UNIVERSITÀ DI PISA

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

Dottorato di Ricerca in Ingegneria dell'Informazione

Doctoral Course

"Modern Broadband Satellite Communications"

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Short Abstract: This PhD course provides a comprehensive introduction to modern broadband satellite communications, covering the technology, systems, and business dynamics shaping the industry. The course begins with the foundations of satellite communications, from orbital mechanics to system architecture, and progresses through the technical building blocks, including antennas, payloads, link budgets, and multiple access techniques. Students will learn to evaluate different satellite systems (GEO, MEO, LEO) and understand the trade-offs that drive system design. The final portion examines the business landscape: successful deployments like Starlink, the distinction between broadband and direct-to-device services, and the wave of partnerships between satellite companies and terrestrial carriers. Students will leave with both technical understanding and critical thinking skills to analyze this rapidly evolving industry.

Course Contents in brief:

Day 1 (4 hours): Foundations of Modern Broadband Satellite Communications

1.1 What is Broadband Satellite Communications? (30 min)

- Definition and scope: what "broadband" means in the satellite context
- End-to-end network diagram: user terminal ↔ satellite ↔ gateway ↔ internet/core network
- Key use cases: consumer broadband, maritime/aviation connectivity, cellular backhaul, IoT, direct-to-device
- The drivers of the current satellite renaissance

1.2 Orbital Mechanics Primer (30 min)

- GEO, MEO, LEO: altitudes, coverage, latency trade-offs
- Orbital periods and visibility windows

- Why LEO changes everything: latency, capacity density, launch economics

1.3 Brief History of Modern Satellite Communications (45 min)

- GEO era (1990s–2010s): VSAT, DTH broadcasting, early HTS
- First LEO attempts: Iridium, Globalstar, Teledesic—lessons learned
- The LEO breakthrough (2015–present): Starlink, OneWeb, Amazon Kuiper, Telesat Lightspeed
- GEO evolution: VHTS, software-defined payloads

1.4 System Architecture and Building Blocks (60 min)

- Space segment: satellite bus, payload, power systems, thermal control
- Ground segment: gateways, network operations center, points of presence
- User segment: fixed terminals, mobile terminals, consumer terminals, direct-to-handset
- Inter-satellite links: RF vs optical, mesh architectures

1.5 Launch Vehicles and Deployment Economics (30 min)

- Current launch landscape: Falcon 9/Heavy, Ariane 6, emerging players
- Reusability revolution and cost per kg to orbit
- Rideshare and dedicated launches for constellations
- Manufacturing at scale: from bespoke to mass production

1.6 Standards and Frequency Bands (45 min)

- Frequency bands: L, S, C, Ku, Ka, Q/V—characteristics and trade-offs
- DVB-S2/S2X: the workhorse standard for satellite broadband
- 3GPP NTN standards (Release 17, 18, 19): integrating satellites into 5G/6G
- Spectrum coordination: ITU filings, GEO/LEO coexistence, interference management

Day 2 (4 hours): Satellite Technology Deep-Dive

2.1 The RF Link: From Ground to Space and Back (45 min)

- The concept of link budget (high-level)
- Path loss: why distance and frequency matter
- Noise and interference basics
- What determines throughput: bandwidth × spectral efficiency

2.2 Antenna Technologies (60 min)

- Reflector antennas: parabolic dishes, offset-fed, multi-feed designs
- Phased arrays: active vs passive, electronic beam steering
- Beamforming fundamentals: how you point a beam without moving the antenna
- Multi-beam architectures: frequency reuse, spot beams, beam hopping
- Trade-offs: cost, power consumption, flexibility, size/weight

2.3 Satellite Payload Architectures (45 min)

- Bent-pipe transponders: analog repeaters, simple but inflexible
- Digital transparent processors: channelization, switching
- Regenerative payloads: full onboard processing
- Software-defined payloads: flexibility, in-orbit reconfiguration

2.4 Coverage, Capacity, and System Design (60 min)

- Coverage geometry: footprint size vs altitude, elevation angle effects
- Spot beam design: beam diameter, reuse patterns
- Capacity calculation (simplified): total bandwidth × reuse factor × spectral efficiency
- Constellation design basics: Walker-Delta vs Walker-Star, orbital planes
- Worked example: compare coverage/capacity of a GEO HTS vs a LEO constellation

2.5 Comparing Real-World Systems (30 min)

- Case studies: GEO HTS (ViaSat-3, SES-17), LEO broadband (Starlink, OneWeb), MEO (O3b mPOWER)
- What differentiates them: target market, terminal complexity, latency, throughput per user

Day 3 (4 hours): Putting It All Together, From Signals to Services

3.1 The Link Budget Concept (45 min)

- The simple question: "Will my signal arrive with enough strength?"
- The chain: transmit power → antenna gain → path loss → receive sensitivity
- Key parameters explained intuitively (EIRP, G/T, C/N)
- What degrades the link: distance, rain, interference, pointing errors
- Rule of thumb calculations: how engineers estimate feasibility

3.2 Getting More Bits Through the Pipe (45 min)

- The trade-off: speed vs reliability
- Modulation: why higher orders give more throughput but need cleaner signals
- Error correction: adding redundancy to fix mistakes
- Adaptive systems: automatically adjusting to conditions (ACM concept)

3.3 Sharing the Satellite Among Many Users (45 min)

- The core problem: one satellite, thousands of users
- Dividing by frequency (FDMA), by time (TDMA), or by code (CDMA)
- How a user terminal requests and gets capacity
- Beam hopping: moving capacity to where demand is
- LEO-specific challenge: handing off users as satellites move overhead

3.4 The Bigger Picture: Satellites in the Network (45 min)

- Where satellites fit: the "last mile" and the "middle mile"

- Ground infrastructure: gateways, data centers, internet interconnection
- Latency budget: what contributes to delay and why LEO helps
- Hybrid networks: combining satellite with terrestrial
- The 5G/NTN story: smartphones talking directly to satellites

3.5 What Users Actually Get (60 min)

- From "system capacity" to "my download speed"—the reality gap
- Contention: sharing with your neighbors
- Weather, obstructions, and availability
- Regulatory realities: why services work differently in different countries
- Comparing user experience across systems: GEO vs MEO vs LEO
- Mini case study: trace a video call from a rural user through the entire system

Day 4 (4 hours): The Business of Satellite—Markets, Partnerships, and the Road Ahead

4.1 Success Stories: Who's Winning and Why (45 min)

- Starlink: what they got right—vertical integration, launch economics, terminal cost
- Other players: OneWeb, Amazon Kuiper, Telesat Lightspeed
- GEO isn't dead: Viasat, SES, Eutelsat—where they still compete
- What does "success" actually mean in this industry?

4.2 Broadband vs Direct-to-Device: Two Different Games (45 min)

- Broadband satellite: fixed terminals, high throughput, replacing/complementing fiber
- Direct-to-Device: unmodified smartphones, lower throughput, ubiquitous coverage
- Why these are fundamentally different businesses with different economics
- Can one company win at both?

4.3 The Partnership Landscape: Why Carriers Need Satellites (60 min)

- The carrier problem: coverage obligations, rural economics, competitive pressure
- The wave of 90+ deals: T-Mobile + SpaceX, AT&T + AST SpaceMobile, Verizon + Amazon Kuiper, and global examples
- What each side brings: spectrum, customers, coverage, technology
- Deal structures: revenue share, capacity purchase, joint ventures
- Critical thinking exercise: if you were a carrier, which partner would you choose?

4.4 Regulatory and Spectrum Realities (30 min)

- Why spectrum is the ultimate constraint
- ITU coordination and landing rights
- The GEO/LEO interference question
- National security considerations

4.5 Where Is This Going? The Next 5-10 Years (45 min)

- Technology trends: optical inter-satellite links, V-band, smaller/cheaper satellites, onboard AI
- Market evolution: consolidation, new verticals, defense and dual-use
- The big questions: complement or replace terrestrial? Room for multiple constellations?

4.6 Wrap-Up and Discussion (15 min)

- Key takeaways
- Open Q&A
- Resources for continued learning

Total # of hours of lecture: 16 hours divided into four 4-hour sessions.

References:

[1] Su, Y., Liu, Y., Zhou, Y., Yuan, J., Cao, H., & Shi, J. (2019). "Broadband LEO Satellite Communications: Architectures and Key Technologies." IEEE Wireless Communications, 26(2), 21-28.

[2] 3GPP TR 38.821. "Solutions for NR to support Non-Terrestrial Networks (NTN)."

[3] ETSI EN 302 307-2. "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 2: DVB-S2 Extensions (DVB-S2X)."

[4] Kodheli, O., et al. (2021). "Satellite Communications in the New Space Era: A Survey and Future Challenges." IEEE Communications Surveys & Tutorials, 23(1), 70-109.

[5] Del Portillo, I., Cameron, B. G., & Crawley, E. F. (2019). "A Technical Comparison of Three Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband." Acta Astronautica, 159, 123-135.

CV of the Teacher

Mario Di Dio is the GM of Network at Nova Labs, overseeing the development & lifecycles of network products that contribute to the Helium network and driving the roadmap for future technologies. With a focus on communication standards like LTE, 5G, and Wi-Fi, Mario works to enhance end-user connectivity experiences and increase network efficiency.

Before joining Nova Labs, Mario was VP of Software and Network Technology at Kyrio and Principal Architect at CableLabs, where he was responsible for researching, conceptualizing, and leading the development of new technologies that became part of the cable industry's future wired and wireless network infrastructures. Before that, he was a Principal Engineer at Artemis Networks, where he co-created one of the first commercial SDR platforms for efficient and flexible LTE mobile network deployment. He also worked as a Research Engineer on several projects funded by the European Space Agency (ESA) and the European Union (EU) for future satellite and aeronautical communication standards.

Mario holds a BSc in Engineering, an MSc in Engineering, a PhD in telecommunications engineering from the University of Pisa, Italy, and an Executive Master in Business Administration from the University of Denver. He has authored several scientific papers and he holds multiple patents issued in the US and abroad.

Final exam: Choose *one* of the following options. Submit a written report (1-2 pages).

Option 1: Partnership Memo

You are advising a telecom operator in a country of your choice. Write a short memo recommending which satellite company they should partner with for direct-to-device or broadband services. Your memo should address:

- The operator's coverage needs and target market
- Regulatory considerations in that country
- Technical fit (orbit, frequency, terminal requirements)
- Commercial considerations

Justify your recommendation with concepts from the course.

Option 2: News Analysis

Find a recent news article (2024 or later) about satellite communications—a new partnership, a launch, a regulatory decision, a technology announcement, etc. Write a brief analysis that includes:

- Summary of the article
- What technical concepts from the course are relevant?
- What business or regulatory dynamics are at play?
- Your assessment: is this significant? Why or why not?

Include a link to the article.

Evaluation: The report will be evaluated based on the interpretation and analysis of the topic. Particular importance will be given to demonstrating critical thinking and connecting concepts from the course.

Room and Schedule

Room: *Aula Riunioni del Dipartimento di Ingegneria dell'Informazione, Via G. Caruso 16, Pisa – Ground Floor*

Schedule:

- 28/05/2026 – 8:00am - 12:00pm
- 29/05/2026 – 8:00am - 12:00pm
- 03/06/2026 – 8:00am - 12:00pm
- 04/06/2026 – 8:00am - 12:00pm

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