The technology, cybersecurity and policy (TCP) program, previously the interdisciplinary telecom program (ITP), offers the core skills that allow students to master the latest technologies associated with aspects of Internet communications: technology, cybersecurity and policy. Further, students also develop aspects of the business skills and policy knowledge essential to achieving success in the companies driving today's rapidly changing high-tech world. Within its core program TCP students should anticipate developing expertise in the growing areas of network engineering, cybersecurity, wireless communication, and telecommunications policy and strategy. As part of its core engagement and education the program continues to offer a multiplicity of rich opportunities for hands-on experience in its world-class labs equipped with state-of-the-art technologies.

TCP also offers graduate certificates, where students can gain foundational knowledge and skills focusing on a specific technology. Students learn best practices and tools, methods and strategies that are immediately applicable to the work environment. Students should expect that graduate certificates aid the development or enhancement of a specialized expertise. TCP certificates also provide the flexibility to allow course credit hours to be applied toward a TCP master's degree.

For more information, visit the Technology, Cybersecurity and Policy Program (http://www.colorado.edu/program/tcp) website.

Course code for this program is CYBR (formerly TLEN).

Master’s Degree

- Telecommunications - Master of Science (MS) (catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/telecommunications/telecommunications-master-science-ms)
- Telecommunications - Professional Master of Science (MST) (catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/telecommunications/telecommunications-professional-master-science-mst)

Doctoral Degree

- Telecommunications - Doctor of Philosophy (PhD) (catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/telecommunications/telecommunications-doctor-philosophy-phd)

Certificates

- Computer and Network Security - Graduate Certificate (catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/telecommunications/computer-network-security-graduate-certificate)
- Network Architecture - Graduate Certificate (catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/telecommunications/network-architecture-graduate-certificate)
- Telecom Policy and Strategy - Graduate Certificate (catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/telecommunications/telecommunications-policy-graduate-certificate)
- Wireless Networks and Technologies - Graduate Certificate (catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/telecommunications/wireless-networks-technologies-graduate-certificate)

Faculty

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

Baker, Ken
Scholar in Residence; PhD, Virginia Polytechnic Institute and State University

Chen, Lijun (https://experts.colorado.edu/display/fisid_149472)
Assistant Professor; PhD, California Institute of Technology

Curry, James H. (https://experts.colorado.edu/display/fisid_105730)
Associate Faculty Director; PhD, University of California, Berkeley

Gifford, Kevin K. (https://experts.colorado.edu/display/fisid_104361)
Research Professor; PhD, University of Colorado Boulder

Ha, Sangtae (https://experts.colorado.edu/display/fisid_153246)
Assistant Professor; PhD, North Carolina State University

Massey, Daniel (https://experts.colorado.edu/display/fisid_159491)
Faculty Director, Professor; PhD, University of California, Los Angeles

Perigo, Levi (https://experts.colorado.edu/display/fisid_155562)
Scholar in Residence; PhD, Nova Southeastern University

Reed, David P. (https://experts.colorado.edu/display/fisid_152458)
Scholar in Residence; PhD, Carnegie Mellon University

Santos, Jose R. (https://experts.colorado.edu/display/fisid_124623)
Senior Instructor; MS, University of Colorado Boulder

Scaife, Nolan
Assistant Professor; PhD, University of Florida

Thrall, Lloyd Gregory (https://experts.colorado.edu/display/fisid_163208)
Scholar in Residence, Associate Faculty Director; MA, University of London (England)

Courses

**CYBR 5001 (3) Fundamentals of Telecom & Broadband Systems**

Students completing this course will develop competencies in most telecommunications and broadband architectures and the underlying Layer-1 and Layer-2 fundamentals these architectures are based on. The foundational concepts learned in this course will be built upon in subsequent courses. Students will learn fundamental Layer-1 concepts that form the basis of telecommunication systems. Topics of focus include: decibels, noise analysis, transmission lines, electronic signals, radio spectrum characteristics, link budgets, analog and digital modulation, techniques, multiplexing, sampling and digital encoding, detection, and Shannon’s Law. They will also be introduced to fundamental building blocks of Layer-2 including coding, framing, an introduction to IP networking, and traffic engineering. Students will apply these Layer-1 and Layer-2 fundamentals to understand several telecommunication systems architectures including: xDSL, PON, CATV, Cellular wireless, WLAN, satellite systems, internet networking and relat

**Grading Basis:** Letter Grade
CYBR 5010 (3) Fundamentals of Data Communication
Combining conceptual knowledge about data communications and core Internet technologies with hands-on labs that reinforce the conceptual knowledge, this course provides students with the ability to create innovative technology solutions in their discipline. Learning how the Internet works and being able to evaluate and operate an Internet network is a valuable skill; students in this course will have a competitive advantage in this foundational field. Formerly TLEN 5330.
Grading Basis: Letter Grade

CYBR 5013 (3) Fundamentals of System Administration and Virtualization
Introduces the basic use and administration of Unix and Linux systems. Topics include booting and system management, scripting, storage and logical volume management, filesystem configuration, account management and password security, process control, software installation, event logging and system auditing. Students will also develop familiarity with virtualization platforms such as VirtualBox and VMware to implement and test their system configurations.
Grading Basis: Letter Grade

CYBR 5050 (3) Network Economics and Finance
Introduces students to the fundamental theoretical framework and tools used by economists to examine decision making under scarcity. Reviews mathematical economics and models. Examines consumer choice and firm supply. These two aspects of the market are brought together to examine how price and output are determined in competitive and imperfectly competitive markets. Introduces financial economics, network effects and public goods. Formerly TLEN 5010.
Requisites: Restricted to students with 87-180 credits (Senior) or graduate students in the College of Engineering or Leeds School of Business only.

CYBR 5150 (3) Network Management and Automation
Teaching both technical and soft skills, this course incorporates best practices and the key theories behind them such as understanding common services needed for network functionality, maintenance, and troubleshooting. The goal of this course is to equip students with the valuable skills and tools they need to hit the ground running in most network management, operation, automation, and DevOps roles within a company. By the end of the course, students will be competent in the technologies, services, and tools used to manage and automate complex networks. Formerly TLEN 5410.
Recommended: Prerequisite background in in Linux system administration, Python programming and computer network engineering/data communications.
Grading Basis: Letter Grade

CYBR 5160 (3) Introduction to Enterprise Networks
Provides direct experience with networking functions and equipment through experiments and demonstrations. Students work individually to learn the fundamental principles and techniques of voice and data switching and routing within an enterprise environment. Procedures require the use of actual commercial equipment (including Cisco, Juniper, and Arista) plus network services and observation using packet analyzers. Weekly experiments and exams are designed to reflect real-world networking scenarios and require an additional eight hours of work. Formerly TLEN 5460.
Recommended: Prerequisite CYBR 5010 or CSCI 4273.

CYBR 5170 (3) IP Routing Protocols and Policies
Explores practical usage and conceptual underpinnings of link state and distance vector routing protocols. The course further explores a holistic view of how the Internet works from a technical routing aspect as well as policy and economics. The course is supplemented with frequent labs to fully explore the specific workings of the routing protocols RIP, OSPF, and BGP and the relationships between them in practical lab based routing scenarios. Formerly TLEN 5370.
Recommended: Prerequisite CYBR 5010.

CYBR 5200 (3) Introduction to Wireless Systems
Overviews the distinctive characteristics of the wireless communications medium. Topics covered include: Analog signals, Antennas and Propagation, Digital Signals, Sampling, Quadrature Signals, Digital Modulation, SNR and SINR Concepts, Channel Models, Channel Statistics, and Link Budgets. The course includes an introduction to MIMO and beam-forming as implemented in modern communication systems. Software Defined Radio (SDR) is introduced to facilitate student hands-on learning of radio operation.
Recommended: Prerequisites CYBR 5010 and CYBR 5012.
Grading Basis: Letter Grade

CYBR 5220 (3) Wireless Local Area Networks
Emphasis on the IEEE 802.11 family of WLAN standards. Students learn the legacy versions of the standard (802.11D/S/b), the current generation of WLAN systems (802.11a/g/n/ac), and will to analyze and critique upcoming versions (802.11ax/ba), and gain insight into proposals for new research in WLAN. Exposure to the interoperability and certification process for WLAN by the Wi-Fi Alliance, study the newest Wi-Fi Certified¿ programs, and will learn how to model and analyze WLAN traffic using industry standard tools.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 5122
Requisites: Requires prerequisite course of CYBR 5010 or CSCI 5273 (minimum grade D-).
Recommended: Prerequisite CYBR 5200.
Grading Basis: Letter Grade

CYBR 5230 (3) Wireless Systems Lab
This Wireless Solutions Architecture course is designed to examine the core concepts of wireless architecture, design and implementation. The course will focus on architecting solutions unlicensed technology, specifically enterprise Wi-Fi networks. Students will learn how to design, implement, troubleshoot and operate enterprise wireless networks. Formerly TLEN 5560.
Requisites: Requires prerequisite course of CYBR 5200 (minimum grade D-).
Recommended: Prerequisite CYBR 5010.

CYBR 5250 (2-4) Technology Law and Policy Clinic
Features technology law advocacy before administrative, legislative and judicial bodies in the public interest. Formerly TLEN 5250. Instructor consent required.
Equivalent - Duplicate Degree Credit Not Granted: LAWS 7809
Requisites: Restricted to CYBR/TLEN graduate students.
Grading Basis: Letter Grade

CYBR 5260 (3) Seminar: Law and Economics of the Information Age
Examines basic regulatory and legal challenges of our information economy and digital age. Emphasizes the “networked” information industries, the proper role of "unbundling" policies to advance competition and how intellectual property and antitrust rules should be developed. Formerly TLEN 5260.
Equivalent - Duplicate Degree Credit Not Granted: LAWS 8341
Requisites: Restricted to CYBR/TLEN graduate students.
CYBR 5300 (3) Introduction to CyberSecurity
Introduces core concepts in cybersecurity including confidentiality, integrity, authentication, risk management, and adversarial thinking. The concepts will be applied to both traditional information technology (IT) systems and cyber physical systems (CPS). The course provides a cyber security foundation that will allow practitioners in other fields apply to understand cyber security trade-offs and will also provide interested students with a basis further study in cyber security. At the conclusion of the course, students should have a solid foundation in cybersecurity and hands-on experience.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5403
Recommended: for graduate students only.
Grading Basis: Letter Grade

CYBR 5310 (3) Immersive Cyber Defense
Immersive Cybersecurity Defense assumes familiarity with core cybersecurity concepts and applies them within a hands-on virtual environment. Students practice offensive skills such as password cracking and exploit development to understand vulnerabilities and then focus on defensive tactics to reduce cyber risk and respond to cyber-attacks. At the conclusion of the course, students will understand how to protect systems against a wide range of threats and have experience using real-world tools to implement these defenses. Previously offered as a special topics course.
Recommended: Familiarity with core cybersecurity concepts such as those covered in CYBR 5300 is recommended but not required.
Grading Basis: Letter Grade

CYBR 5320 (3) Cybersecurity Network Analytics
This Cybersecurity Network Analytics course takes a hands-on approach to detecting malicious activity within network traffic. The course will first introduce methodologies for analyzing cyber data. This knowledge will then be used practically, as the students will be given the chance to test out approaches on real traffic. At the conclusion, students will have both a theoretical understanding of cyber algorithms and their use in a real-world setting.
Requisites: Requires prerequisite courses of CYBR 3300 or CYBR 5300 or CSCI 3403 or CSCI 5403 (minimum grade D-).
Recommended: Requisite C++ and Linux/Unix experience and knowledge of computer networking.
Grading Basis: Letter Grade

CYBR 5330 (3) Digital Forensics
Learn how to identify, collect, examine, analyze, and present digital evidence and the legal challenges associated with conducting digital forensics investigations. Explore various file system types and structures. Learn how to recovery and extract potential evidence from deleted files and directories. Learn how to capture and profile data residing in live memory. Analyze running processes and recover memory artifacts. Learn about various methods data can be hidden on a computing devices, storage media, and within covert communications channels.
Recommended: Prerequisites CYBR 3300, CYBR 5300, CSCI 3403 or CSCI 5403.
Grading Basis: Letter Grade

CYBR 5340 (3) VOIP Network Design
Focuses on VoIP network design and optimization. The emphasis is on the convergence of VoIP, PSTN and cell phone networks and signaling. Topics include voice processing as well as IP and SS7 signaling. In addition there will be a review of ISDN, DSL, Sonet, ATM, SIP and MPLS. There will be a case problem for sizing a VoIP network using silence suppression. Formerly TLEN 5340.
Requisites: Requires corequisite of CYBR 5001. Restricted to CYBR or BUSN graduate students.

CYBR 5350 (3) Security Auditing and Penetration Testing
This course is an introduction to the principles and techniques associated with security auditing and penetration testing. Topics covered include; planning, reconnaissance, scanning, enumeration, exploitation, post-exploitation, and reporting. Students discover how system vulnerabilities can be exploited. Students will develop an understanding of current cybersecurity issues and how user, administrator, and programmer errors can result in security breaches.
Recommended: Prerequisites CYBR 3300, CYBR 5300, CSCI 3403 or CSCI 5403.
Grading Basis: Letter Grade

CYBR 5400 (3) Principles of Internet Policy
Engages in the critical strategic analysis and debate of controversial public policy issues raised by the Internet. Learn how to develop well-reasoned positions on the regulations applied to new Internet-based technologies and business models based on interdisciplinary frameworks that characterize the significant intersection of technology, economics, business, and public policy. Policy topics covered include Broadband as a Universal Service, Net Neutrality, Spectrum Management, Online Privacy, and Cybersecurity. Formerly TLEN 5210.
Grading Basis: Letter Grade

CYBR 5410 (3) Telecommunications Law and Policy
Examines laws governing telecommunications industries, including federal and state regulation and international aspects. Includes telephone, cable, satellite, cellular and other wireless systems and the Internet. Formerly TLEN 5240.
Equivalent - Duplicate Degree Credit Not Granted: LAWS 7241
Repeatable: Repeatable for up to 6.00 total credit hours.
Requisites: Restricted to CYBR or BUSN graduate Students

CYBR 5420 (3) Spectrum Management and Policy
Studies how spectrum policy is developed and implemented. A general framework is developed for understanding telecommunications law and regulatory objectives. Specifically analyzes international and domestic dimensions of spectrum policy. Considers how economics, administrative processes and innovative technologies affects management of the spectrum. Formerly TLEN 5230.
Requisites: Restricted to graduate students only.

CYBR 5480 (3) Future of Video: Technology, Policy, and Economics
Examines the issues that have been created by the shift from analog to digital technologies, the shift from narrowband/wideband systems to broadband systems, and the shift to converged networks (i.e. networks able to convey voice, data, image and video traffic on a common platform) based upon packet switching and Internet Protocol (IP) suite. Equivalent - Duplicate Degree Credit Not Granted: ATLS 5380
Requisites: Requires prerequisite courses of CYBR 5400 (minimum grade D-). Restricted to graduate students only.

CYBR 5505 (3) Leading Oneself
Provides working engineers a background in leadership concepts and methods and enables students to develop practical leadership skills through numerous in-class exercises and experimentation based assignments. Topics include authentic leadership, motivating self and others, cultivating emotional intelligence, personal mastery, creating accountability, conflict resolution, leading change and organizational culture. Required for all Engineering Management degree students.
Equivalent - Duplicate Degree Credit Not Granted: EMEN 5050
Requisites: Restricted to Leeds School of Business or College of Engineering graduate students only.
CYBR 5510 (3) Technology Strategy, Implementation and Results
Working in groups of 2-4, students will leverage their technical skills to learn and apply commercial/business skills via the consideration of a hypothetical competitive technically-oriented business, including its strategy, long-term financial outlook, and operating platform. Upon successful course completion, students should expect to feel confident when speaking with (and ultimately moving into roles of) management and leadership, regarding all critical aspects of business, especially the creation of equity value through scale at pace, aligning interests of all key stakeholders. Open to undergraduates with instructor consent. Formerly TLEN 5130.
Requisites: Restricted to graduate students only.
Grading Basis: Letter Grade

CYBR 5550 (3) Designing for Defense
Designing for Defense/Hacking for Defense is a national service program running at leading research universities across the country. Interdisciplinary teams, chosen by competitive selection, work on real-world national security challenges, in close contact with national security agencies. Teams employ the Lean Launchpad entrepreneurship methodology to develop engineering and business concepts to solve real world challenges for special operations forces, the intelligence community, and other government agencies. Winning teams are eligible for real-world capital investment.
Equivalent - Duplicate Degree Credit Not Granted: COEN 5550 and CSCI 5550
Grading Basis: Letter Grade

CYBR 5600 (1) Seminar in Technology, Cybersecurity and Policy
Introduces students to major topics and research at the interface of technology, cybersecurity, and policy by providing a weekly series of lectures with questions and discussion, including guest speakers. Formerly TLEN 5600.
Repeatable: Repeatable for up to 4.00 total credit hours.
Requisites: Restricted to Telecommunications (TLEN) graduate students only.
Grading Basis: Pass/Fail

CYBR 5700 (3) Graduate Projects I
This two-semester sequence includes CYBR 5700 Graduate Projects I and CYBR 5710 Graduate Projects II. Teaches students how to engineer a complex, inter/multidisciplinary design and implementation problem in a group environment.
Requisites: Restricted to ITP (TLEN-MS) students only.
Grading Basis: Letter Grade

CYBR 5710 (3) Graduate Projects II
This two-semester sequence includes CYBR 5700 Graduate Projects I and CYBR 5710 Graduate Projects II. Teaches students how to engineer a complex, inter/multidisciplinary design and implementation problem in a group environment.
Requisites: Requires prerequisite course of CYBR 5700 (minimum grade D-).
Grading Basis: Letter Grade

CYBR 5830 (1-6) Special Topics
Current topics in Telecommunications. Formerly TLEN 5830.
Repeatable: Repeatable for up to 18.00 total credit hours. Allows multiple enrollment in term.

CYBR 5910 (1-6) Independent Study
Special projects agreed upon by student and instructor. Department consent required. Formerly TLEN 5920.
Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.
Requisites: Restricted to CYBR/TLEN graduate students.

CYBR 6140 (3) Voice Over IP: Voice Network Design and Implementation
Provides an in-depth immersion into the foundational theories and technologies of Voice Over IP (VoIP). This course supplements these theories with direct experience through real-world, hands-on lab experiments and demonstrations. The fundamentals of voice technologies, services, and tools used in industry to design, deploy and troubleshoot VoIP networks will be explored in detail, providing the student with a competitive advantage in the job market. Formerly TLEN 5840.
Requisites: Requires prerequisite course of CYBR 5170 or CYBR 5160 or CYBR 5150 (minimum grade D-).
Grading Basis: Letter Grade

CYBR 6150 (3) Software-Defined Networking
Provides an in-depth immersion into the foundational theories and technologies of Software-Defined Networking (SDN), Network Functions Virtualization (NFV), and emerging technologies for computer networks. Supplements the theoretical knowledge learned through direct experience with real-world lab experiments and demonstrations. This knowledge will give students an advantage in the job market for this in-demand, constantly changing subject. Formerly TLEN 5100.
Requisites: Requires prerequisite course of CYBR 5150 (minimum grade C).
Grading Basis: Letter Grade

CYBR 6151 (3) SDN Virtualization and Orchestration
Provides an advanced, in-depth immersion into the theories and technologies of Software-Defined Networking (SDN), Network Functions Virtualization (NFV), network virtualization/orchestration, and emerging technologies for computer networks. Expands on the real-world lab experiments and theoretical demonstrations learned from the course pre-requisite. The knowledge and critical thinking skills learned from this course will arm students with an advantage in the job market for this in-demand, constantly changing subject. Formerly TLEN 6100.
Requisites: Requires prerequisite of CYBR 6150 (minimum grade B-).
Grading Basis: Letter Grade

CYBR 6160 (3) Datacenter Networks
Covers design and configuration principles required to build highly scalable and highly redundant network solutions used by datacenters. Class makes use of commercial grade equipment to build network topologies and services. Students will work in teams to build a virtualized cluster, load balance application traffic between multiple server blades, assure high availability in Ethernet and IP layers, and able to prioritize important services using QoS. Lab sessions require additional 8-12 hours of work per week. Formerly TLEN 5462.
Requisites: Requires prerequisite of CYBR 5160 (minimum grade C).
CYBR 6161 (3) Internet Service Provider Networks
Presents advanced networking design and implementation techniques through experiments with network measurement equipment, switches, router, and management interfaces. Primarily focuses on Service Provider Transport technologies for capacity, scalability and fault tolerance. Students learn the essential network architectures of last mile and long haul network solutions used for public and private network traffic transport; implementation of SLAs, load balancing, first hop redundancy, and MPLS transport and L2/L3 VPN solutions. Formerly TLEN 5585.
Requisites: Requires prerequisite of CYBR 5160 (minimum grade C).
Recommended: Prerequisite CYBR 5170.
Grading Basis: Letter Grade

CYBR 6170 (3) IP Network Design
Focuses on the design and implementation of network solutions according to the needs of a client. The course helps students develop skills to be a consultant and walks them through the complete life cycle of network project development as a member of a professional services team. Implement fundamentals of IP Routing Protocols and apply them directly to design based networking problems. Design scenarios will incorporate physical and logical design, financial analysis, and laboratory configuration. Formerly TLEN 5570.
Requisites: Requires prerequisite course of CYBR 5170 or CYBR 5160 (minimum grade D-).
Recommended: Prerequisite strong familiarity with network protocol operation and implementation.

CYBR 6200 (3) Advanced Wireless Lab
Provides a comprehensive, hands-on set of laboratory exercises for the teaching and demonstration of key technical skills required to understand, build, test, and analyze both analog and digital wireless communications concepts. In conjunction with lecture-based content to provide a solid foundation in digital communication theory, SDR-based laboratory exercises enable the synthesis of several fundamental concepts utilizing the latest, modern communications systems technologies.
Requisites: Requires prerequisite course of CYBR 5200 (minimum grade D-).
Recommended: Prerequisites CYBR 5210 and CYBR 5220.
Grading Basis: Letter Grade

CYBR 6210 (3) Wireless and Cellular Systems
Studies technologies and architectures employed in modern cellular wireless systems. Major topics include radio propagation, multiple access techniques, analog and digital cellular telephony, and personal communications systems. Presents the necessary tools to understand the wireless industry, its technical details, and its business drivers. Topics include modeling, spectrum, weather, multipath, Doppler effect, and shadowing and covers important aspects of multiple access technologies such as CDMA and OFDMA. Introduces modern radio standards including LTE. Formerly TLEN 5510.
Requisites: Requires prerequisite course of CYBR 5200 (minimum grade D-).
Recommended: Prerequisite CYBR 5010.

CYBR 6940 (1) Master's Candidate for Degree
Formerly TLEN 6940.
Requisites: Restricted to CYBR/TLEN graduate students.
Grading Basis: Pass/Fail

CYBR 6950 (1-6) Master's Thesis
Original and independent research conducted by a graduate student under the supervision of a faculty advisor. Formerly TLEN 6950.
Requisites: Restricted to CYBR/TLEN graduate students.

CYBR 8990 (1-10) Doctoral Dissertation
Investigates specialized topic or field in the area of telecommunications. Approved and supervised by faculty members. Formerly TLEN 8990.
Requisites: Restricted to CYBR/TLEN PhD students.