Real-world performance of current proactive multi-hop mesh protocols

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Abstract

The proliferation of mesh or ad hoc network protocols has lead to a push for protocol standardisation. While there are a number of both open-source and proprietary mesh routing protocols being developed, there is only a small amount of literature available that shows relative strengths and weaknesses of different protocols. This paper investigates the performance of a number of available routing protocols using a real-world testbed. Three routing protocols - Optimised Link State Routing (OLSR), Better Approach To Mobile Ad hoc Network (B.A.T.M.A.N.) and BABEL - were chosen for this study. Our investigations focus on the multi-hopping performance and the ability of each routing protocol to recover from link failures. Our results show that B.A.T.M.A.N. and BABEL outperform OLSR both in terms of multi-hopping performance and in route re-discovery latency.

Keywords

Mesh network testbed, proactive routing

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Real-world Performance of Current Proactive Multi-hop Mesh Protocols

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***Abstract*—The proliferation of mesh or ad hoc network protocols has lead to a push for protocol standardisation. While there are a number of both open-source and proprietary mesh routing protocols being developed, there is only a small amount of literature available that shows relative strengths and weaknesses of different protocols. This paper investigates the performance of a number of available routing protocols using a real-world testbed. Three routing protocols - Optimised Link State Routing (OLSR), Better Approach To Mobile Ad hoc Network (B.A.T.M.A.N.) and BABEL - were chosen for this study. Our investigations focus on the multi-hopping performance and the ability of each routing protocol to recover from link failures. Our results show that B.A.T.M.A.N. and BABEL outperform OLSR both in terms of multi-hopping performance and in route re-discovery latency.**

I. Introduction

During the past four years, mesh networking has rapidly moved from a theoretical networking concept to commercially available devices that promise to create distributed, self-discovering and self-healing networks. The IEEE recently created the 802.11s working group. This is driven by leading industry and research institutes to develop a standard for mesh networks and with the objective of providing interoperability between all mesh network devices. While the 802.11s standard is still under development, there are a number of network protocols that are currently available.

Mesh network protocols are being developed in both commercial/proprietary and open source contexts. In the commercial space, several vendors are now providing mesh networking solutions based on their own proprietary routing solution [1], [2], [3]. The open source efforts are lead by a number of university and research institutes who aim to develop free-to-use network protocols that operate on low cost hardware [4], [5], [6], [7]. While all such developments claim to work well as a mesh network, there has not been any formal, real-world performance comparison between them.

The aim of this paper is to compare the performance of current routing protocols. This paper compares the Optimised Link State Routing (OLSR) [5], that is set to emerge as part of the IETF standard, against two other open-source routing protocols: Better Approach To Mobile Ad hoc Networking (B.A.T.M.A.N.) [6] and BABEL [7], that both claim to provide a new and more effective approach to mesh networking. Our contributions in this paper are as follows. Firstly, we investigate the multi-hopping performance of each mesh routing protocol as the number of hops increases by measuring their bandwidth performance. Next, we observe the packet delivery ratio and the round trip delay of packets in a lightly loaded network. Finally, we measure the convergence time of each protocol and discuss which protocols demonstrate the best convergence characteristics under dynamic network conditions.

The rest of this paper is organised as follows. Section II presents an overview of each mesh routing protocol used in our study. Section III describes the experimental testbed configuration and the metrics used to compare performance. Section IV presents the results and Section V concludes the paper.

II. Protocol Description

Routing protocols generally fall into three broad categories; *reactive*, *proactive* and *hybrid*. Reactive protocols only search for a path between nodes when there is data to send. This method has the advantage of not wasting network bandwidth with control messages when data transmission is not required. Reactive protocols are ideally suited to an ad hoc network with mobile nodes where the data path may change continuously. Conversely, proactive protocols actively establish and maintain data paths for nodes whether data needs to be transferred or not. This allows a lower latency in sending data through the network since an optimised data path is already known. However, this comes at the cost of higher network management overhead in both network control messages and computational processing. Hybrid routing protocols exhibit both reactive and proactive properties. Such protocols generally attempt to use reactive and proactive routing under one protocol framework, albeit in different scenarios, which exploit their strength and hence can result in a higher levels of scalability [8]. Hybrid routing protocols are generally more complex in behaviour, and hence more complex to implement, than purely reactive or proactive protocols.

This paper compares three proactive routing protocols - OLSR, B.A.T.M.A.N. and BABEL - in our mesh network testbed. This experiment provides first hand information on the routing performance of the protocols in a real-world scenario. This study also attempted to include the performance of the AODV protocol in the comparison. However, the current implementation of the AODV protocol failed to maintain (or sometimes even establish) a consistent multi-hop connection and has not been included in the performance measurement and analysis.

A. *Optimised Link State Routing (OLSR)*

The OLSR protocol uses a link-state algorithm to proactively determine the most efficient path between nodes. The network is structured using dynamic Multi-Point Relays (MPRs) that increase the network data throughput by creating an efficient network routing scheme. This is achieved by selecting only a subset of neighbouring nodes to relay data instead of every node acting as a relay. This technique minimises the rebroadcasting contention and the number of control packets required to establish a routing table. MPRs are elected in such a way that every node can communicate with a MPR within one hop. The localised network information is shared between MPRs to maintain network-wide routing paths. This allows every MPR to have a complete routing table while simultaneously minimising the number of topology control messages.

B. *Better Approach To Mobile Ad hoc Networking (B.A.T.M.A.N.)*

B.A.T.M.A.N. is a proactive routing protocol that offers a fundamentally different approach to route selection that is more aligned to the minimal resources available in embedded hardware. The first distinguishing feature is the decentralised knowledge of routing information - no single node has the routes to all destinations across the network. Instead, each node only perceives and maintains the general direction toward the destination and relays the data to the best next-hop neighbour accordingly. Any subsequent relay nodes then use the same mechanism to forward data until the final destination is reached.

The second significant difference is the path determination algorithm. In order to establish the general direction toward the destination, B.A.T.M.A.N. uses the principle that better links will provide faster and more reliable communication. Every node periodically sends out broadcast messages known as originator messages (OGMs) to inform its neighbours of its existence. The neighbours then relay this information to their own neighbours until each node is aware of all other nodes. Given the unreliable nature of broadcast transmission, the OGM flooding will not pass efficiently through congested links. Instead, the best path will be established through links with lower utilisation. This algorithm is shown to be significantly less complex than link-state calculations and has more modest hardware requirements.

C. *BABEL*

BABEL is a proactive routing protocol based on the distance-vector algorithm. This technique is an evolution of the Expected Transmission count (ETX) algorithm [9] and selects routes more intelligently than using a simple hop-count approach. BABEL has two distinctive characteristics that optimise relay performance. First, it uses history-sensitive route selection to minimise the impact of route flaps - the situation where a node continuously changes its preferred route between source and destination pair and leads to route instability. Thus, when there is more than one route of similar link quality, the route selection favours the previously established path rather than alternating between two routes. Second, BABEL executes a reactive update and forces a request for routing information when it detects a link failure from one of its preferred neighbours. Given the link quality measurements were previously completed at initialisation stage, BABEL claims to have almost immediate route convergence time when triggering an explicit update.

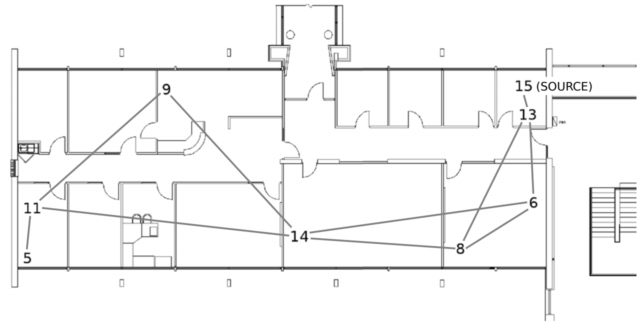

Fig. 1. Location of nodes and communication links

III. Experimental Set-up and Performance Metrics

The evaluation of the routing protocols was conducted in an indoor multi-hop mesh network testbed using the Portable Wireless Ad hoc Node (PWAN) devices described in [10]. The network consisted of eight mesh nodes distributed in a number of offices as shown in Figure 1. All nodes were configured to communicate using IEEE 802.11a (i.e. the 5GHz spectrum) due to the lower noise in this frequency range at our research institute than the 802.11b or g spectrum of 2.4GHz. All protocols were compiled directly from the source code and loaded into a Linux 2.6.23 kernel. BABEL v0.15 and B.A.T.M.A.N. v0.3 protocols used the default configuration options. OLSR v0.5.5 was configured to use higher HELLO and TC intervals to improve the static node performance. This tuning was required since the default configuration could not establish a reliable communication over two hops due to constant route changes.

Three different scenarios were setup to investigate the performance of each routing protocol. The first scenario examined the optimal bandwidth of each protocol over different number of hops. The bandwidth was measured using *iperf* with UDP packets over a period of 400 seconds. While *iperf* was saturating the network, the destination node was sending ICMP packets to the source using *fping*. This measured the number of communication hops in the direction of the main data flow. This information also yielded the Route Change Frequency (RCF) for the protocol under load, that is, the average number of route changes for each minute of communication.

While the first scenario stretched the network limits to determine the maximum average bandwidth, the second scenario used a relatively smaller load (i.e. a constant 50Kbps) to

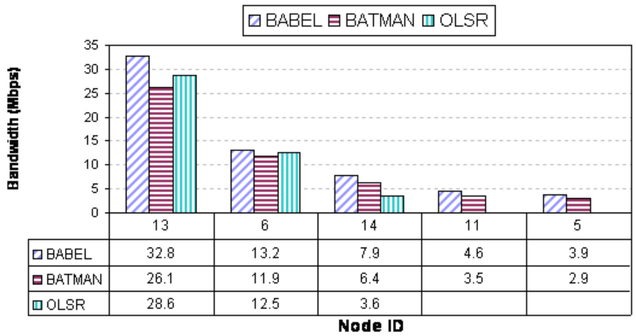

Fig. 2. Bandwidth at each node

observe other performance characteristics of the protocols. In this test, the Packet Delivery Ratio (PDR) and Round Trip Delay (RTD) were collected using *fping* with ICMP packets.

Finally, each protocol's self-healing ability was tested by intentionally disabling a primary link in an active route and observing the route recovery (convergence) time. This test also used a lightly loaded network configuration with the latency measured using ICMP packets. This test involved using *fping* to send an ICMP packet to Node 14 via one of the parallel paths through Node 6 or 8. The data flow route was monitored and the intermediate node, 6 or 8, was reset. The convergence time is given by the difference in the ICMP sequence number between the last packet received via the old path and the first packet of the new path divided by the *fping* rate. The convergence latency test was performed ten times for each protocol.

Node 15 was used as the source node for all tests. This device was connected directly to the control PC to minimise the processor load on the embedded computer that may have influenced the network performance.

IV. Results

This section presents the numeric results collected from the scenarios described in the previous section.

A. Bandwidth Test

The bandwidth performance for all three protocols to the respective destination nodes is depicted in Figure 2. BABEL consistently provided higher bandwidth than all other protocols. OLSR yielded a higher bandwidth than B.A.T.M.A.N. over one and two hops, but performance quickly diminished beyond two hops. B.A.T.M.A.N. generally used more hops than other protocols, which helps explain the reduced data bandwidth.

Table I shows the average hops and the route change frequency (RCF) for the data transmitted from Node 15 to corresponding destination nodes. Our results show the average hops stay relatively constant for all three protocols while the destination is within two hops from the source node. As the minimum number of hops increases to three and beyond, the hop performance of begins to diverge. OLSR, which based on

TABLE I
Average hops and route change frequency for each node

Dest. Node	Protocol	Average Hops	RCF (/min)
13	BABEL	1.00	0.00
	B.A.T.M.A.N.	1.00	0.00
	OLSR	1.00	0.00
6	BABEL	2.01	1.27
	B.A.T.M.A.N.	2.07	1.20
	OLSR	2.00	0.93
14	BABEL	3.07	4.37
	B.A.T.M.A.N.	3.54	1.10
	OLSR	3.00	5.04
11	BABEL	4.51	7.80
	B.A.T.M.A.N.	5.21	2.27
	OLSR	N/A	N/A
5	BABEL	5.29	3.90
	B.A.T.M.A.N.	5.58	3.75
	OLSR	N/A	N/A

hop-count metric, always maintains the minimum number of hops for any given destination. However, this also resulted in frequent route flaps when there were multiple paths of similar quality. This was highlighted when transmitting to Node 14 in our test. OLSR failed to maintain a consistent connection over four hops for more than 10 seconds before *iperf* cancelled the test due to dropped packets. Hence, the results of OLSR are not available for destination Nodes 11 and 5.

The hop performance of B.A.T.M.A.N. and BABEL demonstrated contrasting characteristics. B.A.T.M.A.N. takes more hops to reach the destination as the protocol does not maintain specific routes. B.A.T.M.A.N. also has a lower route change frequency since the routing information is not updated as often. Conversely, BABEL is able to keep the number of hops to a minimum, but undergoes frequent route changes despite the route selection algorithm favouring the previously selected route.

B. Packet Delivery Ratio and Route Trip Delay Tests

The packet delivery ratio (PDR) for all three protocols in the second scenario is illustrated in Figure 3. In this relatively low data test, B.A.T.M.A.N. had a perfect PDR over all tests while BABEL had a PDR of at least 99%. OLSR scaled very poorly in this test with less than one third of the packets making five hops even in a lightly loaded network.

Figure 4 shows the corresponding Route Trip Delay (RTD) for the three protocols in the same test. B.A.T.M.A.N.s RTD scaled well as the number of hops increased. BABEL had the lowest RTD for first few hops, but performance decreased slightly beyond two hops. Finally, OLSR did not scale well and the RTD performance deteriorated rapidly as the number of hops increased.

C. Route Convergence Latency Test

The path convergence test results are shown in Table II. BABEL had the fastest route convergence time with a fastest repair time of nine seconds. Interestingly, it was found in the

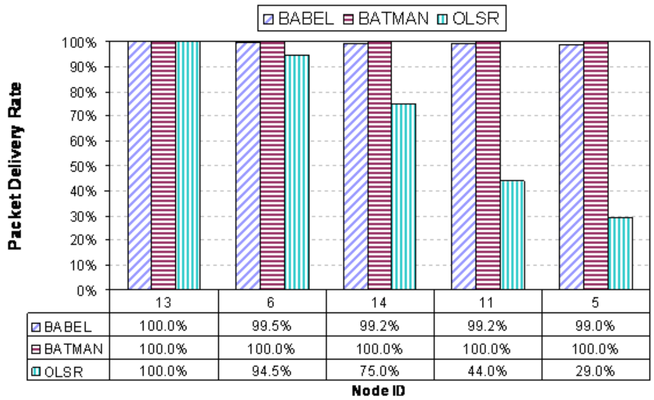

Fig. 3. Packet Delivery Ratio (PDR) at each node

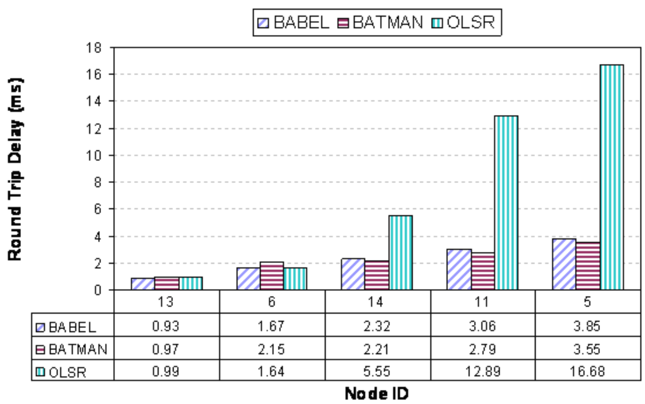

Fig. 4. Round Trip Delay (RTD) at each node

bandwidth test that the route changed in as little as two seconds when parallel paths were available. This suggests the route preference algorithm is more active than the route repair algorithm. B.A.T.M.A.N. had an average route recovery time twice that of BABEL. This behaviour may make B.A.T.M.A.N. unsuitable for highly mobile networks. OLSR had very poor convergence times. This was caused by our increasing of the HELLO and TC packet intervals to increase route stability. However, with these values at their default, repairing a broken link was irrelevant as a two-hop link could not be effectively established due to frequent route changes.

V. Conclusion

This paper has presented a head-to-head performance study of three mesh routing protocols in a real-world testbed. The protocols tested were OLSR, B.A.T.M.A.N. and BABEL. Our results show that B.A.T.M.A.N. achieves the highest level of stability and packet delivery, while BABEL offers the highest multi-hop bandwidth and the fastest route repair time. Both B.A.T.M.A.N. and BABEL outperformed OLSR in all performance metrics examined.

From the relatively slow convergence times in all tests, it could be argued that these protocols may not suitable for highly mobile networks. Hence, the design of a high performance routing protocol for a mobile ad hoc network (MANET) still remains an open research issue. In particular, while much of the current research in MANET routing protocols have been towards developing low-overhead strategies, more work is required to design a more intelligent algorithm that can handle mobility better at the both the Data Link and the Network (routing) layer.

TABLE II
Route convergence performance of protocols

Protocol	Convergence Time (s)		
	Min.	Avg.	Max.
BABEL	9	14.4	19
B.A.T.M.A.N.	15	31.5	61
OLSR	46	61.8	71

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