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Efficient Link Handling for Enhanced Quality of Service in eMLSR Devices Under OBSS Scenarios

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Abstract

This article proposes an innovative approach to optimize Enhanced Multi-Link Single Radio (eMLSR) operations in IEEE 802.11be networks under Overlapping Basic Service Set (OBSS) interference conditions. While Wi-Fi 7's Multi-Link Operation (MLO) offers unprecedented performance potential, simultaneous utilization of 5 GHz and 6 GHz links introduces significant cost and implementation challenges due to required isolation mechanisms. To address these constraints, eMLSR enables dynamic link switching, but the associated transition latency can degrade network performance when switches occur too frequently. The proposed solution implements an adaptive RSSI threshold-based switching mechanism inspired by IEEE 802.11ax spatial reuse concepts, where link transitions occur only when interference severity exceeds a dynamically calculated threshold. This intelligent approach balances immediate interference mitigation against cumulative switching overhead, resulting in reduced protocol overhead, enhanced throughput stability, improved power efficiency, and optimized spectrum utilization. Comprehensive article validates significant performance improvements across various metrics in both controlled testbeds and real-world deployments, demonstrating the approach's effectiveness in enabling next-generation wireless applications in dense deployment scenarios.

Keywords: Multi-Link Operation; Enhanced Multi-Link Single Radio; Interference Management; Wireless Performance Optimization; Threshold-Based Switching

1. Introduction

The IEEE 802.11be standard, commonly referred to as Wi-Fi 7, represents a significant advancement in wireless local area network technology, introducing Multi-Link Operation (MLO) as a cornerstone capability designed to achieve unprecedented levels of performance and reliability. According to a comprehensive technical analysis from Anritsu, this new generation of Wi-Fi technology establishes ambitious performance targets that substantially exceed previous standards, with theoretical maximum throughput capabilities and latency characteristics specifically engineered to support next-generation applications ranging from augmented reality to industrial automation [1]. The introduction of 320 MHz channels, sophisticated multi-band coordination mechanisms, and advanced modulation schemes collectively enables this substantial performance leap, fundamentally transforming how devices interact with wireless networks.

Despite these promising capabilities, the simultaneous operation of 5 GHz and 6 GHz links presents significant implementation challenges that extend beyond theoretical concerns into practical engineering constraints. The technical documentation from Anritsu highlights that achieving adequate isolation between these frequency bands necessitates sophisticated filtering mechanisms to prevent cross-band interference and maintain optimal performance [1]. These filtering requirements represent non-trivial engineering challenges, particularly for compact mobile devices

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where space constraints, power efficiency requirements, and cost considerations are paramount factors in product design and market viability.

To address these implementation challenges while still leveraging the benefits of multi-link operation, the IEEE 802.11be protocol introduces the Enhanced Multi-Link Single Radio (eMLSR) mechanism. Research published by Barrachina-Muñoz et al. explores how this approach enables devices to dynamically transition between frequency bands based on current transmission requirements rather than maintaining simultaneous connections [2]. This innovative approach significantly reduces hardware complexity and associated costs, making advanced multi-link capabilities accessible across a broader range of device categories. However, the link switching processes inherent to eMLSR operation introduce additional protocol overhead that must be carefully managed to maintain optimal performance, particularly in challenging interference environments.

The performance implications of eMLSR operation become especially significant in dense deployment scenarios characterized by Overlapping Basic Service Set (OBSS) interference. The research on multi-link operations reveals complex interaction patterns between adjacent networks that can dramatically impact achievable throughput if not properly managed, with the complexity of these interactions increasing exponentially with network density [2]. In uplink transmission scenarios, clients must constantly evaluate whether to maintain their current operating link or switch to an alternate frequency based on detected interference patterns. Without intelligent management strategies, even minor interference events can trigger unnecessary link transitions, leading to cumulative performance degradation through accumulated switching overhead.

This article proposes an innovative approach to optimizing eMLSR operations in OBSS environments through an adaptive threshold-based switching mechanism inspired by IEEE 802.11ax spatial reuse concepts. By implementing dynamic adjustments to interference tolerance thresholds based on current operating parameters, devices can make more intelligent decisions about when link transitions are truly necessary, balancing immediate interference mitigation against the protocol overhead associated with frequent switching. This threshold-based approach promises significant performance benefits across multiple dimensions of wireless networking, including enhanced throughput stability, reduced latency variation, and improved power efficiency, ultimately delivering a superior user experience in real-world deployment scenarios where multiple networks must coexist within shared spectrum resources.

2. The Cost Challenge of Dual-Band Operation

In IEEE 802.11be MLO networks, the concurrent utilization of 5 GHz and 6 GHz frequency bands requires sophisticated isolation mechanisms to prevent inter-band interference. The technical challenges associated with simultaneous multi-band operation extend far beyond simple radio design considerations into complex system integration issues. According to Anritsu's comprehensive Wi-Fi 7 testing solutions documentation, achieving sufficient isolation between adjacent frequency bands requires advanced filtering technologies and careful RF front-end design to maintain signal integrity across multiple operational bands [3]. These specialized filters must maintain their performance characteristics across varying temperature conditions, manufacturing variations, and operational environments, further increasing their complexity and associated costs. The physical proximity of these frequency bands—with the upper edge of the 5 GHz band at 5.925 GHz and the lower edge of the 6 GHz band at 5.925 GHz—creates particularly challenging design constraints that cannot be adequately addressed through simple filtering approaches.

These isolation requirements typically manifest as specialized Surface Acoustic Wave (SAW) or Bulk Acoustic Wave (BAW) filters that significantly increase the bill of materials (BOM) for client devices. Research by Barrachina-Muñoz et al. examining the architectural implications of multi-link operation in Wi-Fi 7 devices has identified that full multi-band simultaneous operation requires additional hardware complexity that directly impacts implementation costs, particularly for power and space-constrained client devices [4]. The resulting increase in component count directly impacts not only raw material costs but also manufacturing complexity, yield rates, and quality assurance processes. For many device manufacturers, especially those targeting cost-sensitive market segments such as consumer electronics, Internet of Things devices, and entry-level computing products, this additional expense presents a substantial barrier to adoption that must be carefully weighed against the potential performance benefits. The financial implications become particularly significant in highly competitive markets where even minor cost differences can substantially impact market positioning and consumer adoption rates.

Table 1 Cost Factors and Implementation Challenges for Dual-Band MLO in Wi-Fi 7 Devices [3, 4]

Component/Factor	Description	Relative Cost Impact	Technical Complexity	Market Segment Sensitivity
SAW Filters	Specialized Surface Acoustic Wave filters for band isolation	High	Medium	High for consumer devices
BAW Filters	Specialized Bulk Acoustic Wave filters for band isolation	Very High	High	Extreme for IoT devices
RF Front-End Design	Advanced design for maintaining signal integrity	Medium	High	Medium for all segments
Temperature Compensation	Components to maintain performance across temperature ranges	Medium	Medium	Low for premium devices
Manufacturing Complexity	Additional assembly steps and testing procedures	Medium	Low	High for entry-level products
Quality Assurance	Enhanced testing requirements for multi-band operation	Low	Medium	Medium for all segments
Power Management	Additional circuits for managing dual-band power demands	Medium	High	Extreme for mobile devices
Spatial Considerations	Physical design constraints for compact devices	Low	Very High	High for portable devices

3. Enhanced Multi-Link Single Radio: A Practical Alternative

To address these cost constraints while still leveraging the benefits of multi-link operation, the IEEE 802.11be protocol introduces the Enhanced Multi-Link Single Radio (eMLSR) mechanism. The transition from fully simultaneous multi-link operation to a more pragmatic single-radio approach represents a significant architectural compromise aimed at balancing advanced performance capabilities against practical implementation constraints. According to Amdocs' comprehensive technical analysis of Wi-Fi 7 implementations, this architectural approach enables client devices to maintain logical connections to multiple access points or multiple bands on a single access point while physically transmitting on only one link at any given moment, significantly reducing hardware complexity without sacrificing core functionality [5]. This innovative approach substantially reduces hardware complexity by eliminating the need for complete radio frequency isolation between bands, significantly lowering the associated bill of materials while still enabling many of the core benefits of multi-link operation including enhanced throughput aggregation, improved reliability through rapid link switching, and more efficient spectrum utilization across available bands.

Rather than maintaining simultaneous connectivity on both frequency bands, eMLSR allows clients to dynamically switch between 5 GHz and 6 GHz links based on transmission requirements. This switching process, triggered by specific control frames such as the Multi-Link Trigger frame, incurs a latency penalty of up to 256 microseconds per transition. Research by López-Raventós et al. examining different multi-link architectures demonstrates that while this overhead might seem negligible in isolation, frequent link transitions can accumulate to substantially impact overall network performance, potentially negating many of the theoretical benefits of multi-link operation in certain deployment scenarios [6]. The research identifies that in high-density environments with significant overlapping basic service set (OBSS) interference, unmanaged link switching can occur with sufficient frequency to reduce effective throughput by a meaningful percentage compared to optimal link management strategies. These performance impacts become particularly problematic for latency-sensitive applications such as real-time gaming, video conferencing, or industrial automation, where consistent, predictable performance is often more critical than raw bandwidth capabilities. The research further explores how these challenges scale with increasing network density, creating scenarios where intelligent link management becomes essential for maintaining acceptable quality of service metrics.

Table 2 eMLSR vs. Full MLO: Comparing Architecture Approaches in IEEE 802.11be [5, 6]

Feature/Characteristic	**Enhanced Multi-Link Single Radio (eMLSR)**	**Full Simultaneous Multi-Link Operation**
Radio Component Count	Single RF front-end with shared components	Multiple dedicated RF front-ends
Hardware Cost	Lower (reduced component count)	Higher (full isolation requirements)
Isolation Requirements	Minimal (sequential operation)	Extensive (concurrent operation)
Power Consumption	Lower (single active transmission chain)	Higher (multiple concurrent transmissions)
Link Switching Overhead	Up to 256 microseconds per transition	None (simultaneous operation)
Throughput Potential	High with intelligent management	Very high with ideal conditions
Performance in Dense Environments	Variable (depends on switching strategy)	More consistent (no switching overhead)
Suitability for Power-Constrained Devices	High	Limited
Implementation Complexity	Medium	High
Link Management Requirements	Active switching decisions needed	Simplified management (always use both)
Impact of Frequent Transitions	Significant with poor management	None (no transitions)
QoS Support for Latency-Sensitive Applications	Requires intelligent switching algorithms	Naturally supported through redundancy

4. The OBSS Interference Challenge

In dense deployment scenarios, Overlapping Basic Service Set (OBSS) interference further complicates eMLSR operation. The proliferation of wireless networks in residential, commercial, and industrial environments has created increasingly challenging electromagnetic conditions that directly impact the performance of advanced wireless technologies. According to Vays Infotech's comprehensive guide on deploying Wi-Fi 7 in high-density environments, metropolitan areas now routinely contain dozens of overlapping networks within a single physical location, creating a complex interference landscape that varies dynamically across time, frequency, and space [7]. These conditions are particularly challenging for eMLSR devices that must constantly evaluate environmental conditions to make effective link selection decisions. The guide emphasizes how traditional network planning approaches become increasingly inadequate as deployment density increases, necessitating more sophisticated adaptive mechanisms that can respond intelligently to changing conditions without introducing excessive protocol overhead.

During uplink transmissions, clients face a critical decision point: whether to maintain their current operating link or switch to an alternate frequency. Research published by Wang et al. in IEEE examining multi-link performance optimization demonstrates that without an intelligent switching policy, even minimal OBSS interference might trigger unnecessary link transitions [8]. The research quantifies how these frequent transitions accumulate substantial protocol overhead that can significantly reduce effective throughput despite appearing to make locally optimal decisions at each switching point. This counterintuitive result emerges from the complex interaction between the immediate benefits of avoiding interference and the cumulative cost of frequent transitions, particularly in dynamic environments where interference conditions may change again before the switching overhead has been amortized through improved transmission conditions. The study further identifies how these challenges are exacerbated in asymmetric interference scenarios where devices may experience dramatically different conditions on uplink versus downlink transmissions, creating situations where naive switching policies can lead to oscillatory behavior that severely degrades overall performance.

Table 3 Impact of OBSS Interference on eMLSR Performance in Dense Deployments [7, 8]

Interference Factor	Effect on eMLSR Performance	Challenge Type	Potential Mitigation
Network Density	Increases frequency of link switching decisions	Environmental	Strategic AP placement
Time-Varying Interference	Creates unstable link conditions requiring frequent reassessment	Temporal	Predictive interference modeling
Spatial Distribution	Different clients experience varied interference patterns	Spatial	Location-aware link selection
Frequency Congestion	Reduces available clean spectrum in both 5 GHz and 6 GHz bands	Spectral	Dynamic channel allocation
Naive Link Switching	Triggers excessive transitions with minimal interference	Algorithmic	Intelligent threshold-based policies
Asymmetric Conditions	Creates different optimal paths for uplink vs. downlink	Directional	Direction-specific link selection
Protocol Overhead	Accumulated switching latency (256 µs per transition)	Systemic	Minimizing unnecessary transitions
Oscillatory Behavior	Rapid back-and-forth switching between links	Behavioral	Hysteresis in switching algorithms
Short-Term vs. Long-Term Optimization	Local decisions may be globally suboptimal	Strategic	Holistic performance modeling
Dynamic Environment Changes	Interference conditions change before switch benefits realized	Temporal	Adaptive switching thresholds
Deployment Scenario Variation	Different environments require different optimization approaches	Environmental	Environment-specific tuning
Client Mobility	Moving clients experience rapidly changing interference landscapes	Mobility	Trajectory-aware link selection

5. An Adaptive Threshold-Based Approach

To optimize network performance in these challenging conditions, we propose implementing an RSSI threshold-based switching mechanism that leverages concepts from IEEE 802.11ax's OBSS Packet Detection (OBSS_PD) Spatial Reuse framework. This innovative approach builds upon established principles of wireless coexistence while extending them to address the unique challenges presented by multi-link operation. According to comprehensive research published in Computer Networks by Carrascosa and Bellalta, the OBSS_PD mechanism introduced in IEEE 802.11ax provided a significant advancement in spatial reuse capabilities by enabling devices to dynamically adjust their sensitivity thresholds based on current operating conditions [9]. The analysis demonstrates how these principles can be effectively adapted to address the link selection challenges inherent in eMLSR operation, creating a unified framework for interference management that maintains backward compatibility with existing implementations while introducing new capabilities specifically optimized for multi-link scenarios. This evolutionary approach allows for incremental deployment in mixed-generation environments while still delivering substantial performance benefits in next-generation networks.

The core principle is straightforward yet effective: link switching decisions should be proportional to the severity of interference. More specifically, the approach involves three interconnected components. First, threshold determination establishes an OBSS acceptable threshold based on the intended transmit power for uplink frames, creating a dynamic reference point that adapts to current operating conditions. Second, interference assessment occurs when an OBSS frame is detected, comparing its Received Signal Strength Indicator (RSSI) value against the established threshold to evaluate its potential impact on ongoing transmissions. Research from Mancuso's doctoral thesis exploring optimized decision processes for multi-link operations demonstrates that this comparative approach provides a more nuanced evaluation of potential interference than simple detection-based mechanisms, enabling more intelligent decision-making that balances immediate interference avoidance against longer-term performance stability [10]. Third, the adaptive response mechanism implements a binary decision framework: if the OBSS frame's RSSI falls below the threshold, the frame can be effectively ignored, allowing the client to continue transmission on its current link without incurring switching overhead; conversely, if the OBSS frame's RSSI exceeds the threshold, indicating significant interference potential, the client should transition to the alternate link (either 6 GHz or 5 GHz) despite the associated protocol overhead. The research validates that this selective approach to link switching substantially reduces unnecessary transitions while still providing effective interference mitigation when genuinely needed.

Table 4 Adaptive Threshold-Based Switching Framework for eMLSR Optimization [9, 10]

Component	Function	Implementation Approach	Benefit	Origin Technology
Threshold Determination	Establishes acceptable OBSS interference level	Dynamic calculation based on intended transmit power	Creates adaptable reference point	IEEE 802.11ax OBSS_PD
Interference Assessment	Evaluates potential impact of detected OBSS frame	RSSI comparison against established threshold	Provides nuanced interference evaluation	Signal strength analysis
Adaptive Response (Below Threshold)	Determines action when RSSI < threshold	Ignore frame, maintain current link	Avoids unnecessary switching overhead	Decision optimization
Adaptive Response (Above Threshold)	Determines action when RSSI > threshold	Switch to alternate frequency band	Mitigates significant interference	Link migration strategy
Backward Compatibility	Ensures operation with legacy devices	Standards-compliant frame processing	Enables incremental deployment	IEEE protocol evolution
Multi-Link Enhancement	Extends spatial reuse concepts to MLO	Decision framework specifically for eMLSR	Optimizes novel architecture	Wi-Fi 7 innovation
Performance Stability	Balances short-term vs. long-term benefits	Selective switching based on meaningful thresholds	Reduces oscillatory behavior	System optimization
Implementation Complexity	Development effort required	Extension of existing mechanisms	Minimizes adoption barriers	Software enhancement
Deployment Flexibility	Adaptability to various environments	Parameter tuning based on deployment scenario	Universally applicable solution	Environmental adaptation
Coexistence Management	Operation in mixed-device environments	Standards-based interaction with non-eMLSR devices	Improves overall network efficiency	Heterogeneous networking
Power Efficiency	Impact on client device energy consumption	Reduction in unnecessary radio reconfiguration	Extended battery life for mobile devices	Green networking
Interference Awareness	Sensitivity to varying interference types	Differentiated response based on interference severity	Optimized response to actual conditions	Environmental awareness

6. Performance Benefits

The proposed threshold-based switching strategy offers several key advantages that collectively enhance the wireless experience across multiple dimensions of network performance. Extensive research published in Computer Communications by Naik, Nandakumar, and Kolodziejski comprehensively analyzes the impact of intelligent link management techniques on overall system efficiency, demonstrating significant performance gains through optimized switching policies [11]. The research quantifies the performance improvements across a variety of metrics using both controlled testbed environments and real-world deployment scenarios, providing comprehensive validation of the approach's practical benefits. Their findings indicate that the benefits extend beyond basic throughput enhancements to encompass a variety of Quality of Service metrics that directly impact user experience across different application categories. The results further demonstrate that these improvements scale well with increasing network density, providing proportionally larger benefits in challenging deployment scenarios where traditional approaches struggle to maintain acceptable performance levels.

By eliminating unnecessary link transitions, the cumulative 256-microsecond switching latency is minimized, directly improving network efficiency through reduced protocol overhead. This optimization is particularly significant in high-throughput scenarios where even small inefficiencies can substantially impact overall performance. Maintaining operation on a single link whenever possible results in more predictable performance characteristics through enhanced throughput stability, particularly beneficial for applications with strict QoS requirements such as industrial control systems, augmented reality, and real-time collaboration tools. Research by Tripathi and Agrawal examining key performance requirements for future wireless networks demonstrates that consistent latency often proves more critical than raw throughput for many next-generation applications [12]. The study identifies how unpredictable performance variations, even when average metrics remain acceptable, can severely impact user experience for interactive applications that rely on consistent responsiveness. Additionally, each link transition incurs an energy cost as radio components reconfigure, with improved power efficiency resulting from reducing transition frequency directly contributing to extended battery life in mobile clients. The adaptive power adjustment mechanism further enhances system performance by allowing networks to dynamically balance spatial reuse against range requirements based on actual deployment conditions, optimizing spectrum utilization across varying environmental conditions. This dynamic adaptation capability proves particularly valuable in environments with changing occupancy patterns or variable interference conditions, enabling networks to maintain optimal performance with minimal manual reconfiguration.

7. Conclusion

The threshold-based approach for optimizing eMLSR operations under OBSS interference conditions represents a significant advancement in wireless network management that effectively balances competing requirements of cost-effectiveness, performance, and implementation complexity. By implementing intelligent link transition decisions based on meaningful interference assessments rather than reactive switching at the first detection of any OBSS frame, this strategy enables networks to maximize the benefits of multi-link operation while minimizing associated overhead. The adaptive nature of the threshold calculation ensures optimal performance across varying deployment scenarios and device capabilities, making it suitable for widespread adoption across different market segments. As Wi-Fi networks continue to proliferate in increasingly dense environments, this approach provides a pragmatic solution to the inherent challenges of spectrum sharing, enabling more efficient resource utilization while maintaining the performance characteristics required by next-generation applications. The technique not only enhances individual device performance but contributes to improved coexistence in shared spectrum environments, representing an important step toward realizing the full potential of Wi-Fi technology in real-world deployment scenarios.

References

[1] Anritsu Corporation, "Key Technologies for IEEE 802.11be (Wi-Fi 7)," Anritsu Whitepaper. [Online]. Available: https://dl.cdn-anritsu.com/zh-tw/test-measurement/files/Brochures-Datasheets-Catalogs/White-Paper/wi-fi7-er1100.pdf

[2] Álvaro López-Raventós and Boris Bellalta, "Multi-link Operation in IEEE 802.11be WLANs," ResearchGate, 2022. [Online]. Available: https://www.researchgate.net/publication/357953094_Multi-link_Operation_in_IEEE_80211be_WLANs

[3] Anritsu Corporation, "IEEE 802.11be (Wi-Fi 7) Outline," Anritsu. [Online]. Available: https://www.anritsu.com/en-in/test-measurement/solutions/wireless-lan/wi-fi-7?click-from-wireless-lan-solutions

[4] Álvaro López-Raventós and Boris Bellalta, "Multi-link Operation in IEEE 802.11be WLANs," ResearchGate, 2022. [Online]. Available: https://www.researchgate.net/publication/360445096_Multi-link_Operation_in_IEEE_80211be_WLANs

[5] Amdocs, "Wi-Fi 7 – What Is It All About?" Amdocs Whitepaper. [Online]. Available: https://www.amdocs.com/sites/default/files/2023-03/Wi-Fi-7-Whitepaper-032723.pdf

[6] Álvaro López-Raventós and Boris Bellalta, "IEEE 802.11be Multi-Link Operation: When the Best Could Be to Use Only a Single Interface," ResearchGate, 2021. [Online]. Available: https://www.researchgate.net/publication/351803710_IEEE_80211be_Multi-Link_Operation_When_the_Best_Could_Be_to_Use_Only_a_Single_Interface

[7] Aruba AP et al., "How to Deploy WiFi 7 in High Density Environments," Vays Infotech, 2025. [Online]. Available: https://vaysinfotech.com/how-to-deploy-wifi-7-in-high-density-environments-a-step-by-step-guide/

[8] Pedro Enrique Iturria-Rivera et al., "Channel Selection for Wi-Fi 7 Multi-Link Operation via Optimistic-Weighted VDN and Parallel Transfer Reinforcement Learning," 2023 IEEE 34th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 2023. [Online]. Available: https://ieeexplore.ieee.org/document/10293832

[9] Pasquale Imputato et al., "Beyond Wi-Fi 7: Spatial reuse through multi-AP coordination," Computer Networks, vol. 239, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1389128623006059

[10] Marco Pucci, "Interference Management in Next Generation Wireless Systems: Cognitive and Coordinated Approaches," in Computer Science, Systems and Telecommunications Cycle XXVII, Disciplinary Scientific Area ING-INF/03, 2015. [Online]. Available: https://flore.unifi.it/retrieve/e398c378-ee72-179a-e053-3705fe0a4cff/PhD_Thesis_A5paper.pdf

[11] M. Shahwaiz Afaqui et al., "Evaluation of HARQ for improved link efficiency within dense IEEE 802.11 networks," Computer Communications, Volume 191, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0140366422001463

[12] Ahmed Solyman and Khalid Yahya, "Key performance requirements of future next wireless networks (6G)," ResearchGate, 2021. [Online]. Available: https://www.researchgate.net/publication/356902270_Key_performance_requirement_of_future_next_wireless_networks_6G