CPR E 548x: Cyber-Physical Systems Networking

Catalog Description

Cyber-physical systems applications in smart agriculture, transportation, power grid, manufacturing, public safety, health systems, etc.; field area and control networks; industrial Ethernet; time-triggered communication; real-time wireless networks; wireless industrial networks; safety and security of industrial networks; systems platforms for cyber-physical systems networks; team-based learning/projects.

Credits: 3

Prerequisites

CPR E 489, CPR E 530/430, COM S 486, or equivalent.

Reference Books

- Richard Zurawski (editor), *Industrial Communication Technology Handbook* (2nd edition), CRC Press, 2015. (**Strongly Recommended; electronic version available through ISU library**)
- Larry Peterson and Oguz Sunay, *5G Mobile Networks: A Systems Approach*, free online book by the authors
- Edward A. Lee and Sanjit A. Seshia, *Introduction to Embedded Systems, A Cyber-Physical Systems Approach* (2nd edition) , 2017. (free PDF download)
- Anurag Kumar, D. Manjunath, Joy Kuri, *Wireless Networking*, Morgan Kaufmann, 2008.
- Anurag Kumar, D. Manjunath, Joy Kuri, *Communication Networking: An Analytical Approach*, Morgan Kaufmann, 2004.
- Giorgio C. Buttazzo, *Hard Real-Time Computing Systems: Predictable Scheduling Algorithms and Applications* (3rd edition), Springer, 2011
- Sanjoy Baruah, Marko Bertogna, Giorgio Buttazzo, *Multiprocessor Scheduling for Real-Time Systems*, Springer, 2015
- Joseph L. Hellerstein, Yixin Diao, Sujay Parekh, Dawn M. Tilbury, *Feedback Control of Computing Systems*, Wiley-IEEE Press, 2004.

Topics

Seamlessly integrating sensing, networking, and computation with the control of physical devices and processes, cyber-physical systems (CPS) are expected to transform the way we interact with the physical world. Accordingly, CPS will have far-reaching impact on science and engineering and are critical to a wide range of applications such as **augmented reality (AR), smart agriculture, smart transportation, Industrial 4.0, and smart energy grid**. One basic enabler of CPS is embedded networking of sensors, controllers, and actuators. In supporting mission-critical, real-time, and

closed-loop sensing and control, embedded CPS networks represent a significant departure from traditional wired and wireless networks, and it is critical to ensure controllable, predictable communication quality in CPS in the presence of uncertainties. **CPS networking is also a major focus of 5G and 6G wireless systems!**

This course is designed for students who are interested in CPS in general and CPS embedded networking in particular. We will examine a wide range of **topics** including CPS applications (e.g., smart transportation, industrial automation, smart energy grid, smart health, and Internet of Things), field area and control networks (e.g., HART, CIP, Sercos, PROFIBUS, PROFINET), industrial Ethernet, time-triggered communication, fundamentals of wireless communication (e.g., wireless channel, signal propagation, modulation, link models), real-time wireless networks, wireless industrial networks, 5G, safety and security of industrial networks, as well as systems and innovation platforms for CPS networks.

A tentative schedule for the course is as follows: (note: the actual schedule is subject to change depending on class interest and progress.)

Week	*Topics*
Module 1: Introduction	
1	• Introduction to CPS applications, networked control systems, and networked AR/VR systems • Introduction to wired and wireless CPS networks
Module 2: Foundations	
2	• Fundamentals of computer networking, (stochastic) network calculus, effective bandwidth & effective capacity
3	• Fundamentals of wireless communication and networking
4-5	• Fundamentals of real-time systems & scheduling theory • Fundamentals of control theory
6	Open-source network systems platforms (e.g., OpenAirInterface/Mosaic5G, CORD/M-CORD, Contiki)
Module 3: Existing Technologies & Design Principles	
7	• HART device networks • Common Industrial Protocols (CIP) and family of CIP networks (DeviceNet, ControlNet, Ethernet/IP, CompoNet) • PROFIBUS, PROFINET, Foundation Fieldbus
8	• Switches, real-time Ethernet in automation • EtherCAT, Ethernet POWRLINK, Sercos III • Time-Sensitive Networking (TSN) • Clock synchronization via NTP and PTP • Time-triggered communication, time-triggered Ethernet
9	• Automotive networking: CAN, TT-CAN, FlexRay, LIN, MOST, IEEE 802.11p, C-V2X • Avionics and aerospace networking: ARINC 629, SAFEbus, avionics network dimensioning, UAV wireless networking
10	• WirelessHART, ISA100.11a, WIA-PA, 6tisch • PROFIsafe, SafetyNET p, secure industrial communication
Module 4: Adventure	

11-13	Frontiers of predictable, ultra-reliable, low-latency *single-hop* wireless networking: 5G, 6G, Glossy, LWB, PRK, PRKS, CPS, pktR etc
14-15	Frontiers of predictable, ultra-reliable, low-latency *multi-hop* wireless networking: time synchronization, LOF, MTA etc

Besides lectures, the course will offer student-centered in-class presentations/discussions and hands-on projects where students will have the opportunity to investigate, implement, and experiment with emerging protocols and applications of CPS networks.

Course Objectives

The objective of this course is to cultivate the following capabilities among students:

- Students will be able to remember and apply the underlying principles of cyber-physical-systems (CPS) networks. In particular, students will remember and apply the following fundamentals of CPS networking:
    - CPS network architecture
    - CPS network medium access control, scheduling, power control, routing, transport control
    - CPS network planning
    - Field area and control networks
    - Industrial Ethernet
    - Time-triggered communication
    - Fundamentals of wireless communication
    - Real-time wireless networks
    - Wireless industrial networks
    - Safety and security of industrial networks
    - Systems and innovation platforms for CPS networks
    - CPS network applications in agriculture, transportation, power grid, manufacturing, public safety, health systems, etc.
- Students will be able to implement CPS networking protocols.
- Students will be able to cultivate their capability of exploring new CPS networking research areas through course projects.

Student Outcomes

Through the course, students will be able to:

- Demonstrate fundamental principles of CPS networking.
- Use current techniques, skills, and tools necessary for CPS networking practice.
- Apply design and development principles in the construction of CPS networking systems of varying complexity.
- Analyze CPS networking problems and identify and define networking requirements appropriate to their solutions.

- Design, implement, and evaluate a networking system, process, component, or program to meet desired needs.
- Function effectively on teams to accomplish a common goal.

Grading

- The tentative grade weighting for the semester will be:
  - In-Class Presentations: 33%
    - Expected in weeks 11-15 of the semester
    - Instructor- and peer-evaluated
    - Evaluation criteria: timeliness in delivering phased results (e.g., sharing slides and reading materials before class), depth and breadth of presentation on chosen topic, leadership in group discussion, etc
  - Hands-on Project: 33%
    - Applications of CPS networking principles and techniques
    - Semester-long
  - Quizzes: 34%
    - For both instructor-led lectures and student-led presentations
    - Throughout the semester
- Letter grades will be assigned based on performance relative to other students. A tentative grading scale is as follows:

  93 – 100 = A
  90 – 92.99 = A-
  87 – 89.99 = B+
  83 – 86.99 = B
  80 – 82.99 = B-
  77 – 79.99 = C+
  73 – 76.99 = C
  70 – 72.99 = C-
  67 – 69.99 = D+
  63 – 66.99 = D
  60 – 62.99 = D-
  0 – 59.99 = F

Miscellaneous

Iowa State University is committed to assuring that all educational activities are free from discrimination and harassment based on disability status. Students requesting accommodations for a documented disability are required to work directly with staff in Student Accessibility Services (SAS) to establish eligibility and learn about related processes before accommodations will be identified. After eligibility is established, SAS staff will create and issue a Notification Letter for each course listing approved reasonable accommodations. This document will be made available to the student and instructor either electronically or in hard-copy every semester. Students and instructors are encouraged to review contents of the Notification

Letters as early in the semester as possible to identify a specific, timely plan to deliver/receive the indicated accommodations. Reasonable accommodations are not retroactive in nature and are not intended to be an unfair advantage. Additional information or assistance is available online at www.sas.dso.iastate.edu, by contacting SAS staff by email at accessibility@iastate.edu, or by calling 515-294-7220. Student Accessibility Services is a unit in the Dean of Students Office located at 1076 Student Services Building.