BATMAN LAYER3 PROTOCOL IN WIRELESS MESH NETWORKS WMNs

Mohammed M. A. JOBBEH[1], Khaldoun I. KHORZOM[2], Hussein KHAYOU[3]

Wireless Mesh Networks are considered one of the promising trends in terms of developing networks in general, and particularly wireless networks. Mesh networks were developed first of all for military applications, then they have covered the civil fields. Hence, researchers concentrated on the academic research aspects as well as the commercial's standpoints. Mesh networks, based on the approved standards, facilitate the design of wireless networks with large space of coverage at lower cost. 802.11s release, based on HWMP protocol, delivers packets in mesh networks according to physical address on layer 2. In this paper, a brief description of 802.11s standard is presented, after that a comparison will take place with layer 3 BATMAN protocol. This comparison will be in terms of scalability with delay, throughput and PDR parameters, and the simulation is carried out in NS3 environment.

Keywords: HWMP, BATMAN, Layer2, Layer3, NS3

1. Introduction

Nowadays, wireless networks' standards and protocols attract more attention nowadays in academic and research fields. Thus, the increasing complexity of wireless network systems has led to the creation of many networking mechanisms within these wireless networks. New networking mechanisms have added more services to cope with all the requirements of rapid scientific advancement. one of those advancements was working on mesh networks, where wireless mesh networks are described as several hops between interconnected nodes as well as easily implement simple and profitable networks over a wide coverage area.

There are a set of reasons to reduce the need of the wired network that does not support the connections over distances of 100 meters at Ethernet mechanism-While the current 802.11 protocol depends on the wired network as backbone- it is noteworthy to address some of these fundamental reasons:

[1] Eng., Dept. of Telecommunication, Higher Institute for Applied Sciences and Technology (HIAST), Syria, e-mail: mohammed.jobbeh@hiast.edu.sy

[2] Prof., Dept. of Telecommunication, Higher Institute for Applied Sciences and Technology (HIAST), Syria, Senior Researcher, e-mail: khaldoun.khorzom@hiast.edu.sy

[3] Eng., Dept. of Telecommunication, Higher Institute for Applied Sciences and Technology (HIAST), Syria, e-mail: hussein.khayou@hiast.edu.sy

- Reliance on the wired network is expensive and inflexible. Moreover, wireless network coverage cannot be expanded due to its dependence on a fixed backbone.
- Centralized structure does not work effectively with new applications. Such as, in wireless games from peer to peer.
- Stable topology prevents stations from choosing the best routing to connect.

This achieved progress allowed the developing of an alteration to 802.11 networks; that had been applied to mesh networks, so-called 802.11s, where the HWMP " Hybrid Wireless mesh Networks Protocol" was defined and used, which is used for routing the physical address defined at the reference second Layer [1].

The amendment mentioned above 802.11s-which was not limited to the mesh networks, would provide innovative mechanisms, that have been invested by many companies that have been working on the principle of competition to reach the optimal routing protocol in order to achieve the greatest possible output at the mesh networks. In order to approach the introduced research's issue, it is an essential point to define the stated need that has led to the creation of the protocol 802.11s, which may be a new landmark in the mesh networks world. Hence, instead of using the term need, we might call it a paradigm shift or development of the ideas that are looking at the field of mesh networks. Wireless mesh networks that are based on the 802.11s protocol had promised to overcome the identified problems in 802.11 which depends on stable backbone. Many requirements have been met, but the routing mechanism affects the operation of this protocol, as this process was based on the physical address in the routing of packets. Therefore, a set of questions and suggestions were raised. These questions and suggestions will be articulated in this paper later on.

- How will routing be approached in this scientific paper to transfer from physical address to routing on the logical address "IP"?
- Will the adopted mechanism take us to a new stage, or will it place a further burden on mesh networks?
- After obtaining the results, what would the next step be?

The mechanisms of 802.11s will be discussed in the second section. While in the third section of this paper, the modifications that this protocol adds to the structure will be reviewed by presenting the HWMP protocol. After that a brief introduction to BATMAN protocol will be presented.

Section 4 presents BATMAN protocol, which operates on layer3 and offers the same functionality as HWMP which works on Layer2. Within the fifth section, the most significant works related to this subject is reviewed. The created work environment for comparison between the layer3 and layer2 is presented in section 6. Finally, the results will be discussed through section 7.

2. The evolutionary hierarchy from 802.11 to 802.11s

IEEE 802.11 appears as the most dominant standard for wireless networks. IEEE 802.11 standard first released in 2007, it describes a set of parameters and features that define the communication within local wireless network over 2, 3.6, 4, 5 GHz [3]. 802.11 protocol and its releases a, b, g, n, ac permit two types of operations: ad hoc and infrastructure, whereas 802.11s protocol, which appeared during 2011[2], expands the operability of infrastructure networks and permits the construction of a mesh network.

IEEE 802.11 standards can be divided according to following criteria:

1. Basic criterion: it forms the basic operation of the wireless networks and their devices.
2. Improved criterion: it improves the functionality of the basic operation, such as: security improvements, signal transmission, and interactions.
3. Sub-criterion: it supports some specific features of wireless networks, such as security, QOS, and MESH.
4. Un-utilized criterion: for future use.

This paper focuses on the sub-criterion 802.11s, moreover, it demonstrates the difference between the traditional wireless networks and wireless mesh networks. Fig. [1a] shows a wireless network with basic criterion, while Fig. [1b] shows wireless network with sub-criterion. Some definitions are required, and they are listed as the following [4]:

1. BSS (Basics Service Set): is considered a bedrock to 802.11 networks as this set consists of an Access point (AP) with stations (clients) communicating with the AP.
2. DS (Distribution System): is considered as a separation line between wired and wireless systems, and through it, signals will cross from / to wireless medium.
3. ESS (extended Service Set): consists of some BSSs connecting through DS, and it integrates with the local wired networks LANs.
4. DSS (Distributed System Service): is provided by DS to support the transfer of frames among APs, stations, and portals, or between stations within BSS itself in DSS).
5. Portals: logical points to transfer frames from a wired network to DS and vice versa.

The idea behind network structure in Fig. [1b] is adopted from wired distributed internet network connectivity but with wireless connection between transmitting points.

Fig. 1A

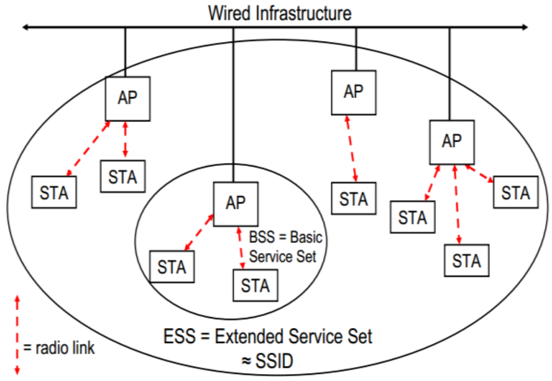

Fig. 1B

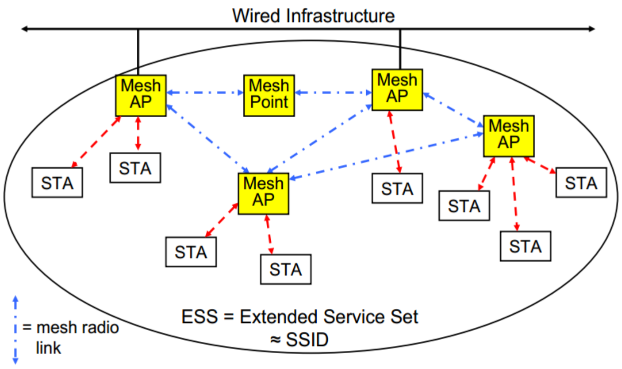

FIG. 1. Difference between mesh network and wireless network.

Fig. [2] illustrates an example of wireless mesh network. Stations in Fig. [2], denoted by a character, can be categorized according to their function in WMN. All H, I, K, L, N, O, Q and R points don't need any special component of Mesh-facility to communicate with their access points, as Mesh-facility is a set of enhanced functions, network's access rules, frames structure, mutual verification methods, and managed resources which are used to manage the data exchange between the autonomously operating stations, which don't have direct contact between each other within the wireless medium.

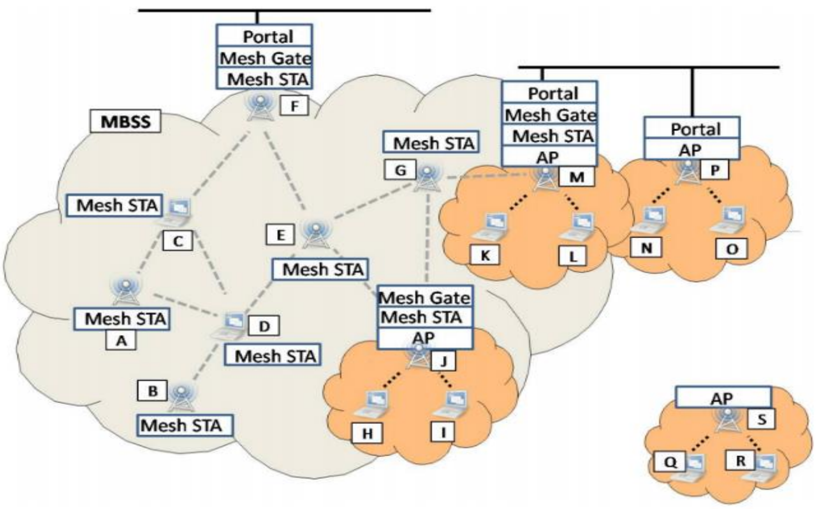

FIG. 2. An example of a WMNs.

- Points A, B, C, D, E, F, G, J, and M are Mesh stations, all of them are access points supported by Mesh-facility, except C and D which are not access points practically (just theoretically).
- Points A, C, D, E, and G are access points which passing the data without using them.
- The classic protocol 802.11 works within these points M, P, J, and S, therefore, we will call them transmission (access) points.
- M and P points work as a connection medium between two stations type PORTAL, it is a logical point, which allows building a bridge between a network supported by 802.11 and another network not supported by the same protocol.
- M and J points work as a connection medium between MESH network and non- MESH network; thus, it is called GATE. It may be any component supported by the function of mesh stations, and it gives the ability of access to one or more of DS through the wireless medium of the MBSS.
- MBSS may contain several gates or may contain none of them, as MBSS is a BSS network supported by mesh functionality between their stations.

And at the top of that, WMNs could be identified as networks consisting of an infrastructure- backbone of WMNs structure, clients receiving the service, and a hybrid wireless network which defines the relation between MESH networks routers according to the implemented protocol, as illustrated in Fig. [3]. Our research is concentrated only on this hybrid mechanism, other standardized components will not be discussed or changed, for example, communication between the transmission points and the clients is standardized by 802.11 protocol.

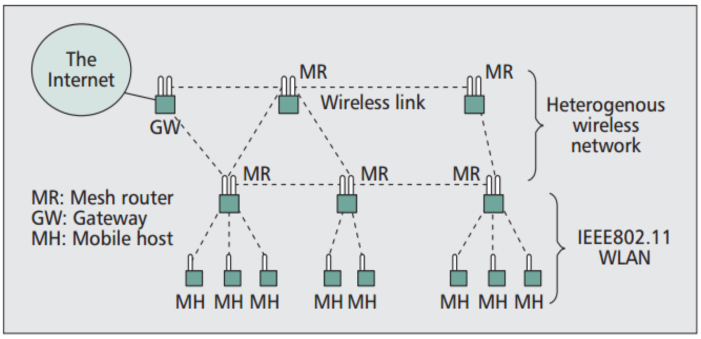

FIG. 3. WMNs divided into three main sections, MR, GW, MH.

3. The general concept of the HWMP and BATMAN protocols within WMNs networks

As stated above, the idea of the standard 802.11s is based on supporting wireless connection in places where wired networks are difficult to deployed. The modified protocol depends on 802.11 protocol when communicating between access points and users from one hand, and from the other hand depends on a hybrid method to communicate between network nodes which support the activation of wireless connection activation. Notably, all communications and packets routing depend on the physical address. Given the pros in the 802.11s protocol we can summarize the following:

1. The protocol has flexibility (as opposed to wired networks), self-processing capability if a node has lost connectivity. Moreover, it has the ability to reconfigure the wireless network with the most appropriate way.
2. Helps to solve some wireless communication's problems. Such as, collisions in dense environments.
3. Adds a type of confidentiality (which might be compromised) in wireless communication

As described in the draft, there are three elements described in the 802.11s based network:

1. The Mesh ID.
2. Path selection factors.
3. Path selection protocol.

Perhaps these three factors together define the general profile of the mesh network. However, we have to notice that the mesh station can support more than one profile, but all nodes in the mesh network must share the same profile.

Two mandatory procedures are used to define the profile (structure) of mesh:

1. The Routing protocol HWMP.
2. The Routing Metric ALM (Airtime Link Metric).

A. HWMP protocol

HWMP protocol's function is based on two methodologies, depending on the different topologies:

1. On-demand/reactive Routing method:
   Adopted for mesh nodes that test the changing environments.
2. Tree-based Routing method:
   Adopted for nodes in fixed networks topology.

Function of HWMP is divided into four stages, starting from establishment and preparation of the path, until the delivery of data, in addition to updating the path in case of failure, these stages are:

- RANN - Root announcement.
- PREQ - Path request.
- PREP - Path reply.
- PERR - Path error.

Moreover, as mentioned above, what the IEEE 802.11s protocol does, is to merge the expansion of the 802.11 protocol in terms of framing format and its general structure. The new version supports four or six physical addresses, as well as a new sub-frame that expands the HWMP's data and management frameworks.

B. Routing Metric ALM

ALM calculations are made according to the equation (1), where a test frame is sent for calculation the amount of the consumed time [15]:

$$Ca = \left[OcaOp + \frac{Bt}{r} \right] \frac{1}{1-ef} \tag{1}$$

Where:

- Oca: channel access overhead.
- Op: protocol overhead that changes according to the physical layer design.
- Bt: length of test frame.
- r: The flow rate, calculated by Mbps for the test frame transmitted by the mesh station.
- ef: Measurement error rate of test frame.

Table 1 shows the values of the previous constants for both 802.11a and 802.11b protocols.

Table 1

Constant values of ALM metric for 802.11a and 802.11b

Parameter	802.11a	802.11b	Description
Oca	75 μs	335 μs	Channel

			access overhead
Op	110 μs	364 μs	Protocol overhead
Bt	8224	8224	#bits in test frame

C. BATMAN Protocol

Firstly, we will talk first about OLSR protocol, because it is the basis of BATMAN protocol.

OLSR is a pro-active protocol that relies on the Link-State algorithm to determine the most efficient path between nodes, it relies on tables and uses a structure called Multi-point Relaying (MPR) which increases the streaming through an effective network routing scheme based on the following [17]:

1. Utilising a subset of the nodes to deliver the data instead of using all the nodes to perform this operation.
2. Reducing the total number of control packets that are required to build routing tables and that is due to lowering the total number of messages when communicating with a partial number of nodes.
3. Each MPR is elected in such a way that each node makes the connection by MPR by just one node.
4. Local network information is shared between each MPR in order to perform maintenance for all tracks across the entire network.
5. The above properties provide each MPR with a complete routing tables for all tracks, which in turn reduces the overall control messages of the existing topology.

BATMAN protocol is a routing protocol for mesh networks, its work based on a distance vector, and this protocol is classified within proactive routing protocols. Each node maintains its routing tables by adding or containing all possible hops for all other nodes that are configured for the WMNs. This protocol is designed to overcome the shortcomings of the OLSR protocol such as spreading and inadequate performance [18].

4. BATMAN protocol within WMNs networks

BATMAN is divided into two Routing Protocols for WMNs – based on layer3 routing- is considered as the most widely spread than BATMAN-adv based on layer2.

Function of both protocols is based on the definition of several parameters:

1. OGM (Originator Message): A message that is broadcast by the originator periodically informs the neighboring local nodes with the originator.

2. RQ (Receiving Link Quality): The number of packets received by the node from other nodes.
3. EQ (Echo Link Quality): The number of packets broadcasted by the originator and which are re-transmitted to it by his vicinity.
4. TQ (Transmission Quality): The ratio of EQ to RQ

Using the TQ parameter, which expresses a compromise solution between fewer hops and more stable links, we can determine which nodes have correctly received OGM and which express a good directing path. Fig. [4] shows the OGM message when it is announced, which is included in the UDP (User Datagram Protocol) packets, where the OGM message contains most important information for the BATMAN routing algorithm.

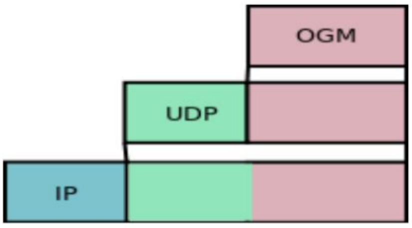

FIG. 4. OGM message encapsulation.

5. Related Work

As stated above, the use of the 802.11s, which uses the HWMP protocol, depends on the physical address instead of the usual routing network which uses the logical address. The routing process affects the operation of this protocol and creates the following obstacles:

1. Bringing the physical addresses consumes excessively the network energy [5].
2. The flow will be considered as a large load on the network in case of approving the physical address for the routing process [6].
3. Adopting the protocol on 6 physical addresses to perform the routing process [7].

These problems have led many academics to search for an alternative and to seek for the routing process through the logical address in WMNs. We will conduct a comparison among the most popular protocols that are employed for WMNs. We will present an overview of the most successful protocols at the layer3 to conclude the reason for selecting the BATMAN protocol among these protocols. The performance of the AODV and BATMAN-adv protocols was discussed in [8]. The study showed the superiority of the BATMAN-Adv protocol in environments with specific interference and in environments with a large distance between its nodes. For AODV protocol that has been used with more than one of its versions, the protocol's function was shown a weakness, when using multiple hops. Then we notice that the superiority of BATMAN protocol over the AODV protocol in uplink flow [9], where the network is simulated with one moving node. In [10] a simulation of a moving robot has been done along a path through three stabled points on that path. BATMAN's superiority over the AODV protocol was shown in terms of the mean of re-routing and packets loss rate. But note that it failed to reset the path initially, therefore, the time to send OGMs was reduced, which in turn increased the protocol's effectiveness.

Studies in [11] showed superiority of the BATMAN protocol over BABEL, AODV and OLSR, where a work platform of 7 fixed wireless points was built, and the results were as the following:

1. BATMAN protocol is more reliable and stable than other protocols.
2. BABEL is slightly superior in terms of flow and convergence time.

For BATMAN-Adv protocol, it was compared to a version called OPEN 802.11S, which is a 802.11s version of the standard before its standardization In [12], Where a four-point platform was used. The study showed superiority of the BATMAN-Adv protocol in terms of stability in building the routing process.

The performance of BATMAN, BABEL and OLSR was compared to BATMAN-Adv in [13], where BABEL outperformed other protocols in terms of routing load.

One comparison was between HWMP and BATMAN protocol in [14]. The study proved superiority to the BATMAN protocol in terms of PDR, flow and re-direct maintenance (as the routing load average). The packet loss is also less in HWMP than BATMAN protocol, while the BATMAN protocol shows a greater performance in terms of delay (end-to-end).

Previous studies have given a clear view of many existing protocols, which in most cases gave the BATMAN superiority over the other protocols in all scenarios. We noted that there was superiority to BABEL in some cases discussed in [15]. But due to the fact that more studies were carried on BATMAN, our study will rely on BATMAN protocol rather than BABEL.

Next, a comparison between HWMP and BATMAN will be carried out.

6. Environment and design

The basic parameters used in comparison are:

1. Average Throughput: Number of bits received divided by the time difference between the arrival time of the first packet and the arrival time of last packet.
2. PDR- Packet Delivery Ratio: Number of packets received divided by number of packages sent.
3. Average End-to-End delay: Total of the delays of the received packets divided by number of packets received.

Most of the comparisons will be with the values which are expressed in the previous parameters.

The scenario of the simulation depends on creating a grid, where the points are distributed on all areas of the network in an orderly manner. The distribution should consider the following situations:

1. Position points for each other and for the network.
2. The duration of each communication between two nodes.
3. The sending node and the receiving node.

The above situations are the same for all applied scenarios. The parameters - that will be changed during simulation- will be Protocol-specific parameters. Attention should be considered to some of the default values represented by some of these parameters, which are:

1. DO flag within the HWMP protocol should be activated.
2. Cancellation the Beacon Collision Avoidance, because it limits the performance of the HWMP protocol and reduces the flow.
3. Activate the fourth version of BATMAN IV.

The values used in Tables 2 and 3 reflect those used for both protocols, whether they are specific values to the protocol or common values to both protocols.

Table 2

Default values for batman and hwmp protocol

BATMAN		**HWMP**	
Version	4	Active Path Timeout	100 second
TTL	50	Active Root Timeout	100 second
Interval between broadcast OGMS	1seccond	Max PREQ Retries	5
Local TQ Window	64	PREQ Threshold	10
Max TQ value	255	Data Threshold	5
Max sequence number	65535	Do flag	Active
Hop Penalty	5	Rf flag	passive

Note that Table 3 does not give specific values for parameters. Such as nodes number, data rate and transmission power. Different values of these parameters will be considered in our simulation to evaluate the performance of our protocols.

Table 3

Common Default values for BATMAN and HWMP protocol at physical layer and channel

Node Velocity	20 m/second
Packet size	1024 Byte
Settling Time	30 second
Simulation Time	200 second
Transmission power	variable
n. of nodes	variable
Data Rate	variable

Physical layer attributes		**Pathloss attributes**	
EnergyDetectionThreshold	-89 dBm	type	Log-distance
CcaMode1Threshold	-62 dBm	Reference distance	1 meter
Tx and Rx Gain	1 dB	Reference loss	46.7 dB
RxNoiseFigure	7 dB	exponent	2.7

Based on the data of the two previous tables, we will build our network within the NS3 simulation environment, which we will apply the scenarios in, the number of nodes, the data rate and the transmission power will be changed. After that, the impact on the performance of the two protocols due to the applied changes will be noted.

7. Results

In the following section, each paragraph represents the simulation results for each protocol according to different scenarios.

7.1. Number of nodes

Number of nodes will take the following values (4-9-16-36-64) and the performance of these two protocols will be presented in the following paragraphs, where we will notice the effect of changing the number of the nodes on BATMAN and hwmp performance.

7.1.1. Packet delivery Ratio PDR

Fig. [5], shows the effect of changing in PDR according to changes of node numbers in the network. We notice the superiority of BATMAN protocol in dense environment, while the worst performance is shown with less dense environments. The performance of both protocols is equal if number of nodes is equal to (11), while the performance of HWMP protocol is very bad in dense environment.

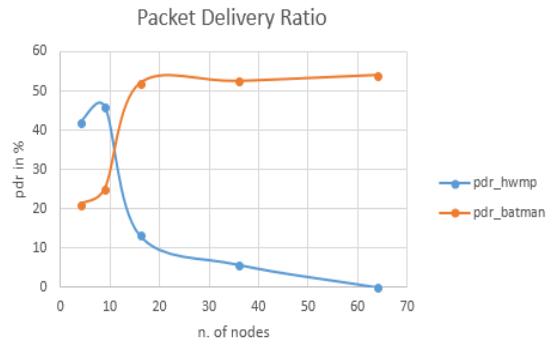

FIG. 5. PDR for n. of nodes.

This issue might be attributed to the inability of the HWMP protocol to perform any data routing between nodes when the number of nodes are greatly increased. Therefore, this protocol is considered within the protocols that work only in limited environments, and that affects adversely the work of the HWMP protocol within mesh networks.

Here, BATMAN shows greater stability and better performance.

7.1.2. End-to-End Delay

Fig. [6] shows the effect of end-to-end delay. We notice performance stability of both protocols in less dense environment, and then, while the number of the nodes increase, end-to-end delay increases accordingly in BATMAN protocol. In HWMP protocol, we notice that there are abnormal points in performance while nodes numbers increase.

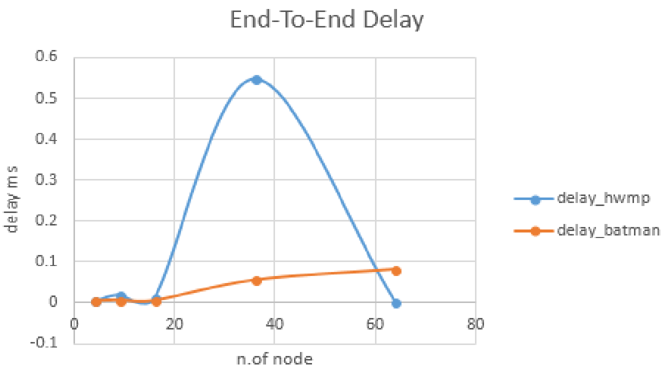

FIG. 6. End-To-End delay for n. of nodes.

This is because increasing the number of nodes increase the routing path. thus, the delay is increasing, the logical delay is increased in BATMAN, while in HWMP we see anomaly at its performance and then reaching a zero delay, which shows that the dense environments negatively affect the performance of this protocol, a way similar to the previous one.

Here, BATMAN protocol shows greater stability.

7.1.3. Throughput

Fig. [7] shows a performance superiority of HWMP protocol over BATMAN protocol, where we note a larger data flow in the HWMP protocol. Note that while nodes number increase, the performance of HWMP protocol decreases, that means there is no routing process with access to the dense environment for HWMP.

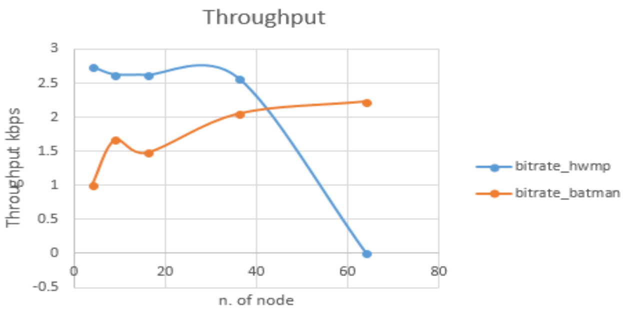

FIG. 7. Throughput for n. of nodes.

To sum up, BATMAN protocol shows greater stability in case of increasing the nodes of the network. Thus, BATMAN protocol overcomes HWMP protocol at this point.

However, we can say that medium-density environments give equal performance to both protocols. On the other hand, the drop-down on the mesh networks – which characterizes and strives to accommodate all nodes- we can say that the BATMAN protocol is the best option in this scenario

In the following scenario, the number of nodes within the network will be 25 nodes, and they will be distributed throughout the network regularly while maintaining the basic network design. Consequently, the work is based on changing the data rate and the transmission power with regard to the stability of the other factors, the data rate or the transmission power.

7.2. Data Rate

Data rate will take the following values (256-1024-4096-8192-16384) Bps and the performance of these two protocols will be presented in the following paragraphs, where we will notice the effect of changing the data rate on the performance of batman and hwmp

7.2.1. Packet delivery Ratio PDR

Fig. [8], shows the superiority of BATMAN protocol, while the performance of HWMP protocol is very bad when we increase data rate. The reason of the significant loss of data is attributed due to the increase number of data transmitted in both protocols, which leads us to prefer small values of data rate.

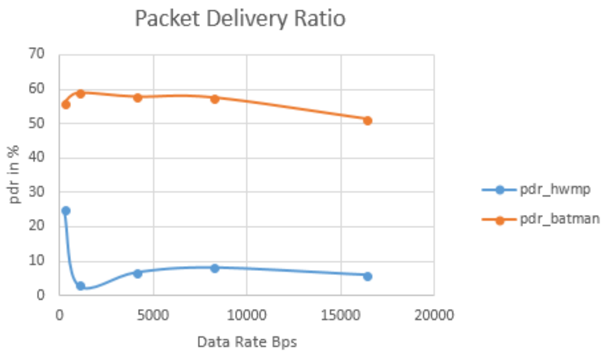

FIG. 8. PDR for data rate (Bps).

Here, BATMAN shows greater stability and better performance.

7.2.2. End-to-End Delay

Fig. [9] shows the effect of end-to-end delay. We notice performance stability of both protocols, but for the low data rate end-to-end delay is greater in HWMP protocol.

This is because the increased data rate increases the consumed data and the packets will be lost, so the logical delay is decreased in both protocols when increase the data rate, so BATMAN protocol shows greater performance.

FIG. 9. End-To-End delay for data rate (Bps).

7.2.3. Throughput

Here we see the superiority of the HWMP protocol over the BATMAN protocol, Fig. [10]. We can say throughput takes values that are close to the total data rate in the HWMP protocol. This is considered as a consumption of all network's resources. Therefore, the HWMP protocol consumes all the network's capabilities to deliver the sent data to the destination.

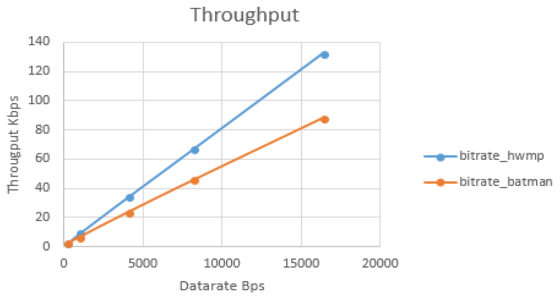

FIG. 10. Throughput for data rate (Bps).

We can say that the BATMAN protocol shows greater performance in case of changing the data rate, Although HWMP is beat in case of throughput, where the reason of the significant loss of data is attributed due to the increase data rate in both protocols, which leads us to prefer small values of data rate, hence, the BATMAN protocol overcomes the HWMP protocol at this point.

7.3. Transmission Power

Transmission power will take the following values (7.5-18-25-50) dbm and the performance of these two protocols will be presented in the following paragraphs, where the impact of changing's power on both will be noticed.

7.3.1. Packet delivery Ratio PDR

Fig. [11], shows the superiority of BATMAN protocol, while the performance of HWMP protocol is very bad.

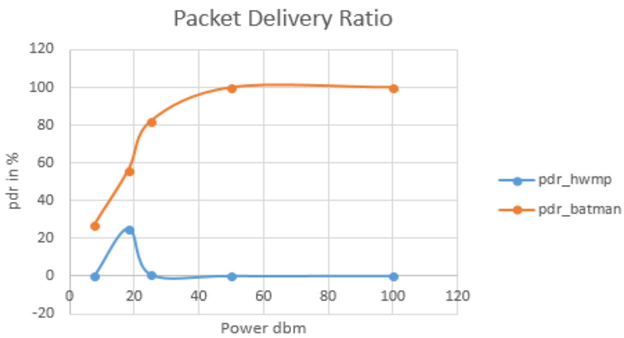

FIG. 11. PDR for power (dbm).

Here, BATMAN shows greater stability and better performance.

7.3.2. End-to-End Delay

Fig. [12] shows the effect of end-to-end delay. We notice performance stability of both protocols, but for the low power end-to-end delay is greater in HWMP protocol.

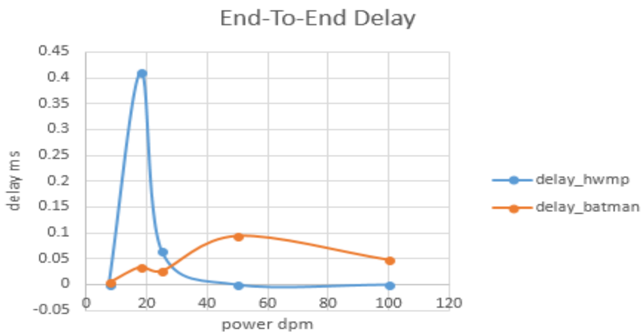

FIG. 12. End-To-End delay for power (dbm).

Here, both protocols show stability.

7.3.3. Throughput

Here we see the superiority of the BATMAN protocol over the HWMP protocol, Fig. [13].

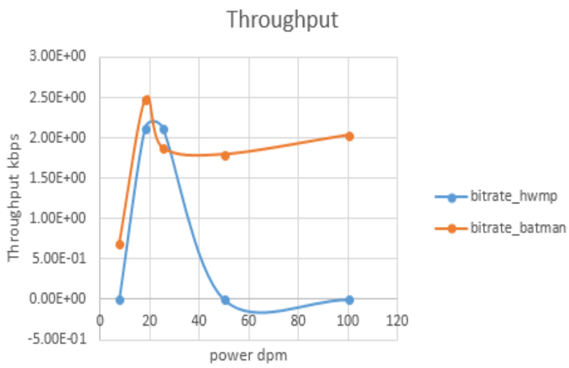

FIG. 13. Throughput for power (dbm).

To summarize up, BATMAN protocol shows greater stability in case of increasing the transmission power in the network, and we notice that the HWMP protocol shows a notable anomaly in many results when we increase the power, so BATMAN protocol overcomes HWMP protocol at this point.

8. Conclusions

In this paper, a practical comparison of a layer 3 protocol to a layer 2 protocol was carried out to examine the performance of routing between IP and Mac address. The BATMAN protocol demonstrated superiority over the HWMP protocol.

The stability of the BATMAN simulation results was observed at PDR, throughput and delay, while the anomaly in delay scenarios showed that work on the layer 2 was less stable and less reliable than working at layer 3. For future researches, we seek to modify the BATMAN protocol at the routing level to become closer to the logic of the WMNs and to see how the results will change when compare it to HWMP protocol.

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