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Keywords

Experimental, evaluation, IEEE, 802, 11s, path, selection, protocols, mesh, testbed

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Experimental Evaluation of IEEE 802.11s Path Selection Protocols in a Mesh Testbed

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***Abstract*—IEEE 802.11s is an upcoming standard that defines how wireless devices can interconnect in a multi-hop configuration. While there are several protocol stacks based on the IEEE 802.11s draft standard, there has not been a formal study or comparison examining their practical performance. This paper evaluates the routing performance of open80211s in a real-world mesh testbed. The experiments benchmark open80211s against two established network layer routing protocols - OLSR and B.A.T.M.A.N.. The experimental results show that open80211s does not outperform existing routing protocols in practice. This indicates that more design and development effort is required for IEEE 802.11s to yield the performance that is expected for an IEEE standard protocol.**

***Index Terms*—IEEE 802.11s, Path Selection Protocols, Testbed Evaluation**

I. Introduction

Mesh networking has rapidly moved from a theoretical concept to commercially available devices providing distributed, self-discovering and self-healing networks. Most current approaches place a proprietary mesh routing protocol in the network layer on top of an IEEE 802.11 wireless network device. However, this paradigm raises interoperability concerns of using proprietary solutions in multi-hop networks. Hence the demand has been growing for the IEEE to provide leadership and create a mesh networking protocol standard. The Mesh Networking Task Group (TGs) was formed in 2003 to develop a standard protocol to provide interoperability between mesh network devices using existing physical layer communication protocols.

The IEEE 802.11s standard is in the draft stage. However, there are several pre-standard implementations based on the draft protocol including *open80211s* [1]. This protocol is an implementation of the draft standard IEEE 802.11s stack for the Linux kernel and provides an initial step towards realising an IEEE 802.11 mesh network. The key developments of open80211s have focused on the 'path selection' component that is used provide multi-hop paths similar to a routing table in a network layer mesh routing protocol. The open80211s MAC layer includes features such as *Mesh Discovery*, *Peer Link Management*, *Mesh Path Selection*, *Hybrid Wireless Mesh Protocol (HWMP)*, *Airtime Link Metric Calculations* and *Mesh Beaconing*.

While open80211s should create a high performance mesh network, no formal study or comparison has been published. This paper presents a practical insight into the real-world performance of an open-source protocol based on the IEEE 802.11s draft specifications. The experiments focus on the distributed multi-hop routing and forwarding capability of open80211s since that is the key advantage of a mesh network over an access-point network configuration. This performance is benchmarked against two other path selection protocols under continuous development - the Optimised Link State Routing protocol (OLSR) [2] and the Better Approach To Mobile Ad hoc Networking protocol (B.A.T.M.A.N.) [3]. Both OLSR and B.A.T.M.A.N. have been considered as well-established ad hoc network solutions and they have been evaluated in our earlier study [4]. This paper extends our prior study by considering the upcoming IEEE 802.11s standard.

This paper summarises the stability and efficiency of open80211s. The protocol stability was investigated by increasing the network load and monitoring the throughput and outage frequency and duration. Conversely, the efficiency was evaluated using the round trip delay and packet delivery ratio of data packets in a lightly loaded network.

The rest of this paper is organised as follows. Section II presents an overview of the mesh routing protocols used. Section III describes the experimental testbed configuration and performance tests that were run. Section IV presents the experimental results and Section V concludes the paper.

II. Protocol Description

This section presents an overview of the HWMP, OLSR and B.A.T.M.A.N. path selection protocols.

A. Hybrid Wireless Mesh Protocol (HWMP)

HWMP is the default routing protocol in the draft IEEE 802.11s standard [5]. The most distinguishing feature of HWMP is that the routing table resides in the MAC layer instead of the network layer. This hides the complexity of the path determination from the upper layers such that they see all devices as a single transmission away.

According to current draft (D4.0), HWMP combines the flexibility of on-demand (reactive) path selection with proactive topology tree extensions. The reactive component is the foundation of HWMP and is based on the Ad-hoc On-demand Distance Vector (AODV) protocol. However, the design was improved to include a radio-aware link metric to determine the best route instead of a simple hop count and is known as Radio-Metric AODV (RM-AODV).

A tree-based proactive routing protocol is also available to HWMP. The proactive mode is applied when the mesh network

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is defined with a mesh portal point and serves as the root of the routing tree. The tree is built and maintained through periodic announcements from the root. The proactive component is designed to be an extension of the reactive operation, allowing both components operate concurrently. All HWMP modes of operation utilize common processing rules and primitives such that the routing information can be shared by both reactive and proactive operations.

B. Optimised Link State Routing (OLSR)

The OLSR protocol uses a link-state algorithm to proactively determine the most efficient path between nodes [2]. 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 such 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.

C. 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 where the routing decision is not made upon state or toplogy information from other nodes. Instead, it utilises statistical and collective intelligence to determine best possible path.

In B.A.T.M.A.N. 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 every node has received it at least once, or the packet is lost, or the packet is expired. Upon reception of OGM, the node logs the local neighbour that relayed the message. By using this information, B.A.T.M.A.N. statistically can determine and mantain a table of local neighbours towards every originator in the network. The advantages of B.A.T.M.A.N. are that the protocol accounts for unreliable nature of wireless networks and the algorithm is significantly less complex than link-state calculations.

III. Experimental Setup

The routing protocols were evaluated in an indoor environment using the Portable Wireless Ad hoc Node (PWAN) devices described in [6]. The PWAN architecture is based on the Wireless Router Application Platform (WRAP) from PCEngines. The WRAP used provides a highly flexible node base that includes two Ethernet interfaces, two mini-PCI slots, a compact flash memory socket and a serial port. The PWAN operates using SAND OS, the custom Linux installation based on Debian Linux, which runs from the Compact Flash memory.

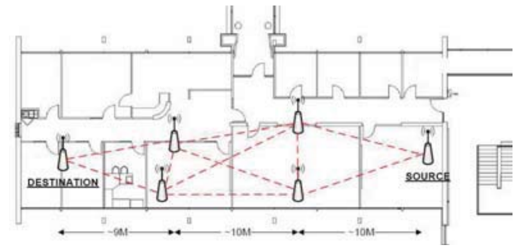

Fig. 1: Nodes were placed to offer parallel communication links between the source and destination

The network consisted of six mesh nodes distributed in a number of offices as shown in Figure 1. All nodes were equipped with one radio interface (Broadcom BMC4306 card) using IEEE 802.11b with a fixed bit rate of 11Mbps. The transmission power was reduced to 10dBm to enforce the multi-hop configuration in a small area where each data flow traversed a minimum of three hops between source to destination.

A Linux 2.6.30.1 kernel was used to compile and run the routing protocols. B.A.T.M.A.N.v0.3.1 [3] and olsrd v0.5.6-r4 [7] were the choices of protocol implementations, while HWMP was included in the open80211s module of the Linux 2.6.30.1 kernel. All protocols used the default parameter values specified by the developers.

The experiments measure a single-flow performance between two nodes as shown in Figure 1. Two test scenarios were set up to investigate the different performance aspects of each protocol. The first test incrementally increased the network throughput to determine the maximum average bandwidth. The bandwidth was measured using *iperf* to send a defined UDP load from source to destination for a period of 15 minutes. The second test scenario evaluated the protocol efficiency by measuring the Round Trip Delay (RTD) and Packet Delivery Ratio (PDR) in a lightly loaded network. This test used *fping* to send ICMP packets at rate of 10 packets per second over a 10 minute period. Each test was repeated on at least three separate occasions to provide a 'fair' sample of environmental influences and the averaged result is presented.

IV. Results

This section presents and discusses the experimental results obtained.

The maximum throughput of HWMP is significantly less than OLSR or B.A.T.M.A.N. in a multi-hop network. While the three protocols had approximately the same throughput for a 128kbps to 512kbps load, the performance of HWMP decreased as the load increased such that it had half the maximum bandwidth of the other protocols. This behaviour is shown in Figure 2. This experiment showed that B.A.T.M.A.N. had the highest maximum throughput despite not having a predetermined transmission path. OLSR had the least consistent

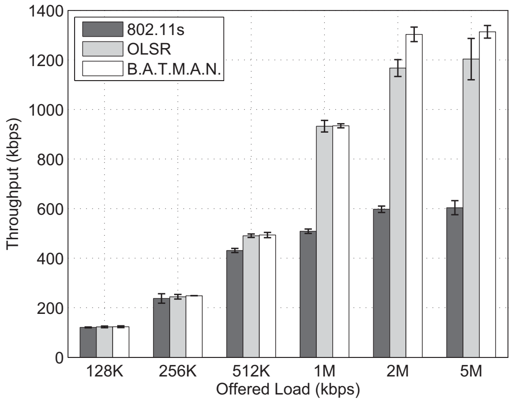

Fig. 2: Network throughput vs. the offered load

TABLE I: Number of Path Outages (per 15 minutes) and Average Outage Duration (in s) in the throughput test

Load	HWMP		OLSR		B.A.T.M.A.N.	
	Outages (/15min)	Dur (s)	Outages (/15min)	Dur (s)	Outages (/15min)	Dur (s)
128K	3.0 ±2.0	2.7 ±1.2	3.0 ±5.3	2.6 ±4.6	0.33 ±1.2	7.7 ±27
256K	3.7 ±7.6	3.3 ±1.2	3.3 ±3.0	3.3 ±4.3	0.33 ±1.2	0.33 ±1.2
512K	9.0 ±7.2	3.0 ±1.2	3.7 ±2.3	1.9 ±1.7	1.0 ±3.5	1.3 ±4.6
1M	53 ±1.2	4.0 ±0.6	2.7 ±5.0	2.1 ±4.0	0.33 ±1.6	0.67 ±2.3
2M	51 ±23	6.3 ±2.0	8.3 ±8.5	6.8 ±7.6	0.33 ±1.2	0.33 ±1.2
5M	52 ±18	5.6 ±2.6	7.0 ±10	11 ±8.7	0.67 ±1.2	1.0 ±2.0

performance as indicated by the 95% confidence interval error bars in Figure 2.

The low maximum throughput of HWMP is partially explained by the high number of transmission outages for loads at 1Mbps and higher. HWMP had nearly an order of magnitude more outages than OLSR at high load and nearly two orders of magnitude more than B.A.T.M.A.N. as shown in Table I. The high outage rate of HWMP is due to the reactive route selection. The reactive routing process can falsely perceive the loss of data packets due to congestion as permanent link breakage and remove the path accordingly. The subsequent packets for the same destination require to trigger another route discovery. The congestion can cause network to undergo constant and rapid route updates. Hence, the probability of contention at a relay increases as the load increases and results in the protocol toggling between alternate routes. This 'route flipping' reduces the transmission efficiency and hence limits the maximum throughput. Conversely, B.A.T.M.A.N. has the lowest transmission outage rate and the lowest outage duration.

The second experiment showed that HWMP had the slowest round trip delay (RTD) of the three protocols. HWMP was

TABLE II: Round Trip Delay (RTD - in ms) and Packet Delivery Ratio (PDR - as %) in a lightly loaded network

HWMP		OLSR		B.A.T.M.A.N.	
RTD (ms)	PDR (%)	RTD (ms)	PDR (%)	RTD (ms)	PDR (%)
7.27 ±0.42	94.5 ±5.02	5.92 ±0.97	89.4 ±16.3	5.93 ±0.31	95.9 ±3.21

more than 20% slower than OLSR or B.A.T.M.A.N. as shown in Table II. This poor result is also due to the delay induced by the reactive routing protocol unnecessarily discovering a new route when a single packet is lost.

This experiment also showed that HWMP had a significantly higher packet delivery ratio (PDR) than OLSR although it was still outperformed by B.A.T.M.A.N.. This is also shown in Table II. These results show that HWMP is more stable than OLSR at the cost of latency, while it falls behind B.A.T.M.A.N. on both accounts.

V. Conclusion

This paper presents a comparison of an early implementation of IEEE 802.11s against two established ad hoc routing protocols, OLSR and B.A.T.M.A.N., using a real-world testbed. The experimental results show the open80211s implementation of HWMP works in a multi-hop environment but does not perform as well as existing network layer routing protocols. The experiments show that HWMP path selection becomes unstable as network congestion increases and this leads to a high outage rate. The bandwidth of HWMP is consequently lower than either OLSR or B.A.T.M.A.N. in a multi-hop environment. Similarly, the average round trip delay is longer than the other protocols due to HWMP dropping the routing table when a packet is lost and forcing a route rediscovery. This result indicates that further refinement may be required before IEEE 802.11s HWMP reaches the performance that can be expected of an IEEE protocol. However, it is important to remember that open80211s is only one implementation of IEEE 802.11s and it is still in the beta phase of development. We will perform more extensive testbed experiments when more IEEE 802.11s HWMP implementations become available.

References

[1] Cozybit, Inc., "open80211s Homepage," 2009.

[2] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum, and L. Viennot, "Optimized link state routing protocol for ad hoc networks," in *Proceedings of IEEE INMIC 2001*, 2001, pp. 62–68.

[3] Open-Mesh.net, "B.A.T.M.A.N. (better approach to mobile ad-hoc networking)."

[4] M. Abolhasan, B. Hagelstein, and J.-P. Wang, "Real-world performance of current proactive multi-hop mesh protocols," in *APCC*, October 2009.

[5] IEEE TGs, *P802.11s/D4.0, Draft STANDARD for Part 11 specifications Amendment 10: Mesh Networking*, December 2009.

[6] M. Abolhasan, J. C.-P. Wang, and D. Franklin, "On indoor multi-hopping capacity of wireless ad-hoc mesh networks," in *IEEE Internatonal Conference on Mobile Adhoc and Sensor Systems (MASS 2007)*, 2007.

[7] A. Tonnesen, T. Lopatic, H. Gredler, B. Petrovitsch, A. Kaplan, S.-O. Tucke *et al.*, "olsrd - an adhoc wireless mesh routing daemon," 2009.