Networking and Communication (NC)

Preamble

Networking and communication play a central role in interconnected computer systems that are transforming the daily lives of billions of people. The public internet provides connectivity for networked applications that serve ever-increasing numbers of individuals and organizations around the world. Complementing the public sector, major proprietary networks leverage their global footprints to support cost-effective distributed computing, storage, and content delivery. Advances in satellite networks expand connectivity to rural areas. Device-to-device communication underlies the emerging Internet of Things.

This knowledge area deals with key concepts in networking and communication, as well as their representative instantiations in the internet and other computer networks. Besides the basic principles of switching and layering, the area at its core provides knowledge on naming, addressing, reliability, error control, flow control, congestion control, domain hierarchy, routing, forwarding, modulation, encoding, framing, and access control. The area also covers knowledge units in network security and mobility, such as security threats, countermeasures, device-to-device communication, and multi-hop wireless networking. In addition to the fundamental principles, the area includes their specific realization of the Internet as well as hands-on skills in the implementation of networking and communication concepts. Finally, the area comprises emerging topics such as network virtualization and quantum networking.

As the main learning outcome, learners develop a thorough understanding of the role and operation of networking and communication in networked computer systems. They learn how network structure and communication protocols affect the behavior of distributed applications. The area can be used to educate not only key principles but also their specific instantiations in the internet and equip the student with hands-on implementation skills. While computer-system, networking, and communication technologies are advancing at a fast pace, the gained fundamental knowledge enables the student to readily apply the concepts in new technological settings.

Changes since CS2013

Compared to the 2013 curricula, the knowledge area broadens its core focus to expand on reliability support, routing, forwarding, and single-hop communication. Due to the enhanced core, learners acquire a deeper understanding of the impact that networking and communication have on the behavior of distributed applications. Reflecting the increased importance of network security, the area adds a respective knowledge unit as a new elective. To track the advancing frontiers in networking and communication knowledge, the social networking knowledge unit was removed and an emerging knowledge unit on topics, such as middleboxes, software-defined networks, and quantum networking, was added. Other changes consist of redistributing all the topics from the old unit on resource allocation among other units to resolve overlap between knowledge units in the 2013 curricula.

Core Hours

Knowledge Unit	CS Core	KA Core
Fundamentals	2.5 + 0.25 (SEP) + 0.25 (SF)	
Networked Applications	3.5 + 0.25 (SEP) + 0.25 (PDC)	
Reliability Support		5.75 + 0.25 (SF)
Routing And Forwarding		4
Single-Hop Communication		3
Mobility Support		4
Network Security		2.25 + 0.5 (SEC) + 0.25 (SEP)
Emerging Topics		4
Total	**7**	**24**

The shared hours correspond to overlapping concepts that are covered from a networking perspective and are only counted here.

Knowledge Units

NC-Fundamentals: Fundamentals

CS Core:

1. Importance of networking in contemporary computing, and associated challenges. (See also: SEP-Context, SEP-Privacy)
2. Organization of the internet (e.g., users, Internet Service Providers, autonomous systems, content providers, content delivery networks)
3. Switching techniques (e.g., circuit and packet)
4. Layers and their roles (application, transport, network, datalink, and physical)
5. Layering principles (e.g., encapsulation and hourglass model) (See also: SF-Foundations)
6. Network elements (e.g., routers, switches, hubs, access points, and hosts)
7. Basic queueing concepts (e.g., relationship with latency, congestion, service levels, etc.)

Illustrative Learning Outcomes:

CS Core:

1. Articulate the organization of the internet.
2. List and define the appropriate network terminology.

3. Describe the layered structure of a typical networked architecture.
4. Identify the different types of complexity in a network (edges, core, etc.).

NC-Applications: Networked Applications

CS Core:

1. Naming and address schemes (e.g., DNS, and Uniform Resource Identifiers)
2. Distributed application paradigms (e.g., client/server, peer-to-peer, cloud, edge, and fog) (See also: PDC-Communication, PDC-Coordination)
3. Diversity of networked application demands (e.g., latency, bandwidth, and loss tolerance) (See also: PDC-Communication, SEP-Sustainability, SEP-Context)
4. Coverage of application-layer protocols (e.g., HTTP)
5. Interactions with TCP, UDP, and Socket APIs (See also: PDC-Programs)

Illustrative Learning Outcomes:

CS Core:

1. Define the principles of naming, addressing, resource location.
2. Analyze the needs of specific networked application demands.
3. Describe the details of one application layer protocol.
4. Implement a simple client-server socket-based application.

NC-Reliability: Reliability Support

KA Core:

1. Unreliable delivery (e.g., UDP)
2. Principles of reliability (e.g., delivery without loss, duplication, or out of order) (See also: SF-Reliability)
3. Error control (e.g., retransmission, error correction)
4. Flow control (e.g., stop and wait, window based)
5. Congestion control (e.g., implicit and explicit congestion notification)
6. TCP and performance issues (e.g., Tahoe, Reno, Vegas, Cubic)

Illustrative Learning Outcomes:

KA Core:

1. Describe the operation of reliable delivery protocols.
2. List the factors that affect the performance of reliable delivery protocols.
3. Describe some TCP reliability design issues.
4. Design and implement a simple reliable protocol.

NC-Routing: Routing and Forwarding

KA Core:

1. Routing paradigms and hierarchy (e.g., intra/inter domain, centralized and decentralized, source routing, virtual circuits, QoS)
2. Forwarding methods (e.g., forwarding tables and matching algorithms)
3. IP and Scalability issues (e.g., NAT, CIDR, BGP, different versions of IP)

Illustrative Learning Outcomes:

KA Core:

1. Describe various routing paradigms and hierarchies.
2. Describe how packets are forwarded in an IP network.
3. Describe how the Internet tackles scalability challenges. .

NC-SingleHop: Single Hop Communication

KA Core:

1. Introduction to modulation, bandwidth, and communication media
2. Encoding and Framing
3. Medium Access Control (MAC) (e.g., random access and scheduled access)
4. Ethernet and WiFi
5. Switching (e.g., spanning trees, VLANS).
6. Local Area Network Topologies (e.g., data center, campus networks).

Illustrative Learning Outcomes:

KA Core:

1. Describe some basic aspects of modulation, bandwidth, and communication media.
2. Describe in detail a MAC protocol.
3. Demonstrate understanding of encoding and framing solution tradeoffs.
4. Describe details of the implementation of Ethernet.
5. Describe how switching works.
6. Describe one kind of a LAN topology.

NC-Security: Network Security

KA Core:

1. General intro about security (Threats, vulnerabilities, and countermeasures) (See also: SEP-Security, SEC-Foundations, SEC-Engineering)
2. Network specific threats and attack types (e.g., denial of service, spoofing, sniffing and traffic redirection, attacker-in-the-middle, message integrity attacks, routing attacks, ransomware, and traffic analysis) (See also: SEC-Foundations, SEC-Engineering)
3. Countermeasures (: SEC-Foundations, SEC-Crypto, SEC-Engineering)
    a. Cryptography (e.g. SSL, TLS, symmetric/asymmetric)
    b. Architectures for secure networks (e.g., secure channels, secure routing protocols, secure DNS, VPNs, DMZ, Zero Trust Network Access, hyper network security, anonymous communication protocols, isolation)
    c. Network monitoring, intrusion detection, firewalls, spoofing and DoS protection, honeypots, tracebacks, BGP Sec, RPKI

Illustrative Learning Outcomes:

KA Core:

1. Describe some of the threat models of network security.

2. Describe specific network-based countermeasures.
3. Analyze various aspects of network security from a case study.

NC-Mobility: Mobility

KA Core:

1. Principles of cellular communication (e.g., 4G, 5G)
2. Principles of Wireless LANs (mainly 802.11)
3. Device to device communication (e.g., IoT communication)
4. Multi-hop wireless networks (e.g., ad hoc networks, opportunistic, delay tolerant)

Illustrative Learning Outcomes:

KA Core:

1. Describe some aspects of cellular communication such as registration
2. Describe how 802.11 supports mobile users
3. Describe practical uses of device-to-device communication, as well as multihop
4. Describe one type of mobile network such as ad hoc

NC-Emerging: Emerging Topics

KA Core:

1. Middleboxes (e.g., advances in usage of AI, intent-based networking, filtering, deep packet inspection, load balancing, NAT, CDN)
2. Network Virtualization (e.g., SDN, Data Center Networks)
3. Quantum Networking (e.g., Intro to the domain, teleportation, security, Quantum Internet)
4. Satellite, mmWave, Visible Light

Illustrative Learning Outcomes:

KA Core:

1. Describe the value of advances in middleboxes in networks.
2. Describe the importance of Software Defined Networks.
3. Describe some of the added value achieved by using Quantum Networking.

Professional Dispositions

- **Meticulous:** Students must be particular about the specifics of understanding and creating networking protocols.
- **Collaborative:** Students must work together to develop multiple components that interact together and to respond to failures and threats.
- **Proactive:** Students must be able to predict failures, threats, and how to deal with them while avoiding reactive modes of operation only.
- **Professional:** Students must comply with the needs of the community and their expectations from a networked environment, and the demands of regulatory bodies.

- **Responsive:** Students must act swiftly to changes in requirements in network configurations and changing user requirements.
- **Adaptive:** Students need to reconfigure systems under varying modes of operation.

Mathematics Requirements

Required:
- MSF-Probability.
- MSF-Statistics.
- MSF-Discrete.
- MSF-Linear Simple queuing theory concepts.

Course Packaging Suggestions

Coverage of the concepts of networking including but not limited to types of applications used by the network, reliability, routing and forwarding, single hop communication, security, and other emerging topics.

Note: both courses cover the same knowledge units but with different allocation of hours for each knowledge unit.

Course objectives: By the end of this course, learners should be able to understand many of the fundamental concepts associated with networking, learn about many types of networked applications, and develop at least one, understand basic routing and forwarding, single hop communications, and deal with some issues pertaining to mobility, security, and emerging areas, all with embedded social, ethical, and issues pertaining to the profession.

Introductory Course:
- NC-Fundamentals (8 hours)
- NC-Applications (12 hours)
- NC-Reliability (6 hours)
- NC-Routing (4 hours)
- NC-SingleHop (3 hours)
- NC-Mobility (3 hours)
- NC-Security (3 hours)
- SEP-Context (1 hour)
- NC-Emerging (2 hours)

Course objectives: By the end of this course, learners would have obtained a refresher about some of the fundamental issues of networking, networked applications, reliability, and routing and forwarding, and indulged in additional details of single hop communications, mobility, security, and emerging topics in the area, all while considering embedded social and ethical issues as well as issues pertaining to the profession.

Advanced Course:

- NC-Fundamentals (3 hours)
- NC-Applications (4 hours)
- NC-Reliability(7 hours)
- NC-Routing (6 hours)
- NC-SingleHop (5 hours)
- NC-Mobility (5 hours)
- NC-Security (5 hours)
- SEP-Privacy, SEP-Security, SEP-Sustainability (2 hours)
- NC-Emerging (5 hours)

Committee

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