Ministry of Higher Education and Scientific Research
Ferhat Abbas University – Setif 1
UFAS - Algeria

THESIS

entitled

Mobile Ad Hoc Networks Routing Protocol Setting Optimization and Selection Using Heuristic Approaches

Presented at
Faculty of Sciences

Departement of
Informatics

by
Mr. Nassir HARRAG

For
Doctor of Sciences Degree

The …………., 2018.

Mr.			Committee Chair
Mr. Allaoua Reffoufi	Pr.	Ferhat Abbas University Setif 1	Thesis Supervisor
Mr.			Committee Member
Mr.			Committee Member
Mr.			Committee Member
Mr.			Committee Member

2018

Abstract

In this thesis, we define and solve an optimization problem using a meta-heuristic approach in order to efficiently and automatically tune optimized routing protocol. The proposed algorithm explores the huge number of all possible feasible routing protocol configurations to find optimized parameter settings. The simulation results obtained using NS2 simulator prove that the developed algorithms allows the choice of an efficient routing protocol configuration that minimizes simultaneously the packet loss ratio and the packet delivery delays as well as network load by limiting control packets. Furthermore, it also permits the Ad Hoc network to adapt itself to each topology change which makes it adaptive to any environment changing.

Keywords: Ad hoc, MANET, Routing, Protocol, Optimization, Metaheuristic, Bio-inspired

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List of Acronyms

MANET	Mobile Ad hoc NETwork
QoS	Quality-of-Service
DSDV	Destination-Sequenced Distance Vector
LSP	Link State Protocol
FSR	Fisheye State Routing
CGSR	Cluster head Gateway Search Routing
DREAM	Distance Routing Effect Algorithm for Mobility
TBRPF	Topology Broadcast based on Reverse-Path Forwarding
OLSR	Optimized Link State Routing
DSR	Dynamic Source Routing
AODV	Ad-hoc On-demand Distance Vector
FORP	Flow-Oriented Routing Protocol
TORA	Temporally Ordered Routing Algorithm
ABR	Associativity-Based Routing (ABR)
PLBR	Preferred Link-Based Routing
SSA	Signal Stability-based Adaptive routing
ZRP	Zone Routing Protocol
IZRP	Independant Zone Routing Protocol
ALARM	Anonymous Location-Aided Routing in suspicious MANETs
ZHLS	Zone-based Hierarchical Link State
SSR	Segment by Segment Routing
ACR	Adaptive Cell Relay
NS-2	Network Simulator version 2
NSGA-II	Non dominated Sorting Genetic Algorithm version II
PSO	Particle Swarm Optimization
2G	Second Generation
LAN	Local Area Network
3G	Third Generation

PDA	Personal Digital Assistant
PAN	Personal Area Network
RREQ	Route Request
RREP	Route Reply
SHARP	Sharp Hybrid Adaptive Routing Protocol
IETF	Internet Engineering Task Force
WRP	Wireless Routing Protocol
GSR	Global State Routing
MPR	MultiPoint Relay
GA	Genetic Algorithm
DE	Differential Evolution
ES	Evolution Srategy
ACO	Ant Colony Optimization
SA	Simulated Annealing
IWD	Invasive Water Drop
TLBO	Teaching Learning Based Optimization
MOA	Magnetic Optimization Algorithm
HS	Harmonic Search
ABC	Ant Bee Colony
FFA	Fire Fly algorithm
VANET	Vehicular Ad hoc NETwork
NRL	Network routing Load
PDR	Packet Delivery Ratio
E2ED	End to End Delay
AEED	Average End to End Delay
AOMDV	Ad-hoc On Demand Multipath Distance Vector
IARP	IntrAzone Routing Protocol
IERP	IntErzone Routing Protocol
BRP	Bradcast Resolution Protocol
NDP	Neighbor Discovery Protocol

PL	Packet Loss
POWEA	Protocol Optimization With Evolutionary Algorithm
TC	Topology Control
MID	Multiple Interface Declaration
HELLO	Hello message

Introduction

In the past two decades, the progress of wireless technology and the increasing use of small portable computers and devices have made wireless networks so popular. Wireless networks allow hosts to roam without the constraints of wired connections and users are free to move independently in any direction, while at the same time being connected to the network. The deployment of wireless networks can be difficult in conditions where there is no infrastructure or the local infrastructure is not reliable. In these situations, a mobile Ad Hoc network can be considered as a better choice [1-2].

A Mobile Ad hoc NETwork (MANET) is a collection of wireless nodes that can dynamically self-organize into an arbitrary and temporary topology to form a network without the need for a pre-existing infrastructure [3-4]. Each node is equipped with a wireless transceiver. Each node may communicate directly to each other even in out-of-range conditions with intermediate nodes performing the routing functions. Thus, node doesn't only play the role of a data terminal, but also acts as a router, that sends packets to desired nodes. Mobile Ad Hoc network has many applications, the most common mentioned are crisis management and military operations; in addition to its application in collaborative and distributed computing, wireless mesh control, wireless sensor networks, hybrid network, medical control and many more [5].

To provide an efficient communication in Mobile Ad Hoc networks, an optimal routing strategy is needed to make better use of resources and to offer a best quality-of-service (QoS)[6-8]. The continuous exchange of routing control packets causes network congestion and can limit the global performance of the network. In this kind of networks, the performance improvement needs to find a well-suited parameters configuration of existing protocols [9-12].

Depending on the process of route discovery, routing protocols are broadly classified into three types:

- Proactive routing protocol, Reactive routing protocol and Hybrid routing protocol. Proactive routing protocol is a protocol where each node in the network maintains routing information for every other node in the network in a routing table that is periodically adjusted to the network topology changes. Among the proactive routing protocol we can mention the following routing protocols: The destination-sequenced distance vector (DSDV) [13], The link state protocol (LSP) [14], the fisheye state routing (FSR) [15], The cluster head gateway search routing (CGSR) [16], The distance routing effect algorithm for mobility (DREAM) [17], The topology broadcast based on reverse-path forwarding (TBRPF) [18], The optimized link state routing (OLSR) [19], …etc.

- With the Reactive routing protocol schema, if a node wants to send a packet to another node, then this protocol searches for the route in an on-demand manner and establishes the connection in order to transmit and receive the packet. The route discovery usually occurs by flooding the route request packets throughout the network. In this category, we can mention: The dynamic source routing (DSR) [20] protocol, The ad-hoc on-demand distance vector (AODV) [21], The flow-oriented routing protocol (FORP) [22], The temporally ordered routing algorithm (TORA) [23], The associativity-based routing (ABR)[24], The preferred link-based routing (PLBR) [25], The signal stability-based adaptive routing (SSA) [26], …etc.
- Hybrid routing protocol category includes only the merits of both aforesaid routing protocol strategies. Some of the renowned hybrid routing protocols are: The zone routing protocol (ZRP) [27], anonymous location-aided routing in suspicious MANETs (ALARM)[28], The zone-based hierarchical link state (ZHLS) [29], the segment by segment routing (SSR) [30], the adaptive cell relay (ACR) [31], …etc.

In this thesis, we define and solve an optimization problem using a meta-heuristic approach in order to efficiently and automatically tune optimized routing protocol. The proposed algorithm explores a huge number of all possible feasible routing protocol configurations to find optimized parameter settings. The simulation results obtained using NS2 simulator prove that the developed algorithms allows the choice of an efficient routing protocol configuration that minimizes simultaneously the packet loss ratio and the packet delivery delays. Furthermore, it permits the Ad Hoc network to adapt itself to each topology change which makes it adaptive to any environment variation.

Thesis outline

The entire research work is presented under four chapters as follows:

Chapter-1: is devoted to Ad hoc networks in which we study history of Ad hoc networks, basic concepts of Ad hoc networks, features, challenges, applications of Ad hoc networks. The last part of this chapter introduces the routing protocols.

Chapter-2: is considered as state of art of bio-inspired approaches used in ad hoc networks to solve several NP-hard problems (topology, energy, …etc). It provile also a detailled review on routing protocol optimization covering the period 2005-2018.

Chapter-3: is dedicated to metaheuristic methods which will be used to optimize the routing protocol configuration leading to an improvement of the routing protocol performances. It introduces the bio-inspired algorithms and describes their adaptation and use to optimize routing protocol parameters.

Chapter-4: outlines the simulation environment that includes introduction, general infoamtion regarding NS-2 simulator and sample simulation scripts. It further deals with simulation study and implementation of routing protocols like OLSR and ZRP as well as their autoconfiguration using NSGAII, PSO and DE metaheuristic algorithms. A huge quantity of results are provided in this chapter with discussion regarding the different tests scenarios used to check the performance improvements.

Conclusion: summarizes the research work with conclusion drawn and possible extension of the present investigation.

References

[1] Mohapatra, P. and Krishnamurthy, S.V., Ad Hoc Networks Technologies and Protocols, Springer Verlag, 2005.

[2] Ilyas, M., The Handbook of Ad Hoc Wireless Networks. CRC Press, Boca Raton, FL, 2003.

[3] Corson, S. and Macker, J., Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations. Internet Draft, 1999. http://www.ietf.org/rfc/rfc2501.txt, Informational RFC.

[4] Macker, J.P. and Corson, S., Mobile ad hoc networks (MANET): Routing technology for dynamic, wireless networking, IEEE Press and John Wiley & Sons, New York, 2004.

[5] Internet Engineering Task Force. MANET mobile ad hoc working group. http://www.ietf.org/html.charters/manet-charter.html.

[6] Asokan, R., A Review of Quality of Service (QoS) Routing Protocols for Mobile Ad hoc Networks, Department of Information Technology, International Conference on Wireless Communication and Sensor Computing (ICWCSC), 2010.

[7] Chen, L. and Heinzelman, W.B., A Survey of Routing Protocols that Support QoS in Mobile Ad Hoc Networks, University of Rochester, IEEE Network, 2007.

[8] Mohapatra, P., Li, J. and Gui, C., QoS In Mobile Ad hoc Networks, University of California, IEEE Wireless Communications, 2003.

[9] Boukerche, A., Turgut, B., Aydin, N., Ahmad, M.Z., Bölöni, L.and Turgut, D., Routing protocols in ad hoc networks: A survey", Computer Networks 55, 2011:3032–3080.

[10] Vijaya Kumar, G., Vasudeva Reddyr, Y. and Nagendra, M., Current Research Work on Routing Protocols for MANET: A Literature Survey, International Journal on Computer Science and Engineering, 2010:2, 3.

[11] Abolhasan, M., Wysocki, T. and Dutkiewicz, E., A Review Of Routing Protocols For Mobile Ad hoc Networks, Journal of Ad hoc Networks, 2004:1-22.

[12] Royer, E.M., A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks, IEEE Personal Communications, 1999:46-55.

[13] Perkins, C. and Bhagwat, P., Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers, Conference on Communications Architectures, Protocols and Applications, 1994:234–244.

[14] Varaprasad, G., Dhanalakshmi, S. and Rajaram, M., New Security Algorithm for Mobile Adhoc Networks Using Zonal Routing Protocol, UBICC Journal, 2009.

[15] Mahajan, V., Natu, M. and Sethi, A., Analysis of Wormhole Intrusion Attacks in Manets, in Military Communications Conference, 2008:1–7.

[16] Abraham, A., Jain, R., Thmas, J. and Han, S.Y., D-SCIDS: Distributed Soft Computing Intrusion Detection System, Journal of Network and Computer Application, 30, 2007:81–98.

[17] Eid, M., Artail, H., Kayssi, A. and Chehab, A., An Adaptive Intrusion Detection and Defense System Based on Mobile Agents, Innovations in Information Technologies, 2004.

[18] Ogier, R.G., Templin, F.L., Bellur, B. and Lewis, M.G., Topology Broadcast Based on Reverse-Path Forwarding (TBRPF), Internet Engineering Task Force (IETF) draft, 2002. http://www.ietf.org/internet-drafts/draft-ietfmanet-tbrpf-06.txt.

[19] Siva Kumar, G., Kaliappan, M. and Jerart Julus, L., Enhancing the Performance of MANET Using EESCP, IEEE International Conference on Pattern Recognition, Informatics and Medical Engineering, 2012:225–230.

[20] Johnson, D.B., Maltz, D.A., Hu, Y. and Jetcheva, J.G., The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR). Routing in Mobile Ad Hoc Networks, 2002. http://www.ietf.org/internet-drafts/draft-ietf-manet-dsr-07.txt.

[21] Perkins, C.E., Royer, E.M. and Das, S.R., Ad hoc on demand distance vector routing (AODV), 2003. http://www.faqs.org/rfcs/rfc3561.html. Internet RFC 3561.

[22] Su, W. and Gerla, M., IPV6 Flow Handoff in Ad hoc Wireless Networks Using Mobility Prediction, IEEE GLOBECOM, 1999:271-275.

[23] Park, V. and Corson, S., Temporally-ordered routing algorithm (TORA) version 1 functional specification, Internet Draft, Internet Engineering Task Force, 2000.

http://www.ietf.org/internet-drafts/draft-ietf-manet-tora-spec-03.txt.

[24] Toh, C.K., Associativity-based routing for ad hoc mobile networks, Wireless Personal Communications Journal, Special Issue on Mobile Networking and Computing Systems, 4, 2, 1997:103–139.

[25] Sisodia, R.S., Manoj B.S. and Siva Ram Murthy, C., A Preferred Link-Based Routing Protocol for Ad hoc Wireless Networks, Journal of Communications and Networks, 4, 1, 2002:14-21.

[26] Dube, R., Signal Stability-based Adaptive Routing Routing (SSA) for Ad Hoc Mobile Networks, IEEE Personal Communications, 4, 1, 1997:36–45.

[27] Haas, Z., Pearlman, M. and Samar, P., Zone routing protocol (ZRP) for ad hoc networks, Internet Draft, Internet Engineering Task Force, 2002.

http://www.ietf.org/internet-drafts/draft-ietf-manet-zone-zrp-04.txt.

[28] El Defrawy, K. and Tsudik, G., ALARM: Anonymous Location-Aided Routing in Suspicious MANETs, IEEE transactions on mobile computing, 10, 9, 2011.

[29] Joa-Ng, M. and Lu, I.T. A Peer-to-Peer Zone-Based Two-Level Link State Routing for Mobile Adhoc Networks, IEEE Journal on Selected Areas in Communications, 17, 8, 1999:1415-1425.

[30] Fuhrmann, T., Scalable routing for networked sensors and actuators, IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, 2005.

[31] Du, X., Adaptive Cell-Relay Routing Protocol, IEEE Transactions on Vehicular Technology, 55, 1, 2006:278-285.

Chapter I

Overview of Mobile Ad Hoc Networks

I.1 Introduction

The field of wireless and mobile communications has experienced an unprecedented growth during the past decade. Current second-generation (2G) cellular systems have reached a high penetration rate, enabling worldwide mobile connectivity. Mobile users can use their cellular phone to check their email and browse the Internet. Recently, an increasing number of wireless local area network (LAN) hot spots is emerging, allowing travelers with portable computers to surf the Internet from airports, railways, hotels and other public locations. Broadband Internet access is driving wireless LAN solutions in the home for sharing access between computers. In the meantime, 2G cellular networks are evolving to 3G, offering higher data rates, infotainment and location-based or personalized services. However, all these networks are conventional wireless networks, conventional in the sense that as prerequisites, a fixed network infrastructure with centralized administration is required for their operation, potentially consuming a lot of time and money for set-up and maintenance. Furthermore, an increasing number of devices such as laptops, personal digital assistants (PDAs), pocket PCs, tablet PCs, smart phones, MP3 players, digital cameras, etc. are provided with short-range wireless interfaces. In addition, these devices are getting smaller, cheaper, more user friendly and more powerful. This evolution is driving a new alternative way for mobile communication, in which mobile devices form a self creating, self-organizing and self-administering wireless network, called a mobile ad hoc network[1].

An Ad hoc network is a collection of mobile nodes, which forms a temporary network without the aid of centralized administration or standard support devices regularly available as conventional networks. These nodes generally have a limited transmission range and, so, each node seeks the assistance of its neighboring nodes in forwarding packets and hence the nodes in an Ad hoc network can act as both routers and hosts. Thus a node may forward packets between other nodes as wellas run user applications [1-2].

Fig. I.1 shows a typical example of a MANET. Suppose node D is outside the range of node A's transmission range (the dotted circle around node A) and node A is outside the range of node D's transmission range. Therefore, these two nodes cannot directly communicate with each other. If nodes A and D wish to exchange a packet, nodes B and C act as routers and forward the packet on behalf of A and D, since B and C are intermediate nodes that are within the transmission range of A and D [3].

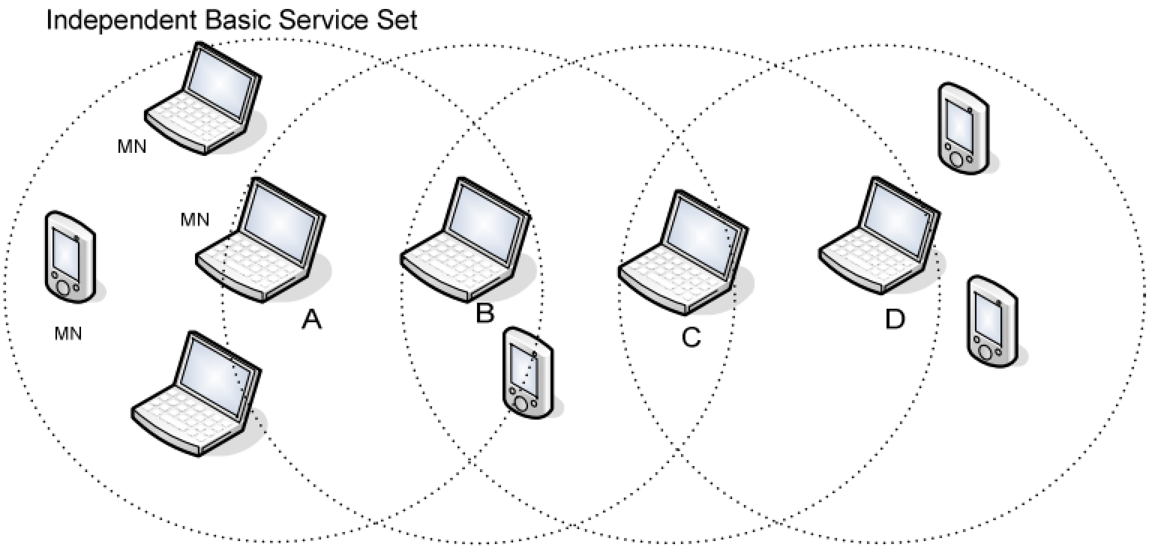

Fig. I.1 A scenario for a Mobile Wireless Ad Hoc Network (MANET).

I.2 Characteristics of MANETs

MANETs are self-organizing and adaptive in that the topology of a formed network can change on-the-fly without the intervention of a system administrator [4-511]. Although MANETs share many of the properties of the traditional wired networks, they possess certain unique characteristics which derive from the inherent nature of their wireless communication medium and the distributed function of their medium access mechanisms. The issues involved may be categorized as follows:

I.2.1 Mobility

The nodes can reposition themselves in matter of seconds, making the mobility pattern of the nodes non deterministic. This mobility pattern had a major effect on the formation of clusters within the network. This mobility and wireless nature is one of the major features of the Ad Hoc networks and helps it to be deployed in any kind of terrain.

I.2.2 Multi hop Network

Since the nodes work as group, a multi hop network is created so that even if a node is not in direct contact with the cluster head it can still get the information via the intermediate nodes by forwarding the same data. This multi hop networks is generated by the conversion of a normal node to a router or gateway[2].

I.2.3 Multiple roles for a node

The Ad Hoc networks should be able to organize itself by generating routers, gateways etc. to maintain communication with all the other nodes. This is done by converting a normal node to a router or a gateway.

I.2.4 Energy Constraints

In an Ad Hoc network the nodes are mobile and communicate over a wireless channel. Being mobile the power is used from a battery and the size needs to be kept at a minimum. Hence there is a need to manage the battery power consumption, so that they do not drop out of the network prematurely due to low power.

I.3 Applications of MANETs

There are a number of possible application areas for MANETs. These can range from simple civil and commercial applications to complicated high-risk emergency services and battlefield operations [1-2]. Below are some significant examples including civil, emergency and military domains; the interested reader can refer to for further details and other examples[2].

I.3.1 Civil and Commercial Applications

Two emerging wireless network scenarios that are soon likely to become part of the daily routines are vehicular communication in an urban environment, and personal area networking. In the vehicular communication scenario, short range wireless communication will be used within the car for monitoring and controlling the vehicle's mechanical components. Another application scenario is for communication with other vehicles on the road. Potential applications include road safety messages, coordinated navigation and other peer-to-peer interactions. Personal area networks (PANs) are formed between various mobile (and immobile) devices mainly in an ad-hoc manner. For example, on a University campus, students can form small workgroups to exchange files and to share presentations, results etc. At conferences, participants can connect their laptops or PDAs to share files and other network services. In an amusement park, groups of young visitors can interconnect to play network games. Their parents can network to exchange photo shots and video clips. But PANs will become more useful when connected to a larger network. Used in this way, PANs can be seen as extensions of the telecom network or Internet. Closely related to this is the concept of ubiquitous/pervasive computing where people, whether transparently or not, will be in close and dynamic interaction with devices in their environment.

I.3.2 Emergency Services

MANETs can be very useful in emergency search and rescue operations [3-5], such as in environments where the conventional infrastructure-based communication facilities are destroyed due to natural calamities such as earthquakes, or simply do not exist. Immediate deployment of MANETs in these scenarios can assist rapid activity coordination. For instance, police squad vehicles and fire brigades can remain connected and exchange information more quickly if they can cooperate to form ad hoc networks.

major factors that favour MANETs for such tasks are their self-configuration capability with minimal overhead, independent of a fixed or centralized infrastructure, the freedom and flexibility of mobility, and the unavailability of conventional communication infrastructures.

I.3.3 Battlefield Operations

In future battlefield operations [1-2], autonomous agents such as unmanned ground vehicles and unmanned airborne vehicles will be projected to the front line for intelligence, surveillance, enemy antiaircraft suppression, damage assessment and other tactical operations. It is envisaged that these agents, acting as mobile nodes, will organize into groups of small unmanned ground, sea and airborne vehicles in order to provide fast wireless communication, perhaps participating in complex missions involving several such groups. Examples of such activities might include: coordinated aerial sweep of large urban/suburban areas, reconnaissance of enemy positions in the battlefield etc .

I.4 Routing in MANETs

Providing efficient routing protocols is one of the most significant challenges in MANETs and is critical for the basic operations of the network. In MANETs, a route consists of an ordered set of intermediate nodes that transport a packet across a network from source to destination by forwarding it from one node to the next. The unique characteristics of MANETs, make routing in MANETs a challenging task. Firstly, the mobility of nodes results in a highly dynamic network with rapid topological changes causing frequent route failures. Secondly, the underlying wireless channel, working as a shared medium, provides a much lower and more variable bandwidth to communicating nodes than in wired networks. As a result, an effective routing protocol for a MANET environment has to dynamically adapt to changing network topology, and should be designed to be bandwidth-efficient by reducing the routing control overhead so that as much as possible of the channel bandwidth is available for the actual data communication [6-7].

Significant research has been devoted to developing routing protocols for MANETs [6-8]. These protocols can be can be classified into three main categories based on the route discovery and routing information update mechanisms employed: proactive (or table driven), reactive (or on-demand driven) and hybrid [8-11].

- **Proactive routing protocols:** such as those described in [6-8] attempt to maintain consistent and up-to-date routing information (routes) from each node to every other node in the network. Topology updates are propagated throughout the network in order to maintain a consistent view of the network. Keeping routes for all destinations has the advantage that communication with arbitrary destinations experiences minimal initial delay. Furthermore, a route could be immediately selected from the route table. However, these protocols have the disadvantage of generating additional control traffic that is needed to continually update stale route entries. Especially in highly mobile environments, communication overhead incurred to implement a proactive algorithm can be prohibitively costly. Typical and well-known examples of proactive routing protocols are destination-sequence distance vector (DSDV) [12] and optimized link state routing (OLSR) [13].
- **Reactive routing protocols:** such as those proposed in [7-8] establish routes only when they are needed. When a source node requires a route to a destination, it initiates a route discovery process by flooding the entire network with a route request (RREQ) packet. Once a route has been established by receiving a route reply (RREP) packet at the source node, some form of route maintenance procedure is used to maintain it, until either the destination becomes inaccessible or the route is no longer desired. These protocols use less bandwidth for maintaining the routing tables at every node compared to proactive routing protocols by avoiding unnecessary periodic updates of routing information. However, route discovery latency can be greatly increased, leading to long packet delays before a communication can start. Ad hoc on-demand distance vector (AODV)[14] and dynamic source routing (DSR) are well-known examples of reactive routing protocols.
- **Hybrid routing:** a hybrid routing protocol attempts to combine the best features of proactive and reactive algorithms. It often consists of the two classical routing

protocols: proactive and reactive. Hybrid protocols divide the network into areas called zones which could be overlapping or non-overlapping depending on the zone creation and management algorithm employed by a particular hybrid protocol. The proactive routing protocol operates inside the zones, and is responsible for establishing and maintaining routes to the destinations located within the zones. On the other hand, the reactive protocol is responsible for establishing and maintaining routes to destinations that are located outside the zones. The zone-based routing protocol (ZRP) and sharp hybrid adaptive routing protocol (SHARP) are well-known examples of hybrid routing protocols.

I.5 Related Work

I.5.1 Conventional Routing Protocols

Since the first proposal of MANETs, there have been continuous research attempts to solve routing problems in MANETs. Many routing protocols have been proposed, evaluated, and implemented by researchers all over the world. The well-known protocols from both general research and standardization by the Internet Engineering Task Force (IETF) are discussed in this section. Similar to literature reviews in many studies, e.g., [6-11], conventional MANET routing protocols are classified into 3 categories: proactive, reactive, and hybrid, as explained below.

I.5.1.1 Proactive Routing Protocols

In proactive routing protocols, each node attempts to maintain the routing information to every other node by periodically exchanging control messages. There are many proactive routing protocols and various methods to maintain the routing information. However, they can be classified into 2 categories: distance vector and link state.

- **Distance vector routing protocols** select the path based on the relayed link cost from every other node in the network. In this kind of protocols, every node advertises its directly connected links and their costs along with the relayed link information and costs received from other nodes. One example of distance vector routing protocols is the destination-sequenced distance-vector protocol (DSDV)[12] , which uses the number of hops to the destination as the cost. The routing information is advertised in a broadcast manner throughout the network along with the sequence number, which is originally generated by the destination. The sequence number is used to avoid a routing loop problem which is a common problem in distance vector routing. DSDV reacts to the topology changes using two kinds of update packets: full dump and incremental. The full dump packets will carry all available routing information at the current node to another while the incremental packets will carry only the information changed since the last full dump. These two types of routing update packets are used to lower the overhead and shorten the update latency. However, the overhead of DSDV is still large due to the large amount of periodic update information, which makes DSDV not scalable.

Another example is the wireless routing protocol (WRP). In WRP, each node maintains four tables: a distance table, a routing table, a link-cost table, and a message retransmission list. WRP uses the predecessor information along with the sequence number to avoid routing loops. In addition to the bandwidth consumption overhead, WRP also has a high memory consumption overhead due to the large amount of information maintained at each node.

- **Link state routing protocols** maintain a complete view of the network and construct a routing tree for data packet forwarding. To obtain a complete network view, a large amount of routing information is exchanged among nodes. Similar to distance vector protocols, link state protocols also have a high overhead where a large amount of bandwidth is consumed by routing control packets. One example of link state routing protocols is the fisheye state routing (FSR) [12-13]. FSR maintains a topology map at each node by exchanging the link state information between neigh bor nodes. However, the link state packets are not broadcasted and only periodically exchanged with the local neighbor nodes. FSR reduces the amount of control overhead by removing the event-based link state update and using only the periodic update. Moreover, the periodic update frequency is reduced by the fisheye technique where the node within the smaller scopes updates more frequently than the node that is farther away. FSR is based on the global state routing (GSR) [14], which can be viewed as a special case of FSR where the scope is 1. The advantages of FSR are that the flooding is minimized and the routing is more accurate for nodes closer to the destination, which makes it suitable for dense networks. However, the slower update for remote nodes affects the accuracy and by using this imperfect topology information an inaccurate route selection could possibly occur.

Another example is the optimized link state routing (OLSR) [13]. In OLSR, each node periodically floods a list of its 1-hop neighbors. However, instead of relaying all link information, OLSR diffuses only the partial link information through the multipoint relays (MPRs) which cover all 2-hop neighbor nodes. Therefore, the complete topology can be obtained while the amount of link state information is reduced. However, flooding the 1-hop neighbor list at each node is still not suitable in MANET and causes high overhead in large networks. Regarding this, there is a proposal of the FSR-OLSR combination which is called OFLSR (or F-OLSR) [15] in the field of wireless mesh networks. According to the evaluation in [16-17], OFLSR offers higher delivery ratio and lower delay than AODV which is a reactive routing protocol. However, the overhead of OFLSR is still much higher than AODV.

In summary, most of the proactive routing protocols are not well scalable due to the amount of routing control overhead. The delivery efficiency and delay are generally better than reactive routing protocols by exploiting this extra amount of overhead. Many attempts have been made to reduce the overhead and one of the considerably successful methods is hierarchical routing like OLSR. However, the selection of representative nodes, like MPR in OLSR or cluster heads in other hierarchical routing is also a disadvantage of this kind of routing protocols in a mobility scenario. As a result, it may require more overhead in MANET where mobility is one of its characteristics.

Additionally, maintaining all the link information can be considered unnecessary because most of the links are not used. Regarding this matter, reactive routing protocols can be considered more suitable in MANETs.

I.5.1.2 Reactive Routing Protocols

Reactive routing protocols, also known as on-demand routing protocols, have been proposed to reduce the number of control overhead by maintaining only the information for active routes. Instead of maintaining all the routes at all times, the protocol starts route discovery on-demand. In the route discovery process, a route request packet (RREQ) is usually flooded until it reaches the destination (or a node that contains the route to the destination). Then, a route reply packet (RREP) is generated and sent back to the source to inform the available route. This route is maintained as long as the connection is active and removed once it is no longer required. In general, on-demand routing protocols can be classified into 2 categories: hop-by-hop routing and source routing.

- **Hop-by-hop routing protocols** maintain the routing information locally at each node. The data packet stores only the destination address in its header and each intermediate node will use its routing table to forward the packet to the specified destination. The advantage of this approach is the high adaptability of the path because each node can react to the changes in the network faster than the end-to-end manner. However, maintaining the routing information at each node requires higher routing overhead and resources. An example of hop-by-hop routing protocols is the ad hoc on-demand distance vector routing (AODV) [6].

  The standard AODV uses the broadcast route request packet to discover the route to the destination. Once the route request arrives at the destination, the route reply packet is sent back to the source using the reverse route previously established by the route request packet. AODV uses a blacklist to avoid using unidirectional links, which are the links established by the route request packet but cannot be utilized by the route reply packet. Moreover, the precursor list is maintained to keep track of the upstream node that is utilizing this route. When a route failure occurs, a route error packet is sent out in broadcast manner if the precursor list is not empty. This route error packet is repeatedly flooded until it reaches the source node or the node with an empty precursor list. Once the source node receives the route error packet, the route recovery which is the same process as the route establishment using route request and route reply packets is repeated. Regarding the route recovery process, the local route repair feature of AODV can be chosen. Instead of re-initiating the route discovery from the source, the delay can be reduced by initiating it from the node that detects the error. Also, another feature of AODV which allows the intermediate nodes to respond to the RREQ can be chosen to further shorten the delay.

- **Source routing protocols** maintain the routing information only at the source. A list of addresses that the packet will traverse until it reaches the destination is embedded into the header of each packet by the source. Each intermediate node has no knowledge of the route to destination and only forwards each data packet by the information in its header. As maintaining the route at each intermediate node is no longer required, the overhead is reduced. However, the probability of route failures could be high when the path becomes long in large networks or when there is a high level of mobility. Moreover, the overhead of embedded route information in the header also affects the performance in large networks. According to these disadvantages, it can be clearly seen that source routing protocols do not scale well. An example of source routing protocols is the dynamic source routing (DSR) [15]. DSR is a simple source routing protocol composed of two mechanisms: route discovery and route maintenance. Both mechanisms operate purely reactive, which means that if there is not any change in the network, then there will be no additional control packet. DSR supports multiple routes which help decrease the delay upon the failure of the currently used route. Other than source-initiated flooding route discovery, each node allows to cache the overheard embedded route information in each data packet which increases the number and freshness of possible routes. When any link on a route is broken, a route error packet (RRER) is sent back to inform the source. Upon the RRER arrival, the broken route is removed and another available route will be selected or the route discovery process will be re-initiated. According to this behavior, DSR should have a very low routing overhead. It has been shown that DSR performs better than AODV in terms of delay and overhead in a less “stressful” scenarios, e.g., low number of sources, low mobility, etc. However, AODV performs better than DSR in terms of delay but still has higher routing overhead in a more stressful scenario, which is more likely to occur in real world applications.

Another source routing protocols is the associativity-based routing for ad-hoc mobile net works (ABR) [28]. ABR is a special case of source routing protocols because it uses a similar route discovery to DSR but also maintain local route information like AODV. Rather than hav ing multiple backup routes like DSR, ABR focuses on the stability of the route. ABR selects the route based on a metric, called associativity tick, which reflects the degree of association stability of mobile nodes. The associativity ticks are maintained by periodic beacons from each node. During the route discovery, not only the addresses are embedded in the packet's header but also the associativity tick is included to allow an intermediate node and the destination to select the best path according to all associativity ticks of upstream nodes. As ABR does not have backup routes, a route reconstruction is required upon link failures. Even though this route reconstruction is performed locally, it can still cause a longer delay and more control overhead. In summary, reactive routing protocols generally require less overhead than proactive routing protocols as they maintain only necessary routing information. It was shown that DSR achieves lower overhead, higher throughput, and longer node lifetime than OLSR over variable mobility and connection patterns. On the other hand, the only strong point of OLSR is the shorter delay as it is the common advantage of proactive routing protocols. According to this research, it can be seen that in general reactive routing protocols are more suitable than proactive routing protocols except where the application requires very short delays. When comparing among different reactive protocols, AODV is more adaptive than DSR as it can maintain higher throughput and shorter delays in the network scenarios with higher dynamics. As we focus on the adaptability of the routing protocol, we use AODV as the reference protocol in this thesis.

I.5.1.3 Hybrid Routing Protocols

Hybrid routing protocols use the combination of proactive routing and reactive routing concepts for the purpose of increasing scalability. In hybrid protocols, the network is partitioned into zones. A proactive routing method is used within each zone while a reactive routing method is used to communicate with nodes that are outside of the zone. With this method, the overhead is reduced because the inefficient control overhead of the proactive approach is limited only within the zone and the lower overhead from reactive routing is used to efficiently connect each zone. Among hybrid routing protocols, we have:

- The first example is the zone routing protocol (ZRP)[16]. ZRP reduces the proactive routing overhead by limiting the scope of proactively maintaining the routing information within a zone. A zone is defined by the hop distance between nodes where the nodes within ϱ hops from the current node are in the same zone. ZRP discovers the path to the node outside the zone using bordercasting, which also reduces the number of flooding messages. In bordercasting, the route request packet is forwarded only by the border node of the current zone. When the route request packet is received, the border node looks up the proactive routing table in its zone and sends back the route reply packet if it has the route to the destination or repeats the bordercasting process otherwise. The routing zone radius ϱ is a very crucial parameter in ZRP which also becomes a disadvantage of ZRP. The radius ϱ must be carefully chosen based on the characteristic of the network. If the radius is too large, then ZRP behaves more like a pure proactive protocol. On the other hand, if the radius is too small, then ZRP behaves more like a pure reactive protocol. In both cases, ZRP loses its advantage of reduced overhead and scalability.
- The second example is the zone-based hierarchical link state (ZHLS)[17-18]. ZHLS is a zone based hierarchical link state routing protocol, which also uses the location information from the global positioning system (GPS). In contrast to ZRP which defines overlapping zones, ZHLR utilizes the location information to partition the network into non-overlapping zones and assign each node a node ID and a zone ID. The hierarchical topology consists of two levels: a node level and a zone level. There is no cluster-head in ZHLS because the zones are pre-designed with regard to their location information. Hence, a single point of failure or bottlenecks can be avoided in ZHLS despite being a hierarchical routing protocol. The routing mechanism consists of intrazone proactive routing and interzone reactive routing which is similar to ZRP. Therefore, the similar advantages can be achieved. Additional advantages of ZHLS are the fixed zone location. Once the source node knows the node ID and the zone ID of the destination, even if the link breaks, ZHLS can still easily find another route to the

destination with less overhead compared to reactive routing protocols. However, this fixed zone location is also the disadvantage of ZHLS as it is required to be preprogrammed before use. In summary, hybrid routing protocols use the integration between proactive and reactive protocols to increase the scalability. Lower delay and overhead can be expected from this kind of protocols even in large scale networks. However, our research objective is to design an adaptive routing protocol. It should be able to adapt to any network without any adjustment. On the other hand, hybrid routing protocols require proper tuning of parameters, like routing zone radius in ZRP or preprogrammed zone maps in ZHLS for each network. Therefore, we do not rely on the hybrid routing approaches in our protocol.

I.6 References

[1] Sharma, R., Mobile ad hoc networks—A holistic overview, 52(21), 2012:31–36.

[2] Jiazi, Y. I., A survey on the applications of MANET. Polytech'Nantes, February 2008, pp. 721–726.

[3] Onwuka, E., Folaponmile, A., & Ahmed, M., Manet: A reliable network in disaster areas. Jorind, 9(2), 2011:105–113.

[4] Monares, A´ ., Ochoa, S. F., Pino, J. A., Herskovic, V., Rodriguez-Covili, J., & Neyem, A., Mobile computing in urban emergency situations: Improving the support to firefighters in the field. Expert Systems with Applications, 38, 2011:1255–1267.

[5] Lenert, L., Chan, T. C., Griswold, W., Killeen, J., Palmer, D., Kirsh, D., Mishra, R., & Rao, R., Wireless internet information system for medical response in disasters (WIISARD). In: AMIA annual symposium proceedings, 2005,pp. 429–433.

[6] Murthy, S., & Gracia, J. J., An efficient routing protocol for Wireless Networks. ACM Journal of Mobile Networks and Applications, 1(2), 1996:183–197.

[7] Hamza, A., Tariq, A., Helge, J., & Ali Al-Bayatti., Data confidentiality in mobile Ad hoc networks. International Journal of Wireless & Mobile Networks (IJWMN), 4(1), 2012.

[8] Royer, E. M., & Toh, C., A review of current routing protocols for ad-hoc mobile wireless networks. IEEE Personal Communications Magazine, 6(2), 1999:46–55.

[9] Abolhasan, M., Wysocki, T., & Dutkiewicz, E., A review of routing protocols for mobile ad hoc networks. Ad Hoc Networks, 2, 2003, 1–22.

[10] Mueller, S., Tsang, R. P., & Ghosal, D. (2004). Multipath routing in mobile ad hoc networks: Issues and challenges. In: M. C. Calzarossa & E. Gelenbe (Eds.), MASCOTS. LNCS (Vol. 2965, 2004, pp. 209–234

[11] Baseer, S., Channa, M. I., & Ahmed, K., A review of routing protocols of heterogeneous networks. IJCA Special Issue on Mobile Adhoc Networks MANETs (2), 58–66.

[12] Perkins, C. E. and Bhagwat, P., Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," Comp. Commun.Rev., Oct. 1994, pp. 234–44.

[13] Clausen T, Jacquet P, RFC 3626-"Optimized Link State Routing Protocol (OLSR)", Oct 2003.

[14] Perkins C.E. and Royer E. M, Ad-hoc, "On-demand Distance Vector Routing", draft-ietf-manet-aodv-02.txt, 1998.

[15] Johnson, D.B., Maltz, D.A.: Dynamic source routing in ad hoc wireless networks. In: Imielinski, Korth (eds.) Mobile Computing, Kluwer Academic Publishers (1996, pp. 153–181.

[16] Haas, Z.J. and Pearlman, M.R., ZRP: a hybrid framework for routing in ad hoc networks, 2001, pp. 221.253.

[17] Joa-Ng, I.T. Lu, A peer-to-peer zone-based two-level link state routing for mobile ad hoc networks," "IEEE Journal on Selected Areas in Communications 17 (8), 1999:1415–1425.

[18] R. Sivakumar, P. Sinha, and V. Bharghavan,"CEDAR: a Core- Extraction Distributed Ad hoc Routing algorithm," "IEEE Journal on Selected Areas in Communications, 17, 8, 1999.

Chapter II

Bio-inspired Routing Protocols - State of the art

II.1 Introduction

The problem of routing in Ad Hoc networks has attracted the attention of many researchers. Although the protocols proposed in the literature present some relevant characteristics, they also have their limitations, especially in terms of high number of mobile nodes or in terms of high number of load-dependent parameters of the Ad Hoc network which are often chosen intuitively by a seasoned expert. This chapter describes our work to solve this difficult task using bio-inspired algorithms to automate the selection process of the routing protocol parameters[1-4].

In the last decade, heuristic algorithms known as bio-inspired techniques have been widely used in Ad Hoc networks. The major reason for their expansion was their powerfulness and applicability as stochastic and optimization techniques to the Ad Hoc problems generally hard to be solved using conventional techniques[5-6].

II.2 Bio-inspired algorithms in Ad hoc networks

Communication networks have highly impacted present-day society. Thirty years ago, no one could envision the incredible success and the participation of mobile phones and their successors (PDAs, tablets, smartphones, etc.) in our everyday life. Technology in networking is evolving faster than information systems; tiny devices are already provided with communication capabilities. But the existing communication systems are not appropriate or efficient for such heterogeneous networks. Self-organization mechanisms able to handle heterogeneity, the dynamic nature, resource constraints, scalability, failures, and the like are needed[7].

It is possible to find similarities when analyzing biological systems: self-organization, recovering from failures, collaborative behavior, minimization resources, finding stability, and so forth. Most of these systems achieved this behavior after evolving for millions years. Thus, many researchers are developing algorithms inspired by nature in order to efficiently tackle different problems. For example, they have been widely applied for network design and optimization in the literature [8]. Below, we give an overview of the some relevant works that apply metaheuristics to address some of the problems we can find in ad hoc networks:

II.2.1 Genetic Algorithms

In Ref. [9], Genetic Algorithms (GA) are used to decide the transmission range of the nodes in static networks, so that the overall energy consumption is optimized, subject to some QoS constraints.

In Ref. [10], authors used a reversed engineered approach. First, near-optimal networks using a GA are created, local features of those networks are discovered, and then local adaptive rules are obtained. Once all the nodes have been deployed and have selected an operating radius based on the heuristic, the local rules are applied to the nodes so that a heterogeneous network characterized by low short paths and congestion is obtained.

In Refs [11-12], the authors focused on the network connectivity and propose the use of bypass links through hybrid networks to optimize it. Different GAs versions (coevolutionary, cellular, panmictic) were used to find the most appropriate devices to connect in order to maximize connectivity and to minimize the number of bypass links used. Later, in Ref. [13], the same concept was used for vehicular ad hoc networks. Some nodes were selected for connecting to a distant device using other kinds of technology.

In Ref. [14], the authors presented a genetic algorithm for the topological design of ad hoc networks with static and mobile nodes for collaborative transport applications. Ns-2 is used as fitness function. They try to find the best node's position and speed to maximize the communication distances.

In Ref. [15], a distributed and scalable genetic algorithm that also uses traditional and evolutionary game theory is proposed for self-spreading autonomous nodes uniformly over a dynamic area.

In Ref. [16], different GAs are studied and compared to hill climbing and random walk in order to obtain a uniform distribution of nodes over a geographical area. Each node contains a mobile agent running a GA, which decides the next direction and speed of the node.

In Ref. [17], a genetic algorithm is used for finding the minimum power broadcast problem in wireless ad hoc networks. It outperforms the well-known Broadcast Incremental Power (BIP) algorithm.

II.2.2 Particle swarm optimization

In Ref. [18], the authors proposed an improved adaptive particle swarm optimization (PSO) algorithm for solving the joint opportunistic power and rate allocation in static wireless ad hoc networks, in which all links share the same frequency band. The goal is to find a configuration that maximizes the sum of all source utilities while minimizing the total power consumption for all links.

In Ref. [19], the authors used a PSO algorithm for connectivity management in MANETs by defining some agents that move around to improve the network. They propose to optimize the movements and locations of these agents. The connectivity is measured using a maximum flow formulation.

In Ref. [20], the authors used a PSO algorithm to solve networks the minimum energy broadcast known as a NP-hard problem in static wireless ad hoc, defined as finding the tree rooted at the source node that minimizes the total energy used to cover all nodes in the network.

II.2.3 Ant colony optimization

In Refs. [21-22], the authors used ACO algorithm to solve the same problem of the minimum energy broadcast in static wireless ad hoc networks investigated in Ref. [20].

In Ref. [23], the authors proposed the GrAnt, a greedy ACO (ACO with a greedy transition rule) for finding the most promising forwarders from a node's social connectivity in delay-tolerant networks. The algorithm calculates the degree centrality, the betweenness utility, and the social proximity using global knowledge (the total number of nodes in the network) for characterizing the connectivity of nodes.

II.3 Bio-inspired routing protocols

Routing algorithms are in charge of finding a reliable route between any source and destination. The lack of central infrastructure, the changing topology, the limited resources, and the decentralized nature of ad hoc networks make routing a challenging service. There are mainly two different approaches in routing algorithms: i) proactive and ii) reactive. The former approach periodically exchanges topology information, thus maintaining routing tables that are available immediately. The drawback of this approach is the cost of maintaining such routing tables, specially if the topology is highly changeable. The reactive strategy only establishes a route when it is needed. Some hybrid approaches have also been proposed with characteristics from both reactive and proactive strategies. A survey on routing algorithms can be found in [24].

As it is a challenging problem in ad hoc networking, the literature reveals many works trying to efficiently route a packet to the destination by means of bioinspired algorithms. There is a big community proposing routing protocols based on ant colony optimization algorithms. The reason is that it can be executed online with local knowledge, making it directly applicable to real ad hoc networks. There are different surveys on ant-based routing algorithms; some of them can be found in [25-27].

In our work, we focus on the routing protocol optimizaton due to the unpredictable and changing topology of mobile ad hoc networks where communication protocols usually rely on some parameters that adapt their behavior to the current circumstances. The performance of the protocol is highly sensitive to small changes in the set of those configuration parameters. Therefore, fine tuning them for optimally configuring a communication protocol is a complex and critical task regarding the multi-objectives nature of MANETs were several objectives like network resources, QoS, energy used, and so forth need to be optimized.

In the next section, we present a huge review on the use of metaheuristics and bio-inspired algorithms for finding the optimal configuration of the parameters conforming a specific protocol.

II.4 Literature survey on routing protocols setting optimization

This section constitutes a review of the use of heuristic algorithms for routing protocol parameters setting in Ad Hoc networks covering the period 2005-2018, as follows:

In Ref. [28], authors have analyzed the use of genetic algorithm in the optimization of parameters setting in an Ad Hoc network system. The proposed approach was tested against hand-tuning in complex and realistic scenario. Experimental results proved that automated parameters tuning using the proposed method can achieve better performances than hand tuning in all considered cases. In addition, the proposed algorithm also showed that no single set of parameters can individually achieve the best performance which confirm the multi-objective nature's of the parameters tuning problem.

In Ref. [29], authors have investigated the use of a cellular multi-objective algorithm for the problem of choosing the best configuration for the network. In this study, the authors defined the problem by considering two basic formulations: the first one with two objectives functions with the coverage objective as a constraint. The second one with three objective functions: a) minimizing the duration of the broadcasting process, b) maximizing network coverage, c) minimizing the network usage. Experimental results obtained using three realistic environments for metropolitan MANETs showed the effectiveness of the proposed algorithm to solve this NP-hard problem with coverage losses below 10%.

In Ref. [30] , authors have investigated the broadcasting strategy in mobile Ad Hoc networks by considering it as a multi-objective problem using particle swarm optimization and evolution strategy with NSGA philosophy. To test the ability of both algorithms to track the Pareto optimal front, the authors used a predefined network structure with a small environment that simulates a commercial shopping center. The parameters optimization adopts the maximum coverage, the minimum bandwidth usage and the minimum make span as objectives functions. The results confirmed the ability of both algorithms to find the Pareto optimal front with good accuracy.

In Ref. [31], authors have exploited the self-configuration nature of genetic algorithm to maintain state information in mobile Ad Hoc networks clustering routing problem. They used genetic algorithms to allow the node to change routing information quickly and efficiently in order to adapt the network topology by increasing lower MAC layer overhead and decreasing the link breakages. The results obtained by authors show that the genetic algorithm is optimizing the operation of the medium access control protocol while reducing the cluster. It shows also that clusters loads are more evenly balanced by factor of ten.

In Ref. [32], authors presented an improvement of NS-2 network simulator by the integration of a new component called POWEA. This improvement allows the network protocol parameters that are automatically optimized by an evolutionary algorithm to meet quality requirements. In this study, the authors described the methodology of using POWEA to optimize new protocols. The first simulation results using the proposed framework showed a significant increase in performance compared to the static conventional routing protocols.

In Ref. [33] , authors have addressed the problem of configuring the file transfer protocol in order to optimize the number of lost packets, the transmission time and the amount of data transferred in realistic vehicular Ad Hoc networks scenarios. In this study, the authors investigated five metaheuristic algorithms: genetic algorithm, particle swarm optimization, simulated annealing, evolution strategy and differential evolution. Simulation results obtained using NS-2 network simulator on two urban and highway environments of vehicular Ad Hoc networks showed that particle swarm optimization algorithm outperforms all other considered metaheuristic algorithms.

In Ref. [34] , authors have implemented a firefly algorithm for the synchronization of devices in the mobile Ad Hoc network. The proposed algorithm determines also the hop counts based on an intentional phase shift of a periodically sent signal. In this work, the authors investigated the effects of different network parameters on the duration and success of synchronization. Experimental results showed that the proposed algorithm reduces the communication overhead leading to mobile device lifetime extending by more resource-efficient operation. In addition, the algorithm has a high accuracy in distance estimation compared to the results of an algorithm which is based on asynchronous exchange of messages.

In Ref. [35] , authors have applied the multi-objective optimization metaheuristic (NSGA-II), in order to find efficient OLSR parameterizations that improve the QoS of the OLSR. The proposed optimized protocol significantly reduces OLSR scalability problems keeping competitive packet delivery rates. By the way, reducing the overhead between 47% and 76% while the delivery times are reduced between 32% and 38%.

In Ref. [36], authors have investigated the use of four metaheuristic algorithms (particle swarm optimization, differential evolution, genetic algorithm and simulated annealing) in order to find automatically the optimal set needed for OLSR routing protocol configurations. The developed algorithms were evaluated by the definition of various realistic vehicular Ad Hoc networks scenarios based in Malaga city. Experimental results obtained using NS-2 network simulator showed that optimized OLSR configurations improve the network routing performances in term of high packet delivery ratio (>84%), low network routing load (<16.5%), low end-to-end delay (<10.3ms) and routing paths lengths (<2hops).

In Ref. [37], authors have investigated the application of nature-inspired differential evolution algorithm in vehicular Ad Hoc networks. In this study, differential evolution was used to explore the energy-efficient configurations space in order to find the optimal configuration reducing the OLSR routing protocol energy consumption. Simulation results of experiments carried out using NS-2 network simulator by analyzing the energy data of realistic VANET scenarios showed an improvement up to 30% (up to 40% in large networks) in saving energy compared to conventional configurations without deterioration of the quality of service.

In Ref. [38], authors have determined the optimal values of up to 8 different configuration parameters. They use PSO, DE, GA, SA, and Random Search to optimize a weighted fitness function that takes into account three important performance parameters such as NRL, E2ED, and PDR. They evaluate the resulting protocol in urban VANET scenarios. On average, all the automatically tuned OLSR versions saved up to 33% of energy, with significant improvements of up to 50% in large and dense networks: All these important energy savings were obtained while keeping a degradation of PDR below 8% compared to the standard OLSR. Considering the performance of the different OLSR tentative configurations, the proposed power-aware OLSR configurations reduced the network overhead by about 20% compared to the standard OLSR. In turn, they shorten packet delivery times (up to 80%), outperforming the standard OLSR in delivering data for real-time applications.

In Ref. [39], authors have used particle swarm optimization to find optimal OLSR parameters by aggregating the response performance metrics generated in a realistic VANETs simulation. The simulation results show that proposed optimized OLSR achieved better performance in urban environment as compared to the ordinary OLSR.

In Ref. [40] , authors have presented a new algorithm named Intelligent Water Drops (IWD) to tune the OLSR parameters. The IWD algorithm finds the optimal paths and provides an effective multi-path data transmission to obtain reliable communications in the case of dense networks. The proposed algorithm has been evaluated in terms of packet delivery Ratio, average end-to end delay and Routing Load to be normalized. The proposed algorithm show good ability to control the overhead generated and improved packet delivery ratio.

In Ref. [41], authors proposed a particle swarm optimization algorithm for the setting of routing protocol parameters in vehicular Ad Hoc network. The proposed algorithm can select the optimal combination of Ad Hoc on demand multipath distance vector routing protocol parameters in order to improve the quality of service. Experimental results showed the ability of the developed algorithm to reduce all considered performance measures: 1.96% for the packet delivery ratio; 37.07% for the network routing load and 80.65% for the average end-to-end delay.

In Ref. [42] , authors have utilised five metaheuristic algorithms (PSO, DE, GA, ES and SA) to evaluate which one best fits the energy-efficient routing optimization problem. Authors have validated that the optimized configurations found by each algorithm, by comparing them with each other and with the standard one in RFC 3626, studying their performance in terms of energy and QoS over 54 VANET scenarios leading to the following conclusions: On average, all the automatically tuned OLSR versions saved up to 33% of energy, with significant improvements of up to 50% in large and dense networks: All these important energy savings were obtained while keeping a degradation of PDR below 8% regarding to the standard OLSR, what is acceptable because of its many other advantages. This justifies the use of our more restricted fitness function applied in this article in comparison to the ones utilized in the previous works that tackled energy-efficiency in VANETs; Considering the performance of the different OLSR tentative configurations, our power-aware OLSR configurations reduced the network overhead (NRL) by about 20% compared to the standard OLSR. In turn, they shorten packet delivery times (up to 80%), outperforming the standard OLSR in delivering data for real-time applications.

In Ref. [43] , authors have used the Teaching-Learning Based Optimization (TLBO) algorithm to find optimal value of Ad-hoc On Demand Multipath Distance Vector (AOMDV) parameters in given real scenario. The Experimental results show drastic improvements in Average End-to-End delay (90.50% drop), Network Routing Load (41.68% drop) and Packet Delivery Ratio (0.39% rise) using value of parameters obtained through TLBO.

In Ref. [44], authors have proposed an algorithm based on Magnetic Optimization Algorithm (MOA) which finds the optimal value of Ad-hoc on demand multipath distance vector routing protocol parameters. The experimental results using the optimized protocol show 81.41% drop in average end-to-end delay, 39.24 % drop in Normalized Routing Loads, and slight rise (0.77%) in the packet delivery ratio as compared to using default value of parameters in Ad-hoc on demand multipath distance vector routing protocol.

In Ref. [45] , authors have proposed an optimization strategy based on GA and PSO to fine-tune few parameters by configuring the OLSR protocol considering some of the quality parameters such as packet delivery ratio, latency, throughput and fitness value for fine tuning OSLR protocol. The simulation results obtained using the implemented work on Red Hat Enterprise Linux 6 platform show that the proposed protocol behaves better than the original routing protocol with intelligence and optimization configuration.

In Ref. [46] , authors have combined Genetic Algorithm and Simulated Annealing algorithm in hybrid (GA-SA) to enhance the performance of OLSR routing protocol. The simulation results show that the tuned OLSR presents better Quality of service (QoS) and communication efficiency than the standard OLSR routing protocol. The proposed algorithm reduce NRL to 15%, reduce E2E delay to less than 2ms and increase PDR to 100%.

In Ref. [47] , authors have studied the impact of tuning on the performance of mobile routing Protocol, OLSR. The simulation results obtained using network simulator prove that tuned-OLSR outperformed standard OLSR protocol. The three basic performance parameters are tuned by applying genetic (GA), simulate annealing (SA) and particle swarm (PSO) algorithms. The proposed tuned OLSR shows considerable increase in throughput, packet delivery ratio and a substantial decrease in delay as compared to the respective performance of standard OLSR.

In Ref. [48], authors have analyzed the use of two parallel multi-objective soft computing algorithms to automatically search for high-quality settings of the Ad hoc On Demand Vector routing protocol for vehicular networks. The experimental analysis demonstrates that the configurations computed by the proposed optimization algorithms outperform other state-of-the-art optimized ones in term of computational efficiency achieved (greater than 87%).

In Ref. [49], authors have proposed a meta-heuristic optimal approach to frame the energy consumption and throughput model of wireless ad hoc communication system based on multiple scenarios using a multi-objective evolutionary algorithm called Non-dominated

Sorting based Genetic Algorithm (NSGA-II) where each state is represented by multi-objective fitness functions and presented as a composite function of one or more radio parameters. The final results are represented as a set of optimal solutions called Pareto-front. The finest individual fitness values which are obtained as the optimal Pareto-front are compared with the results of existing protocol.

In Ref. [50] , authors have proposed an architecture that consists of three stages: simulation network stage used to execute different urban scenarios, the function stage used as a competitive approach to aggregate the weighted cost of the factors in a single value, and optimization stage used to evaluate the communication cost and to obtain the optimal configuration based on the competitive cost. The simulation results show significant performance improvement in terms of the Packet Delivery Ratio (PDR), Normalized Routing Load (NRL), Packet loss (PL), and End-to-End Delay (E2ED).

Table II.1 Summary of heuristic algorithm based Ad Hoc routing protocol.

Reference	Year	Tech.	Remarks
Montana [28]	2005	GA	The GA is used in the optimization of Ad hoc network parameters setting. Experimental results prove that automatic parameters tuning achieves better performances compared to hand parameters tuning .
Alba [29]	2007	cMOGA	The cellular MOGA is used for the choosing of the best network configuration. Experimental results show the effectiveness of the cMOGA with coverage losses below 10%.
Perez [30]	2007	PSO-NSGA	The PSO and NSGA are used to optimized network routing parameters. The results confirm the ability of both algorithms to achieve the maximum coverage with the minimum bandwidth usage.
Al-Ghazali [31]	2007	GA	The GA is used to allow the node changing of the routing information to adapt the network topology. The results prove that GA optimize the medium access control protocol while reducing the cluster.
Tomforde [32]	2009	EA	A new component called POWEA based on evolutionary algorithm allowing automatic tuning of network parameters is integrated to NS-2 simulator. Results show good performance improvement compared to static setting.
Nieto [33]	2010	GA,PSO ,SA, ES,DE	The five algorithms are investigated in order to optimize the file transfer protocol configuring parameters.NS-2 simulation results show that PSO outperforms all other considered metaheuristic algorithms.
Merkel [34]	2012	FFA	The FFA is used for the optimization of network parameters in order to synchronize devices in MANETs.

			Experimental results show that FFA reduce communication overhead, lifetime extending and resource-efficient operation with high accuracy in distance estimation.
Toutouh [35]	2012	NSGA-II	The NSG-II is applied in order to find efficient OLSR parameterizations that improve the QoS of the OLSR protocol. The proposed optimized protocol reduces the overhead by 47% to 76% and the delivery times by 32% to 38%.
Toutouh [36]	2012	GA,PSO , SA,DE	The four algorithms are used to find the optimal OLSR configuration parameters. Experimental results show good improvements in term of high packet delivery ratio (>84%),low network load (<16.5%), low end-to-end delay (<10.3ms) and routing path lengths (<2hops).
Toutouh [37]	2012	DE	The DE is used to explore the energy-efficient configuration space reducing the OLSR energy consumption. Simulations results show an improvement up to 30% (up to 40% in large networks).
Toutouh [38]	2013	PSO, DE, GA, SA, RS	On average, all the automatically tuned OLSR versions saved up to 33% of energy, with significant improvements of up to 50% in large and dense networks while keeping a degradation of PDR below 8% regarding to the standard OLSR. The proposed protocol reduced the NRL by about 20% compared to the standard OLSR. In turn, they shorten packet delivery times (up to 80%).
Zukarnain [39]	2014	GA, PSO	PSO algotrithm is used to find optimal parameters to tune OLSR by aggregating the response performance metrics generated in a realistic VANETs simulation. The simulation results show that the proposed tuned OLSR

			achieved better performance in urban environment as compared to standard OLSR.
Gunasekar [40]	2014	IWD	The IWD algorithm is applied to tune the OLSR parameters leading to the optimal paths and provides an effective multi-path data transmission to obtain reliable communications in the case of dense networks. The proposed algorithm can control the overhead generated and improved packet delivery ratio.
Lobiyala [41]	2015	PSO	The PSO is used for the selection the optimal combination of AODV routing protocol parameters to improve QoS. Experimental results show that the developed algorithm reduce the packet delivery ratio (1.96%), the network routing load (37.07%) and the average end-to-end delay (80.65%).
Toutouh [42]	2015	PSO, DE, GA, SA, ES	All the automatically tuned OLSR versions saved up to 33% of energy, with significant improvements of up to 50% in large and dense networks while keeping a degradation of PDR below 8% regarding to the standard OLSR. The proposed protocol reduced the NRL by about 20% compared to the standard OLSR. In turn, they shorten packet delivery times (up to 80%).
Giri [43]	2015a	TLBO	The Teaching-Learning Based Optimization (TLBO) technique is used to find optimal value of parameters for Ad-hoc On Demand Multipath Distance Vector (AOMDV) in given real scenario. The Experimental results show drastic improvements in Average End-to-End delay (90.50% drop), Network Routing Load (41.68% drop) and Packet Delivery Ratio (0.39% rise) using value of parameters obtained through TLBO.

Giri [44]	2015b	MOA	The Magnetic Optimization Algorithm (MOA) is applied in the tuning of routing protocol. The experimental results, using the optimal value of parameters obtained by MOA show 81.41% drop in average end-to-end delay, 39.24 % drop in Normalized Routing Loads, and slight rise (0.77%) in the packet delivery ratio as compared to using default value of parameters in Ad-hoc on demand multipath distance vector routing protocol.
Bandi [45]	2015	GA, PSO	GA and PSO are used to fine-tune few OLSR parameters. The two algorithms are compared using QoS. The simulation results show that the fine-tuned OSLR protocol behaves better than the original routing protocol with intelligence and optimization configuration.
Gautami [46]	2016	GA-SA	A Hybrid GA -SA is used to enhance the performance OLSR protocol by tuning the OLSR parameters leading to better Quality of service and communication efficiency. The proposed algorithm reduce NRL to 15%, reduce E2E delay to less than 2ms and increase PDR to 100%.
Gupta [47]	2016	GA, PSO, SA	GA, PSO and SA algorithms are applied to tune OLSR parameters routing protocol. Proposed protocol is firstly evaluated in terms of QoS by applying an optimization strategy by coupling two different stages: an optimization procedure and a simulation stage. Proposed protocol shows considerable increase in throughput, packet delivery ratio and a substantial decrease in delay as compared to the respective performance of standard OLSR.
Toutouh [48]	2017	EA,	Two parallel multi-objective soft computing algorithms (EA and SWA) to automatically search for high-quality

		SWA	settings of the Ad hoc On Demand Vector routing protocol for vehicular networks have been investigated. The experimental analysis demonstrates that the configurations computed by our optimization algorithms outperform other state-of-the-art optimized ones(>87 %).
Prusty [49]	2017	NSGA-II	Each state is represented by multi-objective fitness functions and presented as a composite function of one or more radio parameters. The final results are represented as a set of optimal solutions called Pareto-front. The finest individual fitness values which are obtained as the optimal Pareto-front are compared with the results of existing protocol.
Kharasani [50]	2018	PSO	PSO applied in three stages architecture: simulation network stage used to execute different urban scenarios, the function stage used as a competitive approach to aggregate the weighted cost of the factors in a single value, and optimization stage used to evaluate the communication cost and to obtain the optimal configuration based on the competitive cost. The simulation results show significant performance improvement in terms of the PDR, NRL, PL and E2ED.

II.5 Conclusion

In this chapter, we have presented an overview of the most relevant existing literature that uses bioinspired algorithms to solve optimization problems in ad hoc networks, especially the routing protocol problem. A particular interest was given to the routing protocol optimization which constitutes the main axis of this thesis with a state of the art covering the period from 2005 to 2018 playing the role of a springboard for the next chapter.

II.6 References

[1] Boussaïd, I., Lepagnot, J., Siarry, P. (2013), A survey on optimization metaheuristics, Journal Information Sciences.

[2] Parpinelli, R.S. and Lopes, H.S. (2011), New inspirations in swarm intelligence: a survey. Bio-Inspired Computation, 3, 1-16.

[3] Yang, S., Cheng, H. and Wang, F. (2010), Genetic algorithms with immigrants and memory schemes for dynamic shortest path routing problems in mobile ad hoc networks, IEEE Transactions on Systems, Man and Cybernetics, PartC: Applications and Reviews, 40, 1, 52–63.

[4] Xiao-Yan, W. and Yang, L. (2013), Routing Optimizing Algorithm of Mobile Ad-Hoc Network Based on Genetic Algorithm, Advances in Intelligent Systems and Computing, 181, 1205-1211.

[5] Lafta, H.A. and Al-Salih, A.M.M.S. (14), Efficient Routing Protocol in the Mobile Ad-hoc Network (MANET) by using Genetic Algorithm (GA), Journal of Computer Engineering, 16, 1, 47-54.

[6] Elizarraras, O., Panduro, M., Méndez, A.L. and Reyna, A. (2014), MAC Protocol for Ad Hoc Networks Using a Genetic Algorithm, The Scientific World Journal, 1-9.

[7] Lopez, R.B., Sanchez, S.M., Fernandez, E.M., Souza, R.D. and Alves, H. (2014), Genetic algorithm aided transmit power control in cognitive radio networks, International Conference on Cognitive Radio Oriented Wireless Networks and Communications, 61–66.

[8] Dressler, F. and Akan, O.B., A survey on bio-inspired networking. Computer Networks, 54(6), 2010:881–900.

[9] Yadu, K.K., Tiwari, A. and Kakde, O.G., Optimization based topology control for wireless ad hoc networks to meet QoS requirements. In IEEE Symposiumon Reliable Distributed Systems, 2010, pp. 30–36.

[10] Ranganathan, P., Ranganathan, A., Berman, K. and Minai, A., Discovering adaptive heuristics for ad-hoc sensor networks by mining evolved optimal configurations. In

Proceedings of the IEEE Congress on Evolutionary Computation (CEC), 2006, pp. 3064–3070.

[11] Dongmei, Z., Qu, Z., Yang, Y. and Feng, X.. A service negotiation mechanism in mobile ad hoc network. In Proceedings of the 7th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM), 2011, pp. 1–4.

[12] Dorronsoro, B., Danoy, G., Bouvry, P. and Alba, E., Evaluation of different optimization techniques in the design of ad hoc injection networks. In Proceedings of the International Conference High Performance Computing & Simulation (HPCS), in Conjunction with The 22nd European Conference on Modeling and Simulation (ECMS), 2008, pp. 290–296.

[13] Dorronsoro, B., Ruiz, P., Danoy, G., Bouvry, P. and Tardón, L., Towards connectivity improvement in VANETs using bypass links. In Proceedings of the IEEE Congress on Evolutionary Computation (CEC), 2009, pp. 2201–2208.

[14] Gutiérrez-Reina, D., Toral Marín, L., Johnson, P. and Barrero, F., An evolutionary computation approach for designing mobile ad hoc networks. Expert Systems with Applications, 39(8), 2012:6838–6845.

[15] Kusyk, J., Sahin, C.S., Uyar, M.U., Urrea, E. and Gundry, S., Self-organization of nodes in mobile ad hoc networks using evolutionary games and genetic algorithms, Journal of Advanced Research, 2,2011:253–264.

[16] Urrea, E., Sahin, C.S., Hökelek, I., Uyar, M.I., Conner, M., Bertoli, G. and Pizzo, C., Bio-inspired topology control for knowledge sharing mobile agents, Ad Hoc Networks, , 7(4), 2009:677–689.

[17] Wu, X., Wang, X. and Liu, R., Solving minimum power broadcast problem in wireless ad-hoc networks using genetic algorithm. In Proceedings of the Communication Networks and Services Research Conference (CNSR), 2008, pp. 203–207.

[18] Guo, S., Dang, C. and Liao, X., Joint opportunistic power and rate allocation for wireless ad hoc networks: An adaptive particle swarm optimization approach, Journal of Network and Computer Applications , 34(4), 2011:1353–1365.

[19] Gutiérrez-Reina, D., Toral Marín, S.L., Johnson, P. and Barrero, F., An evolutionary computation approach for designing mobile ad hoc networks, Expert Systems with Applications, 39(8), 2012:6838–6845.

[20] Hsiao, P.C., Chiang, T.C. and Fu, L.C., Particle swarm optimization for the minimum energy broadcast problem in wireless ad-hoc networks. In Proceedings of the IEEE Congress on Evolutionary Computation (CEC), 2012, pp. 1–8.

[21] Hernández, H. and Blum, C., Ant colony optimization for multicasting in static wireless ad-hoc networks, Swarm Intelligence , 3, 2009:125–148.

[22] Hernández, H. and Blum, C., Minimum energy broadcasting in wireless sensor networks: An ant colony optimization approach for a realistic antenna model, Applied Soft Computing, 11(8), 2011:5684–5694.

[23] Vendramin, A.C.K., Munaretto, A., Delgado, M.R. and Viana, A.C., GrAnt: Inferring best forwarders from complex networks' dynamics through a greedy ant colony optimization. Computer Networks , 56(3), 2012:997–1015.

[24] Boukerche, A., Turgut, B., Aydin, N., Ahmad, M.Z., Bölöni, L. and Turgut, D., Routing protocols in ad hoc networks: A survey, Computer Networks, 55(13), 2011:3032–3080.

[25] Iyengar, S.S., Wu, H.C., Balakrishnan, N. and Chang, S.Y., Biologically inspired cooperative routing for wireless mobile sensor networks, IEEE Systems Journal, 1(1), 2007:29–37.

[26] De Rango, F. and Socievole, A., Meta-heuristics techniques and swarm intelligence in mobile ad hoc networks. In Mobile Ad Hoc Networks: Applications, 2011, pp. 245–264.

[27] Singh, G., Kumar, N. and Kumar Verma, A., Ant colony algorithms in MANETs: Areview, Journal of Network and Computer Applications, 35(6), 2012:1964–1972.

[28] Montana, D. and Redi, J. (2005), Optimizing Parameters of a Mobile Ad Hoc Network Protocol with a Genetic Algorithm, GECCO'05: Conference on Genetic and Evolutionary Computation, 1993-1998.

[29] Alba, E. Dorronsoro, B., Luna, F., Nebro, A.J., Bouvry P. and Hogie, L. (2007), A cellular multi-objective genetic algorithm for optimal broadcasting strategy in metropolitan MANETs, Computer Communications, 30, 685–697.

[30] Perez-Perez, R., Luque, C. (2007), A. Cervantes and P. Isasi, Multiobjective algorithms to optimize broadcasting parameters in mobile Ad-hoc networks, IEEE Congress on Evolutionary Computation, 3142-3149.

[31] Al-Ghazal, M., El-Sayed A. and Kelash, H. (2007), Routing Optimlzation using Genetic Algorithm in Ad Hoc Networks, IEEE International Symposium on Signal Processing and Information Technology, 497-503.

[32] Tomforde, S. Hoffmann, M., Bernard, Y., Klejnowski L. and Hahner, J. (2009), POWEA: A System for Automated Network Protocol Parameter Optimisation Using Evolutionary Algorithms, Informatik, 3177–3192.

[33] García-Nieto, J. and Alba, E. (2010), Automatic parameter tuning with metaheuristics of the AODV routing protocol for vehicular ad-hoc networks, Applications of Evolutionary Computation, 21-30.

[34] Merkel, S., Becker, C.W. and Schmeck, H. (2012), Firefly-Inspired Synchronization for Energy-Efficient Distance Estimation in Mobile Ad-hoc Networks, Performance Computing and Communications Conference (IPCCC), 205-214.

[35] Toutouh, J. and Alba, E. (2012), Multi-objective OLSR optimization for VANETs, Second International workshop on Vehicular communications and networking.

[36] Toutouh, J., Garcia-Nieto, J. and Alba, E. (2012), Intelligent OLSR Routing Protocol Optimization for VANETs, IEEE Trans. on Vehicular Technology.

[37] Toutouh, J. and Alba, E., Green OLSR in VANETs with Differential Evolution, The 14th annual conference companion on Genetic and evolutionary computation (GECCO'2012), USA, 2012, pp. 11-18.

[38] Toutouh, J., Mesmachnow, S. and Alba, E., Fast energy-aware OLSR routing in VANETs by means of a parallel evolutionary algorithm, Journal Cluster Computing archive, 16(3), 2013:435-450.

[39] Zukarnain, Z.A. and Al-Kharasani, N.M., Subramaniam, S.K. and Hanapi, Z.M., Optimal Configuration for Urban VANETs Routing using Particle Swarm Optimization, International Conference on Artificial Intelligence and Computer Science (AICS 2014), 2014, 1-6.

[40] Gunasekar, M. and Hinduja, S.J., Automatic Tuning Of OLSR Routing Protocol Using IWD in VANET, International Journal of Innovative Research in Computer and Communication Engineering, 2(1), 2014:3455-3461.

[41] Lobiyala, D.K., Kattia, C.P. and Giri, A.K. (2015), Parameter Value Optimization of Ad-hoc On Demand Multipath Distance Vector Routing using Particle Swarm Optimization, Procedia Computer Science, 46, 151–158.

[42] Toutouh, J. and Alba, E., Metaheuristics for energy-efficient data routing in vehicular networks, International Journal of Metaheuristics, 4(1), 2015:27-56.

[43] Giri, A.K., Dobiyal, D.K. and Katti, C.P., Optimization of Value of Parameters in Ad-hoc on Demand Multipath Distance Vector Routing Using Magnetic Optimization Algorithm, International Journal of Computer Network and Information Security, 12, 2015:19-27.

[44] Giri, A.K., Lobiyal, D.K. and Katti, C.P., Optimization of Value of parameters in Ad-hoc On Demand Multipath Distance Vector Routing using Teaching-Learning Based Optimization, Procedia Computer Science 57, 2015:1332–1341.

[45] Bandi, A. and Chandrashekhar, B.N., Parameters Tuning of OLSR Routing Protocol with Metaheuristic Algorithm for VANET, 2015 IEEE International Advance Computing Conference (IACC), India, 2015:1207-1212.

[46] Gautami, R., Sedamkar, R.R. and Patil, H., Application of Hybrid Meta Heuristic Algorithm for OLSR Protocol Optimization in VANET, International Journal of Current Engineering and Technology, 6(3), 2016:755-759.

[47] Gupta, K. S. Kohl, S., Optimizing OLSR Protocol for VANET, Asian Journal of Technology and Management Research (AJTMR), 6(2), 2016:23-32.

[48] Toutouh, J. and Alba, E., Parallel multi-objective metaheuristics for smart communications in vehicular networks, Soft Computing - A Fusion of Foundations, Methodologies and Applications archive, 21(8), 2017:1949-1961.

[49] Prusty, A.S., Nayak, S.. and Kumar, A., Multi-objective optimality in energy efficient routing for heterogeneous wireless ad hoc sensor network with clustering, Intelligent Decision Technologies, 11(1), 2017:61-70.

[50] Al-Kharasani, N.M., Zulkarnain, Z.A., Subramaniam, S. and Hanapi, Z.M. , An Efficient Framework Model for Optimizing Routing Performance in VANETs, Sensors, 18(2), 2018:597.

Chapter III

Proposed Bio-inspired Metaheuristic Routing Protocols

III.1 Why use bio-inspired algorithms for routing protocol setting?

More than 50 years ago, computer scientists and engineers began developing algorithms inspired from natural evolution to conceive solutions for those problems that were too difficult to be tackled by analytical methods [1]. The sophistication, robustness, and adaptability of biological systems represent a powerful motivation for replicating the mechanisms of natural evolution in the attempt to generate software and hardware systems with characteristics comparable to those of biological systems.

Heuristics is a solution strategy by trial-and-error to produce acceptable solutions to a complex problem in a reasonably practical time. The complexity of the problem of interest makes it impossible to search every possible solution or combination, the aim is to find good, feasible solutions in an acceptable timescale. Among heuristic techniques, we can mention: genetic algorithm (GA)[2], simulated annealing (SA)[3], ant colony optimization (ACO)[4], particle swarm optimization (PSO)[5], harmonic search(HS)[6], bee colony (ABC)[7], firefly algorithm (FFA)[8], …etc. This section introduces theoretical basic aspects, principles and operations commun used by bio-inspired algorithms.

III.1.1 Problem formulation

It is a decision problem where a solution among several ones of a computational problem should be found with respect to some objectives. The selected solution is called optimal solution. An optimization problem considered as a Non-deterministic Polynomial resolution or (NP-Hard) if there is no polynomial algorithm to solve this problem. In MANETs, routing can be considered as an optimization problem where an efficient setting parameters will be extracted among several possible configurations leading to optimal routing protocol performances[9].

III.1.2 Problem inputs encoding

Problem inputs are encoded in individuals. Each individual is encoded using a data structure based on boolean, strings, or trees, etc. Some individual encoding types include: binary encoding which consists of a set of binary variables; discrete encoding is based on a discrete vector of integer values; natural encoding in which an individual is represented by a vector of integer values. Encoding plays a major role in the efficiency and effectiveness of the resolution algorithm which helps to reduce the computational complexity[10].

Individuals form a set of solutions chosen from the search space. A population is characterized by its size which represents number of individuals belonging to this population. The population size is an important algorithm parameter impacting the algorithm run time[11].

III.1.3 Objective function

An objective function or fitness function is a formal function used to evaluate a solution in the search space, expressed in a quantitative value. The objective function finds some extreme solution either minimum or maximum based on one or multiple objectives[12]. As an example:

$$\text{Minimize } f = w1*fc1 + w2*fc2 \qquad \text{(III.1)}$$

where

f: is an objective function trying to minimize costs comparing different configurations

fc1 and fc2: represent cost, as bi-objective problem.

wi: represents quality weights related to these objectives (fc1 and fc2)..

III.1.4 Initialization

Initialization is the first step to form the initial population. In this step, a set of solutions are chosen from the search space using, generally, two ways to generate an initial population:

- The first approach is known as the random approach where all individuals of the first population are selected at random from the search space. This approach ensures a certain diversity of population individuals. This approach allows a uniform initialization which means that the individuals are equally likely to be chosen[13];
- The second initialization method is called the greedy approach generating the initial population according to a logical idea contrary to a random process. For example, population individuals can be selected sequentially (one by one). In this category, the simple sequential inhibition process can be cited as a greedy initialization approach. In simple sequential inhibition, a subpopulation is formed by one individual selected randomly from the solution search space. After that, the nearest individual to the selected one is chosen as the second individual and is integrated to the subpopulation. This process is repeated until forming the initial population. We note that the neighborhood distance between two individuals is expressed in terms of the problem objectives[14].

III.1. 5 Stopping criterion

Stopping criterion represents a measured value used to control run time of an optimization algorithm. This criterion can be defined as a fixed number of iterations, fixed before starting the resolution algorithm. In this case, the stopping criterion is called static criterion. However, a dynamic stopping criterion can also be applied to end the optimization algorithm, where the algorithm iterations are carried out and stopped only if the fitness function does not improve after a certain number of times (i.e. the convergence or stagnation state). Note that in the dynamic case, the number of iterations is limited to a maximum threshold to deal with the non-stagnation state[15].

III.2 Bio-inspired algorithms used in routing protocols setting

In this thesis, we apply bio-inspired optimization algorithms called non-dominated sorting genetic algorithm II (NSGA-II), Dynamic Evolution (DE) and Particle Swarme Optimization (PSO) to the problem of routing protocol parameters setting (OLSR and ZRP routing protocols). The parameters setting in this kind of problems is considered as a multi-objective optimization problem involving multiple conflicting objectives to be optimized. Therefore different solutions will produce trade-offs between different objectives and a set of solutions is required to represent the optimal solutions of all objectives corresponding to the optimal routing protocol configuration[16-20].

III.2.1 NSGA-II algorithm

The Non-dominated Sorting Genetic Algorithm-II called NSGA-II is a generic non-explicit multi-objective optimization evolutionary algorithm applied to multi-objective problems. As shown in Fig. III.1, it builds a population of competing individuals, ranks and sorts each individual according to non-domination level, applies evolutionary operations to create new pool of offspring, and then combines the parents and offspring before partitioning the new combined pool into fronts. The NSGA-II then conducts niching by adding a crowding distance to each member. It uses this crowding distance in its selection operator to keep a diverse front by making sure each member stays a crowding distance apart. This keeps the population diverse and helps the algorithm to explore the fitness landscape[21].

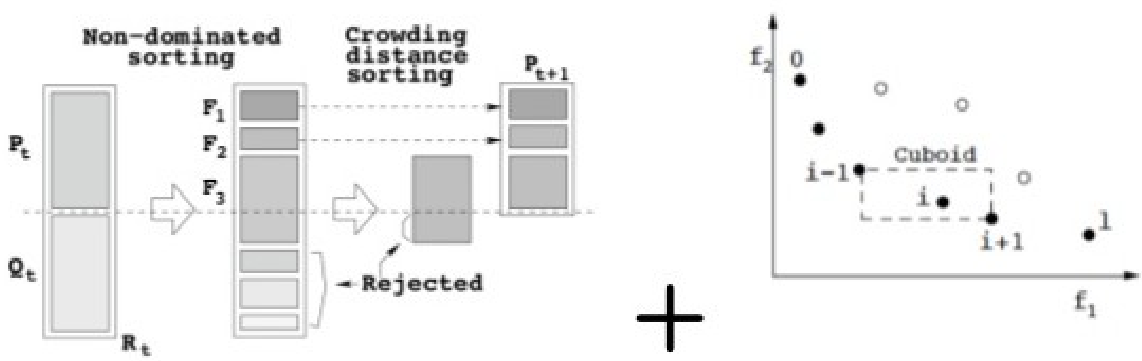

Fig. III.2 Schematic representation of NSGA-II operations.

The overall pseudo code of the NSGA-II improved by Deb & al. is shown below[21-22]:

NSGA-II algorithm pseudo-code

N members evolved g generations to solve $f_k(x)$

Initialize Population P

Generate random population - size N

Evaluate Objective Values

Assign Rank (level) Based on Pareto dominance - sort

Generate Child Population

Binary Tournament Selection

Recombination and Mutation

for i = 1 to g **do**

  for each Parent and Child in Population **do**

    Assign Rank (level) based on Pareto - sort

    Generate sets of non-dominated vectors along PFknown

    Loop (inside) by adding solutions to next generation starting from first

front   until N individuals found determine crowding distance between points on

    each front

  end for

  Select points (elitist) on the lower front (with lower rank) and are outside crowding distance

  reate next generation

  Binary Tournament Selection

  Recombination and Mutation

end for

III.2.2 DE algorithm

Differential evolution, or DE, was developed in R. Storn and K. Price in their nominal papers in 1996 and 1997 [23-24]. DE is a vector-based metaheuristic algorithm, which has some similarity to pattern search and genetic algorithms due to its use of crossover and mutation. In fact, DE can be considered as a further development to genetic algorithms with explicit updating equations, which make it possible to do some theoretical analysis. DE is a stochastic search algorithm with self-organizing tendency and does not use the information of derivatives. Thus, it is a population-based, derivative-free method. In addition, DE uses real numbers as solution strings, so no encoding and decoding is needed.

As in genetic algorithms, design parameters in a d-dimensional search space are represented as vectors, and various genetic operators are operated over their bits of strings. However, unlike genetic algorithms, differential evolution carries out operations over each component (or each dimension of the solution). Almost everything is done in terms of vectors. For example, in genetic algorithms, mutation is carried out at one site or multiple sites of a chromosome, whereas in differential evolution, a difference vector of two randomly chosen population vectors is used to perturb an existing vector. Such vectorized mutation can be viewed as a more efficient approach from the implementation point of view. This kind of perturbation is carried out over each population vector and thus can be expected to be more efficient. Similarly, crossover is also a vector-based, component-wise exchange of chromosomes or vector segments[25].

For a d-dimensional optimization problem with d parameters, a population of n solution vectors are initially generated. We have $\boldsymbol{x}i$, where i = 1, 2, . . . , n. For each solution $\boldsymbol{x}i$ at any generation t, we use the conventional notation as

$$\boldsymbol{x}_i^t = (x_{1,i}^t, x_{2,i}^t, \ldots, x_{d,i}^t), \tag{III.2}$$

which consists of d-components in the d-dimensional space. This vector can be considered the chromosomes or genomes.

Differential evolution consists of three main steps: mutation, crossover, and selection[26]:

- Mutation is carried out by the mutation scheme. For each vector *xi* at any time or generation *t*, we first randomly choose three distinct vectors *xp, xq* , and *xr* at *t* (see Fig. III.1), and then we generate a so-called donor vector by the mutation scheme

$$v_i^{t+1} = x_p^t + F(x_q^t - x_r^t), \quad \text{(III.3)}$$

where F ∈ [0, 2] is a parameter, often referred to as the differentialweight.This requires that the minimum number of the population size is n ≥ 4. In principle, F ∈ [0, 2], but in practice, a scheme with F ∈ [0, 1] is more efficient and stable. In fact, almost all the studies in the literature use F ∈ (0, 1).

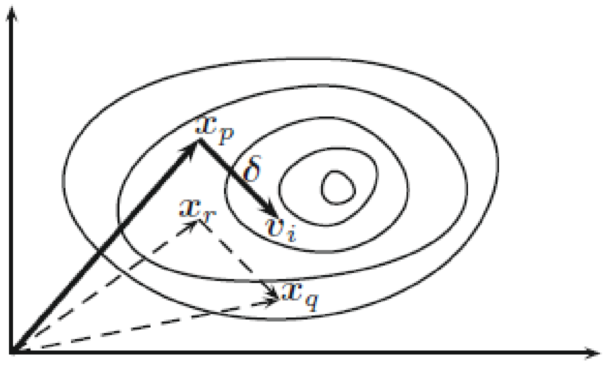

Fig. III.2 Schematic representation of mutation vectors in differential evolution with movement **δ** = *F(xq − xr)*.

From Fig. III.1, we can see that the perturbation **δ** = F(**x**q − **x**r) to the vector **x**p is used to generate a donor vector **vi** , and such perturbation is directed.

- The crossover is controlled by a crossover parameter Cr ∈ [0, 1], controlling the rate or probability for crossover. The actual crossover can be carried out in two ways: binomial and exponential. The binomial scheme performs crossover on each of the d components or variables/parameters. By generating a uniformly distributed random number ri ∈ [0, 1], the j th component of **vi** is manipulated as

$$u_{j,i}^{t+1} = \begin{cases} v_{j,i} & \text{if } r_i \leq C_r, \\ x_{j,i}^{t} & \text{otherwise,} \end{cases} \quad j = 1, 2, \ldots, d. \tag{III.4}$$

This way, it can be decided randomly whether to exchange each component with a donor vector or not.

In the exponential scheme, a segment of the donor vector is selected, and this segment starts with a random integer *k* with a random length *L*, which can include many components.

Mathematically, this is to choose $k \in [0, d-1]$ and $L \in [1, d]$ randomly, and we have

$$u_{j,i}^{t+1} = \begin{cases} v_{j,i}^{t} & \text{for } j = k, \ldots, k - L + 1 \in [1, d], \\ x_{j,i}^{t} & \text{otherwise.} \end{cases} \tag{III.5}$$

Because the binomial is simpler to implement, we will use the binomial crossover in our implementation.

- Selection is essentially the same as that used in genetic algorithms. We select the fittest and, for the minimization problem, the minimum objective value. Therefore, we have

$$x_{i}^{t+1} = \begin{cases} u_{i}^{t+1} & \text{if } f(u_{i}^{t+1}) \leq f(x_{i}^{t}), \\ x_{i}^{t} & \text{otherwise.} \end{cases} \tag{III.6}$$

All three components can be seen in the pseudo code shown below. It is worth pointing out here that the use of *J* is to ensure that *vt*+1*i*_= *xti* , which may increase the evolutionary or exploratory efficiency. The overall search efficiency is controlled by two parameters: the differential weight *F* and the crossover probability *Cr* .

Differential Evolution algorithm pseudo-code

Initialize the population ***x*** with randomly generated solutions

Set the weight $F \in [0, 2]$ and crossover probability $Cr \in [0, 1]$

while (stopping criterion)

for $i = 1$ to n,

For each ***xi***, randomly choose 3 distinct vectors ***xp***, ***xr*** and ***xr***

Generate a new vector ***v*** by DE scheme (Eq. III.3)

Generate a random index $Jr \in \{1, 2, ..., d\}$ by permutation

Generate a randomly distributed number $ri \in [0, 1]$

for $j = 1$ to d,

For each parameter ***vj,i*** (*j*th component of ***vi***), update

$$u_{j,i}^{t+1} = \begin{cases} v_{j,i}^{t+1} & \text{if } r_i \le C_r \text{ or } j = J_r \\ x_{j,i}^{t} & \text{if } r_i > C_r \text{ and } j \ne J_r, \end{cases}$$

end

Select and update the solution (Eq. III.6)

end

end

Post-process and output the best solution found

III.2.3 PSO algorithm

Particle swarm optimization was developed by Kennedy and Eberhart in 1995 based on swarm behavior in nature, such as fish and bird schooling [27]. Rather than using the mutation/crossover or pheromone, it uses real-number randomness and global communication among the swarm particles. Therefore, it is also easier to implement because there is no encoding or decoding of the parameters into binary strings as with those in genetic algorithms where real-number strings can also be used.

The PSO algorithm searches the space of an objective function by adjusting the trajectories of individual agents, called *particles*, as the piecewise paths formed by positional vectors in a quasi-stochastic manner. The movement of a swarming particle consists of two major components:

- a stochastic component;
- and a deterministic component.

Each particle is attracted toward the position of the current global best g^* and its own best location x_i^* in history, while at the same time it has a tendency to move randomly. When a particle finds a location that is better than any previously found locations, updates that location as the new current best for particle i. There is a current best for all n particles at any time t during iterations. The aim is to find the global best among all the current best solutions until the objective no longer improves or after a certain number of iterations. The movement of particles is schematically represented in Fig. III.3 where $x_i^*(t)$ is the current best for particle i, and $g^* \approx \min\{f(x_i)\}$ for $(i = 1, 2, ..., n)$ is the current global best at t.

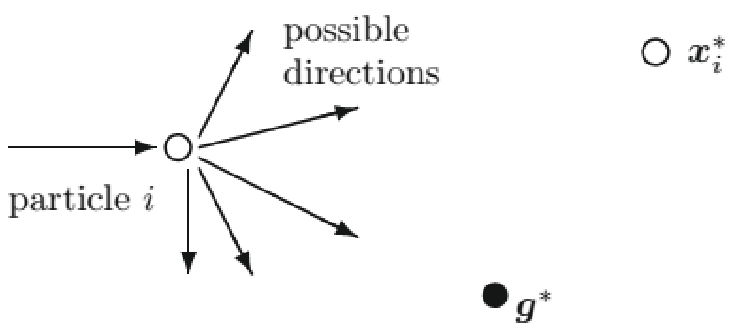

Fig. III.3 Representation of the notion of a particle in PSO.

The new velocity and position vectors are determined by the following formulas:

$$v_i^{t+1} = v_i^t + \alpha\varepsilon_1\left[g^* - x_i^t\right] + \beta\varepsilon_2\left[x_i^{*(t)} - x_i^t\right] \quad \text{(III.7)}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad \text{(III.8)}$$

where

x_i^t is the position vector for particle i at instant t;

v_i^t is the velocity vector for particle i at instant t;

ε_1 and ε_2 are two random vectors, and each entry takes the values between 0 and 1;

α and β are the learning parameters or acceleration constants, which can typically be taken as, say, $\alpha \approx \beta \approx 2$.

The essential steps of the particle swarm optimization can be summarized as the pseudo code below.

Particle Swarm Optimization Algorithm pseudo-code

Objective function $f(\boldsymbol{x})$, $\boldsymbol{x} = (x_1, ..., x_d)^T$

Initialize locations $\boldsymbol{x}_i$ and velocity $\boldsymbol{v}_i$ of n particles.

Find $\boldsymbol{g}^*$ from min $\{f(\boldsymbol{x}_1), ..., f(\boldsymbol{x}_n)\}$ (at t=0)

while (criterion)

  for loop over all n particles and all d dimensions

    Generate new velocity $\boldsymbol{v}_i^{t+1}$

    Calculate new locations $\boldsymbol{x}_i^{t+1} = \boldsymbol{x}_i^t + \boldsymbol{v}_i^{t+1}$

    Evaluate objective functions at new locations $\boldsymbol{x}_i^{t+1}$

    Find the current best for each particle $\boldsymbol{x}_i^*$

  end for

  Find the current global best $\boldsymbol{g}^*$

  Update t=t+1 (pseudo time or iteration counter)

end while

Output the final results $\boldsymbol{x}_i^*$ and $\boldsymbol{g}^*$

The initial positions of all particles should distribute relatively uniformly so that they can sample over most regions, which is especially important for multimodal problems. The initial velocity of a particle can be taken as zero, that is, $v_i^{t=0} = 0$.

III.3 Proposed bio-inspired routing protocols

Bio-inspired protocols proposed in this thesis were based on some of algorithms extracted from the nature of species. In this section, we introduce and explain theoretical aspects, principles and operations of these bio-inspired algorithms in order to simplify the comprehension of their implementations for MANET routing protocols presented in the following section.

III.3.1 OLSR protocol

III.3.1.1 Conventional OLSR protocol

As was seen in Chapter I, routing protocols can be classified into three categories based on the process of route discovery: Proactive routing protocol, Reactive routing protocol and Hybrid routing protocol. The OLSR routing protocol is one of the most known of the proactive routing protocols. This choice is justified by the following characteristics of OLSR routing protocol:

- OLSR exhibits very competitive delays in the transmission of data packets in large networks;
- It adapts well to the continuous topology changes;
- OLSR has simple operation that allows it to be easily integrated into different kinds of systems.

The continuous exchange of OLSR routing control packets causes the appearance of network congestion limiting the global performance. Thus, the quality of service significantly depends on the selection of its parameters, which determine the protocol operation. In addition, OLSR routing protocol has a wide range of improvement by changing the configuration parameters.

OLSR daemons periodically exchange different messages to maintain the topology information of the entire network in the presence of mobility and failures. Functionality of OLSR is basically performed by using different types of messages that are: HELLO, topology control, and multiple interface declaration messages:

- **HELLO messages** are exchanged between nodes in the network (one-hop distance). They are used for link sensing and neighborhoods detection. These messages are generated and transferred periodically between the nodes in the network;
- **Topology control (TC) messages** are generated periodically by multi point relays (MPR) to indicate which other nodes have selected it as their MPR. This information is stored in the topology information of each node, which is used for routing table calculations;
- **Multiple interface declaration (MID) messages** are sent by the nodes to inform about their network interfaces that are actively participating in the network. Such information is needed since the nodes may have multiple interfaces with distinct addresses participating in the communications.

Each messages category has a validity time of the information received, as defined below:

- NEIGHB_HOLD_TIME (HELLO);
- MID_HOLD_TIME (MID);
- TOP_HOLD_TIME (TC).

In addition, the WILLINGNESS of a node to act as an MPR and DUP_HOLD_TIME which represents the time during which the MPRs record information about the forwarded packets.

The OLSR mechanisms are regulated by a set of parameters predefined in the OLSR RFC 3626 [28] are defined in Table. III.1.

III.3.1.2 Proposed NSGA-II-OLSR protocol

The automatic optimization of the OLSR parameters configuration is carried out through two phases, namely evaluation phase and optimization procedure:

- **The optimization phase** is carried out by meta-heuristic method; in this case we used NSGA-II. This method is used to find optimal (or quasi-optimal) solutions in search spaces with more than one objective function;
- **Evaluation phase** is used for assigning a quantitative quality value (fitness) to the OLSR performance of computed configurations. This procedure is carried out using the popular network simulator NS-2[29].

Table III.1 Main OLSR parameters and RFC 3626 specified values.

Parameters	**Standard Configuration**	**Range**
HELLO_INTERVAL	2.0 s	R ∈ [1.0, 30.0]
REFRESH_INTERVAL	2.0 s	R ∈ [1.0, 30.0]
TC_INTERVAL	5.0	R ∈ [1.0, 30.0]
WILLINGNESS	3	Z ∈ [0,7]
NEIGHB_HOLD_TIME	3 × HELLO INTERVAL	R ∈ [3.0, 100.0]
TOP_HOLD_TIME	3 × TC_INTERVAL	R ∈ [3.0, 100.0]
MID_HOLD_TIME	3 × TC_INTERVAL	R ∈ [3.0, 100.0]
DUP_HOLD_TIME	30.0 s	R ∈ [3.0, 100.0]

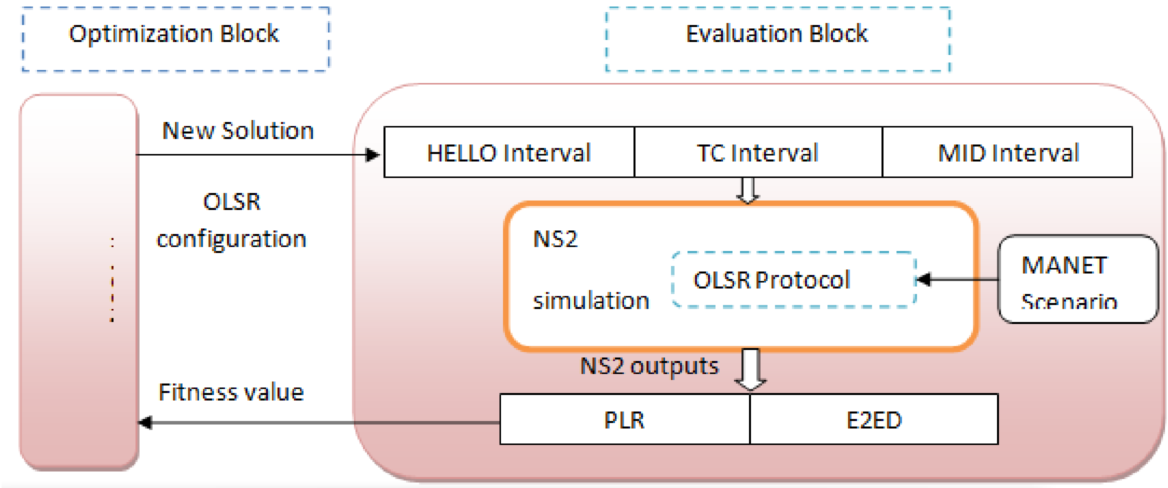

Fig. III.4 Optimization framework for the automatic OLSR configuration in MANETs.

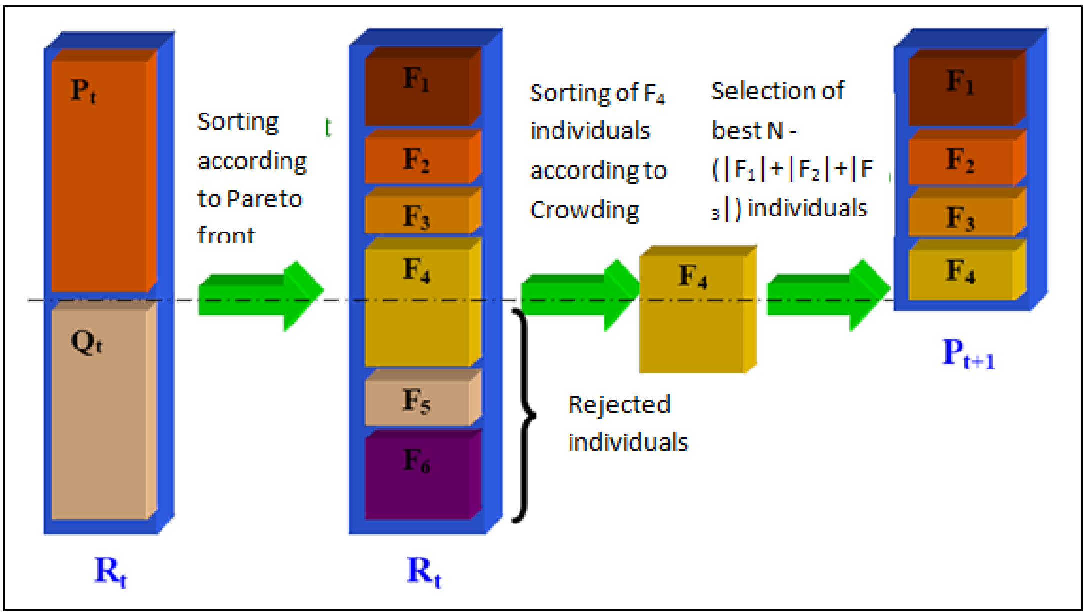

Fig. III.5 Flow diagram of the NSGA-II algorithm: P_t is the parent's population, Q_t is the offspring population at generation t, F_1 are the best solutions from the combined populations (parents and offspring); F_2 are the second best solutions and so on.

The evaluation of the new solutions is performed using the simulation process under the NS-2 software. The evaluation block is invoked by NSGA-II to simulate the MANET scenario by configuring OLSR with the new generated parameter setting as it is shown in Fig. 5. Once the simulation is completed, NS-2 outputs are analyzed to obtain PLR and

E2ED that are used to compute the fitness value to guide the algorithms search. The objective here consists in minimizing PLR and E2ED values.

It should be noted that once the algorithm converges, we obtain a set of OLSR parameters representing the Pareto front. These set of OLSR parameters have the same total cost for the two objectives. It is up to us to choose the best OLSR parameters that help to minimize one or both goals simultaneously.

a) OLSR parameters encoding

For the purpose of OLSR parameters encoding, we opted for a representation by real chromosomes. This representation allows us to encode three parameters to explore a three-dimensional space. Each interval is encoded by a real value bounded by min and max (in our case, min = 1s and max = 30s) as it is shown in Fig. III.6.

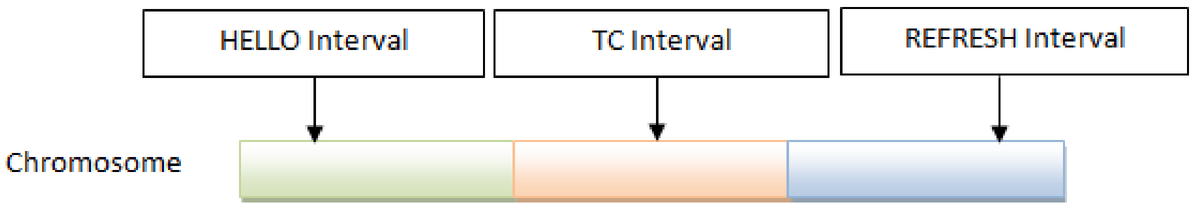

Fig. III.6 Encoding of OLSR parameters.

b) Metrics

To evaluate the quality or fitness of the different OLSR configurations (tentative solutions), a communication cost function has been defined in terms of the most commonly used QoS. The metrics used in this area are defined below[30-33]:

Packet loss ratio (PLR)

The PLR is defined as the number of the packets that are not successfully sent to the destination during transmission. The less value of the packet loss means the better performance of the protocol;

The end-to-end delay (E2ED)

The E2ED is defined as the difference between the time when a data packet is originated by an application and the time this packet is received at its destination.

c) Objective Functions

The Objective functions are decisive for the NSGA-II optimization procedure, as it guides the population during the search process. As mentioned previously, in this study we define two objectives functions:

$$F1 = \text{The Packet loss ratio} \tag{III.9}$$

and

$$F2 = \text{End-to-End Delay} \tag{III.10}$$

The evaluation of the new solutions is performed using the simulation process under the NS-2 software. The evaluation block is invoked by NSGA-II to simulate the MANET scenario by configuring OLSR with the new generated parameter setting as it is shown in Fig. 4. Once the simulation is completed, NS-2 outputs are analyzed to obtain PLR and E2ED that are used to compute the fitness value to guide the algorithms search. The objective here consists in minimizing PLR and E2ED values.

III.3.1.3 Proposed DE-OLSR protocol

In mobile ad hoc networks, Periodic Hello messaging scheme is a widely-used to obtain local link Connectivity information. However, traditional routing protocols use a fixed interval time approach to send hello messages. This implies that before the deployment of the network, all the node need to be initialized with same optimal value of the hello interval parameter estimated by network administrators. The constraint of having the uniform hello interval value for all the nodes may not be desirable. So using an independent hello interval value for each node leading to increase routing performance. For frequent topology change network, it is adequate to select a small value for hello interval parameter; In contrast, a large value is more effective for network with topology remains stable.

The goal of our scheme is to determine the optimal Hello interval of each node in the network that can improve the global performance of the network. According to that, we consider a solution vector of integer variables, each one representing a given hello interval value for a given node as shown in Fig III.7.

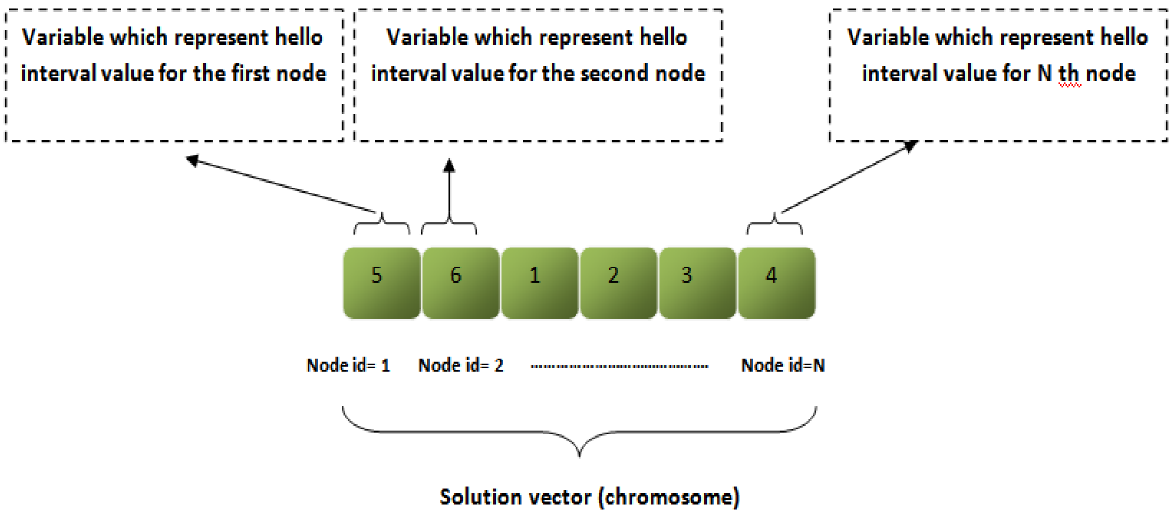

Fig. III.7 Representation of solution vector.

The solution vector can be tuned automatically by an optimization technique, with the aim of obtaining efficient hello interval configuration leading to increase Qos of the network represented by packet delivery ratio (PDR), average end to end delay (AEED) and network routing Load (NRL).

III.3.2 ZRP protocol

III.3.2.1 Conventional ZRP protocol

a) Zone Routing Protocol Overview

Zone routine protocol is a hybrid routing protocol that is most suitable for large-scale networks [34-35]. It was proposed to reduce the control overhead of proactive routing protocols and decrease the latency caused by routing discover in reactive routing protocols. In ZRP, the network is divided into a number of overlapping zones centered at each node. The size of the zone is given by a radius value (R), where R is the number of hops to the perimeter of the zone. Thus, zones include all nodes whose distance in hops from the central node is equal to R. Figure 1 illustrates the routing zone concept with value of radius equal to 2 hops, where the routing zone of S includes the nodes A–K, but not L.

In addition, the nodes of a zone are divided into:

- Peripheral nodes, in which minimum distance to the center is exactly equal to zone radius R (Blue color nodes from I to K in Fig. III.8);
- Interior nodes whose minimum distance to the center is less than zone radius (gray color nodes from node A to H in Fig. III.8);

- Outside nodes whose minimum distance to the center is greater than zone radius (node L in Fig. III.8 example).

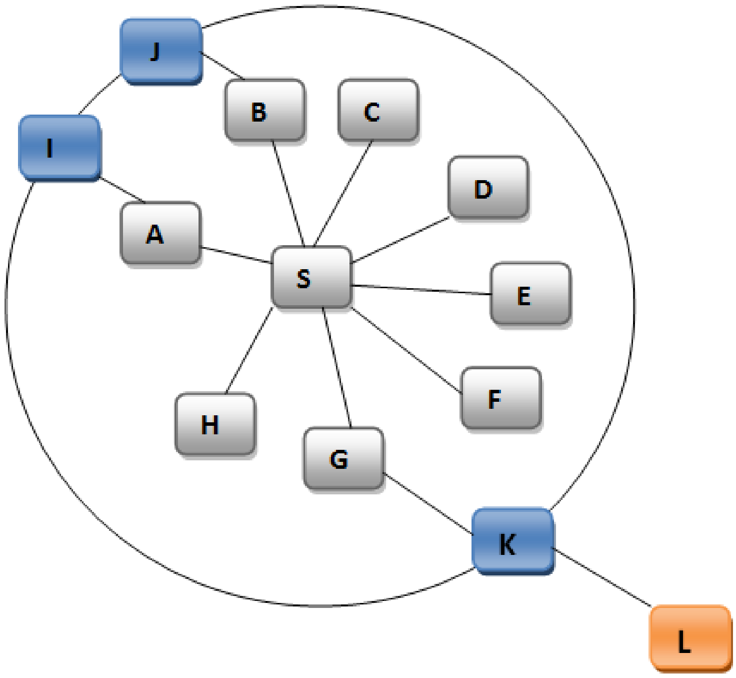

Fig. III.8 Routing zone with radius R = 2.

b) Zone Routing Protocol Architecture

Zone routing protocol is basically performed using two separate routing components: the proactive routing component (i.e IntrAzone Routing Protocol (IARP)) and the reactive routing component (i.e IntErzone Routing Protocol (IERP)). IARP maintains routing information for nodes that are within the routing zone of the node. Correspondingly, IERP is a family of reactive routing protocols that offer enhanced route discovery and route maintenance services based on local connectivity monitored by IARP. In addition, IERP uses another protocol called Bordercast Resolution Protocol (BRP) [34] to only transmit route requests to peripheral nodes instead of flooding it to all nodes. Finally, each node in the network has the capability of periodically broadcasting "hello" message to keep its map of neighbors up to date. This is assured by a third protocol known as Neighbor Discovery Protocol (NDP) [29-30]. The relationship between all these components is illustrated in Fig. III.9.

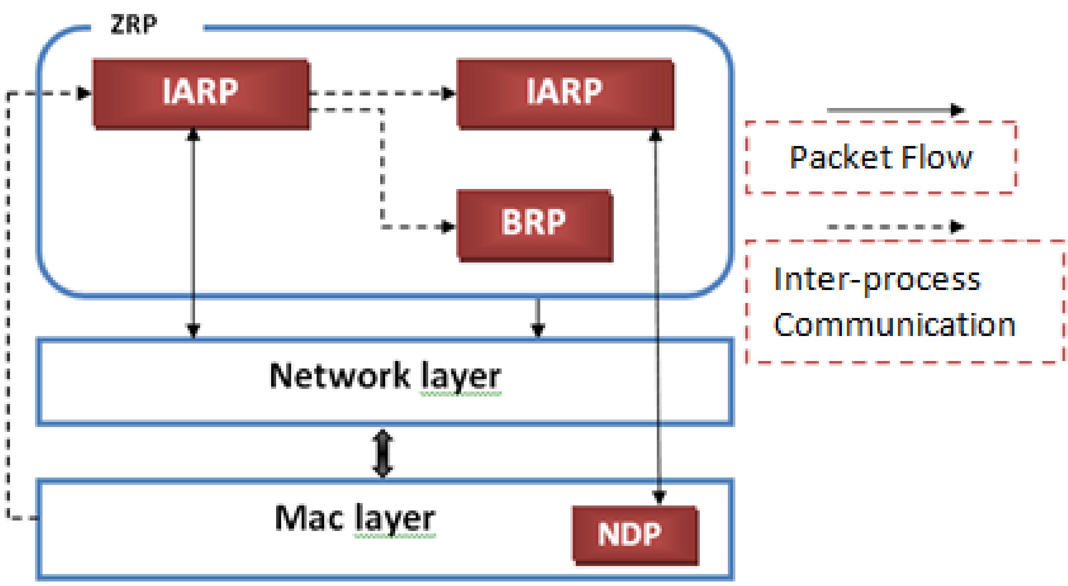

Fig. III.9 Zone routing protocol architecture.

When the local neighborhood of the node will be changed, a route updates are triggered by NDP, leading to update neighbor table which notifies IARP. Then, IERP uses the routing table of IARP to respond to route queries. To forward queries, IERP uses BRP depending on the routing table of IARP to guide route queries away from the query source [34-35].

c) Routing in ZRP

In order to forward a packet, a node first searches the destination on its local zone using information provided by IARP; in that case, the packet can be routed proactively. In contrast, if the destination is outside the zone, reactive routing will be used by performing two separate phases:

- The route request phase;
- The route reply phase.

In the route request phase, a request packet is sent to the peripheral nodes using BRP. If the destination is known by the receiver, it responds by sending a route reply back to the source. Otherwise, the process of bordercasting the packet will be continuing. The reply is sent by any node that can provide a route to the destination. When the request is sent through the network, routing information must be recorded in the routing request. If the destination is reached, the sequence of addresses is reversed and copied to the route reply packet [34-35].

III.3.2.2 Proposed PSO-IZRP protocol

In this study, we propose a new enhancement of the conventional ZRP routing protocol based on the use of the meta-heuristic particle swarm optimization estimation of the ZRP radius allowing the ZRP protocol to dynamically adapt to any environment changes by varying each node's zone radius. The proposed algorithm is described below.

a) PSO-IZRP implementation

In this study, we propose an optimization framework composed of two parts:

- An optimization algorithm;
- A simulation procedure.

Figures III.10 and III.11 show the optimization framework and process.

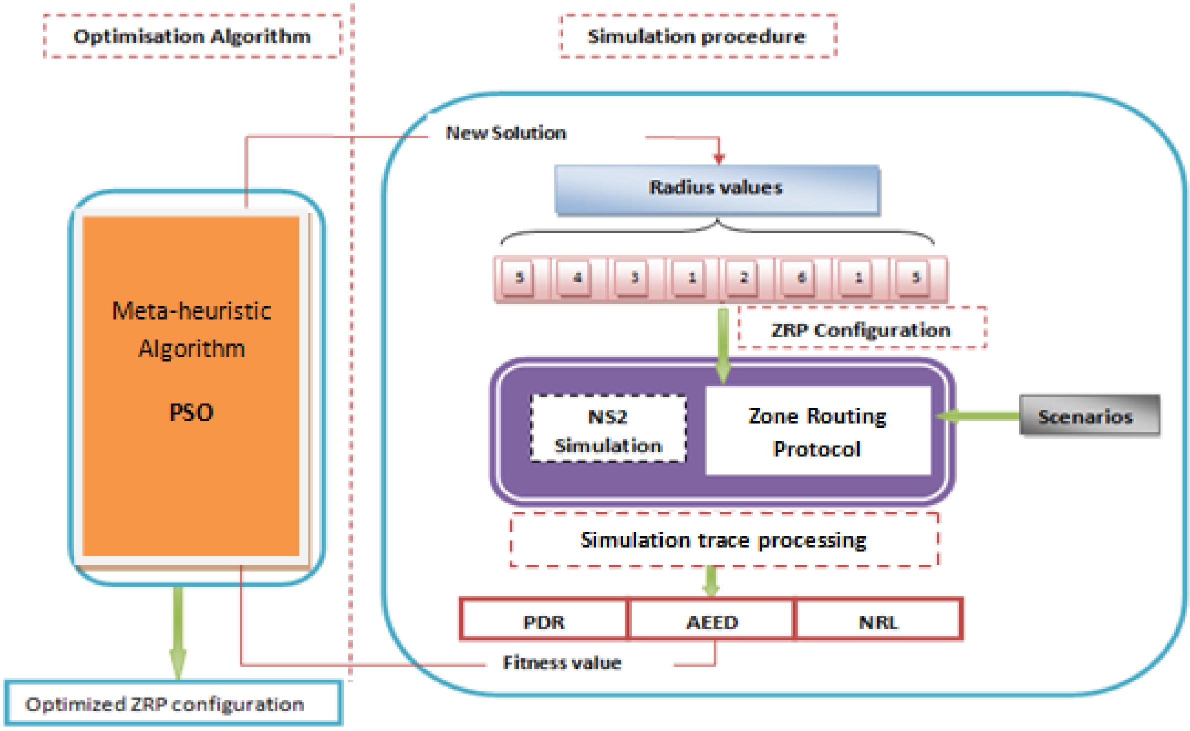

Fig. III.10 Proposed optimization framework.

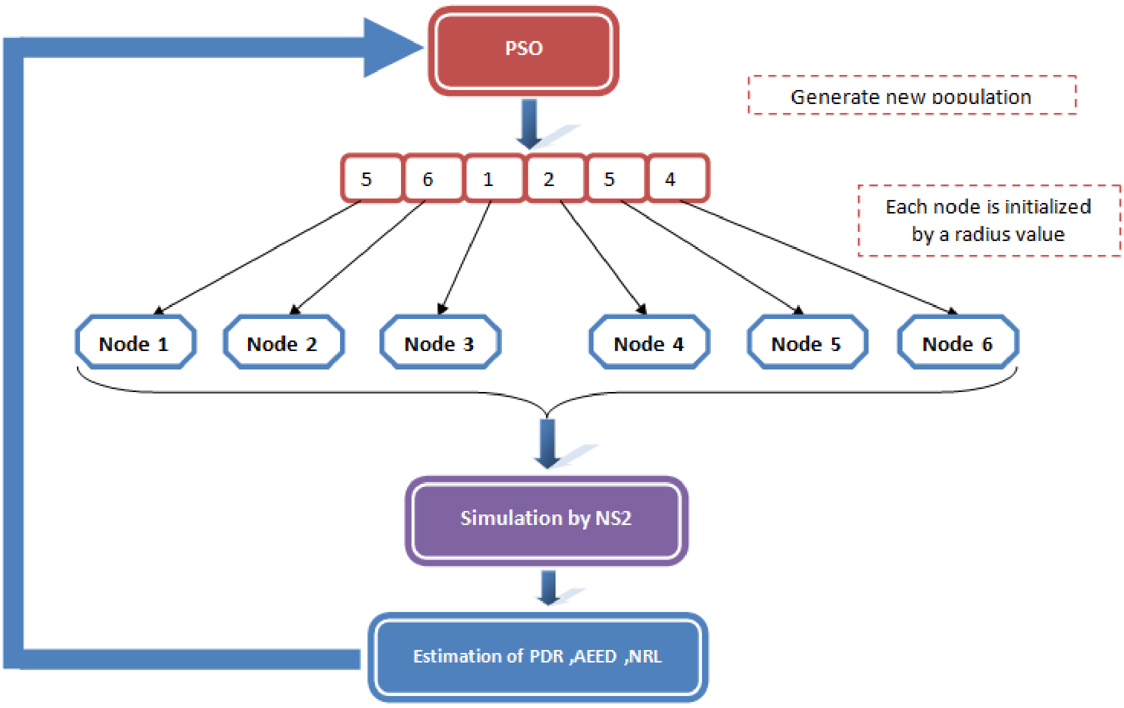

Fig. III.11 Process of optimization.

a) Radius Encoding

In the optimization part, we use the PSO algorithm to generate an initial population with a group of random particles. Every particle has n values where each value represent radius zone for each node. This codification allows the nodes in the network to obtain an initial independent zone radius. The Fig. III.12 shows the representation of a particle.

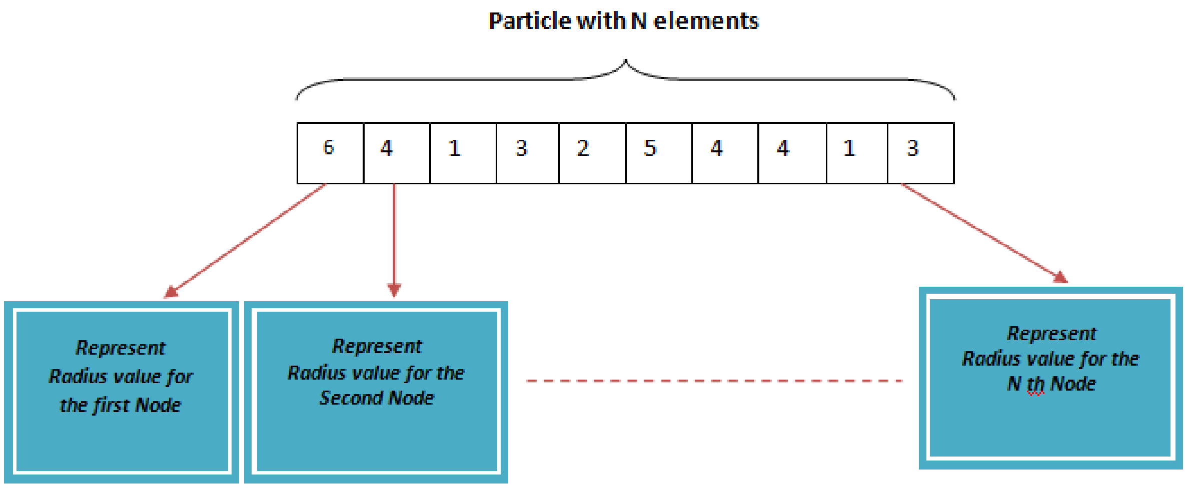

Fig. III.12 Representation of particle.

b) Metrics

Packet Delivery Ratio (PDR)

PDR is the ratio of the data packets delivered to the destination successfully to those generated by the source nodes. PDR describes the information about packet loss rate. Higher value of PDR for the network indicates a better reliability for the protocol.

$$PDR = \frac{\text{Number of Packets received by destination}}{\text{Number of Packet sent by source}} \qquad \text{(III.11)}$$

Average End to End Delay (AEED)

End-to-end delay indicates how long a packet will take travel from the CBR source to the application layer at the destination. This includes all possible delays that will be caused by: buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, Propagation and transfer times. The average end-to-end delay can be calculated by summing the times taken by all received packets divided by their total numbers. The Average End-to-End Delay should be less when it comes to high performance.

$$\text{E2ED}=\frac{\sum_{\text{packetid}=1}^{N}(\text{Number of Received}_{\text{packetid}} - \text{Number of Sent}_{\text{Packetid}})}{N} \quad \text{(III.12)}$$

where N is the number of data packets successfully transmitted over the MANET, $\text{Received}_{\text{packetid}}$ is the time of the packet's reception and $\text{Sent}_{\text{packetid}}$ is the time of the packet's emission.

Normalize Routing Load (NRL)

NRL is the number of routing packets transmitted within the network per data packets .

$$\text{NRL}=\frac{\text{Number of routing packet transmitted}}{\text{Total number of packet received}} \quad \text{(III.13)}$$

c) Objective function

When PSO generate new solution (particle), it is immediately used for configuring ZRP protocol. In this stage, the second part of our framework which is the simulation procedure is intervening in order to perform the simulation and evaluation. After each simulation done by the NS-2 simulator, this later produces a set of global information about the fitness value. Packet Delivery Ratio (PDR), the Normalized Routing Load (NRL), and the Average End-to-End Delay (AEED) of the whole network scenario. Based on these performance metrics, we define the following fitness function:

$$\text{Fitness} = w_1.(\text{NRL}) + w_2.(\text{AEED}) + w_3.(1/\text{PDR}) \quad \text{(III.14)}$$

where w_1, w_2 and w_3 are the weighting coefficients used to scale each performance measure importance. The objective of this equation is to minimize both NRL and AEED while maximizing PDR. In this work, we use 0.3, 0.2 and 0.5 as weighting coefficients for

w_1, w_2 and w_3 respectively. We can see that we are giving more importance to PDR than NRL and E2ED. This is based on the fact that we are first looking to improve the communication efficiency then the routing effectiveness. Guided by the defined fitness function, the PSO algorithm tries to find the optimal configuration of the ZRP protocol which is tailored to a given scenario instance and to an improvement of the network QoS.

III.4 Conclusion

This chapter provides a detailed knowledge concerning biologically inspired approaches used in this work for MANET routing protocols setting. It starts with motivations for using such methods in MANET routing and describes different basic bio-inspired algorithms used NSGA-II, DE and PSO algorithms. Afterward, basic concepts and operations of bio-inspired protocols routing implemented (OLSR and ZRP) are detailled. Moreover, this chapter outlines the motivation to use the bio-inspired approache to optimize the routing protocols configurations. It includes the encoding, metrics and objective functions used for each proposed bio-inspired routing protocol, which were used in chapter IV giving the simulation results.

III.5 References

[1] Holland, J.H., Adaptation in Natural and Artificial Systems, University of Michigan Press, 1975.

[2] Goldberg, D.E. (1993), Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley.

[3] Kirkpatrick, S, Gelatt, C.D. and Vecchi, M.P. (1983), Optimization by simulated annealing, Science, 220, 4598, 671–80.

[4] Dorigo, M. and Stützle, T. (2004), Ant colony optimization. Cambridge, MA, USA: MIT Press.

[5] Kennedy, J. and R.C. Eberhart. 1995. "Particle swarm optimization" Paper presented at IEEE International Conference on Neural Networks. Piscataway 27 Nov-01 Dec 1995. doi: 10.1109/ICNN.1995.488968

[6] Geem, Z.W., Kim, J.H. and Loganathan, G.V. (2001), A new heuristic optimization algorithm: harmony search. Simulation, 76, 1, 60–8.

[7] Karaboga, D. (2005), An idea based on honeybee swarm for numerical optimization, Technical Report, Erciyes University, Turkey.

[8] Yang, X.S. (2009), Firefly algorithms for multimodal optimization, Symposium on stochastic algorithms, foundations and applications, Lecture notes in computer science, 5792, 169–78.

[9] Bitam, S. and Mellouk, A., Mellouk, Bio-inspired Routing Protocols for Vehicular Ad Hoc Networks, ISTE Ltd John Wiley & Sons, London, 2014.

[10] Yang, X.S., Nature-Inspired Optimization Algorithms, Elsevier, London, 2014.

[11] Talbi, E. G., Mellouk, A., Metaheuristics: From Design to Implementation, Wiley Edition, 2009.

[12] Câmara, D., Bio-inspired Networking, ISTE Press Ltd and Elsevier Ltd, London, 2015.

[13] Diaz-Gomez, P.A. and Hougen, D.F., Initial Population for Genetic Algorithms - A Metric Approach, GEM, Las Vegas, 2007: 43-49.

[14] Wang, Z., Duan, H. and Zhang, X., An Improved Greedy Genetic Algorithm for Solving Travelling Salesman Problem, 5th ICNC 2009, Tianjian, China, 5, 2009, pp. 374-378.

[15] Wahde, M., Biologically Inspired Optimization Methods, Southampton, 2008.

[16] Gautami, R., Sedamkar, R.R. and Patil, H., Application of Hybrid Meta Heuristic Algorithm for OLSR Protocol Optimization in VANET, International Journal of Current Engineering and Technology, 6(3), 2016:755-759.

[17] Gupta, K. and Kohl, S., Optimizing OLSR Protocol for VANET, Asian Journal of Technology and Management Research (AJTMR), 6(2), 2016:23-32.

[18] Toutouh, J. and Alba, E., Parallel multi-objective metaheuristics for smart communications in vehicular networks, Soft Computing - A Fusion of Foundations, Methodologies and Applications archive, 21(8), 2017:1949-1961.

[19] Prusty, A.S., Nayak, S. and Kumar, A., Multi-objective optimality in energy efficient routing for heterogeneous wireless ad hoc sensor network with clustering, Intelligent Decision Technologies, 11(1), 2017:61-70.

[20] Al-Kharasani, N.M., Zulkarnain, Z.A., Subramaniam, S. and HanapiOrcid, Z.M., An Efficient Framework Model for Optimizing Routing Performance in VANETs, Sensors, 18(2), 2018:597

[21] Deb, K., Pratap, A., Agarwal, S. and Meyarivan, T. (2002), A Fast and Elitist Multi-objective Genetic Algorithm: NSGA-II, IEEE Trans. on Evolutionary Computation, 6, 2, 182-197.

[22] Sharifi, M. Pourkarim Guilani, P., Shahriari, M., Using NSGA II Algorithm for a Three-Objective Redundancy Allocation Problem with k-out-ofn Sub-Systems, Journal of Optimization in Industrial Engineering 19 (2016) 87-95

[23] Storn R. On the usage of differential evolution for function optimization. In: Biennial conference of the North American fuzzy information processing society (NAFIPS); 1996.

p. 519–23.

[24] Storn R, Price K. Differential evolution: a simple and efficient heuristic for global optimization over continuous spaces. J Global Optimization 1997;11:341–59.

[25] Price K, Storn R, Lampinen J. Differential evolution: a practical approach to global optimization. Germany: Springer; 2005.

[26] Das S, Suganthan PN. Differential evolution: a survey of the state-of-the-art. IEEE Trans Evol Comput 2011;15(1):4–31.

[27] Kennedy, J., R. Eberhart and Y. Shi. 2001. *"Swarm intelligence"* San Francisco: Morgan Kaufmann.

[28] Gomez, C., Garcıa, D. and Paradells, J. (2005), Improving performance of a real Ad Hoc network by tuning OLSR parameters, IEEE Symposium on Computers and Communications. Washington, 16–21.

[29] F.S. Kong and B.B. Cui, Performance evaluation of AODV, DSR and DSDV in mobile ad-hoc network using NS-2, The 4th Annual International Conference on Information Technology and Applications (ITA 2017), 12, **2017**:e04007.

[30] MZ.S. Houssaini, I. Zaimi, M. Oumsis and S.E.A Ouatik, Comparative Study of Routing Protocols Performance for Vehicular Ad-hoc Networks International Journal of Applied Engineering Research, 12(13), 2017:3867-3878

[31] J.N.R. Araujo, C. de Castro Monteiro and L. de Souza Batista, Multicriteria QoS-aware Solution in Wireless Multi-hop Networks ICWMC 2017 : The Thirteenth International Conference on Wireless and Mobile Communications, **2017**, 17-23.

[32] F.T. AL-Dhief, N. Sabri, M.S. Salim, S. Fouad and S.A. Aljunid, MANET Routing Protocols Evaluation: AODV, DSR and DSDV Perspective MATEC Web of Conferences 150, **2018**: e06024.

[33] L. Naik, R.U. Khan and R.B. Mishra, Comparative Performance Analysis on Revised MANET Routing Protocols, International Journal of Applied Engineering Research, 13(5), **2018**:2443-2451.

[34] Haas, Z.J., M.R. Pearlman and P. Samar. 2001. "The Intrazone Routing Protocol (IARP) for Ad Hoc Networks." https://tools.ietf.org/id/draft-ietf-manet-zone-iarp-01.txt.

[35] Haas, Z.J., M.R. Pearlman and P. Samar. 2002. "The Bordercast Resolution Protocol (BRP) for Ad Hoc Networks." https://tools.ietf.org/id/draft-ietf-manet-zone-brp-01.txt.

Chapter IV

Simulation and Results

IV.1 Presentation

The network simulations have been carried out using Network Simulator version 2 (NS-2.35). NS2 was implemented to simulate the NSGA-II-OLSR, DE-OLSR, ZRP and PSO-IZRP frameworks, respectively. We chose a Linux platform i.e. Ubuntu 12.04, as Linux offers a number of programming development tools that can be used with the simulation process. We analyzed the experimental results generated in the output trace files by using the AWK command.

NS-2 uses as input a file in "tcl" language, this file contains the scenario of the network that we want to simulate. NS-2 will generate two files: trace file and Nam file:

• **Trace file:** with a ".tr" extension that contains all the events done in the scenario. This file is generally used to calculate parameters related to the performance of the network, for example the rate of lost packets, the average time of the packets ... etc;

• **Nam file**: This file is used with a program called animator to visualize the scenario described in the input file "tcl".

IV.2 Results and Discussions

IV.2.1 OLSR Routing Protocol

IV.2.1.1 Using NSGA-II Algorithm

To prove the robustness and reliability of the proposed algorithm, we test its ability to optimize the OLSR parameters leading to Pareto front minimizing both objectives in both cases:

a) **low node mobility:** representing stable case

b) **high node mobility:** representing an unstable case

Table IV.1 gives the NSGA-II Parameters.

Table. IV.1 Simulation parameters.

NSGA-II Parameters			
Population size	100	Crossover	0.6
Objective	2	Mutation	0.1
Nb. of variables	3		

a) Low node mobility

This first experiment is used to simulate the low node mobility by varying the speed from 5m/s to 10m/s (Table IV.2).

Table. IV.2 OLSR parameters.

OLSR Parameters	
Nodes	20
Connections	20
Min speed	5 m/s
Max speed	10 m/s
Pause time	5 s
Area size	1000 m^2
Mobility model	Random way point

Table IV.3 gives an Example of the data file generated by the NSGA-II algorithm (Initial population for low node mobility).

Table. IV.3 Example of the data file generated by the NSGA-II algorithm (Initial population for low node mobility).

Obj. 1	Obj. 2	Hello interval	TC interval	Refresh interval
0.00986	593	7.88	7.99	18.8
$1.0\text{x}10^{14}$	0.00	26.8	17.5	4.86
$1.0\text{x}10^{14}$	0.00	17.4	18.8	2.83
0.0130	773	1.77	10.1	11.6
$1.0\text{x}10^{14}$	0.00	21.1	29.3	5.75
……	…….	…….	…….	…….

Fig. IV.1 shows the distribution of triplets of parameters (a triplet point represents the settings of Hello interval, TC interval and Refresh interval) in the objective space (for the initial population).

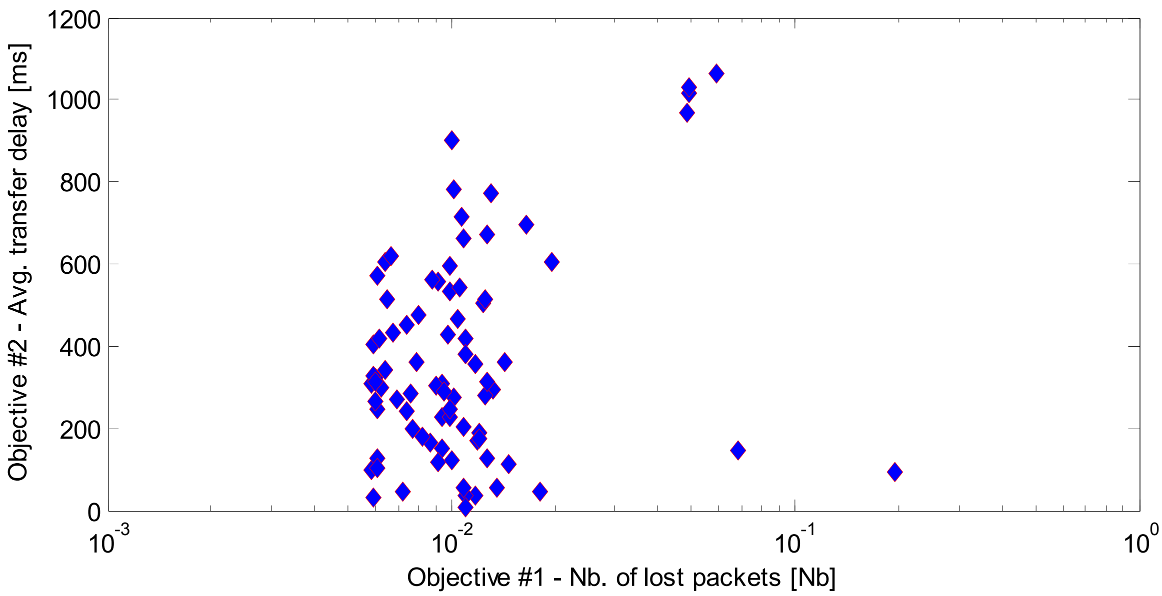

Fig. IV.1 Initial population chromosomes distribution.

Table IV.4 and Fig. IV.2 show the three points representing the three triplets of parameters found by NSGA-II algorithm. These triplets are three possible settings for OLSR configuration. Fig. IV.3 shows the Pareto front found by our algorithm; while Fig. IV.4 shows that we have more than three possible triples (three groups of overlapped points).

Table. IV.4 Final population.

Obj. 1	Obj. 2	Hello interval	TC interval	Refresh interval
0.00575	91.0	28.3	10.6	18.0
0.00585	0.00	28.3	28.8	22.9
0.00582	18.0	26.8	8.09	10.5

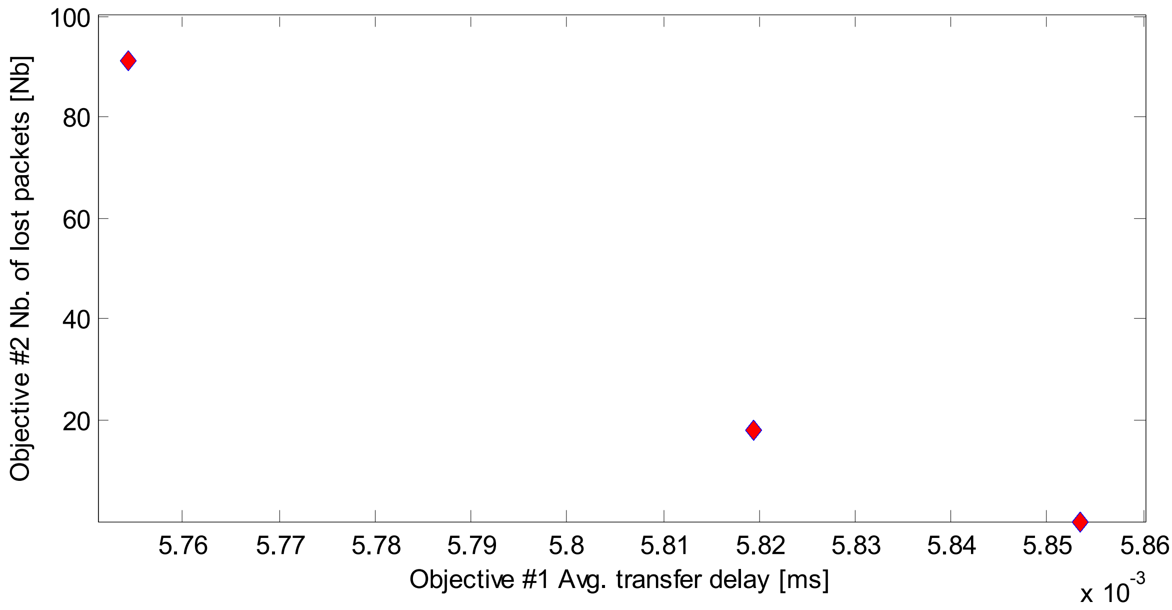

Fig. IV.2 Final population chromosomes distribution.

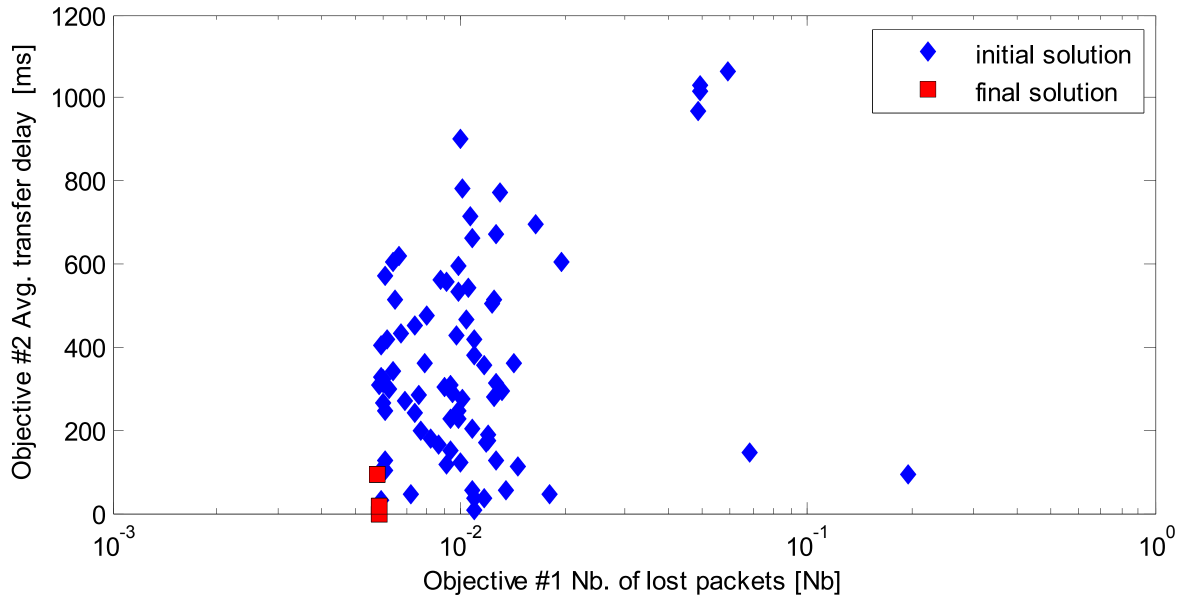

Fig. IV.3 Pareto front for low nodes mobility scenario.

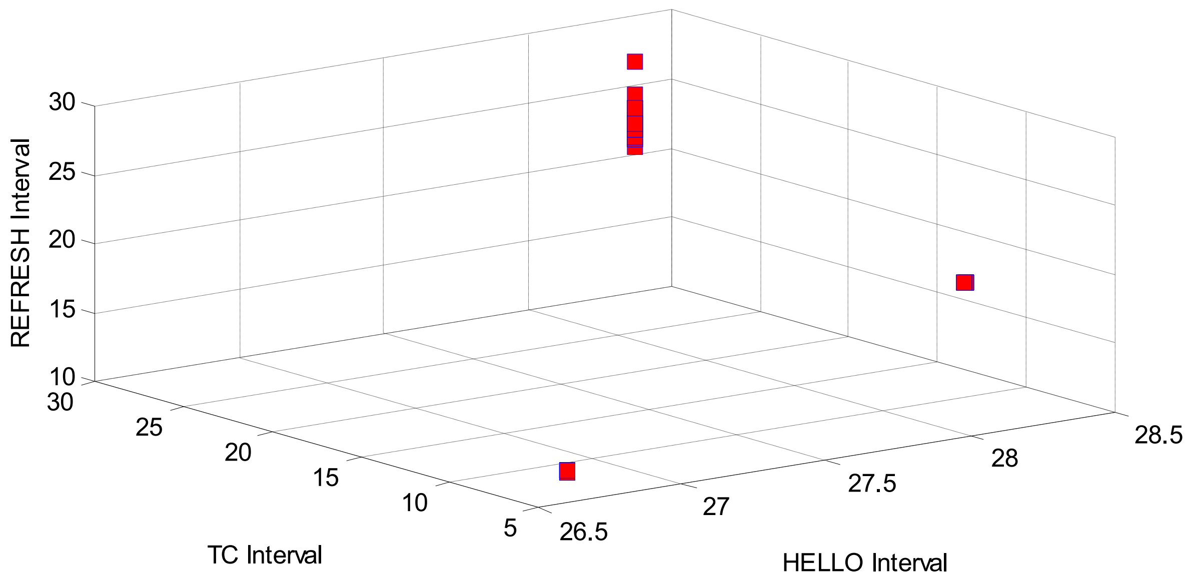

Fig. IV.4 Distribution of the final OLSR parameters.

b) High node mobility

The second experiment is used to simulate high node mobility by varying the speed from 5m/s to 55m/s. Table IV.5 gives the new simulation parameters.

Table. IV.5 Simulation parameters.

OLSR Parameters	
Node	20
Connections	20
Min speed	5 m/s
Max speed	55 m/s
Pause time	5 s
Area size	1000 m^2

Table IV.6 an example of the data file generated by the NSGA-II algorithm (the file of the initial population) including the objectives to be minimized and the parameters to be optimized.

Table. IV.6 Example of the data file generated by the NSGA-II algorithm (Initial population for high node mobility).

Obj. 1	Obj. 2	Hello interval	TC interval	Refresh interval
0.00973	526	7.88	7.99	18.8
0.00132	432	1.77	10.1	11.6
0.00100	129	16.0	24.0	29.6
0.00661	0.00	27.5	15.5	17.9
0.10300	288	6.69	19.7	28.9
……	…….	…….	…….	…….

Fig. IV.5 shows the distribution of triplets of parameters in the objective space (for the initial population).

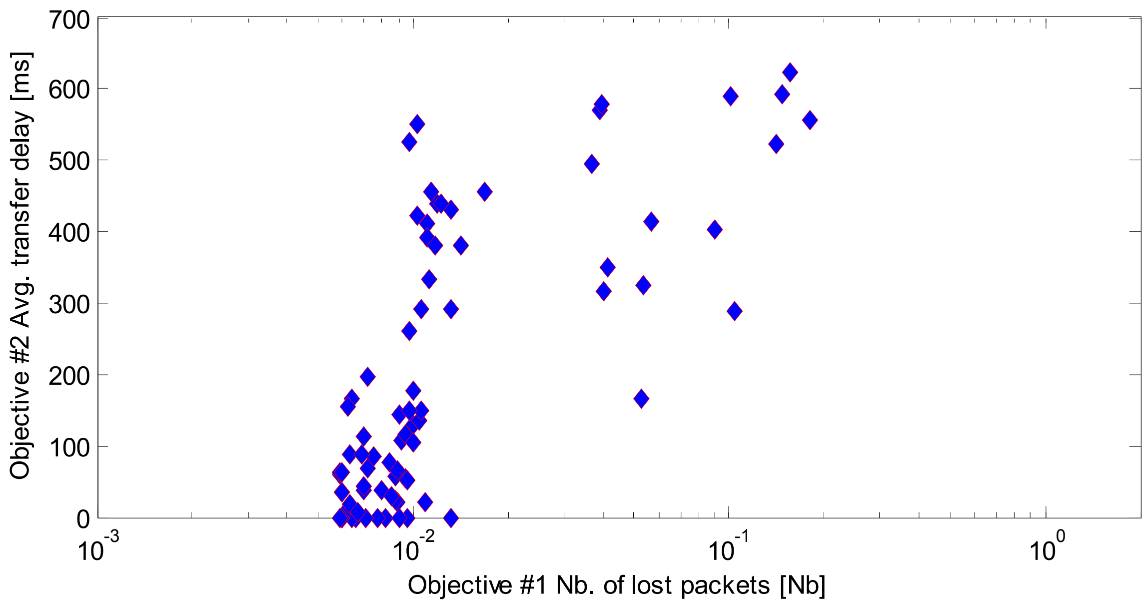

Fig. IV.5 Initial population chromosomes distribution.

Table IV.7 and Fig. IV.6 give a point representing the three triplets of parameters found by NSGA-II algorithm. These triplets are three possible settings for OLSR configuration setting.

Table. IV.7 Final population.

Obj. 1	Obj. 2	Hello interval	TC interval	Refresh interval
0.00579	0.00	24.2	24.7	10.4
0.00579	0.00	24.2	24.7	9.83
0.00579	0.00	24.2	24.7	9.81

Fig. IV.7 shows the Pareto front found by our algorithm; while Fig. IV.8 shows the best solution parameters space. We can see clearly that we have several overlapping points.

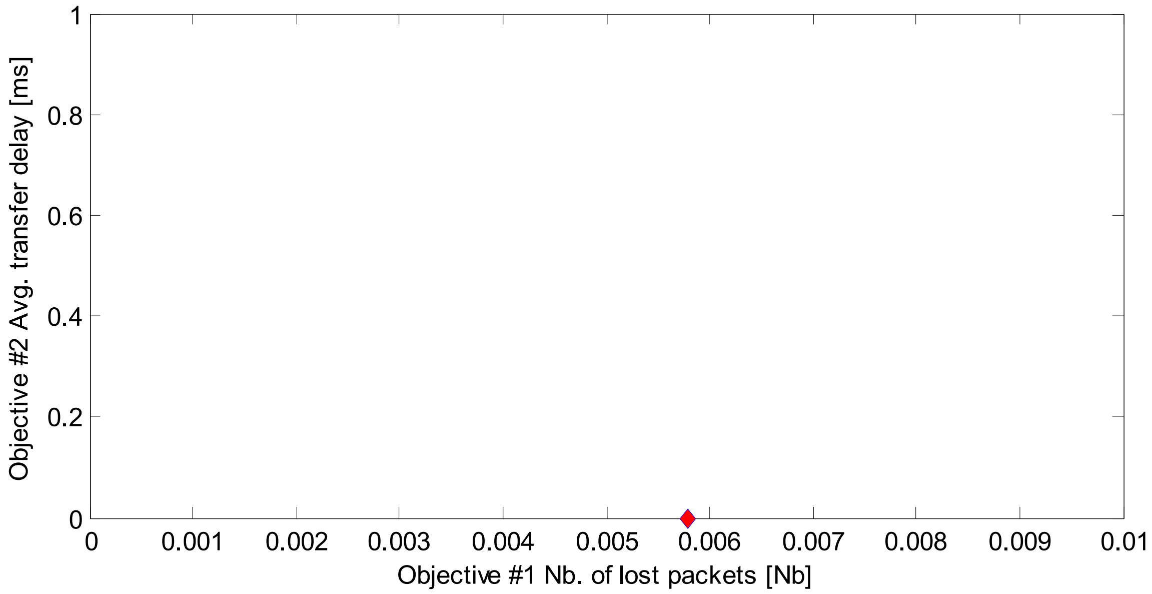

Fig. IV.6 Final population chromosomes distribution.

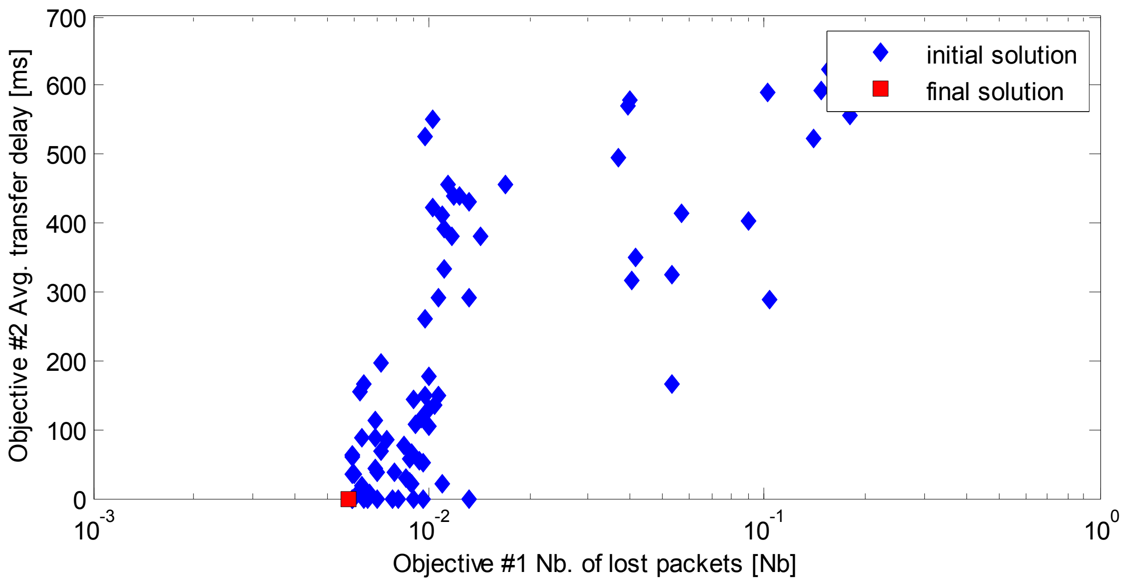

Fig. IV.7 Pareto Front for high nodes mobility scenario.

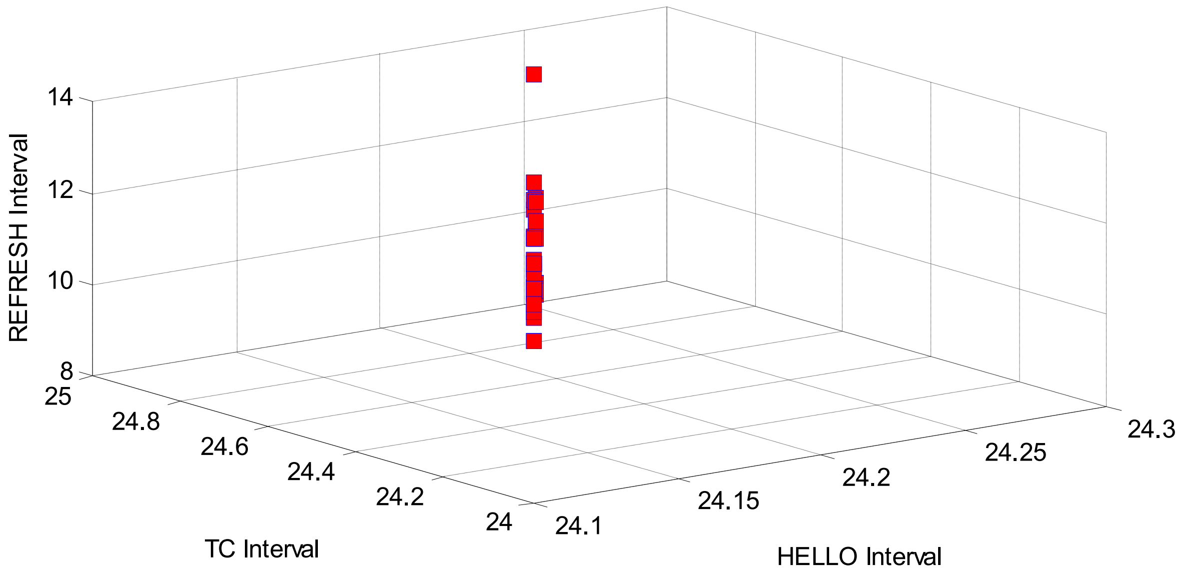

Fig. IV.8 Distribution of the final OLSR parameters.

The experiments have shown the effectiveness of the developed algorithm for the optimization of OLSR parameters setting. Indeed, the choice of parameters in a multi-parameters and multi-objectives is very difficult or even impossible, due to the difficulty to choose the parameters taking into account the correlation between them, something that is done without worries by the NSGA-II algorithm which operates on a parameter space (with population of parameters) rather than a single set of parameter at a time. In addition, this version of the genetic algorithm works well on several objectives rather than a single both which allowed us to estimate the correct parameters while minimizing two objectives chosen a priori. The experiments illustrate the reaction of the proposed algorithm to track the changing environment of OLSR (i.e. mobility). This means that the proposed algorithm in addition of being a good solution for automating the choice of parameters, it can also considered as an optimal choice to minimize the overall objectives and to be more adaptive to the environment changes.

c) Comparison between standard OLSR and the proposed NSGA-II OLSR

To validate the effectiveness of the proposed NSGA-II-OLSR, we compare it to standard OLSR using three different scenarios:

- **Scenario 1:** same as exp 1 (Low node mobility) with pause time variation 0s, 5s, 10s and 15s;

- **Scenario 2:** same as exp 2 (High node mobility) with pause time variation 0s, 5s, 10s and 15s;
- **Scenario 3:** new experiment using PLR, E2ED and NRL performance metrics to analyze the performance of both routing protocols regarding the energy consumption (NRL) in the two cases considered in exp 1 and exp 2 (i.e. Low node mobility and High node mobility).

Scenario 1: Low node mobility

In this experiment, we used the low node mobility by varying the speed from 5m/s to 10m/s for both protocols the standard OLSR and the proposed NSGA-II-OLSR. For the standard OLSR, we use the standard value for the Hello Interval, the TC Interval and the Refresh Interval; 2s, 5s and 2s, respectively. For the NSGA-II-OLSR we use the values found by the NSGA-II in experiment I.

Table IX shows the obtained results using the considered metrics PLR and E2ED.

Table. IV.8 PLR and E2ED for both Standard OLSR and NSGA-II-OLSR: Experiment I.

Pause time	PLR (%)		E2ED (ms)	
	Standard OLSR	NSGA-II-OLSR	Standard OLSR	NSGA-II-OLSR
0s	29.03	**26.54**	0.78	**0.61**
5s	26.71	**24.37**	0.79	**0.65**
10s	14.53	**10.93**	1.05	**0.81**
15s	11.97	**7.80**	1.12	**0.81**

Figures IV.9 and IV.10 show the PLR and E2ED considering both protocols in case of low node mobility..

From Table IV.8 and Figures IV.9 and IV.10 we can see clearly that the proposed NSGA-II-OLSR outperforms the standard OLSR regarding all considered metrics. The PLR is reduced: from 29.03% to 26.54% for 0s pause time; from 26.71% to 24.37% for 5s pause time; from 14.53% to 10.93% for 10s pause time; and from 11.97% to 7.80% for 15s pause time. While the E2Ed is reduced: from 0.78ms to 0.61ms for 0s pause time; from 0.79ms to 0.65ms for 5s pause time; from 1.05ms to 0.81ms for 10s pause time; and from 1.12ms to 0.81ms for 15s pause time.

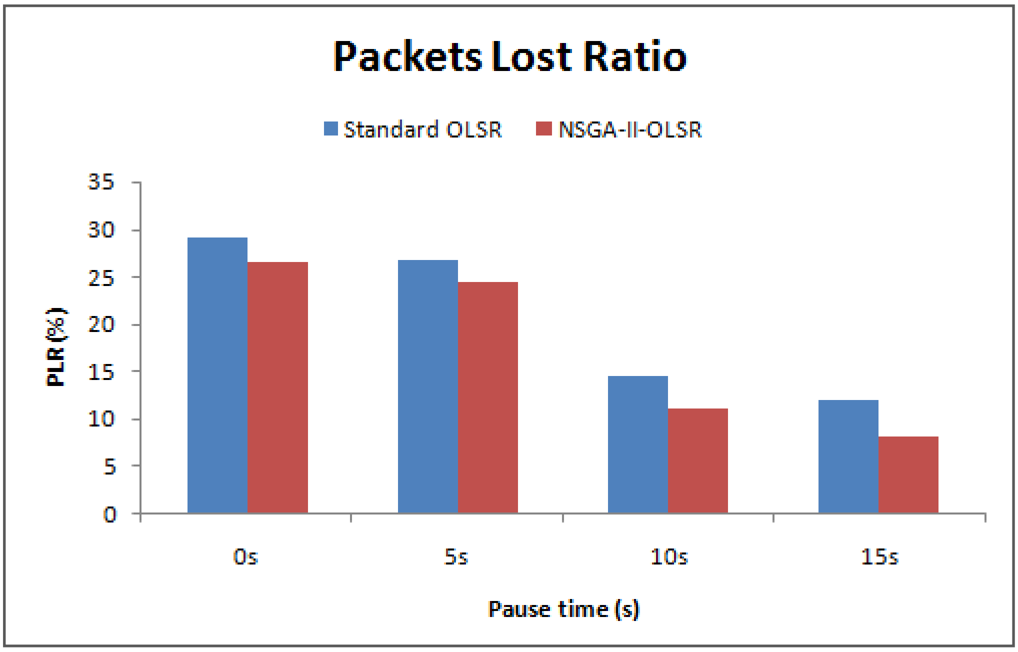

Fig. IV.9 PLR for standard OLSR and NSGA(II-OLSR: Experiment I.

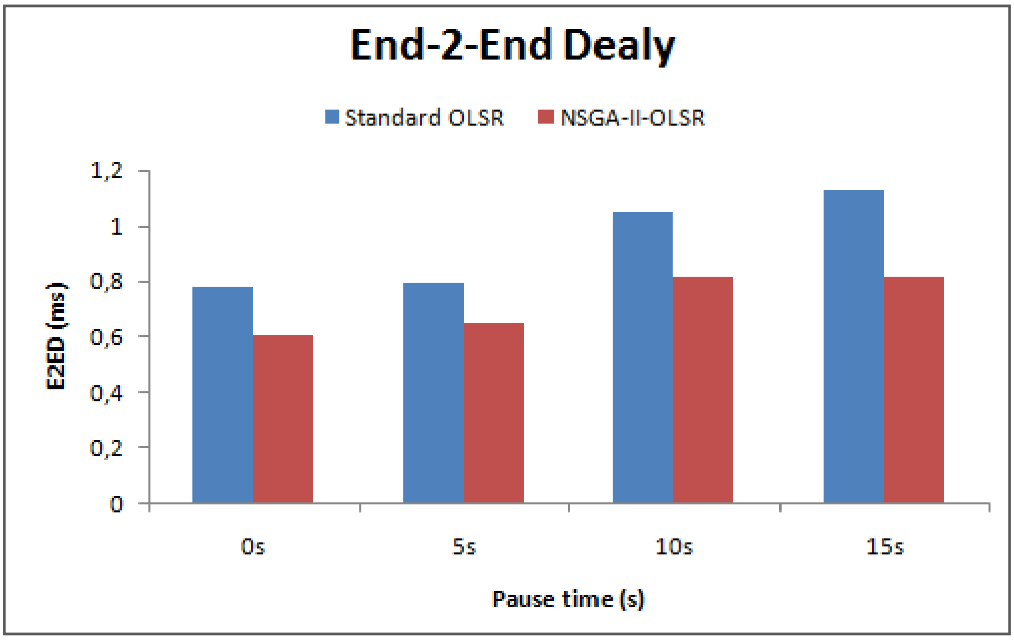

Fig. IV.10 E2ED for standard OLSR and NSGA(II-OLSR: Experiment I.

Scenario 2: High node mobility

In this experiment, we used the high node mobility by varying the speed from 5m/s to 55m/s for both protocols the standard OLSR and the proposed NSGA-II-OLSR. As for the first scenario, for the standard OLSR we use the standard value for the Hello Interval, the TC Interval and The Refresh Interval; 2s, 5s and 2s, respectively. For the NSGA-II-OLSR we use the values found by the NSGA-II in experiment II. Table IV.9 shows the obtained results using the considered metrics PLR and E2ED.

Table. IV.9 PLR and E2ED for both Standard OLSR and NSGA-II-OLSR: Experiment II.

pause time	PLR (%)		E2ED (ms)	
	Standard OLSR	NSGA-II-OLSR	Standard OLSR	NSGA-II-OLSR
0s	42.47	**40.99**	0.68	**0.67**
5s	35.38	**33.13**	0.86	**0.80**
10s	31.95	**29.24**	0.83	**0.80**
15s	27.98	**25.20**	0.77	**0.70**

Figures IV.11 and IV.12 show the PLR and E2ED considering both protocols in case of high node mobility..

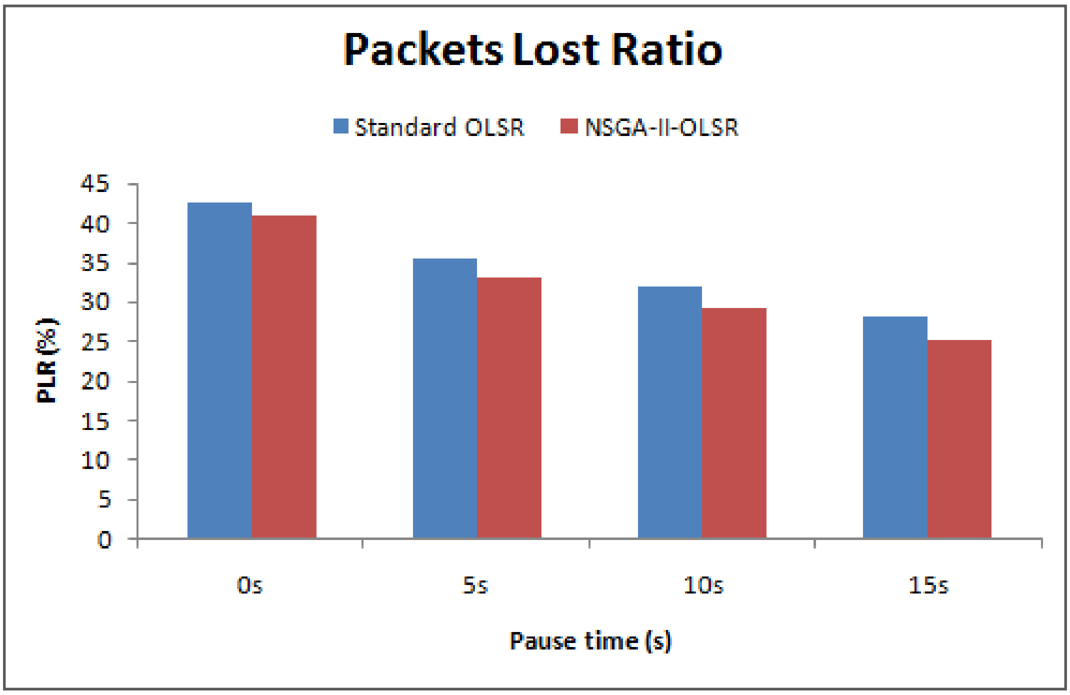

Fig. IV.11 PLR for standard OLSR and NSGA(II-OLSR: Experiment II.

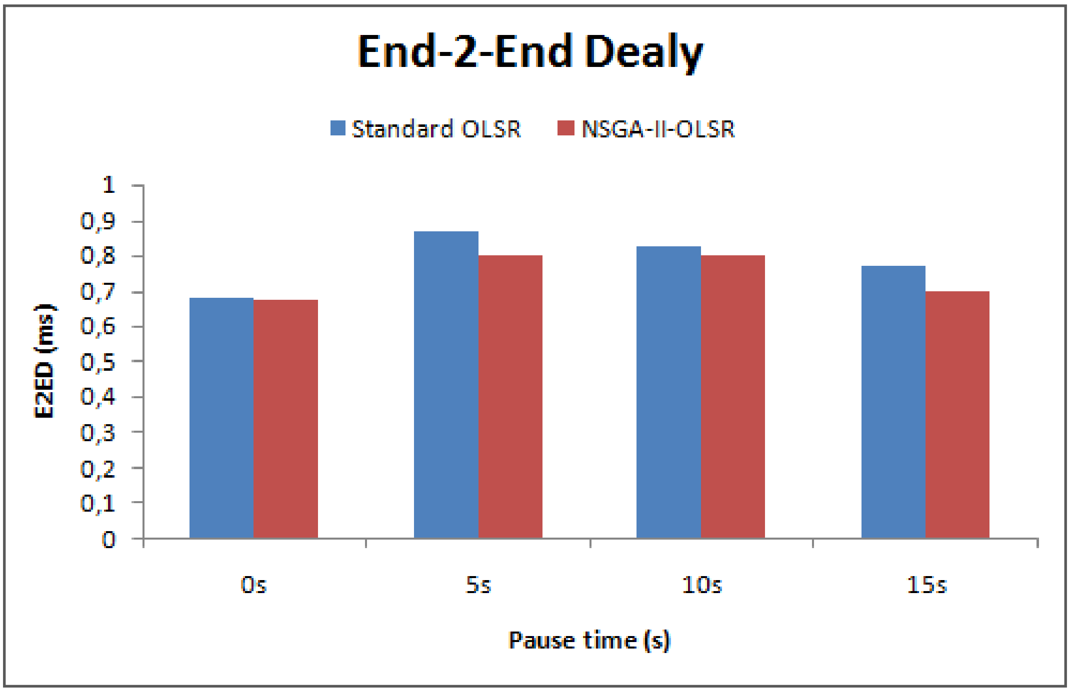

Fig. IV.12 E2ED for standard OLSR and NSGA(II-OLSR: Experiment II.

From Table IV.9 and Figures IV.11 and IV.12, we note also that the proposed NSGA-II-OLSR performs better than the standard OLSR regarding all considered performance metrics. The PLR is reduced: from 42.47% to 40.99% for 0s pause time; from 35.38% to 33.13% for 5s pause time; from 31.95% to 29.24% for 10s pause time; and from 27.98% to 25.20% for 15s pause time. While the E2Ed is reduced: from 0.68ms to 0.67ms for 0s pause time; from 0.86ms to 0.80ms for 5s pause time; from 0.83ms to 0.80ms for 10s pause time; and from 0.77ms to 0.70ms for 15s pause time.

Scenario 3: Energy conservation

Case of low nod mobility

In this experiment, we compute the NRL for the low node mobility defined in experiment I (section 5.3.1). Table IV.10 and Fig. IV.13 show the obtained results using both protocols for different pause time.

From Table IV.10 and Fig. IV.13 that the proposed NSGA-II OLSR have the lowest NRL compared to the standard OLSR routing protocol. The proposed NSGA-II-OLSR reduces the NRL: from 16.79% to 10.85% for 0s pause time; from 16.25% to 10.53% for 5s pause time; from 13.95% to 8.93% for 10s pause time; and from 13.58% to 8.61% for 15s pause time.

Table. IV.10 NRL comparison in case of low node mobility.

pause time	NLR (%)	
	Standard OLSR	NSGA-II-OLSR
0s	16.79	**10.85**
5s	16.25	**10.53**
10s	13.95	**8.93**
15s	13.58	**8.61**

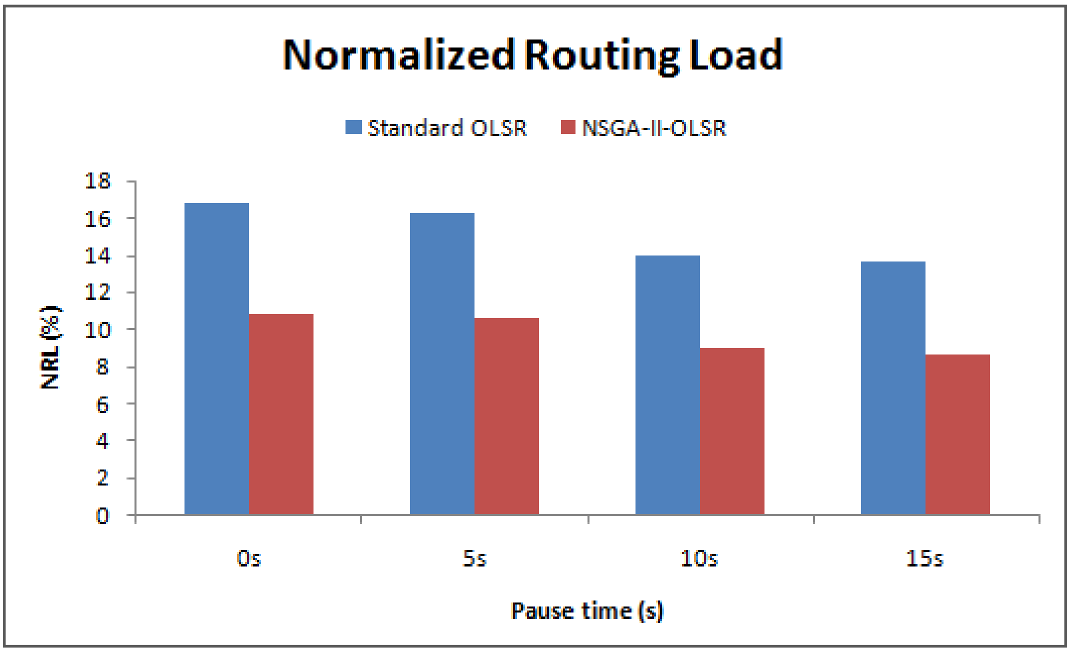

Fig. IV.13 NRL comparison in case of low node mobility.

Case of high nod mobility

In this experiment, the NRL is calculated in case of high node mobility defined in experiment II. Table IV.11 and Fig. IV.14 show the obtained results using both protocols for different pause time.

Table. IV.11 NRL comparison in case of high node mobility.

pause time	NLR (%)	
	Standard OLSR	NSGA-II-OLSR
0s	20.71	**20.23**
5s	18.43	**18.00**
10s	17.52	**17.20**
15s	16.55	**16.53**

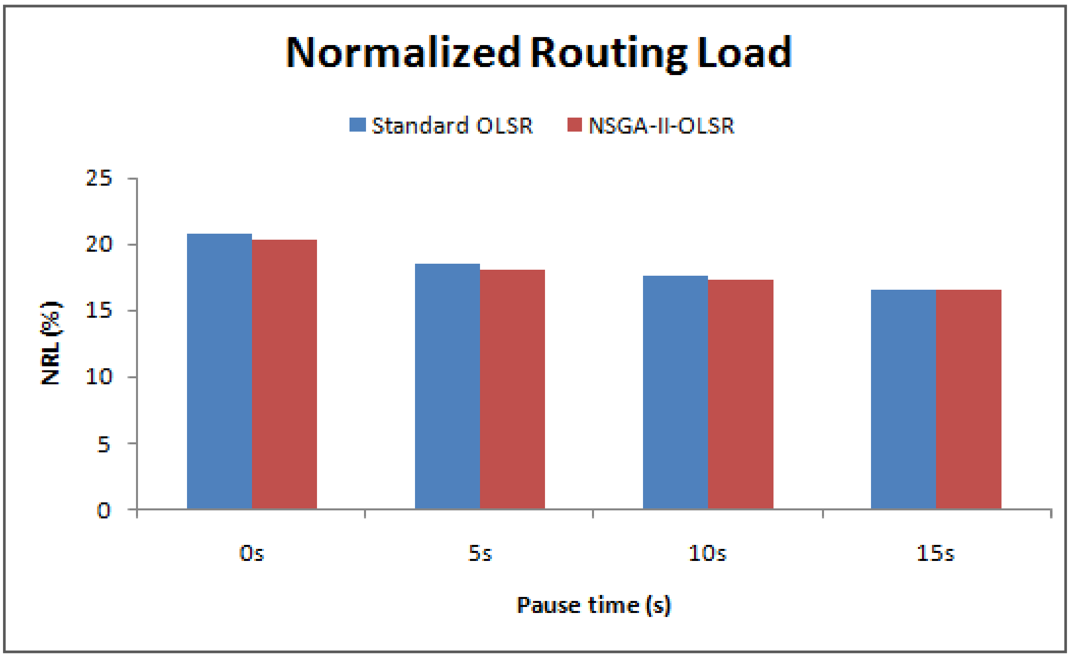

Fig. IV.14 NRL comparison in case of high node mobility.

From Table IV.11 and Fig. IV.14, we can see that the proposed NSGA-II OLSR have the lowest NRL compared to the standard OLSR. The proposed NSGA-II-OLSR reduces the NRL: from 20.71% to 20.23% for 0s pause time; from 18.43% to 18.00% for 5s pause time; from 17.52% to 17.20% for 10s pause time; and from 16.55% to 16.53% for 15s pause time.

A very important finding is that despite the fact that the parameters used were optimized using just the PLR and the E2ED objectives, the NSGA-II-OLSR performs better than the standard OLSR. The proposed NSGA-II-OLSR reduces the NRL in both studied cases: low node mobility and high node mobility which will as a consequence reduce the battery energy consumption.

Discussions

The experiments have shown the effectiveness of the developed algorithm for the optimization of OLSR parameters setting in all considered cases. Tables IV.12 and IV.13 below give the gain ratio between the standard OLSR and the proposed NSGA-II-OLSR regarding the considered metrics (PLR, E2ED and NRL).

Table. IV.12 Gain ratio: Case of low node mobility (Experiment I).

pause time	PLR (%)	E2ED (%)	NRL (%)
0s	8.59	21.76	35.36
5s	8.76	18.17	35.18
10s	24.72	22.24	35.98
15s	33.17	27.56	36.60

Table. IV.13 Gain ratio: Case of high node mobility (Experiment II).

pause time	PLR (%)	E2ED (%)	NRL (%)
0s	3.47	1.47	2.33
5s	6.36	7.40	2.34
10s	8.50	3.26	1.82
15s	9.94	9.40	0.14

We observe that in case of low node mobility (Table IV.12), we can see that the proposed NSGA-II-OLSR improves the PLR between 8.59% and 33.17%; the E2ED between 18.17% and 27.56%; and the NRL between 35.18% and 36.60%. We notice that more the network is stable better is the gain ratio for PLR and E2ED. For the NRL we note that we have a gain ratio approximately around 35%.

For the case of high node mobility (Table IV.13), we observe that the proposed NSGA-II-OLSR improves the PLR between 3.47% and 9.94%; the E2ED between 1.47% and 9.40%; and the NRL between 0.14% and 2.34%. The gain rates in this latter case are a little lower which is quite normal considering the speed envisaged 55m/s (> 180kms/h) keeping a better performance for the proposed NSGA-II-OLSR.

As a conclusion, we see that at low or high node mobility, the proposed NSGA-II-OLSR performs better than the standard OLSR regarding all considered metrics which results in a gain in performance regardless of the real-time application, file transfer, multimedia. In addition the proposed NSGA-II-OLSR reduces the consumption of the battery in all cases.

The main contributions of this work are summarized below:

- The NSGA-II choice instead of a weighted multi-objective solution where goal weighting is smoothed into the goal function.
- The NSGA-II algorithm offers a multitude of solutions all on the Pareto front ensuring the optimal cost and while giving the choice to the end-user to choose the routing protocol parameters set that meets his needs according to the application:
    - In a real-time application, the choice of E2ED is essential;
    - In an file transfer application, the choice of the PLR is essential;
    - In an application that takes into account the state of the battery, the choice of the PLR is essential;
    - In an application that consider both objectives (i.e. multimedia application), the choice of the two parameters becomes paramount.
- Despite the fact that the parameters used were optimized using just the PLR and the E2ED objectives, the NSGA-II-OLSR performs better than the standard OLSR and reduces the NRL in both studied cases: low node mobility and high node mobility.

This concept has been successfully applied to the OLSR routing protocol which has been used as a validation protocol and remains valid for any other routing protocol which generalizes this contribution of this work to other applications that will be the subject of new works in the near future.

IV.2.1.2 Using DE Algorithm

In this section, the performance of the standard OLSR protocol is compared with the routing performance of the proposed scheme, By varied the node density, we obtained two figure, the first figure represent network with low density (n=10) and the second simulate network with high density (n=20). Each figure is subdivided into three subfigure (a), (b) and (c), which plot PDR, AEED and NRL for the two simulated protocols, the standard OLSR and the proposed one by varying the node speed in the range [0, 30].

As shown in Fig. IV.15, the proposed scheme performs as well as standard OLSR configured with a fixed hello interval (hello interval = 2s) but with much less overhead. We notice the proposed algorithm considerably reduces the amount of overhead compared to the original OLSR.

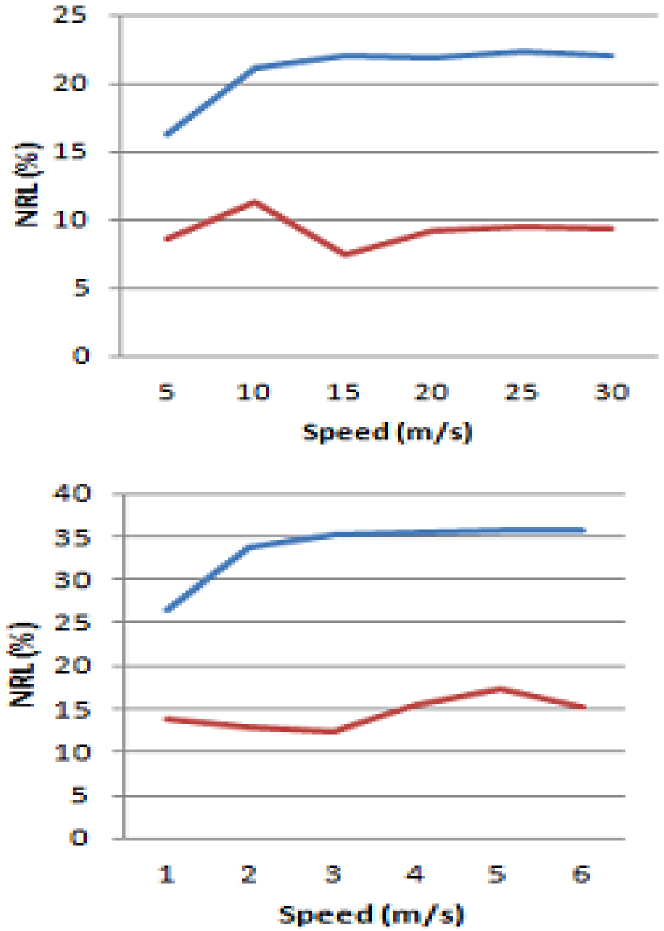

Fig. IV.15 Network Routing load (Blue: OLSR, Mag: DE-OLSR):

Top) Low density (n=10); Bottom) High density (n=20).

From Fig. IV.15, we observe the amount of overhead generated by using our approach of almost ~52% lower than standard OLSR. In case of no network changes, the control overhead is reduced due automatically adjustment of the hello interval value to a large value. Fig. IV.15 shows also a similarity shape of curves for OLSR protocol in the both cases: low and high network density which means the OLSR reacts with same behavior for any scenarios. This is due to the fact that conventional OLSR uses a fixed timer approach. In contrary, the proposed algorithm plots dissimilar curve for low and high network density, which explain that the proposed OLSR react effectively to the network topology changes by reducing the hello message sending rate in case of low frequently change network (at low speeds). In opposition, the proposed scheme increases the rate when there are more changes (at high speeds). As seen in Fig. IV.16, our proposed scheme shows high reliability compared to original OLSR. The proposed one has in average ~3-5 % more PDR.

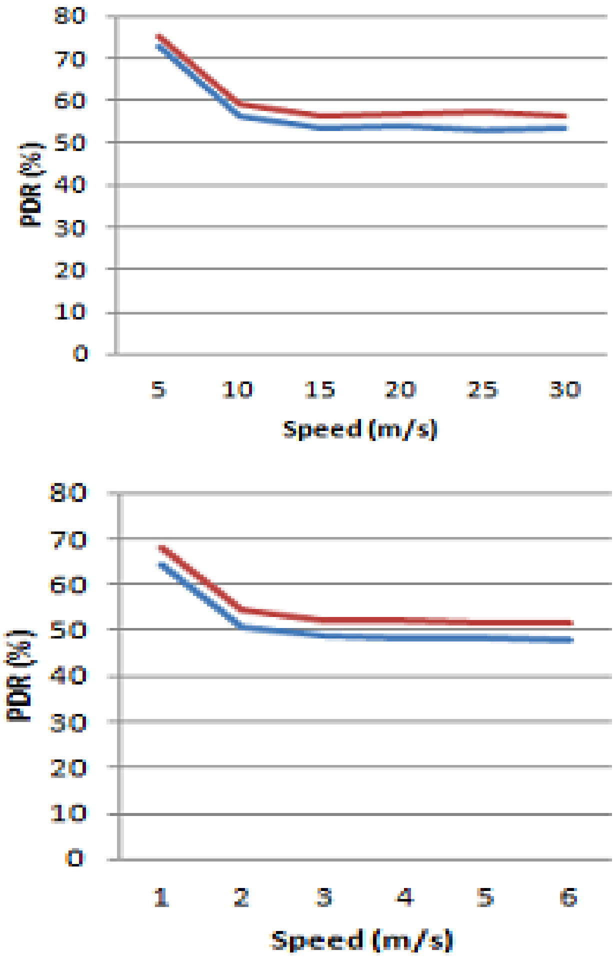

Fig. IV.16 Packer Delivery Ratio (Blue: OLSR, Mag: DE-OLSR):
Top) Low density (n=10); Bottom) High density (n=20).

From, Fig. IV. 17 below, the AEED is not consequently affected by using our scheme. We notice an AEED degradation of almost ~0.2 ms compared to the original OLSR. This degradation is due to the increment the number of data packets successfully received represented by the improvement of PDR realized by our protocol leading to increase the time taken by all data packets to reach their destination.

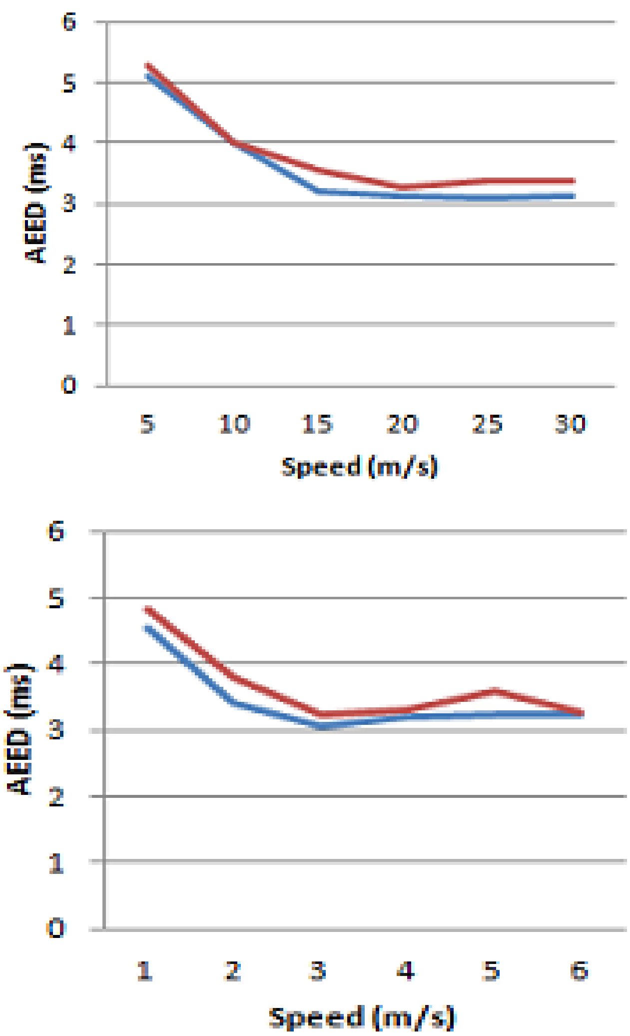

Fig. IV.17 Average End to End Delay (Blue: OLSR, Mag: DE-OLSR):

Top) Low density (n=10); Bottom) High density (n=20).

From Tables IV.14 and IV.15, it is clear that for low density networks, the improvement of PDR is at most ~5 % higher using the proposed scheme. In contrary, for high density networks, the gain of PDR is almost ~3%. This PDR enhancement achieved by our proposed scheme caused by the using an efficient algorithm to maintain the local connections up-to-date and track neighbor relationship between the nodes.

Table IV.14 Performance metrics averages (Low density).

Perf. Metrics	OLSR	DE-OLSR	Improv. rate
PDR (%)	62.82	65.75	Gain ~ 5
NRL (%)	19.28	9.35	Gain ~ 52
AEED (ms)	4.09	4.27	Degradation ~ 0.2

Table IV.15 Performance metrics averages (High density).

Perf. Metrics	OLSR	DE-OLSR	Improv. rate
PDR (%)	56.08	57.85	Gain ~ 3
NRL (%)	31.16	14.89	Gain ~ 52
AEED (ms)	3.81	4.03	Degradation ~ 0.2

IV.2.2 ZRP Routing Protocol Setting

In order to study PSO-IZRP's performance in different operational conditions, three different Scenarios were considered using the simulation parameters defined in Table IV.16. In these scenarios PSO-IZRP and ZRP were evaluated for wide ranges of: "number of nodes", "nodes pause time" and "traffic rate". In each scenario the proposed Algorithm is compared with ZRP in terms of Quality of Service (QoS) parameters.

Table IV.16 Simulation parameters.

Parameter	Value
Simulation time	100 seconds
Simulation area	1000*1000 m2
Node speed	0-20 m/s
Propagation model	Two Ray Ground
Mobility model	random way point
Radio frequency	2.47GHz
Channel bandwidth	2 Mbps
Mac protocol	IEEE 802.11
Type dataflow	CBR

Results and Discussions

To validate the effectiveness of the proposed PSO-IZRP, we tested it using four different scenarios:

- Scenario 1: pause time variation;
- Scenario 2: traffic rate variation;
- Scenario 3: number of nodes variation;
- Scenario 4: speed variation.

a) Scenario 1: Pause time variation

In this scenario, different pause times were used for the simulation of PSO-IZRP and ZRP in order to study the effect of those pause times on the algorithms. To this end, nodes' count were fixed to 20, nodes' sending rate to 10 packets per second and the network simulation was repeated for different pause times i.e. : 0, 10, 20, 30 and 40 seconds. Simulation results are shown in Figures IV.18 to IV.20.

According to Figures IV.18 to IV.20, we can notice that the proposed PSO-IZRP protocol outperforms the conventional ZRP protocol in all considered performances measures with respect to the pause time variation showing improvement between 1.34% and 7.50% for PDR; between 0.84% and 1.14% for the NRL; and between 18.58ms and 56.28ms for the AE2ED.

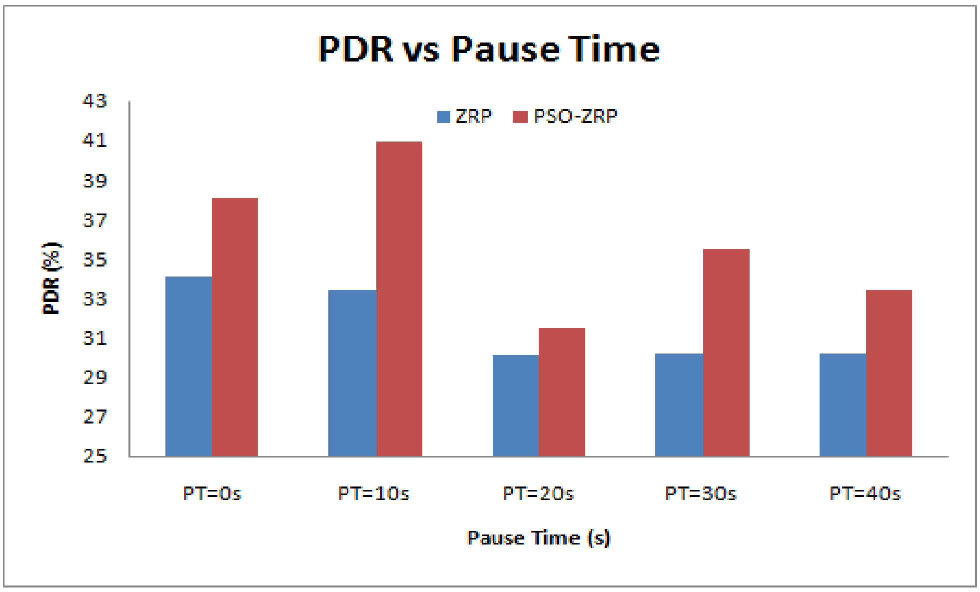

Fig. IV.18. Impact of pause time variation on PDR using ZRP and PSO-IZRP.

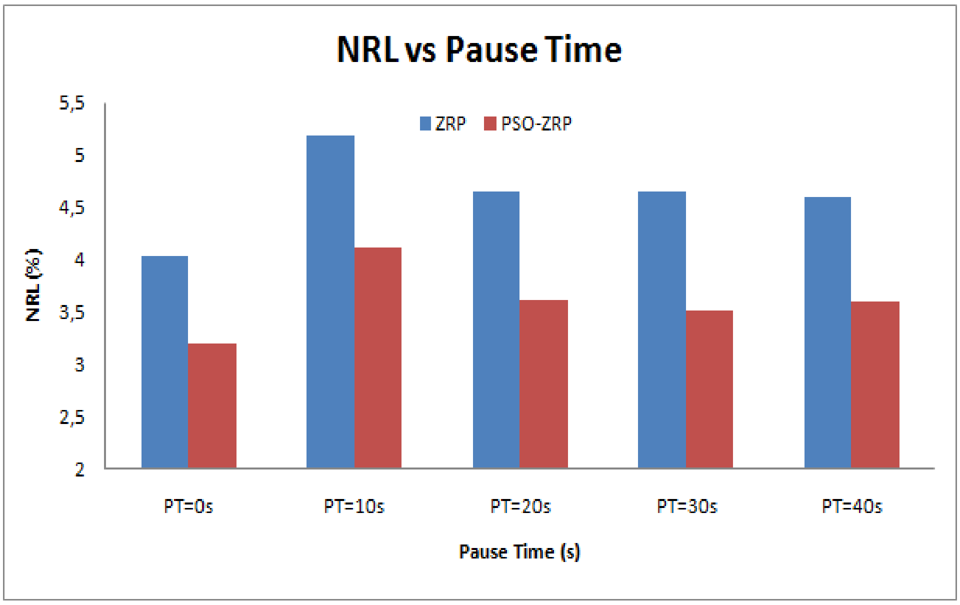

Fig. IV.19 Impact of pause time variation on NRL using ZRP and PSO-IZRP..

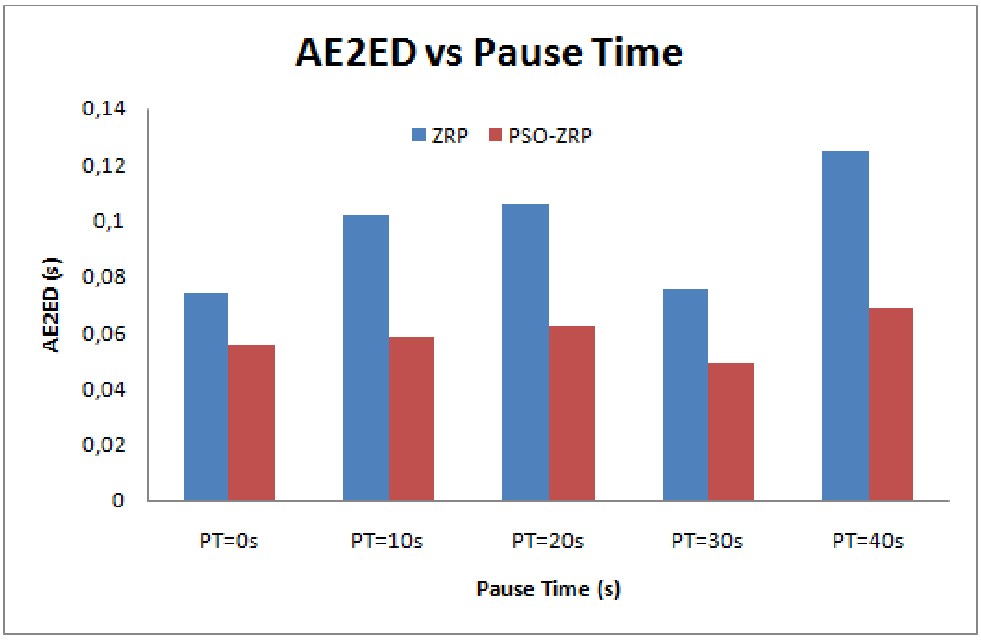

Fig. IV.20 Impact of pause time variation on AE2ED using ZRP and PSO-IZRP.

b) Scenario 2: Traffic rate variation

In this scenario, we studied how the proposed algorithm can behave under different amount of the network load. For this purpose, 3 different levels of traffic rates were considered for each node i.e. Low (5 packets per second), Medium (10 packets per second), High (15 packets per second). The behavior of ZRP and PSO-IZRP protocols was then examined under the different levels of traffic intensity. The simulation results are shown in Figures IV.21 to IV.23.

From Figures IV.21 to IV.23 below, as in case of pause time variation, the proposed PSO-IZRP protocol is shown to provide better results than the conventional ZRP protocol with respect to traffic rate variation showing improvement between 2.91% and 3.76% for PDR; between 0.50% and 0.76% for the NRL; and between 4.92ms and 36.89ms for the AE2ED.

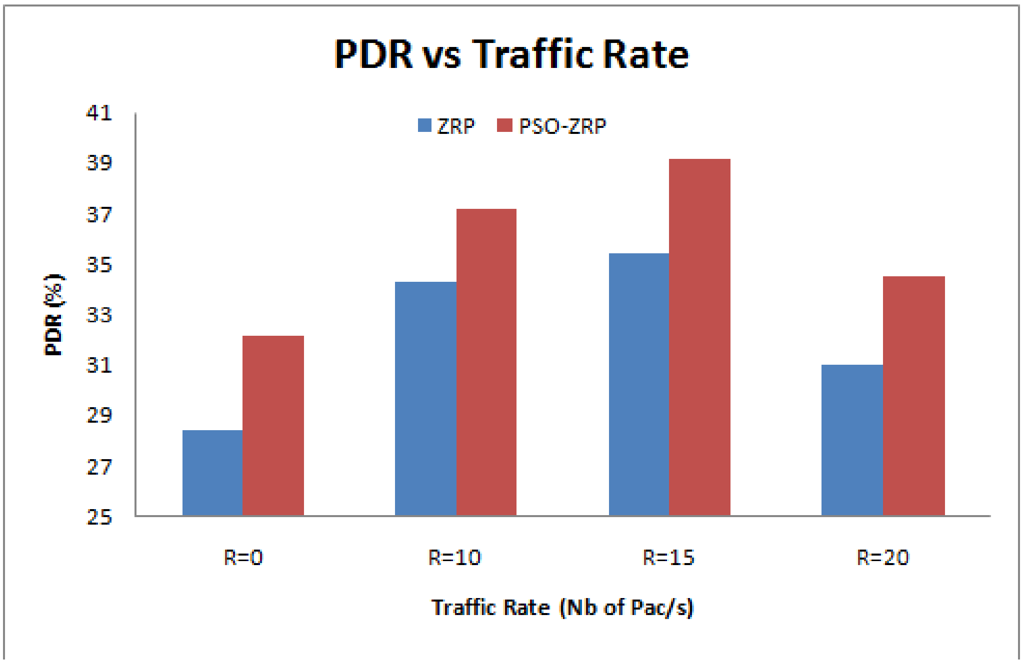

Fig. IV.21 Impact of traffic rate variation on PDR using ZRP and PSO-IZRP.

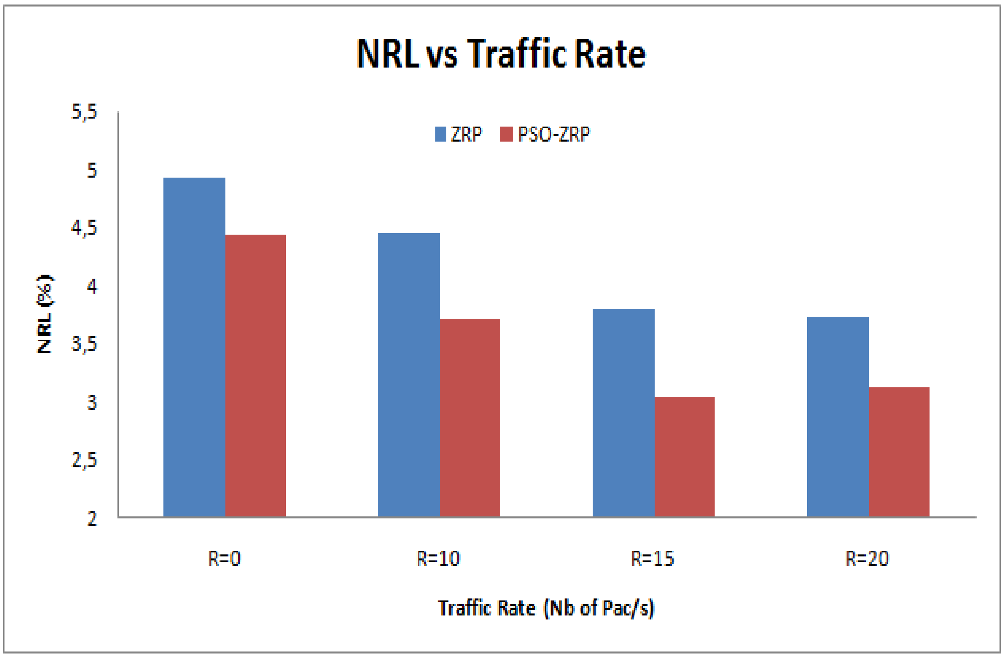

Fig. IV.22 Impact of traffic rate variation on NRL using ZRP and PSO-IZRP.

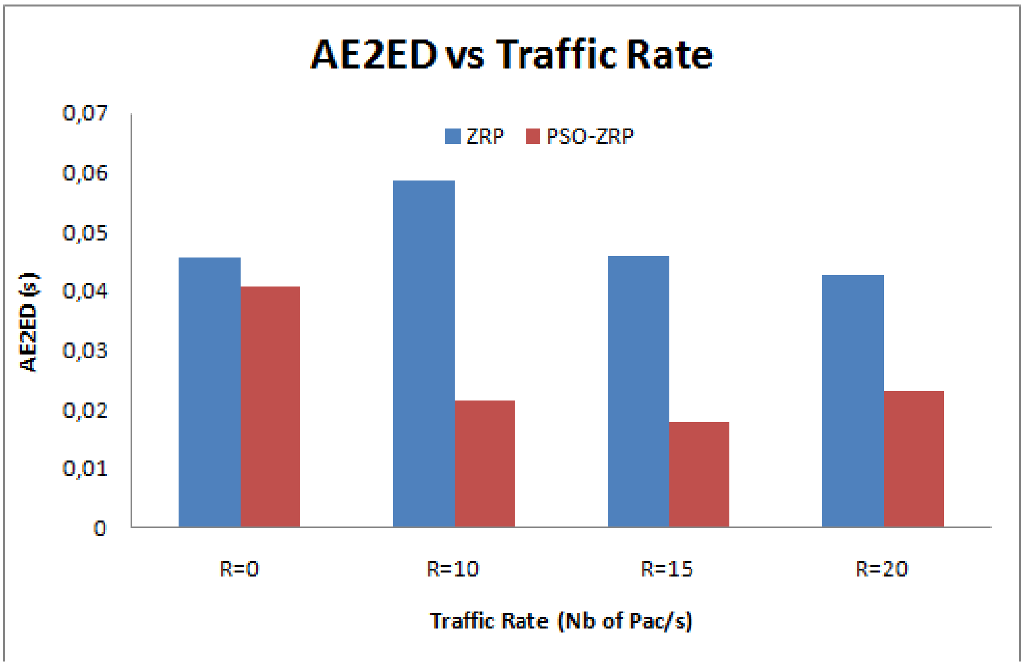

Fig. IV.23 Impact of traffic rate variation on AE2ED using ZRP and PSO-IZRP.

c) Scenario 3: Number of nodes variation

In this scenario, PSO-IZRP and ZRP were simulated and their behavior was studied under different numbers of nodes. To this end, nodes' pause time was fixed to 10 seconds, nodes' sending rate to 10 packets per second and the network simulation is repeated for different numbers of nodes i.e. 10, 20, 30, and 40 nodes. The behavior of ZRP and PSO-IZRP protocols under the different number of nodes is shown in Figures IV.24 to IV.26.

From Figures IV.24 to IV.26, excepting the case of AE2ED measure with N=10 (+17.96ms), the proposed PSO-IZRP protocol shows better performances than the conventional ZRP protocol with respect to number of nodes variation showing improvement: between 0.77% and 6.30% for PDR; between 0.07% and 1.48% for the NRL; and between 2.17ms and 58.53ms for the AE2ED.

In this scenario, we compared the performance measures (PR, NRL and AE2ED) of the proposed PSO-IZRP protocol and the conventional ZRP protocol in case of speed variation (1-10m/s, 10-20m/s and 20-30m/s). Figures IV.22 to IV.24 show the corresponding results.

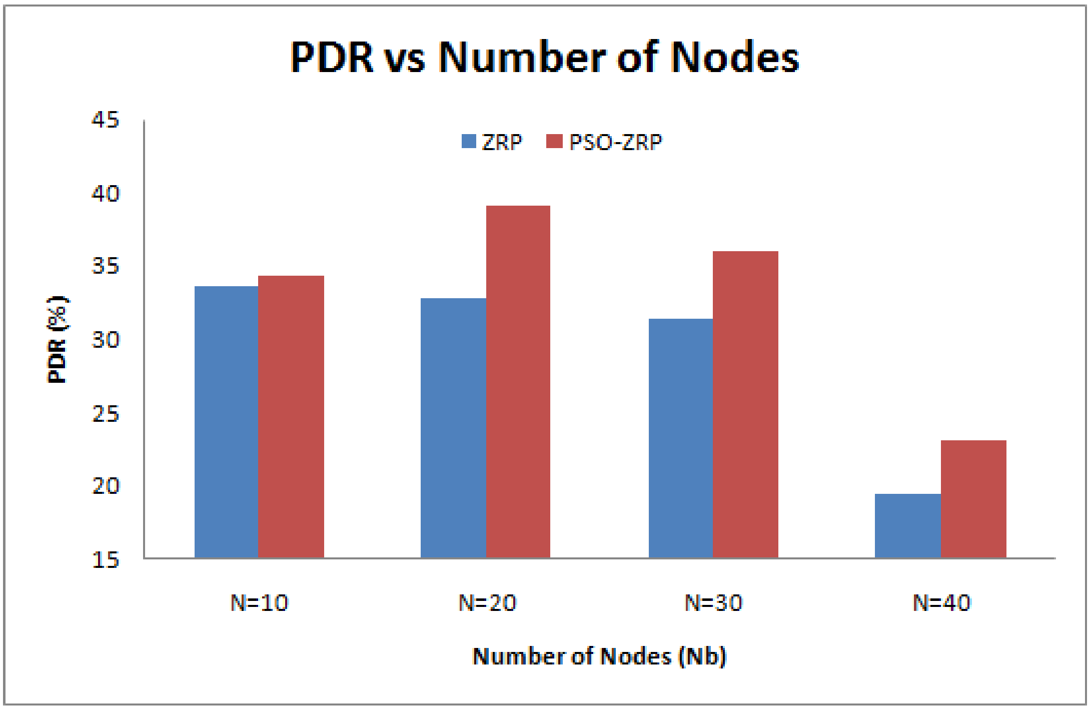

Fig. IV.24 Impact of number of nodes variation on PDR using ZRP and PSO-IZRP.

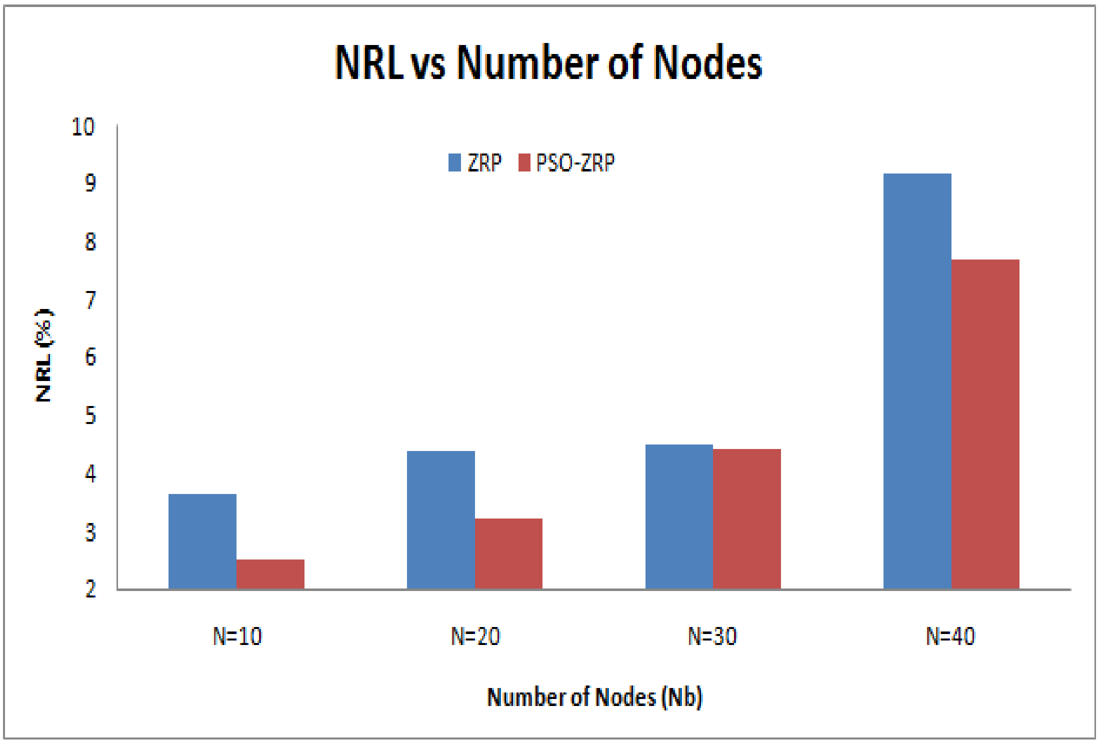

Fig. IV.25 Impact of number of nodes variation on NRL using ZRP and PSO-IZRP.

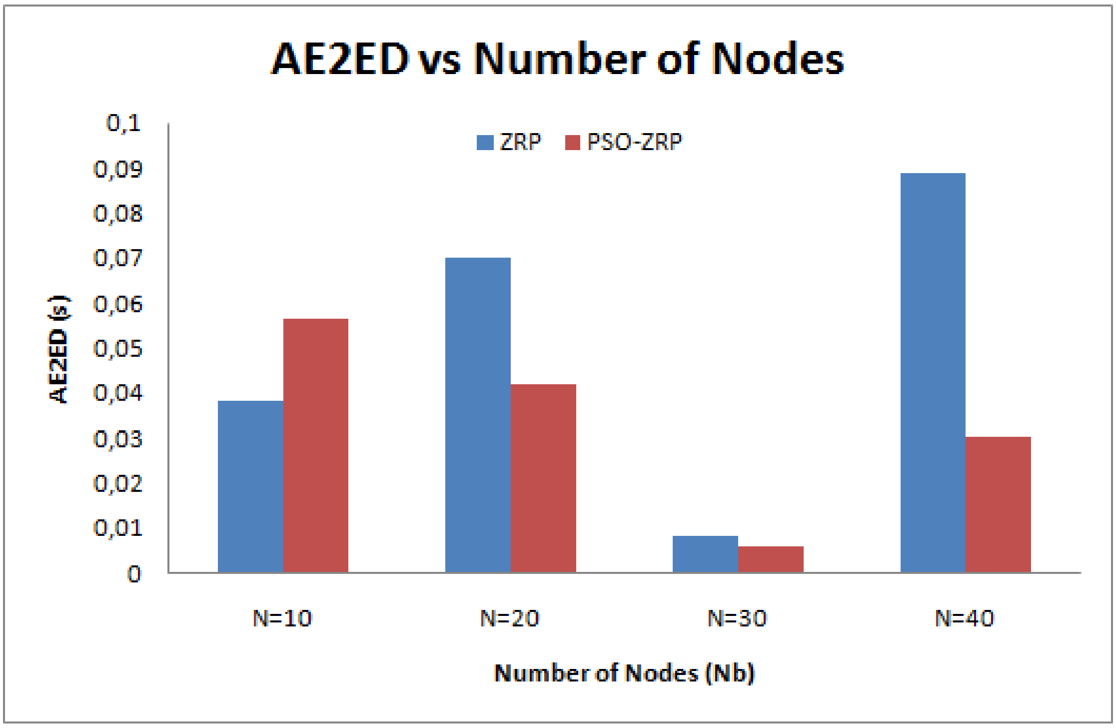

Fig. IV.26 Impact of number of nodes variation on AE2ED using ZRP and PSO-IZRP.

d) Scenario 4: Speed variation

From Figures IV.27 to IV.29, and with respect to the speed variation, the proposed PSO-IZRP protocol shows better performances than the conventional ZRP protocol: between 1.42% and 2.78% for the PDR; between 0.43% and 1.54% for the NRL; and between 3.33ms and 86.66ms for the AE2ED.The improvement rate of the ZRP protocol using PSO algorithm to set the radius in the considered tests scenarios are summarized in Tables IV.17 to IV.20 below:

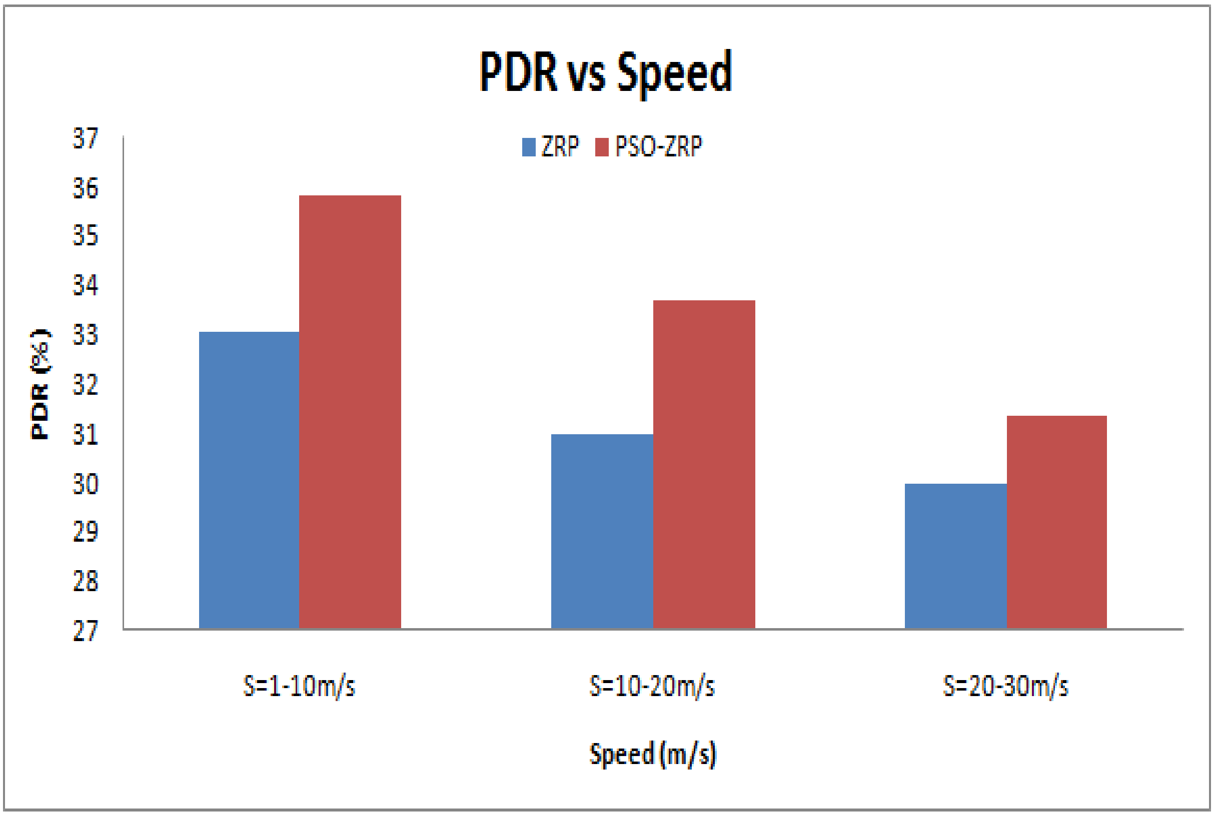

Fig. IV.27 Impact of speed variation on PDR using ZRP and PSO-IZRP.

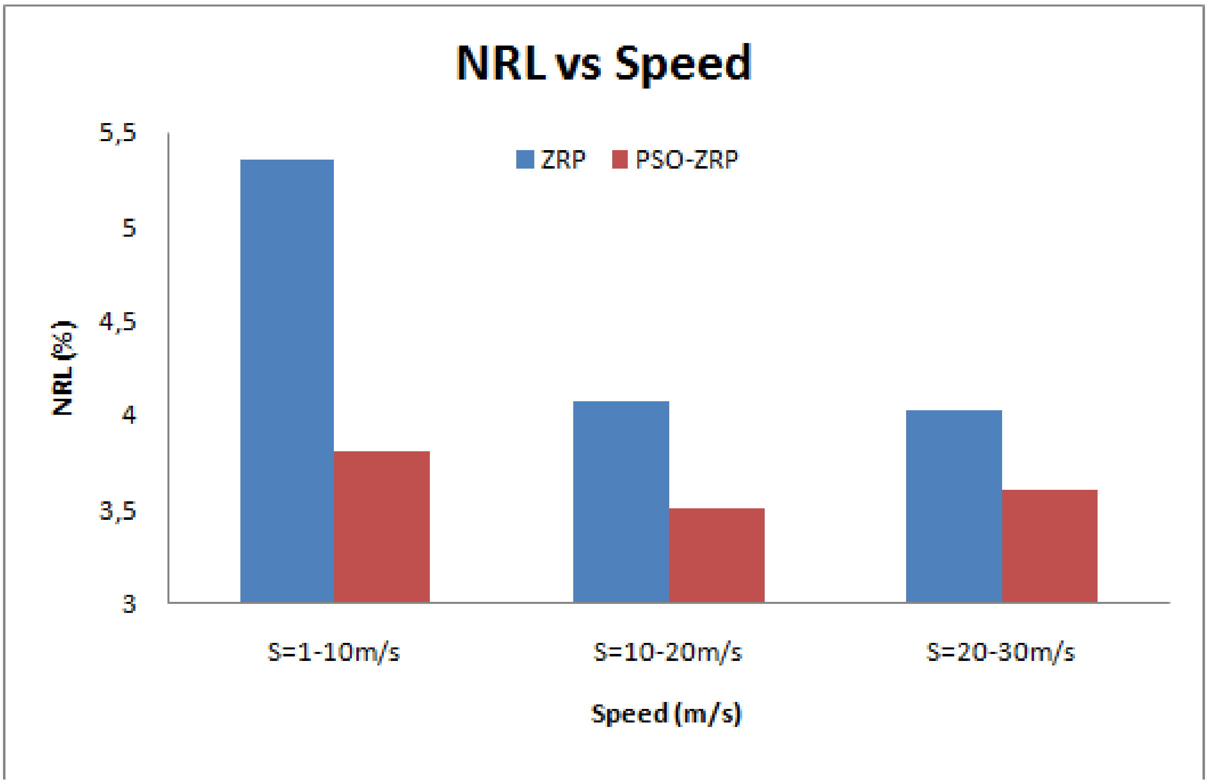

Fig. IV.28 Impact of speed variation on NRL using ZRP and PSO-IZRP.

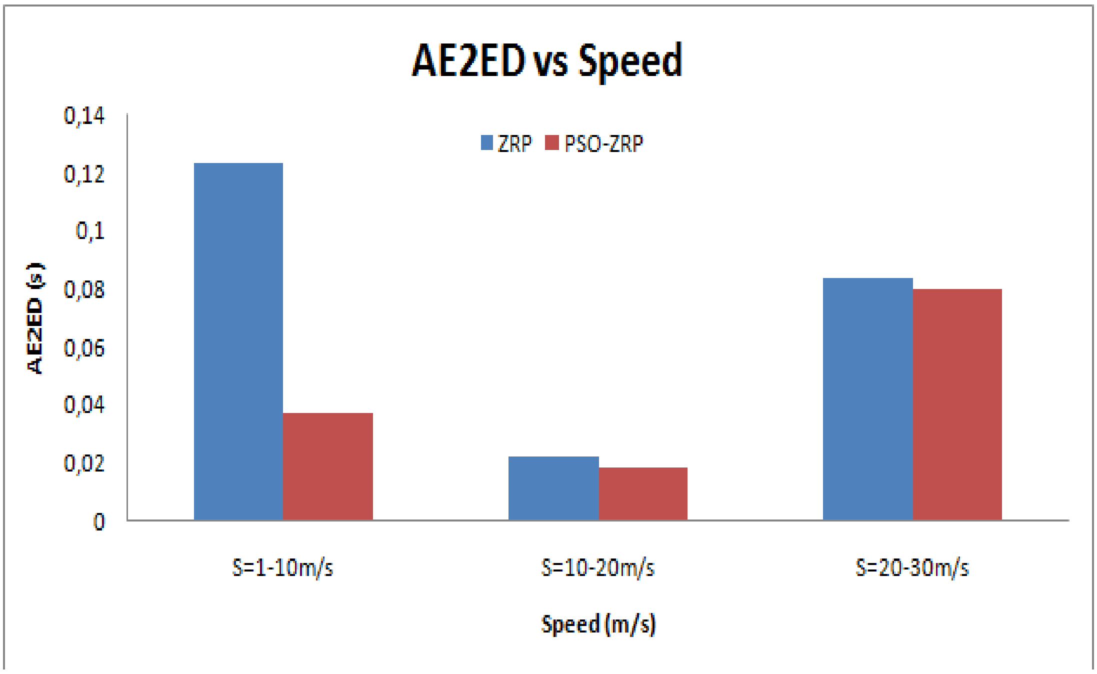

Fig. IV.29 Impact of speed variation on AE2ED using ZRP and PSO-IZRP.

Table IV.17 PSO-IZRP improvement rate with respect to pause time variation.

	PT=0s	PT=10s	PT=20s	PT=30s	PT=40s	Min	Max	Avg
PDR	11,78	22,42	4,46	17,31	10,39	4,46	22,42	13,27
NRL	20,98	20,54	22,12	24,54	21,77	20,54	24,54	21,99
AE2ED	25,05	42,56	41,47	34,85	45,04	25,05	45,04	37,79

Table IV.18 PSO-IZRP improvement rate with respect to traffic rate variation.

	R=0	R=10	R=15	R=20	Min	Max	Avg
PDR	13,14	8,47	10,62	11,22	8,47	13,14	10,86
NRL	10,18	16,59	19,96	16,47	10,18	19,96	15,80
AE2ED	10,80	63,10	61,23	45,91	10,80	63,10	45,26

Table IV.19 PSO-IZRP improvement rate with respect to number of nodes variation.

	N=10	N=20	N=30	N=40	Min	Max	Avg
PDR	2,30	19,21	14,58	18,58	2,30	19,21	13,67
NRL	31,35	26,21	1,65	16,15	1,65	31,35	18,84
AE2ED	46,64	40,05	26,04	65,82	26,04	65,82	44,64

Table IV.20 PSO-IZRP improvement rate with respect to speed variation.

	S=1-10m/s	S=10-20m/s	S=20-30m/s	Min	Max	Avg
PDR	8,42	8,76	4,76	4,76	8,76	7,31
NRL	28,76	13,96	10,65	10,65	28,76	17,79
AE2ED	69,99	15,04	4,03	4,03	69,99	29,69

Form Tables IV.17 to IV.20, we can see that the average value of PDR improvement rate is around 11.28% (between 7.31% and 13.67%). Considering all tests, we have an improvement rate varying between 2.30% (the minimum) and 22.42% (the maximum). For the NRL improvement rate, the average value is around 18.60% (between 15.80% and 21.99%). The NRL improvement rate varies for all cases between 1.65% (the minimum) and 31.35% (the maximum). Finally, for the AE2ED improvement rate, the average value is around 39.34% (between 29.69% and 45.26%). The AE2ED improvement rate for all test scenarios varies between 4.03% (the minimum) and 69.99% (the maximum).

From the obtained results, it is undeniably clear that the proposed PSO-IZRP protocol has improved the overall performances of the conventional ZRP protocol with respect to all considered metrics. Table IV.21 show the performances comparison between related works and our proposed PSO-IZRP protocol with respect to radius estimation.

Table IV.21 Performance's comparison of PSO-IZRP and some related works.

Ref.	Prot.	Algorithm	Metrics	Improvement rate
[1]	Zone Routing protocol (ZRP)	• min searching • adaptive traffic	▪ Normalized routing load (NRL)	NRL: 7% (min searching) 1%-2% (adaptive traffic)
[2]		• min searching • adaptive traffic	▪ Packet delivery ratio (PDR) ▪ Route discovery delay (RDD) ▪ Normalized routing load (NRL)	PDR: <0% - 0 % RDD: 4% - 7% NRL: 60%
[3]		Artificial bee colony algorithm (ABC)	▪ Packet delivery ratio (PDR) ▪ Average end to end delay (AEED) ▪ Normalized routing load (NRL)	PDR: <<< 0% AEED: 0% - 0.1% NRL: 30% - 40%
PSO-IZRP		**Particle Swarm Optimization (PSO)**	**▪ Packet delivery ratio (PDR) ▪ Average end to end delay (AEED) ▪ Normalized routing load (NRL)**	**PDR: 7% - 14% AEED: 16% - 22% NRL: 30% - 45%**

From Table IV.21 below, we can see clearly that the values of our proposed PSO-IZRP protocol outperform those of different related works in term of used metrics and dynamic configuration. This is leading to an enhancement of performances for the zone routing protocol and by the way is improving the network QoS.

IV.3 Conclusion

The experiments using NSGA-II-OLSR have shown the effectiveness of the developed algorithm for the optimization of OLSR parameters setting. Indeed, the choice of parameters in a multi-parameters and multi-objectives is very difficult or even impossible, due to the difficulty to choose the parameters taking into account the correlation between them, something that is done without worries by the NSGA-II algorithm which operates on a parameter space (with population of parameters) rather than a single set of parameter at a time. In addition, this version of the genetic algorithm works well on several objectives rather than a single both which allowed us to estimate the correct parameters while minimizing two objectives chosen a priori. The experiments illustrate the reaction of the proposed algorithm to track the changing environment of OLSR (i.e. mobility). This means that the proposed algorithm in addition of being a good solution for automating the choice of parameters, it can also considered as an optimal choice to minimize the overall objectives and to be more adaptive to the environment changes.

The realized experiments showed the reactivity of the proposed NGSA-II-OLSR to any change of protocol's environment. In case of low node mobility, the proposed NSGA-II-OLSR improves the PLR between 8.59% and 33.17%; the E2ED between 18.17% and 27.56%; and the NRL between 35.18% and 36.60%. While in case of high mobility node, it improves the PLR between 3.47% and 9.94%; the E2ED between 1.47% and 9.40%; and the NRL between 0.14% and 2.34%, which results in a gain in performance regardless of the real-time application, file transfer, multimedia. In addition the proposed NSGA-II-OLSR reduces the consumption of the battery in all cases.

While the experiment using the DE-OLSR shown that:

- the proposed scheme performs as well as standard OLSR configured with a fixed hello interval (hello interval = 2s) but with much less overhead. We notice the proposed algorithm considerably reduces the amount of overhead compared to the original OLSR;

- the amount of overhead generated by using our approach of almost ~52% lower than standard OLSR. In case of no network changes, the control overhead is reduced due automatically adjustment of the hello interval value to a large value. We note also a similarity shape of curves for OLSR protocol in the both cases: low and high network density which means the OLSR reacts with same behavior for any scenarios. This is due to the fact that conventional OLSR uses a fixed timer approach. In contrary, the proposed algorithm plots dissimilar curve for low and high network density, which explain that the proposed OLSR react effectively to the network topology changes by reducing the hello message sending rate in case of low frequently change network (at low speeds). In opposition, the proposed scheme increases the rate when there are more changes (at high speeds). The proposed scheme shows high reliability compared to original OLSR. The proposed one has in average ~3-5 % more packet delivery ratio;
- the AEED is not consequently affected by using our scheme. We notice an AEED degradation of almost ~0.2 ms compared to the original OLSR. This degradation is due to the increment the number of data packets successfully received represented by the improvement of PDR realized by our protocol leading to increase the time taken by all data packets to reach their destination.

For the experiment using the PSO-IZRP, we can notice that:

- in case of pause time variation, the proposed PSO-IZRP protocol outperforms the conventional ZRP protocol in all considered performances measures with respect to the pause time variation showing improvement between 1.34% and 7.50% for PDR; between 0.84% and 1.14% for the NRL; and between 18.58ms and 56.28ms for the AE2ED;
- in case of traffic rate variation, the proposed PSO-IZRP protocol is shown to provide better results than the conventional ZRP protocol with respect to traffic rate variation showing improvement between 2.91% and 3.76% for PDR; between 0.50% and 0.76% for the NRL; and between 4.92ms and 36.89ms for the AE2ED;

- in case of number of nodes variation, excepting the case of AE2ED measure with N=10 (+17.96ms), the proposed PSO-IZRP protocol shows better performances than the conventional ZRP protocol with respect to number of nodes variation showing improvement: between 0.77% and 6.30% for PDR; between 0.07% and 1.48% for the NRL; and between 2.17ms and 58.53ms for the AE2ED;
- in case of speed variation, and with respect to the speed variation, the proposed PSO-IZRP protocol shows better performances than the conventional ZRP protocol: between 1.42% and 2.78% for the PDR; between 0.43% and 1.54% for the NRL; and between 3.33ms and 86.66ms for the AE2ED.

We can see that the average value of PDR improvement rate is around 11.28% (between 7.31% and 13.67%). Considering all tests, we have an improvement rate varying between 2.30% (the minimum) and 22.42% (the maximum). For the NRL improvement rate, the average value is around 18.60% (between 15.80% and 21.99%). The NRL improvement rate varies for all cases between 1.65% (the minimum) and 31.35% (the maximum). Finally, for the AE2ED improvement rate, the average value is around 39.34% (between 29.69% and 45.26%). The AE2ED improvement rate for all test scenarios varies between 4.03% (the minimum) and 69.99% (the maximum).

From the obtained results, it is undeniably clear that the proposed PSO-IZRP protocol has improved the overall performances of the conventional ZRP protocol with respect to all considered metrics. The performances comparison between related works and our proposed prove the efficiency and the superiority of our algorithm regarding all considered comparison metrics.

IV.4 References

[1] Patel, B. 2007. "ZRP Agent for NS2" http://magnet.daiict.ac.in/magnet_members/MTech/2007/PatelBrijesh/Thesis_files/MyZRP/ZRPManual.pdf.

[2] Patel, D.N., S.B. Patel, H.R. Kothadiya, P.D. Jethwa and R.H. Jhaveri. 2014. "A survey of reactive routing protocols in MANETs." Paper presented at IEEE 2014 International Conference on Information Communication and Embedded Systems (ICICES'2014), Chennai 27-29 Nov 2014..

[3] Pearlman, M.R. and Z.J. Haas. 1999. "Determining the Optimal Configuration for the Zone Routing Protocol." *IEEE Journal of Selected Areas in Communications* 17 (8): 1395-1414.

Conclusion and Future Extensions

Routing algorithms are in charge of finding a reliable route between any source and destination. The lack of central infrastructure, the changing topology, the limited resources, and the decentralized nature of ad hoc networks make routing a challenging service. There are mainly two different approaches in routing algorithms: i) proactive and ii) reactive. The former approach periodically exchanges topology information, thus maintaining routing tables that are available immediately. The drawback of this approach is the cost of maintaining such routing tables, specially if the topology is highly changeable. The reactive strategy only establishes a route when it is needed. Some hybrid approaches have also been proposed with characteristics from both reactive and proactive strategies..

In this work, we focus on the routing protocol optimizaton due to the unpredictable and changing topology of mobile ad hoc networks where communication protocols usually rely on some parameters that adapt their behavior to the current circumstances. The performance of the protocol is highly sensitive to small changes in the set of those configuration parameters. Therefore, fine tuning them for optimally configuring a communication protocol is a complex and critical task regarding the multi-objectives nature of MANETs were several objectives like network resources, QoS, energy used, and so forth need to be optimized. To achieve this goal, we divide the research work as presented as follows:

- In Chapter1, we introduced the ad hoc networks basic concepts of Ad hoc networks, features, challenges and applications. The last part of this chapter introduces the routing protocols;
- In Chapter 2, we have presented an overview of the most relevant existing literature that uses bioinspired algorithms to solve optimization problems in ad hoc networks, especially the routing protocol problem. A particular interest was given to the routing protocol optimization which constitutes the main axis of this thesis with a state of the

art covering the period from 2005 to 2018 playing the role of a springboard for the next chapter.

- In Chapter 3, we provide a detailed knowledge concerning biologically inspired approaches used in this work for MANET routing protocols setting. It starts with motivations for using such methods in MANET routing and describes different basic bio-inspired algorithms used NSGA-II, DE and PSO algorithms. Afterward, basic concepts and operations of bio-inspired protocols routing implemented (OLSR and ZRP) are detailled. Moreover, this chapter includes the encoding, metrics and objective functions used for each proposed bio-inspired routing protocol, which were be used in chapter IV giving the simulations results;
- In the last Chapter, Chapter 4, we describe the simulation environment that includes introduction, general infoamtion regarding NS-2 simulator and deal with simulation study and implementation of routing protocols OLSR and ZRP, respectively. The simulations results are presented using tables and figures proviing a huge information proving the efficiency of the proposed algorithms. The main results and contribution of this work are presented below:
  - The experiments using NSGA-II-OLSR have shown the effectiveness of the developed algorithm for the optimization of OLSR parameters setting. Indeed, the choice of parameters in a multi-parameters and multi-objectives is very difficult or even impossible, due to the difficulty to choose the parameters taking into account the correlation between them, something that is done without worries by the NSGA-II algorithm which operates on a parameter space (with population of parameters) rather than a single set of parameter at a time. In addition, this version of the genetic algorithm works well on several objectives rather than a single both which allowed us to estimate the correct parameters while minimizing two objectives chosen a priori. The experiments illustrate the reaction of the proposed algorithm to track the changing environment of OLSR (i.e. mobility). This means that the proposed algorithm in addition of being a good solution for automating the choice of parameters, it can also considered as an optimal choice to minimize the overall objectives and to be more adaptive to the environment changes.

The realized experiments showed the reactivity of the proposed NGSA-II-OLSR to any change of protocol's environment. In case of low node mobility, the proposed NSGA-II-OLSR improves the PLR between 8.59% and 33.17%; the E2ED between 18.17% and 27.56%; and the NRL between 35.18% and 36.60%. While in case of high mobility node, it improves the PLR between 3.47% and 9.94%; the E2ED between 1.47% and 9.40%; and the NRL between 0.14% and 2.34%, which results in a gain in performance regardless of the real-time application, file transfer, multimedia. In addition the proposed NSGA-II-OLSR reduces the consumption of the battery in all cases.

- While the experiment using the DE-OLSR shown that:

  The proposed scheme performs as well as standard OLSR configured with a fixed hello interval (hello interval = 2s) but with much less overhead. We notice the proposed algorithm considerably reduces the amount of overhead compared to the original OLSR;

  The amount of overhead generated by using our approach of almost ~52% lower than standard OLSR. In case of no network changes, the control overhead is reduced due automatically adjustment of the hello interval value to a large value. We note also a similarity shape of curves for OLSR protocol in the both cases: low and high network density which means the OLSR reacts with same behavior for any scenarios. This is due to the fact that conventional OLSR uses a fixed timer approach. In contrary, the proposed algorithm plots dissimilar curve for low and high network density, which explain that the proposed OLSR react effectively to the network topology changes by reducing the hello message sending rate in case of low frequently change network (at low speeds). In opposition, the proposed scheme increases the rate when there are more changes (at high speeds). The proposed scheme shows high reliability compared to original OLSR. The proposed one has in average ~3-5 % more packet delivery ratio;

  The AEED is not consequently affected by using our scheme. We notice an AEED degradation of almost ~0.2 ms compared to the original OLSR. This degradation is due to the increment the number of data packets successfully received represented by the improvement of PDR realized by our protocol leading to increase the time taken by all data packets to reach their destination.

- For the experiment using the PSO-IZRP, we can notice that:

  In case of pause time variation, the proposed PSO-IZRP protocol outperforms the conventional ZRP protocol in all considered performances measures with respect to the pause time variation showing improvement between 1.34% and 7.50% for PDR; between 0.84% and 1.14% for the NRL; and between 18.58ms and 56.28ms for the AE2ED;

  In case of traffic rate variation, the proposed PSO-IZRP protocol is shown to provide better results than the conventional ZRP protocol with respect to traffic rate variation showing improvement between 2.91% and 3.76% for PDR; between 0.50% and 0.76% for the NRL; and between 4.92ms and 36.89ms for the AE2ED;

  In case of number of nodes variation, excepting the case of AE2ED measure with N=10 (+17.96ms), the proposed PSO-IZRP protocol shows better performances than the conventional ZRP protocol with respect to number of nodes variation showing improvement: between 0.77% and 6.30% for PDR; between 0.07% and 1.48% for the NRL; and between 2.17ms and 58.53ms for the AE2ED;

  In case of speed variation, and with respect to the speed variation, the proposed PSO-IZRP protocol shows better performances than the conventional ZRP protocol: between 1.42% and 2.78% for the PDR; between 0.43% and 1.54% for the NRL; and between 3.33ms and 86.66ms for the AE2ED.

  We can see that the average value of PDR improvement rate is around 11.28% (between 7.31% and 13.67%). Considering all tests, we have an improvement rate varying between 2.30% (the minimum) and 22.42% (the maximum). For the NRL improvement rate, the average value is around 18.60% (between 15.80% and 21.99%). The NRL improvement rate varies for all cases between 1.65% (the minimum) and 31.35% (the maximum). Finally, for the AE2ED improvement rate, the average value is around 39.34% (between 29.69% and 45.26%). The AE2ED improvement rate for all test scenarios varies between 4.03% (the minimum) and 69.99% (the maximum).

From the obtained results, it is undeniably clear that the proposed PSO-IZRP protocol has improved the overall performances of the conventional ZRP protocol with respect to all considered metrics. The performances comparison between related works and our proposed prove the efficiency and the superiority of our algorithm regarding all considered comparison metrics.

This work opens up new possibilities for optimizing the parameters of the active, proactive and hybrid routing protocols and to make its nature adaptive to any changing environment. This perspective deserves a continuation of the work to validate the robustness of the system and its generalization to other types of protocols and including new parameters like energy and using new -bio-inspired algorithms.

Contributions

International Publications

<table>
<tr><td rowspan="7">International Publications</td><td>Title:</td><td colspan="2">PSO-IZRP: New Enhanced Zone Routing Protocol Based on PSO Independent Zone Radius Estimation</td></tr>
<tr><td rowspan="3">Autors:</td><td>Last Name : Harrag</td><td>First Name : Nassir</td></tr>
<tr><td>Last Name : Refoufi</td><td>First Name : Allaoua</td></tr>
<tr><td>Last Name : Harrag</td><td>First Name : Abdelghani</td></tr>
<tr><td>Year:</td><td colspan="2">2018</td></tr>
<tr><td>Journal</td><td colspan="2">International Journal of Numerical Modelling: Electronic Networks, Devices and Fields (ISI IF 2016 = 0.622)</td></tr>
<tr><td>URL</td><td colspan="2">https://onlinelibrary.wiley.com/journal/10991204</td></tr>
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International Conferences

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<tr><td rowspan="7">International Conferences</td><td>Title:</td><td colspan="2">Neighbor Discovery using Novel DE-based Adaptive Hello Messaging Scheme Improving OLSR Routing Protocol Performances</td></tr>
<tr><td rowspan="3">Autors:</td><td>Last Name : Harrag</td><td>First Name : Nassir</td></tr>
<tr><td>Last Name : Refoufi</td><td>First Name : Allaoua</td></tr>
<tr><td>Last Name : Harrag</td><td>First Name : Abdelghani</td></tr>
<tr><td>Conference:</td><td colspan="2">The 6th International Conference on Systems and Control (ICSC'2017)</td></tr>
<tr><td>Year:</td><td colspan="2">2017</td></tr>
<tr><td>Location:</td><td colspan="2">Batna, Algérie</td></tr>
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<tr><td rowspan="7">International Conferences</td><td>Title:</td><td colspan="2">Improving OLSR Routing Protocol Performances by Neighbor Discovery using Novel DE-based Adaptive Hello Messaging Scheme</td></tr>
<tr><td rowspan="3">Autors:</td><td>Last Name : Harrag</td><td>First Name : Nassir</td></tr>
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<tr><td>Last Name : Harrag</td><td>First Name : Abdelghani</td></tr>
<tr><td>Conference:</td><td colspan="2">The International Conference of Embedded Systems in Telecommunications and Instrumentation (ICESTI'16)</td></tr>
<tr><td>Year:</td><td colspan="2">2016</td></tr>
<tr><td>Location:</td><td colspan="2">Annaba, Algérie</td></tr>
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Abstract

In this thesis, we define and solve an optimization problem using a meta-heuristic approach in order to efficiently and automatically tune optimized routing protocol. The proposed algorithm explores the huge number of all possible feasible routing protocol configurations to find optimized parameter settings. The simulation results obtained using NS2 simulator prove that the developed algorithms allows the choice of an efficient routing protocol configuration that minimizes simultaneously the packet loss ratio and the packet delivery delays as well as network load by limiting control packets. Furthermore, it also permits the Ad Hoc network to adapt itself to each topology change which makes it adaptive to any environment changing.

Keywords: Ad hoc, MANET, Routing, Protocol, Optimization, Metaheuristic, Bio-inspired

Résumé

Dans cette thèse, nous proposons un protocole de routage amélioré utilisant une approche méta-heuristique afin d'optimiser la qualité du service considéré comme le problème majeur de tous les protocoles standards. L'approche proposée explore l'espace de configurations possibles dans le but de sélectionner les meilleures ayant comme conséquence l'amélioration des performances du protocole optimisé. Les résultats de simulation obtenus à l'aide du simulateur NS-2 prouvent l'efficacité des algorithmes développés dans le choix d'une configuration de protocole de routage minimisant le taux de perte de paquets, les délais de latence du réseau ainsi que la charge du réseau limitant les paquets de contrôle. En outre, il permet également au réseau Ad Hoc de s'adapter à chaque changement de topologie, ce qui le rend adaptable à tout changement environnement.

Mot clés: Ad hoc, MANET, Routage, Protocole, Optimisation, Méta-heuristique, Bio-inspirés

ملخص

في هذه الأطروحة، نقترح بروتوكول توجيه محسّنً باستخدام منهج ميتا هوريستيكي لتحسين جودة الخدمة التي تعتبر المشكلة الرئيسية لجميع البروتوكولات. يستكشف المنهج المقترح فضاء الحلول الممكنة من أجل تحديد أفضلها مما يؤدي إلى تحسين أداء البروتوكول. تثبت نتائج المحاكاة التي تم الحصول عليها باستخدام محاكي NS-2 فعالية الخوارزميات التي تم تطويرها في اختيار برمجة بروتوكول التوجيه مما يقلل من معدل خسارة البيانات، ويقلل من معدل تعطل الشبكة بالإضافة إلى تشبع الشبكة وهذا بالحد من بيانات التحكم. بالإضافة إلى ذلك ، يسمح أيضًا لشبكة Ad Hoc بالتوافق مع كل تغيير في الشبكة، مما يجعلها قابلة للتكيف مع أي تغيير في البيئة.

الكلمات المفتاحية: أد هوك، مانات، توجيه، بروتوكول، تحسين، ميتا هوريستيك، مقتبس عن الطبيعة