EE 595 / EEP 569 Final Project

1 Guidelines

1.1 Project Goals

The course project should be designed as a performance evaluation study related to wireless networking, a contribution to the ns-3 simulator, or both. Ideally, this project will allow you to explore a specific topic in greater depth, providing you with an opportunity to produce a small technical study while also learning about open-source software development. You may explore areas such as protocol evaluation, multi-link operation in Wi-Fi 7, energy efficiency strategies, or interference management in dense wireless environments.

1.2 Project Deliverables

The primary deliverable is a comprehensive written report in the style of a technical paper. This report should be well-formatted, with attention to correct grammar, punctuation, and spelling, and include clearly produced figures and data visualizations. Any references, including academic papers or open-source contributions, must be properly cited.

In addition to the written report, each student will give a brief summary presentation during the final week of the course, lasting 10-15 minutes. This presentation should succinctly explain the project's goals, methods, and findings, followed by a Q&A session.

Finally, we will review your software implementation. The key evaluation criteria here are correctness and repeatability. We should be able to regenerate the data shown in your report and presentation using the code and instructions you provide.

1.3 Time Commitment

During the first two months, you will complete weekly homework or ns-3 assignments. Starting in Week 4, we will begin focusing on project definition and getting started on your individual project. Week 7 will be the last week with an assignment to allow you to fully concentrate on your final project. Students are encouraged to start gathering ideas and preliminary data for their projects early to maximize time for development and experimentation.

1.4 Honor Policy

University of Washington policies regarding academic integrity will be followed[1]. It is strictly forbidden to submit work that is not your own, including but not limited to paying for external services to complete your ns-3 project. You are encouraged to ask for help from instructors, TAs, and other students, or on forums such as the ns-3 users mailing list, but your final submission must be substantially your own work.

[1] http://www.washington.edu/teaching/teaching-resources/preparing-to-teach/cheating-or-plagiarism/

1.5 Policy for Using GenAI Tools

Generative AI tools like ChatGPT can be valuable aids in your project development, but there are strict limitations on their usage. You are encouraged to use these tools for tasks such as:

- Writing and debugging ns-3 code.
- Analyzing and interpreting data.
- Improving grammar and style in technical writing.

However, the use of GenAI tools to generate entire sections of text for your project proposal or final report is prohibited. The focus should remain on your own work, especially when it comes to explaining methodologies, discussing results, and drawing conclusions. Any AI-assisted code generation or analysis should be fully understood by the student and integrated into the project with proper commentary. Misuse of GenAI tools will be considered a violation of the honor policy.

2 Grading and Key Dates

The final project will contribute 40% to your overall course grade. Grading will be based on both the difficulty and the completeness of the project, including the quality of your presentation, report, and code submission. The grades for each team member may differ based on individual participation and contributions. Contributions will be monitored through various tools, including code commits, document revision history on platforms such as Overleaf, and activity on Google Slides. This ensures that each student's efforts are fairly assessed.

2.1 Grading Breakdown

- **Week 6 (11/07 before class):** Project Proposal Due (1 page) [25 points]
- **Final Week (12/03):** Project Presentation [25 points]
- **Exam Week (12/10):** Final Report and Code Submission (3 pages) [50 points]

2.2 Difficulty Weights

The project difficulty level will scale your score to account for the challenge you take on:

- **Easy:** Weight = 1.0
- **Medium:** Weight = 1.2
- **Hard:** Weight = 1.5

2.3 Example Calculation

For example, if you score 80 points on a project classified as "Hard" difficulty, your adjusted score will be calculated as:

$$\textit{Adjusted score} = 1.5 \times 80 \times 0.40 = 48$$

This would contribute 48 points toward your final grade. Additionally, since (48 - 40) = 8 points exceed the value of one homework assignment (7.5 points), you could waive one of your homework grades.

3 Project Ideas

The final project offers various levels of difficulty, allowing students to choose projects based on their comfort and expertise. Projects range from simple simulations with existing code to complex research-oriented tasks that may require substantial modification of the ns-3 simulator. Projects can also be self-proposed, provided they align with the course's focus on Wi-Fi and ns-3.

3.1 Easy Difficulty

Projects in this category require running simulations using existing scripts, either from previous lab assignments or from supplementary mathematical models. Minimal modifications to the source code are needed, but students will need to conduct multiple experiments with different configurations. The outputs are typically predictable and straightforward to generate. These projects are suitable for small teams, and only teams of two people may sign up for projects at this difficulty level.

3.1.1 Validation of DCF Protocol for Latency and Throughput

In this project, you will validate the Distributed Coordination Function (DCF) protocol by correlating the ns-3 simulation results with an analytical model based on the Bianchi framework. The goal is to compare the latency and throughput of the ns-3 implementation with predictions from the mathematical model under various network conditions. The script for the analytical model will be provided to assist in this process.
Reference: WNS3 2024 Delay Validation [4]
Codebase: Lab1
Requirements:

- Define the specific experiments and scenarios for validation, including variations in network load, number of nodes, and other key parameters.
- Run the experiments and collect data to analyze the performance metrics (latency and throughput).
- Compare the results between the ns-3 simulations and the analytical model.
- Extend the validation to multiple scenarios, ensuring robustness across a range

3.1.2 Validate the MLO STR performance

In this project, you will validate the Multi-lik operation feature in Wi-Fi 7 by correlating the ns-3 simulation results with an analytical model based on the Bianchi framework. The goal is to compare the latency and throughput of the ns-3 implementation with predictions from the mathematical model under various network conditions. The script for the analytical model will be provided to assist in this process.
Reference: WNS3 2024 Delay Validation [4]
Codebase: Lab2
Requirements:

- Define the specific experiments and scenarios for validation, including variations in network load, number of nodes, and other key parameters.

- Run the experiments and collect data to analyze the performance metrics (latency and throughput).
- Compare the results between the ns-3 simulations and the analytical model.
- Extend the validation to multiple scenarios, ensuring robustness across a range

3.1.3 Optimizing MLO STR Performance through Traffic Allocation

In this project, you will explore different traffic allocation strategies in the Multi-Link Operation (MLO) of Wi-Fi 7. The objective is to investigate how varying parameters such as Modulation and Coding Scheme (MCS), bandwidth, and interference levels affect the delay and throughput performance of Simultaneous Transmission and Reception (STR) in MLO. By experimenting with different traffic splitting methods across multiple links, you will analyze the impact on overall MLO efficiency.
Reference: WNS3 2024 Delay Validation [4]
Codebase: Lab2
Requirements:

- Define specific experiments and scenarios, including variations in traffic load, MCS, bandwidth, and interference conditions.
- Conduct experiments to gather performance data, focusing on delay and throughput metrics.
- Analyze the results under different MLO traffic

3.1.4 Comparison of Rate Control Algorithms in ns-3

This project focuses on evaluating and comparing different rate control algorithms available in the ns-3 simulator, such as Minstrel, AARF, and CARA. The aim is to investigate how these algorithms perform in various network scenarios, particularly in terms of throughput, latency, and packet loss. You will analyze the behavior of each algorithm under different conditions, including changes in link quality, interference, and mobility, to determine which algorithm performs best in specific environments.
Reference: WNS3 2024 Rate Adaptation [2]; AI-Based SOTA algorithm [5]
Codebase: `https://gitlab.com/juanvleonr/ns-3-dev/-/tree/raa-verification`
Requirements:

- Define the experiments and scenarios, varying parameters such as network load, mobility patterns, and interference levels.
- Implement and configure different rate control algorithms in ns-3.
- Collect performance data, focusing on throughput, latency, and packet loss metrics.
- Compare the results across the algorithms to identify their strengths and weaknesses in different conditions.

3.1.5 Multi-BSS Simulations with CCA-PD

This project aims to investigate the performance of Multi-Basic Service Sets (Multi-BSSs) in dense Wi-Fi environments using Clear Channel Assessment with Physical Carrier Sensing Detection (CCA-PD). You will conduct simulations in ns-3 to explore how adjusting the CCA-PD threshold impacts network performance, particularly in terms of throughput, latency, and fairness across multiple BSSs. The goal is to analyze how these settings influence the coexistence of multiple overlapping BSSs, and to evaluate their effect on overall spectrum efficiency.
Reference: Lab3
Codebase: Lab3
Requirements:

- Define the experiments, focusing on variations in CCA-PD threshold, number of BSSs, and interference levels.
- Simulate different scenarios with multiple BSSs and measure key performance indicators such as throughput, latency, and fairness.
- Analyze the impact of varying the CCA-PD threshold on network performance and spectrum efficiency.
- Provide recommendations for optimal CCA-PD settings in dense Wi-Fi environments.

3.2 Medium Difficulty

Medium difficulty projects involve modifying ns-3 code to create new configurations or extend existing functionalities. Students will be expected to explore different scenarios, provide insights, and present new results based on their experiments. While these projects are more challenging, they still offer manageable goals. Teams for medium difficulty projects may consist of 2 or 3 students.

3.2.1 Validation of EDCA Protocol for Latency and Throughput

In this advanced project, you will validate the Enhanced Distributed Channel Access (EDCA) protocol by correlating the latency and throughput observed in ns-3 simulations with an analytical model. The objective is to explore the impact of different Access Categories (ACs) on the performance of Wi-Fi networks, with a particular focus on Quality of Service (QoS) differentiation. By analyzing various network scenarios, you will investigate how EDCA manages traffic priority and how it affects the overall network performance.
Reference: WNS3 2024 Delay [4]
Codebase: Lab1
Requirements:

- Define experiments with varying Access Categories (ACs), network loads, and traffic types.
- Validate latency and throughput performance in comparison with an analytical model.
- Analyze how EDCA handles priority traffic and impacts different types of data flows.

3.2.2 Comparison of STR and eMLSR Performance in MLO

This project focuses on comparing the performance of Simultaneous Transmission and Reception (STR) with Enhanced Multi-Link Single Radio (eMLSR) in Multi-Link Operation (MLO) of Wi-Fi 7. You will investigate how each technique handles traffic allocation and network performance under different scenarios, such as varying link quality, bandwidth, and interference levels. The goal is to understand the trade-offs between STR and eMLSR in terms of latency, throughput, and energy efficiency.
Reference: WNS3 2024 MLO Performance Analysis [4]
Codebase: Lab2
Requirements:

- Define scenarios comparing STR and eMLSR, varying MCS, bandwidth, and interference.
- Collect and analyze performance metrics, including latency, throughput, and energy efficiency.
- Compare the results to determine the strengths and weaknesses of STR versus eMLSR in different environments.

3.2.3 XR Traffic Performance Evaluation for SLO and MLO

In this project, you will evaluate the performance of XR (Extended Reality) traffic under both Single-Link Operation (SLO) and Multi-Link Operation (MLO) in Wi-Fi 7. XR traffic has stringent requirements in terms of latency, jitter, and packet loss, making this project critical for optimizing wireless networks for immersive applications. You will simulate XR traffic in ns-3 and compare the performance of SLO and MLO across different network conditions, focusing on ensuring quality of experience for XR users.
Reference: WNS3 2024 MLO [4]; XR traffic model in ns-3 [1]
Codebase: Lab2
Requirements:

- Define scenarios that evaluate XR traffic in both SLO and MLO environments.
- Measure key performance indicators such as latency, jitter, and packet loss for XR applications.
- Compare the performance of SLO and MLO in delivering seamless XR experiences.

3.2.4 Multi-BSS Simulations under TGax Scenarios

This project involves simulating multiple Basic Service Sets (Multi-BSS) under TGax scenarios as defined in the IEEE 802.11ax standard. You will simulate dense network environments to evaluate how the TGax features, such as OFDMA, spatial reuse, and uplink/downlink scheduling, impact performance. The goal is to analyze how these enhancements improve network capacity, reduce latency, and ensure fairness in dense deployment scenarios.
Reference: Lab3; IEEE TGax simulation scenarios documents [3]
Codebase: Lab3
Requirements:

- Test under TGax scenarios with multiple BSSs and varying interference levels.
- Simulate and collect performance metrics including throughput, latency, and fairness.

- Analyze how TGax features improve network performance in dense environments.

3.2.5 Multi-BSS Simulations with OBSS-PD and Channel Bonding

This advanced project focuses on evaluating the performance of Multi-BSS networks when using Overlapping Basic Service Set Packet Detection (OBSS-PD) combined with channel bonding. The objective is to explore how these techniques, designed to enhance spectral efficiency and coexistence in dense environments, affect network performance. You will simulate different network conditions in ns-3 to analyze how adjusting OBSS-PD thresholds and channel bonding widths influence throughput, latency, and fairness in densely populated Wi-Fi networks.
Reference: Lab3
Codebase: Lab3
Requirements:

- Define scenarios that vary OBSS-PD thresholds and channel bonding settings across multiple BSSs.
- Collect and analyze performance metrics, focusing on throughput, latency, and spectrum efficiency.
- Evaluate the trade-offs between spectral efficiency and fairness in dense network environments.

3.3 Hard Difficulty

Projects in the hard difficulty category require significant modifications to ns-3, such as implementing new features or protocols. These projects are more research-oriented, meaning that some results may be uncertain, but they offer the potential to gain valuable insights and contribute to the ns-3 simulator or its community. The complexity of these projects means that they are ideal for students looking for a challenging and exploratory experience. Teams of 2 or 3 students are allowed for hard difficulty projects.

3.3.1 Validation of Coexistence of Different QoS Traffic in EDCA

This project focuses on the validation of Enhanced Distributed Channel Access (EDCA) for managing multiple traffic types with different Quality of Service (QoS) requirements. The goal is to evaluate how EDCA ensures fair coexistence between high-priority traffic (e.g., voice or video) and lower-priority traffic (e.g., background data). You will simulate various traffic mixes and network loads in ns-3, analyzing how well EDCA prioritizes time-sensitive traffic while maintaining overall network efficiency. This project will explore scenarios with heavy congestion to test the limits of QoS differentiation.
Codebase: Lab1
Requirements:

- Design experiments with mixed QoS traffic (voice, video, best effort, background) under different network conditions.
- Simulate the coexistence of different traffic types and collect performance metrics such as latency, jitter, and throughput.
- Analyze how well EDCA handles traffic prioritization and the impact on lower-priority traffic under congestion.

- Provide recommendations for optimizing QoS settings in dense networks.

3.3.2 FTM Implementation and Testing in ns-3

This project involves implementing and testing Fine Timing Measurement (FTM) in ns-3, a key feature in Wi-Fi for location and ranging services. The objective is to develop an ns-3 model for FTM and validate its accuracy and efficiency in various network scenarios. You will evaluate how environmental factors such as interference, mobility, and signal strength impact FTM accuracy. The goal is to test the implementation under realistic conditions and optimize it for accurate location estimation in Wi-Fi networks.
Requirements:

- Implement the FTM protocol in ns-3, ensuring compatibility with existing Wi-Fi modules.
- Design and execute experiments to test the accuracy and performance of FTM under various conditions (e.g., interference, mobility, distance).
- Analyze the accuracy of FTM location estimates and identify scenarios where performance degrades.
- Suggest optimizations for improving FTM accuracy in challenging environments.

3.3.3 Dynamic Traffic Splitting and CW Control in MLO with AI/ML

This advanced project pushes the boundaries of Multi-Link Operation (MLO) by incorporating AI/ML techniques to dynamically manage traffic splitting and Contention Window (CW) control. The goal is to design and implement AI/ML algorithms that can adaptively split traffic across multiple links in MLO based on real-time network conditions, such as channel load, interference, and traffic patterns. Additionally, the project will focus on optimizing CW settings dynamically to improve throughput and reduce latency. The AI/ML model should be trained to make intelligent decisions to enhance overall network performance.
Codebase: Lab2
Requirements:

- Implement AI/ML algorithms for dynamic traffic splitting across multiple links in MLO.
- Train the model using real-time network data, such as channel load, interference, and traffic patterns.
- Implement dynamic CW control based on AI/ML predictions to optimize performance.
- Simulate scenarios with varying traffic loads and interference, and evaluate the impact on throughput, latency, and fairness.
- Provide an analysis of the effectiveness of AI/ML in improving MLO performance and suggest further areas for optimization.

3.4 Self-Proposed Projects

Students who are engaged in related research are encouraged to propose their own final project, provided it aligns with the course's focus on Wi-Fi and ns-3. Self-proposed projects require approval from the instructors, and they should demonstrate similar levels of effort and relevance to the provided project categories.

4 Submissions

4.1 Proposal - One Page

The proposal should include the following sections:

1. **Introduction**

   Clearly state the goals of your project and explain why it is of interest or significance.

2. **Background and Related Work**

   Provide a list of potential reference materials you plan to consult, including any relevant research or prior work in the area.

3. **Experiment Plan**

   List the experiments you intend to perform.

These sections can be reused in the final project report. The proposal should be submitted via Canvas.

4.2 Final Report

The final report should be formatted in a conference-style paper, no less than 3 pages, and include the following sections:

1. **Introduction**

   Clearly state the goals of your project and why it is of interest. Summarize your key findings and provide a brief outline of the rest of the report.

2. **Background and Related Work**

   List and describe the references that were used to guide your research and development. Discuss relevant prior work.

3. **Methodology**

   Detail the methodology you applied, including the steps taken to develop and validate your results.

4. **Results**

   Present and analyze the results of your project. Include any figures or tables that help demonstrate your findings. Provide a link to your code for open access.

5. **Summary and Future Work**

   Summarize the main contributions of your project and suggest potential future work, particularly opportunities to integrate **AI/ML and ns3-ai models** to extend or enhance your project.

The final project report will be submitted to arXiv to increase its visibility and impact. It is required to be written in LaTeX using Overleaf with template provided.

References

[1] Mattia Lecci, Andrea Zanella, and Michele Zorzi. An ns-3 implementation of a bursty traffic framework for virtual reality sources. In *Proceedings of the 2021 Workshop on ns-3*, pages 73–80, 2021.

[2] Juan Leon, Thomas R. Henderson, and Sumit Roy. Verification of ns-3 wi-fi rate adaptation models on awgn channels. In *Proceedings of the 2023 Workshop on Ns-3*, WNS3 '23, page 109–114, New York, NY, USA, 2023. Association for Computing Machinery.

[3] Simone Merlin et al. Tgax simulation scenarios. Technical Report IEEE 802.11-14/0980r6, IEEE, 11 2015.

[4] Muyuan Shen, Jie Zhang, Hao Yin, Sumit Roy, and Yayu Gao. Delay in multi-link operation in ns-3: Validation and impact of traffic splitting. In *Proc. Workshop on Ns-3*, pages 19–26, June 2024.

[5] Hao Yin, Murali Ramanujam, Joe Schaefer, Stan Adermann, Srihari Narlanka, Perry Lea, Ravi Netravali, and Krishna Chintalapudi. ADR-X: ANN-Assisted wireless link rate adaptation for Compute-Constrained embedded gaming devices. In *Proc. NSDI*, Apr. 2024.