if one exists.

Due to the fact that there is a wide variety of possible scenarios and applications, and the needs to investigate the algorithms behavior, investigation about the performance and operation of MANETs is still an active research topic. In particular, with regards to the routing algorithms for these networks, several interesting study topics remains unexplored or overlooked. For instance, effects of hidden terminals in transmissions, the influence of the different propagation models, conditions necessary for packet transmission to nodes that are not directly connected, increase network throughput and ensure the smaller energy consumption of the network, generally due to the restricted battery resources.

In general, studies of routing algorithms for MANETs consider simpler propagation models, such the free-space and two-ray ground. These are very simple deterministic propagation models that do not consider the existence of obstacles between transmitter and receiver. Therefore, the use of shadowing model in this work offer results that are closer to the actual propagation environments.

1.3 Objectives and contributions

The bibliographic review compiled for this work of the last years constitutes concepts about ad hoc networks, work related to this knowledge area including performance comparisons, network simulations and discussion about the works related here.

The main objective of this work is to present a complete study of the DSR algorithm's operation, a protocol widely used in ad hoc networks. Tests were carried out considering shadowing, two-ray ground and free-space propagation models, with different scenarios and configuration parameters. The metrics evaluated are delay, overhead, packet loss, percentage of packet delivery, total load of control and route maintenance packets, as detailed in Sect 5. In the study presented here, NS-2 (Network Simulator version 2) is used to examine several scenarios, offering new insights into the behavior of MANETs, and in particular the routing algorithm for such networks. The use of simulation is justified due of the greater flexibility in terms of modeling, and the duration of the experiment (JAIN, 1991).

VANETs have been a topic that has been widely studied in the scientific community, and it is also of great interest to large vehicle manufacturers. Simulations were also performed to evaluate the DSR algorithm for VANETs. This study highlights the conditions necessary for packet transmission to nodes that are not directly connected. Also, it is considered various scenarios with distributed nodes in different positions, the required radio setting, and the use of different channels and configurations to increase network throughput.

With implementations described in this work it is possible to evaluate the achievable performance with the use of DSR and compare the influence of the environment on the signal fading. The study also highlights the influence of shadowing in the system performance, showing difficulties for the algorithm to maintain routes in severe fading environments.

1.4 Organization of text

This work is organized as follows. Sect. 2 presents a survey of works related to the theme. Sect. 3 describes the network simulator used. Sect. 4 presents the operation of DSR. Sect. 5 includes the experiments and discussions about the results obtained, showing the needs for network designers to design networks with nodes that best adapt their environment, positioning them to reduce overhead, adjust power, minimize interference from other devices, improving delay, overhead, throughput, and power consumption. Finally, the Sect. 6 presents conclusions, final comments and future works.

2

Review

2.1 Basic concepts

Several routing algorithms have been proposed for MANETs. Generally, they are classified as proactive or reactive. Proactive protocols send frequent route request messages to update their routing tables and constantly check for changes in the network topology. The idea is to continually evaluate routes and when a route is requested, it can be used promptly. The updating of these tables occurs at a predefined rate, resulting in constant bandwidth consumption. On the other hand, reactive protocols send route request messages only when there is a need for data transmission to a destination, to which a route is unknown or unavailable, e.g., when a stored route is no longer valid. In the following, a list of the most common routing algorithms is given.

The routing protocols mentioned in this work are divided following their mechanisms of route detection: proactive and reactive. This separation is described below.

- **Proactive Detection:** Through the analysis of the routing tables, each node constantly monitors the network in an attempt to obtain route information before it is necessary. At fixed intervals, information and updates are sent to each node to keep the routing tables up to date (BAI et al., 2017). In proactive routing protocols, each node manages and updates one or more tables containing information from other nodes. Therefore, when a route is requested, it can be used immediately if it is still valid.

- **Reactive Detection:** It establishes the route to the destination only when there are packets to be sent, i.e., if there is no need to send or until inconsistencies are reported in the routing tables, no action is taken.

  In reactive protocols, there is no need for nodes in the network to maintain routing information. Whenever a node needs to send data to a destination, a route generation mechanism will create a route based on the current network situation (BAI et al., 2017).

- **Hybrid:** It combines features of the two categories: proactive e reactive.

The first approach requires significantly more bandwidth than the second, but route requests can be answered immediately. In the second approach, there is a saving of bandwidth, but in contrast, the time to respond to a route request is longer. For ad hoc networks, there are algorithms based on the three approaches.

2.2 Algorithm

Below, a brief description of the main routing protocols is presented. All the algorithms listed here are describe in the following.

2.2.1 Proactive algorithms

- CGSR (Clusterhead Gateway Switch Routing): It is a clustered algorithm for multi-hop mobile wireless network with heuristic routing schemes. CGSR uses gateway nodes as the underlying routing scheme. Gateway nodes are nodes that are within communication range of two or more cluster heads. Using this method, each node keeps a “cluster member table” where it stores the destination cluster head for each mobile node in the network. These cluster members send messages by broadcast for each node periodically. Nodes update their cluster member tables on reception of such a table from a neighbor (ROYER and TOH, 1999).

- DSDV (Destination-Sequenced Distance-Vector): It is a table-driven routing scheme for ad hoc mobile networks based on the Bellman-Ford algorithm. The main contribution and work of the algorithm was to solve the routing loop problem. Routing information is distributed between nodes by sending full dumps infrequently and smaller incremental updates more frequently (SIVAKUMAR et al., 2012).

- FSR (Fisheye State Routing): The FSR protocol works with the probabilistic approach to flooding as a means of reducing redundant rebroadcast messages and alleviating the detrimental effects of the broadcast. In the probabilistic scheme, when receiving a message for the first time, a node rebroadcasts the message with a pre-determined probability p; every node has the same probability to rebroadcast the message.

- GRP (Geographical Routing Protocol): It is a kind of position-based protocol. Each position of the node will be marked by GPS and flooding will be optimized by quadrants. A "hello packet" is exchanged between nodes to identify their neighbors and their positions. At the same time, by means of route locking, a node can return its packet to the last node when it can not keep on sending the packet to the next node (ZHIYUAN, 2009).

- OLSR (Optimized Link State Routing): It is a proactive table driven routing protocol for MANETs. It generates a constant overhead of control packets and involves no route lookup delay. In OLSR basically everything is related to tables. These tables are maintained by receiving information about the network and the time period during which that information remains valid (DHURANDHER et al., 2010).

- WRP (Wireless Routing Protocol): It is based on the routing zone, which is defined for each node, and includes the nodes whose distance (e.g., in hops) is at most some predefined number. Each node is required to know the topology of the network within its routing zone only, and the nodes are updated about topological changes only within their routing zone. Thus, even when the network is very large, the updates are only locally propagated. (HAAS, 1997).

2.2.2 Reactive algorithms

- ABR (Associativity-Based Routing): It is an algorithm based on associativity of the nodes. All moving nodes in the network broadcast “here I'm” messages to all available nodes. During this period the nodes also receive “here I'm” messages which are also called associativity tick (AT), from all other nodes. These AT messages can only be received if the received power is greater than a predefined threshold power value. By separately counting the number of AT messages received from each node and calculating an AT threshold value, each node creates and keeps its own table which is used to inform all other nodes about the network state (PREVEZE and SAFAK, 2009).

- AOMDV (Ad Hoc On-Demand Multipath Distance Vector Routing): It is a modification of AODV (Ad Hoc On-Demand Distance Vector) routing protocol. Instead of finding one path between a given source and destination, AOMDV tries to discover multiple paths. This protocol guarantees loop free paths similar to that in AODV routing protocol (SHAWARA et al., 2017).

- DSR (Dynamic Source Routing): With DSR protocol, mobile nodes in the network store the routing information obtained by forwarding and listening other transmissions. When a node intents to transmit packets, it checks its cache routing table to determine if there is a route of the desired destination node. If there is a route, the data packet is sent. Otherwise, the node will start the route discovery process to obtain the route that can reach the destination node (ZHANG et al., 2018).

  According BARVE et al. (2016), routing algorithms in ad hoc networks, as the DSR, use flooding for route discovery. In flooding, each device forwards packets to its neighbors, to ensure that packets reach the desired destination. Clearly, routing redundant packets create extra overhead for the network traffic.

- SSA (Signal Stability-based Adaptive): It is a reactive routing protocol in which routes are selected on temporal stability of wireless links, i.e., the basis of signal strength and location stability. Signal stability is evaluated by the signal strength of packets received and remaining battery power of the nodes. With SSA, routes are chosen based on stronger connectivity (JAIN and AGRAWAL, 2017). Stability or lifetime of a route is determined by the number of links that compose the route and the stability of each link in the route (KAUR and SALUJA, 2012).

- TORA (Temporally Ordered Routing Algorithm): It is a distributed on-demand routing protocol. This algorithm is one in a family referred to as link reversal algorithms. TORA is designed to minimize reaction to topological changes. A key concept in this design is that the control messages are typically localized to a very small set of nodes. It guarantees that all routes are loop-free and typically provides multiple routes for any source/destination pair.

2.2.3 Hybrid algorithms

- HRP (Hybrid Routing Protocol): It is a hybrid protocol that separates the network into several zones. HRP is based on GPS (Global positioning system), which allows each node to identify the physical position of others nodes, by mapping an area (CHAHIDI and EZZATI, 2012).

- ZRP (Zone Routing Protocol): It is a well-known hybrid routing protocol most suitable for large-scale networks. The ZRP is designed to provide a balance between proactive and reactive routing approaches. Its name is derived from the use of “zones” that define the transmission radius for every participating node. This protocol uses a proactive mechanism of node discovery within a node’s neighborhood, while inter-zone communication is carried out by using reactive approaches (RAVILLA et al., 2011).

2.3 Related work

2.3.1 Applications

The concept of ad hoc networks began in the 1970s, with a project to use networks to send and receive radio packets in a military environment called ”packet radio” network. Other projects were developed, such as SURAM (Survivable Adaptive Network) in 1993 by DARPA (Defense Advanced Research Projects Agency), to develop protocols capable of supporting significant topology changes for military applications.

Another research, also sponsored by DARPA, was the GloMo (Global Mobile Information System), target at deploying a wireless network infrastructure that was expandable, adaptive and low-power (LEINER et al., 1996). Even today, DARPA plays a key role in the development of innovative technologies linked to North American national security.

To be used to help locate victims in natural disasters, such as tornadoes and earthquakes, and to send information about risk situations, GONCALVES et al. (2014) developed a tool for decentralized communication. The work highlights the network’s performance from a management’s point of view and identifies the importance of its availability and overall performance in supporting and enabling disaster response. However, the tool does not guarantee the delivery of the information to the recipient, and it is not possible to ensure a level of confidence to the information transmitted.

Also, in the line of applications to locate people in case of natural disasters, LIN et al. (2015) propose the use of the Wi-Fi structure and communication of the IPv6 (Internet

Protocol version 6) network of Android smartphones, in the development of an application in which each device is used as information transfer route to assist in locating people. However, to achieve the expected effect it was necessary to change system permissions by installing additional applications, thus making the use of system a bit inconvenient for users.

2.3.2 Performance comparative

In order to the effectiveness of routing protocols based on metrics such as packet delivery, delay and throughput, SRIVASTAVA et al. (2019) evaluate WRP, AODV and DSR routing protocols. The authors show that WRP is a better protocol for MANETs compared to AODV and DSR. However, the authors also highlighted that the DSR routing protocol gives better (lower) delay when compared with the others protocols.

NAIN and HOSSAIN (2019) compare results such as throughput, delay, percentage of packet delivery and dropped packet of three routing protocols, AODV, DSDV and DSR. With the result analysis, the authors highlighted that the AODV protocols provide greater throughput and percentage of packet delivery. The DSR protocol also produced good results for some parameters like lower delay and minimum packets dropped.

In BHUSHAN et al. (2019), the main objective was to make a comparative study between AODV and DSR in a WMN (Wireless Mesh Network)[1], from different mobility scenarios. In this paper, the authors have taken two mobile ad hoc network protocols, AODV and DSR, with which they implemented WMN. Using NS-2.34 simulator, the results were compared to assess packet delivery ratio, packet loss, routing overhead, normalized routing load, throughput and delay. The authors conclude that when the network is not changing dynamically then both AODV and DSR routing protocols provide almost similar results for packet delivery ratio and throughput, and with increased random mobility, DSR performs better than AODV.

LAMBOR and JOSHI (2011) analyze the relationship between network lifetime and energy consumption in a multi-hop WSN (Wireless Sensor Network). The authors used CBR[2] (Constant Bit Rate), radio frequency of 914 MHz and AODV protocol. The results show that the network energy consumption decreases and the network lifetime increases

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[1] The Wireless Mesh Network is a network that can be integrated with communication systems and that can also be left stand alone. It is a network with static wireless relay nodes used to develop a distributed infrastructure for client nodes, and that also uses partial mesh topology. A Wireless Mesh Network is organized and configured by itself (BHUSHAN et al., 2019).

[2] Constant Bit Rate (CBR) applies to connections that require fixed bit rate. Typical applications are: interactive audio (telephony), distribution of audio and video (television, pay-per-view, etc.), audio and video on demand.

with the increase in the number of nodes. This work also shows that with an increase in the numbers of intermediates nodes from 2 to 12, the energy consumption decreases from 100% to 42%. Similar results are also shown in LAMBOR and JOSHI (2010), where the percentage energy consumption decreases with the increase in the number of nodes, i.e., with a decrease in the required transmission power, energy consumption is reduced, indicating that a relationship exists between the network lifetime and the energy consumed in a multi-hop wireless sensor network. However in their work, the authors do not considered the energy consumption for packet receiving.

GRUPTA and KUMAR (2015) compare throughput and packet delivery for DSR, AODV and TORA routing algorithms. The conclusion was that DSR algorithm obtained the lowest packet loss rate. The results obtained by NS-2 simulator also indicated that DSR algorithm offers greater guarantee of receiving packets in a not-fully connected network. However, the mobility of the nodes was not clearly described, leaving room for further research on the behavior of these algorithms.

In order to evaluate the performance of DSR, AODV and AOMDV algorithms, metrics, such as throughput, was verified by ARAGHI et al. (2013). Comparing several situations with different numbers of nodes, it was verified that DSR algorithm offers better performance figures for networks with just a few nodes, whereas algorithms AODV and AOMDV have better performance for networks with larger number of nodes.

TORA is an adaptive and distributed MANET routing protocol that relies on the Internet MANET Encapsulation Protocol (IMEP) services for its various necessary functions, such as link status detection. Incorrect link failure detection by IMEP leads to congested network creation. Thus, KAUR and MITTAL (2014) report the need for improvements in the link detection mechanism provided by IMEP to improve link detection in TORA. The results show that the performance of enhanced TORA was better than that of the original TORA when the nodes are moving in random directions.

BARKOUK and EN-NAIMI (2015) compare the performance of the AODV, DSDV (Destination Sequenced Distance Vector) and OLSR (Optimized Link State Routing) algorithms, considering the impact of node mobility and network density of these protocols in VANETs. The researchers calculated the average of packet delivery rate, throughput and packet delivery time with variations in the network environment such as mobility, density and pause time of the nodes. Using the SUMO-MOVE-2.92 network simulator, results indicated that the AODV algorithm obtained higher transfer values at low mobility. In this case, it was more efficient compared to DSDV and OLSR protocols. The results also demonstrated that AODV has best performance in terms of throughput and packet delivery rate while OLSR has better packet delivery time performance.

Continuing with performance analyzes of routing algorithms for VANETs networks, CHOUHAN and DESHNUKH (2015) employed simulations to obtain results related to the packet loss and overhead rates, comparing the performance of DSDV, OLSR and AODV algorithms with low number of mobile and stationary nodes. The Nakagami-m distribution was used to characterize the fading of the radio signal. According to the authors, OLSR algorithm presented the best packet delivery rate and the lowest packet overhead in the evaluated scenarios.

In BAI et al. (2017), the authors analyze and compare the operation of routing algorithms such as DSDV, DSR, AODV and FSR (Fisheye State Routing) using NS-2 simulator based on metrics such as throughput, packet delivery rate and delay, with tests in a 500x500 meters space and 5, 10 and 30 nodes, UDP[3] (User Datagram Protocol), packet size of 64, 256 and 512 kb and two-ray ground[4] as the radio propagation model. As the size of the data packet increased, the delay intensified. The research indicated that DSDV, FSR (proactive) and AODV (reactive) algorithms show very close results in the analyzed environment. The DSR algorithm was the protocol with the worst performance in the tests. However, the authors performed tests with few nodes, only one radio propagation model and a network with fixed nodes.

BILANDI and KAUR (2016) consider the propagation models free-space[5], two-ray ground and shadowing[6], investigating the impact these models have on the performance of the DSR routing algorithm. For the performance analysis of the algorithm, the average values for packet delivery rate, energy consumption and throughput were used as metrics. Results were collected from a simulation considering a 1000 x 1000 meters area, number of nodes 25, 50, 75, 100 and 125, 512 kb data packet size and CBR-UDP traffic. The study concluded that for the DSR protocol, two-ray ground propagation model provides better results than the shadowing model in terms of average delay, packet delivery rate, energy consumption and throughput. Also, for future work, it was suggested the use of similar propagation models for other protocols, such as OLSR, AODV and DSDV.

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[3] Non-connection-oriented protocol. It does not establish connections before sending data and does not provide reliability in transmission. It sends the packets without any guarantee that they will arrive at their destination.

[4] KAUR and BILANDI (2016) cite that this structure consists of the direct path as well as the path of ground reflection. The authors cite two-ray ground as the propagation structure best suited for long-distance transmission.

[5] Free-space propagation model assumes the ideal propagation condition where there is only the line of sight propagation path between the transmitter and receiver.

[6] Shadowing is the effect that causes the signal to fade due to objects, obstructing the propagation path between the transmitter and receiver. During propagation, fading of the signal is caused by buildings or other large objects obstructing the propagation path. The shadowing model better reflects this characteristic of the received signal power in urban and suburban environments than the free-space loss model (PENG, 2015).

In this article of PRIYA and MALHOTRA (2016), performance evaluation was done to identify the efficient routing protocol for VANETs. Both proactive and reactive routing protocols are compared in terms of parameters such as packet collision rate, packet drop rate, and throughput. In this work, the authors analyze that the reactive protocols provide better results than the proactive protocols, especially with an increase in nodes speed. Proactive protocols obtained the higher rates of packet drop and the collision rate of packets than reactive protocols, while the throughput is comparatively lower. This document also compares the performance parameters of the 802.11p[7] interface with the 802.11a[8] interface. For the 802.11a interface, AODV was chosen as the best routing protocol, with maximum throughput rate, while with 802.11p interface, DSR is more efficient.

PAN (2015) reports that with high node mobility, many routing responses in the DSR routing protocol may not reach the destination node. Thus, the routing requests that are transmit for these nodes produce a lot of unnecessary use of bandwidth. This paper presents a type of dynamic routing protocol based on mobility. The changes suggested by the authors aim to reduce the flooding of route requests in MANETs high speed mobile networks. The simulation results show that the new routing protocol is better than DSR at routing discovery time, route request propagation, and route response.

KAUR and MITTAL (2014) present a study considering the algorithms AODV, DSR and ZRP (Zone Routing Protocol), listing advantages and disadvantages of each one. The performance of the protocols are measured in quantitative and qualitative categories, presenting in a comparative table the performance results and behavior of these algorithms. The authors also highlight the need for improvements in the operation of routing protocols.

The work presented by KOCHHER and MEHTA (2016) evaluates the performance of AODV and DSR reactive routing protocols with hybrid GRP protocol in MANET network using parameters like end-to-end delay, packet delivery ratio and throughput. As a result of the experimental simulation, it was observed that GRP performs better than AODV and DSR in terms of QoS. With an increase in the node density, AODV and DSR algorithms degraded when compared to GRP. The authors highlight that network congestion is the major reason for end-to-end delay in the DSR protocol.

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[7] This is an approved amendment to the IEEE 802.11 standard for adding wireless access to WAVE environments. It defines improvements to the 802.11 protocol required to support applications including the exchange of data between high-speed vehicles and between vehicles and the road infrastructure at the frequency of 5.9 GHz.

[8] Uses the frequency of 5 GHz and offers a theoretical speed of 54 Mb, but in smaller distances if compared at 2.4 GHz band.

KUMAR et al. (2012) investigate the main reasons for a link break, i.e., the high mobility of a device and the battery‘s low energy level. The authors propose an improvement to the DSR algorithm, which would allow diffusion of information about the battery’s energy level of the target device and the intermediate devices. If the battery energy level of any of the devices in a route is below a certain threshold, the route would not be placed neither as primary nor as alternative route to other devices.

In the work of DAS and NAND (2016), an algorithm of encryption is proposed to guarantee the security of the network for sending route discovery messages. The authors note that the DSR protocol maintenance mechanism does not provide local repair of broken links and that alternative route storage may reduce the route discovery overhead, emphasizing the need for implementations of improvements for this protocol. The authors argue that the DSR algorithm works better in low mobility networks and that its performance degrades rapidly with increasing node mobility.

In HOSSAIN et al. (2010), the effects of shadowing on the performance of an ad hoc network are investigated. The study shows that the performance of the network deteriorates very quickly if shadowing effects are taken into account. The results show that, in the shadowing propagation model, routing packets or MAC packets may not be successfully received by a mobile device due to the low signal level, causing problems to the protocol operation. As a solution, a power level increase is proposed and an increase in the number of packet transmission attempts is suggested. However, TCP and higher values for fading parameters were not considered in the study.

BARVE et al. (2016) work‘s main objective is to propose a model for the DSR routing algorithm based on the hashing technique, which would make it more secure. However, the proposed changes were not validated by simulation in order to compare performance with DSR protocol in terms of throughput, packet delivery rate and end-to-end delay. The authors highlight the flooding problem, i.e., the forwarding of packets to its neighbors to ensure that the packets reach their intended destination can create redundant flood packets, generating extra overhead on the network bandwidth.

In GARROSI et al. (2017), a review of the latest generation routing protocols for urban VANETs is present. However, the research does not report studies with traditional routing algorithms, such as the DSR.

2.3.3 Simulations

Using the NS-2 simulator, SHARMA and KUMAR (2016) propose a comparative study for OLSR, DSDV, DSR, AODV and TORA routing algorithms. With simulation and comparison results presented, the authors highlight that the AODV algorithm offers better throughput and packet delivery rate, and the OLSR algorithm offers better performance to select routes without loops. The study also points out the main advantages and disadvantages of each algorithm studied.

In the research of MOBIN et al. (2016) the adequacy of the NS-2 as a network simulator is discussed, presenting simulations of network traffic such as CBR and single-hop[9] traffic, and compares it to multi-hop[10] scenarios. The results indicate a strong relationship between simulated results and theoretical estimation. Therefore, the simulations using the NS-2 as simulator have been authenticated when compared to real data. In order to evaluate the performance of routing algorithms in ad hoc networks, the experiments performed by the authors provide a great guideline for the reliability of the use of NS-2 for network researchers and engineers.

2.3.4 Energy consumption

The conclusions about the advantages of short-hops and multi-hops are varied depending on the approach taken and criteria considered , with the discussion being raised by many authors in recent years. The discussion of issues about the number of required hops for packets to reach the destination are researched and discussed in various articles, that is, multi hops and single-hops routing has its own advantages and disadvantages.

RAFI et al. (2013) propose a study of the comparative efficiency of different scenarios with specific numbers of sensors. The scenarios are a square grid, a random layout and a scenario proposed by the authors called Seven Node Hexagonal Deployment (SNHD), i.e., seven regular hexagons form the basic structure with one at the center and the six others placed at each edge of the center hexagon. Analysis of the relationship between area covered by nodes and sending radius of nodes were performed. SNHD allows the covering of greater areas with less overlapping regions than the others scenarios. In these regions, minimum overlapping produces minimum number of similar data and less sensing energy. The results of the proposed model showed greater network lifetime when compared to other deployments. The results were confirmed by simulation and mathematical analysis, but it was not informed the propagation model, the routing protocol and other information to allow the reproduction of the experiments.

Energy efficiency is analyzed in PESOVIC et al. (2010), and considers which approach is more energy efficient: single-hop or multi-hop transmission. In this work, radio power

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[9] Single hop network is a network in which endpoints (i.e., source and destination) are the only devices on which the packet travels.

[10] Allows a packet to go through more than one device until it reaches the destination.

adjustments were necessary to reach the desired number of hops. The authors evaluate that multi-hop routing is more energetically efficient through mathematical equations, putting in discussion the cost generated in receiving packets.

FEDOR and COLLIER (2007) consider that in very dense networks with many nodes, a short hop routing scheme may not be more advantageous than long hopping, mainly due to the significant energy consumption for the packet reception. The authors point out that there is a minimum distance range between origin and destination for which direct communication is an ideal alternative. This is due to the fact that the savings in transmission power by the multi-hop scheme does not compensate for the resulting additional receiving cost. Therefore the increase in the distance between source and destination will reach a limit for which routing becomes more advantageous. As a result, if we want to know which routing strategy is the most energy efficient for a particular topology, we need to compare the energy consumption of the transmission with one hop and with multiple hops. In the simulations performed, the authors showed when multi-hopping is more energy efficient if compared to a direct transmission. However, the scenario was with nodes aligned, thus leaving the need for such experiments in other scenarios.

LAMBOR and JOSHI (2011) analyzed the relationship between the useful lifetime of the network and the energy consumption in a network of wireless multi-hop sensors considering constant distance between source and destination of 100 meters. Other nodes are introduced between the source and the target in this experiment. The work showed that the percentage of energy consumption decreases with the increase in the number of hops. It was observed that the lifetime of the network increases exponentially with the number of hops and saturates gradually, showing that although the increase in the number of intermediate nodes decreases the percentage of energy consumed, this decrease becomes insignificant after a critical number of hops. In this paper, the authors did not consider energy consumption in receiving and processing packets. With this work, the authors also attest that multi-hop transmission is more energy efficient than single-hop transmissions.

KHEIREDDINE and ABDELLATIF (2011) check the minimum power consumption by choosing the optimal hop length. The authors point out that routing in many short hop minimizes transmission power, which increases with distance from the destination. However, sending packets through long distance jumps reduces the cost of receiving (as the number of nodes involved in the data routing decreases). The scenario created for the experiments was an initial area with 5 nodes queued and, with each new row, a greater number of nodes is inserted. The distance from the origin to the destination is

760 meters. In this work, the authors concluded that 16 hops promotes the smaller energy consumption in the scenario evaluated, and with a larger number of jumps, the energy consumption starts to increase.

LAMBOR and JOSHI (2010) calculate the number of critical hops for energy savings up to the saturation of that economy. The authors simulate a scenario where a source device sends packets to a destination. With each simulation, new devices are inserted between the source and the destination, reducing transmission power. The work showed that the lifetime of the network increases with the number of nodes and saturates after a critical number of nodes.

The work in HE et al. (2017) discusses the under-battery consumption in the shadowing propagation model with three transmission models including the direct transmission model, the transmission model in vehicular cell with fixed relay nodes and mobile relay nodes. However, the work does not show results of overhead, packet loss and other metrics.

2.4 Discussions

In this chapter we present some concepts about routing protocols, some of their problems, advantages and disadvantages when compared with each other. These algorithms are the basis of most current algorithms used for ad hoc networks. Some characteristics of DSR algorithm found in the papers related in this work are showed in the following.

- Lowest rate of packet loss compared to AODV and TORA (GRUPTA and KUMAR, 2015).
- Better receiving packets on non-fully-connected networks compared to AODV and TORA (GRUPTA and KUMAR, 2015).
- Better performance in networks with few nodes compared to AODV and AOMDV (ARAGHI et al., 2013) algorithms.
- Algorithm with worse performance when the number of nodes and size of the packets increase (BAI et al., 2017).
- Better results with the use of the two-ray ground propagation model when compared to shadowing model in terms of average delay, packet delivery rate, power consumption and throughput. (BILANDI and KAUR, 2016).
- Performance of DSR well in low mobility networks, its performance degrades quickly in increasing mobility (DAS and NAND, 2016).

The algorithms AODV and AOMDV are considered in a few works. The main characteristics reported are as follows:

- Better performance in networks with a large number of nodes (ARAGHI et al., 2013).
- AODV with high transfer value with nodes with low mobility when compared to OLSR (BARKOUK and EN-NAIMI, 2015).
- AODV with better performance in packet delivery compared to DSR and ZRP algorithms (NEMADE and BHOLE, 2015).

The OLSR routing algorithm has the following advantages against algorithms such as AODV and DSDV cited by BARKOUK and EN-NAIMI (2015):

- Better performance in terms of packet delivery.
- Lower packet overhead.

BAI et al. (2017) cite the DSR protocol with the worst performance in the tests carried out. However, in the work of GRUPTA and KUMAR (2015) the same algorithm obtained the lowest packet loss rate and better packets delivery. These works demonstrate contradictions in the results of the authors, making clear the need for a better investigation of the operation and performance of the algorithm in several scenarios.

3

Simulation Tool

Many technologies have been created in the last decades to assist the information exchange process efficiently and creatively. The activity of communication through networks of devices has been growing intensely. Based on this, it is necessary to know what will be the real needs and requirements for the correct operation of these networks and, for this, the use of simulation is very important, allowing the test of systems from models created in computers, i.e., usually a reduced cost when compared with real scenarios constructs. In addition, certain scenarios can be more easily created in simulation and tests can be repeated several times allowing performances comparison between different configuration variables in the network.

A computer network is generally defined as a collection of interconnected computers for collecting, processing, and distributing information (ISSARIYAKUL and HOSSAIN, 2012). Rules that allow communication between computers are defined in protocols. These in turn are divided into layers, where each layer is responsible for a set of functions assigned to the protocol. The set of layers is usually called Protocol Stack. Layered division aims to facilitate the design and allow flexibility of implementation. Each layer communicates with their neighboring layers, above and below the protocol stack, providing services to the layer above and using services offered by the layer below. One of the great advantages of this division is the independence of layers, i.e., the goal is to allow that any change in one layer protocol does not affect the operation of other layers. The network simulator used in this work contains modules for various network components, such as routing, transport and application layer protocol (ISSARIYAKUL and HOSSAIN, 2012).

Since its inception in 1989, NS-2 has continuously gained tremendous interest from industry (ISSARIYAKUL and HOSSAIN, 2012). Afterwards, NS-2 emerged as one of the most used simulator, being able to evaluate the behavior of data packets, node energy, channel propagation and routing algorithms.

Simulation of the DSR protocol functionality is incorporated into NS-2 and to change this functionality, an understanding of the simulator operation is necessary. At this point, the lack of update documentation of the NS-2, which allows us to understand the procedure required to include new features, was perhaps one of the biggest obstacle.

3.1 Network simulator

Based on events and especially used for network simulations, the NS-2 (Network Simulator version 2) is a very popular open source simulator for investigating the operation of devices networks. The project started in 1989 and has evolved considerably as a simulation tool. For operation of the NS-2, some tools, such as Tcl (Tool Command Language), Tcltk (Toolkit Graphical User Interface), OTcl (Object-oriented Tcl) and Tclcl (Tool Command Language with Classes) are necessary.

NS-2 consists of two main languages: C++ and Object-Oriented Tool Command Language (OTcl). C++ is used to define the internal mechanism of the simulation (back-end) and OTcl configures the simulation by assembling and configuring the objects, as well as scheduling discrete events (front-end). These two languages are linked together using Tclcl.

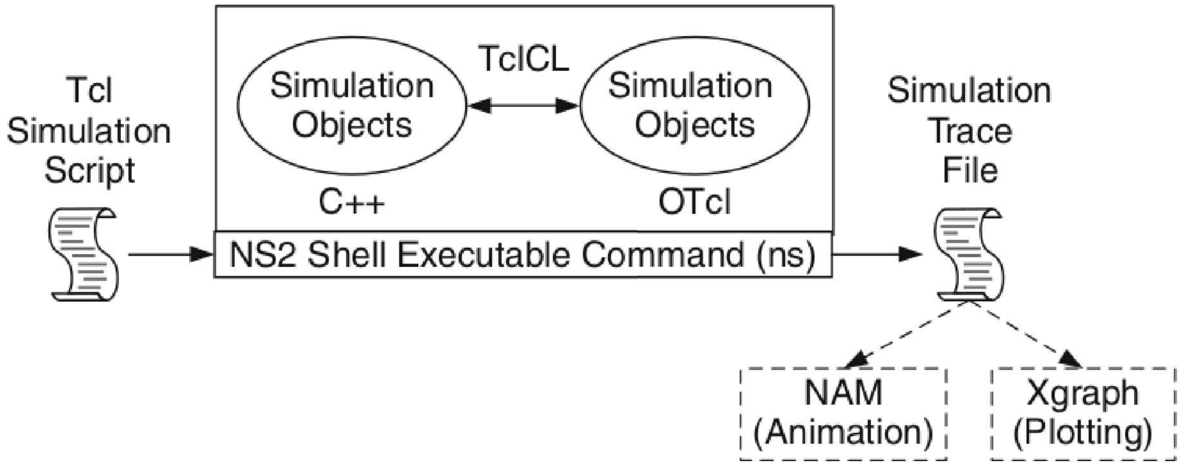


Figure 3.1: NS-2 modules (ISSARIYAKUL and HOSSAIN, 2012).

Figure - 3.1 shows the modules that compose NS-2. The core of NS-2 is written in C++, which allows easy bit manipulation, facilitating packet processing and providing low computational execution time. To parameterize the modules programmed in C++, Tcl language is used. In addition to the parameterization, Tcl code allows direct access to attributes of objects programmed in C++, i.e., the code in Tcl language is used to change the behavior of an existing module or operations of package manipulation and scenario settings.

The simulation starts with the simulation scripts (OTcl). Then, it is submitted to the NS-2 core for execution and, finally, it generates simulation results for analysis. To investigate the behavior of the simulated network, output files (termed trace files) generated by NS-2 record all the events that occurred during the simulation process (ISSARIYAKUL and HOSSAIN, 2012). Output files, such as trace files, need to be parsed to extract useful information. The analysis can be done using programming languages or software such as Matlab, Excel and others. To evaluate parameters like delay, throughput, packet loss, level energy and routing path in the trace files, other tools are required.

The NS-2 tool integrates visualization modules such as NAM (Network Animator) in order to facilitate the understanding of a simulation. NAM is a Tcltk based animation tool developed as an open source project to visualize the data traffic in the network simulation. It supports topology layout, package level animation, and various data inspection tools.

Some advantages of NS-2 are given below.

- NS-2 does not require costly equipment and results can be quickly obtained;
- NS-2 supports various protocols and platforms;
- Parameters such as packet size, traffic patterns, and node coordinates are easily workable;
- Packet sizes can also be changed at run-time, crucial for estimating the optimal packet size (CHEN et al., 2007);
- The energy level may be used to stipulate the battery consumption for specific devices, as well as for the whole network during packet transmission (MOBIN et al., 2016); and
- NS-2 does not require a license to run and it is used by a large community.

Some disadvantages of NS-2 are given below.

- Tools like Awk, Perl, Matlab, Excel, python or others are required to extract and analyze the simulation results and trace files. In many cases, the analysis ends up to be manual, making data exploration a time consuming work;

- The process of installation and customization of source code may be complex and long; and

- Documentation incomplete or outdated for the complete understanding of the source code and for the operation of NS-2.

  Maybe because NS-2 is an open-source tool, produced cooperatively, if fails to have a comprehensive and up to date set of documents explaining its operation. As a result, it is difficult to change the code and introduce new implementations and test new features. Due to the fact that the Linux operating system has a number of different distributions, such as Fedora, Ubuntu, Debian, and others, the installation of NS-2 modules requires knowledge of its source code, because for each distribution, some changes in the NS-2 source code may be necessary to complete the installation without error. Therefore, the lack of up-to-date NS-2 documentation was perhaps one of the biggest obstacle.

If one compares its advantages and disadvantages, NS-2 is generally accepted as one of the most beneficial tools for conducting network research simulations (MOBIN et al., 2016).

4

DSR (Dynamic Source Routing)

Routing is one of the pivotal preoccupations in ad hoc networks. In order to deal with the mobility of devices and the need to steer packets from source to destination, many routing protocols have been proposed. The routing in which the source node informs the complete hop sequence through which the packet will travel is known as source routing.

Introduced by DAS and NAND (2016), DSR (Dynamic Source Routing) is a reactive routing protocol for mobile ad hoc networks. Reactive means that only when a route is required by an upcoming packet transmission, then the algorithm initiates the route establishment procedure.

Differently than traditional reactive routing protocols, DSR has some additional functionality. While most protocols cache the main or actual route once it is known, DSR, besides the main route, stores alternative routes to be used if the main route is no longer valid.

The network using the DSR algorithm also maintain routing information for others nodes in the route caches. The information in each cache is updated when nodes retransmits packets and when they hear a route response from another nodes. Support for multiple routes allows quick reaction to routing changes since a node may try other cached route if the main one fails. The main phases in the algorithm operation are route discovery and route maintenance. These two phases work together for discovery and maintenance of routes (JOHNSON et al., 2001).

4.1 Route discovery

Routing algorithms for MANETs, such as DSR, usually use flooding as the main mechanism for route discovery. Route discovery phase occurs when the source node intends to send data to a destination to which a route is unknown. If the route exists, and it is still valid, the source node starts sending data packets. If it does not exist, the node initiates the route discovery process, broadcasting a RREQ (Route Request) packet to its neighbors. When the number of routes is 0, it means that the packet has no route defined yet, so, the route discovery process is started. Otherwise, the algorithm describes the complete route.

4.1.1 Route request packet

Each node that receives a RREQ packet, if it does not have a valid route to the destination, rebroadcast it to its neighbors, updating the hop table found in the packet header. This procedure is repeated until the destination is reached, or a route to the destination is known by a receiving node along the way.

Intermediate nodes update their routing table by adding the new RREQ packet's identifier. As shown in Figure - 4.1, the RREQ packet is relayed from neighbor to neighbor. Each node adds an identifier in the packet path header, until it reaches the destination node or reaches a node that knows how to get to the desired destination. Pending transmission data packets are cached when a node initializes a route discovery procedure. These packets remain for a period of time in the source node cache until a route is discovered or a timeout occurs. At such time, the packet is removed from the buffer and discarded, avoiding the send buffer's overflow.

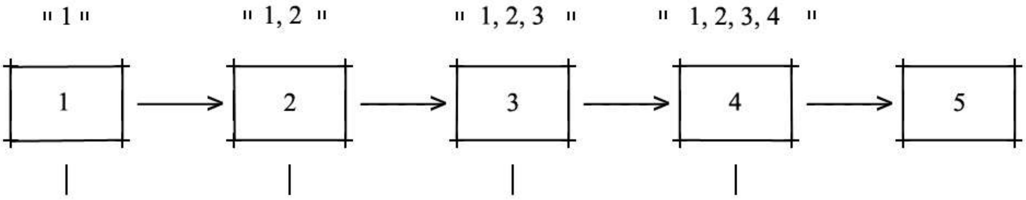


Figure 4.1: RREQ packet path to the desired destination. Source: author.

When a RREQ packet is retransmitted between neighbors nodes until reaches the destination, redundant packets are propagated over the network. Intermediary nodes that receive route requests and that has not a destination defined route may limit the rate at which it forwards RREQ packets. In this case, an exponential removal algorithm may be used to limit the rate of sending route discoveries packets.

Nodes that receive RREQ packets and does not have a route to the desired destination, cache this RREQ packet for future responses when the route is discovered. After discovering the route to the desired destination, the intermediary node that received requests can respond them and discard the RREQ that was cached and have not yet been forwarded. In Figure - 4.2, the RREQ packet format is depicted.

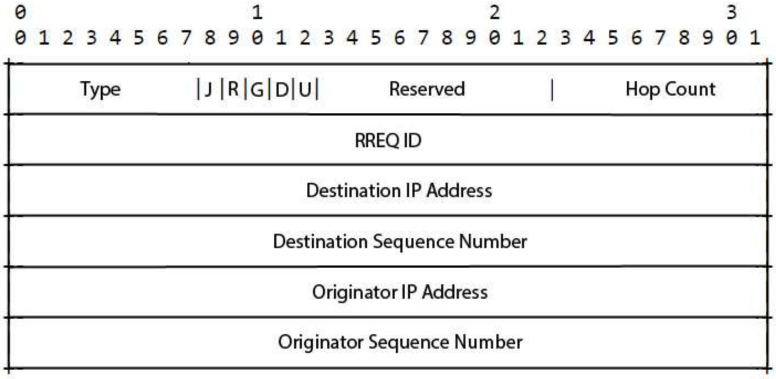


Figure 4.2: RREQ packet format. Source: author.

The RREQ packet contains the following fields:

Type J: Reserved for multicast.

R: Indicates that the RREQ message is a route repair.

G: Indicates if a RREQ should be unicast.

D: Indicates that only the destination can respond to this RREQ.

U: Indicates that the sequence number of destination is unknown.

Reserved: Sent as 0; Ignored at reception.

Hop Count: Number of jumps from the source to the node that is receiving the packet.

RREQ ID: Sequence number that uniquely identifies the RREQ.

Destination IP address: The IP address of destination to which a route is desired.

Destination sequence number: Most recent sequence number received by the source node to any route to the destination.

Source IP address: IP address of the node that originated the route request.

Sequence number of origin: The current sequence number to be used in the input of the route.

4.1.2 Route reply packet

Once an intermediate node receives a RREQ packet to a destination to which a route is known, it sends to the originator node a Route Reply (RREP) packet using the reverse path specified in the RREQ packet header. In Figure - 4.3, the RREP packet format is depicted.

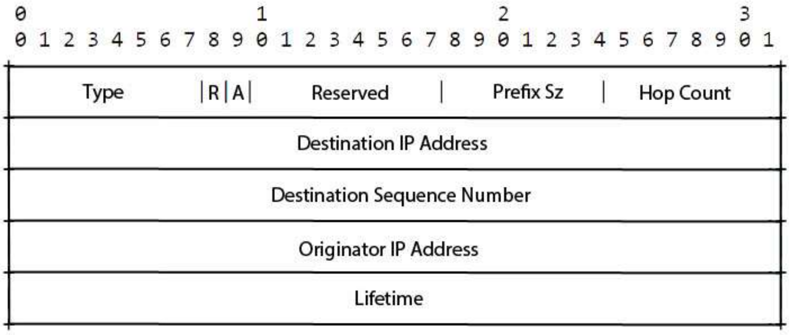


Figure 4.3: RREP packet format. Source: author.

The RREP packet contains the following fields:

R: Repair flag. Used for multicast.

A: Required recognition.

Reserved: Sent as 0. Ignored at reception.

Prefix size: If it is not zero, the 5-bit prefix size specifies that the next hop indicated can be used by any node with the same routing prefix.

Hop count: Number of hops from the source IP address to the destination IP address.

Destination IP address: IP address of the destination to which a route is provided.

Destination sequence number: Destination sequence number associated with the route.

Originator IP address: IP address of the node that originated the RREQ to which the route is provided.

Lifetime: Time in milliseconds for which nodes that received RREP packet must consider the route as valid.

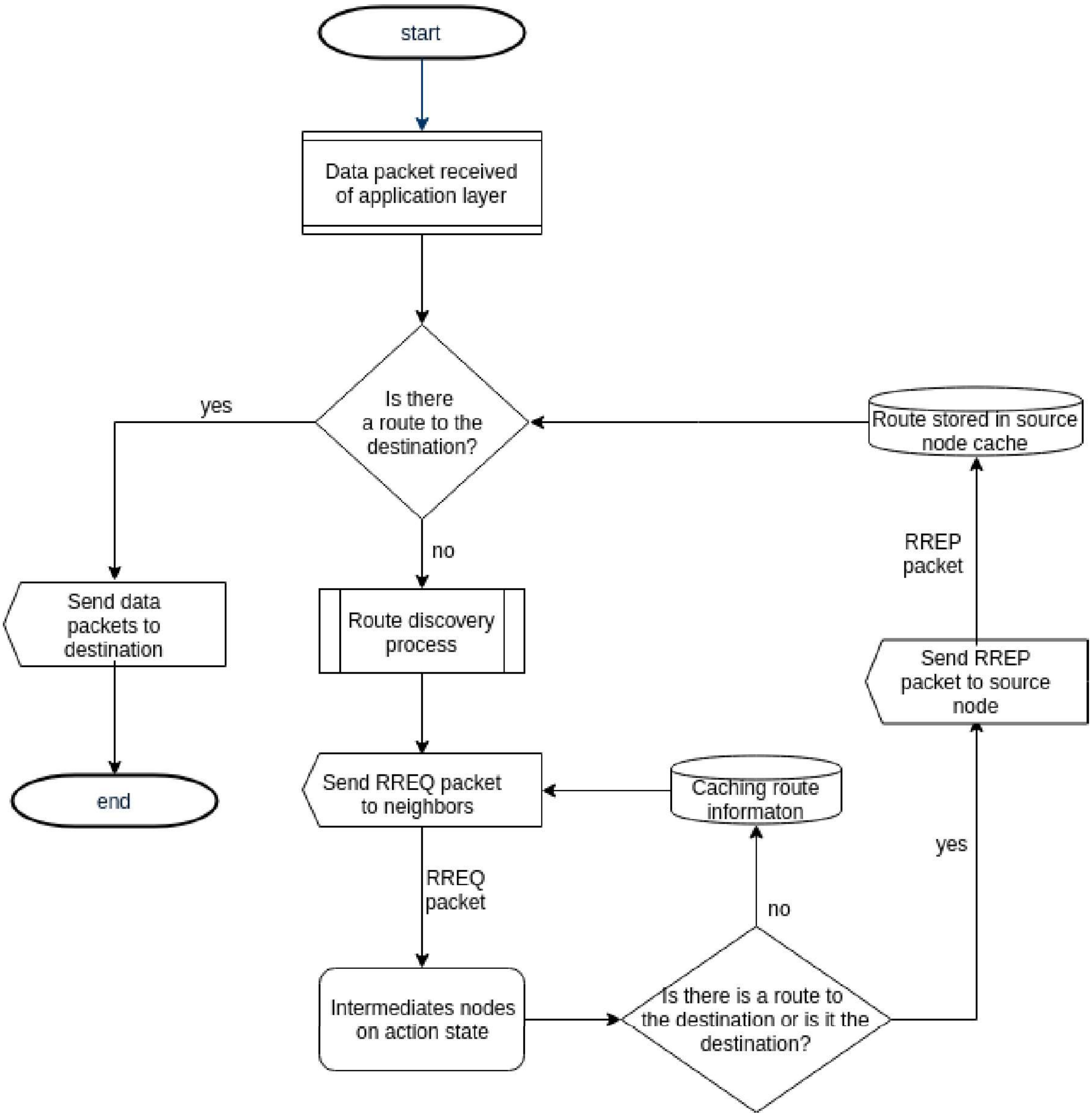


Figure 4.4: Sequence diagram for route discovery. Source: author.

Figure - 4.4 shows the execution sequence for the DSR route discovery procedure, starting with the intent of the source node in sending data packets. If there is a route to the desired destination, the node sends data packets to the destination; if not, the route discovery process starts by sending the RREQ packet to the nearest nodes. If the node that receives the RREQ packet is not the desired destination and it does not have a route for the desired destination, then it retransmits the packet to its neighboring nodes.

Otherwise, if the node knows a route or is the destination, then it replies with a RREP packet using the reverse path. The RREQ packet is retransmitted until the destination node responds with an RREP packet. Figure - 4.5 to Figure - 4.10 illustrate the RREQ and RREP packet's propagation by flooding in the network.

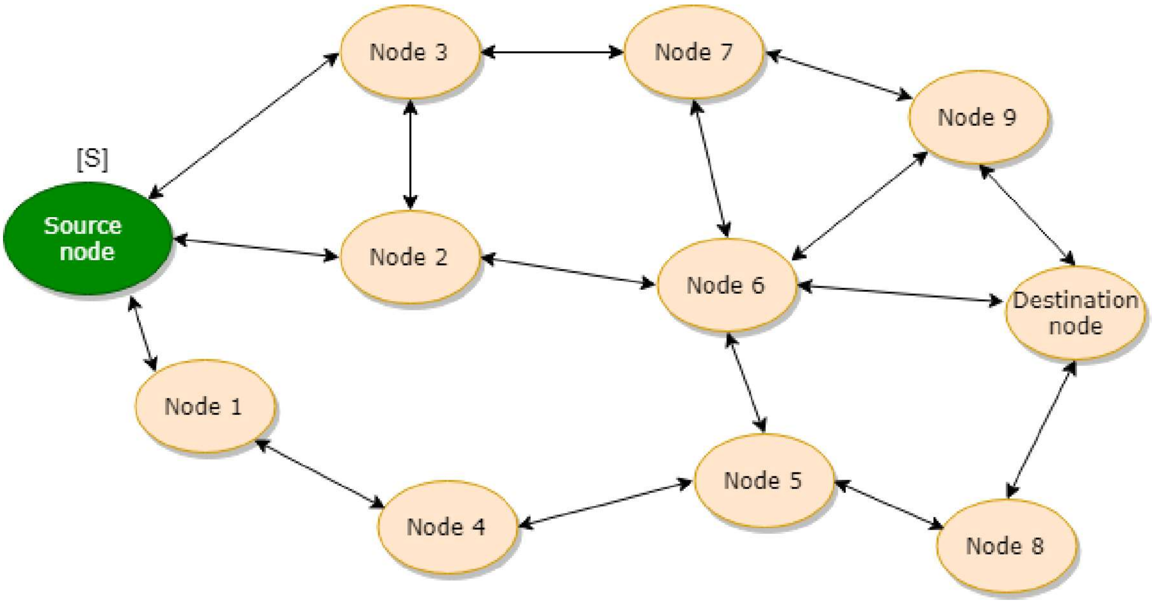


Figure 4.5: RREQ and RREP packets transmissions - step 1. Source: author.

Figure - 4.5 depicts the initial state, when the node intents to send data packets to the destination. This situation initiates the route discovery process, when the node checks in its route cache if a route exists to the destination.

The source node initiates the route discovery process by sending RREQ packets to its neighbors, as illustrated in Figure - 4.6, when nodes 1, 2 and 3 receive the RREQ packet. These nodes update the path by adding the node identifier at the end of packet header.

Figure - 4.7 shows nodes 4, 6 and 7 receiving the RREQ packet. In this figure it is noticeable that the identifier node 2 is not appended to the end of the node 3 packet header, due to the fact that this node had previously received the RREQ packet. On the other hand, nodes 4, 6, and 7 that still have not received the RREQ packet and that do not have a route to the destination, add their respective path identifiers at the end of file header.

Figure - 4.8 shows the RREQ packet arriving at the destination node in addition to reaching nodes 5 and 9. The final node upon receiving the RREQ packet, identifies the request from the source node to send data packets and informs which path these data packets must use.

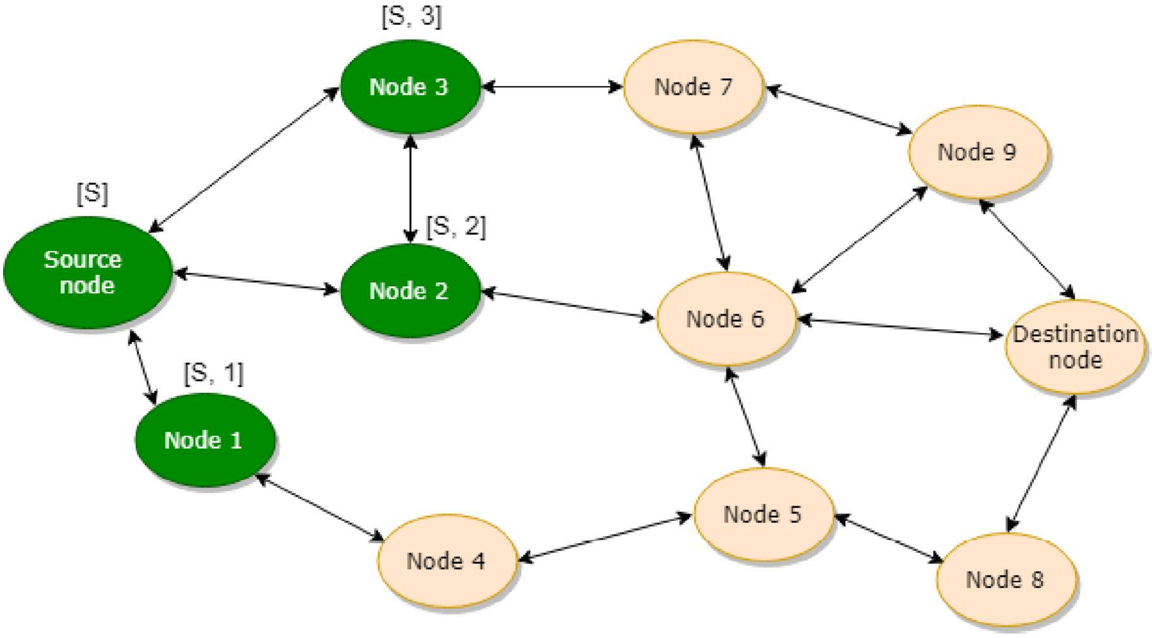


Figure 4.6: RREQ and RREP packets transmissions - step 2. Source: author.

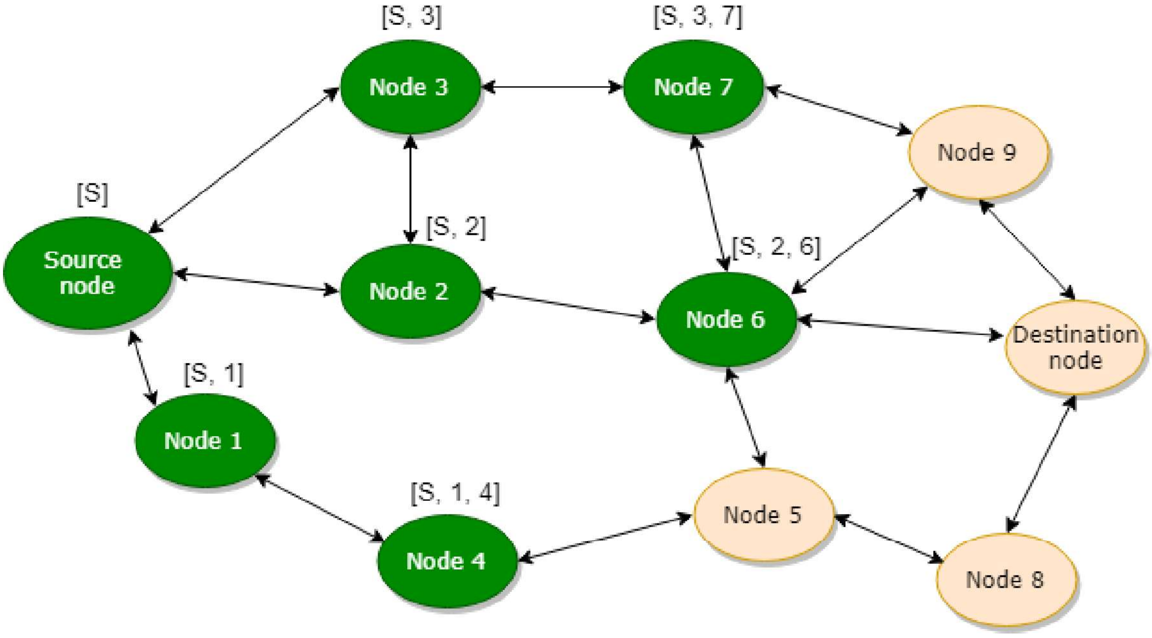


Figure 4.7: RREQ and RREP packets transmissions - step 3. Source: author.

Figure - 4.9 shows the RREP packet passing through the entire reverse route that was contained in the RREQ packet header. Upon receiving the RREP packet, the source node can send data packets to the destination node, using the discovered route.

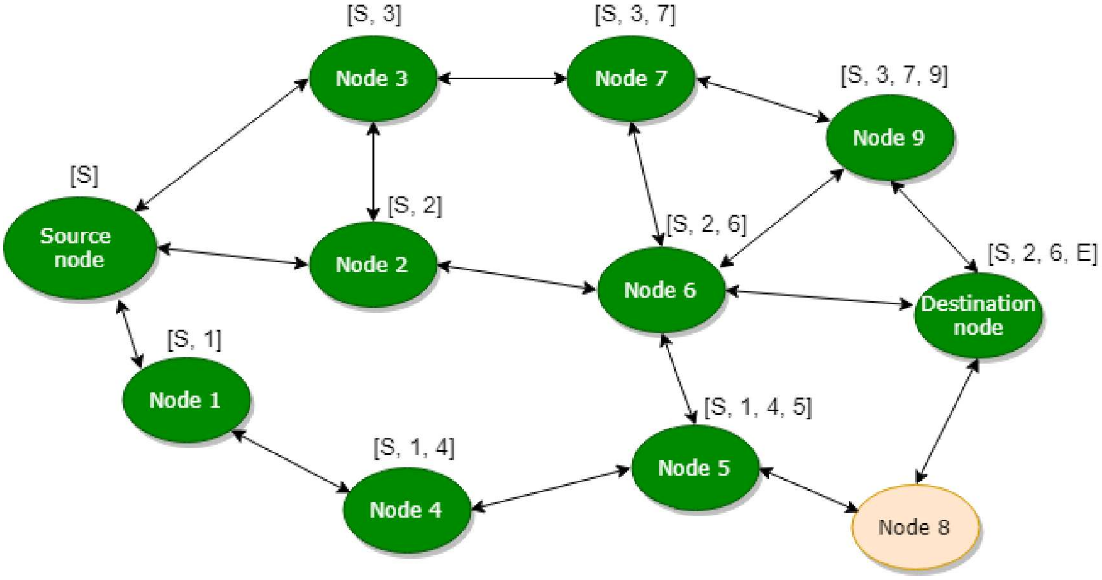


Figure 4.8: RREQ and RREP packets transmissions - step 4. Source: author.

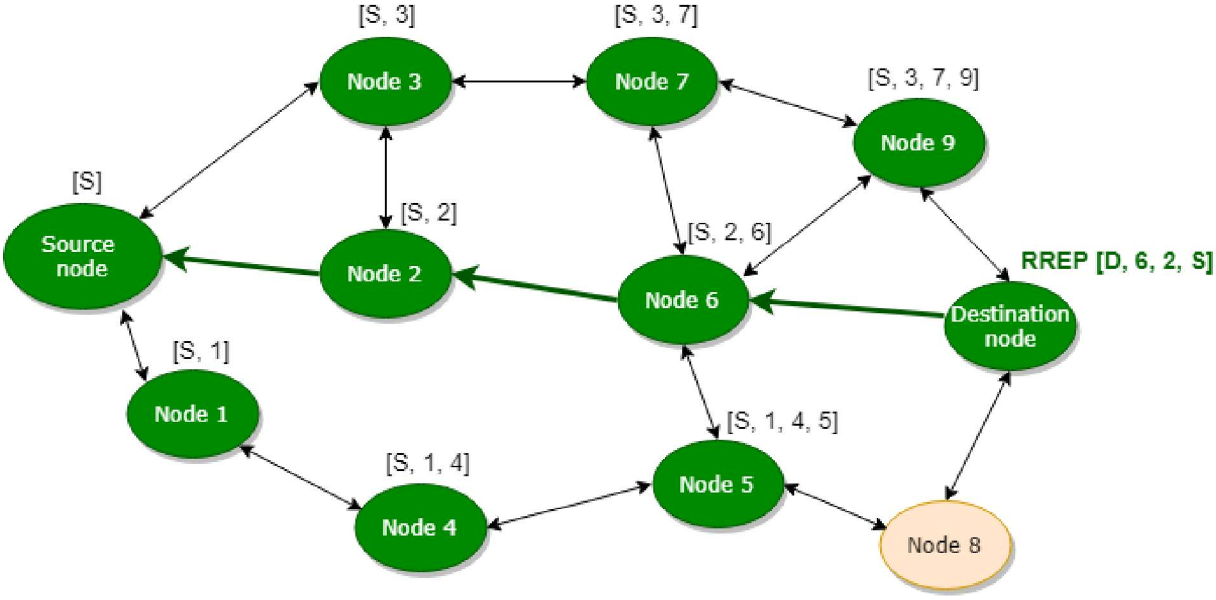


Figure 4.9: RREQ and RREP packets transmissions - step 5. Source: author.

Once have the source node receives a RREP packet containing a route to the desired destination, data packets are sent from the indicated route, as show in Figure - 4.10.

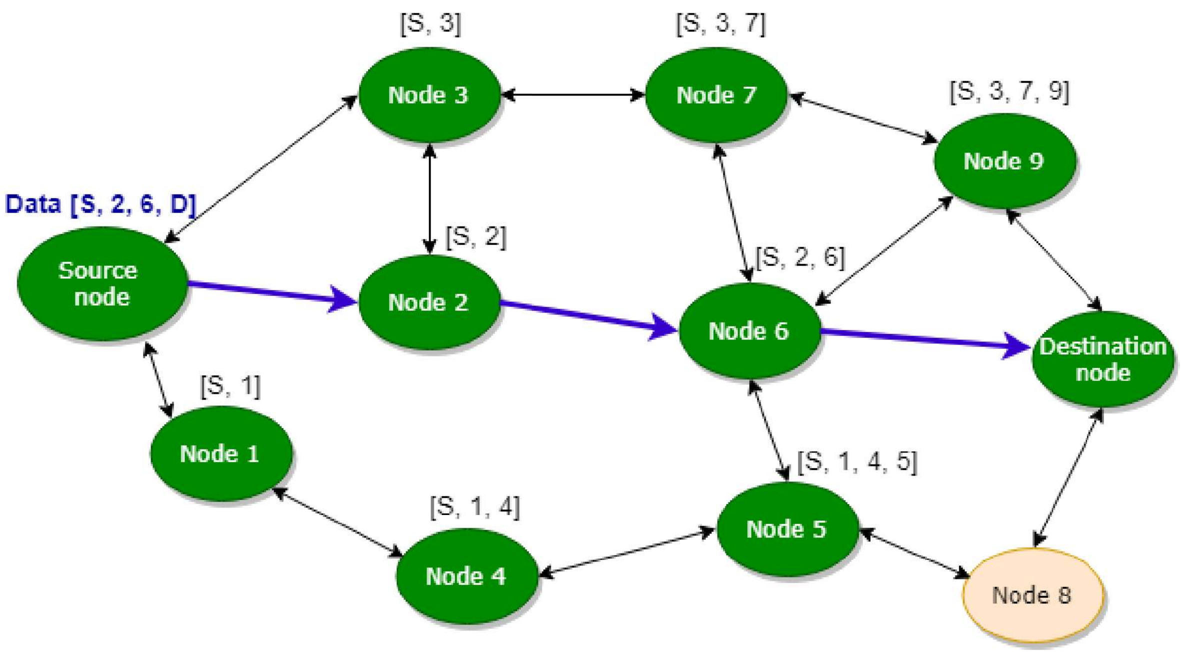


Figure 4.10: RREQ and RREP packets transmissions - step 6. Source: author.

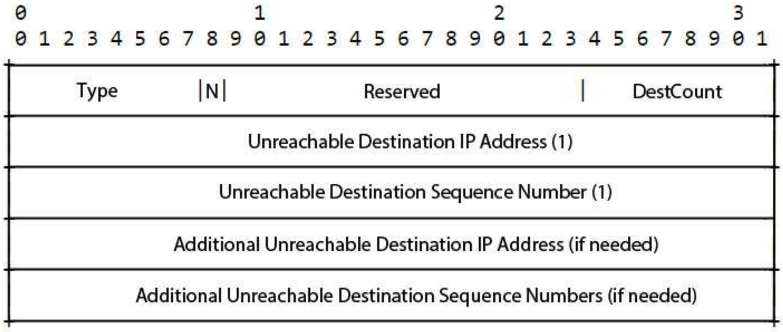
4.2 Route maintenance

Route maintenance is a procedure by which one node tries to detect if a route is broken or if the network environment has changed. Thereby, when the route maintenance detects a change that makes a route unavailable, it may use some other known route, if exits, or it may invoke the route discovery procedure to find a new route.

DSR requires no transmission of any kind of periodic packets in order to detect the network conditions, i.e., DSR does not use any periodic routing advertisement, link status sensing or neighbor detection packets, and it does not depend on these functions from any underlying protocols in the network. In DSR, link breaks are detected when packet data are dropped because the route between nodes no longer exists or is valid.

4.2.1 Route error packet

Link breaks may occur due to nodes movements or due to the low battery level in the nodes. Nodes affected by a link break send a RERR (Request Error) packet to the source node to inform the event, passing on the message to other nodes for them to register and update their own routing tables, i.e., if a packet could not be forward by some node for some reason, this node returns a RERR packet to the source node identifying the broken link. In Figure - 4.11, the RERR packet format is depicted.



Type	N	Reserved	DestCount
Unreachable Destination IP Address (1)			
Unreachable Destination Sequence Number (1)			
Additional Unreachable Destination IP Address (if needed)			
Additional Unreachable Destination Sequence Numbers (if needed)			

Figure 4.11: RERR packet format. Source: author.

The format of the RERR packet, which is illustrated in Figure - 4.11, contains the following fields:

N: Defined when a node has performed a local repair of a link, and the nodes should not delete the route.

Reserved: Sent as 0. Ignored at reception.

DestCount: Number of inaccessible destinations. Must be at least 1.

Unreachable Destination IP Address: Destination IP address that became inaccessible due to a link break.

Unreachable Destination Sequence Number: Sequence number in the routing table entry for the destination with IP address field not accessible.

Additional Unreachable Destination IP Address (if needed): Additional sequence number IP that has became unreachable.

Additional Unreachable Destination Sequence Number (if needed): Additional sequence number in the route table entry for the destination with IP address field not accessible.

Upon reception of a RERR packet, a node that has a route which uses the broken link deletes the route from its routing table. In turn, an alternative route (if exists) becomes the main route. However, it is not verified if the alternative route is still valid. If the alternate route is also broken, the packet sent will be lost, thereby, increasing the packet loss rate.

Due to the fact that a link may no longer exist between two nodes, a send buffer is used in each intermediate nodes to store data packets that cannot be sent at the moment.

A lifetime is associated to each data packet that is stored in intermediate nodes send buffers, and the packet is discarded if a route is not discovered until this time expires. When a route is discovered, these packets have their headers updated with the new route, removed from buffer, and sent to the desired destination.

4.3 Additional route discovery features

With the intent of reducing network overload, some optimization features are included in DSR. For instance, each node caches the identifier numbers of received RREQ packets so that it avoids retransmiting an already propagated packet. Once a node receives a RREQ packet addressed to it, automatically a route to the source node is learned and cached for future transmissions or, if necessary, to answer a RREQ with a RREP packet.

Other additional route discovery features are listed below.

- Route shortening
  - Main routes can be shortened when a node receives data packets transmissions. If an intermediate node has a shorter route to a destination, it may notify the source, through a RREP packet, that one or more nodes are not needed in a particular route, informing the shorter route. Figure - 4.12 illustrates the scenario where node 1 sends packets to node 7. Each time that a packet is forwarded to the next hop, described in packet header, the intermediate nodes hears and compares the route. If there exists a route with less hops, the intermediate node sends a RREP packet to the source node, informing the shorter route known by the intermediate node. The same figure illustrates an example where node 2 knows a smaller route to the destination and informs node 1, the existence of a shorter route to node 7.

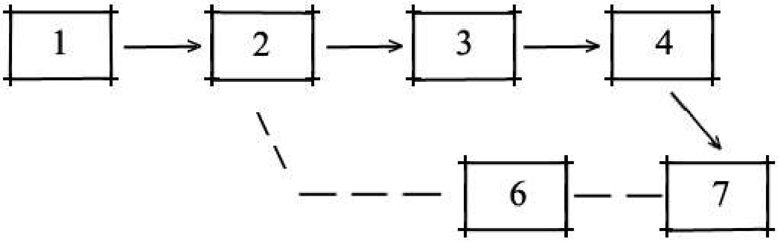


Figure 4.12: Route shortening example. Source: author.

- Catching overhead routing information

  - A node, as it handles data, RREQ, and RREP packets, learns from these packets and can update its routing table. This update is performed by reading the path that the packet is traversing, informed by its packet header.

- Replying to route request using cached route
  - Before answering to a route request, the intermediate node that knows the route to a destination, checks in its own routing table if any node contained in the RREQ packet header is already part of the route that will be added to the RREP packet that will be returned. If it already exists, the intermediate node will ensure that this node will not be duplicated in the route.

- Preventing route reply storm
  - In some cases, simultaneous RREP packets can be sent when more than one node, which knows a route to the destination, receives a RREQ packet at the same time, producing a high bandwidth consumption and greater possibilities of packet collision in this area. This event is called route reply storm. To prevent this, before the node responds to a route request with a RREP packet, it should wait for a short period of time to prevent responses from all nodes to happen at the same time. For this, the random wait time is calculated using the equation $d = H(h-1+r)$, in which h is the number of jumps to the source, r is a random number between 0 and 1, and H is a constant delay.

- Route request hop limits
  - A jump limit can be specified on each RREQ packet to limit the number of hops until the desired destination is found. With this mechanism, RREQ packets are prevented from propagating indefinitely. One approach that may be implemented is to add one extra hop to the hop limit for each new attempt to find a route.

4.4 Additional route maintenance features

- Packet salvaging
  - The node that detects a link break may store the packet for a short period of time and sends it in the near future in an alternative route if it finds it before the packet times out.

- Caching negative information
    - When a node receives a RERR packet reporting a link break, a time limit is specified to prevent this link from being used again or added as a route to a destination. At the end of this timeout, the route may be cached again when informed by an RREP packet.

4.5 Limitations of algorithm

The main algorithm limitations are:

- Replicated messages are generated corresponding to the same route request.
- DSR does not generates beacon from time to time, like "Hello messages", to check link status to neighboring nodes (KAUR et al., 2016), (GRUPTA and KUMAR, 2015). Therefore, the delay many times is higher if compared to proactive protocols.
- The route management engine does not repair broken links (DAS and NAND, 2016).
- DSR does not contain any explicit mechanism to expire stale routes in cache (DAS and NAND, 2016).
- As the network grows larger, the number routing protocol packets (which contain complete routing information) also becomes larger. Clearly, this has a negative impact on the limited bandwidth available (PARK and CORSON, 1997).

5

Computational experiments

In order to evaluate the performance of routing algorithms in ad hoc networks, the experiments carried out in (MOBIN et al., 2016) offer an assurance that the use of NS-2 open-source simulator produces reliable data that is confirmed by real experiments. Therefore, in the current study, we use the NS-2 for simulation of ad hoc networks.

5.1 Radio equipment and simulation environment

In our experiments, equally to used in (HOSSAIN et al., 2010; JOHNSON et al., 2001; MALTZ et al., 1999; PERKINS et al., 1999), WaveLAN, an equipment similar to Lucent Technologies' Orinoco driver commercial radio, is used. It is a shared medium radio with a nominal radio range of 250 meters and a nominal bit-rate of 2 Mb/second. Although there are newer equipment currently in use, the radio used in this work is the one implemented in NS-2. A detailed description of the radio operation bands and medium access protocol are given in (FALL et al., 1997). For all simulations, we assume the following conditions:

1. All nodes have the same isotropic and omnidirectional antenna.
2. All nodes have the same radio equipment and configuration.

For all simulations performed in this work, the parameters listed in Table - 5.1 are used.

Table 5.1: Simulation parameters for all simulations.

Network interface	Wireless
Channel type	Wireless channel
Routing protocol	DSR
Interface queue type	CMUPriQueue
Packet size	512 bytes
Radio interface	Lucent WaveLAN DSSS
Radio potency	24 dBm (factory standard)
Carrier frequency	914 MHz (factory standard)
Receive range	200 meters
Carrier sensing range	250 meters
Capture phenomenon	10x
Antenna model	Ominidirectional
MAC interface	802.11h
Traffic types	FTP-TCP and CBR-UDP

The simulations were carried out using File Transfer Protocol (FTP) on the TCP Vegas[1] variant, and Constant Bit Rate (CBR) on UDP[2]. In the case of CBR, it was stipulated traffic rate at 4 packets/seconds, a value also used and justified in (JOHNSON et al., 2001) and used in (BHUSHAN et al., 2019). Higher rates caused an exponential increase of packet loss due the fact that the intermediate nodes were unable to process and forward data packets due to the increase in the network congestion. For experiments using shadowing propagation model, only three different RNG Seeds were used to produce the average results due the computational stress that could be caused with more simulations.

Observations have been carried out in the simulations performed in this work. For the figures and tables given below, the following acronyms apply:

- TPS: total packets sent;
- TPR: total packets received;
- TPL: total lost packets;
- %PD: percentage packet delivery;

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[1] TCP Vegas is a TCP variant which uses a congestion avoidance algorithm that emphasizes packet delay, rather than packet loss, with a signal to help determine the rate at which to send packets. TCP Vegas detects congestion based on increasing Round-Trip Time (RTT) values of the packets in the connection, unlike other algorithms, which detect congestion only after it has actually happened via packet loss (BRAKMO et al., 1994).

[2] In this protocol, transmission of data is performed in bursts, and there is no verification of the network congestion. CBR service is used for connections that require fixed (static) bandwidth, and it has as typical applications interactive audio (telephony), audio and video distribution.

- TBR: total KBytes received;
- TPDSR: total DSR packets trafficked;
- TPCTR: total control packets trafficked;
- TPRERR: total RERR packets trafficked;
- TPDSRLOSS: total DSR packets loss;
- TPCTRLOSS: total control packets packets loss;
- TPC: Total power consumption in all nodes;
- WoM: without node movement;
- WM: with node movement;
- WoHT: without hidden terminals; and
- WHT: with hidden terminals.

The metrics evaluated in our simulations are:

- Delay: time difference between the transmission at the source node and the reception at the destination of a data packet;
- Overhead: number of bits of control packets required during transmission for correctly receiving messages at the destination;
- Packet Loss: total data packet loss over a period of time;
- Delivery Percentage: percentage of correctly delivered packets over a period of time. It indicates the loss rate that occurs in the network, and determines the maximum throughput that the network can support. This metric characterizes the integrity and efficiency of the routing protocol (MALTZ et al., 1999);
- Normalized Routing Load: number of routing packets transmitted per data packet delivered at the destination; and
- Normalized MAC Load: number of control packets, i.e., Acknowledgment (ACK), Address Resolution Protocol (ARP), Clear To Send (CTS), Request To Send (RTS) packets, on successful transmissions to the destination.

The propagation models are detailed with their characteristics, functionalities and mathematical formulation in the following.

5.2 Propagation models

A radio propagation model is a mathematical representation of electromagnetic waves propagation. These models have the objective of predicting, under certain characteristics, the signal power when it reaches the receiver. The attenuation of the signal depends on the carrier frequency, distance between transmitter and receiver, height of the antennas, among other factors. The radio channel between transmitter and receiver can be established only when the strength of the received radio signal is greater than the receiver's sensitivity threshold.

The reduction in signal power, on the path between transmitter and receiver is called path loss. Realistic path loss modeling can be a very complex task because transmitted radio waves could be reflected, absorbed or scattered by the obstacles. Receivers in a real environment receive not only one but many delayed components of the original signal (PESOVIC et al., 2010).

In the following, propagation models are detailed with their characteristics, functionalities and mathematical formulation.

5.2.1 Free-space model

The free-space propagation model is characterized by the fact that both the source and destination have complete view of each other, i.e., there are no obstacles between them and no other objects around them. The model predicts that power decreases with increasing distance between transmitter and receiver (PARSONS, 2001). The received power P_r is given by the Friis formula as

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{5.1}$$

in which P_t is the transmitted signal power, G_t and G_r are the antenna gains of the transmitter and the receiver, respectively, d is the distance between the antennas, L is other losses in the system[3] and λ is the carrier wavelength.

In a mobile radio channel, a single direct path between the base station and a mobile node is hardly the only physical means for propagation, and hence free-space in most cases is inaccurate when used alone (RAPPAPORT, 2002).

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[3] Other losses not associated with propagation loss. It includes loss at the antenna, attenuation, loss at filters and others. Generally this factor is greater than 1 or equal to 1 if there are no such losses in the system.

5.2.2 Two-ray ground model

The two-ray ground propagation model expands the free-space model to include a reflection component of the signal on the ground surface, i.e., it models the interference between the direct signal emitted from the transmitter to the receiver and the one reflected on the ground. As a result, the signal estimation accuracy is greater at longer distances than the free-space model (RAPPAPORT, 2002). The received power P_r is the result of contributions from the direct and reflected waves, and is given as

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \tag{5.2}$$

in which h_t and h_r are the heights of the transmit and receive antennas, respectively.

With the increase in the distance, Eq. (5.2) shows a power loss larger than Eq. (5.1). However, due to the oscillation caused by the constructive and destructive combination of the two rays, the two-ray ground model does not give good results at short distances.

Propagation models such as free-space and two-ray ground are considered simpler and may be inaccurate. However, they have been largely used in many works simulations of routing algorithms for MANETs. They are deterministic propagation models that do not consider the existence of obstacles between transmitter and receiver. With the shadowing propagation model, the signal level can vary in accordance to the statistical distribution selected (in this case, the log-normal distribution). Therefore, it offers results that are closer to the actual propagation environments. The characteristics of shadowing model is detailed in the following.

5.2.3 Shadowing model

Some of the problems related to wireless communications are multipath propagation, path loss, and interference. Due to the fact that the nature of the terrain is not the same everywhere, it is difficult to obtain an accurate and general estimation of the path loss during communication (JAYAKUMAR and GANAPATHY, 2007).

As indicated in (RAPPAPORT, 2002), environmental and infrastructural conditions are factors that influence the signal degradation in wireless communications. The shadowing propagation model is a static and non-deterministic model that assumes that there are a large number of obstacles between source and destination. The path loss is expressed, in dB, as

$$P_L(d) = -10\beta \log\left(\frac{d}{d_0}\right) + G(\mu, \sigma^2) \tag{5.3}$$

in which β is the path loss exponent, varying from 2 (free-space environment) to 4 (urban environment) or above, G is a log-normal random variable with mean value μ and variance σ^2, d is the distance between antennas, and d_0 is a reference distance.

5.3 Analysis I - Hidden terminals

Wireless networks are generally of broadcast type and all nodes share the same common channel. This might cause problems because eventually collisions may occur, i.e, when two or more nodes transmit at the same time. To solve this problem, physical access control protocols have been created to try to detect and prevent collisions. However, even with such protocols, it is difficult to detect if some node is already using the channel due the radio signal propagation characteristics and due to significant differences in the power of transmitted and received signals. This situation may cause what is known as the hidden terminal problem.

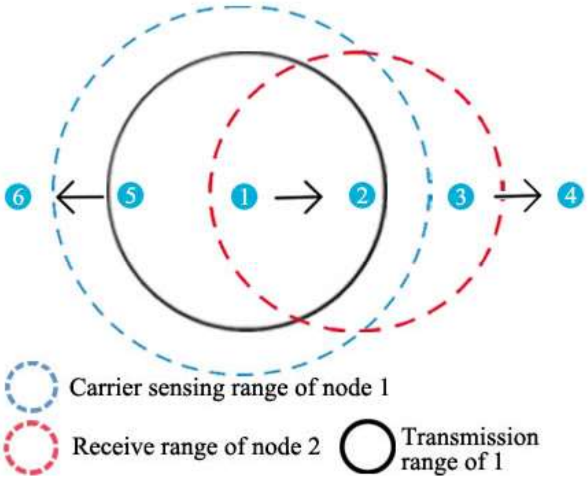
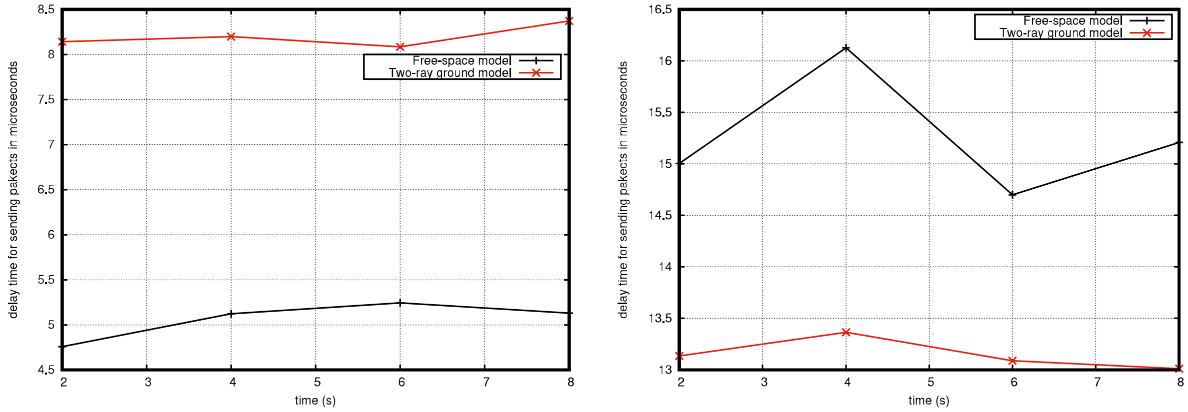


Figure 5.1: The hidden terminal problem example.

The hidden terminal problem occurs when there are nodes that are unable to detect other nodes transmissions. Thereby, it concludes that the channel is inactive and it may start transmitting packets simultaneously with other nodes that are not visible to it, causing collisions. In this case, delay, throughput, and other performance metrics are greatly affected (MARIN et al., 2018). Figure - 5.1 exemplifies these scenarios. When node 1 begins transmitting to node 2, node 3 does not detect that the channel is busy. If node 3 starts transmitting too, a collision might occur at node 2.



(a) Delay results without the presence of hidden terminals.

(b) Delay results with the presence of hidden terminals.

Figure 5.2: Delay with and without hidden terminals present.

5.3.1 Experiment I

To observe the interference caused by hidden terminals, and its influence in the performance results, simulations were performed in a scenario with five line-queued and static nodes, each placed at a distance of 200 meters from its closest neighbors, illustrated in Figure - 5.1. The same radio equipment described in Table - 5.1 was used with the following transport protocols and propagation models described in Table - 5.2:

Table 5.2: Simulation parameters for hidden terminal simulations.

Propagation models	Two-ray ground, free-space and shadowing
Traffic types	FTP-TCP and CBR-UDP

Figure - 5.2(a) shows simulations results with one node sending packets without the presence of hidden terminals. In this figure, the two-ray ground has almost double the delay compared to the free-space model. Figure - 5.2(b) shows the results of simulations with two nodes sending packets, characterizing the presence of hidden terminals. In this figure, two-ray ground has a lower delay compared to the free-space model. Firstly, it can be observed that the presence of hidden terminals worsens significantly the delay results for any of the two propagation models considered. In addition, stronger effects of hidden terminals are felt when free-space model is employed, indicating that the more severe attenuation found in the two-ray models minimizes the interference and, as a result, the nocive consequences of hidden terminals. To further probe the influence of the interference, please see Experiment II on Section 5.4.

Simulations to evaluate the effects hidden terminals were also performed with shadowing for $\beta = 2.5$ and different σ values. Table - 5.3 and Table - 5.4 show these results, highlighting the significant influence of the fading parameters. For $\sigma = 1$, the source node transmits packets directly to the destination. For $\sigma = 2$, the source node uses intermediate nodes in some moments to reach the destination, but often the transmission is direct due to the use of route shortening made by DSR. When the source node uses intermediate nodes to transmit packets, almost 100% of them reach their destination. When the node tries to send packet directly to the destination, the signal fading and broken links cause higher packet loss and greater need for packet retransmissions.

Figure - 5.3 shows the throughput with different σ values and $\beta = 2.5$. It is noticeable that the throughput is lower with higher σ values (which represents more severe fading). Also, the influence of hidden terminals is more evident with lower σ values (which represents milder fading). These results are in line with those already presented above, i.e., more severe attenuation of the radio signal negatively affects the network performance but, at the same time, minimizes the effect that hidden terminals produces.

Table 5.3: Results with hidden terminals and shadowing model with $\beta = 2.5$ and different σ values.

	TPS	TPR	TPDSR	TPRERR	TPCTRL
$\sigma = 1:$	1,212	1,207	33	1	15,304
$\sigma = 2:$	1,229	1,221	34	0	15,548
$\sigma = 3:$	1,303	1,298	30	1	16,511
$\sigma = 4:$	1,226	1,223	40	1	16,318
$\sigma = 5:$	993	990	43	2	14,596
$\sigma = 6:$	732	725	102	12	12,521
$\sigma = 7:$	505	500	288	45	10,896

Table 5.4: Results without hidden terminals and shadowing model with $\beta = 2.5$ and different σ values.

	TPS	TPR	TPDSR	TPRERR	TPCTRL
$\sigma = 1:$	1,308	1,305	21	0	16,252
$\sigma = 2:$	1,196	1,193	21	1	14,895
$\sigma = 3:$	1,341	1,339	24	1	16,808
$\sigma = 4:$	1,256	1,253	17	0	16,419
$\sigma = 5:$	1,090	1,088	25	1	15,564
$\sigma = 6:$	604	601	109	16	10,322
$\sigma = 7:$	343	340	104	14	6,811

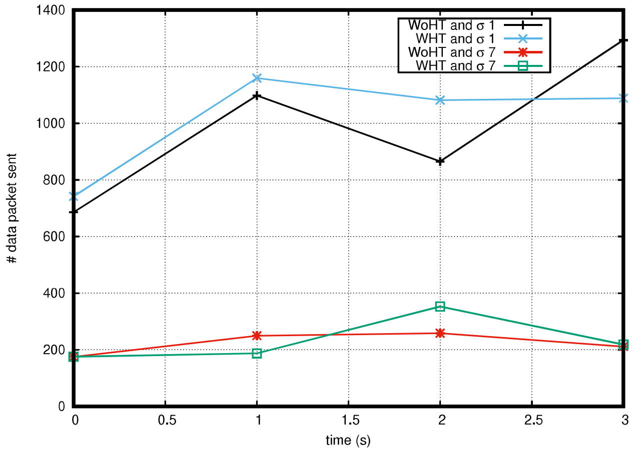


Figure 5.3: Results of throughput for shadowing with $\beta = 2.5$ and different values for σ.

5.3.2 Results and conclusions

Analysis of hidden terminal effect was described in this experiment. Results show the degradation of performance (in particular, delay and throughput metrics) due to the interference caused by hidden terminals in different propagation models. In our experiments, we emphasize the influence of signal attenuation in some propagation models, and concluded that the higher attenuation produces less interference in the channel.

To observe the effects of the presence of hidden terminals in the network with different propagation model (with their different signal attenuation), see Experiment I and II on Section 5.4 in the following.

5.4 Analysis II - Performance evaluation of DSR for MANETs with channel fading

Given that there is a wide variety of possible scenarios and applications, investigation about the performance and operation of MANETs is still an active research topic. In particular, with regards to the routing algorithms for these networks, several interesting study topics remains unexplored or overlooked.

Our aim in this analysis is to evaluate the performance and behavior of the DSR protocol in MANETs. Tests were carried out considering shadowing, two-ray ground, and free-space propagation models, with different configuration parameters and, TCP and UDP as transport protocols. The metrics evaluated are delay, overhead, packet loss, percentage of packet delivery, total load of control and route maintenance packets, which were detailed in Section 5.1. In the study presented here, simulation is used to examine several scenarios, offering new insights into the behavior of MANETs, and in particular the routing algorithms for such networks. The use of simulation is, again, justified due the greater flexibility in terms of modeling and the duration of the experiments (JAIN, 1991).

5.4.1 Experiment I

In this experiment, 50 nodes were randomly positioned in an 1000 x 1000 meters area, with ten of these nodes originating traffic addressed to a single destination, i.e., the drain of the network. In addition, shadowing was used, and network nodes were set to move in a constant speed of 20 km/h at random directions. In order to limit NS-2 log files, the maximum simulation time was set to 900 seconds. The nodes started moving for about 60 seconds until they stop at a random selected point[4]. This is repeated again at every 100 seconds until the end of the simulation. Table - 5.5 details the parameters used in the simulation environment.

In addition, the following assumptions are made:

1. Considering the scenarios with movement of nodes, all of them move independently of others.
2. The average distance between a node and its 7 closest neighbors is 187 meters[5].
3. The average distance between the nodes and the drain is 311 meters.

Interestingly, Table - 5.6 and Table - 5.7 show higher percentage of packet delivery when nodes are moving in comparison to the static case, for both set of fading parameters values. Also, TCP shows better performance when compared to UDP. The latter protocol has a very small percentage of packet delivery when severe fading is considered.

Considering the average delay, simulations indicate that the two-ray ground model outperforms free-space and shadowing, as shown in Figure - 5.4(a), and compared to

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[4] This is a widely used mobility model for study of ad hoc networks (JOHNSON et al., 2001). In such model, each mobile node begins at a random location and moves independently during the simulation. Each node remains stationary for a specified period that it called pause time, then moves in a straight line to some new randomly chosen location at a randomly chosen speed up to some maximum speed, and continues to repeat this behavior throughout the simulation run. According to (JOHNSON et al., 2001), this model produce large amounts node movement, with network topology change and a good stress in the DSR operation.

[5] The distance between two points in a plane with Cartesian coordinates A(x1,y1) and B(x2,y2) is given by the Pythagorean Theorem, which has the segment $\overline{AB}$ as its hypotenuse.

Table 5.5: Simulation parameters for experiment I.

Mobility	20 km/h
Simulation time	900 s
Number of nodess	50
Occupation area	1000 x 1000 meters
Mobility	Random way point
Antenna gain	3.5 dBi
Receive range	200 meters
Carrier sensing range	250 meters
Propagation models	Free-space, shadowing and two-ray ground

Table 5.6: Results of TCP simulations with shadowing.

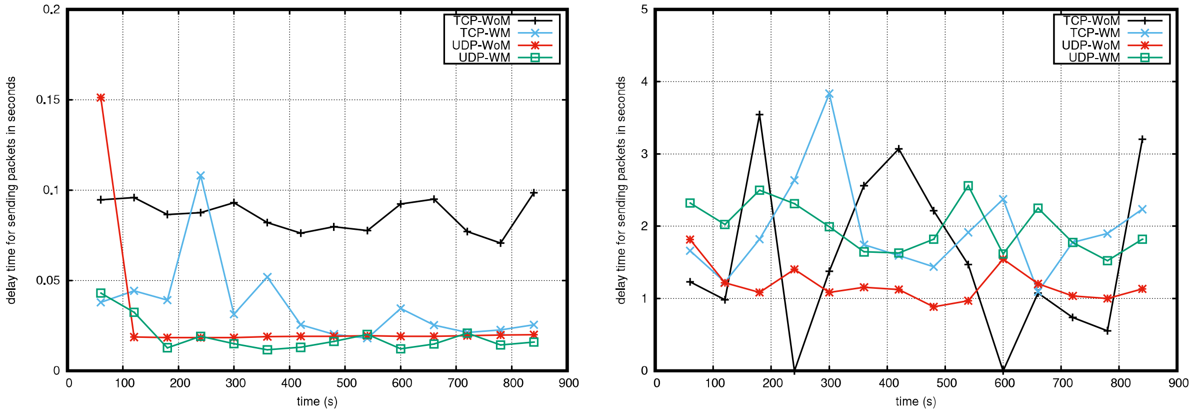
	$\beta = 2$ and $\sigma = 5$		$\beta = 3$ and $\sigma = 10$	
	WoM	WM	WoM	WM
TPS:	569	2,010	369	463
TPR:	201	1,576	1	88
TPL:	367	434	368	375
%PD:	35.19%	77.79%	0.36%	17.54%
TBR:	824,693	6,456,811	5,461	360,523
TPDSR:	1,160,370	878,029	1,128,295	937,054

Table 5.7: Results of UDP simulations with shadowing

	$\beta = 2$ and $\sigma = 5$		$\beta = 3$ and $\sigma = 10$	
	WoM	WM	WoM	WM
TPS:	28,800	28,800	28,441	28,775
TPR:	2,446	11,272	23	858
TPL:	26,354	17,528	28,418	27,917
%PD:	8.49%	39.14%	0.08%	2.98%
TBR:	10,020,736	46,169,749	95,808	3,516,021
TPDSR:	1,124,476	848,942	1,048,538	895,467

Figure - 5.4(b), Figure - 5.5(a) and Figure - 5.5(b). This difference occurs due to smaller interference seen in the two-ray model, as already mentioned. Node movement has small influence in the results obtained with free-space and two-ray channel models. For shadowing, simulation results for scenarios using $\{\beta, \sigma\} = \{2, 5dB\}$, and $\{3, 10dB\}$ are somewhat similar, as shown in Figure - 5.5(a) and Figure - 5.5(b), but with lower delays seen for the more severe fading conditions.

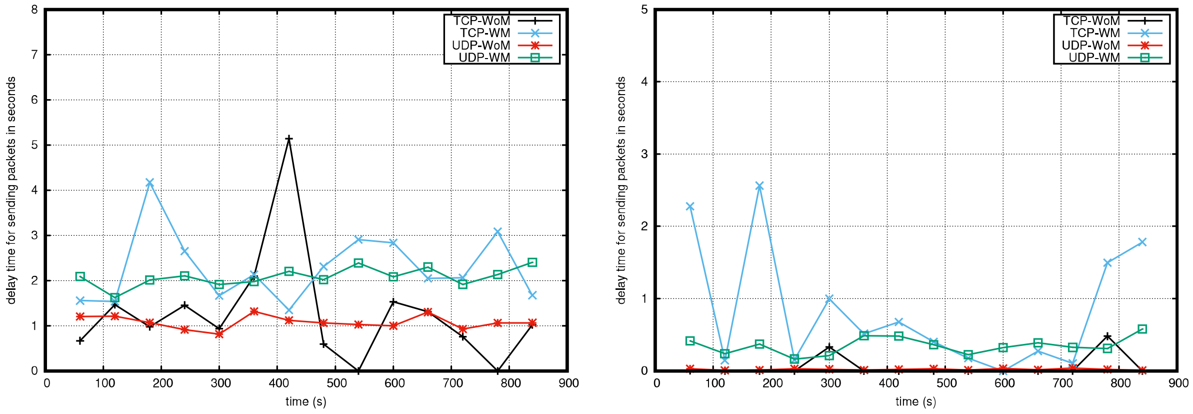
In general, two-ray ground model offers better results for the metrics evaluated here when compared to the other propagation models. For instance, Figure - 5.6(a) shows



(a) Delay in two-ray ground propagation model.

(b) Delay in free-space propagation model.

Figure 5.4: Delay in two-ray ground and free-space propagation model with and without nodes movement, at TCP and UDP transmissions.

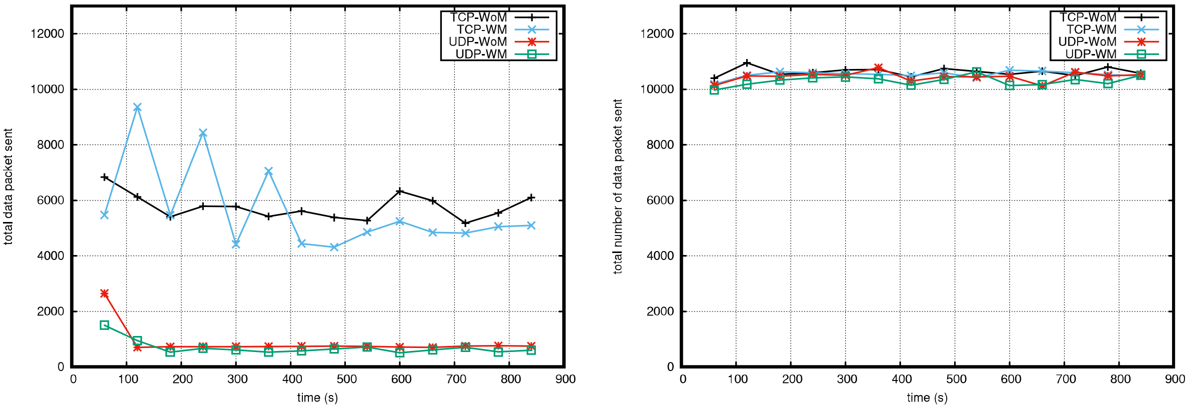


(a) Delay in shadowing propagation model with low values for β and σ.

(b) Delay in shadowing propagation model with high values β and σ.

Figure 5.5: Delay in shadowing propagation model with and without nodes movement, at TCP and UDP transmissions.

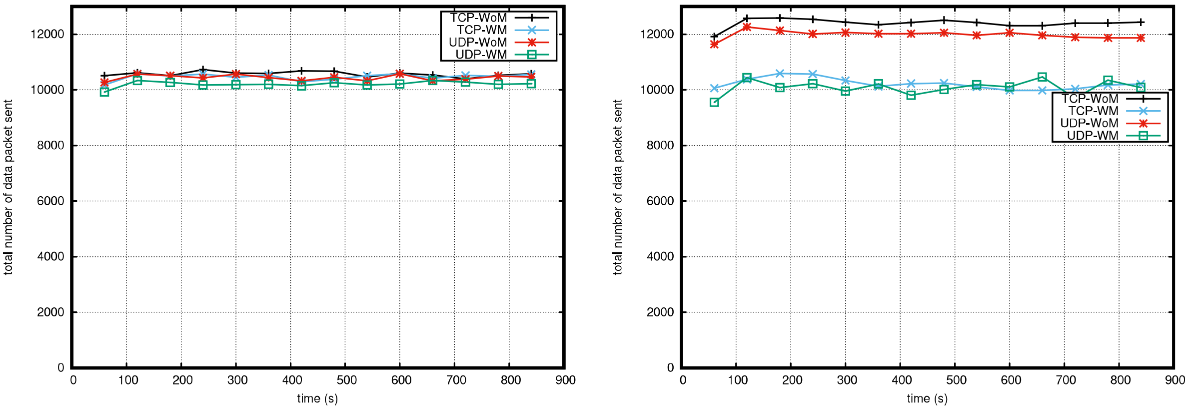
simulations results for the overhead with two-ray ground model, noticing that higher overhead is expected for TCP transmissions because of its greater use of control packets. For free-space and shadowing models the observed overhead is higher, as can be seen in Figure - 5.6(b), Figure - 5.7(a) and Figure - 5.7(b). In these figures, UDP and TCP transmissions produce similar results for free-space and shadowing propagation models. Also, it is noticeable that shadowing results for mild fading (lower values of σ) exhibit better performance. This is due the fact that in the free-space propagation model, the attenuation in closer to the square of the distance. However, the attenuation in two-ray ground is proportional to the fourth power of the distance.



(a) Overhead in two-ray ground propagation model.

(b) Overhead in free-space propagation model.

Figure 5.6: Overhead in two-ray ground and free-space propagation model with and without nodes movement, at TCP and UDP transmissions.

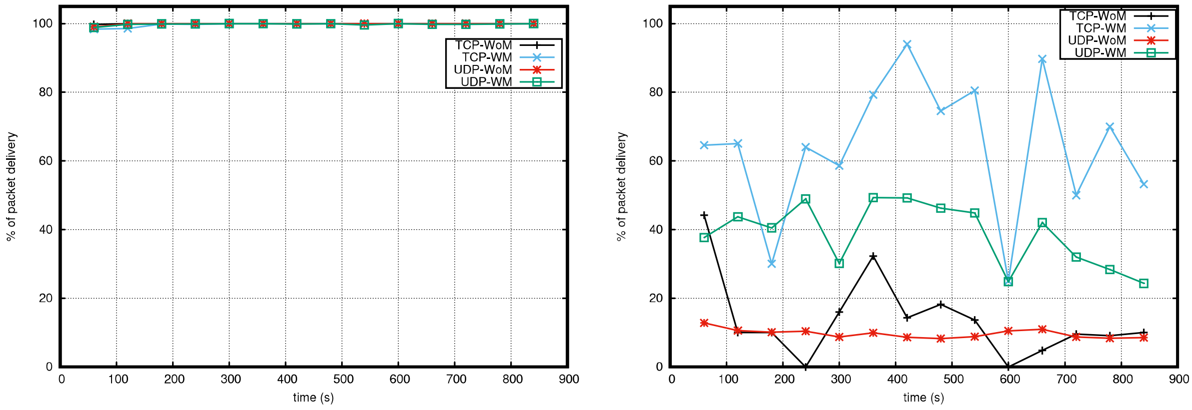


(a) Overhead in shadowing model with low values for β and σ.

(b) Overhead in shadowing model with high values for β and σ.

Figure 5.7: Overhead in shadowing propagation model with and without nodes movement, at TCP and UDP transmissions.

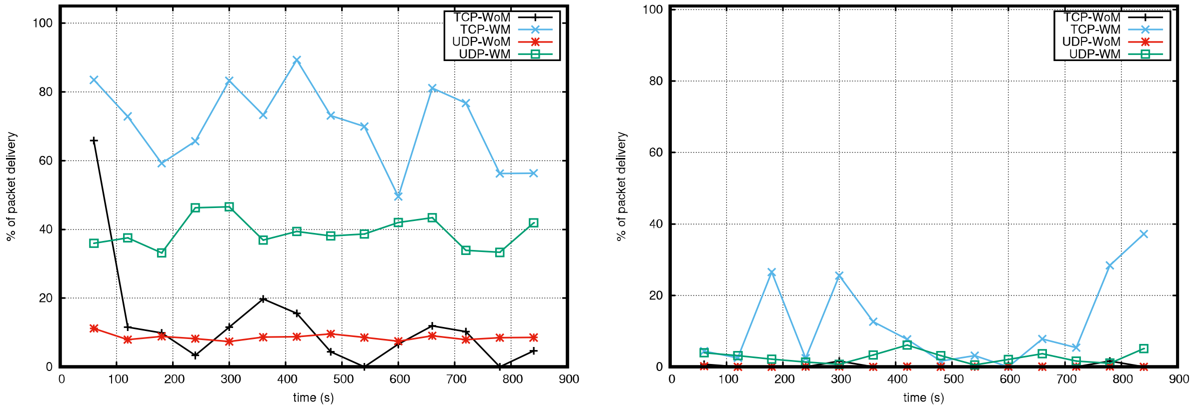
In Figure - 5.8(a) to Figure - 5.9(b), it is possible to compare the results for packet delivery percentage with two-ray ground, free-space and shadowing propagation models. Clearly, two-ray ground offers better results due to smaller radio interference observed.



(a) Percentage of packet delivery in two-ray ground propagation model.

(b) Percentage of packet delivery in free-space propagation model.

Figure 5.8: Percentage of packet delivery in two-ray ground and free-space propagation model with and without nodes movement, at TCP and UDP transmissions.



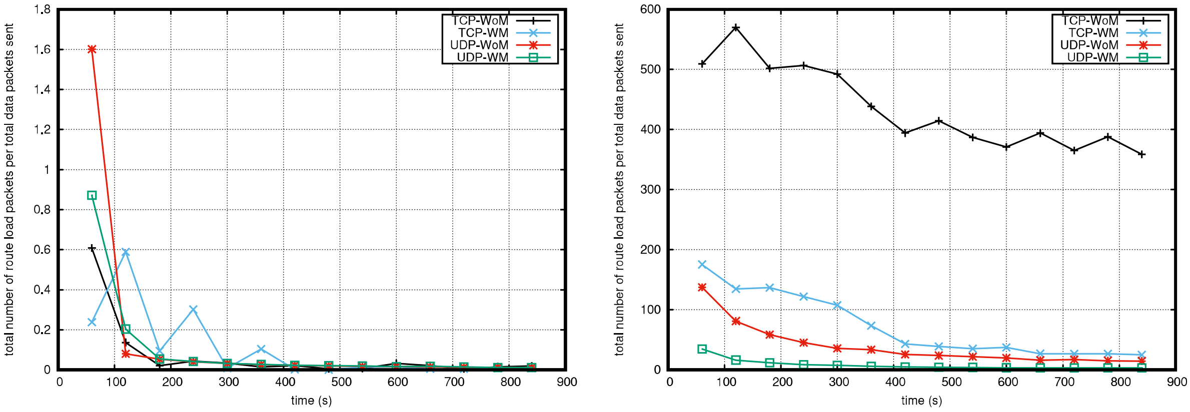
(a) Percentage of packet delivery in shadowing model with $\beta = 2$ and $\sigma = 5$.

(b) Percentage of packet delivery in shadowing model with $\beta = 3$ and $\sigma = 10$.

Figure 5.9: Percentage of packet delivery in shadowing propagation model with and without nodes movement, at TCP and UDP transmissions.

Also, from the figures it can be seen that TCP transmissions offer better results, which might be because TCP can change the time in which packets are sent, according to its perception of the network capacity, collected from the Acknowledgment Messages (ACKs) that the destination transmits. In addition, for the shadowing model, best results are obtained for mild fading (low β and σ values). In these figures, it is noticeable the better percentage of packet delivery with lower values of σ. This is due to the fact that higher σ values represent more severe fading.

Figure - 5.10(a) and Figure - 5.10(b) show results regarding the amount of DSR packets that are required for discovery and maintenance routes with two-ray ground and free-space environments, respectively, and Figure - 5.11(a) and Figure - 5.11(b) show the use of MAC packets protocol with the two-ray ground and free-space models, respectively. The graphs demonstrate the higher use of these packets in TCP compared to UDP transmissions, due to the amount of ACK packets used by former. In the simulated scenarios, Normalized MAC Load is larger than Normalized Route Load due to the fact that for each DSR packet transmission (RREP, RERR and RSHORT), carrier detection is required, and MAC packets are also used for each send of DSR packets.



(a) Normalized Routing Load in two-ray ground propagation model.

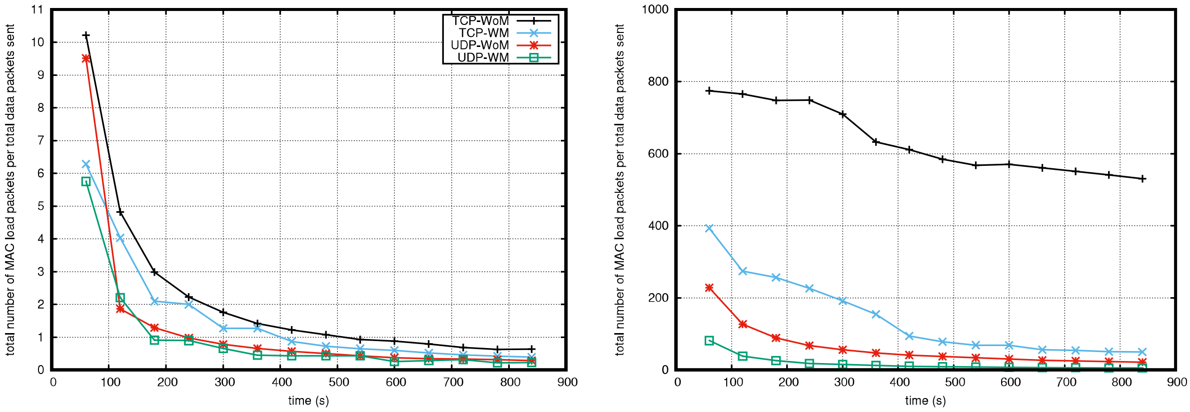
(b) Normalized Routing Load in free-space propagation model.

Figure 5.10: Normalized Routing Load in two-ray ground and free-space propagation model with and without nodes movement, at TCP and UDP transmissions.

Table 5.8: Results of TCP simulations with free-space and two-ray ground model.

	RTS	CTS	RREQ	RREP	RERR
Free-space:	844810	588698	352889	299311	18727
Two-ray ground:	736875	478588	14879	6062	5746

Due to lower signal attenuation in free-space environments when compared to two-ray ground environments, higher number of packet collisions and channel interference occurs. Therefore, a larger amount of MAC and DSR packet transmissions is observed in the mentioned figures, mainly in TCP transmissions. Table - 5.8 shows the total packet transmissions of MAC and DSR protocols during simulations in environments characterized by free-space and two-ray ground models. It is noticeable the larger number of transmissions of these packets in the free-space model. This is due to the lower attenuation of the signal in this model, causing greater number of collisions and with this, greater need for resending these packets. As previously mentioned, further experiments aimed at exemplifying the effects of the lower attenuation of the free-space model and a possible solution to the related problem will be elucidated in Experiment II.



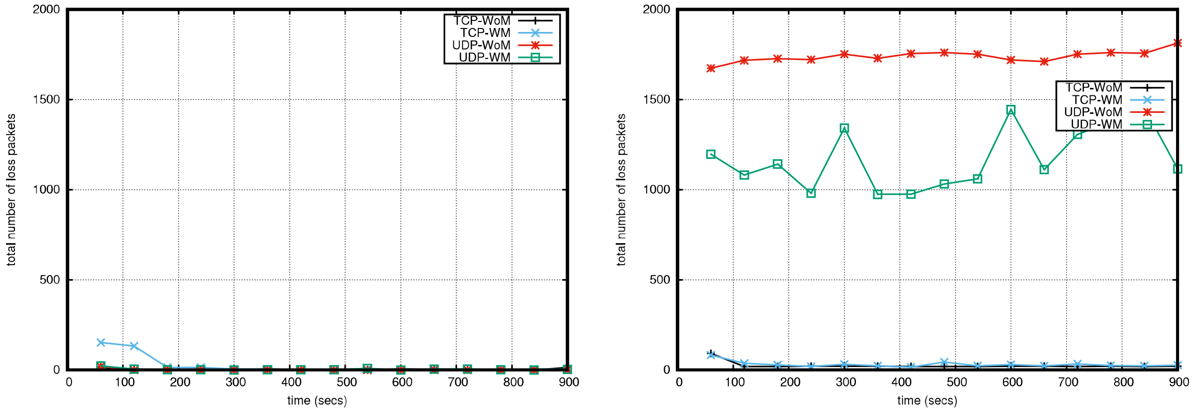
(a) Normalized MAC Load in two-ray ground propagation model.

(b) Normalized MAC Load in free-space propagation model.

Figure 5.11: Normalized MAC Load in two-ray ground and free-space propagation model with and without nodes movement, at TCP and UDP transmissions.

Figure - 5.10(b) and Figure - 5.11(b) present the behavior and performance results of the algorithm under free-space propagation model, reporting the use of DSR and control packets, respectively. The graphs show the difficulty in route establishment and route maintenance for packet transmissions, causing high use of these packets, in particular in the simulation with static nodes and TCP transmissions. One factor that influences the high consumption of control packets is the fact that the signal attenuation of free-space is less severe, causing more interference in the channel when compared of two-ray ground. However, when nodes ar moving, DSR does a good job in maintaining routes with less use of control and maintenance packets. The same graphs demonstrate the low use of control packets with UDP, since this protocol does not use them as often as TCP.

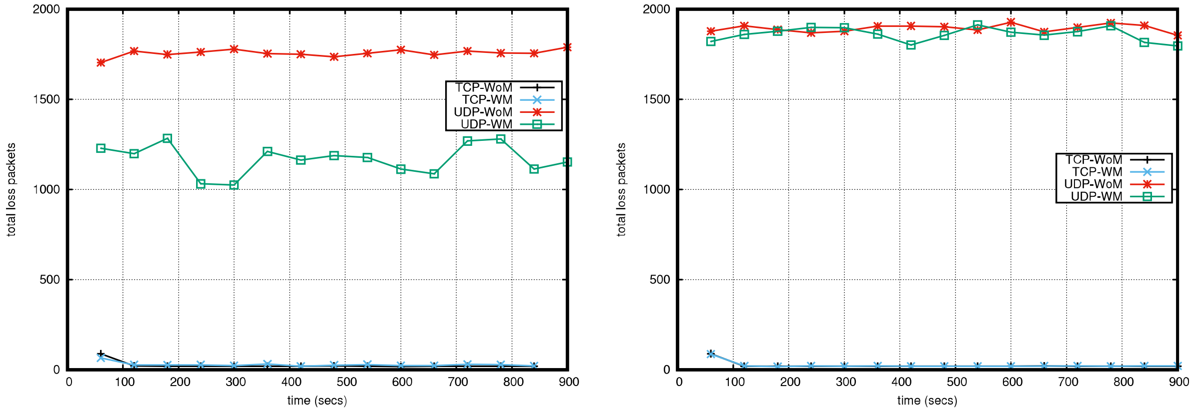
Figure - 5.12(b) to Figure - 5.13(b) show the packet loss for the propagation models free-space and two-ray ground with and without node movement, and shadowing with low and higher β and σ values, respectively. Figures for TCP traffic is similar for all models considered; however, for UDP traffic, figures for the two-ray ground are significantly



(a) Loss packet two-ray ground propagation model.

(b) Loss packet free-space propagation model.

Figure 5.12: Loss packet in two-ray ground and free-space propagation model with and without nodes movement, at TCP and UDP transmissions.



(a) Loss packet in shadowing model with $\beta = 2$ and $\sigma = 5$.

(b) Loss packet in shadowing model with $\beta = 3$ and $\sigma = 10$.

Figure 5.13: Loss packet in shadowing propagation model with low and higher β and σ values respectively, at TCP and UDP transmissions.

lower than those for the other models. As indicated above, lower interference seen in the two-ray ground models explains the results, noting that TCP seems less impacted by this situation than UDP traffic. Finally, for shadowing model mainly for UDP transmissions, it is noticeable that packet loss is higher with higher values of β and σ. Table - 5.6 and Table - 5.7 summarize the results of both simulations.

The following experiment explores why the two-ray ground model shows better delay results when compared to the other propagation models.

5.4.2 Experiment II

Results obtained in Experiment I, especially with free-space and two-ray ground models, indicate a large delay difference for these propagation models. This is due to the different attenuation with distance from the transmitting antenna experienced by the signal for these models. In the free-space model, the signal attenuation is proportional to the square of the distance (see Equation 5.1), whereas in the two-ray ground model the signal decays proportionally to the fourth power of the distance (see Equation 5.2). Therefore, the two-ray ground model causes less interference in the channel because its attenuation is greater in comparison to the free-space model. An example of this can be seen in Figure - 5.4(a) and Figure - 5.4(b), which highlights the smaller delay in simulations with two-ray ground model.

A possible solution to the interference problem caused by lower attenuation in some propagation models is to transmit packets with only the minimum power required to reach the desired destination. For this, adjustments in the radio's transmission power may be performed depending on the distance between transmitter and receiver.

In this experiment, we assume the following:

- All nodes have the same radio configuration, carrier sense and reception range.
- The antenna gain at set is 1.5 dBi.

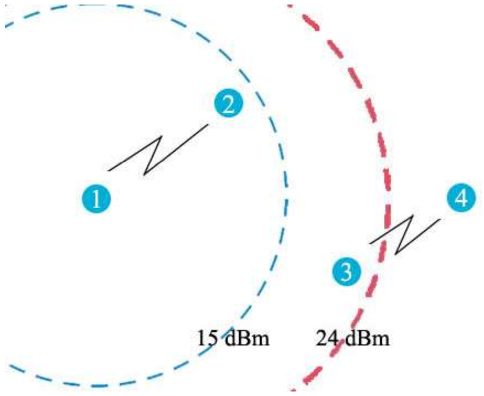


Figure 5.14: Representation of node 1's signal range for radio power at 15 and 24 dBm.

Figure - 5.14 shows the situation considered here, with the aim of exploring the interference caused by higher radio's transmission power. In this scenario, node 1 intends to send packets to node 2 and node 3 intends to send packets to node 4. In this figure, it is noticeable that using the original configuration of the radio (transmit power at 24 dBm), node 1 causes greater interference in the channel because its radio signal reaches all other nodes. However, by reducing the radio power to 15 dBm, which is the minimum necessary to reach the desired destination, it reduces the interference in the network and allows for parallel transmissions to occur.

Table 5.9: Results for transmissions with different radio power.

	TPS	TPR	%PD	RREQ	RTS	CTS	ACK
24 dBm:	20	20	100%	4	46	44	44
15 dBm:	20	20	100%	6	22	2	22

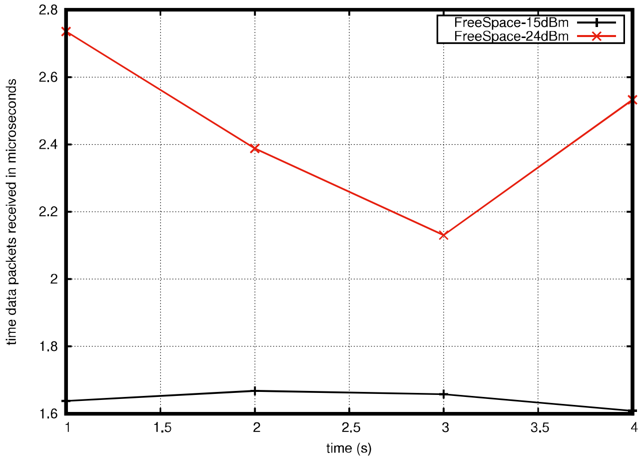


Figure 5.15: Delay in free-space model at different transmission powers.

Table - 5.9 shows the results of transmissions with the two different radio power settings, highlighting the good packet delivery percentage in the free-space model for both simulated power (15 dBm and 24 dBm). However, in the simulation where the radio power was adjusted to 24 dBm, it is noticeable the greater amount of control packets (RTS, CTS and ACK) needed to transmit data, resulting in longer wait compared to simulations where the radio was set to 15 dBm. These results can also be seen in Figure - 5.15, highlighting the smaller delay in the free-space model when radio power was set at 15 dBm.

5.4.3 Results and conclusions

In the current Experiments, performance of the DSR algorithm for ad hoc networks is presented. We observe that the algorithm has low delay and overhead for both two-ray ground and free-space propagation model, and two-ray ground has a packet delivery close to 100% for both TCP and UDP transmissions. An important reason for this is the fact that DSR operates fully on demand, as described in (JOHNSON et al., 2001). However, for a good operation of the algorithm, adjustments in the antenna gain or radio power might be necessary in order to minimize interference. In fact, the successful operation of the network might be based on the careful selection of the radio power level, as indicated above. The interference level and the presence of hidden terminals influences significantly the performance figures, and if one wishes to optimize the network operation this might be a very good parameter to start at.

Analysis of hidden terminal effect showed the degradation of performance (in particular, delay and throughput metrics) due to the interference caused by hidden terminals in different propagation models. In our experiments, we emphasize the influence of signal attenuation in some propagation models, and concluded that the higher attenuation in the two-ray ground model is a benefit in dense networks (see Experiments I and II), since it produces less interference in the channel.

For all tests, two-ray ground and free-space propagation models, with the static and moving nodes, obtained very close results for overhead. In our results, it is clear that the better performance of the algorithm with regards to the percentage of packet delivery and other metrics is seen when TCP is used. In our simulation, results indicated the good performance of the algorithm's route maintenance mechanism when the nodes are in movement, showing a better packet delivery percentage.

In our simulations, we found that shadowing propagation model has good results in mild fading environments. However, such scenarios may not accurately represent urban environments. Therefore, when performing the simulations in more severe fading environments, with buildings and other constructions, the simulation with shadowing propagation model shows low packet delivery and high overhead results. In this propagation environment, the route management of DSR may not work correctly because often RERR messages (link breakage) may not reach the source node and, in such case, it may continue sending packets via a broken link.

5.5 Analysis III - Performance of DSR algorithm in VANETs

Vehicular Ad Hoc Networks (VANETs) are one of the most common application of MANETs. Two main possibilities of implementation are devised: Vehicle-to-Vehicle (V2V) in which automobiles transmit information without a coordination infrastructure; and Vehicle-to-Infrastructure (V2I) in which repeaters along the roads communicate between vehicles (CARVALHO et al., 2015). Simulations were performed with V2V and V2I data communications and were carried out considering TCP traffic with shadowing propagation model, with different configuration parameters, in order to maximize throughput, and reduce delay. Figure - 5.16 exemplifies the scenario we used in this simulations.

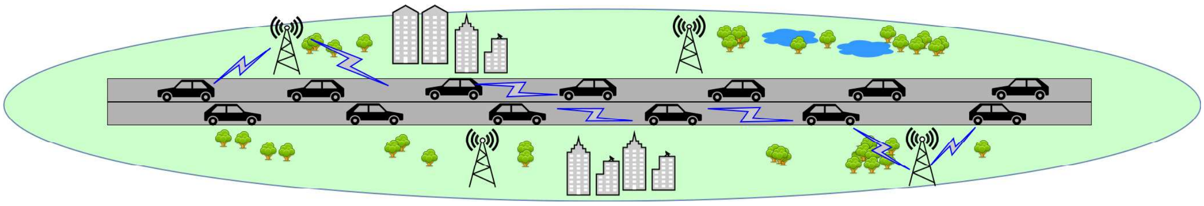


Figure 5.16: Scenario used in simulations.

5.5.1 Experiment I

We performed tests with 100 nodes positioned along a two lane-road in a 1500 x 300 meters space, using the radio configuration of the previous experiments. The average distance between same-lane nodes was 30 meters and the range of communication in this scenario was 550 meters and, with this distance, packets can be transmitted between nodes and between poles and nodes. The height of the retransmission poles was set at 8 meters. It was noticed that retransmission poles placed 500 meters apart showed the best arrangement, which is in line with the radio communication range. Larger distances between poles causes increased overhead, lower throughput and greater packet loss. Smaller distances did not cause any severe impact on the performance of the network. Two cases were considered: single and dual-channel arrangements. In the former, vehicles on different lanes communicate with each other and with the poles using the single channel available. In the latter case, each channel was dedicated to a single lane, i.e., channel was assign according to the direction of vehicle flow.

For simulations in this study we used the same radio configuration described on Table - 5.1; also, simulation time was set to 15 seconds in order to guarantee that vehicles are

Table 5.10: Simulation parameters.

Package size	512 bytes
Mobility	50 km/h
Simulation time	15 s
Number of nodes	100
Occupation area	1500 x 300 meters
Antenna gain	5.5 dBi
Type of traffic	FTP-TCP
Model of propagation	Shadowing

still within radio range for the entire simulation. Table - 5.10 summarizes the parameters used in the simulation environment.

Table 5.11: Results for different distance between poles.

	500 meters	600 meters
Total packets sent:	2,381	2,184
Total packets received:	2,366	2,174
Total lost packets:	15	10
Percentage of packet delivery:	99.29%	99.54%
Total KBytes received:	969,2597	890,6069
Total DSR packets trafficked:	1,384	836
Total control packets trafficked:	24,862	22,938

Table - 5.11 shows some results for poles separated by 500 and 600 meters when two vehicles are transferring data, with only one channel available. The results highlight the lower packet delivery in the scenario with distribution of poles at 600 meters of distance, and also the higher use of control packets and routes maintenance packets.

For Table - 5.12 and all the figures, the following applies:

- DTrans: direct vehicle to vehicle transmission;
- 1T1C: one vehicle transmitting, with poles, and using a single channel;
- 2T1C: two vehicles transmitting, with poles, and using a single channel; and
- 2T2C: two vehicles transmitting, with poles, and using double channels, one per direction of vehicle traffic flow.

Table - 5.12 presents results obtained assuming that $\beta = 2.5$ and $\sigma = 7$ for the shadowing propagation model. As it can be seen, in the scenarios evaluated the percentage

Table 5.12: Results for FTP-TCP and shadowing

	DTrans	1T1C	2T1C	2T2C
TPS:	164	2,256	2,381	5,530
TPR:	161	2,250	2,366	5,524
TLP:	3	6	15	6
%PD:	67.15%	99.55%	99.29%	99.85%
TBR:	658,091	921,6000	969,2597	22,624,939
TPDSR:	311	198	1,384	330
TPCTRL:	3,959	18,775	24,862	43,377

of package delivery is very close to 100% in almost all cases. However, the results differ when throughput, DSR packets and control packets are considered. When two vehicles are transferring data, with only one channel available, the use of DSR packets for route stabilization and maintenance increases by 599%, and the use of control packets increases by 32%, when compared to results with only one vehicle transmitting. The results also show a difference in the number of packets sent. In the scenario where two channels are available, one for each direction of the vehicle traffic flow, there is a considerable increase in the number of packets sent when compared to the single channel scenario.

Figure - 5.17 shows results for overhead. The lowest overhead is seen when there is only one vehicle transmitting. However, in all cases, a peak in the overhead is observed around 6 seconds of simulation, which is when the vehicles distance themselves from the retransmission poles.

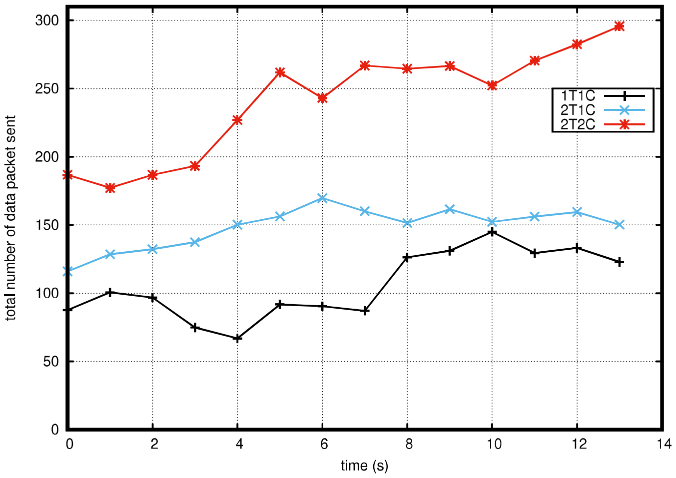


Figure 5.17: Overhead for FTP-TCP in shadowing environment.

All scenarios shows very good percentage of packet delivery, which can be seen in Figure - 5.18. This is due to the fact that TCP uses packet retransmission if a previous attempts fails.

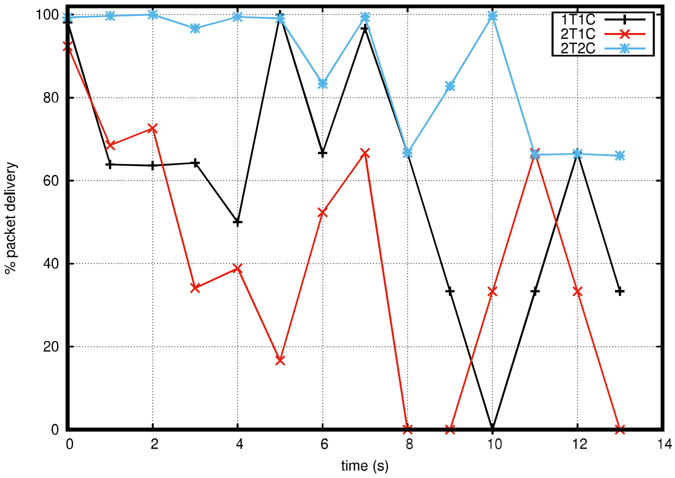
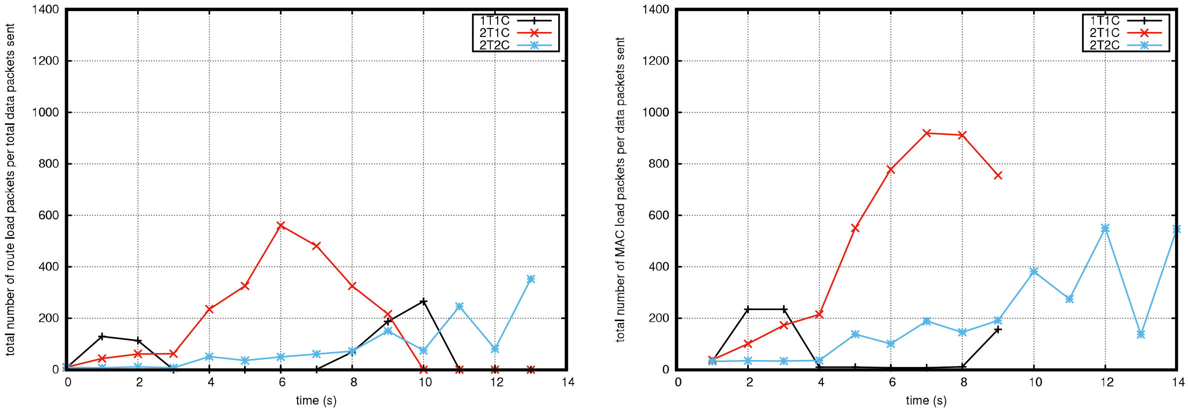


Figure 5.18: Percentage of delivery for FTP-TCP in shadowing environment.

Figure - 5.19(a) presents the usage of control and DSR packets during the dialogs. The curves indicate the cost to establish, maintain and acknowledge the transmissions. Note that at around 6 to 8 seconds of simulation, once the sender vehicle moves away from the retransmission pole, there is a significant increase in the number of DSR packets. The same situation can be seen with the use of control packets in Figure - 5.19(b) at the same instant of time.

Figure - 5.19(b) shows the traffic of MAC control frames, i.e., RTS, CTS, ACK, ARP, and others. It can be noted that there is a peak in the traffic of these messages in the second half of the simulation. This is caused by the sender vehicle moving away from the pole, and it is due to attempts to establish an alternative route using other vehicles available.

Figure - 5.20 shows results for total packets loss. It can be seen that, regardless of the numbers of channels available, packet loss is fairly low throughout the simulation time. Figure - 5.21 shows the throughput during the simulation. It is noticeable that the best throughput rate happens when there are two separate channels, one for each lane. At around 6 seconds of simulation one notices a drop in the throughput due to the fact that the destination vehicle distances itself from the retransmission pole. In addition, the figure shows the efficiency of the algorithm in route maintenance, returning a rate of throughput close to the rate at the beginning of the simulation.



(a) Normalized routing load for FTP-TCP in shadowing environment.

(b) MAC routing load for FTP-TCP in shadowing environment.

Figure 5.19: Normalized and MAC routing load for FTP-TCP in shadowing model, at TCP and UDP transmissions.

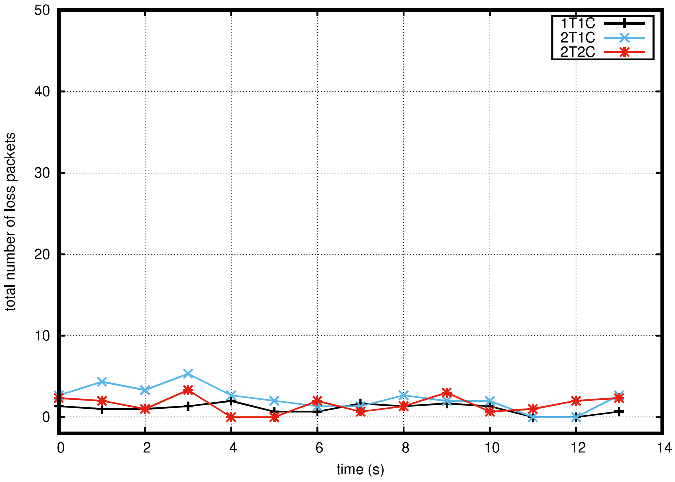


Figure 5.20: Packet loss for FTP-TCP in shadowing environment.

Figure - 5.22 shows results for the delay in the evaluated scenarios. Lower delay is noticed up to the moment when vehicles reach the transmission pole in all scenarios. From the moment vehicles move away from the poles, the routing protocol uses alternate routes using other vehicles to route the data packets to the destination. As a result, an increase in the delay can be observed.

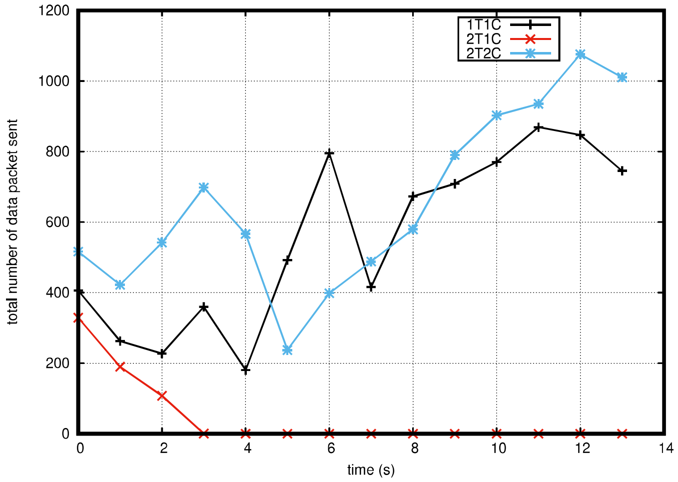


Figure 5.21: Throughput for FTP-TCP in shadowing environment.

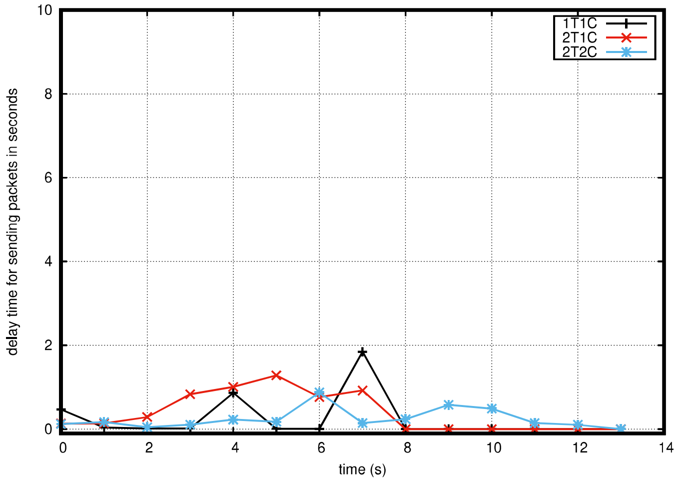


Figure 5.22: Delay for FTP-TCP in shadowing environment.

5.5.2 Results and conclusions

In the experiment presented here, simulations were performed in a 1500 x 300 meters space with 100 mobile nodes (vehicles) evenly divided between two road lanes, each going in an opposite direction. In all cases, the nodes were moving at a constant speed of 50 km/h. The goal was to analyze the performance of the DSR algorithm for VANETs. Results showed that the overhead varied depending on the particular scenario used. Also, since FTP-TCP was used, and TCP tries to retransmit any failed transmission, the packet delivery was close to 100% in all cases. In addition, results showed that the percentage of packet lost were similar in all scenarios. It can be noticed that if dual-channel is used, one for each vehicle traffic direction with retransmissions poles, the overall performance is enhanced.

As expected, it was noticed that retransmission poles placed 500 meters apart showed the best arrangement. Larger distances between poles causes increased overhead and greater need for packet retransmission. Smaller distances did not cause any severe impact on the performance of the network.

As mentioned in Sect. 4, routing protocols that use the on-demand route discovery scheme should include some kind of route caching, so that the originator does not need to perform a route discovery operation every time it has a packet to transmit. In particular, DSR makes even greater use of the route caching by not only storing the primary and secondary routes, but also allowing intermediate nodes to respond to route requests even if they are not the desired destination. This might be one of the reasons DSR shows good results in the simulations presented in this experiment.

5.6 Analysis IV - Evaluation of energy consumption in sensors nodes based on energetic efficiency

MANETs work on the assumption that every node in the network, receives data and forwards it to its neighbors. This process is repeated until the data reaches the destination node.

Nodes with a large number of neighbors might receive multiple copies of the same message. This creates a problem of broadcast flooding in MANETs, which is an important factor for higher energy consumption in mobile nodes.

In this analysis, we show the evaluation of energy consumption in different ad hoc network scenarios, investigating the influence of the number of hops, shadowing parameters and the difficulty of the algorithm to maintain routes in an environments with higher noise levels, and how to save battery with a good distribution of sensors.

5.6.1 Energy consumption as a function

In each network node, energy is spent by three ways: in transmissions, in detection/reception of data, and in data processing. Therefore, the energy consumption is given as

$$E = E_t + E_r + E_p \tag{5.4}$$

in witch E_t is the energy spent for packet transmission, E_r is the energy spent with packet reception, and E_p is the energy spent with packet processing.

5.6.2 Experiment I

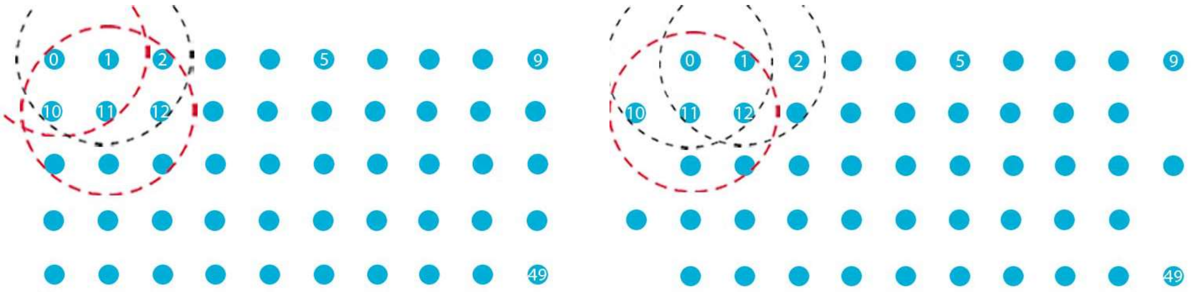
In this experiment, we consider a case with 50 nodes that are spread out to cover an area of 1500 x 1000 meters, as shown in Figure - 5.23(a) and Figure - 5.23(b). UDP was used as transport protocol and two-ray ground as propagation model. Figure - 5.23(a) and Figure - 5.23(b) show simulated scenarios of this experiment highlighted the different distribution nodes in an area of 1500 x 1000 meters. The first experiment in these scenarios, nodes 1, 5 and 9 intends in transmission data packets to node 49 (the drain of the network). Table - 5.13 show the parameters and configuration of simulated environment for this experiment.

Table 5.13: Simulation Parameters.

Mobility	0 km/h
Simulation time	15 s
Number of nodes	50
Occupation area	1500 x 1000 meters
Antenna gain	3.5 dBi
Traffic types	CBR-UDP
Propagation models	Two-ray ground

For all simulations of this experiment, we assume the following condition:

1. A specific number of packets was sent in each simulation.



(a) Scenario 1.

(b) Scenario 2.

Figure 5.23: Distribution of nodes in different scenarios.

Figure - 5.24 shows the power consumption in the simulated scenarios. In the same figure, it is noticeable the lower energy consumption of scenario 2. This is due to the fact that in scenario 2 nodes were organized in such a way as to optimize the radio coverage and at the same time avoiding the reception of duplicate control and data packets.

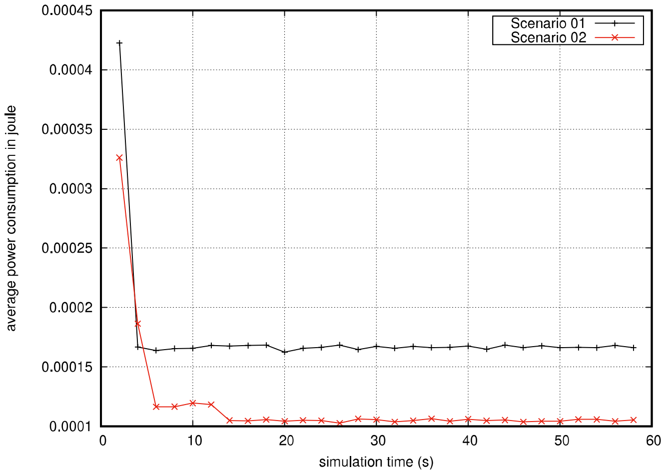


Figure 5.24: Comparative of energy consumption with two-ray model UDP transmission between scenarios 1 and 2.

In Figure - 5.23(a), it is noticeable that node 10, receives at least three RREQ packets for route discovery (sent by nodes 0, 1 and 11). Moreover, Figure - 5.23(b) shows that the same node receives only two RREQ packet (sent by nodes 0 and 11), resulting in less energy consumption for such environment. Results collected from simulations performed in this experiment are presented in Table - 5.14.

Table - 5.14 shows simulations results for scenarios 1 and 2, highlighting the use of 202 DSR packets (RREQ, RREP, RERR and RSHORT) in scenario 2, compared to 587 used in scenario 1 over the same period of time. Also, the same table indicates benefit of optimized node distribution of scenario 2 when compared to scenario 1, showing 12.08% higher power consumption for the latter, and 13.98% and 190.59% higher use of MAC and DSR packets.

Table 5.14: Comparison of results from scenarios 1 and 2.

	TPS	TPR	%PD	TPCTRL	TPDSR	AEC
Scenario 1:	720	712	98.9%	11,685	587	0.00436
Scenario 2:	720	720	100%	10,252	202	0.00389

Figure - 5.25 shows the influence the distance between source and destination node might have on energy consumption of scenarios 1 and 2. In these simulations, when the

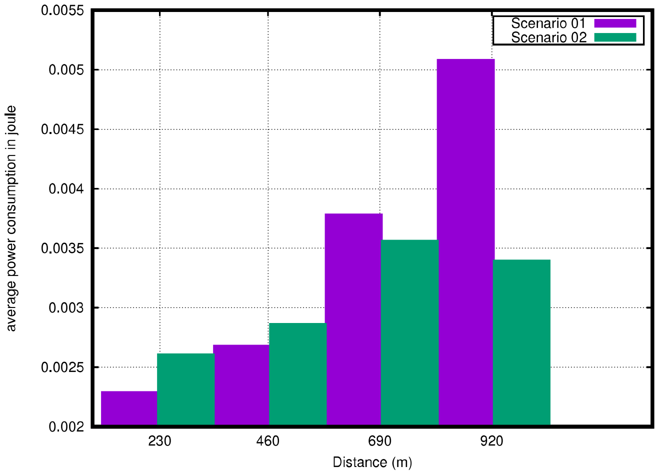


Figure 5.25: Average power consumption with two-ray ground UDP transmission at different source to destination distances.

source and destination are closer, there is no significant difference in power consumption. However, when the distance between source and destination increases, the scenario 2 has lower power consumption due to smaller propagation of DSR e control packets. As a result, scenario 2 seems to be a good model of sensor placement.

5.6.3 Experiment II

In this experiment, using two-ray ground model, nodes were inserted between origin and destination, causing an increase in the distance between source and destination. The nodes were inserted at 290 meters of each other. Figure - 5.26 shows results of power consumption as a function of the number of hops. As expected, energy consumption increases with the increase in the number of hops for both TCP and UDP transmissions. For this experiment, we assume that:

1. The same radio power were defined for each simulation;
2. The antenna gain was set in 0.5 dBi for all simulations;
3. A specific number of packets was sent in each simulation; and
4. The shadowing model parameters were $\beta = 2$ and $\sigma = 5$.

Figure - 5.26 shows the average power consumption from source to destination with transmissions using different numbers of hops. In the same figure, it is noticeable that the single-hop transmission has lower average consumption when compared to multi-hop

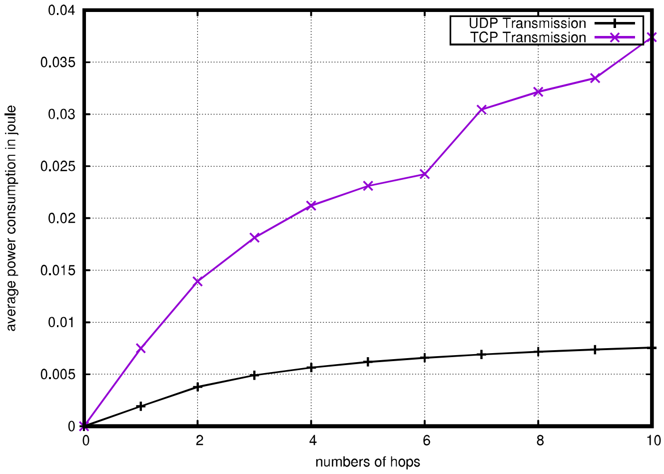
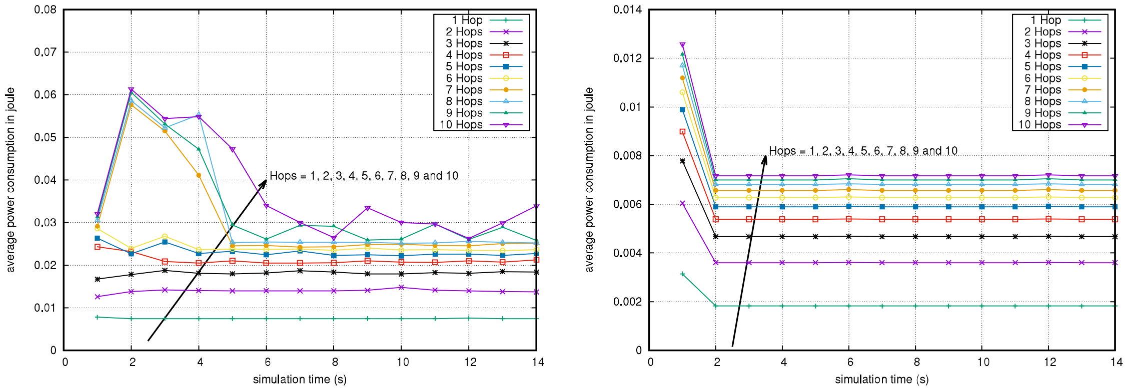


Figure 5.26: Power consumption in two-ray ground model TCP and UDP transmissions.



(a) Energy consumption in two-ray ground model TCP transmissions with different number of hops.

(b) Energy consumption in two-ray ground model UDP transmissions with different number of hops.

Figure 5.27: Energy consumption in two-ray ground model.

transmissions for any numbers of hops. The same results are confirmed in Figure - 5.27(a) and Figure - 5.27(b), highlighting that single-hop is energetically more efficient. In both figures, it is noticeable that the energy spent tends to saturate after a number of hops.

In addition to transmissions using two-ray ground model, experiments were also performed to evaluate the power consumption for shadowing environments, using TCP and UDP. Figure - 5.28 shows a higher power consumption for TCP transmissions when compared to UDP. This is due to the fact that with TCP, acknowledgment packets (ACK) are required for confirmation of packet delivery, unlike UDP that does not use such mechanism. Figure - 5.28 also highlights that the shadowing model seems to require greater use of DSR and packet control, and therefore, consuming more power as the number of hops increases. In the same figure, it is noticeable the decrease of power consumption after 8 hops. It is due the fact that of lower DSR, MAC and data packets transmissions, showing the difficult of the algorithm in maintenance and discovery routes in fading environment, characterized by shadowing model.

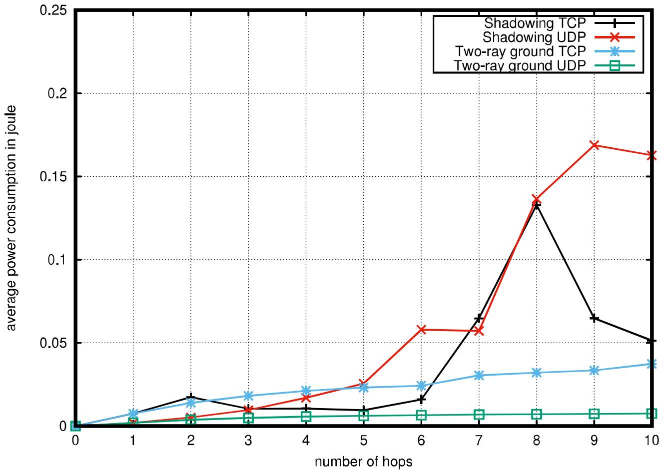


Figure 5.28: Power consumption shadowing and two-ray ground model TCP and UDP transmissions.

5.6.4 Experiment III

In this experiment, we consider a scenario in which the nodes are positioned in a straight line. For each new simulation, other nodes are inserted between the source and the destination, so that the required power of the radio can be decreased, resulting in a greater number of jumps. For this experiment, we assume that:

1. Different radio power were defined for each simulation;
2. The antenna gain was set in 0.5 dBi for all simulations;
3. The source node and the desired destination are at the same distance in all simulations, independently of the number of hops;
4. A specific number of packets was sent in each simulation; and

Figure - 5.29 shows the results of energy consumption with different numbers of hops from source to destination. It can be seen that the energy consumption tends to saturate after around 6 hops.

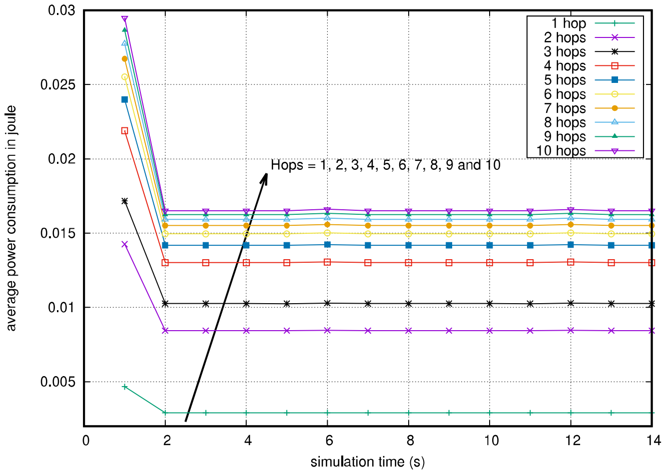


Figure 5.29: Average power consumption with two-ray ground model UDP transmission in single-hop and multi-hops.

Also, as seen in experiment II above, energy consumption saturates at about 6 hops. In the same figures, it is also possible to see the higher energy consumption observed for TCP transmissions when compared to UDP.

With the experiments performed in experiment II and III of this analysis, it is possible to see that single-hop is more energy efficient than multi-hop, making it clear that it is more advantageous to discover the location of the destination node and to adjust the power of the radio to try to send packets directly to the destination, avoiding the use of intermediate nodes. However, direct transmission may produce more interference affecting negatively the network throughput.

5.6.5 Experiment IV

Much of the power consumption researches focus only on developing topologies resulting the least energy consumption or focus only on analysis of radio power settings, in order to transmit packets directly to the destination node(without use of intermediaries nodes). However, researches that focus on study of topology and also on radio power adjustment are still underexplored in the current literature. Therefore, in this experiment we show that only the construction of better topologies or only of radio power adjustment are not enough to obtain the lowest power consumption, but rather, the two approaches must be explored during the WNSs construction.

Differently of analysis IV experiment I where only three devices send packets to the same destination, in this experiment all devices send packets to the same destination.

Scenario 2 was chosen for this new experiment due to the lower energy consumption as seen in Figure - 5.24.

For this experiment, we assume that:

1. The parameters and scenario 2 used are the same of experiment I and described in Table - 5.13; and
2. A specific number of packets was sent in each simulation.

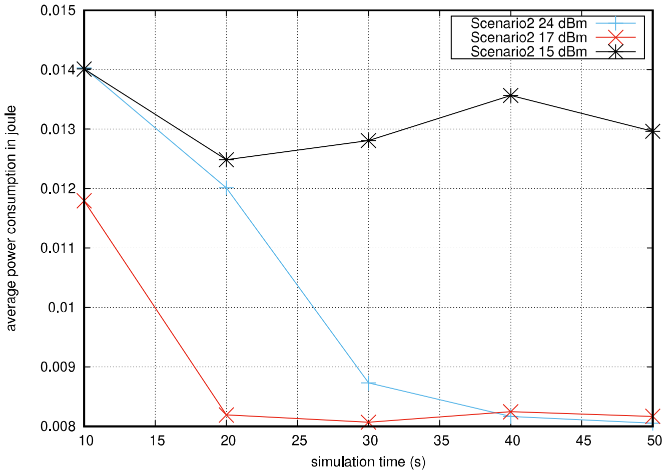


Figure 5.30: Average power consumption of scenario 2 in two-ray ground model, UDP transmissions and different power radio settings.

Figure - 5.30 shows the power consumption in scenario 2 with different power radio settings. It is noticeable the lower energy consumption with the radio power adjust for 17 dBm when compared with transmissions using radio standard power (24 dBm). However, the same figure highlights the higher power consumption when we set the radio power to 15 dBm (sufficient power for packet transmission to closer neighbors nodes).

Table 5.15: Comparison of results from scenario 2 with different power radio.

	TPS	%PD	TPDSR	TPDSRLOSS	TPCRT	TPC
24 dBm:	11760	90.88%	13894	1577	168182	2.950431
17 dBm:	11760	98.18%	5231	191	198830	2.634164
15 dBm:	11760	77.93%	7383	208	298481	3.928956

Table - 5.15 shows the results of power consumption and total packets transmitted during the simulation on scenario 2 with different radio power settings. It is noticeable the smaller use of discovery and maintenance route packets with smaller radio transmission power. In this experiment, there was an increase of 166% DSR packets transmitted when the 24 dBm power radio settings was used compared with 17 dBm transmissions, and an increase of 41% use of those packets when compared with transmissions in 17 and 15 dBm. The table also highlights the lower DSR packets loss when we set the radio's power with lower values. However, the table also highlight the higher power consumption when the radio's power was set in 15 dBm (lower power required for transmissions nodes with their nearest neighbors), showing the increase of 49% total power consumption on the simulations with radio set in 15 dBm when compared with simulations in 17 dBm, and 33% higher total energy consumption when compared with 24 dBm.

In this experiment it is noticeable the higher power consumption on simulation scenarios when the radio is adjusted to 15 dBm when compared with 17 dBm simulations. Its due to the fact that it is difficult to discover and maintain routes and the bigger dispute for packets transmissions, as highlighted in the Table - 5.15 showing the amount of DSR and control packets used during these simulations.

In this experiment, it is noticeable that only the increase of radio power to reach distant destinations or only of the reduction on radio power to the minimum necessary to reach only the neighboring nodes are not enough to lower the power consumption on WNS.

5.6.6 Results and conclusions

Most works published before 2010 highlights that multi-hop has better energy efficiency than single-hop, and in some cases referring to it as the "state of the art". However, it can be verified that in several cases the authors did not consider the energy consumed during the reception and the processing of packets, considering only the energy spent in the transmission. On the other hand, most works published from 2011 considers the energy spent during packet reception, indicating that single-hop has better energy efficiency.

In an ad hoc network, devices typically have a limited battery life. In this analysis, evaluation of energy consumption for ad hoc networks using DSR algorithm is presented. A preferable scenario for a WSN with nodes distributed around a 1500 x 1000 meters area is presented, resulting in a smaller use route discovery messages when compared to the traditional square-placed nodes.

We also observed that single-hop has a lower average power consumption, resulting in longer network lifetime compared to multi-hop. For a WSN with nodes equidistantly and linearly placed, the power used to transmit data must be inversely proportional to the number of hops n, added to a constant power used in the data reception and processing. Therefore, the energy consumption may be calculated by equation given by

$$E_c = \log(n) \times p \times t + G_r + G_p \times t \times n \tag{5.5}$$

in witch E_c is the energy consumed to transmit one packet, n is the number of hops, $\log(n) \times p$ is the energy transmission power proportional to n, t is the transmission time, and G_r and G_p are the required power to receive and process packet data, respectively.

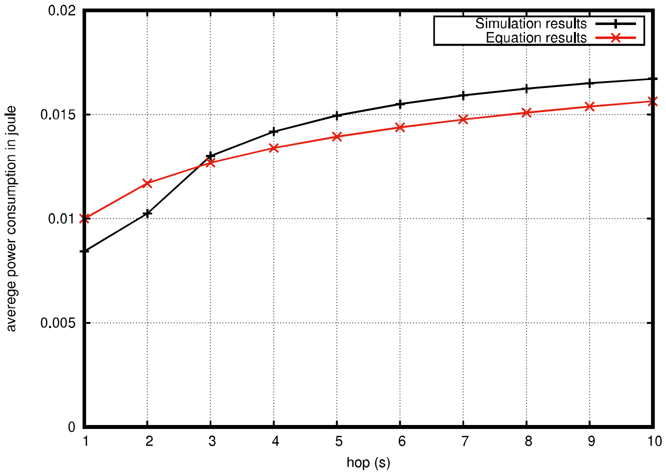


Figure 5.31: Power consumption of simulation results and equation 5.5 results.

Figure - 5.31 show the power consumption based of Eq. 5.5 results, assigning the same values used in the simulation and with different numbers of hops (with intermediate nodes). It is noticeable that the results obtained from the equation is close to the simulation results, indicating that the Eq. 5.5 is a good estimation of the average power consumption in ad hoc network.

Therefore, with this experiment it is possible to report the great importance of evaluating when nodes should retransmit packets using intermediate nodes or try to send them directly to the final destination, considering the scenario and the information to be sent.

The energy savings can be considered a key part in a WNS, i.e., sending a packet with the fewest possible hops can result in energy savings. On the other hand, in a vehicular network it may be necessary for the data packets to circulate to all vehicles. In this case, multi hop may be the better, accepted approach also considering that energy consumption in vehicles may not be a worrying factor.

5.7 Methodology of results analysis

All simulations in this work were performed with the use of the NS-2 simulator. For the interpretation of the results generated in the log (nam) and trace (tr) files, the open source Visual Studio Code[6] was used in conjunction with scripts written in Python[7] language, because of the functionality of the word processing modules included in its standard library.

The graphs were generated with the help of Gnuplot[8], for the ease of generating output directly on the screen and in many graphic file formats and the ease of working with mathematical equations.

The log and trace files were read line by line and at each iteration, vectors were filled in with relevant data depending on what was sought. After reading the files, the generated vectors were interpreted and the results and graphics were generated. The results generated were Total Packets Sent, Total Packets Received, Total Packets Lost, % Packet Delivery, Total Bytes Received, Total Control Packets (RTS, CTS, ARP, ARQ, ARK) and Total DSR Packages (RREQ, RREP, RERR and RSHORT).

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[6] Visual Studio Code is a source code editor developed by Microsoft for Windows, Linux and MacOS. It includes support for debugging, embedded Git control, syntax highlighting, intelligent code complementation, and code refactoring.

[7] Python is a high-level programming language, interpreted, scripted, imperative, object-oriented, functional, dynamic and strong typing, widely used in Data Science.

[8] Gnuplot is a portable command-line driven graphing utility for Linux, OS/2, MS Windows, OSX and many other platforms. The source code is copyrighted but freely distributed.

6

Conclusion and contribution

With DSR, route discovery and route maintenance operate entirely "on demand". In particular, unlike other protocols, DSR does not do use any kind of periodic packets to evaluate network connections, i.e., DSR does not use any periodic routing advertisement, link status sensing, or neighbor detection packets, and does not rely on these functions from any others protocols in the network. This on-demand behavior and the lack of periodic activity, allows that the overhead caused by DSR remains close to zero, in particular when all nodes are stationary and all routes needed for communication have already been discovered. At the moment when nodes begin to move, the overhead automatically increases to the necessary to maintenance routes currently in use.

The presence of hidden terminals and the low signal attenuation in some propagation models were presented in this work as an alarming problem affecting ad hoc network performance. The experiments presented here demonstrate the need for network designers, to design networks in which nodes best adapt to the environment, positioning themselves so that overhead is reduced, or adjust radio power as to minimize interference to other devices and, in this way, improving delay, overhead, throughput, energy consumption and other metrics.

Due the fact that it is considered a key part of the WSNs lifetime, energy consumption has also been discussed in this work, investigating weather single-hop or multi-hops is more energy efficient. For this, experiments in different scenarios were carried out which allow network designers to better understand, define, and design WNS with awareness of energy consumption.

Currently, VANETs are an important research area. This work explored the scenarios that would enable fast and good communication between vehicles on a highway using retransmission poles. Thus, vehicles would be able to send information to each others, such as road conditions, traffic, advertising or any other information. Therefore, the use of DSR in the present work may stimulate in the future, the designing of interconnected roads, since it produced good performance results in terms of throughput, package delivery and overhead.

A radio propagation model is deterministic when a known set of inputs always determines the same set of outputs. In models like free-space and two ray ground, if the node is located within the transmission range of another one, it will certainly receive always the radio packets with the same signal strength. Statistical models, on the other hand, do not produce deterministic but rather random outputs, which are considered estimates of the medium characteristics. Given the multitude of causes that impact radio signal propagation, statistical models tend to offer results that are closer to reality for the majority of scenarios considered. With shadowing, there is no guarantee that a node will receive the radio packet sent but instead there is a chance (probability) that the successful reception might happen. Therefore, the analysis of radio propagation that uses statistical models may require a different optimization approach if compared to when deterministic models are used.

The nodes localization and the effects of signal fading are not considered by DSR when establishing routes. Therefore, as greater the distance between nodes, less is the probability of receive messages, and when these nodes are part of routes, these routes tend to break up more easily. The consequences of this can be seen in the percentage of package delivery in Figure - 5.9(a) and Figure - 5.9(b). Thus, getting the distance of closer neighborhoods nodes during the transmission control packets and evaluating the energy receive, and with this, try to send data packets using only the sufficient power to reach intermediate node, it is expected that a better packet delivery, lower delay and a reduction in the average energy consumption. One example of this can be seen in Figure - 5.15.

6.1 Future work

A shortcoming of the DSR protocol is to ensure that alternative routes are still valid for use. When the source device receives a RERR packet, an alternate route, if one exists, becomes the main route. However, DSR does not evaluate if this route that has become the main route is still valid. If the secondary route is also broken, the source node will use it to send packets that will not reach the destination. In this regard, future implementations may add a confirmation that DSR verifies if the secondary route is still a good choice before making it the main route. With this change, it is estimated a decrease in the packet loss and consequently higher throughput.

In the experiments performed, we verified that the great attenuation of radio signal in some scenarios were beneficial, contributing to a lower delay and lower energy consumption. Another expected observation was that when the radio power was set at the minimum enough value to reach the desired destination, the interference was less severe and there were less cases of channel dispute and collision, thus, resulting in smaller delay in the network. Therefore, assessments to constantly update the distance between transmitter and receiver can be performed in order to optimize the radio power needed to reach the receiver.

Probabilistic models like Shadowing may not characterize an urban environment accurately enough. Therefore, other probabilistic propagation models may be used as required.

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Appendices

A

Performance of DSR algorithm in VANETs

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