Poster: BATMAN-ADV Routing Challenges and Optimizations

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ABSTRACT

Wireless Mesh Networks (WMNs) are crucial for addressing modern networking requirements, meeting the increasing demand for scalable, robust, and flexible communication infrastructures. BATMAN-adv, a Layer 2 routing protocol designed specifically for WMNs, facilitates efficient data routing by utilizing real-time link quality metrics, without Layer 3 overhead. In this work, we identified several key performance challenges and proposed targeted optimizations to enhance throughput stability and seamless interface switching. Experimental results demonstrate significant improvements in routing stability, making BATMAN-adv more resilient and adaptable to dynamic and complex network environments.

CCS CONCEPTS

• **Networks** → *Network performance analysis.*

KEYWORDS

BATMAN-adv, Wireless Mesh Networks, Routing Optimizations

1 INTRODUCTION

Wireless Mesh Networks (WMNs) are critical in emergency and disaster relief sites, enabling rapid deployment of self-healing communication networks without relying on existing infrastructure [1]. Routing plays a crucial role in WMNs, making the selection of reliable protocols essential. Layer 2 protocols are often preferred for their lower latency, reduced complexity, and better performance in dynamic environments. BATMAN-adv (Better Approach To Mobile Ad-hoc Network Advanced) and HWMP (Hybrid Wireless Mesh Protocol) are popular L2 routing protocols for WMNs. BATMAN-adv offers key advantages over HWMP, including:

- *Proactive Routing*: BATMAN-adv proactively routes for all nodes, unlike HWMP, which maintains routes only to a root node.
- *Multi-Radio Flexibility*: BATMAN-adv supports multi-radio and multi-interface environments, allowing nodes to use different radio interfaces (e.g., Wi-Fi, HaLow) within a single mesh network for improved network performance.
- *Enhanced Security*: BATMAN-adv integrates seamlessly with additional security layers like MACsec [2], encrypting both data and routing frames at Layer 2. In contrast, when MACsec is used with HWMP, routing management frames remain unencrypted. BATMAN-adv with MACsec ensures comprehensive protection by providing confidentiality, integrity, and authenticity for all transmitted frames across the mesh network.

Despite these advantages, BATMAN-adv faces challenges in managing network dynamics, optimizing link quality, and addressing throughput issues in multi-radio environments. This paper proposes optimizations to improve routing efficiency. We used BATMAN-adv version 2024.1 for this study [3].

2 BATMAN-ADV ROUTING CHALLENGES AND OPTIMIZATIONS

BATMAN-adv Routing Selection: BATMAN-adv supports two routing versions, BATMAN-IV and BATMAN-V, which differ significantly in their operations and are not compatible with each other. BATMAN-IV relies on Originator Messages (OGMs) to determine link quality (LQ). However, because these messages are broadcasted, often transmitted using lower modulation rates, the protocol tends to overestimate link quality. This can lead to suboptimal routing decisions and reduced network performance. BATMAN-V introduces several key improvements over its predecessor to address these shortcomings:

- *Throughput-Based Metric:* This metric uses feedback from wireless drivers to provide a more accurate measure of link quality (LQ) by considering expected throughput instead of just packet reachability. It also accounts for throughput reduction when the same radio is used for both incoming and outgoing traffic by applying an additional penalty.
- *Echo Location Protocol (ELP):* ELP is a localized discovery protocol that reduces the flooding of control messages by focusing on immediate neighbors, resulting in more efficient and precise local link assessments.
- *Originator Messages Version 2 (OGMv2):* BATMAN-V introduces OGMv2, which continues to propagate LQ information across the mesh but does so more efficiently, reducing overhead while maintaining the accuracy of link information.

To ensure the routing protocol responds to recent network changes, a 500ms interval for both ELP and OGM is recommended.

Throughput Metric from Virtual Interfaces: When wireless interfaces are added to batman-adv, it retrieves LQ information, such as expected throughput, using cfg80211 calls. cfg80211 is primarily designed for IEEE 802.11 (Wi-Fi) devices, enabling batman to obtain critical link metrics from the underlying wireless drivers. This process functions smoothly when wireless interfaces are added directly to batman interface. It even works correctly when there is one additional layer, such as ‘wlan0 -> macsec -> bat0‘. However, when more than one virtual interface is added, such as ‘wlan0 -> macsec -> macsecbridge -> bat0‘, batman cannot extract link quality information and defaults to 1 Mbps. To resolve this issue, we implemented the following optimizations in the batman-adv kernel:

- Updated the batman interface structure to store information about the real wireless interface (‘wireless_phy_iface‘).
- Whenever a new interface is added or an existing one changes, identify the real wireless interface mapped to the batman-attached interface using MAC address information.
- In the ELP throughput calculation, initiate cfg80211 calls using the real wireless interface instead of the batman-attached virtual interface.

Exp.Throughput Slow Convergence: When there is a significant change in expected throughput from wireless drivers, batman takes longer to reflect this change due to the application of EWMA (Exponential Weighted Moving Average). In the context of EWMA, the smoothing factor controls how much weight is given to the latest value versus the historical average. The EWMA in `batman-adv` can be expressed with the following formula:

$$\text{EWMA}_{t+1} = \alpha x_t + (1 - \alpha)\text{EWMA}_t$$

Where, EWMA_{t+1} is the updated EWMA value at time $t+1$, x_t is the new throughput value at time t, $\alpha = \frac{1}{\_\text{weight\_rcp}}$ is the smoothing factor, defined by the reciprocal of the weight, $1 - \alpha$ represents the weight of the old EWMA value. For `DECLARE_EWMA(throughput, 10, 8)` used in batman-adv implementations:

- $\alpha = \frac{1}{8} = 0.125$, meaning the new value contributes 12.5% to the updated EWMA,
- The old EWMA retains a weight of $1 - 0.125 = 0.875$, contributing 87.5% to the updated value.

Due to the higher weight (87.5%) given to the old value, when there is a sudden change in the LQ (due to movement or obstacles), it takes longer for batman routing to switch to another link. As shown in Fig. 1(a), when the driver reports a drop in expected throughput from 50Mbps to 5Mbps, batman routing takes around 10 seconds to reflect the new value, resulting in sub-optimal performance during this period. To address this, we modified the EWMA _weight_rcp to 2, resulting in equal weight being given to new and old values. This adjustment allows the EWMA to follow the input data more closely, making it more responsive to sudden changes in throughput.

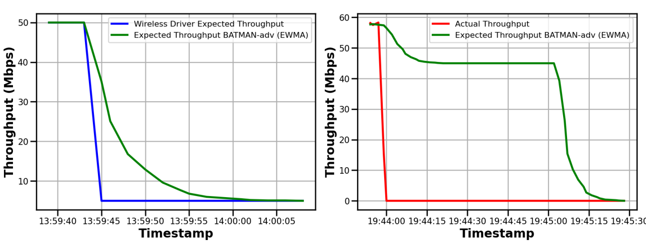

Figure 1: (a) Throughout Slow Convergence, (b) Link Loss

Invalid Exp.Throughput during link loss: When radio link is down due to remote device shutdown or moved out of coverage, most driver implementation is not recalculating expected throughput values and provide last obtained value (when link was alive) until link timeout (usually 30 to 60 seconds). This creates problem at BATMAN-adv routing, and data routed via the link which is already lost. In an experiment with ath9k based chipset, we have measured actual throughput using iperf and expected throughput values from driver. After certain time, we have shutdown one device, hence actual throughput went to 0, but expected throughput remains last value until considerable time as shown in Fig1(b). We have done optimization by considering inactivity information from retrieved from driver. Along with previous optimizations, we have performed an moving experiment containing far line of sight, and non line of sight to make frequent disconnection and measure actual throughput and batman expected throughput. The optimized expected throughput value is closely matched the actual throughput even during link loss and recovery, as shown in Fig.2.

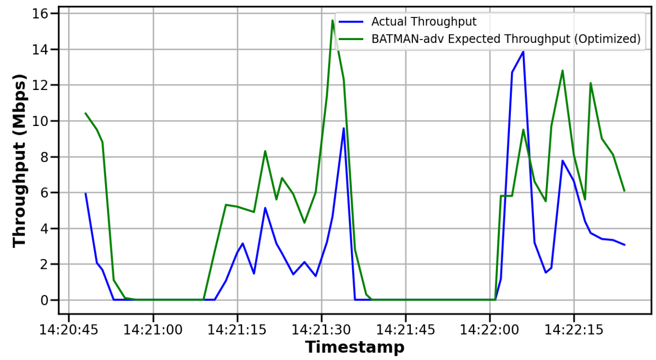

Figure 2: Optimized Expected vs Actual Throughput

Link Asymmetry in Multi-Radio Networks: BATMAN-adv supports multiple radio interfaces (e.g., Wi-Fi and HaLow) within a single mesh network. Wi-Fi is used for better throughput, while HaLow provides extended coverage. In such scenarios, BATMAN-adv is expected to switch from Wi-Fi to HaLow as devices move farther apart. However, our testing revealed issues due to the discrepancy in expected throughput between these interfaces. Wi-Fi, when operating in 802.11n mode, has a minimum data rate of 6 Mbps (with an expected throughput of around 3 Mbps), whereas HaLow's maximum expected throughput is 3 Mbps (single spatial stream, 2 MHz bandwidth). This disparity complicates smooth interface switching. We conducted a moving test in a multi-radio network with one static node and one moving node. The results indicated that the switch from Wi-Fi to HaLow was not smooth. To address this issue, we optimized the expected throughput by applying Dynamic Penalty Scaling based on signal strength. As the signal approaches the disconnect threshold, a penalty is applied to the expected throughput values retrieved from the driver. This ensures that BATMAN-adv prioritizes switching to a more stable link before complete disconnection occurs, ultimately improving overall network performance.

3 CONCLUSION

In this paper, we identified several challenges in BATMAN-adv routing, particularly in throughput estimation, and link stability in multi-radio scenarios. Our optimizations, including Dynamic Penalty Scaling, modifications to EWMA parameters, and improvements in handling virtual interfaces, demonstrated significant improvements in throughput convergence and link switching stability. These enhancements ensure that BATMAN-adv can more effectively handle dynamic network conditions, providing more responsive and reliable performance in wireless mesh networks, especially in scenarios with varying link qualities and multi-radio setups.

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