A Pragmatic Evaluation of Distance Vector Proactive Routing in MANETs via Open Space Real-World Experiments

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Abstract. Mobile Ad hoc Networks constitute a promising and fast developing technology that could significantly enhance user freedom. The flexibility provided by such networks is accompanied by unreliability due to notably dynamic conditions that render routing quite problematic. For that reason, the research community has proposed multiple protocols claimed to address this issue, however, only few have been tested via real experiments, while even fewer have reached maturity to become readily available to end users. The main purpose of this paper is to pragmatically evaluate a promising, complete, and finalized MANET protocol via real-world experimentation in open space environment. The considered protocol, with the acronym B.A.T.M.A.N, which is based on distance vector proactive routing, was tested in different networking scenarios that revealed its ability to satisfactorily handle traffic under different conditions.

Keywords: MANET · Proactive routing · Distance vector · B.A.T.M.A.N

1 Introduction

The rapid technological development during the last years offered significantly better communication opportunities between people worldwide. Extensive use of Internet by millions of people enhances collaboration and information sharing. As networking activities are expanded, the demand to enable fast and reliable exchange of information between users increases and its fulfilment becomes more challenging. To meet these requirements, new types of networks have emerged and have been combined with traditional networks.

Taking into consideration the dynamic features of modern users' behaviour, the need for mobility support in regards to communications is inevitable. Apparently, wireless networks are playing a crucial role in providing this type of support. Meanwhile, technology enhancements via the development of more powerful devices allow the adoption of advanced and complex software, which leads to increased demands for network capacity. In this context, multi-hop ad hoc networks where introduced to address networking issues in infrastructureless environments [1]. The most popular type of such networks draws significant interest from the related industry and research community;

P. Pillai et al. (Eds.): WiSATS 2015, LNICST 154, pp. 345–358, 2015.
DOI: 10.1007/978-3-319-25479-1_26

Mobile Ad Hoc Networks (MANETs) are multi-hop networks with the ability to support user mobility [2].

MANETs were initially intended for military environments and disaster or emergency operations, attributed to their ability of networking without being depended on a fixed infrastructure. Nowadays, this type of networking is considered promising for everyday tasks as well and is expected to contribute directly to the enhancement of existing wireless and cellular systems. In order to understand the basic concept of multi-hop ad hoc networks, it is initially clarified that the simplest ad hoc network, or peer to peer network, is the direct connection of two stations or mobile devices which lie inside each other's range. This type of networks, where entities always communicate directly in pairs, is known as single hop, since data are sent using only one hop, from a specific device to another, therefore there is no need for routing decisions. Bluetooth piconet (Master – Slave) is a typical example of single hop network [3].

The main limitation of single hop networks is the requirement for nodes to be mutually in range in order to communicate. To overcome this restriction, the multi-hop ad hoc model was introduced. In general, a multi-hop ad hoc network can be considered as the union of three or more wireless devices that form an autonomous system connected via wireless links, which do not rely on a fixed base station or predefined network architecture and they are free to dynamically and unpredictably enter or leave the network. The basic prerequisite for the realization of such a system is the responsibility of nodes in range to dynamically discover each other [4]. Multi-hop networking allows packet forwarding in an ad hoc fashion, where the intermediate nodes enable end-to-end packet delivery between out of range nodes.

The possible applications and potential uses of MANETs are practically endless; new application fields keep rising leading to the certainty that this type of networking can find wide acceptance in the near future. In fact, some of the related individual application fields have now matured enough to constitute new areas of research. General purpose MANETs refer to infrastructureless scenarios, where there is no central authority in charge. Hence, in such cases, network behaviour totally depends on the participating devices; as a result there are significant complexities and design concerns due to unpredictable topology changes and battery constraints. A really challenging environment for the deployment of MANETs is military. One of the first needs for infrastructureless networking was originated by military services for the interconnection of soldiers and vehicles in the battlefield. The harsh and highly dynamic conditions of such an environment place significant limitations in realizing reliable communications. For that reason, MANETs are introduced as promising approach. The use of ad hoc networking by emergency services is also a leading application field. The inability to rely on existing infrastructure in cases of disaster increases the demand for dynamic connections.

Another related architectural concept that has attracted significant attention from both the research community and industry is the combination of mobile nodes with fixed networks, also known as hybrid MANETs. The flexibility and scalability of this type of networks allow easy extension of the services provided by the existing infrastructure over a large area, while allowing direct communication between the mobile entities. A promising example is VANET (Vehicular Ad hoc Network), which consists of communicating vehicles as well as fixed devices along the transportation infrastructure (signs, traffic lights, road sensors). The possible individual applications can take advantage of the following three communication types: inter-vehicle, vehicle-to-roadside, and inter-roadside [5].

The main feature that distinguishes MANET from any other type of network is its ability to effectively route information over unreliable and dynamic links in a changing topology. For that purpose, numerous protocols have been proposed, which most of the times are evaluated through theoretical models, simulators or custom prototypes, raising this way concerns about immediate practical applicability. The main motivation of this paper was to explore the actual network behaviour when applying a widely available and ready to use MANET routing protocol via experimentation in real-world scenarios. The rest of the paper is organized as follows: Sect. 2 studies background issues in multi-hop ad hoc routing and related state of the art work, the next section presents the followed network evaluation methodology, Sect. 4 provides and discusses the experimental results, and the paper is concluded in Sect. 5.

2 Background

2.1 MANET Routing Protocols

The most important characteristic of MANETs is efficient data routing and forwarding. Routing is responsible to identify a path toward a destination, and forwarding is in charge of delivering packets through this path. Even though MANETs are quite promising for the future of networking, several challenges must be considered, such as scalability, quality of service, energy efficiency, bandwidth constraints, device heterogeneity, and security. In combination with the unreliable nature of wireless networks makes clear why traditional routing protocols for wired networks are not sufficient for MANETs, where the routing process should take into account the topology dynamism and unpredictability. For that reason, a number of MANET routing protocols have been recently proposed in literature, which can be classified as proactive, reactive, and hybrid [1, 4].

Proactive routing protocols dictate the exchange of routing control information periodically and on topological changes. Typical examples of proactive routing protocols for multi-hop ad hoc networks are: Destination Sequenced Distance Vector (DSDV) [6], Global State Routing (GSR) [7], Hierarchical State Routing (HSR) [8], Optimized Link State Routing Protocol (OLSR) [9], and Better Approach to Mobile Ad Hoc Networks (B.A.T.M.A.N) [10]. Reactive routing protocols create forwarding paths on-demand. Typical examples of reactive (on-demand) routing protocols are: DSR (Dynamic Source Routing) [11], AODV (Ad-Hoc on-Demand Distance Vector) [12], TORA (Temporally Ordered Routing Algorithm) [13], and ABR (Associativity Based Routing) [14]. Hybrid routing protocols are actually the combination of proactive and reactive routing protocols, which means that routes within node's zone are kept up-to-date proactively, whereas distant routes or routes in node's neighbouring zones are set up via reactive routing protocols.

OLSR is one of the most popular protocols for MANETs. It is a proactive, link state routing protocol which employs periodic message exchange to update the topological information in each node for neighbourhood discovery and topology information dissemination, making the routes always available when required. This protocol is optimized for multi-hop ad hoc networks, since it compacts message size and reduces the number of retransmissions needed to flood these messages. Specifically, OLSR includes three generic mechanisms [9]: neighbour sensing, efficient flooding of control traffic, and sufficient diffusing of topological information for optimal routes provision.

Even though OLSR is currently one of the most widely adopted routing protocols in MANETs, it has significant drawbacks. Inefficient bandwidth usage is considered as one of the main weaknesses of OLSR, since each node periodically sends updated information regarding network topology throughout the entire network. Moreover, in order to reduce network flooding, MultiPoint Relays (MPRs) are used to forward topological messages. Thus, in a highly dynamic network environment with rapidly moving nodes, the efficiency of OLSR in supporting data forwarding heavily depends on the network's ability to fulfil frequent exchanges of control messages [15]; a process which is quite unreliable. Despite the fact that latest versions of the protocol are enhanced with new features, the existing limitations remain challenging, due to the rapid growth of mesh networks and the protocol behaviour when calculating the whole topology. For instance, calculating a network topology consisting of 450 nodes takes several seconds for a small CPU [16, 10]. For these reasons, the development of alternative approaches became imperative.

2.2 B.A.T.M.A.N. Routing Protocol

A new solution known as B.A.T.M.A.N algorithm offers a decentralized fashion of spreading topology information by dividing the knowledge of best end-to-end path to all network nodes. The intention is to maintain the knowledge only for the best next hop to all other nodes in the network, thus, there is no need to keep information about the entire network. Moreover, B.A.T.M.A.N offers a flooding mechanism which is event-based and timeless, in order to prevent the increase of opposing topology information and also to restrict the quantity of flooding mesh topology messages. This mechanism contributes in the network performance by limiting control-traffic overhead, making the protocol suitable for networks composed of unreliable links.

According to the algorithm implemented in the B.A.T.M.A.N protocol, nodes announce their presence to their neighbours by transmitting broadcast messages known as originator messages or OGMs. Moreover, the neighbours re-broadcast the OGMs to inform their neighbouring nodes about the presence of the initiator of the OGM message in the network. This process continues until the initiator's OGM is delivered to all nodes, hence, the network is flooded with originator messages. The OGM packet size is 52 bytes including IP and UDP headers. It contains the originator address, the address of the node transmitting the packet, a TTL value and a sequence number. If the mesh includes poor quality wireless links, the OGMs that follow unreliable paths suffer high packet loss or delay, so OGMs that travel over high quality links propagate faster and more reliably. Given that an OGM may be received numerous times by a node, it can be distinguished by the included sequence number. Moreover, "each node re-broadcasts each received OGM at most once and only those messages received from the neighbour which has been identified as the currently best next hop (best ranking neighbour) towards the original initiator of the OGM are used". This is known as selective flooding of OGMs, used to announce the presence of a node in a mesh network. In a nutshell, the working principle is that each node maintains only information about the next link through which the node can find the best route, unlike OLSR, where nodes broadcast "Hello" messages to maintain topological information about the entire network.

B.A.T.M.A.N. advanced (often referenced as B.A.T.M.A.N-adv) is the latest version of the related proactive distance vector routing protocol and is under continuous improvement. It is actually an implementation of the B.A.T.M.A.N protocol at layer 2 of the ISO/OSI model, in the form of a Linux kernel module. In fact, the terms "B.A.T.M.A.N" and "B.A.T.M.A.N-adv" are now used interchangeably, since the latest version of the protocol is the only real option today. It is noted that most of the routing protocols for wireless networks, including the previous implementation called B.A.T.M.A.Nd, transmit and receive routing information and make relevant decisions at layer 3 by manipulating the kernel routing tables. Over the years, with the intention to improve routing performance, B.A.T.M.A.N has evolved from layer 3 to layer 2, without alternating the principles of the underlying routing algorithm. Layer 2 implementation of B.A.T.M.A.N (i.e. B.A.T.M.A.N-adv) transports data traffic as well as routing information using raw Ethernet frames. This is achieved by emulating a virtual network switch of all participating nodes, until the encapsulated traffic is forwarded and delivered to the destination node. In this manner, network topology changes do not affect the participating nodes, since they appear to be link local and unaware of the network topology.

B.A.T.M.A.N-adv is implemented as a kernel driver, in order to provide minor packet processing overhead under heavy load. The objective is to utilize a minimum number of CPU cycles for packet processing, considering that when in user space each packet had to go through the "read()" and "write()" functions to the kernel and back, which procedure was limiting the available bandwidth especially in low-end devices. B.A.T.M.A.N-adv resolves this problem, since it is implemented in Linux kernel.

This work adopts the B.A.T.M.A.N-adv protocol to evaluate the network behaviour of distance vector proactive routing in MANETs with ready-to-use solutions under realistic conditions. Toward this direction, we deployed open space scenarios and employed suitable network evaluation tools, described in the next section.

3 Evaluation Methodology

3.1 Evaluation Tools and Metrics

In order to setup and reveal diagnostic information for the testing network, the Batctl tool was employed [17]. It can be used to configure the B.A.T.M.A.N-adv kernel module and also for presenting information regarding originator tables, translation tables, and debug log. Batctl also includes commands such as ping, traceroute, and tcpdump which are modified to layer 2 functionality. For instance, we used the command "batctl tcpdump interface" to sniff traffic in the forwarder (middle) node.

Furthermore, indicators about the quality of the wireless links were evaluated using the JPerf (Java Performance and Scalability Testing) measurement tool [18]. JPerf is the graphical frontend for Iperf [19], written in Java. Therefore, all the features of Iperf are also supported by JPerf, with the difference that the latter provides a graphical interface which enables easy setup and output visualization. Iperf is a client-server application able to measure bandwidth, latency, jitter, and loss over a network link.

The last evaluation tool that was used in our experiments was a socket-based application we developed for the specific purpose. Our goal was to create controlled conditions, where individual parameters could be configured and tested. The developed software focuses on measuring data loss over TCP and UDP communications. The application operates in client-server mode, it was developed in Java, and offers a simple and effective user interface.

Regarding the network metrics that were considered for the network evaluation, the following were measured during the experiments: Bandwidth (maximum achievable data rate in bits per second), Loss (data sent but not successfully received), RTT (Round Trip Time), and Jitter (variation in delay of received packets). The measurements were taken individually for each one of the different scenarios and for various packet sizes.

3.2 Experimental Setup and Scenarios

The experiments were conducted in open outdoor space allowing adequately long distances between nodes, which enforces routing as stations get out of range. Moreover, the experimental environment makes possible the formation of clear topologies, where there is enough space for nodes to move, hence, to evaluate network behaviour under mobility conditions.

For the purposes of our experiments, four laptops where setup and used as ad hoc nodes. In each laptop, B.A.T.M.A.N-adv was installed, along with the necessary evaluation tools. The ad hoc network was formed using the laptops' Wi-Fi Network Interface Cards. The nodes were elevated approximately 40 cm from the ground. The main specifications of each laptop are the following:

- 1 Dell Inspiron N5110 – NIC: Qualcomm Atheros Dell Wireless 1702 (802.11b/g/n)
- 2 IBM ThinkPad X.41- NIC: Qualcomm Atheros AR5212 (802.11a/g/n)
- 1 Dell Latitude E6400 – NIC: Intel Wireless Wi-Fi Link 4965AGN (802.11a/g/n)

The first testing scenario is illustrated in Fig. 1 and is considered as the base (control) scenario. It is noted that for clarity reasons in the following four figures representing the testing scenarios the circles do not denote ranges, but illustrate connectivity between the corresponding nodes. The first scenario is actually a single hop network, since its topology consists of only two nodes running the B.A.T.M.A.N-adv protocol and operating in a client/server mode. There is no routing in this scenario, due to direct connectivity. To establish the connection, the nodes must be in range; the distance between the nodes is 85 m. This scenario is used to compare results against the other scenarios where routing actually takes place.

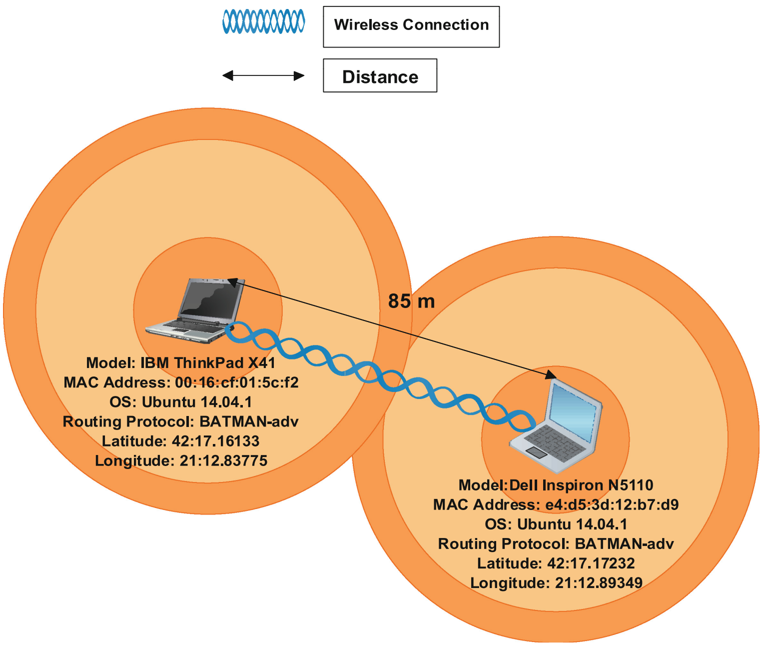

Fig. 1. First experimental scenario network topology

The second scenario consists of three nodes forming a multihop network, as shown in Fig. 2. The node with MAC address “00:16:cf:01:62:56” (source) is placed out of range of the node with MAC address “e4:d5:3d:12:b7:d9” (destination). The node with MAC address “00:16:cf:01:5c:f2” (forwarder) is placed between the two nodes in order to allow the creation of a routing path. So, the source node actually uses the forwarder node in order to transmit packets to the destination node. It is noted that the ground between the source and the forwarder is flat, so the line of sight is good, whereas there is some curvature between the forwarder and the destination. The main intention of this scenario is to reveal the behaviour of the routing protocol in a dual-hop network without mobility.

In the third scenario, the nodes are placed exactly at the same positions as in the second scenario, as shown in Fig. 3. The only difference is that the middle (forwarder) node is in a moving state, so it is mobile (not static). Specifically, it moves with human walking speed in a square area of 30-by-30 m during all experimental measurements. It is important to note that the height of the forwarder is around 1.5 m above the ground, since it is kept in hand while moving, which provides a better line of sight. The intention here is to explore the performance of B.A.T.M.A.N-adv, when there is relative mobility in the routing path.

The fourth scenario is the most complex one; it involves four nodes deployed at different locations. Three nodes are static and one is moving with human walking speed, as illustrated in Fig. 4. The nodes with MAC addresses “e4:d5:3d:12:b7:d9”, “00:16:cf:01:5c:f2” and “00:16:cf:01:62:56” are static, whereas the node with MAC address

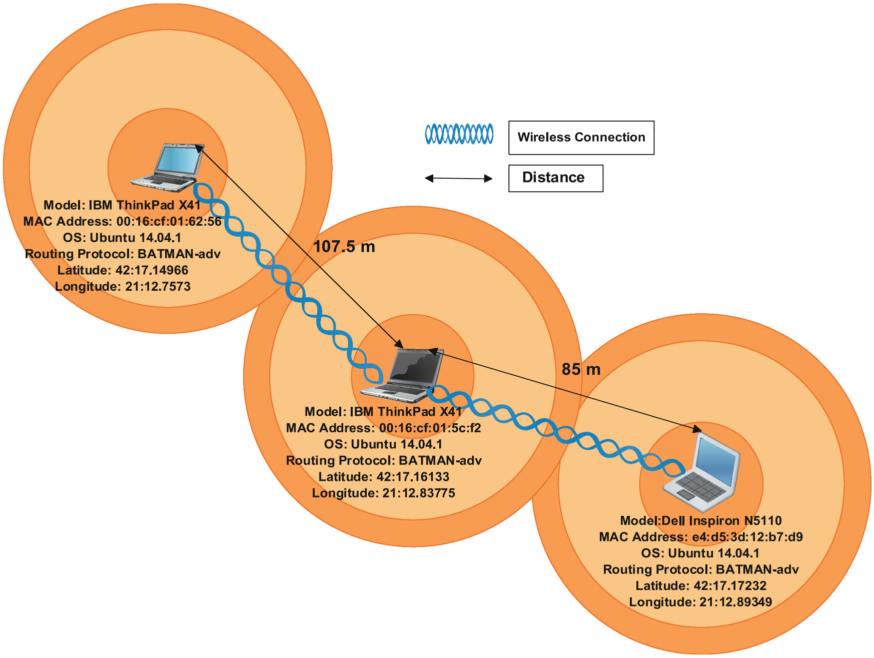

Fig. 2. Second experimental scenario network topology

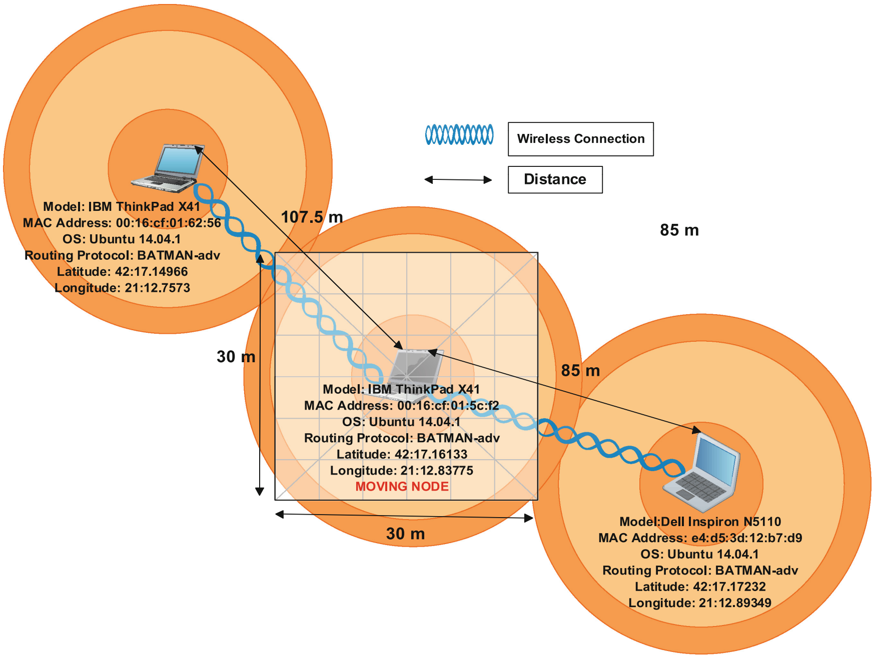

Fig. 3. Third experimental scenario network topology

"00:24:d8:a3:1b:b4" is mobile. The static node at the bottom acts as server, while the mobile node acts as client. The two middle nodes perform data forwarding. Our intention here is to evaluate the ability of the routing protocol to dynamically switch forwarders, hence, alternating routing paths.

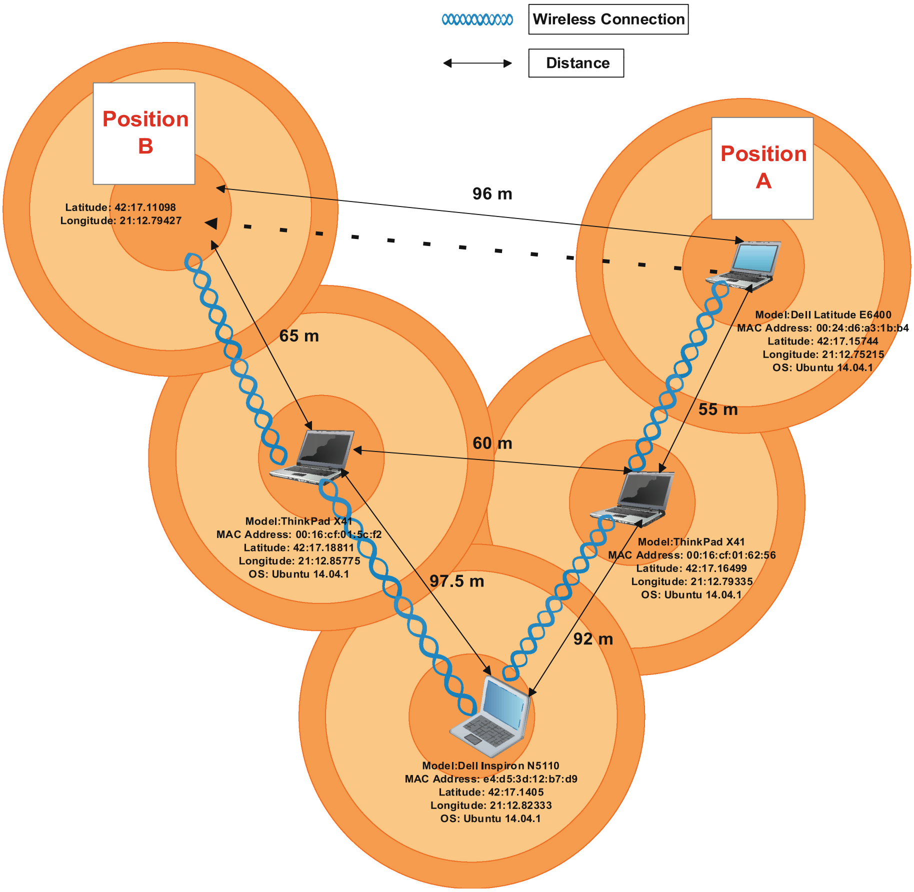

Fig. 4. Fourth experimental scenario network topology

4 Experimental Results and Discussion

In this section, we provide and discuss the results of the experiments conducted based on the aforementioned methodology, employing the described tools and implementing the presented scenarios. Our goal is the evaluation of the performance of B.A.T.M.A.N-adv, as a representative ready-to-use distance vector proactive routing protocol for MANETs, via comparative experimental results under realistic open-space conditions.

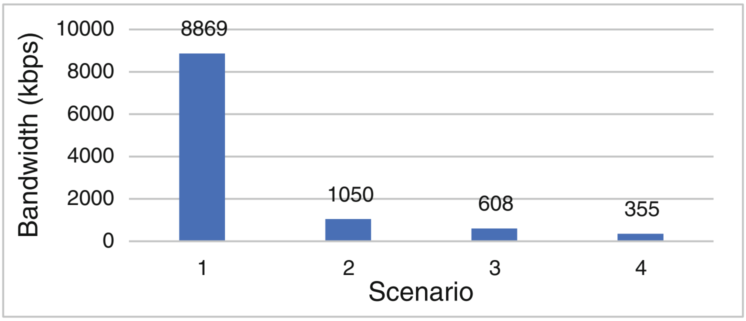

Fig. 5. Bandwidth achieved using JPerf

Bandwidth, in terms of achieved data rate, is one of the most significant performance metrics and reveals network capacity. It is defined as the supported transmission rate from source to destination. In our experiments, bandwidth measurements were performed using the JPERF tool and refers to TCP communication. The results, which are depicted in Fig. 5, show that routing greatly affects the achieved bandwidth. It is evident that the direct link between source and destination (scenario 1) allows successfully delivering significantly higher amount of traffic in the same time interval, compared to the other scenarios. Moreover, mobility also has a notable impact on the specific metric and this is the reason why scenario 3, which dictates forwarder movement, performs worse than scenario 2. Lastly, the complex conditions present in scenario 4, where mobility is combined with path alternation, lead to the worst performance. It is noted that similar behaviour can be observed for the same reasons in the following presented results, as well.

Figure 6 presents the average Round Trip Time results collected for all four scenarios using the batctl-ping tool. The specific metric is representative of the experienced delay when data is transmitted over the network. As expected, the single hop topology of the first scenario induces the lowest delay. On the other end, mobility and forwarder switching delays lead to worst performance for the fourth scenario considering RTT.

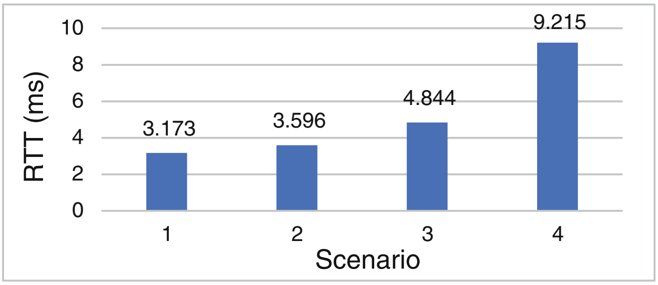

Fig. 6. Average Round Trip Time (RTT) using batctl-ping

In order to have a better view of the resulted latency, we have also conducted related measurements using our custom socket-based tool. The specific experiment involves the

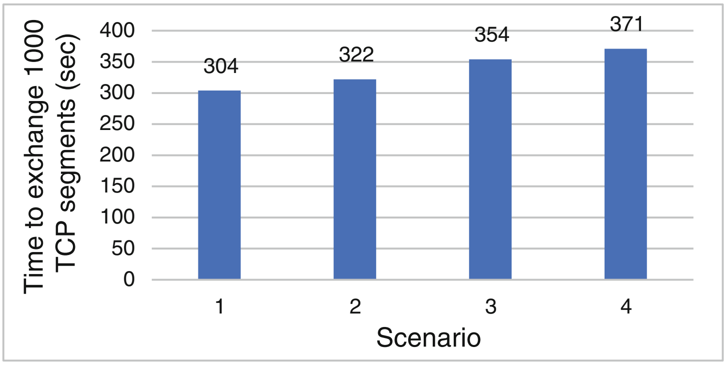

Fig. 7. Time required to exchange 1000 TCP segments using custom socket-based tool

establishment of a bidirectional TCP communication, where a 1400-byte segment is created every 100 ms and transmitted over the network. As soon as it is received by the destination node, the same segment is sent back to the source. Figure 7 shows the time needed for the successful completion of 1000 segments exchange (i.e. 1000 segments sent back and forth). It can be seen that the more the hops and the less stable the topology is, the more the time required for the exchange.

Figure 8 depicts packet loss as percentage of UDP datagrams not received over the total datagrams sent. JPerf was employed to generate 2 MB/s UDP traffic and transmit it over the network towards the destination node. It is evident that the highly dynamic conditions present in the fourth scenario lead to unreliable data paths, which cause significantly increased datagram losses.

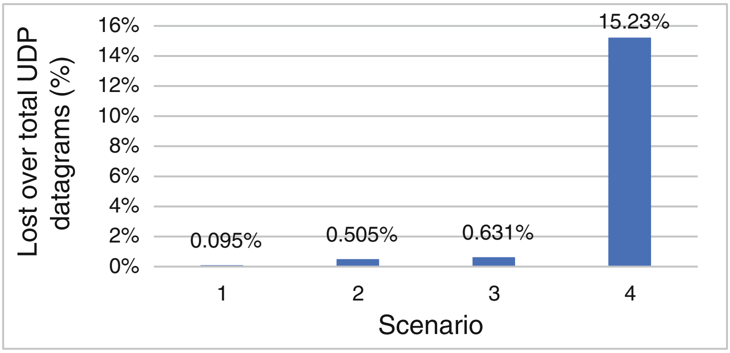

Fig. 8. Percentage of lost UDP datagrams over total sent using JPerf

The last metric that is considered throughout our experiments is jitter. This is a significant indication of the network's ability to efficiently support traffic in a consistent manner causing minimum variations. These delay variations have a major impact on the Quality of Service (QoS) provided especially to multimedia network traffic. This is definitely a challenge for unstable networks, such as dynamic MANETs, as it becomes evident from the results depicted in Fig. 9. Apparently, the highly unreliable conditions present in the fourth scenario lead to so much increased jitter, which actually prohibits serving good quality multimedia streams.

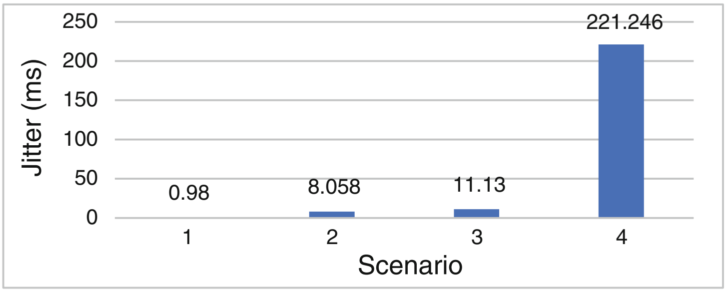

Fig. 9. Jitter in UDP communication using JPerf

Summing up the presented results, it is clear that the B.A.T.M.A.N routing protocol can definitely support communications over a MANET, however, the particular network characteristics affect performance to a significant degree. Specifically, the existence of multiple hops notably limits the available network capacity, meaning that the supported data rate is quite decreased. Mobility also has a notable effect on network behaviour, however, when it does not lead to route changes, the impact is not major. Considering real-world network applications, we could deduce based on the experimental results that B.A.T.M.A.N can satisfactorily support data communications over MANETs when they are not time sensitive, however, in cases where the highly dynamic conditions cause excessive path alternations, reliability is significantly affected and the quality of the provided service is marginal.

5 Conclusion

One of the main challenges of modern networking is meeting the rapidly growing requirements while facilitating participants' autonomy. Working towards that direction, the routing protocols developed for MANETs try to handle the highly dynamic conditions and enhance connectivity. This paper provided an evaluation of a promising MANET protocol which is readily available to end users. B.A.T.M.A.N was installed and configured in different mobile nodes, while four networking scenarios were designed for deployment in open space. The performed real world experiments managed to reveal network behavior under different conditions via studying the collected metrics. Specifically, the results made evident that the protocol is able to satisfactorily serve traffic under most considered conditions, however, there is a great impact on performance when the number of hops or the degree of mobility increase. As expected, the type of network applications which are affected the most are the ones that are quite sensitive to extensive variations, such as real-time streams. In the future, we plan to apply more MANET protocols and perform multi-node real-world experiments to evaluate the performance of specific multimedia streams, emulating the actual usage of the corresponding applications. In that manner, conclusions on optimal protocol configuration can be drawn, as well as directions can be provided for improving existing routing techniques and possibly introducing new more efficient ones.

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