ECE 506 PMP
Fundamentals of Wireless Communications: Capacity, Load, and Delay

Spring 2026 — Provisional Syllabus

1. Course Description

This course develops a systems view of wireless communication networks, organized around the interacting concepts of **capacity, load, and delay**. Rather than treating wireless solely as a physical-layer subject or as protocol memorization, the course studies how bottlenecks emerge and migrate across layers, how airtime functions as the central scarce resource, and how queueing, scheduling, random access, transport control, and physical-layer design combine to determine end-to-end behavior. The course emphasizes engineering judgment, modeling, and cross-layer reasoning.

2. Course Objectives

By the end of the course, students should be able to:

1. Explain wireless systems in terms of **airtime, service, occupancy, and bottlenecks**.
2. Relate **load, capacity, and delay** using queueing and systems models.
3. Interpret wireless MAC behavior through **contention, scheduling, fairness, and resource allocation**.
4. Connect physical-layer concepts such as bandwidth, SNR, coding, OFDM, and MIMO to **effective service rate**.
5. Analyze how transport protocols, buffering, and control loops behave over wireless links.
6. Evaluate design tradeoffs in Wi-Fi, cellular, and related wireless systems using a unified systems perspective.
7. Present and critique technical material at the level expected of a professional master's course.

3. Course Themes

The course is built around several recurring ideas:

- **Airtime is the fundamental resource.**
- **Load is demand for airtime.**
- **Capacity is the system's ability to serve that demand.**
- **Delay is the consequence of mismatch between the two.**
- **Bottlenecks migrate upward through the stack as lower-layer capacity improves.**
- **Wireless systems are best understood as coupled service systems, not isolated protocol layers.**

4. Prerequisites

Students are expected to have prior exposure to:

- signals and systems,

- basic probability,
- linear systems and transforms,
- introductory communications or networking.

A prior wireless communications course is helpful but not strictly required if the student is comfortable with quantitative modeling.

5. Format

- 10 weeks
- One 3-hour evening meeting per week
- A mix of lecture, worked modeling examples, in-class discussion, student presentations or critique, and project development

The course structure is designed around alternating emphases: some weeks center on new technical material, while others center on synthesis, presentation, and critique.

6. Pedagogical Position

The course deliberately differs from a standard wireless course. A traditional course often begins with waveform models, channel models, modulation, and information-theoretic limits, and only later discusses system loading and delay. This course instead foregrounds:

- queueing and service,
- occupancy and airtime,
- random access and scheduling,
- transport interaction,
- bottleneck analysis.

Physical-layer material is still covered, but as part of the explanation of what determines service capability.

7. Weekly Outline

7.1. Week 1: Wireless Systems as Service Systems

- Why wireless should be viewed as a system of shared constrained resources
- Airtime as service time
- Load, capacity, and delay as the organizing triad
- Human attention and other intuitive queueing analogies
- Little's law, utilization, and first performance relationships
- Course overview and project structure

7.2. Week 2: Queueing Foundations for Wireless Networks

- Arrivals, service, occupancy, and waiting
- $M/M/1$, $M/G/1$, and engineering interpretations

- Kingman-style variability insight
- Why burstiness matters
- Bottlenecks and backlog
- What exact queueing models explain well, and where approximations are more useful

7.3. Week 3: Multiple Access and Shared Medium Design

- Why multiple access exists
- Scheduled vs. random access systems
- Reservation, contention, polling, and partitioning ideas
- Time, frequency, code, and spatial resource splitting
- Service-discipline interpretation of MAC design
- Comparison of alternative multiple access designs

7.4. Week 4: Fairness and Scheduling

- What fairness means in wireless systems
- Throughput-optimality vs. delay vs. user experience
- Opportunistic scheduling
- Max-min, proportional fairness, and related notions
- How scheduling changes the effective service seen by users and flows
- Student presentation and critique component

7.5. Week 5: TCP over Wireless

- Why transport protocols misread wireless losses
- Congestion control interacting with variable service
- RTT inflation through queueing
- Retransmissions, buffering, and hidden coupling across layers
- Wireless link adaptation versus transport-layer inference
- Model-based discussion of unstable or misleading control signals

7.6. Week 6: Control Loops in Wireless Systems

- Feedback systems in communications
- Rate control, link adaptation, HARQ-style logic, scheduling feedback
- Stability, lag, oscillation, and overreaction
- Comparison to classical control loops
- System-level consequences of delayed or noisy state information

7.7. Week 7: Measurement and Inference in Wireless Networks

- What can actually be measured in wireless systems
- Throughput, delay, loss, occupancy, airtime, and utilization
- Passive versus active measurement
- Measurement bias induced by protocol behavior

- Why observed rate is not the same as service capability
- Relating field measurements back to models

7.8. Week 8: Finite Buffers and Loss

- Queues are not infinite
- Buffer overflow, blocking, and drop behavior
- Tradeoffs among throughput, delay, and packet loss
- Bufferbloat and the cost of large buffers
- Admission control as a system response to overload
- Examples from routers, wireless access, and shared infrastructure

7.9. Week 9: Multihop Wireless Networks

- Why multihop is fundamentally different
- Interference coupling across links
- Spatial reuse and contention domains
- Per-hop service versus end-to-end service
- Hidden bottlenecks and relaying
- Delay accumulation and instability across multiple stages

7.10. Week 10: Energy per Bit, Spectrum, and System Constraints

- Energy per bit as a system metric
- Regulatory structure: licensed versus unlicensed spectrum
- Spectrum as a constrained shared national resource
- Coverage, reuse, interference, and architecture
- Tradeoffs among energy, bandwidth, delay, and control
- Final synthesis: capacity, load, and delay across the full system

8. Core Technical Modules

The following modules form the backbone of the course:

1. Multiple Access Designs
2. Fairness and Scheduling
3. TCP over Wireless
4. Control Loops
5. Measurement
6. Finite Buffers
7. Multihop
8. Energy per Bit in Wireless
9. Regulation, Spectrum, Licensed vs. Unlicensed

These sit on top of the earlier framing around airtime, queueing, load, capacity, delay, and bottleneck migration across the stack.

9. Assessment Structure

The precise grading split remains provisional, but the intended structure includes:

- homework or short technical writeups,
- student presentation(s),
- a final project or final synthesis report,
- participation in discussion and critique.

The course is not primarily framed as a traditional derivation-only exam course. It is positioned instead as a professional master's course emphasizing:

- conceptual synthesis,
- design reasoning,
- technical communication,
- model-based argument.

10. Representative Questions

Representative questions the course tries to answer include:

- What is a wireless system actually serving?
- How does airtime become the common currency across layers?
- Why does adding raw PHY rate not automatically solve delay?
- How do burstiness and contention produce long delays even when average load seems moderate?
- When is the bottleneck the channel, the scheduler, the transport protocol, or the backhaul?
- How should engineers think about fairness when different users experience different channels?
- Why do control loops in wireless systems often oscillate or misinterpret conditions?
- What do common measurements really mean, and what do they hide?

11. Reading Posture

The course is not tied to a single conventional textbook. Instead, it is built as a curated systems-oriented course drawing from classical wireless communications, queueing theory, computer systems performance analysis, networking, MAC and transport behavior, and spectrum policy. In spirit, the course is closer to a synthesized set of notes than to a one-book course.

12. Catalog-Style Description

ECE 506 PMP — Fundamentals of Wireless Communications: Capacity, Load, and Delay. A systems-oriented study of wireless communication networks emphasizing airtime, service, queueing, scheduling, transport interaction, and bottleneck analysis. Topics include multiple access, fairness, TCP over wireless, control loops, measurement, finite buffers, multihop systems, energy per bit, and spectrum structure. The course develops cross-layer engineering models linking physical-layer capability to network load and delay.