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An optimized link state routing protocol on ad-hoc wireless networks based on Internet connectivity

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An optimized link state routing protocol on ad-hoc wireless networks based on Internet connectivity

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Abstract

A mobile ad-hoc network (MANET) can be defined as a collection of autonomous nodes that can achieve wireless communication with each other without any centralise administration. Quality of service (QoS) and efficient routing protocol are the mechanisms which support the multimedia applications of the network. Recent technologies have intergraded wireless communication and Internet services in order to expand the traditional Internet applications. This thesis investigates a novel approach on MANETs, which support Internet services and can be used to establish an Internet connection between the network's nodes.

This thesis introduces a new concept of Internet-connected MANET routing protocol based on optimised link state routing algorithm. Backbone Internet-Connected – Optimised Link State Routing (BIC-OLSR) protocol is enhanced to provide QoS by utilising Internet connection and weighting algorithm in order to reduce end-to-end delay, increase the throughput and the packet fraction of the network. With detailed analysis, the research work investigates current routing protocols and technologies, which support Internet services.

BIC-OLSR is defined by the control messages, weighting algorithm and multipoint relay algorithm (MPR). The control messages identify the Internet connected nodes, the topology of the network and nodes neighbours. On the other hand, weighting algorithm based on control messages reveals the most efficient routing path based on the perspective of each node involved in the data transmission. MPR algorithm clusters the network and selects a Cluster Head based on the weighting algorithm. Simulations have shown that BIC-OLSR routing protocol provides QoS performance in different scenarios compared with OLSR routing protocol.

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Acronyms and abbreviations

AODV	Ad-hoc On-Demand Distance Vector Routing
BER	Bit Error Rate
BIC-OLSR	Backbone Internet Connected Optimized Link State Routing
C++	Programming Language
CA	Collision Avoidance
CH	Cluster Head
CoS	Class of Service
DARPA	Defense Advanced Research Projects Agency
DSDV	Destination-Sequenced Distance-Vector Routing
DSR	Dynamic Source Routing
EMPR	Efficient Multipoint Relay
FTP	File Transfer Protocol
GLBF	Gateways Load Balance Factor
GW_ADV	Gateway Advertisement
HNA	Host and Network Association
IA	Internet Access
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IHello	Internet Hello
IIM	Integrated Internet MANET
IoT	Internet of Things
IP	Internet Protocol
LAN	Local Area Network
LBRA	Load Balancing Routing Algorithm
MAC	Medium Access Control
MANET	Mobile Ad-hoc Network

MATLAB	Simulator
MCIS	Minimizing Cost-Inefficiency Selection
MG	Mobile Gateway
MID	Multiple Interface Declaration
MIMS	Maximizing Integration Metric Selection
MQES	Maximizing QoS-Efficiency Selection
MPR	Multipoint Relaying
NAM	Network Animator
NED	Native File Extension
NFA	Necessity First Algorithm
NS2	Network Simulator 2
NS3	Network Simulator 3
NPDU	Network Packet Data Unit
QOLSR	Quality-OLSR
QMPR	Quality Multipoint Relay
QoS	Quality of Service
OFDM	Orthogonal Frequency Division Multiplexing
OLSR	Optimized Link State Routing
OMNET++	Network Simulator
OTcl	Tool Command Language
PCAP	File extension
PDR	Packet Delivery Ratio
RESA	Resource Aware
RREP	Route Reply
RREQ	Route Request
RTS	Request-To-Send
SURAN	Survivable Radio Network
TC	Topology Control

TORA	Temporally Ordered Routing Algorithm
Wi-Fi	Wireless Fidelity
WAN	Wide Area Network
WLB-AODV	Workload Balancing Ad-hoc On-Demand Distance Vector Routing
ZHLS	Zone-based Hierarchical Link State
ZRP	Zone Routing Protocol

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Chapter 1 - Introduction

1.1 Overview and motivation

The ad-hoc wireless network is defined as a collection of mobile nodes with wireless capabilities, whereas intermediate nodes exchange information between the source and the destination nodes. The idea behind the specific wireless networks is to facilitate information exchange between the nodes without the need of central administration; therefore, the network can be described as an autonomous system. The advantages of the ad-hoc wireless network are that they can be organised, configured and capable of developing their own infrastructure (Dung 2012). Ad-hoc networks characterised by the dynamic topologies, bandwidth constraints, variable capacity links, and limited physical security. Each node can become the host of the source or the destination and the intermediate nodes routers in order to forward data from one end to another. These nodes have the ability to communicate with each other even though there is no existence of base station, access point or any other preinstalled infrastructure in the network.

The autonomy of the system on the specific concept of wireless networks has proven its capability of exchanging information and interfering with the source, destination, and intermediate nodes. The network is surrounded by routing protocols in order to transfer data packets between the nodes. The foundations of the wireless networks have been improved, as the years pass new hardware improvements has been made over the last years, but the need for utilising the network abilities in full capacity is required. The end users these days are demanding video, audio and document data transitions in real time over the ad-hoc Wireless networks. Therefore, the requirement to combine hardware and software capabilities is vital. Changing the hardware of each device is not an easy task, so the industry has focused on routing protocols. The protocol coordinates data packets transmitted from the source to its destination under the dynamic traffic condition of the network. Protocols are responsible for the data traffic in the network and the complexity of their algorithms is based on the scalability of the network, the data size of the packets, broken links, overhead and mobility of the nodes. The dynamic topology of ad-hoc Wireless networks has been achieved with the utilisation of multi-hop path in order to forward data packets. On the other hand, the dynamic topology will likely result in data loss, the end-to-end delay and broken links, which are reducing the network performance (Yu 2007).

As the time passed, end users are demanding a high quality of video and audio files, however the networking perspective cannot support the streaming of these files in real time. The project is seeking the improvement of the data flooding in the network by achieving a reliable and stable connection between the nodes. The researchers in the area address some of the issues while the data forwards from one node to another. These are listed as follows: the end-to-end delay, data loss, broken links, the overhead of the system, waste of wireless channels and shortest paths. Routing protocols have been categorised and focusing on specific demands of each network environment. However, none of them has utilised Internet access of the same nodes as an advantage to create neighbour clusters that were not in range on the wireless signal as an advantage of the network. In addition, the complexity of expansion of each routing protocol while the numbers of hosts are rising is required to study, because of the performance of the network decreases (Nicopolitidis 2004).

1.2 Routing in ad-hoc network

The main concern of designing an efficient routing protocol on ad-hoc wireless networks is the ability to choose an efficient path for the communication between two nodes. One of the challenges of routing protocol is to maintain the topological information of the nodes while they are moving drastically and unpredictably. Routing protocols for ad-hoc wireless networks are listed as proactive, reactive and hybrid. Proactive routing protocols are defined as the protocols which are utilising periodically messages in order to refresh their topology and routing table. They are focusing on stable or low mobility nodes and they can provide route paths immediately. Table-driven routing protocols are not suited for high mobility scenarios as the messages contained the topological information increase the network overhead, because of the limited bandwidth and power constraint. Reactive routing protocols have a different approach to create their routing table. The routing table starts the procedure of discovery under request. The specific routing protocols focus on managing high mobility nodes to reduce the effort to maintain routes, which they might not use. The on-demand routing protocol is to save bandwidth and the overhead of the network is low unless they are generating a routing path. At last, hybrid routing protocols are the combination of the proactive and reactive types of routing protocols (Yadav 2012).

A variety of optimisation techniques have been developed to address the unique characteristics of ad-hoc wireless networks such as dynamic topology, bandwidth constraints, constrained processing and storing capabilities. Some of those characteristics have been inherited by the wired connections. A number of ad-hoc wireless protocols build and utilise only one path from the source to the destination node, which underutilised resources when the single route is occupied by another process. Table-driven routing protocols maintain the most efficient path between the source and the destination node, and the latency of the data is lower compared with the on-demand routing protocols. On the other hand, proactive routing protocols have to maintain their routes which cause constantly the increase of overhead to the network.

1.3 Research Hypothesis

Optimized Link State Routing (OLSR) routing protocol has the ability to blend with other networks because of the ability to use Backbone capabilities. From secondary literature review is noticeable that the selection of Cluster Heads does not consider that a node might be connected to the Internet and therefore to be able to connect to the Internet. The project seeks to develop a new Multipoint relays (MPR) selection algorithm based on weight algorithm which will take the Internet connection of the nodes under consideration, in order to select a Cluster Head. The project is seeking the expansion of the network with other networks will be able to provide information from the Internet, as the Cluster Head will lead this information to the network.

Table-driven routing protocols have the need to know the entire routing table and keep maintain the node connections. OLSR in particularly counts the number of nodes from one node to another in order to structure the routing table of the network. The project seeks to establish Internet connections with the inner Internet-connected nodes in order to connect disjoint nodes and clusters of the network. The reduction of hop between the source and destination during the data transfer will eliminate the interference of intermediate nodes as their services will not need. BIC-OLSR would be able to reduce the congestion, collisions, end-to-end delay and increase the performance of the network by increasing the packet delivery ratio and throughput.

Finally, the creation of new Hello and Internet Access messages structure will provide all the necessary information for the MPR and weighting algorithm. We are assuming that the routing table will be structured rabidly as the number of hops between the nodes has been reduced and we will achieve a direct communication between the Cluster Heads. The new structure of MPR might reduce the control messages in the network; however, the new Internet Access messages might increase more than the OLSR as a result to increase the overhead of the network.

1.4 Research aims and objectives

The project has the intention to implement a different way of selecting the MPR nodes on the OLSR protocol. The scenario of having nodes with Backbone capabilities has not taken into account in the prototype protocol. Backbone provides accesses to the network nodes out of their network, but none have considered that can be used to interlink the long-distance nodes of the same network. The target of the research is to expand the data transferring from the source node to the destination by using multiple ways of transferring data. The modified OLSR protocol will divide the network nodes into groups. The protocol will determine each node by their state; therefore, each node will have its role in the network. As the group will be created a leader node should take care of the member nodes by providing the topology, routing tables and access out of the network when they need them. The traffic management will be provided by the group leader of each group, therefore overhead of the network will be reduced.

In order to change the way of MPR selection an algorithm of weighting the nodes in the network is introduced. The weighting algorithm will also be the measurement of selecting the most efficient path of data transfer. This algorithm will take information based on the known one-hop nodes, the reachability of the node in the network, the Internet-connected nodes, and the battery status. The information of the weighting algorithm is taken from the messages. The prototype messages cannot provide all the information of this technique. Therefore, a new structure of Hello messages has to be developed.

The main idea of the project is to build one-hop connections between the Internet-connected nodes no matter how far there are from each other, as a result, to reduce the number of hops between the source and the destination nodes. The Internet-connected nodes will utilise the Internet path if they have two-hops or more. If it is one-hop they are keeping their initial connection. OLSR is employed with MPR mechanism which is an election Cluster Head technique. Since the proposed protocol considers the Internet connection as the first option to send data between nodes if it is available, the Cluster Head criteria of the selection have to change. A node weight mechanism considering the number of one-hop nodes, the Internet-connected nodes, the length of reachability with other nodes and the battery status. According to the criteria, the nodes are assigned with a weight value as the mechanism to choose the Cluster Head. The mechanism aims to assign an Internet-connected node as Cluster Head in order to minimise the involvement of the intermediate nodes.

The first phase of this project consists of making an in-depth study of the OLSR protocol, which will mainly have focused on how OLSR performs the flooding of topology information throughout the network. The aim of this study is to identify all the factors involved in the generation and broadcasting of this information and analyse whether it is possible or not to reduce the amount of topology data transmission. The evaluation of the protocol will have performed over different network environment scenarios. The performance metrics will provide all the information to analyse how the topology information flooding varies depending on the scenario configuration and determine in which cases this information could be redundant, i.e. the messages sent contains almost always the same data due to the fact that the network topology does not extremely change.

The project approach is to utilise extra spectrum using multiple Internet technologies on some of the nodes, to accomplish tasks over the Internet. The project aims to show that the new structure of the protocol will provide significant benefits in terms of functionality and performance by utilising multiple technologies. The new protocol targets large topological fields, so it is not recommended using in-home appliance.

1.4.1 BIC-OLSR design objectives

The main objective of this project is to develop an efficient multi-interface optimised link state routing protocol based on OLSR protocol for ad-hoc wireless networks. The key idea in this approach is to overcome the weakness of the range of one-hop neighbours by providing Internet connection on some of the nodes to connect as a single hop when they are not. This approach will be able to interconnect one cluster with another and even more, the topology of the entire network will be discovered rapidly.

Although is difficult to have the entire network covered with efficient paths, this approach aims to establish a long live connection between the nodes. The Internet connection between the nodes reduces the congestion and collision as the intermediate nodes are reduced. The nodes could connect directly from one end to the other without interfere with the intermediate clusters or nodes. Therefore, the end-to-end delay and throughput will be more efficient as the source and destination nodes will rely on a lower amount or not even use intermediate nodes. One of the main failures of transmitting data in the ad-hoc wireless network is because the packets are dropped or lost while the intermediate nodes are forwarding those messages. The MPR algorithm is responsible to choose the most suitable Cluster Heads by utilising the weight criteria's.

The benefits of establishing Internet-connected paths are reliable to QoS support, increasing the bandwidth of the network and balance the network congestion. BIC-OLSR aims to be a new generation of optimising link state routing protocol by offering QoS advantages such as reliability, reducing congestions, avoid collisions, increase the throughput, minimising the end-to-end delay and minimising the number of hops.

1.4.1.1 List of Objectives

- Creation of three different environments (12, 25 and 50 nodes) written on OTcl script language in order to compare four prototype routing protocols (AODV, OLSR, DSR and DSDV routing protocols) over different data transmissions in NS2 simulation.
- Design BIC-OLSR routing protocol base on OLSR protocol running over MATLAB simulation.
    - Introduce a new type of message to provide information regards the Internet-connected nodes of the network named Internet Access messages.
    - Creation of a new structure of Hello messages among with the newly introduce IHello messages which will provide a more detailed information regards the neighbour nodes.
    - Implementation of a virtual Backbone structure routing protocol.
    - Development of a weighting algorithm to provide the most efficient selection of the routing paths by revealing the strongest nodes in the network.
    - Implementation of a new MPR algorithm, which based on weighting algorithm, will create a less overhead environment and an efficient selection of the Cluster Head.
- Creation of an energy model that the power consumption will be reduced based on the simulation procedures.
- Implementation of three topological scenarios (15, 25 and 40 nodes) in order to compare BIC-OLSR and OLSR over different data transmissions.
- An Increase of routing efficiency by increasing packet delivery ratio and throughput and by reducing the number of hops from one end to another and end-to-end delay.
- Resolve major drawbacks of the optimised link state routing such as underutilising resources, alleviating the congestion problem and load balancing.

1.5 Original contributions

The proposed protocol is an encashment of the OLSR routing protocol. The key feature of the BIC-OLSR is the ability to use the Internet-connected nodes to establish one-hop Internet links. The foundation of the protocol is messages (Hello, IHello, IA, and TC) which they pass information from one node to another regards their neighbour nodes. The development of a new structure of Hello message is vital as the proposed weighting algorithm will use this data in order to process calculations and choose the most appropriate path to transfer data in the network. The weighting algorithm is responsible to assign a value to each node. The highest value marks the most important node in the network for the specific process in the network. That value can be critical for the maintenance of the most efficient path in any direction or even elect the most appropriate node to be elected as Cluster Head.

The creation of Internet Access messages helps the Internet-connected nodes who have not connected to other Internet-connected nodes, to broadcast their capability to connect to the Internet. Therefore, establish Internet-connected links with other Internet-connected nodes. The mechanism provides identification of Internet-connected nodes in the network especially where the number of Internet-connected nodes is limited and in distance. The

Internet Access messages are generated only by the Internet-connected nodes and broadcasted only from the non-Internet connected nodes.

The protocol targets low-density networks and links disjoint one-hop nodes through the Internet connection if they are capable of, or reduce the maximum number of hops between the nodes. OLSR by its own is able to use virtual backbone capabilities to blend with other networks or even with the Internet; however, none has used this advantage to increase the efficiency of performance in the network. The backbone structure on BIC-OLSR is providing a more efficient environment as the nodes are having multiple ways to identify the other nodes in the networks and the entire routing table is implemented faster.

1.6 Thesis organisation

The remainder of this thesis is organised as follows:

Chapter 2 introduces Mobile ad-hoc networks based on their topology and routing techniques. This Chapter also introduces the basics of wireless data-communication, other related technology and application areas of OLSR protocol.

Chapter 3 expands the methodology of the project in order to conclude to its final decisions.

Chapter 4 is a lab-based research between the four prototype routing protocols tested under multiple scenarios. The conclusion of this research is the reason of the designing the BIC-OLSR as the author manage to understand the limitations of the routing protocols and how is able to increase the efficiency of one of the protocols.

Chapter 5 Introduces the design of BIC-OLSR routing protocol followed by an overview of the mechanisms that utilise to achieve the efficiency that the project seeks.

Chapter 6 provides data analysis of the simulations over multiples scenarios in order to evaluate the OLSR and BIC-OLSR.

Chapter 7 concludes the thesis with the summary of research work conducted. In addition, it offers some suggestions and directions for future work.

Chapter 2 – Literature Review

2.1 Introduction

The routing protocol is an essential procedure during the packet delivery in order to create a route from the source node to its destination by utilising one or several nodes. The importance of the routing protocol is to find the path between the source and destination nodes and deliver the packet to the correct destination node. Routing protocols in ad-hoc wireless networks are utilised to dynamically discover and maintain up to date routes between the communicating nodes.

Initially, the ad-hoc wireless network was developed by the military in the 1970s as they wanted to develop a technology capable of supporting communications between devices in modern battlefields. The Defence Advanced Research Projects Agency (DARPA) has sponsored the Survivable, Adaptive Networks (SURAN) Program in order to improve the features of their ad-hoc wireless networks in the early 1980s (Beyer 1990). Some of those features of ad-hoc wireless networks trying to improve are:

- Mobility
- Distributed self-management.
- Internetworking.
- The flexibility of handling a large number of nodes in their geographical distribution.
- Ability to adapt when the traffic and link condition change.
- Data security during the data transmission
- Manipulation of the transmitted signal in order to minimise the interference, reduction of the link errors, provision of multiple simultaneous transmissions and minimising the probability of interception.

The interest on ad-hoc wireless networks was increased not only for military purposes but for commercial use as well in the late 90s. Internet Engineering Task Force (IETF) working group was expanded and developed the Mobile Ad-hoc Networking (MANET) department. MANET working group standardised routing protocols for ad-hoc networks (Macker and Corson 1998).

Nowadays multiple protocols are used to connect various devices in order to transmit data from various sources in the network. The devices are interlinked with a powerful communication mechanism which is described by its complexity and flexibility. There are a variety of communications standards which every device has to support more than one standard to be capable to communicate and exchange data with other devices. Network access to the end user can be done either with cable by using LAN connection or wireless by using WLAN connection. These days' wireless networks are popular because the users succeed to communicate without the need of any cable and they provide the mobility on the connected devices. Some of the routing ideas have been inherited from the cable networks to wireless networks such as dynamic topology, storing capabilities, bandwidth and processing constraints.

This Chapter started with an introduction to historical information of ad-hoc wireless networks. Section 2.2 reveals the classification of ad-hoc routing protocols based on their topology. Section 2.3 provides information about the routing techniques that are utilised by four routing protocols. In section 2.4, the author reveals it is interest over the OLSR routing protocol based on related work along with some application scenarios. Internet connectivity and ad-hoc wireless networks collaboration are revealed in section 2.5. Quality of Service (QoS) based on different layers, routing schemes and challenges while developing a new routing protocol are presented in section 2.6. A brief introduction on the simulations available for this type of projects will be described in section 2.7. Finally, section 2.8 summarises the Chapter.

2.2 Classification of ad-hoc routing protocols. (Topology based)

Ad-hoc wireless network protocols are defined by self-organising decentralised control and from their ability to change topology in mobile networks. The data transmission between direct neighbours can be achieved straightforwardly; however, the data transmission between distant nodes requires the knowledge of network topology. Routing protocols are responsible for delivering data communications between the source and the correct destination node. The choice of the most efficient path will avoid the high number of collisions as it will utilise the appropriate amount of bandwidth of the specific need of the network. Ad-hoc routing protocols are categorised as proactive, reactive and hybrid protocols.

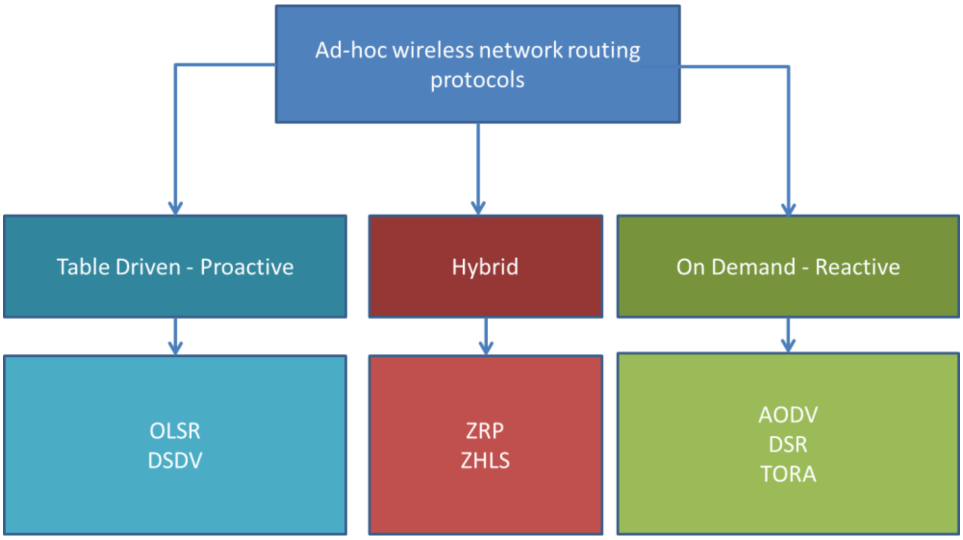

Figure 2. 1: Classification of ad-hoc wireless routing protocols topology based

2.2.1 The precompute table-based routing schemes (Proactive)

The first category of routing protocols topology based is the proactive routing and it utilises a table-driven approach. These types of protocols are maintaining the routing information of each node in the network by utilising periodic control messages. The proactive routing algorithm in each protocol is responsible to store in different tables topology information which are updated periodically or when changes occur in the network. The number of necessary routing tables and the method which node responds to changes in the network structure are deferent between the proactive routing protocols. Proactive routing protocols are having the ability to structure the routing table from the beginning of the network connection, as a result, to be ready to respond to any packet exchange in the network immediately. The two disadvantages of the proactive routing protocols are the overhead created when the network is idle, caused by the control messages and their ability to adjust to topology changes (Yadav 2012).

2.2.2 The on demand sourced based routing schemes (Reactive)

The second option of routing protocols topology based on the reactive routing protocols which are source-initiated on-demand routing protocols. The aforementioned routing protocols are creating routing paths only when requested by the source node. When the nodes require a routing path they trigger the route discovery procedure in order to create a connection between the source and the destination node. The route discovery process continues until the routing path has been structured or all the possible combinations of nodes provide the most efficient routing path. Once the routing discovery procedure finishes, the routes have to maintain. The maintenance procedure takes place as long the request from the source node remains or the communication between the source and destination node is inaccessible. Advantages of the reactive routing protocols are the adjustment on topological changes and the minimised of overhead caused by the control messages. The major disadvantage of the proactive routing protocols is the overhead produced during the routing discovery procedure and by the ability to choose the most efficient path (Jacquet 2001).

2.2.3 The hybrid routing schemes

Finally, the hybrid routing schemes are a combination of proactive and reactive routing protocols. Hybrid routing protocols are trying to leverage the advantage features of both proactive and reactive routing protocols. Mostly the hybrid routing protocols are utilising a proactive algorithm within local clusters of nodes and a reactive algorithm between clusters. Hybrid routing protocols are used in large networks.

2.3 Routing protocol types technique

A numerous of ad-hoc wireless protocols have been developed however only four protocols will be considered for the following research. Brief information about the DSR, AODV, DSDV and OLSR routing protocols operation will be provided.

2.3.1 Source routing

Dynamic Source Routing (DSR) is one of the leading routing protocols for ad-hoc wireless networks and is listed as reactive. The main mechanisms of this protocol are the route discovery and route maintenance. Route discovery algorithm provides the path discovery under the request of the source node and then stores the information on the source caches. As in the second procedure, the protocol maintains the source caches. DSR is utilising shortest path policy to determine the best routing procedure of data packets in the network. If a new path has been established or an old path has broken then the routing caches rearrange the shortest path. Route caches have been developed to prevent the early overflow of the network, overhead of the system and the end-to-end delay (Yadav 2012). Saleh, Saman, and Rahman (2013) have optimised the prototype DSR protocol in order to create a better policy on the shortest path selection, as they discover of the failure of the prototype protocol to select an alternative path in cases where the primary route was not available. On the other hand, if the route path is not established yet, it initiates the route discovery by broadcasting a “route request” packet. The packet contains the address of the destination combined with the source node’s address and unique identification number. When the nodes receive that packet if they do not have that entry in their cache they updated and then they forward the packet to their neighbours. The propagation happens only when the destination node is not discovered by any of its neighbours as a result to limit the requests. The requested packet contains a route record of all the appropriate hops that required until they reach destination node.

A route reply packet is generated when the requested packet has reached the destination node, or if an intermediate node contains the path for the destination node in its route cache. The responding route may use the initiator of the route cache if the route is contained. Otherwise, if symmetric links are supported the responding node may reverse the route from the requested packet. In case that the symmetric link is not supported, the responding node starts a new discovery mechanism.

The route maintenance mechanism utilises the route error packets and acknowledgments. When the data link layer encounters a serious transmission problem then the error packets are generated at a node. The error packet contains the information about the fatal node in the network. When the nodes receive the error packet, they are informed about the broken link and remove the hop from their cache. Error route messages and acknowledgments are also helping on the verification of the corresponding links. The acknowledgments are also including passive transitions in order for the nodes to be able to overhear the nearby hop's packets (Saleh et al. 2013).

2.3.2 Distance Vector routing protocol

2.3.2.1 Destination-Sequenced Distance-Vector (DSDV)

DSDV is a table-driven routing protocol and its algorithm is based on Bellman-Ford routing mechanism. The particular mechanism has been improved in such a way to provide free loops abilities in routing tables. The nodes in the network maintain the routing table with the entire possible destination in the network and record the required number of hops for each destination. Table entries are including a sequence number which has been provided by the destination node, in order to distinguish the already known routes from the new ones and avoid the routing loops. The maintaining procedure of the protocol is updated by using periodically transitions through the network nodes (Effatparvar 2010).

The avoidance of overloaded traffic during the update is achieved with the employment of two types of packets. The first packet is known as "full dump" and is responsible to carry all the available routing information. In addition, required multiple network protocol data units is utilised during the procedure (NPDU). In case of movement scenario, the aforementioned packets are transmitting occasionally in order to avoid the transmission failure. The second type of packet is smaller in size than the full dump packet and is responsible to update only the specific information that has been changed since the full dump transmission. The smaller incremental packets are developed in such a way to fit into the NPDU, as a result, to provide a less bandwidth consumption. In addition, the nodes are structuring the second table, as they store the data, which sent during the incremental routing information packet procedure.

The routing broadcast contains the address of the destination, the required number of hops to reach the destination, the new and the already known sequence number of information. The routing protocol utilised the most recent sequence number for the routing path. The sequence number provides a metric number to compare the new and the current sequence for the specific destination route, in order to choose the shortest path and update the table if it is needed. Furthermore, metrics such as settling time of routes or calculations of the average time that it will take to reach the destination route are considered for the election of the path.

2.3.2.2 Ad-hoc On-Demand Distance Vector (AODV)

AODV is categorised as reactive routing protocol which is built on DSDV algorithm. The improvement of the protocol is achieved with the minimisation of the required number of broadcasting by creating routes only when is desired by the source node. AODV routing protocol described as pure on-demand acquisition system, as the routing protocol does not require maintaining the routing information in the network as the DSDV (Effatparvar 2010). The procedure of route discovery in the network begins when the source node sends a message to a destination node without having a valid table route for the destination node. The location of other nodes is archived by broadcasting route request (RREQ) packet to the neighbour nodes. The neighbour nodes are forwarding the packet to their neighbours until the RREQ packet reaches the destination or a node has already addressed the route for the specific node from an earlier discovery procedure. In order to ensure that all routes are loop-free and they are containing the latest version of the route, the nodes are maintaining a destination sequence number and broadcast ID. The RREQ packet is uniquely identified by the node’s IP address and a method which increases the broadcast ID for every forwarded RREQ packet created during the discovery procedure. The source node includes a sequence number which specifies the latest version of the generated message. The link nodes are allowed to reply to the RREQ only if they have a root for the seeking node.

The linked nodes are developing their own route tables during the forwarding procedure. The routes with the longest path are discarded. When the destination node has reached it responds with a unicast route reply (RREP), which completes the discovery procedure. A route timer is utilised in route entry in order to delete the inactive path. Furthermore, in case of the movement of the source node a new discovery procedure takes place. On the other hand, in case of any other node moves away and the neighbour node notices a link failure, a notification message is contacted to inform the state of the route in the network.

Finally, periodically, a Hello message is contacted in the network in order to inform the nodes about their neighbours in order to maintain the local connectivity of the nodes. The Hello message is not required if the nodes have listened to a retransmission of data packet. Those techniques are used to ensure that the next hop is reachable.

2.3.3 Link state routing protocols

OLSR is a proactive routing protocol for mobile ad-hoc networks based on the link state algorithm. One of the main characteristics of this protocol is the way that maintains the topology information of the network by utilising periodic exchange messages. The aforementioned messages provide a compact size of data and reduction of the retransmission in the network. The protocol achieves its stability due to its inheritance of the link state algorithm. Since the OLSR protocol is categorised as table-driven the route availability is instantly when it is needed (Guizani 2012).

The protocol is an optimised version of the link state algorithm developed for the mobile ad-hoc networks. There are two procedures as the protocol operates. Firstly, reduces the size of the controlled packet by assigning a subset of links with its neighbour's nodes which are known as multipoint relay selectors (MPR). Secondly, reduces the flooding of the controlled traffic with the assigned nodes. In other words, the retransmission of the message in the network is provided by the multipoint relay nodes as a result to reduce the broadcast messages in the network as well as the overhead (Zheng 2008).

OLSR has been developed in such a way to be independent of any central entity. The requirement of a reliable transmission of the control message is not necessary because of the periodically control messages that send it by every node in the network. Collisions are avoided due to the mechanism that utilises a sequence number on every message that has been sent. In addition, by the sequence number, we can determine if the message is recent or even if has been retransmitted (Jacquet 2001).

MPR selection: Is the mechanism that is responsible to link every node in the network. Each node calculates its own set of MPRs as a subset of their symmetric neighbour nodes which have the maximum distance of 2 hop neighbours. All the nodes should be able to reach each other through the MPR (Malik 2012). The benefits of the mechanism are to provide an easy access to the topology of the network even if they have changed the reduction of maximum interval time of the periodic control message transmission. Furthermore, the routes are maintaining continually to all destinations in the network, which is the best suitable option for a large network as scalability is one of the main advantages of this protocol (Busson 2005).

2.4 Discussion on OLSR

On the previous section, the project identifies some of the techniques used for the operation of four prototype routing protocols. In Chapter 4, the research expands its knowledge over the utilisation and performance of these protocols. Based on those two research techniques the project was led to focus on the improvement of the OLSR routing protocol. The author based on RFC 3626 which is the standardised draft for the OLSR routing protocol identified that the protocol is able to connect to the Internet because of its gateway and backbone capabilities. However, the utilisations of those abilities are limited. OLSR was designed to share information over a single channel in a given network and exchange information over the Internet if requested. Since the data transfer between the nodes in the network takes place through a single channel the protocol is likely to face significant throughput degradation as the number of active nodes and load increases. The challenge is to design a routing protocol which will be able to provide Internet of Things (IoT) in the network.

2.4.1 Application Scenarios

In this section, the most appropriate application scenarios that BIC-OLSR can be utilised will be revealed.

- As mentioned earlier in this Chapter, MANET's initially developed for military communication on the battlefields. BIC-OLSR routing protocol would be an advantage on military operations and communications. In cases that some of the main group leader nodes have been provided with satellite Internet access, they will be able to provide data to the member nodes (Pullin and Pattinson 2008).

- The utilisation of the protocol among with wireless sensors in order to track environmental applications such as tracking animal behaviour, detection of chemical and weather changes, will be the most appropriate use (Puccinelli and Haenggi 2005).
- The protocol will be beneficial for public Internet access as the users would be able to connect their devices through technologies to the Internet access points (Bruno et al. 2005).
- BIC-OLSR would be beneficial on emergency services where a catastrophic disaster occurs such as earthquakes, hurricanes, tsunamis etc. as it will be easy to retrieve the network infrastructure in the area (Lien et al. 2009).

2.4.2 Related work based on MPR selection scheme of OLSR

MPR selection algorithm is the key feature of the OLSR protocol; therefore, researchers have suggested various improvements. Romanic et al. (2016) have developed resources aware routing protocol based on optimised link state routing protocol called RESA-OLSR, which is designed for military operations. The routing protocol targets reliability and lifetime of the network by calculating the node performance metrics from local resources such as battery level and available bandwidth. The bandwidth estimation is done in the MAC layer for each node separately. This metrics are calculated and globally used to define Willingness value. The Willingness of each node is broadcasted through Hello messages which are providing the information to neighbour nodes to select MPR's. Their research was simulated on OMNET++ network simulation tool. Their study focuses on the number of dead nodes by the end of simulation time, the maximum lifetime of the network and packet delivery ratio based on various node mobility scenarios. The authors compared the prototype OLSR with the RESA-OLSR in three different states of weighting battery and traffic load. The results have shown that the results of networks life are 25% to 30% when the traffic load weighted 70% and the battery 30% and it is increasing as the weight of the battery state valued for more percentage. On the other hand, when the traffic load was weighted less than the battery, the packet delivery ratio of RESA-OLSR was slightly lower than the prototype OLSR. RESA-OLSR would be better balanced if the weighting of battery and traffic load changed during network procedure as the battery level is low or important traffic comes along.

A group of researchers (Boushaba et al., 2012) have managed to decrease the number of TC messages by extending the vision up to three hops of neighbour nodes while they are selecting MPRs. Their study comes across over two variants of calculating the degree of isolated nodes or the nodes that could not be assigned as MPR nodes which are called absorbed degree variants. In order to forward the information on neighbour nodes, they have included the absorbed degree in the Hello messages and they have extended the local resources of each node to withhold this information. The absorbed degree is utilised in the MPR selection as an extending parameter when two nodes have the same matching criteria to be selected as MPRs. Their research was simulated on NS2 simulation tool on a mobility scenario and compared the prototype OLSR, the OLSR with isolated nodes variant and the OLSR with non-MPR variant. The TC messages have reduced in both suggested variants by the authors with the isolated nodes variant to perform better. The routing cost of the network has shown also improvement of the encashment OLSR. At last the network efficiency of the modified OLSR routing protocols has been improved compared with the standard OLSR. The downside of this methodology is the increase of the discovery and maintenance messages size which will reduce the battery lifetime of the network.

Li et al. (2008) have approached the TC message overhead of the OLSR differently. They have developed the necessity first algorithm (NFA) for the selection of MPRs in OLSR. NFA reduces the MPRs and the TC messages by giving priority to creating clusters with nodes which can connect with only one neighbour node. The procedure is called “necessity of selecting”. When the MPR is selected the algorithm deletes the covered nodes to reduce the overlap with other clusters. The authors have utilised OPNET simulation tool to compare the NFA and greedy OLSR algorithms. The results revealed that the NFA algorithm reduces MPR nodes between 2% and 11% compared with the greedy algorithm. In addition, the number of NFA’s TC messages has been reduced more than 7.6% compared with the greedy algorithm. The reduction of MPR nodes and TC messages will increase the battery efficiency of the network as the algorithm prioritising the necessary nodes over the quality nodes.

Koga et al. (2009) focused on QoS efficiency of the OLSR. They have studied the drawbacks of the OLSR during the MPR selection procedure. Based on QOLSR (Quality-OLSR) routing protocol they have introduced three high efficient MPR selection procedures. QOLSR utilises an additional MPR procedure called QMPR (quality multipoint relay) which focuses on selecting the best QoS path for data transmission. The researchers have altered the QMPR selection to EMPR (efficient multipoint relay) to increase the efficiency of the protocol. The first EMPR selection scheme is called MIMS (maximizing integration metric selection) which focuses on achieving maximum QoS performance with lowest maintaining cost. The second EMPR selection scheme is named MQES (maximizing QoS-efficiency selection) which aims to improve the QoS effectiveness of each EMPR. The final EMPR selection scheme is introduced as MCIS (minimizing cost-inefficiency selection) which eliminates the inefficient EMPRs to decrease the maintenance cost and increase the QoS performance. They have utilised the NS-2 network simulation to evaluate the performance of the OLSR, QOLSR, MIMS, MQES, and MCIS based on throughput, average number of MPRs, average number of TC messages and efficiency. Throughput evaluation reveals that the QOLSR and MCIS have the best performance. The number of MPRs and TC messages has been reduced on the researchers’ protocol compared with the QOLSR. In addition, the efficiency of the MIMS, MQES and MCIS routing protocols has increased compared with OLSR and QOLSR.

On the other hand, the authors Kunavut and Sanguankotchakorn (2011) developed a weighting algorithm based on connectivity index (CI) and delay called Shortest-Highest algorithm. Their algorithm improves QoS without additional MPR procedure as the QOLSR. By utilising the native MPR procedure they have minimised the MPRs and the TC overhead of the network. The authors have modified Randic index algorithm which is used as a topological index for molecular attributes to define the best path considering the link capacity and link connectivity. The Shortest-Highest algorithm takes place in the MPR selection procedure when one or more two hops nodes are not covered by an MPR. The algorithm selects the highest weighted CI and shortest delay link as MPR for the node. In case there are two nodes to act as MPR with the same weighted value the node which covers the maximum number of uncovered nodes is chosen. The authors have utilised NS-2 simulation tool on a mobility environment and they have tested throughput, PDR, the end-to-end delay and control overhead to compare Shortest-Highest with additional MPR, Shortest-Highest with native MPR and prototype OLSR. The Shortest-Highest algorithm provides better QoS over the OLSR in terms of throughput (18%-27% increase), delay (30% decrease) and PDR (9%-17% increase) with the additional MPR procedure leading them metrics. The OLSR and Shortest-Highest with native MPR have almost identical control overhead which is 14% less than the Shortest-Highest with additional MPR.

Ahn and Lee (2014) have identified the downside of reducing duplicated retransmission in OLSR. They believed that OLSR is vulnerable to packet errors, collisions, and hidden nodes. Therefore, they proposed an MPR selection method for robust broadcasting over the OLSR. Their proposed method selects eliminates the poorly covered nodes by utilising additional MPR nodes in order to cover 2 hop MPR nodes several times. The researchers have simulated a static environment for studying throughput, the end-to-end delay, PDR and forward efficiency. The results of the study show that the throughput and PDR have been improved compared to the prototype OLSR. The number of the MPR nodes and the TC messages are also increased and that is the main reason that forwarding efficiency has been reduced.

2.5 Internet Connectivity for MANET's

MANET is described as an infrastructure-less network which can be applied to emergency situations or situations that developing an infrastructure network is not applicable. Involving Internet connectivity onto those networks is an advantage as we are gaining a more flexible environment on our network. The interests of connecting MANET's to the Internet have increased the recent years. The implementation of Internet connection on MANET's should be carefully organised the route discovery to the Internet might affect the route discovery abilities of the internal network.

There are two ways that Internet access to the network can be provided. The first Internet connection can be deployed by having a based station to our network which is connected wire connected to the Internet Service provider and can act only as a gateway to the Internet. Therefore, the nodes in the network will be able to connect to the Internet if they requested. The second way of gaining Internet connection and which this project studies, is the scenario where the nodes are able to connect to the Internet by its self. For example, a laptop which provides two interfaces wireless and wired connection or a smartphone with Wi-Fi and cellular (2G/3G/4G/5G) interfaces. Both examples could be utilised as a gateway for Internet and can provide this feature to other nodes in the network. Some of the issues which are addressed with Internet-connected MANET's are the addressing of the gateway, load balancing of the network traffic, efficiency of the gateway discovery by other nodes in the network, network's security and the use of efficient routing packets (Zaman et al. 2014).

2.5.1 Related work based on Internet Connectivity for MANET's

The Internet connectivity for MANET's has concerns researchers to develop the technology on various ad-hoc wireless routing protocols. The improvements made by these years will be discussed in this section. Sun et al (2009) have realised the benefits of Internet connection on MANETs, therefore have introduced a new protocol called MG-

OLSR (Mobile Gateway OLSR). MG-OLSR utilises a proactive Mobile IP to connect mobile nodes to the Internet through multiple gateways. They manage to reduce the Mobile IP broadcast by modifying the HNA messages to broadcast the gateway announcements. They modified the Hello messages to varying when an MG broadcast it and, in this case, the Hello messages extend its hop. In addition, carry's the information of node energy, the number of waiting packets, the number of registered MANET nodes and the mobility of this MG which are preserved additional 32-bit on the message. The TC messages have also been modified to send an additional TC message whenever an MG is in the neighbour who includes all the necessary information of the MG in order to weight the metrics and choose the MG to register the nodes. The simulation results have shown that MG-OLSR has reduced the overhead of Mobile IP in the network compared with the prototype OLSR in terms of a number of gateways and mobility. However, the Hello, HNA and TC messages have increased the carried data size to serve the protocols needs.

Yan et al. have study OLSR connected to the Internet and they realised gateways which provide internet access to the network cannot handle a large amount of data and that causes congestions to the network. They developed a new load balancing routing algorithm on OLSR called LBRA which aims to balance the traffic load. The load traffic load is defined by the gateways load balance factor (GLBF) which evaluates the available bandwidth of each gateway. The LBRA is utilising the shortest path method to provide to member nodes the shortest path to their gateways. When the gateways remaining bandwidth is not enough, is revise GLBF to distribute the traffic to another gateway and increases the routing path length. The simulation revealed that LBRA has provided a better distribution of traffic load by utilising multiple gateways and have a better restriction in terms of the increase of routing path compared to the shortest path routing algorithm. The LBRA should utilise a method which will prioritising the large traffic as there is a risk to overhead the network when a large amount of data is utilised the increased path.

Zaman et al. have studied the Integrated Internet MANET (IIM) which are mainly hybrid routing protocols whereas is utilising wired Internet-based stations in order to provide Internet to host nodes. The researchers have addressed the issues of load balance in the network and gateway discovery as one problem. They approached these issues by modifying Weight Load Balance - AODV (WLB-AODV) routing protocol. Their protocol controls the load balance of the network and by the utilisation of Mamdani Architecture for Fuzzy Control are managing the parameters to identify the most efficient gateway with the gateway advertisement messages (GW_ADV). The gateways discovery is divided on the adjustment of TTL value, and the maximum source coverage with the GW_ADV messages. The gateway load balance algorithm weights the number of hops, the aggregate routing table entries and the aggregate interface queue length. Each parameter is evaluated differently based on triangular function. The authors have compared the modified routing protocol with the original WLB-AODV over the NS2 network simulator. The proposed protocol has improved the end-to-end delay, PDR, and the routing load compared with WLB-AODV. The protocol has shown improvement, however, could achieve better results if the triangulation of the parameters occurs dynamically according to the needs of the traffic load.

2.6 Quality of Service

Quality of service (QoS) can be defined as measurement criteria of service of a particular transmission data in the network. The network should be able to support a set of measurable results of service attributes to the users in terms of end-to-end performance in matters of delay, bandwidth, the reliability of delivered packets, jitter and power consumption. Some of these challenges in order to provide a desirable QoS results are discussed as follows.

The topology in mobile ad-hoc wireless networks expected to be dynamically in order to provide to the user the mobility attribute in the network. Therefore, the development of the protocol for the specific result is difficult to provide guaranteed results.

The desirable protocol or scheme of development should be light-weight because the resources of the devices are limited. For example, the protocol has to provide low power consumption, simple in computational algorithms during the transmissions and overheads avoidance of the network (Sarkar et al. 2007).

2.6.1 QoS in Different Layers

Application layer: Is responsible for the data flow of the packet in the network by requesting particular Class of Service (CoS). The layer is also responsible to adapt the CoS according to the network state in order to prevent the failure of the data packets.

Session or presentation layer: Acts as classifiers to separate the different CoS and map data belonging in order to prepare the data queues for the transport layer.

Transport layer: Distinguishes the services with higher CoS priority and maps into three CoS to different network layer channels.

Network layer: Provides different routing mechanism for each CoS and send the data in three different queues into the data-link layer.

Data-link layer: Utilises differences for each CoS according to the criteria faster, better, and assured service. In other words, provides an error-correction and decides if the specific data is deliverable.

Physical layer: Supports a better error-correction that the data-link layer. The layer is able to change the modulation scheme according to the state of the channel. Therefore, even when the channel bit error rate (BER) is high, it is still capable to provide services.

2.6.2 Quality of Service (QoS) Routing

The routing scheme development with guidelines of QoS for ad-hoc wireless networks usually consists the optimisation of hop distance metric. Therefore, most of the developers are focusing on the shortest path. However, the shortest path might be sufficient for the datagram traffic. The nature of the MANETs provide wireless links environment where are self-organised, typically scare and dynamic. Consequently, the utilisation of efficient recourses or the executions of real-time applications is challengeable in those environments. The development of a QoS routing support is mandatory in order to control the total traffic transmission of the network. The routing mechanism is choosing which routes are determined, by instructing the resource availability in the network, along with the QoS requirements.

The QoS routing could be defined as the selection of routes with sufficient resources for the requested QoS attributes. Each data transmission in the network is different, and that is the main reason for considering multiple constraints and allocates traffic on different paths, according to the QoS requirements (Kaaniche 2011). On the other hand, bottleneck issues have been revealed on routing traffics because of the selection of the shortest path. The most important criteria for are the following:

- most reliable path
- most stable path
- maximum total power remained path
- maximum available bandwidth path

2.6.3 Challenges to Be Faced on QoS

Varying physical link properties: Is difficult to ensure the minimum level of QoS because the wiles link is unpredictable and occurs in different periods.

Medium access issues: Issues occur while applying the QoS policies because the wireless channel is shared with multiple nodes and is difficult to manage them.

Routing: The mobility of the network causes frequently changes at the topology of the network. Therefore, the routes and the links are required to update.

Power consumption: Power consumption has to be considered, because the mobile nodes are having limited power capacity.

Characterization of the link state: A prediction and detection mechanism is required in order to define the network state at any time.

Dynamic topologies: Are difficult to provide guaranty results because of the nature of the nodes to move arbitrarily (Granelli 2007).

2.7 Network Simulator

Designing a new ad-hoc wireless protocol is a complicated task not just because its complexity to develop new algorithms but also it is difficulty in simulating multiple scenarios in the real world. The application of the mobile nodes can be used in multiple areas. There are a number of network simulators related to ad-hoc wireless networks.

2.7.1 NS2 and NS3

In order to develop a new protocol event-driven simulator is required especially for research in computer communication networks. The most commonly used network simulators are the NS2 and the newest edition is NS3.The simulators are running on UNIX operating systems (OS). Techniques such as virtual machines and Cygwin are allowed to the simulator to run on Windows operating systems.

NS2 is an open-source application, which has been utilised continuously to serve different purposes by industry, academic, and government. The simulator includes all the appropriate network components that are required for the development of a new protocol. The simulator consists of two key programming languages. The NS2 is utilising C++ and object-oriented tool command language (OTcl). The C++ defines the internal mechanism of the simulation objects, while the OTcl sets up simulation by assembling and configuring the objects as well as the discrete events. TclCL is utilised in order to combine the C++

and the OTcl. The computations of the simulator may be returned as text-based or animation-based. The animation-based environment has been achieved with the tools of NAM (Network AniMator) and XGraph where they represent the results of the simulation geographically and interactively. Analysis of the particular network can be achieved by exporting the data of a specific subset of text form. Another key feature of the simulator is the export of “pcap” files where can be utilised by network monitor applications such as Wireshark (The Network Simulator, 2014).

2.7.2 OMNET++

OMNET++ is a commercial simulator, however, is more powerful than NS2. OMNET++ is a C++ based discrete event simulator for modelling communication networks and other distributed or parallel systems. The OMNET includes an Integrated Development Environment with a graphical editor, which is utilising NED as its native file format. It also has animation and tracing ability in order to monitor the results of the simulation (Omnetpp.org, 2017).

2.7.3 MATLAB

MATLAB is a commercial simulator and is optimised in such a way to help engineers and scientists to solve their complex problems. MATLAB is a script and matrix-based language which provides a natural way of expressing mathematical computations. As the NS2, NS3, and OMNET, MATLAB has integrated libraries for animation and graphical representation of the data. (Uk.mathworks.com, 2017)

2.7.4 Summary

The project will initially utilise the NS2 in order to compare the four prototype routing protocols discussed in Section 2.3 as the protocols are already included in the libraries of the simulator. However, for the development of the new routing protocol, the project will be based on MATLAB.

2.8 Summary

A routing protocol is a vital factor for the performance of a network. In this Chapter, we have discussed some routing protocols and their ability to overcome some weakness of the network. Each routing protocol discussed in this Chapter has it is own purpose as the network state regarding mobility and data usage are the main factors of utilising the right protocol in each case scenario. Discussion over the selected protocol and its prior research has been revealed in Section 2.4. Furthermore, the project utilises Internet connectivity therefore further information regarding prior projects has also been exposed. A strongly structured routing protocol has to maintain its Quality of Service as analysed in Section 2.6 regarding the different layers, on routing scheme, on MAC protocols and challenges to improve QoS. At the final section, the author provides information about the simulation tools that can be used in order to develop a new routing protocol and to evaluate prototype routing protocols.

Chapter 3 - Methodology

3.1 Introduction

As all the long-term projects included this one is based on milestones and targets in order to move forward and achieve the most appropriate results. The following Chapter includes a detailed explanation of the methodology was used in order to accomplish the development of the new protocol suggested in previous Chapters. The author decided to follow this particular methodology after careful consideration of the literature already in place as presented in Chapter 2.

3.2 Approach to development

The starting point contains the analysis and comparison of the current multiple access network protocols in wireless ad-hoc networks based on prior research by other authors and by lab-based research performed by this case study. In addition, they provide a discussion on the limitations of the services and improvements that can be made.

3.2.1 Background research

In this section, the author analyses the structure of the case study based on the secondary research located in the Literature Review. In addition, the author provides information about the considerations that have been taken, along with his justifications in order to develop the new protocol.

Secondary research participates partially in the Introduction Chapter and in the Second Chapter. The demand of the industry of new protocols has been described. The aims and objectives in the Introduction Chapter, it was to familiarise the readers in order to understand the nature of the network and the impact of the QoS while the network and data size grows. The first section of the Literature Review provides an overview of ad-hoc wireless networks. The specific section describes, in brief, the capabilities of the autonomous network and the manipulation of the data traffic by the routing protocols.

In the second section of the Literature Review, the author categorised the routing protocols based on their abilities to identify the nodes in the network. The three categories are categorised in such a way to reveal the purpose and topology of the network. The author provides this information on his thesis to familiarise the readers with basic information over the ad-hoc wireless networks. On the next section, the author has carefully chosen one of the prototype protocols to take into consideration for the development of the new protocol. The DSDV, AODV, DSR, and OLSR are among others the foundation of routing protocols in ad-hoc wireless networks (Hamatta 2014). The reader will be familiarising with those four routing protocols according to their operations such as route discovery, selection of shortest path and maintenance of the route. At the end of this section, the author extracts the advantage and disadvantage, in order to evaluate and analyse the previously described protocols.

Based on prior research and lab-based research the author concludes to focus on OLSR routing protocol. Therefore, the author expands projects knowledge regards the OLSR routing protocol along with some justifications why studied the particular protocol. During the aforementioned section, the author reveals some applications scenarios that the OLSR will be useful in humanity. During the discussion based on OLSR, the project provides information regards the improvements that prior research made by the years and how the newly developed routing protocol targets similar improvements. The case study focuses on Internet connectivity on MANET’s, therefore on next section, the project includes the benefits of Internet connectivity in those environments along with some related projects made on other routing protocols.

During the analysis of the prototype protocols have been provided a brief discussion about the QoS metrics such as overhead, traffic delay, scalability etc. At this point of secondary research, the author reveals some limitations that have been marked by other research projects. However, a clear view of the limitations will be presented in a different Chapter of the case study. The prototype routing protocols have to be evaluated according to the QoS metrics. At section five of the Literature Review, the author explains the definition of QoS, along with their operations over different layers. The author provides information about the routing scheme by following the QoS requirements (Kaaniche 2011). The most important factors of the routing algorithm according to the requirements are also presented. Furthermore, major issues such as hidden and exposed terminals are mention, in order to familiarise the readers with the limitations of routing protocols as they do not support collision avoidance scheme. In addition, some of the project challenges that the author will be considered, during the development of the new protocol are revealed.

At the last section of the Literature Review, the author provides information about the network simulators. The tool places critical part of the case study, as it will be utilised to create the environment of the network and represent the data transmission over the prototypes and proposed routing protocols. Under a small research, the author has decided to use the NS2 for network simulator because the prototype routing protocols that the lab-based research are included. NS2 supports C++ combined with OTcl. The NS2 will be utilised only for the comparison between the prototype routing protocols, however, the development of new protocol will be on MATLAB among with the chosen prototype protocol.

3.2.2 Lab-based research

At this point of secondary research, the author created a lab-based network environment whereas the prototypes protocol will be analysed and compared. In order to develop a new protocol or to provide a new function on the prototype protocols, the specific procedure must be completed. The author cannot apply any research that has been made by previous research projects as he will not be able to provide the same environment as the other projects.

The environment has to be customised according to the needs of the project. As mentioned on the literature review an investigation according to the DSR, AODV, DSDV and OLSR protocols has to be provided in order to move on the development of the proposed protocol or the proposed function which can be developed on the prototype protocols. The configuration of the environment according to the author’s aspirations will be based on the IEEE 802.11 standard.

In order to create the ideal environment for the research project the following parameters will be considered and configured:

- Routing Protocols

- Simulation Time
- Traffic Type
- Maximum Connections
- Transmission Rate
- Packet Size
- Pause Time
- Number of Nodes
- Network Area
- Interface Queue

As the parameters have been configured and the environment is ready to run, the four prototypes routing protocols will be evaluated with the performance metrics. There is a variety of performance metrics which are used to analyse the networks however in this project we will use only six of them (Khiavi 2012). The metrics are the following:

- Packet Delivery Ratio:
- End-to-End Delay:
- Throughput:
- Packets Dropped:
- Received Packets
- Generated Packets

The author will utilise the trace file produced by the simulation of the scenarios in order to produce the metrics in a simplified format. The metrics are represented in tables whereas will be analysed and supported with a conclusion for each routing protocol in each phase. Finally, the author will provide all the limitations on the prototype protocols and his considerations for improvements by designing a new protocol.

3.3 Simulation Methodology and model

The project utilised NS2 simulator for the comparison between the prototypes routing protocols however the development of the new protocol will be created with MATLAB. In this section of Chapter, three main configurations will be taken into consideration, the network environment, application model and performance metrics.

3.3.1 Environment model

The importance of the measurement criteria of the QoS in deferent layers has been given in order to achieve the maximum performance of the routing protocol in the network. The new protocol is difficult to outperform all the current protocols metrics, as each protocol provides a unique technique of data transfer which is more likely to perform better in specific scenarios.

In this Chapter, the author has to prepare a variety of case scenarios whereas ad-hoc wireless networks could be implemented in a network. In those case scenarios, the author should be able to demonstrate some of the issues that have been operating better than the other protocols as the issues that have not (Ezreik 2012). The issues that are commonly appearing in the ad-hoc wireless network are the followings:

- Varying physical link properties: Is difficult to ensure the minimum level of service according to the QoS because the wireless link is unpredictable and occurs in different timelines.
- Medium access issues: Issues occurs while applying the QoS policies because the wireless channel is shared by multiple nodes and is difficult to manage them.
- Routing: The mobility of the network causes frequently changes at the topology of the network. Therefore, the routes and the links required to be updated.
- Characterization of the link state: Prediction and detection mechanism is required in order to define the network state at any time.
- Dynamic topologies: Is difficult to provide guaranty results because of the nature of the nodes to move arbitrarily.

As we mentioned earlier the parameters of the environment that have been creating by utilising the environments scripts files will change in order to evaluate the protocol under certain conditions. For example, a possible scenario is to change the number of the given nodes in order to define the performance of the protocol under the heavy or light user interference. A second possible scenario is to change the transmission time in order to clarify the operation of continually data traffic through the network. All the parameters that have been given for the structure of the environment are vital for the use of the protocol in real-time data traffic. The author should be able to specify the appropriate configurations and environmental scenarios in order to achieve the maximum performance of its network. For instance, if the network shows overhead during the data transferring procedure the protocol developer should change the parameters as the transmission rate in order to achieve a more stable connection between the nodes.

3.3.2 Application Model

The second part of the methodology it will be the design of the protocol which includes the specification of the algorithm, implementations, and recommendations of the traffic management approach. Mathematical models will be used for the creation of the algorithm.

3.3.2.1 Designing the algorithm

The author has considered possible ways to implement the new protocol. In this Chapter, the author provides mathematical models such as Dijkstra's, Bellman–Ford and State Link algorithms which are able to find the shortest path in the network (Royer 1999). The project needs to identify the most suitable structure of the routing scheme in order to utilise all the abilities of the nodes in the network to increase the performance. As we mentioned earlier each routing protocol technique is used for different purposes and they are associated with specific environments. As the algorithm for the protocol has been developed a more detailed explanation and justification for the central idea of the algorithm will be given.

The implementation of the algorithm will be supported with MATLAB libraries as it is required to embed the new protocol. The nature of the new algorithm requires a file to keep the routing scheme of our network. As we mentioned in the literature review DSDV and OLSR categorised as a proactive routing scheme which is utilising table in order to provide the routing information to the nodes. On the other hand, similar implementation can be adjusted on the reactive routing scheme by providing a cache file, as has been utilised on the DSR and AODV routing protocols. The author will also be in the position to answer the question in that critical part of the implementation.

3.3.2.2 Implementation of the algorithm on the Network Simulator

In the literature review, the author has specified the utilisation of the MATLAB as a network simulator to support the development of the new protocol. MATLAB is the least chosen path on ad-hoc wireless routing protocols, and the reason is they have not embed any routing protocols, the creation of the prototype and new protocol files are needed to embed on the simulator. MATLAB provides mathematical libraries which will support the implementation of the new algorithm, as well as the creation of the new protocol.

3.3.2.3 Performance Metrics

Similar to the NS2, we will utilise a trace file on MATLAB which will record all the procedures during the simulation in order to extract the performance metrics. Therefore, we will use another script file from MATLAB to process the most valuable information from the script file for the export of the following metrics:

- Packet delivery ratio
- End-to-end Delay
- Data throughput
- Controlled packets
- Packet Loss
- Packet dropped

3.4 Simulation Results and Discussion

In Chapter 6, the project will evaluate and test the routing protocols. In this stage, a number of test cases and scenarios will be developed and experimented on in the prototype system. In this Chapter, the author provides a sequence of cases in order to test and evaluate the new protocol. The author will choose the most appropriate data which has been collected through the network simulator. The data from MATLAB is provided by text files and by the animation libraries.

The author will provide an objective metric review according to the facts of the results of the evaluation and testing results. However, because the routing protocols appearing to reveal more issues during their operations on heavy load data traffic a subjective metric opinion of the author also will be given. Tables and graphs will provide the comparison among protocols and in some cases in more detailed data presentation of the newly developed protocol. The metrics the comparison will focus are the followings:

- Packet Delivery Ratio: Packet delivery ratio is the ratio of the number of packets received at the destination nodes to the number of packets sent from the source nodes. The performance is better when packet delivery ratio is high.
- End-to-End Delay: End-to-end delay is the average time delay for data packets from the source node to the destination node. To find out the end-to-end delay the difference of packet sent and received time was stored and then dividing the total time difference over the total number of packet received gave the average end-to-end delay for the received packets. The performance is better when packet end-to-end delay is low.

- Throughput: It is defined as the rate of generated packets through the network delivered from the source to the destination node and vice versa over the simulation time (Rohal 2013).
- Packets Dropped: Dropped packets are the amount of data packets that have been discarded from the receiving node.
- Received Packets: Received packets are defining the number of packets that have been received by the destination node.
- Generated Packets: Generated packets are the amount of data packets generated by the source node.

All the information of the testing will start with an explanation of the current test performance and conclude with final thoughts.

3.5 Summary

This Chapter has been structured in such a way that the readers will be able to understand the reasons behind the structure of this research. Chapter 3 has provided all information based on the secondary research and how the project will move on the primary research. Secondary research provides prior research and a lab experiment where the prototype routing protocols (AODV, DSDV, DSR, and OLSR) are compared with NS2. Primary research consists the design of BIC-OLSR protocol with its key features and experiments based on QoS between BIC-OLSR and OLSR routing protocols. Furthermore, the lab research metrics regarding the QoS criteria have been defined.

Chapter 4 – Analysis between the prototype protocols

4.1 Introduction.

During the Literature Review, the author provided information regards the characteristics of each routing protocol developed for MANET's. As part of the secondary research, the project required a performance measurement of each routing protocol running under specific conditions. As mentioned in previous Chapters each protocol provides a unique solution based on the environment of the network. This Chapter intention is to reveal some of the protocol characteristics over a lab experiment which is simulated with the NS2 network simulator. By this analysis, the project is demonstrating strong and weak features of the protocols and leads the project to focus on one routing protocol in order improve it.

The Chapter includes basic network environment information of the NS2. Furthermore, will provide discussion on each QoS metric gathered from the routing protocols and reveal them in tables. Finally, an overall performance discussion between the prototype routing protocols will take place.

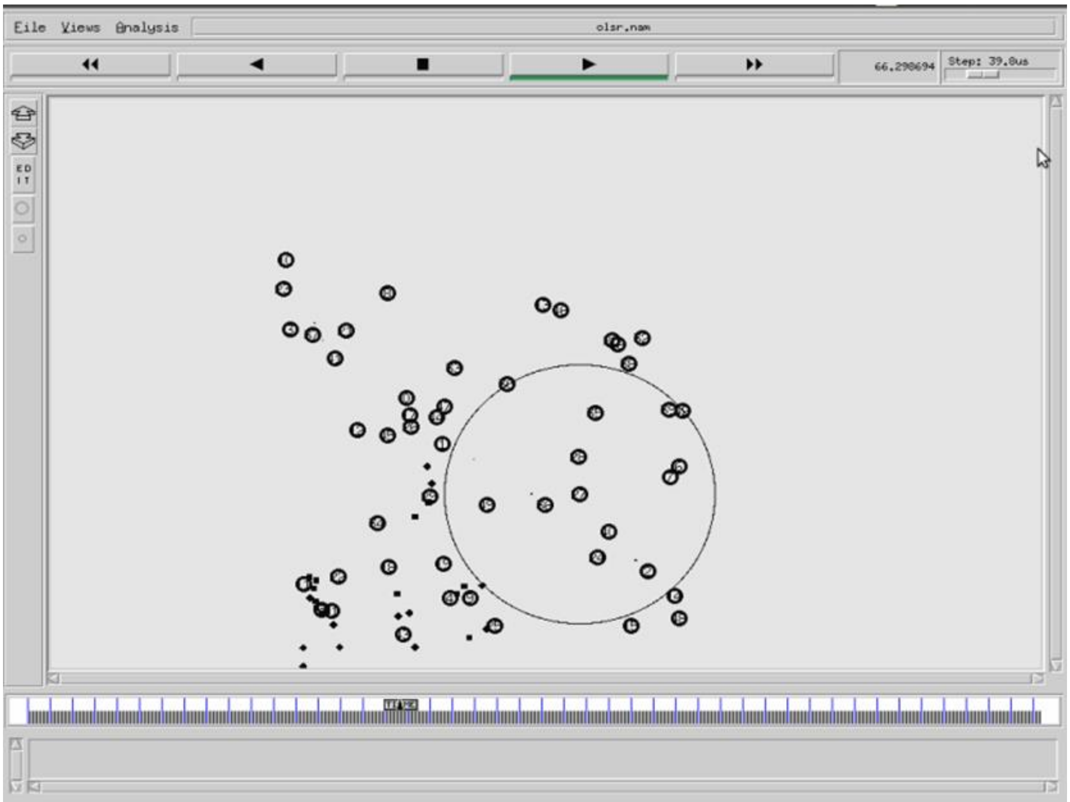

Figure 4. 1: Network Animator

4.2 Simulation Setup

The comparison between the prototype routing protocols will be performed on NS2 network simulator. The topology environment of the simulation has been structured randomly by utilising the feature of the NS2 to create topology files. The random topology files can be found on Appendix A - 1 (placed on the CD) and are including 12, 25 and 50 nodes. The data traffic environment has been created with a different feature of NS2 and is including 4, 6 and 8 number of connections. The files of the data traffic can be found on the Appendix A - 2 (placed on the CD). The environmental files are embedded in the main OTcl file in order to run the simulation over different routing protocol per time in different environment conditions. Simulation environment OTcl file can be found in Appendix A – 3 (placed on the CD). When the simulation finishes, a trace file is generated and contains all the transmissions occurred during the simulation time. The generated trace file can be examined with the use of the AWK file which can extract the data in a simple readable form. The trace files file and the OTcl format can be found on the Appendix A - 4 (placed on the CD). Simulation setup attributes are shown in the below table:

Simulation network environment setup	
Area size	600 x 600, 600 x 600, 800 x 800 m^2
Routing Protocols	AODV, DSR, DSDV, OLSR
Number of nodes	12, 25, 50
Maximum node speed	0 m/s
Simulation time	200 s
Number of connections	4, 6, 8
Data type	FTP
Data rate	300 kB
Packet size	256 Bytes
Buffer size	50 packets
Number of connections	4, 6, 8

Table 4. 1: Simulation network environment setup

4.2. Metrics

In this section, the case study will represent the metrics gathered from the trace file during the simulation time. Trace files can be found on Appendix A – 5 (placed on the CD). The trace file has been processed by the AWK file in order to reveal the following metric:

- Throughput
- Packet Delay
- Packet Delivery Ratio (PDR)
- Packets Dropped
- Received Packets
- Generated Packets

The gathered data has been placed into tables and then represented as bar charts. The image below shows the format of the data gathering of AWK file from the trace file.

```
alex@alex-VirtualBox:~/comparison/static nodes/AODV/4$ awk -f throu.awk trace1.tr
Average Throughput =  75.1783kbps
Average End-to-End Delay =  61.324ms
Generated Packets =  13398
Received Packets =  13378
Packet Delivery Ratio =  99.8507%
Total Dropped Packets =  20
```

Figure 4. 2: Output of the AWK file

4.2.1. Throughput

The first metric of our comparison is the throughput of the network measured in kilobits per second, higher performance of the throughput is better for the network. Reactive routing protocols are performing better on small networks with the DSR leading slightly over the rest of protocols. AODV overtakes the rest of the protocols while the number of the nodes is increasing. OLSR routing protocol performing provides stability while the network environment increases from small to medium and medium network, and remain in second place during the topology change of the network. Proactive routing protocols are performing better on a medium network with the DSDV overtake the rest of the routing protocols.

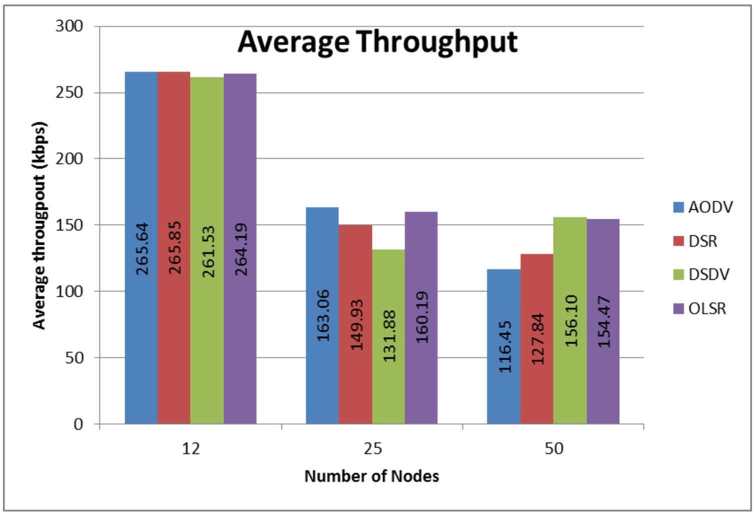

Figure 4. 3: Average Throughput

4.2.2. Packet Delay

The second bar chart shows the packet delay between the protocols, the measurement of the data is in milliseconds and lower delay means the better response of the traffic flow. In the first case, the proactive routing protocols are slightly leading over the proactive routing protocols with DSR performing with lower delay. In case of a small to medium network, the delay has been affected by the high rate of the data transmission. The buffer becomes full much quicker and it affects the performance of the network. AODV and DSDV are having the lowest delay respectively. On medium network the proactive routing protocols have shown that they have well established their routing table, therefore are showing the lowest response of the traffic flow. OLSR routing protocol packet delay is higher responsive than the rest of the protocols as the number of nodes are increasing in the network.

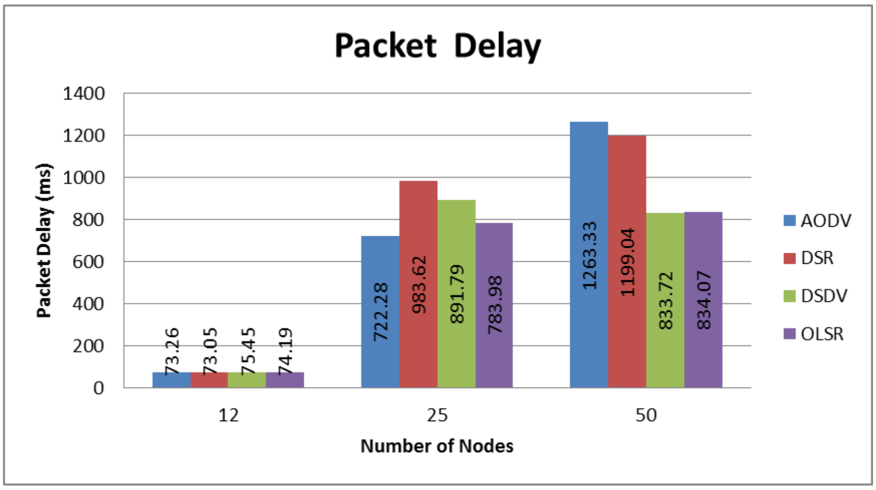

Figure 4. 4 Packet Delay

4.2.3. Packet Delivery Ratio

The bar chart below reveals the packet delivery ratio percentage. This metric shows the percentage of the successful data transmission from source to destination nodes. On the small networks, the reactive routing protocols outperformed the proactive routing protocols. AODV has the highest percentage of packet delivery ratio on small and small to medium networks. As the number of the nodes is increasing OLSR routing protocol remains in second place. Finally, DSDV accomplished the maximum packet delivery ratio on a medium network environment.

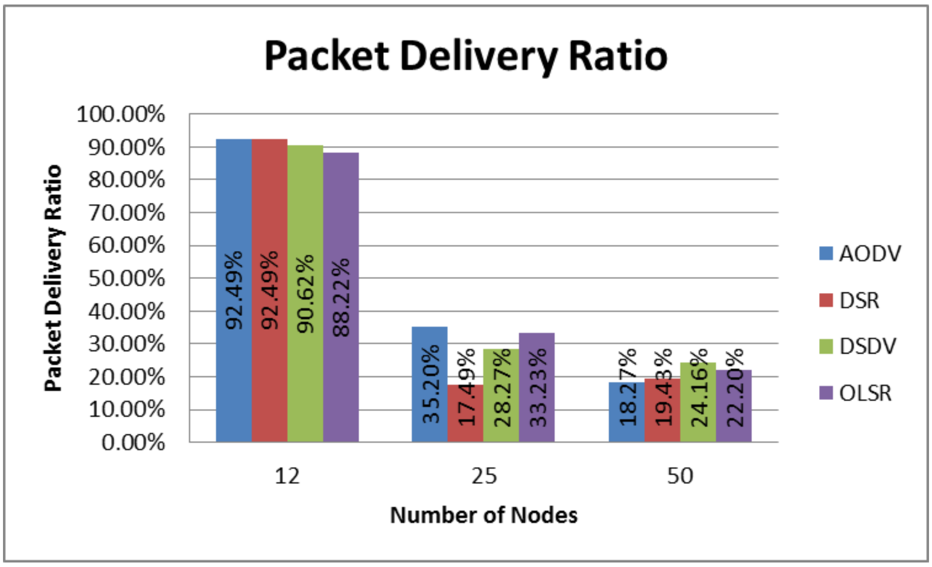

Figure 4. 5: Packet Delivery Ratio

4.2.4. Packets Dropped

The following bar chart provides the data of the packets that were dropped during the traffic flow, lower packet drop means better traffic control by the routing protocols. In the first scenario, reactive routing protocols are having the lowest packet drop of the network with the DSR leading. On second scenario AODV has been placed as first with the lower number of packet dropped and followed by OLSR with approximately 400 packets deference. On the final scenario, the proactive routing protocols have been in the first two places with the OLSR leading with approximately 550 packets.

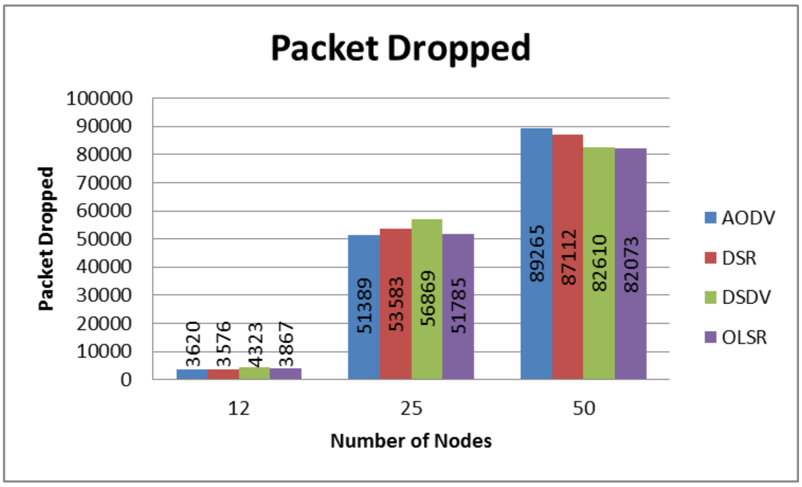

Figure 4. 6: Packets Dropped

4.2.5. Received Packets

The below bar shows the number of packets that have been received by the nodes in the network successfully, higher is better in this occasion. Reactive routing protocols have the higher received number of packets with the DSR on the top in the first scenario. On the second case, the AODV has received the highest number of packets and the second highest is placed the OLSR routing protocol. At the final scenario, the proactive routing protocols are leading with the DSDV having approximately 300 more packets received. The number of receiving packets has been reduced as the number of nodes and traffic has increased from all the protocols, therefore the interference between the nodes are decreasing our network efficiency.

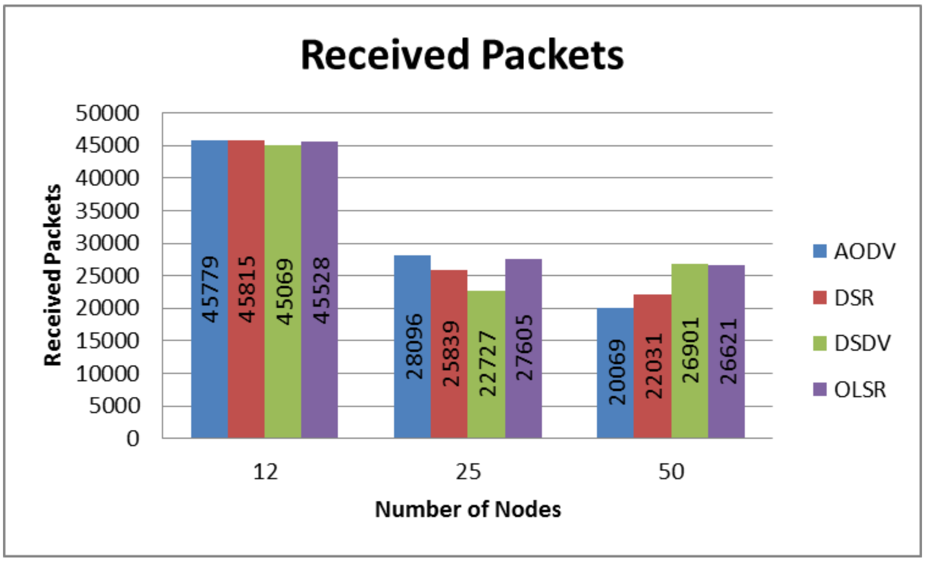

Figure 4. 7: Received Packets

4.2.6. Generated Packets

The following bar provides the generated packets that have been created in each scenario of the simulation. In this table, the author shows the highest amount of generated packet, however that does not means that higher or lower is better because we have to compare it with the received packets in order to conclude somewhere. In the first scenarios, the proactive routing protocols have generated the higher number of packets with the OLSR leading. On the second case scenario, DSR has overtaken the leading of generated packet with the massive amount packets. In second place was the OLSR. Finally, the last scenario shows at first place the OLSR and at second place the DSR. DSR has reduced its packets generation by approximately 30000 packets from the last scenario.

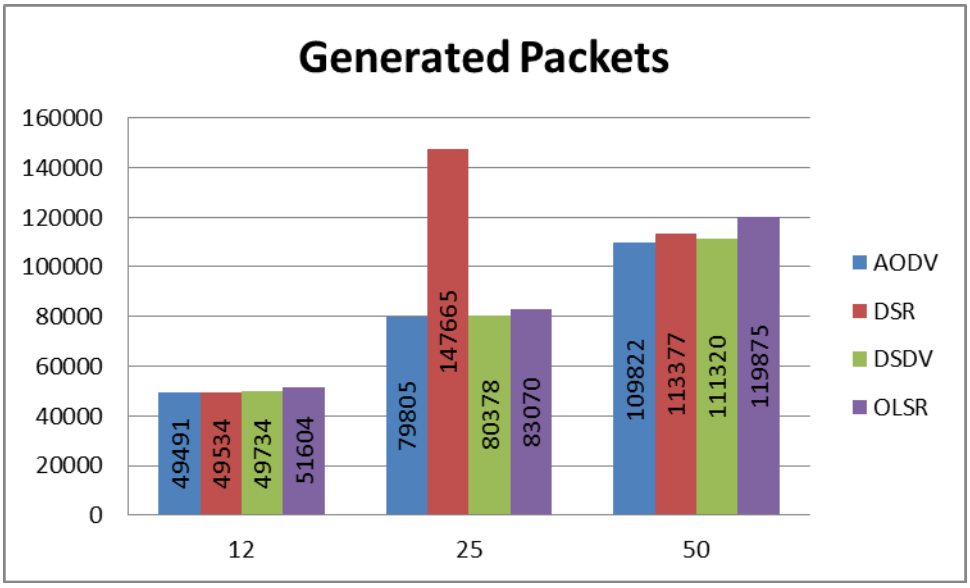

Figure 4. 8: Generated Packets

4.2.7 Discussion on all metrics

In previous sections, the author has provided individually metrics and explanation in each case of three different network environments, however, that tables cannot stand on their own. In this section, the author will provide an out of the box comparison of the four prototype protocols. All the metrics are taken in an overall consideration of each protocol performance. Our main metrics are the throughput, packet delay, and packet delivery ratio however in some cases we are advising the rest of the metrics as well.

Reactive routing protocols as discussed in the Literature Review they are performing better in an environment with moving nodes. In our scenarios, we have used a static topology formation where the proactive routing protocols. In order to balance the comparison between the protocols, we have used small to medium network environments where the reactive routing protocols have the advantage. With a first look, we can see that the reactive routing protocols are outperforming the proactive routing in small networks. DSR routing protocol is the leading protocol when the network consists a small group of nodes as the throughput, packet delay and packet delivery ratio on average basics are better than any other routing protocol compared in this scenario. AODV has also exceptional performance as it has a slightly lower performance than DSR in the small networks, but has the lead on the second scenario. The performance according to the PDR of the AODV is the best in the first two scenarios which are showing the efficiency of the protocol.

On the other hand, proactive routing protocols are taking the lead in the more complex environment of this project as they outperform the reactive protocols on the last scenario. DSDV have been performed better than any other protocol that has been compared. In the last two scenarios, OLSR routing protocol might have been shown as second during the comparison however on average basics the results are better than the rest of the protocols.

4.3 Conclusion

In this analysis, we have shown how the protocols are reacting differently when the number of nodes and connections are increasing. The results are showing that AODV is the best option to use in a small network as it has the ability to perform better even if the number of the nodes is increasing. On the other hand, for a medium network, OLSR is a well-balanced option which can handle situations even if the disconnected from the network.

The project interests rose over the OLSR routing protocol as the results shown that requires most of the packets to identify the topology of the network. The reduction of the TC and Hello packets that are responsible for the topological information of the network could be reduced with the addition of a weighting mechanism over the MPR selection algorithm. Additionally, as mentioned previously in Literature Review, OLSR structure is able to provide Internet connection to its network without any additional modification.

Chapter -5 Approach to Development Backbone Internet Connected OLSR

5.1 Introduction

The design of efficient routing protocol is a major challenge in such dynamically wireless environment which is utilising multi-hop and multi-interfaces functionalities. The BIC-OLSR is based on OLSR routing protocol, which is established in 2003 and since then after modifications by multiple researchers has gained its place on ad-hoc wireless networks. As mentioned in previous Chapters, the OLSR has attracted much attention because of the feature of providing a table-driven routing protocol with power efficiency and its adaptability to communicate with other networks based on other routing protocols by utilising its backbone feature. This protocol provides a solid network and is suitable for a medium network. The option of utilising the interface addresses gives the opportunity to connect the network with external addresses. In other words, hosts in the ad-hoc network can act as gateways to an external network. Multiple Interface Declaration (MID) message is used to inform the host of the network that the announcing host can support OLSR interface addresses. The messages are broadcasting to the entire network through MPRs (Toutouh 2012). In addition, the external routing information in order to link the external addresses of the network is operating through the Host and Network Association (HNA) messages. The HNA messages are transferring information about the network addresses and the netmask addresses. The importance of this message is to provide the ability of the announcing host to act as a gateway to the announcing set of addresses. HNA message information is removed when the expiration time pass (Yang 2009).

The time interval of the Hello message can be adjusted in such a way to be able to provide a better status update of topological changes. The information withholds through the routing table are built and support in such a way to rapidly change. Control messages are sending periodically without the need of utilising the sequence number mechanism, therefore no affection happens to the protocol if the links are not reliable. Existing operating systems can easily adapt with the OLSR protocol since the protocol is utilising interfaces, that means changes on the header of the IP messages will not be necessary as happens on other protocols (Yang 2009). This protocol provides a solid network and is suitable for a medium network. The option of utilising the interface addresses gives the opportunity to connect the network with external addresses. In other words, hosts in the ad-hoc network can act as gateways to an external network.

Multi-interface techniques have significant effect on performance on routing protocols as the nodes can transmit data through different interfaces. This kind of techniques is distinguished by the single-interface as the network bandwidth is increased along with the data load. In addition, multi-interface are providing options for mobility scenarios which table driven nodes are not of performing well. If one of those interfaces provides an Internet connection and each group has one node with that kind of interface a new Internet-connected path is created among the groups. A new mechanism of distribution data is created and the network load is balanced as the data forwards by less intermediate nodes.

Primary research was the starting point of this project in order to improve the performance of the OLSR. By employing additional functionalities on the prototype routing protocol by proposing a new Internet-connected table-driven routing protocol with backbone capabilities.

Node	1 hop neighbour	2 hop neighbour	MPR
6	1, 3, 7	2, 4, 5	3

Source Node	1 hop neighbour	1 hop Internet neighbour	2 hop neighbour	MPR
6	1, 3, 7	4	2, 5	3

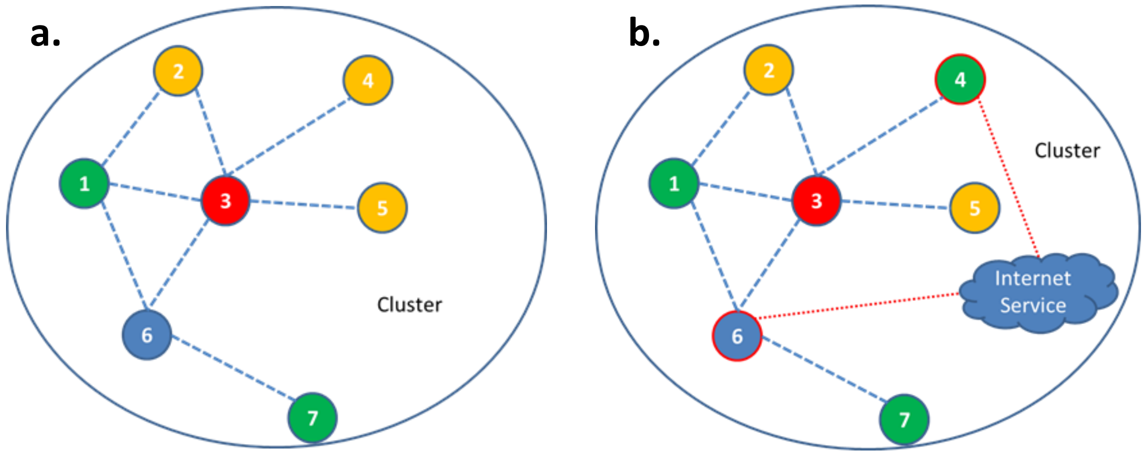

Figure 5. 1: (a) OLSR's MPR selection example; (b) BIC-OLSR's MPR selection example

The main idea of the project is to build one-hop connections between the Internet-connected nodes no matter how far there are from each other, as a result, to reduce the number of hops between the source and the destination nodes. The Internet-connected nodes will utilise the Internet path if there on second hop and more if it is one-hop they are keeping their initial connection. As we mentioned in previous Chapters OLSR is employed with MPR mechanism which is an election Cluster Head technique. Since the proposed protocol considers the Internet connection as the first option to send data between nodes if it is available, the Cluster Head criteria of the selection have to change. A node weight mechanism considering the number of one-hop nodes, the Internet-connected nodes, the length of reachability with other nodes and the battery status. According to the criteria the node is assigned with a weight value whereas will help the mechanism to choose the Cluster Head. The mechanism assigns an Internet-connected node as Cluster Head in order to minimise the involvement of the intermediate nodes.

5.1.1 Problem Definition

OLSR is performing well in some scenarios, however, on some other scenarios has certain drawbacks. The following are the major weakness concluded by the previous Chapters and from other literature reviews.

OLSR is table driven proactive routing protocol which has the need to know the topology of the entire network. The maintenance of this topological information is provided by the periodic Topology Control messages whereas on mobility scenarios the routing table may recompute, as a result, of the overhead network.

The available bandwidth is limited as the protocol is utilising most of the bandwidth to receive topological information of the network. Therefore, a limitation of the throughput while the data is transferring, caused by the available bandwidth of the network.

Cluster Head nodes are using more processing power than the member nodes, as they compute optimal paths, as a result to provoke faster battery consumption on key nodes. The MPR algorithm is limited by the willingness of each node to precede any data; however, that affect the performance of the network. Some nodes are more important than others and their location is vital for reachability and willingness to transmit data, therefore their replacement is reducing the performance of the network.

5.2 BIC-OLSR protocol overview

During this Chapter, an Internet-connected cluster-based proactive routing protocol is proposed. BIC-OLSR is a novel approach on optimise link state routing and increases the QoS of the network, by establishing Internet connections between the nodes. The protocol avoids congestions and collisions by reducing the number of lost and dropped packets while they are forward from the source to the destination node. By utilising the concept of optimised link state routing, BIC-OLSR intends to improve the performance by choosing an Internet-connected node as Cluster Head and providing a more reliable and efficient path for transferring data in the network.

As the prototype OLSR protocol aims a routing scheme for medium to large network as the nature of this type of protocol seeks scalability from its nature. The author believes that OLSR protocol suffers from packet loss, therefore the idea behind of its development is to reduce the collisions and the noise during the transition of the network. The network will organise into clusters to reduce the overhead along with the packet loss. In this proposition, the author believes that choosing the best metric-based node and then assigned as a cluster head divides the network into smaller networks. The proposed protocol changes the MPR selection procedure. Currently, the OLSR considering only the willingness and the length in order to choose the cluster head, the proposed algorithm will consider the battery status (similar to willingness), the connection to the Internet, the length based on one-hop connections and the covered nodes. The idea behind this provides a less stress to the network as they will be a virtual connection to the not reached wirelessly clusters.

The general idea of the project is to divide the network into clusters and assign CH in order to inter-link the clusters. Therefore, the utilisation of the one-hop clustering algorithm will be utilised in order to have the appropriate clustering foundations of the network. As the previously mentioned protocols, the proposed protocol will create its structure by utilising the Hello messages. The first procedure of the protocol is to detect the nodes in the network and assign the cluster radius of each CH. As the CH has been assigned, the CHs are creating TC messages in order to receive topology information. The risk of increasing the overhead of the network is critical as the above mention protocols are trying to reduce either the size of the routing table or the number of broadcast messages. Network topology as all the OLSR variations is utilising three types of messages which are Hello, IHello, IA, and TC. The Hello messages are the foundation message of the protocol because are used to detect the neighbourhood and therefore create the cluster structure. The messages are used locally and are calculating the local routes. IHello messages are triggered from the Internet-connected nodes as soon as the node collects the information that one node during the network discovery has an Internet connection and in order to establish the connection with that node generates the messages. In cases, whereas the Internet-connected nodes have not found any other Internet-connected nodes they generate IA messages which are advertising their Internet connection. IA messages are forward by the non-Internet connected nodes. The TC messages are created by the CH and broadcasted to the entire network. Their effort to the network healthiness is vital since they are linking the topology of each cluster topology.

5.3 Description of BIC-OLSR routing mechanism

5.3.1 Nodes detection procedure

The connection between the nodes in the ad-hoc wireless network can be unidirectional or bidirectional in order to identify and receive information each node for the neighbour nodes. Initially, the Hello messages are broadcasted periodically in order to identify the neighbourhood of the network. The Hello message can only broadcast only one-hop away and no further. When the host receives the Hello message from a neighbour host, it sets the status of the neighbour host as asymmetric in the routing table. The receiver host withholds the data of the sender host and replies back to the initial sender with the extra data attached to the message. The initial sender sets the host status as symmetric in its own routing table because of the attached data. Finally, the initial sender replies back with Hello message, with the updated status link, and then the initial receiver updates its own routing table status as symmetric. The two hosts have learned their neighbour, the link is alive and the connection is bidirectional (Li 2008). IHello messages as mention earlier are generated by the Internet-connected nodes when they receive information that some node beyond the single hop range has access to the Internet as well. Similar to the Hello message procedure, IHello messages are sending from the source to destination node with the intention of creating a symmetric link as virtually single hop connection. Sometimes Internet-connected nodes cannot receive Internet nodes information through Hello messages and the broadcast Internet Access (IA) messages to advertise their ability to virtually connect with other nodes.

The link type categorised as symmetric, asymmetric or the link is lost. On the other hand, the neighbour type can be symmetric, MPR or not neighbour. The MPR type points that the link to the neighbour is symmetric and that this host is able to act as MPR.

5.3.2 Multipoint Relays (MPR)

MPR is the key factor behind the OLSR protocol in order to achieve the overhead reduction during the information exchange. By utilising the MPR the number of the host which are broadcasting the information through the network we are reducing the number of hosts whereas are utilising the routing tables. MPR can be described as the one-hop neighbour who is able to forward its messages to another host. The number of the MPR set of hosts is limited so we can achieve a better performance of our protocol. OLSR has assigned the MPR nodes to forward the data through the network. The optimal MPR set is calculated by the appropriate information to withhold by the host such as the symmetric one-hop and two-hop neighbours. The specific information has been covered by the Hello and IHello messages because they contain all the hosts' neighbours. The MPR selection algorithm is responsible for the minimum selection of one-hop neighbours in the network, whereas being able to cover all the two-hop neighbours including the virtual neighbours.

The MPR selector mechanism provides the information to the network of which hosts have been selected to act as MPR and the hosts are covered by them. The MPR selector set has to forward the message when the message's sender interface address is in the list. The Hello messages are used in order to have all the changes updated continuously in the network (Jacquet 2001).

5.3.2.1 Multipoint Relays Selection

The MPR selection algorithm requires an MPR set which contains a number of the one-hop symmetric neighbours from which is able to reach all the symmetrical two-hop neighbours. The host must have the appropriate information about the one and two-hops neighbours in order to start the calculations of the algorithm. The information is broadcasted by utilising Hello and IHello messages. Algorithm for selecting Multipoint Relay set procedure:

1. Identify all the symmetric one-hop neighbours which are eligible to act as MPR
2. Calculate the entire neighbour host with the following requirements: Symmetric neighbours, two-hops away from the calculating source.
3. List the entire symmetric host to the MPR set. Remove the chosen host neighbours from the two-hop neighbour set if it is the only neighbour from which is able to get the specific two-hop neighbour.
4. In case that some of the hosts of two-hop neighbour set, then a calculation of reachability will apply, in order to eliminate all the isolated two-hop neighbour from the MPR set. It is choosing the node with the highest weighting value.
5. The procedure repeats the previous step until the two-hop neighbours set are empty.

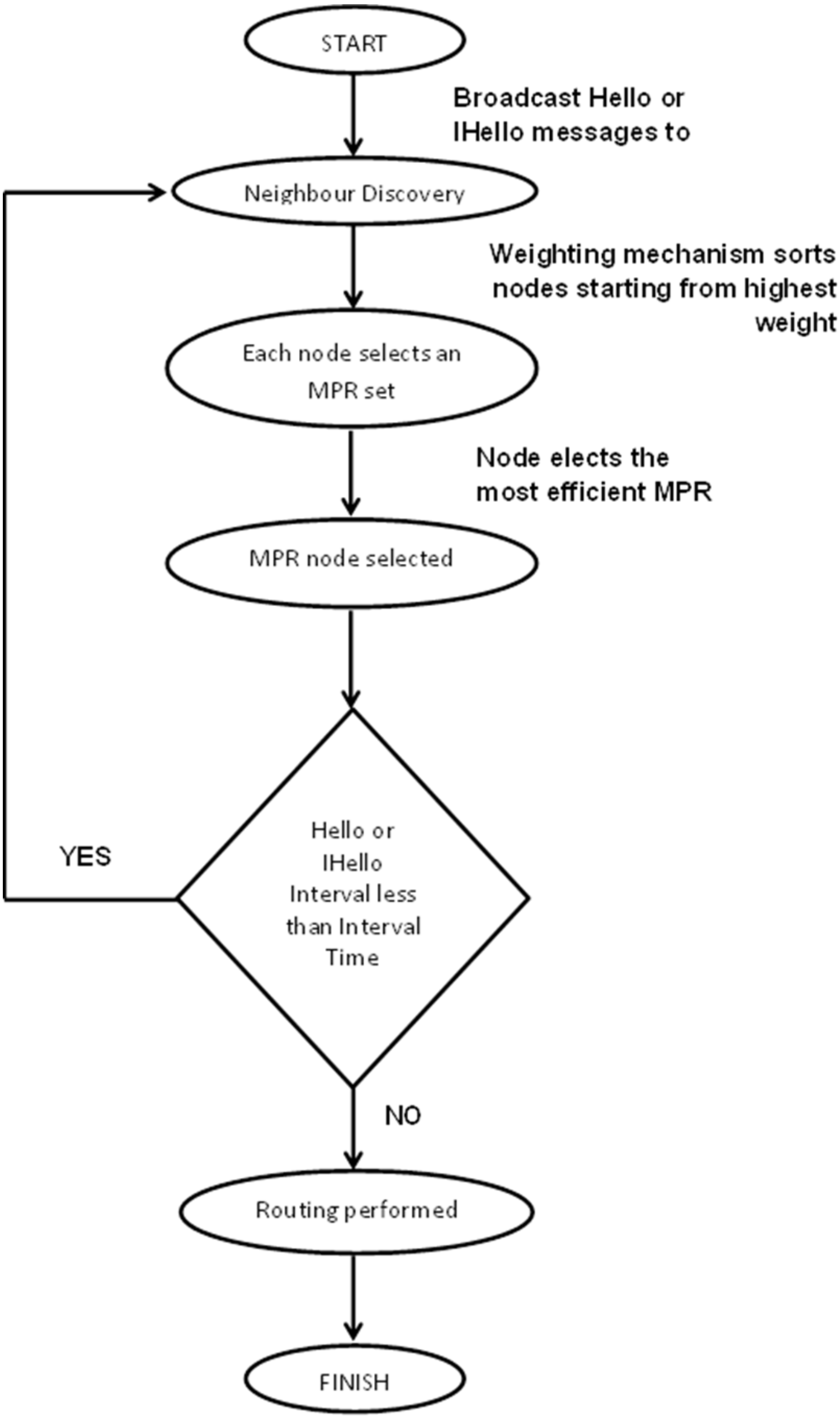

Figure 5. 2: Weighting approach of MPR algorithm

5.3.4 Topology Information

The protocol utilised the TC messages send it through MPR host in order to receive information according to the topology and therefore to build its topology information of the network. The TC messages are broadcasted periodically only through MPR. The specific messages are used to advertise the links in the network of the MPR selector set. TC messages are structured with a sequence number in order to avoid loops and providing information of the freshness of the message. In cases where the host receives the message and its sequence number is smaller than the last update then the message is discarded without any changes. The sequence number increases when the links are added or removed by the host as a notification that the topological information has been changed. The sequence numbers are wrapped around. Each time the host broadcasting the link sets the list becomes empty in order to point to the network that previous messages have to remove. In that case, the host sends empty TC messages for a specific amount of time. When the TC messages are having valuable information, they are broadcasting again. Sometimes the size of the TC messages is containing a large amount of data which makes it difficult to transfer it as one packet. There is a mechanism which divides the packet into parts and then the receiver has to combine all the parts under a specific amount of time. The host is having also the ability to increase the transition rate to avoid possible link failures. The existence of a flag in the MPR selector set, authorise the retransmission of the TC messages when a link failure happens (Belhassen 2011).

5.3.4.1 Messages of the proposed protocol

5.3.4.1.1 Hello message

The major purpose of the Hello message is to receive information about the neighbourhood and the neighbours in the network. The periodic nature of the message is utilised to detect the links, the neighbours and the MPR selection process. The message is structured in such a way to provide information such as:

- How regularly the host node broadcast Hello messages
- Provide the weight value of the host
- Withhold information about the neighbour nodes (interface address, link type, and neighbour type).

The Hello message will broadcast periodically to its one-hop neighbours. The message will contain the following information:

- The source node address
- The cluster address of the source node
- The list of neighbour nodes address
    - One-hop neighbours
    - Virtually Internet-connected one-hop neighbours
    - Neighbours with Internet connection
- The list of cluster address of neighbour nodes

The Hello messages are used in such a way to provide to the nodes the next two-hops topology. The messages are sent periodically and they are utilising a reachability timer. If the time of the message expires before it reaches its destination, then the link with the neighbour is lost. Hello messages maintain the set of the direct (one-hop) and two-hop neighbours.

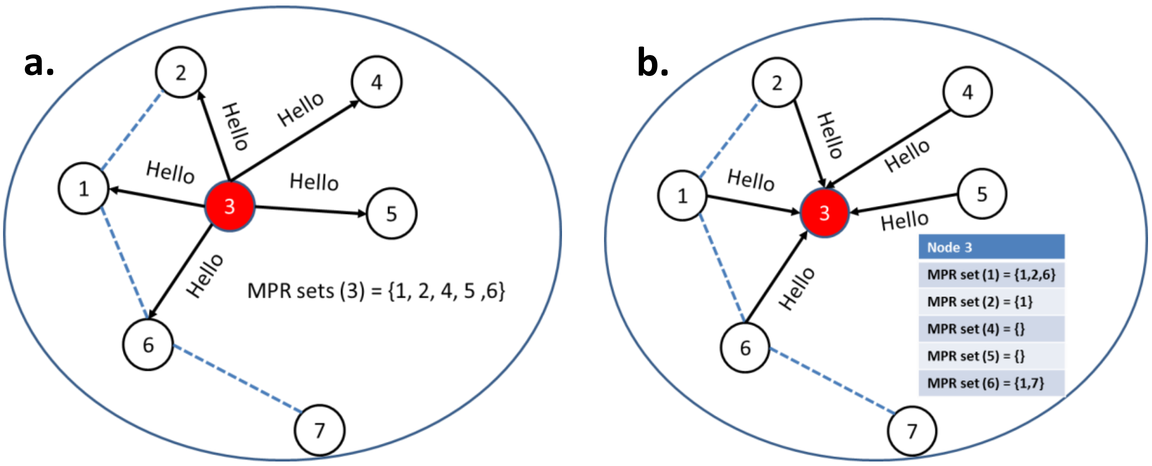

Figure 5. 3: (a) Node 3 sends Hello messages to neighbour nodes. (b) Node 3 receives Hello message from neighbour nodes.

5.3.4.1.2 IHello message

IHello messages generating after the host receives information that some of the nodes are providing Internet connection as well. This kind of message shares the same information as the Hello message with the differences that are only broadcast from Internet-connected nodes through the Internet.

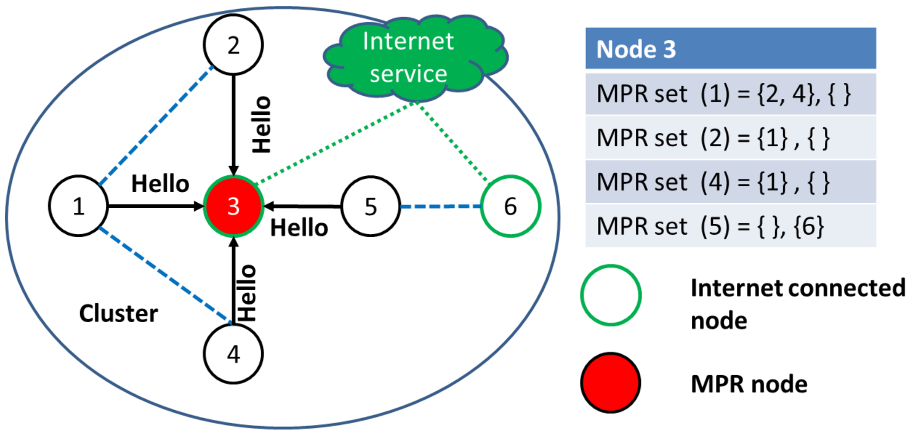

Figure 5. 4 : Represents the identification of Internet connected nodes

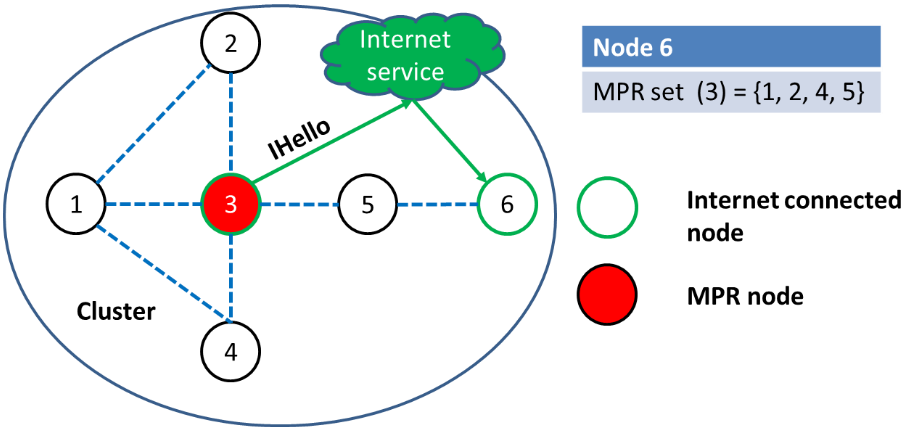

Figure 5. 5: Represents the generated IHello message from node 3 to node 6

5.3.4.1.3 Internet Access (IA) message

IA messages are generated from Internet access nodes only if they have not established any Internet connection with any other Internet-connected nodes. Therefore, they broadcast their intention to the network in order to establish an Internet connection. The message shares only the source node address. The non-Internet connected nodes received the message and forward it until an Internet-connected node receives it.

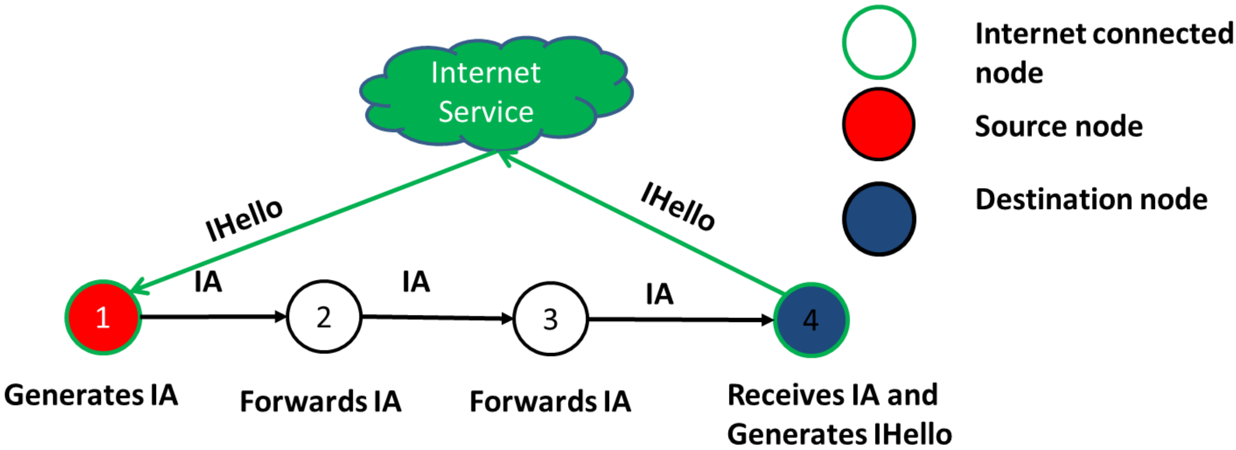

Figure 5. 6: Shows the way that intermediate nodes forward IA messages to advertise the Internet capability of the source node.

5.3.4.1.4 Traffic Control message

The clusters have to maintain the network topology between them, therefore the TC messages are wrapping all the clusters together. CHs are creating TC messages in order to gain information of the neighbour topology clusters. The messages are containing the following information:

- The address of the source cluster
- The sequence numbers
- The list of the members in the source cluster
- The list of the address of the neighbour clusters
- The list of the distances to neighbour clusters

The message due to its data size has the ability to split into parts. Therefore the receiver has a specific time to combine messages parts. TC messages are maintaining the topological information of the clusters.

5.3.5 Routing Table Calculations

MPRs are responsible to maintain the routing table. The routing table contains information such as: destination address, next address (next hop host), number of hops to the destination and local interface address. The information of the routing table has been structure through the broadcasting of the TC message for the topological information and from the Hello and IHello messages for the local link information. The routing table updates when changes occur in the above data. One of the main advantages of the proactive nature is to support the path for each node immediately, so the table should be able to provide immediately routes to all the available nodes in the network. Note that only the healthy links of the network are stored in the routing table. The routes which are provided through the routing table are using the weighting algorithm.

The Hello, IHello and TC messages are used for the topology information in the network. According to the given data calculation of the weighting algorithm must procedure, in order to reach all the nodes in the network. The following rules will apply:

- Add one route for each one-hop neighbours
- Add one route for each node in the two-hops neighbour
- Add one route for each neighbour CH which is not in the two-hops neighbour
- Add one route to each cluster-head in the network by using the weighting algorithm.

5.3.5.1 Proposed Weighting MPR selector Algorithm

The proposed algorithm takes place as all the nodes have been defined with the weighting metric. Weighting algorithm calculates the current battery status of the node, reachability of one-hop nodes, reachability of other nodes in the network and the number of Internet-connected nodes. The weighting function is called when Hello or IHallo message has been received. The node extract from the messages the four factors needed for the weighting algorithm. Each factor is valued differently. The mathematical model for the weighting of the nodes is the following:

- The first factor is the battery status of the node. The percentage of the battery status of the node is valued 40 percent in the weighting algorithm.

$$weight\ battery = \frac{40}{100} \times \frac{battery\ status}{maximum\ battery\ status}$$

- The second factor of our weighting algorithm is the number of one hop nodes reached by the source. The one hope nodes are divided by the Network nodes except the source node and have been valued at 20 percent of weight.

$$weight\ 1-hop = \frac{20}{100} \times \frac{1-hop\ nodes}{Network\ nodes-1}$$

- The third factor is the number of reachable nodes of the source node. The number of reachable nodes is divided by maximum of reachable nodes and is valued at 10 percent.

$$weight\ reachable\ nodes = \frac{10}{100} \times \frac{reachable\ nodes}{Network\ nodes-1}$$

- The fourth factor is the number of Internet-connected nodes with the source node. The number of internet-connected nodes divided by the maximum possible internet connected nodes and is valued 30 percent of the weighting algorithm.

$$weight\ internet\ connected\ nodes = \frac{30}{100} \times \frac{Internet\ connected\ nodes}{Network\ nodes - 1}$$

- Finally, the weighting algorithm summarised the four factors which produce the weight percentage of the source node as shown in Figure 5.7.

$$weight = w.battery + w.1 - hop + w.reachable\ nodes + w.Internet\ connected\ nodes$$

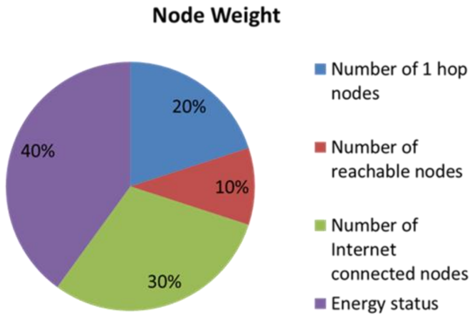

Figure 5. 7 Node weight percentage

The destination node creates the neighbour table among with the weighting value of the source node. The weighting algorithm procedure is shown in Figure 5.8.

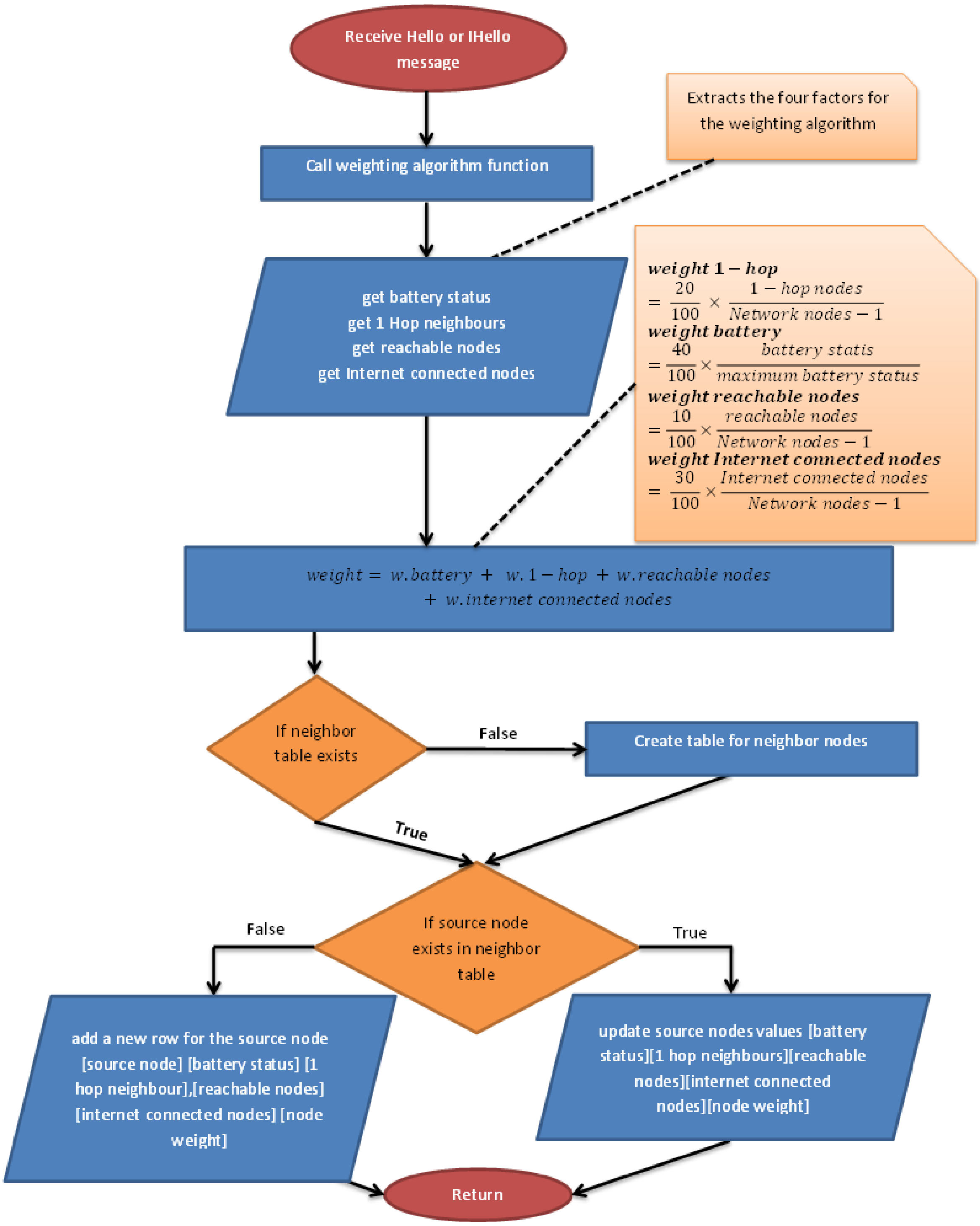

Figure 5. 8: Represents the weighting algorithm

Each node stores its gateway nodes which are the link to send data to the cluster and neighbour clusters. The weighting algorithm is utilised to choose the most appropriate node to create those links. The procedure has been divided into four phases.

- In the first phase, the MPR function has been called during the discovery and maintenance procedure. The node utilises the source node, 1 - hop nodes, 2 - hop nodes and reachable nodes of 2 in order to create two tables. The first table called 'ns' represents the source node and the 1 – hop nodes connected to the source node. The second table called 'ns2' represents the source node, the 2 – hop node reached by the source node and the degree of reachable 2 – hop nodes. Figure 5.9 represents the first phase of the MPR set procedure.

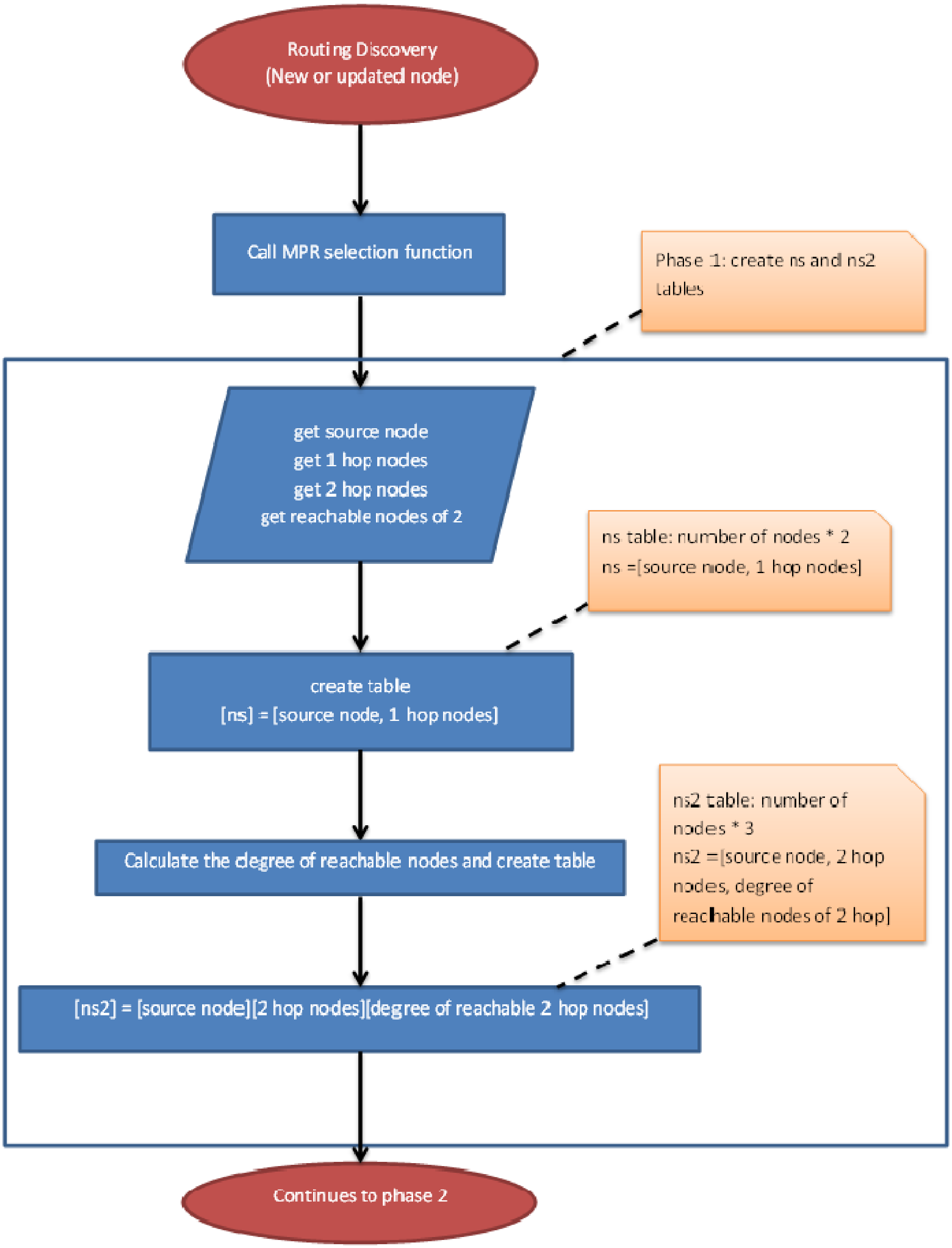

Figure 5. 9 First phase of the MPR set procedure

- The second phase utilise the 'ns2' table in order to create the 'n2' table. The table stores the unique 2 – hop nodes of the source node. The procedure is shown in Figure 5.10.

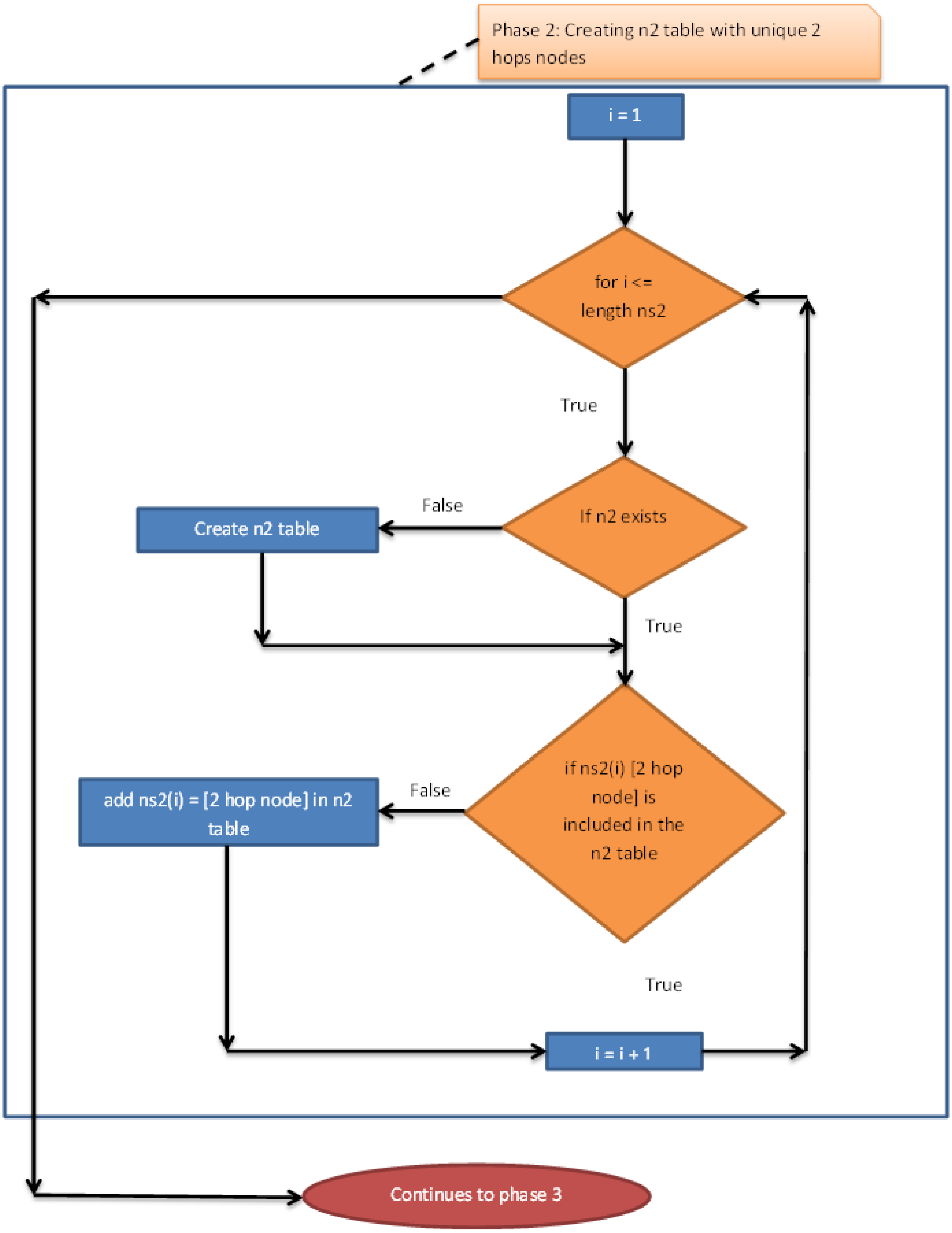

Figure 5. 10 Second phase of the MPR set procedure

- On the third phase, 'n2' is utilised to find the necessary nodes and store them in the MPR set list of the node. Necessary nodes are defined as the nodes which can reach nodes that none of the rest nodes are able. The third phase is presented in Figure 5.11.

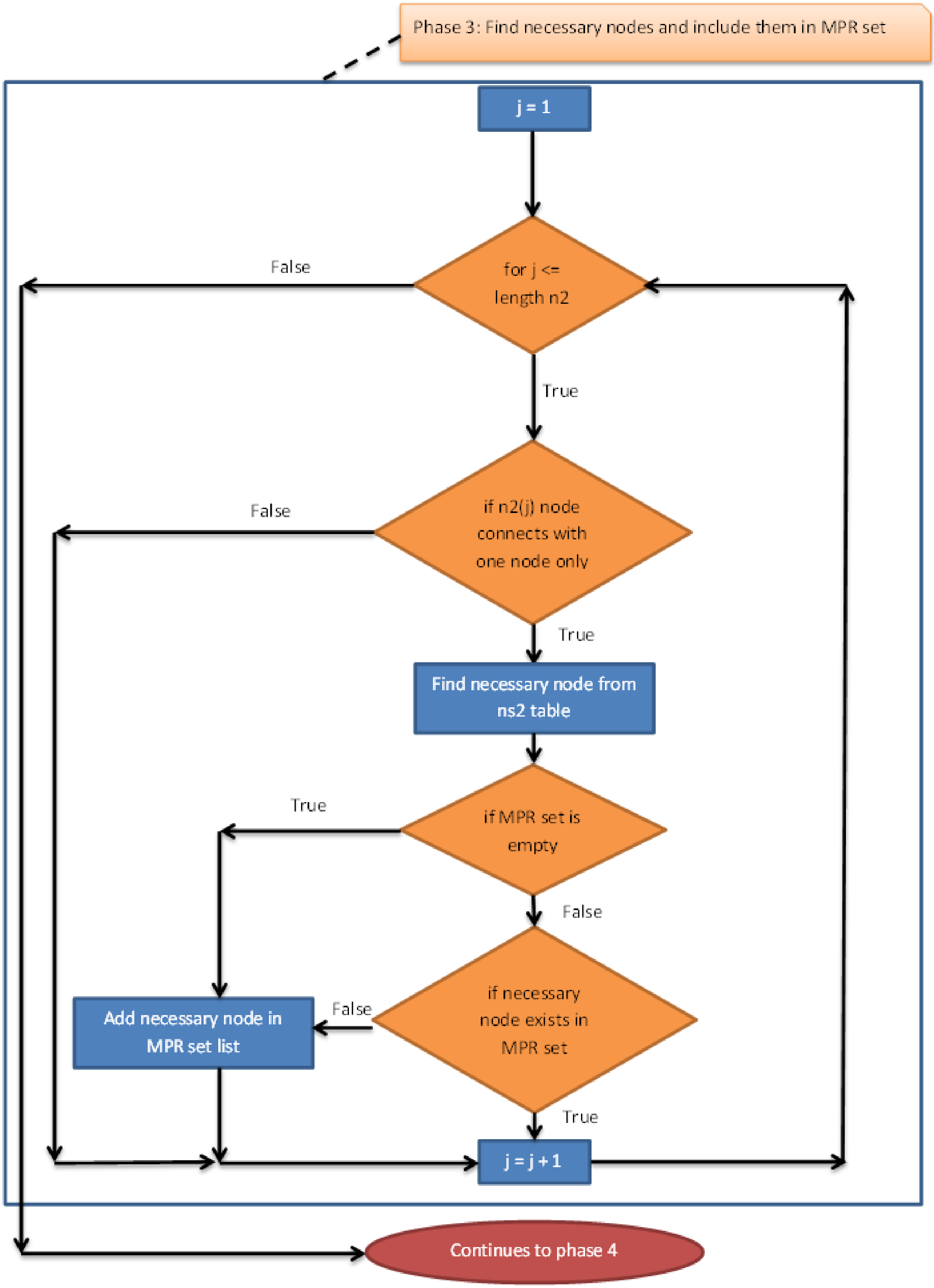

Figure 5. 11 Third phase of the MPR set procedure

- The final phase of MPR set procedure creates the 'mprs' table by utilising the MPR set list and weighting values. The 'mprs' table is sorted regards the weighting values of the MPR set nodes and then stored in the MPR set list. The final procedure is shown in Figure 5.12.

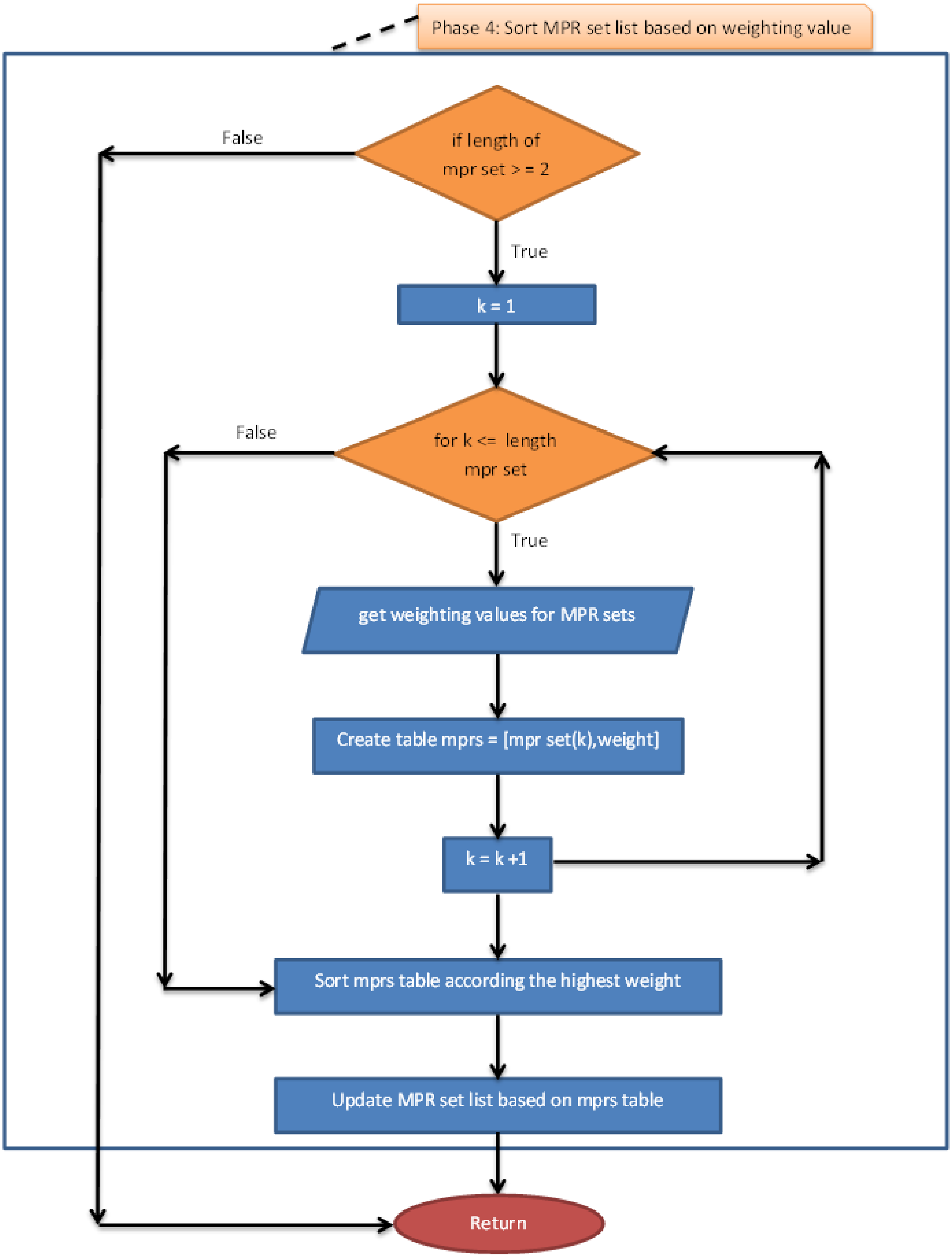

Figure 5. 12 Fourth phase of the MPR set procedure

The Cluster Head election procedure in the first phase utilises the MPR set procedure to extract the first MPR set node from each node in the network. The first phase of the cluster head election is shown in Figure 5.13.

Figure 5. 13 First phase of the Cluster Head election procedure

In the second phase, the MPR set nodes are calculated and the node with the most common use is chosen as a Cluster Head. The nodes which are covered by the CH up to 2 - hops are extracted in 'ch' table. Once the covered nodes procedure finishes, the nodes are removed from the 'cluster' table and repeat the procedure until all the network nodes are covered with a CH. The Figure 5.14 shows the second phase of the Cluster Head election procedure.

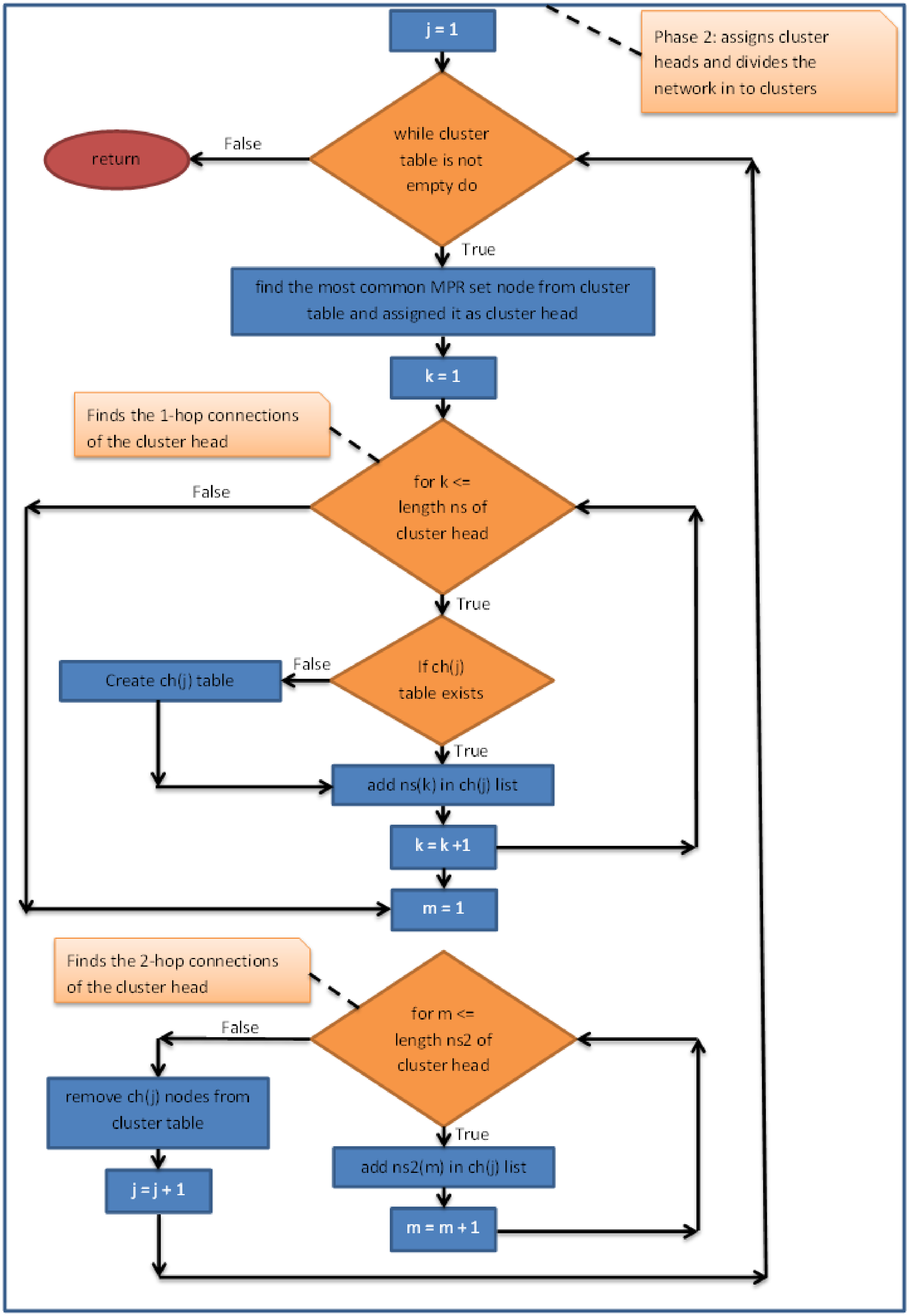

Figure 5. 14 Second phase of the Cluster Head election procedure

5.3.5.2 Proposed Clustering Algorithm

As a first step of the algorithm is the selection of the CH. The selection of the CH will be based on the one-hop clustering algorithm. The algorithm is utilising three states for each node. The three states are unallocated, member and able to be CH. The role of each node will be decided when all the nodes in the network are detected and assigned their neighbourhood. The author has chosen the three states because on each occasion it might help the better performance of the network. The following rules will apply to the formation and maintenance of the network:

- Rule 1: The node with the highest weight and is able to be CH will be assigned as CH.
- Rule 2: The node which is one-hop from the CH will become a member of its cluster.
- Rule 3: If there is not any node to fulfil the requirement of being CH then reformation of the cluster is needed and we are going back to rules 1, 2 and 3.

5.3.6 Virtual Backbone

The broadcasting TC messages are able to provide a mesh backbone formation by utilising a connecting dominating set. The CH has been chosen; therefore, the need of connecting them in order to communicate a decision according to the chosen gateway must be given. The gateway has a vital importance on the network as is responsible for the connection of the CHs of the network. Each CH must choose one gateway which allows reaching neighbour CH. As mentioned earlier only CHs are able to forward TC messages. Each pair of neighbour CHs must choose the same gateways in order to be connected to the virtual backbone. Rules are following for the connections of the CHs:

- Rule 1: If there is only one intermediate node between the two CHs then is elected as a gateway. If there are more intermediate nodes for that position, then the one with the best metric is elected as a gateway.
- Rule 2: If the connection between the two CHs cannot achieve by only one intermediate but it requires two then both of the nodes are elected as gateways. In case that there are more than two nodes able to provide their services for gateways, then the pair with the best metrics is selected.

5.4 Summary

The Chapter proposes a new approach for ad-hoc wireless networks where the goal is to apply a new weighting routing technique on Internet-connected nodes in a stable environment. This protocol virtually connects the Internet-capable nodes as single hop nodes and based on their weighting criteria assigns the nodes as CHs. The reduction of the number of hops in the network, consequently reduce the end-to-end delay, increase the throughput and packet delivery ratio.

Chapter 6 – BIC-OLSR analysis

6.1 Introduction

The well-known features optimised link state mechanism gives the ability to the BIC-OLSR to reduce the number of controlled packets as the topology-controlled messages are generated only by the Cluster Head. The proposed protocol enhances routing efficiency of by employing multiple routing mechanisms that build one-hop connections on disjoint nodes by the utilisation of Internet connection. These routes are selected through the weighting mechanism which is selecting the most appropriate routing path for data transmission. The idea behind the mechanism is to increase the number of member in the cluster and select an Internet-connected node as Cluster Head to extend the network's features. An Internet-connected Cluster Head will provide Internet access to the nodes in the network and will escalate the reachability of the cluster. Utilising Internet-connected nodes to establish one-hop connections with distance nodes will reduce the interaction of intermediate nodes, the number of hops between the source and destination, traffic encounters and the time of creating the entire routing table. Therefore, will achieve the desired end-to-end delay, packet delivery ratio, overhead, and throughput.

Providing efficient and stable routing paths in such mobile environment is a very critical issue. The way that the link breakage is minimizing and avoid the recalculation of the routing table is one of the most important factors of the BIC-OLSR protocol design. It is clear that table driven routing protocols are overhead, because of the topology messages and especially in occasions whereas the Internet-connected nodes have not achieved any Internet-connected connections with other nodes, the Internet Access messages are increasing temporarily the overhead in the network. All these will have a direct overhead influence initially however once the entire routing table is created the network will benefit the reduction of the end-to-end delay and the increase of throughput and packet delivery fraction. The mechanism of BIC-OLSR, reduce the traffic congestion of the intermediate nodes and provide a load balance in the network.

In this Chapter, the aim is to provide a detailed analysis of the BIC-OLSR routing protocol compared to the prototype OLSR. The routing protocols are analysed according to the number of controlled packets which are leading to overhead, end-to-end delay, packet delivery ratio, network density, and throughput. The allegations of the author about the improvement based on the newly implemented protocol are taking place with the data created by the simulations of a variety case scenario.

6.2 Network environment model

The efficiency of the BIC-OLSR compared with the prototype OLSR have been obtained by utilising MATLAB simulator. The simulation environment has been configured and modified with Internet connected nodes. Simulation topology is build approximating the architecture of ad-hoc wireless mesh network. The attributes are assumed such as (i) Number of static mesh nodes have been fixed in all simulation scenarios, (ii) random nodes are Internet connected (depends from the scenario), (iii) only one data transmission takes place in each simulation (iv) and the simulation last for 40 seconds. The environment of the simulator consists 15, 25 and 40 nodes which are tested over OLSR and BIC-OLSR routing protocols. BIC-OLSR protocol is tested under three scenarios of not having Internet connected nodes, quarterly Internet connected nodes and half Internet connected nodes. Template BIC-OLSR source code is located in Appendix B – 1 (placed on the CD).

Simulations are creating a log file whereas we can run an extraction file in order to analyse the behaviour of the network. Simulations log files can be found in Appendix B -2 (placed on the CD). The extraction file provides information such as end-to-end delay, generated control traffic, generated data, received data, data packet delivery ratio and throughput. Simulations extraction file can be found in Appendix B – 3 (placed on the CD).

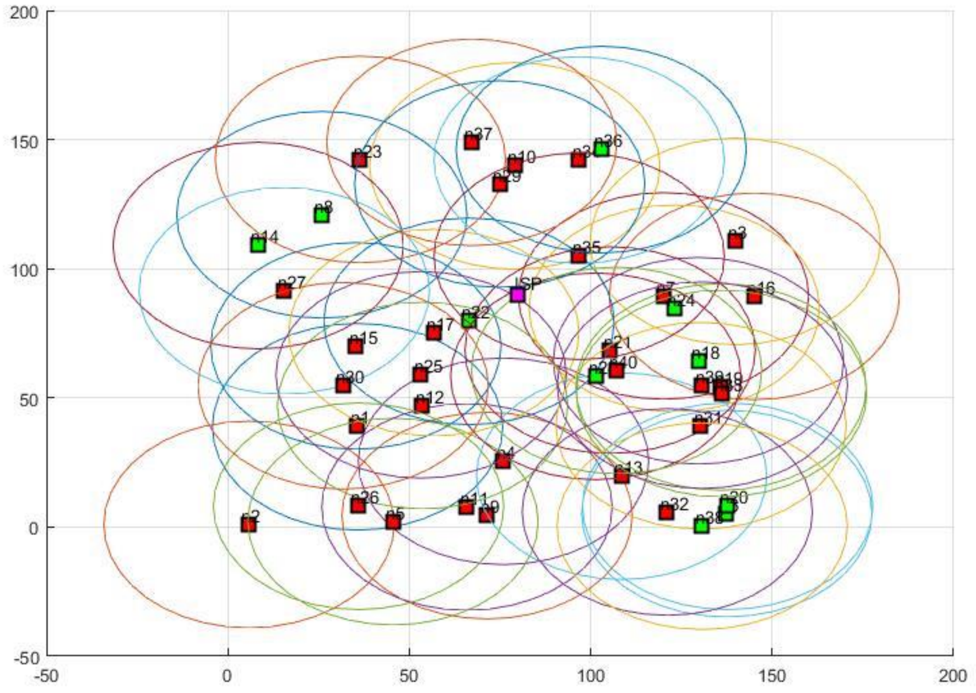

Figure 6. 1: MATLABs Plot example

6.3 Protocol analysis

This section presents a detailed analysis of the BIC-OLSR compared with OLSR routing protocol. The efficiency of the newly developed routing protocol compared with the prototype regards the end-to-end delay, throughput, and packet delivery ratio.

6.3.1 Routing overhead analysis (Control messages)

Optimise link state routing protocols are minimising the overhead by clustering the network. The maintenance of topological information is utilised Topology Control messages generated only by Cluster Heads. BIC-OLSR is generating Internet Access messages which are no generated by the prototype OLSR. The number of the control packets on BIC-OLSR when the nodes are connected to the Internet is increasing the number of the control packets initially as they are looking forward to establishing an Internet connection with other nodes. On the below chart the generated control packets are revealed through the simulation results. When the number of Internet-connected nodes is low, the need of the Internet-connected node to establish Internet connection increasing the number of control packets. Therefore, the number of control packets among with the network overhead is increased during this procedure. On the other hand, when the number of Internet-connected nodes and the number of nodes is high BIC-OLSR shows the most efficient generation of control packets as has the lowest number of control packets. The results of BIC-OLSR on a low number of nodes such as 15 and 25 are not comparable with the prototype OLSR. BIC-OLSR in same conditions with OLSR the results are slightly better as the number of packets is lower on 25 and 40 nodes scenarios.

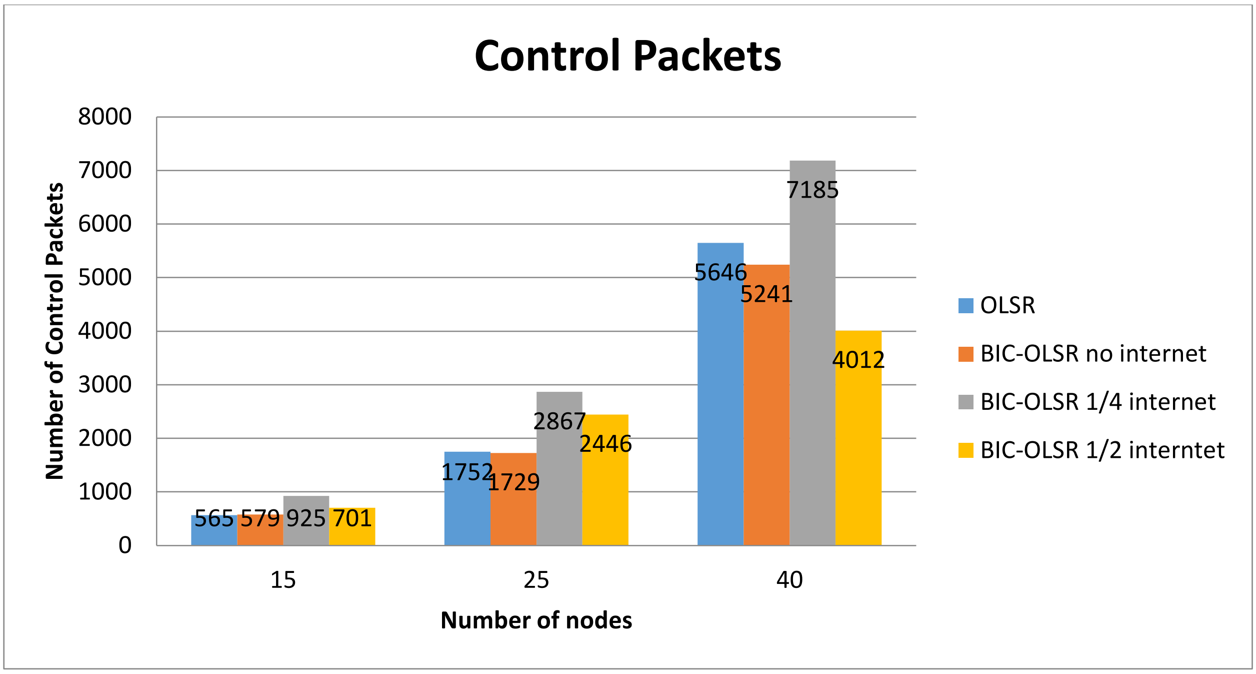

Figure 6. 2: Control Packets generated during simulation time

6.3.1.1 Summary

The new MPR algorithm has shown an improvement of the way that the nodes are transferring information on the network. BIC-OLSR has shown that the overhead has decreased which allows as using the Internet Connection messages to establish on hop connections with the Internet-connected nodes in order to increase network performance regards end-to-end delay, throughput, and packet delivery ratio. The author was expecting to see an increased number of Controlled messages as the BIC-OLSR utilises Internet Connected messages, however, those kinds of messages are generated at the beginning of the simulation as the nodes are trying to discover other Internet-connected nodes. Once the discovery finishes the Internet Access messages are not generated.

6.3.2 End-to-end delay analysis

Table-driven routing protocols are well-known for their ability to start data transmission upon request immediately. In this section, we are analysing the time taken to transmit from the source to its destination. BIC-OLSR in scenarios on the below figure shows that in almost all the scenarios have a better response time for transferring data. Only one scenario of BIC-OLSR whereas the low Internet connection of the nodes operates is notice an increase of the end-to-end delay. Probably this happens because the network is busy by sharing network information of the Internet-connected nodes as seen in Figure 6.2. OLSR routing protocol cannot overtake the swiftness of the BIC-OLSR on data transmission.

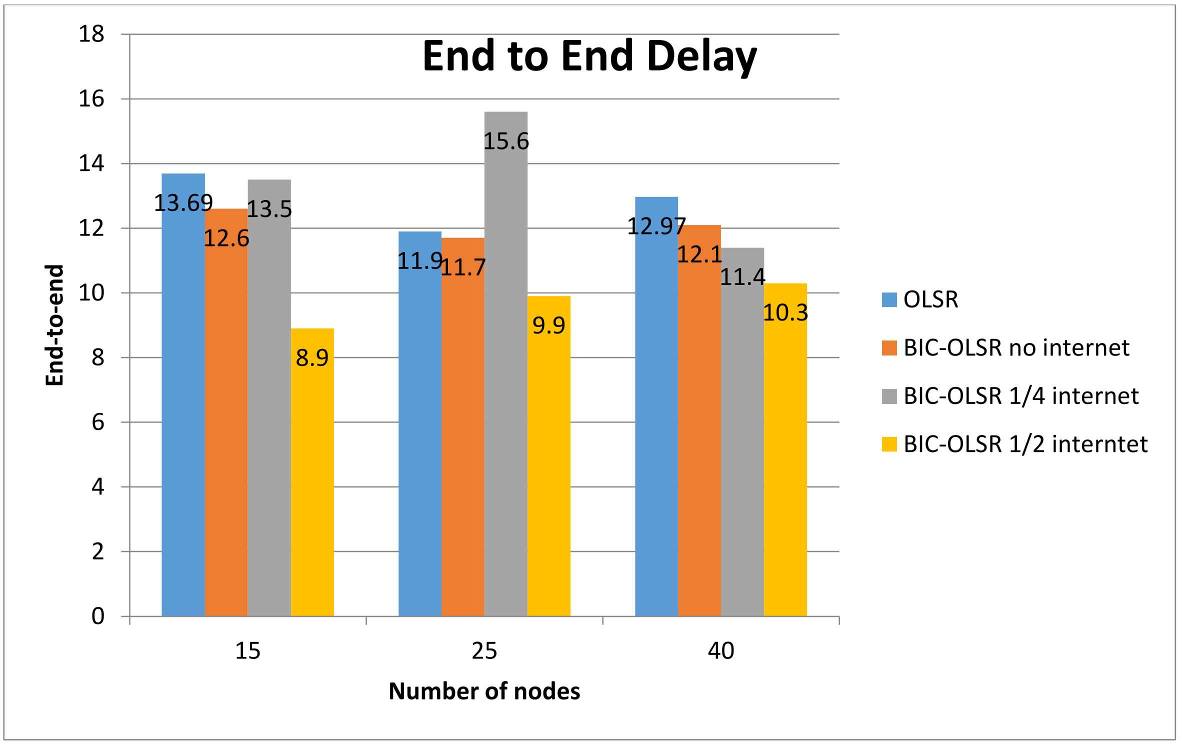

Figure 6. 3: End-to-end delay of data transmission during simulation time

6.3.2.1 Summary

The new structure of OLSR protocol seems to overtake the prototype OLSR. With or without an Internet connection the BIC-OLSR has better time response during data transmission. It is worth to mention that from the log files of the simulation, the BIC-OLSR is utilising different paths for requesting and replying which makes the environment less overhead. Each node has a different perspective of the most efficient path which resolves some of the bottleneck issues during the data transmission.

6.3.3 Connection throughput analysis

Connection throughput can be defined as the average transmission rate of a connection in the network. From the below figure we can see that the results are showing the BIC-OLSR with high Internet connectivity on the top of the list in every scenario, followed by the lower Internet-connected nodes, BIC-OLSR without an Internet connection and finally from the prototype OLSR. It seems that BIC-OLSR with high Internet-connected nodes is utilising all the capacity of bandwidth as is the most stable throughput compared to other simulations.

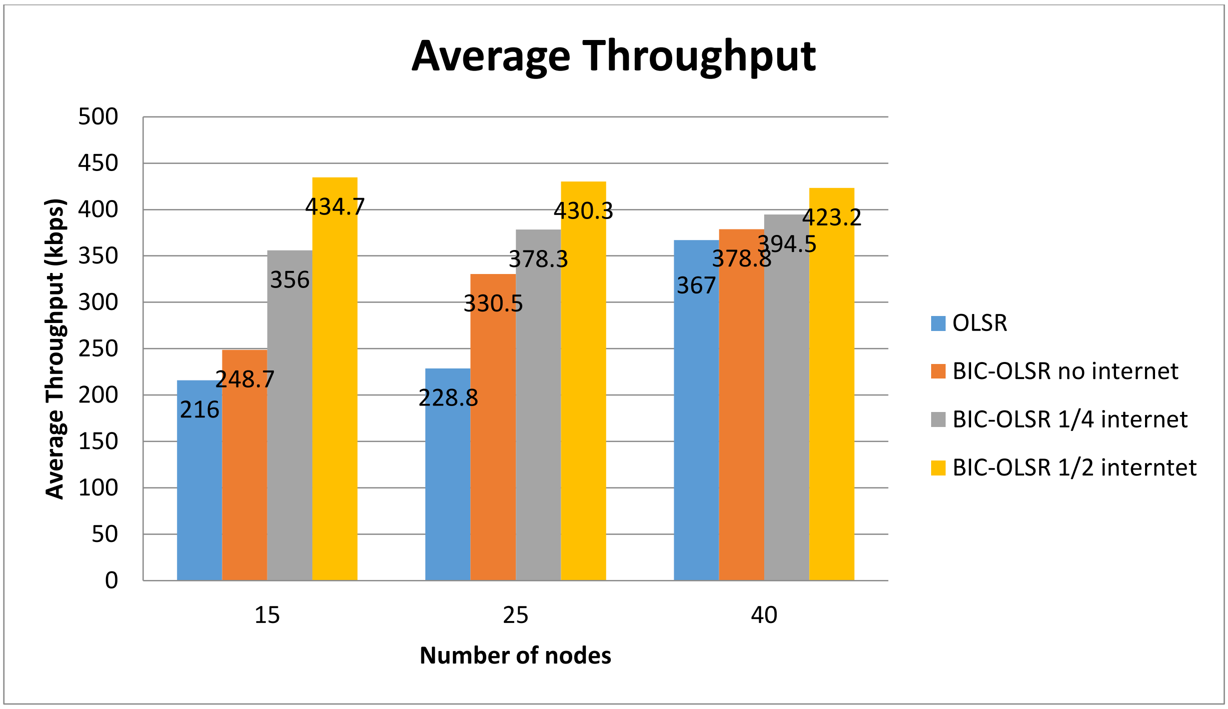

Figure 6. 4: Average throughput of data transmission during simulation time

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6.3.3.1 Summary

BIC-OLSR has shown that has increased the performance of the network regards the average throughput. The mechanisms that BIC-OLSR showed again that efficiency of the network has been made, with or without the Internet-connected nodes. However, the Internet-connected cases proofed that are worth to consider the Internet-connected nodes as an advantage in order to increase the network performance.

6.3.4 Packet delivery ratio analysis

Packet delivery ratio can be defined as the percentage of the data received by the destination to those generated by the source. All the cases have generated the same number of data packets, however, as you can see on the below figure the data packets have not entirely received by the destination node. BIC-OLSR once again has the most efficient packet delivery ratio on this comparison. The Internet-connected BIC-OLSR as expected, overcome the highest percentage of data. OLSR in high node density environment operates better, however, BIC-OLSR has shown stability with Internet-connected nodes.

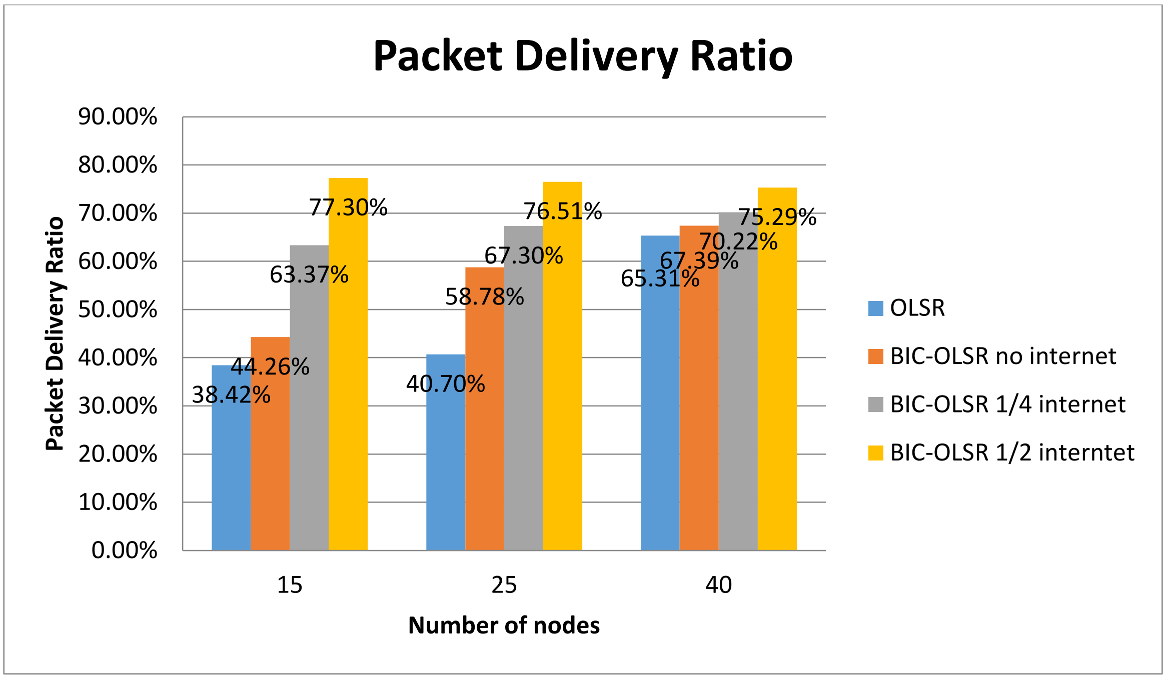

Figure 6. 5: Packet Delivery ratio of data transmission during simulation time.

6.3.4.1 Summary

BIC-OLSR has shown it is efficiency regards the packets received compare with the generated packets. OLSR even on high node density environment cannot overcome the performance of BIC-OLSR. The newly establish routing mechanism once again showed how well the MPR algorithm and weighting algorithm are synchronised and provoke the best performance of the network.

6.4 BIC-OLSR evaluation

The analysis by the quantitative model has been presented in previous sections, which provides a basic understanding of the performance impact of both BIC-OLSR and OLSR routing protocols. BIC-OLSR achieves better performance compared to OLSR in terms of end-to-end delay, packet delivery ratio, and throughput. Table 6.1 reveals the average performance of the two aforementioned protocols.

	Average OLSR	Average BIC-OLSR
The number of Control Packets Transmitted:	4348.1	4435.7
The number of control packets are dropped:	475.7	515.7
The number of data packets are send:	1376	1376
The number of data packets are received:	785.8	960.7
The number of data packets are lost:	262.4	81
The number of data packets are dropped:	327.8	334.2
The average throughput is (kbps):	320.9	392.4
The packet delivery ratio is:	57.11%	69.82%
The end-to-end delay is (ms):	12.6	11.6

Table 6. 1: Overall comparison of OLSR and BIC-OLSR

BIC-OLSR outperforms the prototype OLSR according to the following advantages:

- BIC-OLSR provides multiple completed paths to the destination. In case that the primary path is busy the second path takes over the data transmission.
- Provision of load balance as the BIC-OLSR utilises Internet connection to reduce the number of hops between the source and the destination nodes. In addition, the protocol reducing the traffic congestion and the queue size of the intermediate nodes.
- Reduction of the number of hops increases the power saving of the intermediate nodes, as their services are not needed for some routing paths.
- Weighting algorithm selects the most efficient routing path based on the nodes prospective. Provision of path criteria based on the number of neighbours, routing table and battery status.
- MPR selection algorithm selects the most appropriate node to act as Cluster Head based on weighting algorithm. In case that the Cluster Head is not any longer the most efficient node for that position the second in place to act a Cluster Head overtakes the responsibility.
- Increase the reachability of the cluster. When Cluster Head is connected to Internet and Internet connection established with a distance node, the table of two-hop nodes is increasing.

In addition to the quantitative analysis according to the above advantages the author would like to refer to the following prior works that show the advantages of utilising Internet connection and weighting algorithm approach. The simulation scenarios created for this project confirmed that utilising the aforementioned mechanisms outperformed the prototype routing protocol caused by the following mechanism:

- It has been shown in Figures 6.3 and 6.4 that the reduction of the number of hops with the utilisation of Internet connection the routing discovery has been improved as a result to provoke better end-to-end delay response time and higher throughput speed.
- In Figures 6.3 and 6.5 have been shown that the load balance of the network by utilising the most efficient routing path regards the perspective of each node can handle simultaneous data transmission as a result to increase the packet delivery ratio and less end-to-end delay.
- In Figure 6.2 has been shown that the BIC-OLSR has decrease the control packets when the network has not support Internet connection, which allows increasing the number of control packets with Internet Access messages in order to let other nodes, that are nodes with an Internet connection which have not manage to use this ability. The generated control packets are shown that is higher than the prototype routing protocol, however they provoke a temporary overhead with those messages until Internet connection has been established with all the nodes using that service.
- In Table 6.1 has been shown that the new protocol has more control of the data packets as the packets are more likely to drop than lost.

BIC-OLSR is different compared to the prototype routing protocol. The focus of the project was concentrating on improving packet delivery ratio, throughput, and end-to-end delay, whereas the prototype routing protocol was focused on minimising the number of the control packet and overhead. In addition, BIC-OLSR has been designed to be more efficient with the route breakage, congested nodes, node failures and node failure resource utilisation.

Finally, it can be said that the number of control packets showed that they have potentials to decrease as on Figure 6.2 the high Internet-connected scenario showed that the discovery of the entire routing table structured by generating a surprisingly lower number of control packets.

6.6 Summary

In this Chapter, the analysis of BIC-OLSR and OLSR routing protocols has been presented. Initially focus on quantitative case scenarios base on the simulation results. It has shown how the novel mechanism of weighting algorithm and MPR selector procedure along with the utilisation of Internet connections can improve the performance of the network. The improvements shown in this analysis is the end-to-end delay, throughput and packet delivery ratio. It has been demonstrated that BIC-OLSR advantages create a better environment for the nodes in the network. However, the increases of control packets during the Internet Access discovery procedure, producing an initial overhead to the network, similar to the reactive routing protocols route discovery procedure. The Internet-connected nodes are created randomly which did not allow to the author to choose the most appropriate locations for those nodes. Therefore, some of the Internet-connected links have been wasted.

Chapter 7 - Conclusions and Future work

7.1 Introduction

This research has investigated the QoS over the prototype routing protocols by using the NS2 simulator and developed a new routing protocol based on optimised link state algorithm by utilising MATLAB simulation environment. The modelling of the network environment has been simulated with various parameters such as network traffic, node topology, transmission ranges and nodes interfaces. As part of the study, some of the nodes are able to connect to the Internet and establish Internet-connected links with network's nodes. This project analyses the effectiveness of the network while the Internet-connected nodes varying in the network environment. The concluded Chapter summarises the research results, highlight the contribution in the area of the project and discuss future research.

7.2 Conclusions

The absence of infrastructure in the ad-hoc wireless networks made the routing design of the protocols to be challenging as they are limited to bounded resources such as bandwidth, energy, and processing power. The projects over the MANET's initially were developed for military operations and over the years have increased their popularity, therefore have been deployed for rescue operations, wireless sensors and public use. The real-time applications have increased the size of the data transmission and some of MANETs routing protocols are unable to support QoS. Another issue identified by this research is the limitation of available abilities of the nodes such as Internet connection.

To the best of our knowledge, the thesis provides information about the categories of routing protocols and divides them based on three routing algorithms. Based on examination of these protocols through NS2 simulation has been taken place regards the QoS of the routing protocols. From background research, we can conclude that reactive routing protocols are designed to facilitate small networks and proactive routing protocols are suitable to manage medium networks. The lab-based research reveals Optimised Link State Routing (OLSR) protocol as the most stable solution between the small to medium and medium network as the QoS does not affect the performance metrics. Furthermore, prior research has shown that protocols with Internet connection capabilities have modified network structure into clusters in order to create gateways for Internet access. For this reason, we have designed and implemented a new proactive Internet-connected routing protocol that is based on the well-known OLSR protocol.

The preliminary design of the new proactive Internet-connected routing protocol is based on a modification of the MPR algorithm of the prototype OLSR protocol. An embedded weighting algorithm has been implemented in order to calculate and assigned weight the four objective criteria (battery status of the node, the reachability of one-hop nodes, reachability of other nodes in the network and the number of Internet-connected nodes). The weighting algorithm has the advantage to provide to each node a different perspective of the efficient path as the paths varies on the last updated information of the node. The information of the weighting mechanism is based on the new structure of the Hello messages as they have been modified to advertise their Internet connectivity to the neighbour nodes. In addition, the neighbour nodes as they receive the message that the neighbour node is connected to the Internet they can advertise their one-hop connection from Internet access. Once the Internet-connected nodes which are two-hops away from each other they try to establish a one-hop Internet-connected link by utilising the IHello messages. IHello messages are structured similarly to Hello messages, but they utilise Internet-connected links. The Internet connection in this kind of routing protocols provides redundancy and collision-less environment, save bandwidth, and minimises end-to-end delay of the network.

In some cases, the Internet-connected nodes could not establish Internet connection because they have not received any information as the Hello messages reach up to two-hop neighbours. The BIC-OLSR has been revised and new IA messages were developed. IA messages are generated by the Internet-connected nodes in order to advertise their Internet connection capabilities. Those messages are forwarded by neighbour nodes to make gateway aware to the Internet. The BIC-OLSR pursuits to select an Internet-connected node as MPR, but in some cases, this is not possible.

The evaluation of the new protocol has been compared with the prototype OLSR routing protocol, as the previously compared routing protocols were not included on MATLAB simulator. The project compares three different states of the BIC-OLSR based on Internet-connected nodes. The protocols are compared in four different network environments. The results have shown that the BIC-OLSR weighting algorithm can stand by its own as the performance over QoS metrics is more efficient than the OLSR's. With the utilisation of the weighting algorithm, BIC-OLSR has managed to reduce its generated packets. Furthermore, while the BIC-OLSR utilise the Internet-connected links the generated packets were increased especially where the Internet-connected nodes were limited. On the other hand, in the maximum node scenario where the number of Internet-connected nodes is approximately half the number of nodes of the network, an impressive reduction of the control packets is noticed. Except for the generated packets, overall the BIC-OLSR performs better in all case scenarios in experiments. The packet delivery ratio of BIC-OLSR is almost 13% higher than OLSR, the throughput of BIC-OLSRs network is approximately 73 kbps faster than OLSR and the end-to-end delay is one second more responsive than OLSR.

7.3 Future research areas

Through this research, there are several areas that can be extended for future investigation. These are outlined as follows:

- This thesis has created an energy model based on power consumption of the nodes in order to support the weighting algorithm. The project did not focus on the lifetime of the network environment though. An interesting research direction is to include BIC-OLSR's lifetime in the model.
- The project utilised MATLAB simulator for the implementation of the BIC-OLSR routing protocol. MATLAB simulator is not common to be utilised for developing routing protocols based on MANETs as they have not included any MANET protocols in their libraries. It will be motivated to implement BIC-OLSR over the NS2 simulator in order to apply simulation scenarios and compare it with more routing protocols.
- The simulation scenarios applied to this study have been developed with static topology and structured based on small to medium networks. The implementation

of a mobility scenario or a larger network to investigate the performance of BIC-OLSR protocol would be an interesting research area.

- During the evaluation of the BIC-OLSR, it revealed the increase of the control packets. Due to the increase of the IA messages trying to locate other Internet-connected nodes. A further investigation regarding the IA messages could be applied in order to reduce the control packets of the network.
- The scenarios applied during the evaluation along with the attributes of the nodes have been randomly chosen. During the simulation, the results have been notified that some of the Internet-connected nodes where one-hop neighbours and it was a waste link to Internet connection. When it comes to real life scenarios a new optimisation algorithm to form the topology of the Internet-connected nodes is an interesting research area.

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