

A Comparative Analysis of MANET Routing Protocols for Low Cost Rural Telemetry Wireless Mesh Networks

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Abstract— In rural areas in Africa, the topographical conditions vary, including hilly areas or flat open areas with bushes, trees and vegetation. In some cases, road and infrastructure conditions are exceedingly poor, making it challenging and costly to provide necessary maintenance and support to communication networks. When a node goes offline the remaining nodes must be able to re-establish links with each other and maintain connectivity. The routing protocol must discover an alternative shortest path route and use this path to deliver the data. The maintenance time can be slow and it might take days to attend to the faulty node in a rural area. Due to this, the network must be able to operate for long periods with the faulty node(s) and provide the best possible Quality of Service (QoS). In the past few years, Wireless Mesh Networks (WMNs) have attracted an increase in research and use due to their attractive characteristics, which include low deployment cost, a low cost option to extend network coverage and ease of maintenance due to their self healing properties. In WMNs, with an increase in scalability, the throughput of the network tends to decrease. In this paper, we carried out a performance analysis for failing node scenarios for rural telemetry networks using three protocols, namely OLSR (a proactive protocol), DSR (a reactive protocol) and HWMP (a hybrid protocol). The performance analysis of these protocols was carried out using three backhaul network topology scenarios. The simulation results were obtained using OMNET++ and the INETMANET framework. Performance metrics used for the analysis and study were packet loss and end-to-end latency as these are major factors considered for providing guaranteed Quality of Service (QoS).

Keywords — DSR, HWMP, MANET, OLSR, Wireless Mesh Networks

I. INTRODUCTION

In the past few years, there has been an increase in Wireless Mesh Networks (WMNs) research and use due to their attractive characteristics, which include low deployment cost, a low cost option to extend network coverage and ease of maintenance due to their self healing properties. Literature records many researches done and published in various areas of WMNs which includes routing metrics, optimum routing, security, scheduling, cross layer designs and physical layer techniques. WMNs are often divided into three main categories namely backhaul mesh networks, client mesh

networks and hybrid mesh networks [1]. In this study we consider the mesh network for a backhaul network.

In most cases, a rural village in Africa is up to a thousand kilometres away from urban areas and villages are also widely scattered and separated [2]. The cost of covering this distance to reach scattered rural villages is very high. As a result, a low cost alternative to cover these areas will be to use wireless mesh networks in the backhaul network. In rural areas in Africa, dwellings are usually sparsely distributed. The topographical conditions in rural areas are also varied, including hilly areas or flat open areas with bushes, trees and vegetation. In some cases, road and infrastructure conditions are exceedingly poor, making it challenging and costly to provide necessary maintenance and support to communication networks [3]. We say that WMNs are a low cost alternative, as hardware can operate in the unlicensed Industrial, Scientific and Medical (ISM) band and provide lower cost as compared to the use of licensed spectrum. Also, hardware with a single radio and single channel can lower cost. The simulations carried out in this paper are based on single radio and single channel techniques.

Many researches have been carried out on performance evaluation of different routing protocols. Different protocols perform well under different network conditions such as mobility, traffic load levels and network link quality. No single protocol has been discovered to be optimal in all operational scenarios [4]. In this paper, WMNs with static nodes are considered. The goal of this paper is to characterize the performance of the Dynamic Source Routing (DSR), Optimized Link State Routing (OLSR) and Hybrid Wireless Mesh Protocol (HWMP) protocols for static, distributed, multihop, wireless mesh networks for operation in a rural environment. This research ascertains the suitability of a routing protocol for a WMN in a rural environment setting where long maintenance periods are expected with possibilities of nodes switching off, becoming faulty, or being stolen.

The rest of the paper is organised as follows. In section 2, the objectives to carry out this research are presented. Section 3 presents a brief overview of WMNs and the IEEE802.11s standard. Section 4 presents an overview of the routing protocols used in this study. Section 5 presents an overview of

the simulation models and scenarios setup. The performance results are presented in section 6 and section 7 concludes the paper.

II. OBJECTIVES OF THE STUDY

The objectives of this study are:

- To evaluate the performance of DSR, OLSR and HWMP protocols under different topology scenarios.
- To ascertain which protocol adapts quickly to topology changes and provides the best QoS in terms of least packet loss, least end-to-end latency and highest throughput.

III. WIRELESS MESH NETWORKS

WMNs consist of 3 devices namely mesh routers, mesh clients and mesh gateways. The mesh gateway routers are responsible of providing the network with internet access. The mesh routers are responsible for developing the main backbone of the wireless network and form the mesh network connections. The mesh clients provide network access to the users in the network [5]. When nodes become faulty or when one node goes offline, WMNs are able to dynamically self-organise and reconfigure themselves and therefore, get connected with an alternate connection [6].

The architectures of WMNs can be categorised into three main groups based on their roles and functions of the nodes:

- Backbone WMNs:* In this architectural setup, the mesh routers connect in a mesh way to which clients can be connected. This type of WMN architecture is very common in real world implementations [6]. In this paper, we focus on this type of WMNs.
- Client WMNs:* In this architecture, clients form a mesh among themselves. These client nodes perform additional functionalities such as routing and re-configuration as well as their normal functionalities of providing end user applications to users. Hence, mesh routers and mesh gateways are not needed in this type of architecture [6].
- Hybrid WMNs:* This architecture is the combination of the above two architectures consisting of backbone and client mesh. The mesh clients can access the network through either mesh routers or directly [6].

The IEEE 802.11s standard is developed for wireless mesh networks and mainly uses the 2.4GHz and 5 GHz unlicensed carrier frequencies [7]. In this standard, frame forwarding in WMN is based on the MAC addresses. In this standard, routing is done at the MAC layer (layer 2) and not at the network layer (layer 3) [8]. The idea to use layer 2 for routing comes from the fact that wireless links are prone to channel fading, path loss and shadowing, while wired links are not. A multi-hop routing protocol operating in a wireless environment must take into account these environmental conditions of the wireless links. In this standard, path selection is done by using MAC-addresses for routing [7].

This WMN standard known as IEEE 802.11s uses the Hybrid Wireless Mesh Protocol (HWMP) as its default protocol as described in section 4. A typical hybrid WMN architecture is shown in figure 1. The main components that make up a WMN in this standard are:

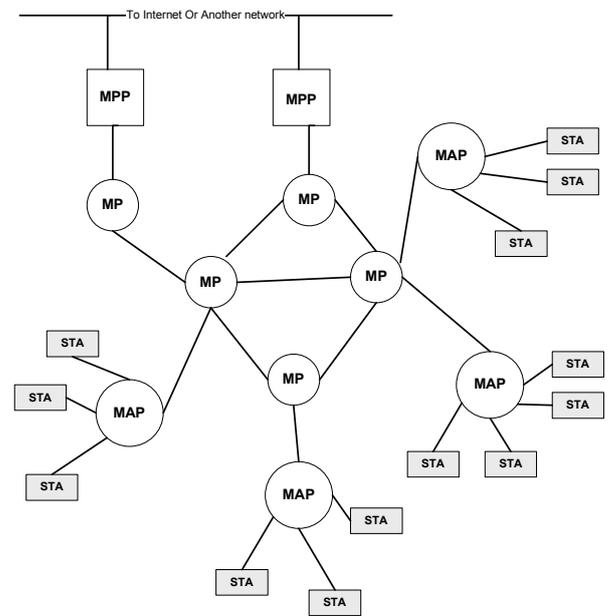


Fig 1: A typical WMN architecture for the IEEE 802.11s standard.

Mesh Points (MP): These nodes form mesh connections and provide services such as control and management [9]. They are responsible for establishing links with other MP's, MPPs or MAPs in their reach.

Mesh Access Points (MAP): These devices provide access to client stations (STAs) or other nodes that don't form mesh connections [9]. They provide access to stations to the mesh network.

Mesh Portal (MPP): These devices provide connection to the internet or to other networks [9].

Stations (STAs): These devices provide users access to the network.

IV. ROUTING PROTOCOLS

As discovered in literature, routing protocols for WMNs can be classified as proactive, reactive or hybrid. The proactive routing protocols are also commonly known as "table-driven" routing protocols. They check routes to all accessible nodes and ensure all nodes have up-to-date routing information in their routing tables. They do this by periodically distributing routing tables throughout the network to have up-to-date fresh lists of destinations and routes. Examples of such protocols are Wireless routing protocol (WRP), Destination Sequenced Distance Vector (DSDV) and Optimised Link State Routing (OLSR). In this study, the OLSR protocol is used. The reactive routing protocols are commonly known as "on-demand" routing protocols. These protocols search for paths from the source to the destination only when they are required to carry out routing. When a source node wants to send packets to the destination node and does not have route information available for that destination, it initiates a route discovery operation. The route discovery is done by sending our Route Request (RREQ) messages. The receiving nodes rebroadcast these messages if they are not the intended destination. When the destination node receives these RREQ messages, it replies with a Route Reply (RREP) packet.

If the link is not available or goes down, error messages of RERR packet are transmitted. Examples of reactive routing protocols are Dynamic Source Routing (DSR) and Ad-hoc On Demand Distance Vector (AODV). Reactive routing protocols are known to have less overhead and to provide better scalability than proactive routing protocols [10]. In this study the DSR protocol is used. Hybrid protocols have features of reactive and proactive protocols. In this study the Hybrid Wireless Mesh Protocol (HWMP) is used, which is a form of a hybrid protocol.

A. Dynamic Source Routing (DSR) Protocol

The DSR protocol works on the principle of Source Routing. In source routing, the sender determines the complete path containing nodes through which to forward packets. DSR mainly has two phases of operation, namely route discovery and route maintenance [11]. In the route discovery process, a source node broadcasts a RREQ packet to all its peers (neighbours) when a route is required. The RREQ packet records in its header, each node's ID to reach the destination. The RREQ packets are flooded throughout the network. The destination node on receiving this PREQ packet(s), generates a route reply message that is transmitted back along the discovered path to the source [12]. The source node on receiving the reply, updates its routing table with the path information containing all the nodes in its path to reach the destination [11]. This is also known as the route maintenance phase, where each node maintains a route cache and records the path information (hop-by-hop) to reach the destination. Route maintenance also detects network changes, and it updates its route cache.

When a node fails in the network, the upstream node on realising this immediately sends out a RERR message to its source node. When the source node receives this RERR message, it deletes all routes in the cache that contained the failing node in their path. If the source node does not contain alternate route information, it reinitiates the route discovery process. This protocol can contain many (alternate) paths to reach its destination node in its cache. If a node has failed, immediately an alternate path (route), if it exists in the cache, can be used to transfer data to the destination. This technique, therefore, reduces flooding of RREQ messages [11].

B. Optimized Link State Routing (OLSR)

OLSR uses a periodic update mechanism where alternate routes are immediately available when one node fails in the network [12]. Unlike DSR, OLSR does not perform source routing. Instead it performs hop-by-hop routing by each node using the most recent information in its routing table to exchange packets. The OLSR protocol uses Hello and Topology Control (TC) messages to perform link changes or discovery and spread this information throughout the network. The nodes in the network use this topology information to determine the suitable next hop(s) using the shortest hop forwarding path. In OLSR, the Hello messages are used by the nodes to discover the 2-hop neighbour information, as well as to perform a distributed election of a set of multipoint distribution relays (MPRs). Each node in the network selects their MPR. The neighbours of a node which are not in the same MPR set can only read and process packets, but cannot

perform retransmission of broadcast packets. In OLSR, each node also maintains a set of neighbours known as the MPR Selectors. These MPR nodes can source and forward TC messages contained in the MPR selectors [13].

C. Hybrid Wireless Mesh Protocol (HWMP)

As mentioned earlier, the IEEE 802.11s standard for WMNs uses a default routing protocol called HWMP which uses the airtime metric. The airtime metric uses a measure of link quality by using information from both the physical (PHY) and MAC layers. The metric is given in the equation below.

$$C_a = \left[O_{ca} + O_p + \frac{B_t}{r} \right] * \frac{1}{1 - e_{pt}}$$

where O_{ca} is the channel access constant, O_p is the protocol overhead, B_t is the number of bits in the test frame, r is the node transmission rate in Mb/s and e_{pt} frame error rate for the test frame having size equal to B_t .

HWMP operates in 2 modes, namely on-demand routing and in tree based routing. These two processes can be run concurrently to provide fast route discovery. The tree-based proactive mode performs a centralised operation using a root node. Due to the traffic flowing to this root node by other nodes in the network, the root node is prone to congestion [9]. If the MP is configured as a root MP, it then periodically broadcasts PREQ messages. If the root MP is not configured, the route is discovered through the on-demand component. In the reactive on-demand mode, this protocol initiates path discovery by broadcasting PREQ messages. The on-demand operation of HWMP is based on the Ad hoc On-demand Distance Vector routing (AODV). The on-demand operation uses MAC addresses with layer 2 routing and the radio-aware routing metric (airtime) for routing (radio metric (RM)-AODV). It does not use IP-addresses for routing and hop count as the routing metric as is the case in AODV working at layer 3 (the network layer) [14]. In the reactive operation, the network does not require routes through the root node as is the case with the tree-based operation.

The HWMP protocol is known to use this reactive (on-demand) routing for mobile devices and proactive tree-based routing for fixed devices in the network [9]. The MPs use RREQ and RREP messages to determine link metric information required by the airtime metric. HWMP caches each alternate route, so that if a node fails, an alternate route is available immediately [9].

In the proactive mode, there are two methods used to send routing information on how to reach the root MP. The first method uses RREQ messages and is mainly intended to form paths (routes) between the root node and all the MPs. In the second method, Root Announcement (RANN) messages are used which send out root information on how to reach the root. The PREQ method uses relatively higher resources than the RANN method.

The tree based routing process uses MP, if it exists. As mentioned earlier, the proactive tree-based routing is a centralized method and its operation depends on the root node. Routes are discovered and maintained using distance vector

routing [14]. The root node periodically sends out PREQ messages to all the nodes (broadcasts). The intermediate nodes also rebroadcast these PREQ messages and all the nodes that receive these PREQs, reply using PREP messages sent back to root node. This results in a proactive tree built, with the root node containing the routing table. This routing table contains all destinations within the network [15]. Sequence numbers are used by the root MP in their announcement roots. When an announcement is made, each node updates their metric and each MP chooses their preferred parent and also caches other potential parents. The sequence number is also used to determine how stale the route is. The nodes then send out periodic RREQs to the parents to maintain the path to the root. In the case, when the connection to the parent is lost, the MPs will notify its children, so they may locate their new parent and let the root node know by sending a RREP to the root [9].

In [16], a performance comparison was carried out for AODV, DSR and DSDV under various network conditions such as streaming MPEG4 traffic, network security attacks, routing misbehaving nodes and network load. In [13], a comparative analysis was done between AODV, DSR, OLSR and the TORA protocols. Two sets of simulation tests were carried out using 15 and 50 nodes. The HTTP traffic was used in their simulations. In [17], the performance analysis of AODV, OLSR and HWMP was carried out for a network of 100 static nodes that were placed randomly within an 800m x 800m area. The performance was determined by considering a number of network parameters such as traffic loads, network sizes and the number of sources. Their simulated results showed that HWMP offers the highest average throughput and lower end-to-end delay in comparison to AODV and OLSR [17]. Others papers carry out performance evaluations of protocols in mobile network scenarios where the nodes are moving, such as in [18] and [19].

The novel contribution of our work is that in this paper we perform a comparative evaluation of the DSR, OLSR and HWMP protocols in static mesh network in three network topology changing scenarios. The changing topology conditions are supposed to depict QoS provided by these protocols in these scenarios.

V. SIMULATION SETUP

For the performance evaluation of DSR, OLSR and HWMP, simulations were set up in OMNET++ using the INETMANET framework. OMNET++ is an open source application. Table 1 gives details of the experiment setup that that was done in OMNET++ using the INETMANET framework. The networks set up were for the backbone mesh WMNs. The Two Ray Ground radio propagation model was used in our simulations to emulate the physical rural environment.

The following metrics were utilised to carry out the comparative analysis of the protocols:

A. End-to-end Latency

This is a measure of the average time taken by a data packet to reach the destination from the source [23]. This measure includes all delays caused during the period it is being transmitted such as delay caused by the intermediate hops,

TABLE I: SIMULATION ENVIRONMENT

Network Setup	
Simulation Time	200 seconds
Topologies type:	Square Grid Topology
Number of Nodes	9,16,25 and 36 for the backbone
Mesh Sizes for Backbone nodes	3x3, 4x4, 5x5, 6x6
Backbone separation Distance	300m between nodes
Area	2.2km x 2.2km = 4.84km ²
Propagation Model	Two Ray Ground Model
Carrier Frequency	2.4 GHz
Data Rate	54Mbits/s
Application Data	UDP Basic Burst Packets
Radio Type	IEEE 802.11g
MAC Protocol	IEEE 802.11 DCF
Packet Size	512bytes
Rate of Transmission	100 packets/second

route discovery, interlayer delay, queuing, scheduling and other processes.

B. Packet Loss

This is the measure of the percentage of packets lost from the source to the destination. This value was measured at the destination:

$$Packet\ Loss\ (\%) = \frac{(Packet\ transmitted - packets\ received) * 100}{Packets\ Transmitted}$$

C. Receiver Throughput

This is a measure of the average rate of messages successfully received at the destination over a communication channel [24]. It measures the number of packets received per given time period.

Simulation Scenarios

We considered networks defined by a finite set of edges L and finite set of routers R (or vertices) on a directed graph $G = (R, L)$. The objective of our design is to find the shortest path when other vertices fail and reroute data between a source s , and a destination d . Three simulation scenarios were set up with different variable network topologies as shown in figure 2.

Scenario 1: In this scenario, at the start of the simulation, all the routers are functional and able to route data. At time $t = 50$ seconds, the second row nodes switch off, except the corner node. This forces routing to take the longest path to the destination. At time $t = 100$ seconds, the first node in the second row comes on, while the last one in that row switches off. This causes routing to switch direction and take another route to the destination. The scenario is shown in figure 2. The scenario was evaluated for 3x3, 4x4, 5x5 and 6x6 backhaul networks.

Scenario 2: In this scenario, the 6 x 6 network is used for the simulation. At time $t = 0$ seconds, all the nodes are functioning. At time $t = 25$ seconds, all the shortest path nodes switch off. At time $t = 50$ seconds, the second shortest paths nodes switch off. Finally at time $t = 75$ seconds, the remaining shortest path nodes switch off.

Scenario 3: In this scenario, the 6 x 6 network is used for the simulation. At time $t = 0$ seconds, all the nodes are functioning. At time $t = 50$ seconds, the centre four nodes switch off. At

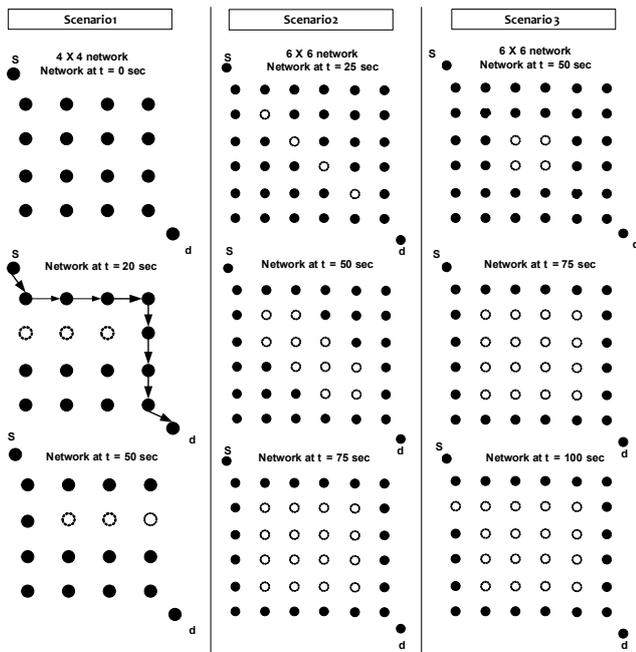


Fig 2: Network setups for the experimental scenarios.

time $t = 75$ seconds, the centre 4×4 nodes switch off leaving only the outer nodes functioning.

VI. RESULTS

The comparative analysis of the DSR, OLSR and HWMP protocols were evaluated under three network topology scenarios. In figure 3, a graph is presented that displays the packet loss percentage against the number of nodes for scenario 1. Networks sizes of 9, 16, 25 and 36 for the backbone nodes were used in these simulations. It can be seen from the bar chart that for the performance of the protocols under scenario 1, OLSR experiences the most packet loss for a network of 9, 16, and 36 nodes. The HWMP protocol experienced the least packet loss for all the measured network sizes.

The performance of the three protocols was measured in scenario 2 and the packet loss for a network size of 36 is shown in figure 4. In this scenario, the DSR protocol experienced the highest packet loss, followed by OLSR and with HWMP experiencing the least packet loss.

The performance of the three protocols was measured in scenario 3 and the packet loss experienced for a network size of 36 is shown in figure 5. In this scenario, the DSR protocol experienced the highest packet loss, followed by OLSR and with HWMP experiencing the least packet loss. For all three tested scenarios, it can be seen that HWMP experiences the least packet loss. HWMP is a more reliable for operation in environment with frequent failing nodes.

The end-to-end latency of the three protocols is measured in all three scenarios. Figure 6 shows the end-to-end latency experienced in a network size of 36. DSR had the most end-to-

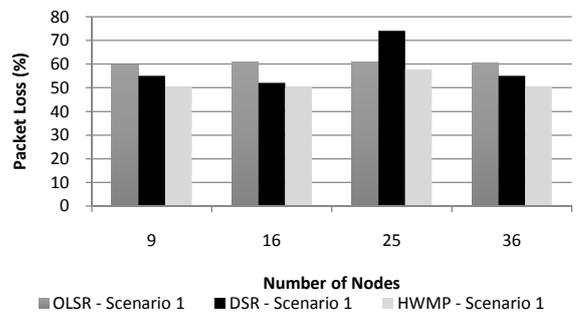


Fig 3: Packet loss measured for Scenario 1.

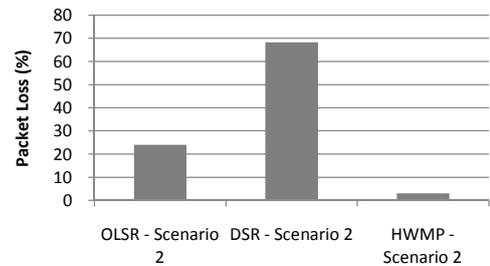


Fig 4: Packet loss measured for Scenario 2 in a network size of 36 nodes.

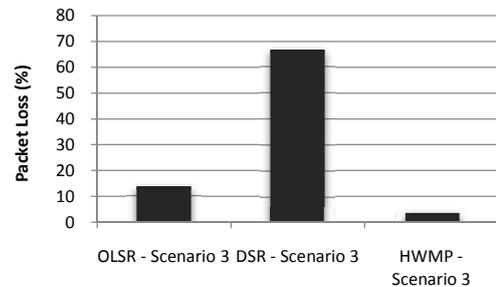


Fig 5: Packet loss measured for Scenario 3 in a network size of 36 nodes.

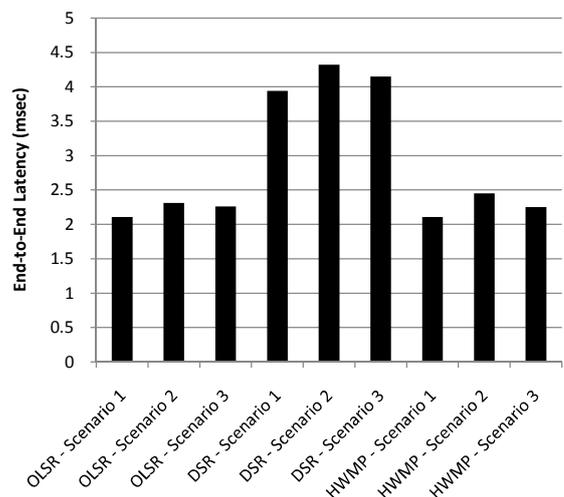


Fig 6: End-to-End Latency measured in the different scenario in a network size of 36 nodes.

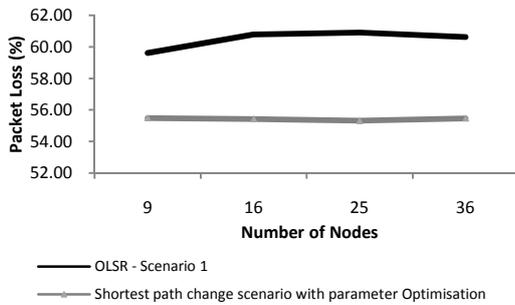


Fig 7: OLSR optimization performance after reducing TC messages and Hello messages interval durations.

end latency for all three scenarios. The end-to-end latency experienced by OLSR and HWMP in these scenarios was very close with HWMP having slightly higher delay.

Throughput is proportional to packet loss. Networks with more packet loss will experience lower throughput compared to networks with less packet loss. One can conclude from this, that the HWMP offers the highest throughput in all three scenarios.

For all the above simulations, it was assumed that our network does not experience any hidden terminal problem or exposed terminal problem. The OLSR protocol was also optimized by reducing the Hello messages interval from the default value of 2 seconds to 1 second and by reducing the Topology Control (TC) messages emission interval from the default value of 5s to 0.5s. The performance of OLSR was improved considerably with this optimization as can be seen in figure 7. The performance however, was still lower than HWMP under scenario 1 conditions. Lowering of the TC messages interval and Hello messages interval, the network is expected to experience more overhead.

VII. CONCLUSION

In this paper, a comparative analysis of the DSR, OLSR and HWMP protocols in wireless mesh networks using static nodes in the context of rural telemetry mesh networks was carried out. Simulated results obtained using OMNET++ and the INETMANET framework showed that the HWMP protocol had the least packet loss compared to DSR and OLSR for networks with frequently changing topologies. The OLSR protocol was optimized by reducing the hello messages interval and by reducing the topology control messages emission interval. Although the performance of OLSR was improved considerably, the performance was still lower than with HWMP in terms of packet loss. The OLSR and HWMP protocols experienced the least end-to-end latency within the same range, with HWMP experiencing slightly higher end-to-end latency. In the source initiated on-demand routing protocol, namely DSR, the routes are created when required, while with the proactive protocol, OLSR, up-to-date route

information is maintained at every node. For a rural telemetry network using WMNs under conditions of changing network topologies, the HWMP will be a better choice due to its better reliability in terms of less packet loss and low end-to-end latency. The HWMP provides better QoS compared to DSR and OLSR for the period of time before the network fault is attended to, favouring rural telemetry network deployment. Further enhancements to HWMP type strategies are still being considered.

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