Wavemetrik

Enhancing Wi-Fi Performance: The Critical Role of Co-Channel and Adjacent Channel Interference Mitigation

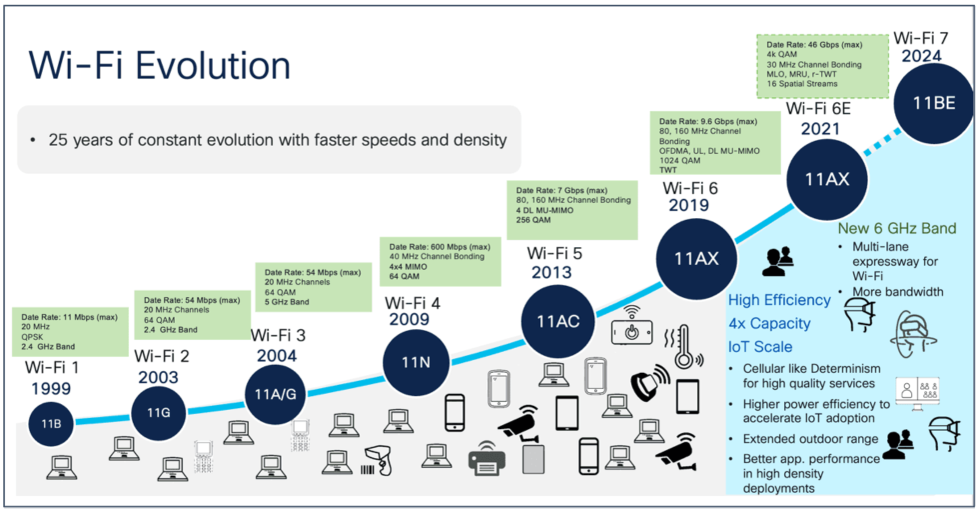
1. Introduction

Wi-Fi technology is a cornerstone of modern communication, playing a pivotal role in homes, offices, and public spaces. As the demand for wireless connectivity grows, so does the need for high-performance networks. Despite the evolution of Wi-Fi standards like IEEE 802.11ax (Wi-Fi 6) and the upcoming 802.11be (Wi-Fi 7), interference issues, specifically Co-Channel Interference (CCI) and Adjacent Channel Interference (ACI), remain significant challenges that impede optimal network performance.

While much attention has been paid to increasing data rates and expanding bandwidth, these advancements alone are not sufficient to address real-world performance bottlenecks. This document explores the evolution of Wi-Fi standards, the critical role of interference mitigation, and practical strategies to enhance Wi-Fi performance by managing CCI and ACI effectively. The integration of advanced interference generation tools, such as WaveMetrik Technologies' MT-Wave, offers a cutting-edge approach to replicating real-world conditions in lab settings.

2. Evolution of Wi-Fi Standards: From 802.11b to 802.11be

Wi-Fi technology has evolved significantly since its inception, marked by a series of IEEE 802.11 standards designed to improve speed, efficiency, and reliability. Below is a comprehensive overview of key Wi-Fi standards and their enhancements:



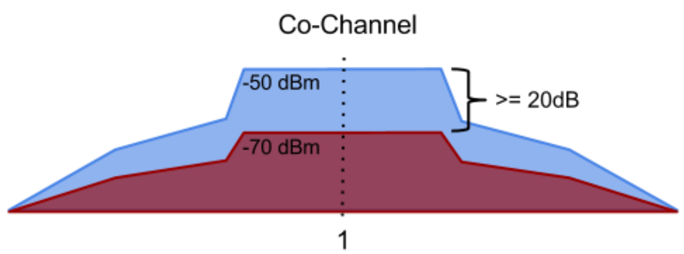
- **802.11b (1999)**: The first widely adopted Wi-Fi standard, operating at 2.4 GHz with data rates up to 11 Mbps. Its simplicity and low cost drove initial adoption but also introduced vulnerability to interference from devices like microwaves and cordless phones.
- **802.11a/g (2003)**: 802.11a introduced the 5 GHz band, which offered less interference and higher data rates (up to 54 Mbps). 802.11g combined the benefits of 802.11b's 2.4 GHz range with the higher speeds of 802.11a, providing a balanced approach.
- **802.11n (2009)**: Marked a major leap with MIMO (Multiple Input, Multiple Output) technology, channel bonding (up to 40 MHz), and support for both 2.4 GHz and 5 GHz bands. These improvements boosted throughput up to 600 Mbps, addressing previous interference issues to some extent.
- **802.11ac (2013)**: Enhanced channel bonding (up to 160 MHz), introduced Beamforming, and utilized Multi-User MIMO (MU-MIMO), significantly increasing data rates up to 6.9 Gbps. Despite these advancements, challenges with CCI and ACI persisted, especially in high-density environments.
- **802.11ax (Wi-Fi 6, 2019)**: Focused on improving efficiency in congested environments with OFDMA (Orthogonal Frequency Division Multiple Access), BSS Coloring, and Target Wake Time (TWT). These technologies helped to manage multiple users simultaneously, with data rates reaching 9.6 Gbps.
- **802.11be (Wi-Fi 7, upcoming)**: Aims to deliver Extremely High Throughput (EHT) up to 46 Gbps by utilizing 320 MHz channels, 16 spatial streams, and advanced modulation schemes like 4096-QAM. 802.11be also introduces Multi-Link Operation (MLO) for improved interference management, marking a significant advancement over previous standards.

3. The Limitations of Current Standards in Handling Interference

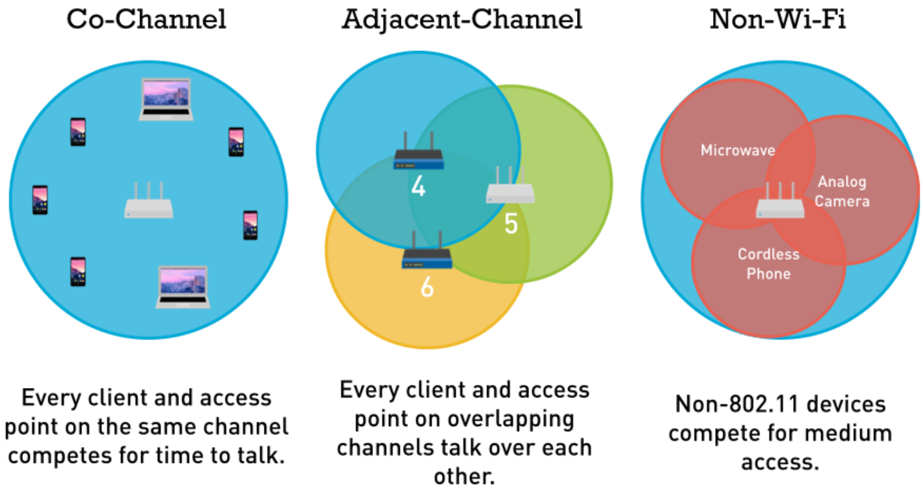
While each new standard brought higher speeds and greater capacity, managing interference effectively has remained a challenging aspect. The IEEE 802.11ax and 802.11be standards include minimal specifications for interference management, including CCI and ACI, but these requirements often represent only the bare minimum.

Key Specifications for ACI and CCI in IEEE 802.11ax/be:

- **Co-Channel Interference (CCI) Tolerance**: APs are expected to manage a co-channel rejection ratio of 20 dB, ensuring they can effectively differentiate between signals and interference on the same channel.



- **Adjacent Channel Interference (ACI) Tolerance**: no pre-defined specification



However, these standards alone are insufficient for real-world deployments. Many commercially available access points fail to meet these interference specifications when subjected to real-world traffic, where signal environments are dynamic and unpredictable.

Real-World Challenges:

- **Dynamic Interference Patterns**: Unlike lab environments, where interference can be controlled and predictable, real-world networks face fluctuating interference from various sources, including neighbouring Wi-Fi networks, Bluetooth devices, and other electronic equipment.
- **Performance Degradation in Dense Environments**: Office buildings, apartment complexes, and public areas often experience high levels of CCI and ACI, resulting in reduced throughput, increased latency, and overall poor user experience.
- **Mismatch Between Lab and Real-World Performance**: Traditional lab instruments used to simulate interference often fall short of replicating the complexity and variability of real-world conditions. APs optimized in such controlled environments frequently underperform when deployed in actual settings due to their inability to handle realistic interference levels.

4. Addressing Interference with Advanced Testing Tools: Introducing MT-Wave

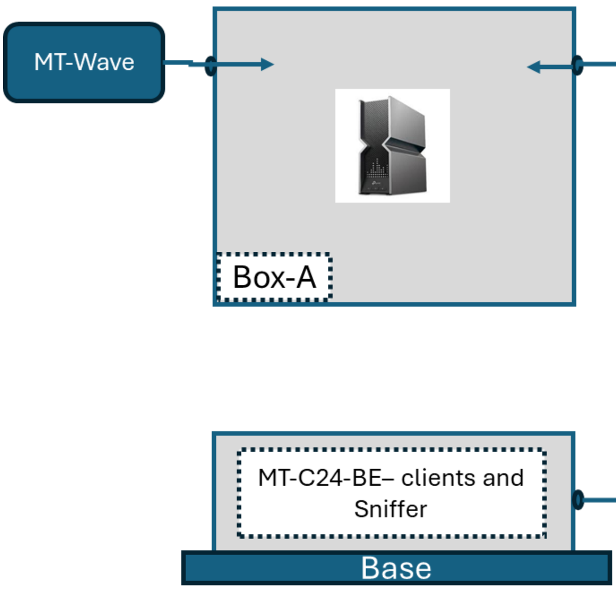
To bridge the gap between lab and real-world performance, **WaveMetrik Technologies** has developed the **MT-Wave**, a state-of-the-art Wi-Fi interference generator designed to replicate the most realistic interference scenarios. The MT-Wave offers advanced capabilities that go beyond conventional testing tools, providing precise control over interference variables and enabling a more accurate evaluation of AP performance.

Key Features and Benefits of MT-Wave:

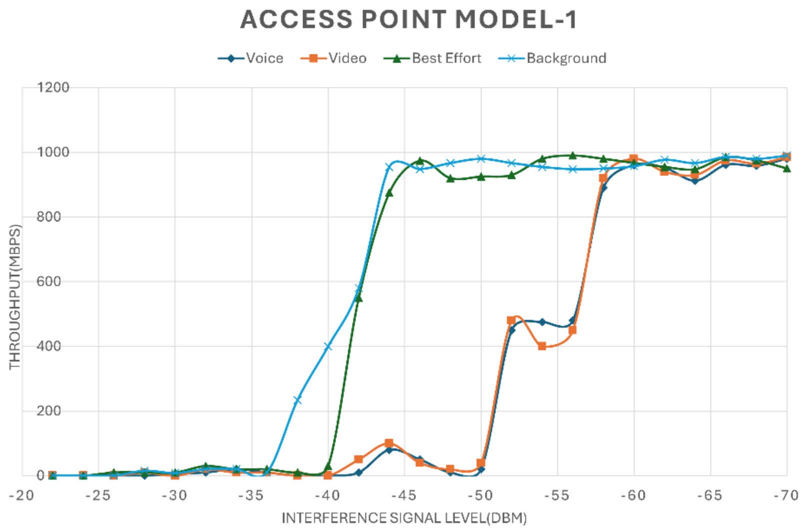
- **Frequency Range**: Supports all three major bands—2.4 GHz, 5 GHz, and 6 GHz—covering most Wi-Fi channels, including 6E.
- **Co-Channel and Adjacent Channel Interference Generation**: Provides accurate control over power levels from -30 dBm to +20 dBm, ensuring realistic simulation of interference conditions.
- **Wide Dynamic Power Range**: Maintains consistent performance across all Modulation and Coding Schemes (MCS) rates and bandwidths, with an adjustable dynamic power range suitable for diverse testing requirements.
- **Realistic Traffic Emulation**: Simulates congestion in networks by controlling inter-frame spacing down to 16 μs, equivalent to Short Inter-Frame Space (SIFS), generating maximum realistic congestion.
- **Configurable Parameters**: Allows for the adjustment of standard, channel, bandwidth, MCS rate, WMM priority, IFS, power level, and payload, providing comprehensive testing scenarios.
- **WMM Priorities Support**: Supports all Wi-Fi Multimedia priorities—Voice, Video, Best Effort, and Background—ensuring a thorough evaluation of interference handling across traffic types.

The MT-Wave provides a critical tool for testing APs under interference conditions that closely mimic real-world scenarios, significantly improving the ability of network engineers to optimize performance before deployment.

We conducted tests on two popular access points using the WaveMetrik MT-SYS-1 test solution, which incorporates the advanced MT-Wave interference generator. Below are sample results showcasing the performance under realistic interference conditions.

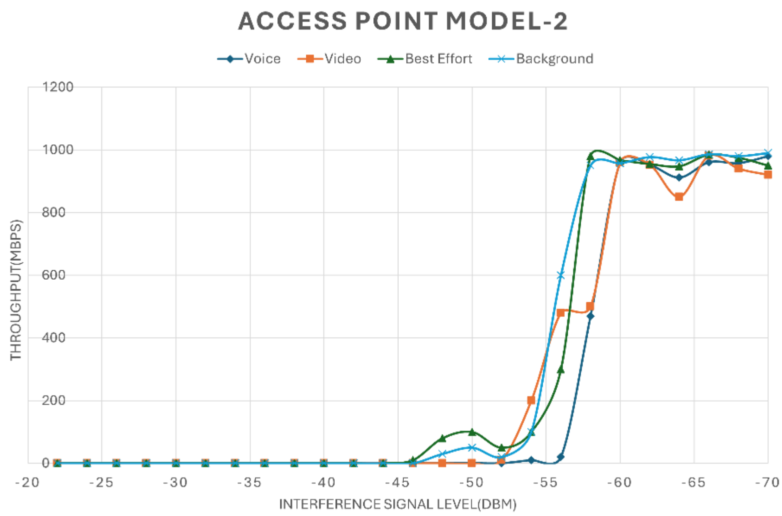


The **MT-SYS-1** is a leading Wi-Fi 7 performance testing system, featuring a semi-anechoic chamber equipped with specially designed(achieve higher SNR) broadband antennas offering an 9 dB gain. This setup ensures precise and reliable testing conditions. Accompanying the system is the **MT-C24-BE**, a rack-mountable Wi-Fi 7 client emulator boasting 24 physical radios. The MT-C24-BE supports critical Wi-Fi 7 features, including Enhanced Multi-Link Single Radio (EMLSR), Multi-Link Multi-Radio (MLMR), preamble puncturing, advanced sniffing capabilities, and much more, making it an essential tool for comprehensive Wi-Fi 7 performance evaluation.



Access Point-Model 1

- Client RSSI -30dBm
- **Rapid Reconnection**: The AP swiftly re-establishes connection with the client after interference is disabled.
- **Superior Rejection Performance**: Achieves better than -20 dB rejection for voice and video interference signals, ensuring clear and uninterrupted communication.
- **Efficient Interference Handling**: Provides better than -10 dB rejection for best effort and background signals, maintaining optimal performance even under challenging conditions.



Access Point-Model 1

- Client RSSI -30dBm
- **Slower Reconnection Time**: Reconnection takes longer after interference is turned off, impacting overall performance.
- **Suboptimal Rejection Performance**: Exhibits less than -20 dB rejection across various types of interference signals, affecting signal clarity.
- **Slow Throughput Recovery**: The system experiences sluggish recovery in throughput after interference, hindering network efficiency.

5. Optimizing Access Point Performance in Realistic Lab Environments

Testing APs in realistic conditions that simulate the complex nature of real-world interference is crucial. Standard lab tests often fail to replicate the dynamic interference scenarios seen in everyday deployments. The MT-Wave offers a powerful solution to this challenge.

5.1 Importance of Realistic Lab Testing

- **Controlled Interference Simulations**: The MT-Wave introduces controlled levels of CCI and ACI that reflect actual operating conditions, including variable traffic loads, overlapping networks, and non-Wi-Fi interference sources.
- **Performance Metrics**: Evaluate AP performance not just on throughput and latency, but also on resilience to interference, channel stability, and error rates.
- **Iterative Optimization**: Continuous testing and optimization cycles with MT-Wave help refine AP performance, ensuring robustness against interference before market deployment.

6. The Role of WMM Priorities, IFS Values, and Payload Length in Mitigation

Wi-Fi Multimedia (WMM) is a key component in managing traffic prioritization and mitigating interference. WMM categorizes traffic into different Access Categories (ACs), each with its own set of priorities, IFS values, and payload lengths.

6.1 WMM Priorities and IFS Values

WMM defines four priority levels to ensure efficient management of traffic, particularly under interference conditions:

Priority Level	Access Category (AC)	IFS Value(uSec)	Typical Payload Length(Bytes)
1	Voice (AC_VO)	42	64 - 256
2	Video (AC_VI)	42	512 - 1500
3	Best Effort (AC_BE)	55	1500 - 3000
4	Background (AC_BK)	107	1500 - 4000

6.2 Payload Length Optimization

The payload length for each priority category is tailored to match the traffic type, ensuring that higher-priority traffic uses shorter packets to minimize latency and reduce collision risk:

6.3 Impact on Interference Mitigation

- **Improved Channel Access**: Adjusting IFS values and prioritizing critical traffic helps manage interference by reducing wait times for high-priority transmissions.
- **Collision Reduction**: Shorter packets for high-priority categories mean less airtime, reducing the chance of collisions and improving overall network performance.

7. Conclusion

While advancements in Wi-Fi standards like 802.11ax and 802.11be have significantly improved data rates, the critical role of interference mitigation cannot be overlooked. Co-Channel and Adjacent Channel Interference are major barriers to achieving optimal performance, especially in dense deployments. Focusing solely on increasing data rates and expanding bandwidth is not sufficient; equal emphasis must be placed on realistic lab testing against interference, dynamic interference management strategies, and the effective use of WMM priorities, IFS values, and payload lengths.

The introduction of advanced testing tools like WaveMetrik Technologies' MT-Wave provides a significant leap forward in replicating real-world interference, enabling a balanced approach that includes both advanced data handling and interference mitigation techniques to unleash the full potential of next-generation wireless networks.