MLO STR Performance through Traffic Allocation

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***Abstract*—The system model used in this study consists of a single transceiver radio capable of multi-link operation. The transceiver operates under various traffic conditions and interference levels.**

I. Introduction

Multi-Link Operation (MLO) in Single Transceiver Radio (STR) systems is a critical area of research in wireless communications. This paper aims to explore the performance of MLO STR systems under different traffic conditions and interference levels. We focus on three main aspects: the impact of MCS, bandwidth, and interference on STR performance and delay.

II. System Model

The system model used in this study consists of a single transceiver radio capable of multi-link operation. The transceiver operates under various traffic conditions and interference levels. The key parameters and assumptions of the system model are as follows:

- **Modulation and Coding Scheme (MCS)**: Different MCS levels are used to evaluate their impact on STR performance.
- **Bandwidth**: The system operates under different bandwidth settings to analyze their effect on throughput and delay.
- **Interference**: Various levels of interference are introduced to study their impact on system performance.

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III. Simulation

The simulation was conducted to evaluate the impact of various parameters on STR performance. The following aspects were considered:

The simulations were executed using the `mlo.py` script against the `single-bss-mld.cc` C++ file with the following parameters:

A. MCS Impact

MCS values were iterated from 1 to 11, and throughput was measured for each value.

B. Bandwidth Impact

Bandwidths of 20, 40, and 80 MHz were used to measure the throughput.

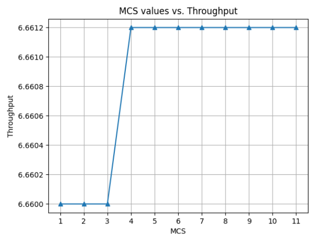
C. Interference Impact

Different levels of interference were simulated by varying the offered load values:

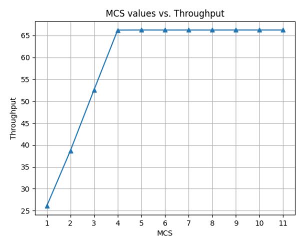
- **Low Interference**:
  - Number of MLD STAs (`nMldSta`): 5
  - Channel Width (`channelWidth`, `channelWidth2`): 40 MHz
  - Access Category (AC) Parameters:
    * `acBECwminLink1`, `acBECwminLink2`: 15
    * `acBECwStageLink1`, `acBECwStageLink2`: 4
  - MCS (`mcs`, `mcs2`): 6
  - Splitting Probability (`mldProbLink1`): 0.1
- **Medium Interference**:
  - Number of MLD STAs (`nMldSta`): 15
  - Channel Width (`channelWidth`, `channelWidth2`): 20 MHz
  - Access Category (AC) Parameters:
    * `acBECwminLink1`, `acBECwminLink2`: 7
    * `acBECwStageLink1`, `acBECwStageLink2`: 3
- **High Interference**:
  - Number of MLD STAs (`nMldSta`): 30
  - Channel Width (`channelWidth`, `channelWidth2`): 20 MHz
  - Access Category (AC) Parameters:
    * `acBECwminLink1`, `acBECwminLink2`: 4
    * `acBECwStageLink1`, `acBECwStageLink2`: 2
  - MCS (`mcs`, `mcs2`): 2
  - Splitting Probability (`mldProbLink1`): 0.8

IV. Simulation Results

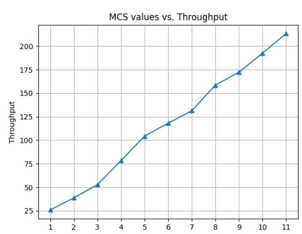
A. Impact of MCS on STR Performance and Delay



(a) Impact of MCS on STR Throughput - Low Traffic

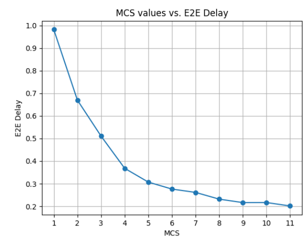


(b) Impact of MCS on STR Throughput - Medium Traffic

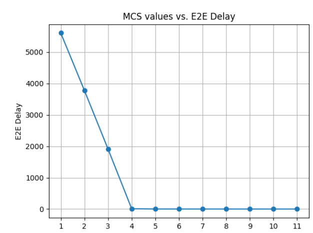


(c) Impact of MCS on STR Throughput - High Traffic

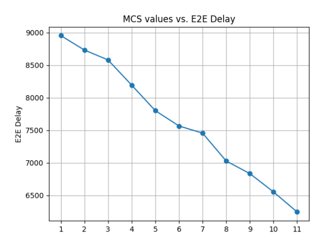
Fig. 1: Impact of MCS on STR Throughput at different traffic levels.



(a) Impact of MCS on STR E2E Delay - Low Traffic



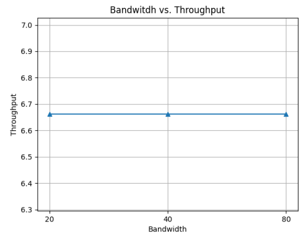
(b) Impact of MCS on STR E2E Delay - Medium Traffic



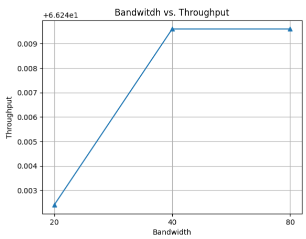
(c) Impact of MCS on STR E2E Delay - High Traffic

Fig. 2: Impact of MCS on STR End-to-End (E2E) Delay at different traffic levels.

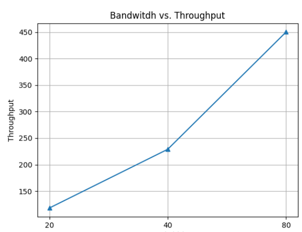
B. Impact of Bandwidth on STR Performance and Delay



(a) Impact of Bandwidth on STR Throughput - Low Traffic

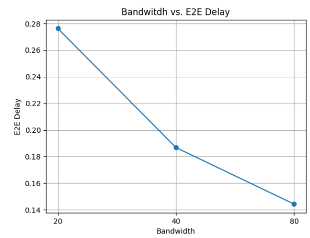


(b) Impact of Bandwidth on STR Throughput - Medium Traffic

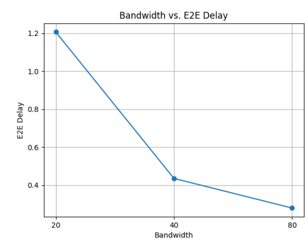


(c) Impact of Bandwidth on STR Throughput - High Traffic

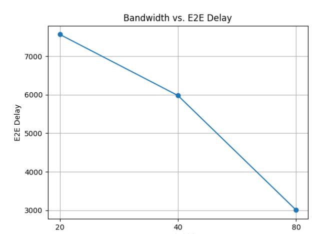
Fig. 3: Impact of Bandwidth on STR Throughput at different traffic levels.



(a) Impact of Bandwidth on STR E2E Delay - Low Traffic



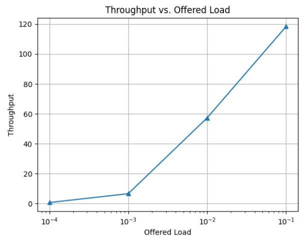
(b) Impact of Bandwidth on STR E2E Delay - Medium Traffic



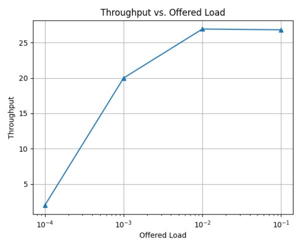
(c) Impact of Bandwidth on STR E2E Delay - High Traffic

Fig. 4: Impact of Bandwidth on STR End-to-End (E2E) Delay at different traffic levels.

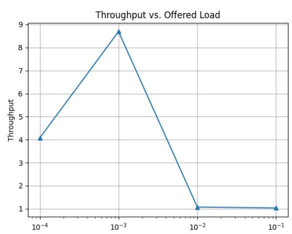
C. Impact of Interference on STR Performance and Delay



(a) Impact of Interference on STR Throughput - Low Interference

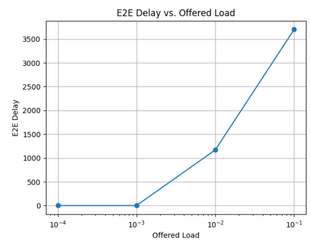


(b) Impact of Interference on STR Throughput - Medium Interference

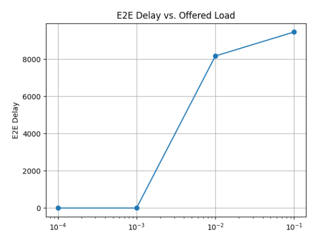


(c) Impact of Interference on STR Throughput - High Interference

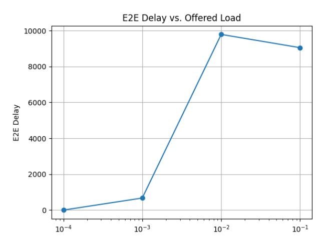
Fig. 5: Impact of Interference on STR Throughput at different interference levels.



(a) Impact of Interference on STR E2E Delay - Low Interference



(b) Impact of Interference on STR E2E Delay - Medium Interference



(c) Impact of Interference on STR E2E Delay - High Interference

Fig. 6: Impact of Interference on STR End-to-End (E2E) Delay at different interference levels.

V. Conclusion and Future Work

A. Conclusion

To achieve higher throughput, it is recommended to use higher MCS values (e.g., MCS 7-9 for 802.11ac). Higher MCS values utilize more complex modulation schemes such as 64-QAM or 256-QAM, which can transmit more data per symbol but require a stronger signal and better Signal-to-Noise Ratio (SNR).

Using wider channel widths (e.g., 40 MHz, 80, etc. MHz for 802.11ac and 802.11ax) can also increase throughput. Wider channels allow more data to be transmitted simultaneously, thereby reducing end-to-end delay.

To minimize interference, ensure that your network operates on less congested channels. Employ dynamic channel selection and avoid overlapping channels. Additionally, reducing the number of devices operating on the same channel can help minimize interference.

Lower MCS values ensure stability under high interference environments for several reasons:

- **Simpler Modulation Schemes**: Lower MCS values use simpler modulation schemes, such as BPSK (Binary Phase Shift Keying) or QPSK (Quadrature Phase Shift Keying), which are more robust against interference. These schemes have greater differences between symbols, making them less susceptible to errors caused by noise and interference.
- **Higher Error Correction**: Lower MCS values typically have higher coding rates, meaning they include more error correction bits. This helps in detecting and correcting errors caused by interference, ensuring more reliable data transmission.
- **Better Signal-to-Noise Ratio (SNR) Requirements**: Lower MCS values require a lower SNR to maintain a stable connection. In high interference environments, the SNR can be significantly degraded, so using lower MCS values helps maintain a reliable link.
- **Reduced Retransmissions**: With lower MCS values, the likelihood of successful packet transmission increases, reducing the need for retransmissions. This helps maintain throughput and reduces latency, even in the presence of interference.

By using lower MCS values, the network can maintain a more stable and reliable connection, even when interference levels are high. This trade-off between data rate and robustness is crucial for ensuring consistent performance in challenging environments.

B. Future Work

The current study provides a comprehensive analysis of the impact of MCS values, bandwidth, and interference on STR performance. However, several areas remain for future exploration:

- **Advanced Modulation Techniques**: Investigate the potential of emerging modulation schemes beyond 256-QAM, such as 1024-QAM, to further enhance throughput while maintaining signal integrity.
- **Adaptive Bandwidth Allocation**: Develop and evaluate algorithms for dynamic bandwidth allocation that can adapt in real-time to varying network conditions and user demands.
- **Interference Mitigation Strategies**: Explore advanced interference mitigation techniques, including machine learning-based dynamic channel selection and power control mechanisms, to further reduce the impact of interference on network performance.
- **Multi-User MIMO (MU-MIMO)**: Study the effects of implementing MU-MIMO technology in conjunction with different MCS levels and bandwidth settings to optimize throughput and spectral efficiency.
- **Cross-Layer Optimization**: Investigate cross-layer optimization approaches that consider interactions between the physical layer and higher network layers to enhance overall system performance.
- **Real-World Deployment Scenarios**: Conduct extensive field trials in diverse real-world environments to validate the simulation results and refine the models based on empirical data.
- **Energy Efficiency**: Evaluate the energy efficiency of different MCS levels and bandwidth settings, particularly in high-interference environments, to develop strategies for reducing power consumption without compromising performance.

These future directions will help in further understanding and improving the performance of wireless networks under various conditions, contributing to the development of more robust and efficient communication systems.

VI. REFERENCES

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