Poster: A Multi-Radio Aware Mesh Platform for Resilient Human-to-Human Communication

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Abstract

First responder use cases require ad-hoc, infrastructure-less communication setups. To address these needs, we present *MRAM*, a custom handheld platform equipped with a multi-radio mesh system utilizing long-range Wi-Fi and HaLow. *MRAM* leverages B.A.T.M.A.N. multi-radio enhancements for optimal link selection, aggregation, and full-duplex communication. Real-world urban evaluations demonstrate that *MRAM* maintains reliable video call performance throughout an entire route, even under dynamic conditions, outperforming single-radio solutions.

CCS Concepts

• **Networks → Network experimentation**; *Network reliability*.

Keywords

Long range mesh network, Multi-radio, Resilient networking.

1 Introduction

In the current Internet of Things era, long-range communication is gaining traction, particularly for Human-to-Human (H2H) communication at ground level. Long-range Wi-Fi and HaLow radios complement this need, but integrating mesh capabilities and concurrent operations remains challenging. These challenges include link selection complexity based on varying conditions, latency and throughput trade-offs, overall power consumption, and adjustments to the mesh protocol. We propose the Multi-Radio Aware Mesh (*MRAM*) platform, which provides advanced multi-radio communication across mesh nodes equipped with long-range radios like Wi-Fi [1] and HaLow [2]. *MRAM* supports dynamic link selection, aggregation, and full-duplex communication to enhance network performance and reliability, as depicted in Figure 1.

In link selection, *MRAM* chooses the optimal link between Wi-Fi or HaLow for uplink (UL) and downlink (DL) to maximize throughput and minimize interference. Link aggregation uses multiple radio interfaces concurrently, increasing bandwidth and providing redundancy. Full-duplex communication leverages separate channels in Wi-Fi and HaLow for simultaneous UL and DL, enabling efficient bidirectional data flow. These features make *MRAM* ideal for disaster management scenarios, where flexible, and resilient multi-radio communication is crucial for uninterrupted connectivity.

2 Proposed *MRAM* Hand-held platform for H2H Long Range Mesh System

We built the *MRAM* platform using commercial off-the-shelf components, as shown in Figure 2. The core is a Raspberry Pi CM4 Compute Module with 4GB RAM, serving as the central processing unit

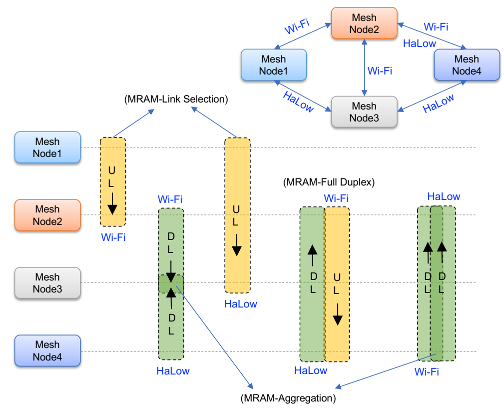

Figure 1: Overview of *MRAM* Platform Scenarios

for multi-radio communication. The platform includes industrial-grade Wi-Fi (Doodle Labs NM-DB-3U) and HaLow (GW16146 Mini-PCIe Radio) transceivers, providing robust long-range connectivity across 2.4 GHz, 5 GHz, and sub-GHz frequencies (902-928 MHz), making it ideal for reliable H2H communication at ground level.

On the software side, we developed an 802.11s Wi-Fi and HaLow mesh for concurrent operations, using the B.A.T.M.A.N. Advanced routing protocol for multi-radio operations. These modules were built on top of open-source Wi-Fi and HaLow subsystems, including drivers and firmware in the Linux Wi-Fi framework, as shown in Figure 3. The *MRAM* platform's algorithms for link selection, aggregation, and full duplex were implemented on top of multi-radio B.A.T.M.A.N., enabling efficient traffic distribution and ensuring reliable mesh networking.

The *MRAM* platform integrates Wi-Fi and HaLow radios with complementary capabilities, as shown in Table 1. Wi-Fi provides higher data rates over short to medium ranges (300-500m) with MIMO (3x3:3) and channel bandwidth of 5/10 MHz (custom options), while HaLow extends range (>1 km) using SISO (1x1:1) for long-range, low-power communication. The multi-radio B.A.T.M.A.N. protocol optimizes link selection by considering the PHY and MAC characteristics of these radios, ensuring balanced connectivity between neighbors.

3 Results and Discussions

In our real-world urban setup with the *MRAM* platform, Node 1 was placed in a car park, Node 2 on a rooftop for enhanced coverage, and Node 3 moved along a predefined route covering large villas, a mosque, and open areas over a 260x300 meter area, as shown in Figure 4. Designated testing points included A1, B1, C1, and D1. We evaluated the video call performance between fixed Node 1 and

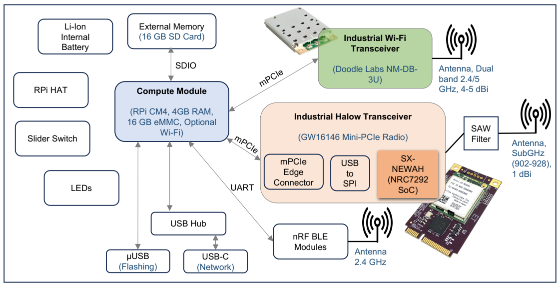

Figure 2: *MRAM* Hardware Component

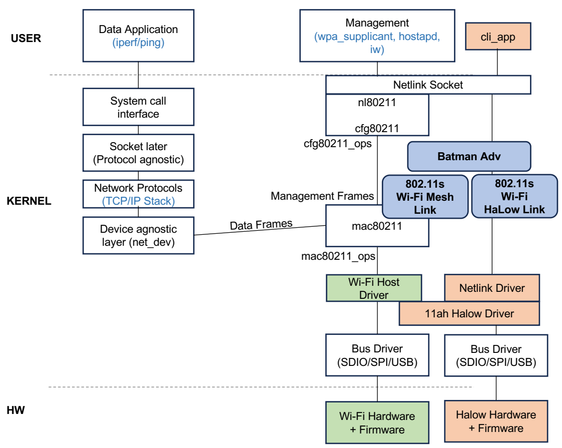

Figure 3: *MRAM* Software Architecture

Table 1: Wi-Fi and HaLow Radio Profile for Long Range Mesh

Radio Parameters	Long Range Wi-Fi (802.11n)	Long Range HaLow (802.11ah)
Tx Power	27 dBm	23 dBm
Rx Min Sensitivity	-97 dBm	-106 dBm
MIMO Configuration	MIMO (3x3:3)	SISO (1x1:1)
Frequency	5825 / 2442 MHz	902-928 MHz
Channel Bandwidth	5/10 MHz	1/2/4 MHz

moving Node 3 using our in-house Mesh Call App, a P2P application running on a Google Pixel 8 connected to the *MRAM* platform with link selection configurations. During the test, we monitored throughput across all three nodes via Wi-Fi and HaLow radios.

The *MRAM* platform consistently maintained stable video call performance by leveraging an optimal topology: a Wi-Fi link between Nodes 1 and 2 (due to their fixed positions and proximity) and a HaLow link between Nodes 2 and 3, as shown in Figures 5 and 6. Node 3 initially connected to Node 1 via Wi-Fi, but most of the time along the route, it switched to the HaLow link via relay Node 2. Video quality remained consistent even when Node 3 moved at 40 km/h in a car. In comparison, using single radio platform, Wi-Fi link in all three nodes provided 63% [1], and HaLow provided 30% video call bandwidth. Thus, the *MRAM* platform demonstrated reliable performance for H2H communication at ground level, effectively managing N-LoS conditions and providing consistent connectivity across multiple link types.

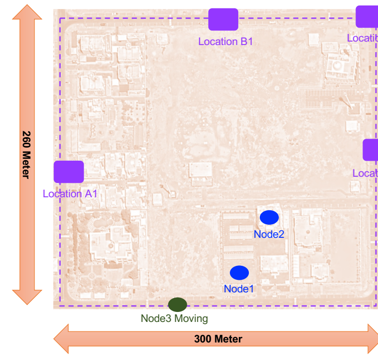

Figure 4: Real-World Urban Environment setup

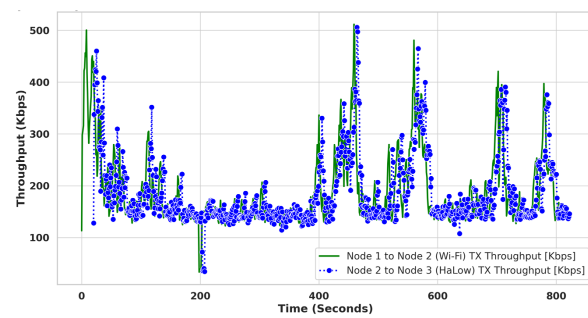

Figure 5: Throughput analysis from Node 1 to 3 via Node 2

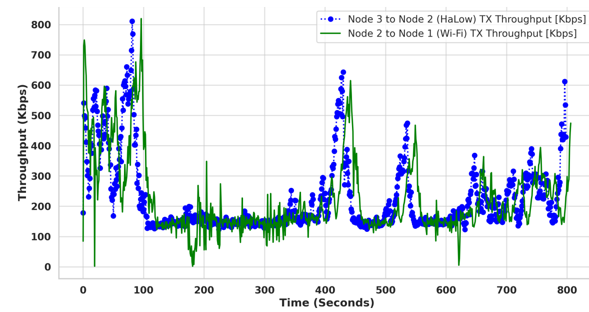

Figure 6: Throughput analysis from Node 3 to 1 via Node 2

4 Conclusions

The *MRAM* platform integrates Wi-Fi and HaLow radios with multi-radio B.A.T.M.A.N. enhancements for robust long-range mesh network. Evaluations in urban, N-LoS conditions showed reliable video communication throughout the route, even with a node moving at 40 km/h. *MRAM* outperformed single-radio setups, which provided only partial video call bandwidth, demonstrating its effectiveness in maintaining reliable communication through intelligent link selection. This makes *MRAM* ideal for challenging environments that require extended coverage, scalability, and resilience.

References

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