Master of Science in Internet of Things

1. Program description

The Institute for the Wireless Internet of Things and the Department of Electrical and Computer Engineering together with the Khoury College of Computer Sciences propose a new **Interdisciplinary Master of Science** in **Internet of Things (IoT)**. This program is aimed at preparing highly qualified researchers and a specialized workforce that will lead the development of a globally interconnected continuum of untethered devices and objects interacting with the physical environment, people, and each other. The program will provide students with the necessary knowledge and skills to understand, design and implement autonomous wireless networked systems of tomorrow operating in uncertain, challenging, extreme environments, through a combination of coursework, master thesis research and/or industry experience.

The Master of Science in IoT is structured as follows: a total of 32 credits are required, which students can obtain by following one of two tracks, namely, *course-only* and *thesis-course*. All students are required to complete 20 *semester hours* (SH) in *core courses* (five courses of 4 SH each). Course-only students will complete their requirements by taking 12 SH in *elective courses*, whereas thesis-course students will complete their requirements by taking 4 SH in *elective courses* and 8 SH in *thesis credits*. **Core courses combine existing offerings in the ECE and CS curricula.** Similarly, elective courses include options within many departments in the College of Engineering and Khoury College of Computer Sciences as well as D'Amore-McKim School of Business (e.g., relating to business models for IoT applications), School of Law (e.g., relating to legal and ethical aspects of pervasive data-collecting IoT systems), and Bouvé College of Health Sciences (e.g., focused on medical IoT and health informatics).

2. Program contributions to the university's mission

The proposed program is well aligned with department, college, institute, and university objectives:

- At the **department level**, the program builds on the strengths of electrical engineering (nanoelectronics, embedded systems, communications, signal processing and control), computer engineering (computer networking, security and data science), and computer science (security) and offers an integrated path for students who want to cover the three key components of the IoT, namely, the Internet (communication networks), the Things (embedded systems) and an overlaying *pervasive intelligence* (AI, data analytics and optimization). Traditionally, this has not been the case as students are asked to select a concentration either within the *Internet* component of the IoT, usually Communications, Control and Signal Processing (CCSP) or the Computer Networks and Security (CNWS), or within the *Things* component, usually Microsystems, Materials, and Devices (MSMD). This program will prepare students to think at the system level (Internet) while being able to contribute at each individual level, starting from the devices (Things).
- At the **college level**, the program builds on the existing strengths and international leadership of our faculty in research initiatives that continue to shape the future of our hyperconnected society.
- At the **institute level**, the Institute for the Wireless Internet of Things (WIoT) is at the forefront of IoT research in the country, including next generation wireless and wired communication networks, the

use of machine learning for network orchestration and management, and, overall, large scale experimental research. All these will be key components of the proposed program.

- At the **university level**, the program contributes to the mission of providing an innovative, experientially driven education to students who can make a positive impact on society. Students graduating from this program will be equipped with theoretical and experimental tools to address critical societal needs, such as the development of technologies at the basis of smart homes, cities and transportation networks, transformative healthcare applications, and climate change studies.

3. Program market analysis

a. Projected Demand

Within the last two decades, major breakthroughs in the field of electronics, embedded systems and wireless communications have paved the way for the development of the IoT as we know it today. The IoT defines a truly cyber-physical system in which all sorts of physical devices, ranging from standalone sensors and actuators to home appliances and vehicles, are interconnected and able to autonomously interact with each other. This new form of seamless connectivity is the enabler of many diverse applications in the fields of smart healthcare, home monitoring and automation, environmental monitoring and pollution control, smart grid and infrastructure management, real time monitoring of industrial processes, and intelligent transportation of people and goods, among many others.

Not surprisingly, it has been predicted that by 2023 there will be over 14.7 billion machine-to-machine (M2M) connections or half of the total global connected devices and connections over the Internet (up from 33% in 2018).* While IoT devices are and will be used in all types of industry verticals and consumer markets (including healthcare, manufacturing, and retailing), connected home applications will have nearly half or 48% of M2M share by 2023, and connected car applications will grow the fastest at 30% compound annual growth rate over the forecast period (2018–2023). To enable and sustain that growth, both public agencies and the private sector are making multi-billion-dollar investments. **The Master of Science in IoT will provide students with the necessary theoretical and practical skills to contribute to the IoT revolution and growth, ranging from sensors and embedded system design to data streaming and analysis.**

* *Cisco Annual Internet Report (2018–2023) White Paper*
https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

b. Relation with Existing Programs at Northeastern University

The proposed program integrates key elements from different concentrations within the Master of Science in Electrical and Computer Engineering, mostly from Communications, Control and Signal Processing (CCSP), Computer Networks and Security (CNWS), and Microsystems, Materials, and Devices (MSMD). This is a different approach to that of the existing program, in which specialization in one concentration is needed. As mentioned above (Sec. 2), this program aims at preparing inter-disciplinary engineers that can cover all aspects of the IoT, from devices to data applications.

The other potentially related program in the Master of Science in Cyber Physical Systems offered directly by the College of Engineering under the MGEN programs. The MGEN program does not have the inter-disciplinary component that is unique to the proposed MS in IoT program. The MGEN program concerns preparing *IT practitioners* of *current* IoT systems, and it does not leverage the research capabilities and resources available to the Department of ECE and to the Institute for the Wireless Internet of Things. In addition, it has no focus on *future* wireless networked systems and does not cover issues such as softwarization and virtualization that are relevant to NextG networks.

c. Relation with Industry and Opportunities for Coop

WIoT has strong relationships with several companies in the wireless, defense, computing, and manufacturing areas, which are sponsoring WIoT's research or partnering in various ways with WIoT faculty and researchers. These companies, which include AT&T, Raytheon, Verizon, MITRE, Interdigital, Mavenir, Dell, NVIDIA, Qualcomm, Draper, Facebook, Red Hat, Mathworks, JMA Wireless, VIAVI, Keysight, National Instruments, US Ignite, Intelligent Automation, Andro Computational Solutions, Airanaculus, will be targeted as coop partners for the new program.

d. Competition from Other Programs

With the continuously growing demand for IoT engineers, it is not surprising that other top institutions are revamping their offerings in the same. Nevertheless, **none of the existing programs** in other institutions (summarized in Table 1) currently offer or **can match the unique experiential components that, through the Institute for the WIoT, this program offers**. These include, among others, access to Colosseum, the world's largest wireless RF emulation platform, and X-Mili and TeraNova, i.e., the largest millimeter-wave and terahertz networking platforms in the nation. Our testbeds leverage the exclusive Innovation Zone designation of both Boston and Burlington's campuses by the US Federal Communications Commission (FCC). (There are only a handful of such Innovation Zones in the country.)

University Name	Location	Program and Link
UCLA	LA, CA	MS in IoT Systems
Purdue	West Lafayette, IN	MS in ECE: IoT Track
Stanford	Stanford, CA	Graduate Certificate in IoT
University at Buffalo	Buffalo, NY	Engineering Science MS: Focus on Internet of Things
Florida International University	Miami, FL	MS in IoT
University of New Mexico	Albuquerque, NM	MS in Computer Engineering: IoT Concentration
Illinois Tech	Chicago, IL	MS in Computer Engineering in IoT

4. Program requirements

a. Admission criteria and process

The Master of Science in Internet of Things will apply the high standards and admission criteria of all the ECE Graduate Programs. In general, successful applicants to the program will have a background in electrical and/or computer engineering, in computer science, or other related disciplines. **Strong candidates in other STEM disciplines,** including both engineering and sciences (e.g., physics, math) with prior exposure to calculus, linear algebra, probability theory and programming will also be considered.

The admission criteria for the program are:

- Undergraduate degree with a minimum GPA of 3.00.
- Statement of purpose including description of relevant work experience.
- TOEFL: 100 (for international applicants with a bachelor's degree from a non-native
- English speaking country).
- Two (2) letters of recommendation from professional and/or academic references.

We explicitly **remove the GRE requirement** from this list, as it does generally not reflect the actual skills needed by a wireless and network engineer. This is in line with other graduate programs in top engineering institutions in the nation.

The applicants to the program will be reviewed by an admission committee created within the WIoT with ECE/COE and Khoury representation, and chaired by the MS program director.

b. Degree requirements

The program requires 32 credits in total. To meet this requirement, students are required to take a varying number of *semester hours* (SH) in depth and breadth courses as well as in experiential components (either

industry experience or research experience), according to their program track. In particular, the program defines three tracks:

- **Course-only track:**
  - 20 credits in the form of 6 core courses
  - 12 credits in the form of 3 elective courses
- **Thesis-course track:**
  - 20 credits in the form of 6 core courses
  - 8 credits in the form of a MS thesis
  - 4 credits in the form of 1 elective course

Core courses are structured as follows:

1. EECE 5155. Wireless Sensor Networks and the Internet of Things.
2. **One wireless communications/networking course:**
   a. EECE 5576. Wireless Communication Systems
   b. EECE 7364. Mobile and Wireless Networking
3. **One data analysis/machine learning course:**
   a. EECE 5612. Statistical Inference: An Introduction for Engineers and Data Analysts
   b. EECE 5644. Introduction to Machine Learning and Pattern Recognition
   c. EECE 5698. ST Machine Learning for Wireless Systems
   d. CS 6140. Machine Learning
   e. CS 7150. Deep Learning
4. **One course in embedded systems or sensors:**
   a. EECE 7368. High-Level Design of Hardware-Software Systems
   b. EECE 7244. Introduction to Microelectromechanical Systems (MEMS)
   c. EECE 7247. Radio Frequency Integrated Circuit Design
5. **One course in security:**
   a. CY 5120 Applied Cryptography
   b. CY 6740 Network Security
   c. CY 5240 Cyberlaw: Privacy, Ethics, and Digital Rights
   d. CY 5150 Network Security Practices
   e. CY 6750 Cryptography and Communications Security
   f. EECE 5641: Introduction to Software Security
   g. EECE 5699. Computer Hardware and System Security
   h. CY 6760. Security of Wireless and Mobile Systems

Elective courses can be chosen from an extensive list of options within COE/Khoury and across colleges on campus. Please see Appendix 1.

5. Program assessment (based on the NECHE E-series)

a. Student Learning Outcomes

Students who complete the Master of Science in Internet of Things will be able to:

- **Outcome 1:** Understand the state-of-the-art solutions relating to the building blocks from the IoT, from sensors and embedded systems, through communication and networking, to data application and analytics.
- **Outcome 2:** Design, implement and orchestrate IoT systems, utilizing theoretical, numerical, and experimental tools.
- **Outcome 3:** Anticipate and adapt to new distributed data application requirements, networking architectures and communication techniques.

b. Assessment

Collection and Interpretation of Evidence

In addition to the students' GPA and, when applicable, the MS thesis grade, the ability of the program to provide students with the targeted learning outcomes will be assessed through as follows:

- **Direct assessment:** this will include an anonymized assessment of student coursework to be sampled at random from the depth courses. Selected work will be cumulative and synthetic to each course, such as final projects. The program faculty will develop quality rubric to assess the outcomes of each course and the level of achievement by current students. Coursework will be sampled annually.
- **Indirect assessment:** this will include standard institutional metrics including but not limited application statistics, enrollment data, completion and persistence rates, TRACE evaluations, and student surveys (current and graduate). The program will also conduct student interviews (group and individual) to understand student perceptions of program and course operation.

The collected information will be interpreted by the MS Program Director together with the WIoT Education and Workforce Development (EWD) Committee. The assessment will be utilized to continually improve the admissions rubric, identify curricular gaps, employment/coop trends, as well as program strengths and weaknesses. The Assessment, Evaluation, Feedback & Intervention System (AEFIS) platform, which is already well-integrated with Canvas and other assessment information requirement tools at Northeastern, will be adopted from the beginning to facilitate the program assessment.

The timeline for assessment will be as follows:

- **Current student survey:** every summer
- **MS thesis grade:** every semester
- **Graduate surveys:** annually after graduation of first cohort
- **TRACE evaluation:** every semester
- **Program data** (which includes admission rubric review, persistence and completion rate, and grade distribution review): every summer

6. Program accreditation or adherence to licensing standards (if applicable)

Not applicable currently.

7. Resources

The Master of Science in Internet of Things program will be based upon existing resources in the Department of Electrical and Computer Engineering, the Institute for the Wireless Internet of Things, the College of Engineering, and the Khoury College of Computer Sciences.

8. Budget (for Provost Office review only)

a. *Provide detailed information on the start-up budget needed (prior to any revenue) including marketing expenses.*
b. *Using the form below, provide projected enrollment and estimated revenue and expenses for the first five years of the program.*

Year	Application Fees	Total Projected Full-Time Headcount	Total Projected Part-Time Headcount	Total Student Credit Hrs Taught	Projected Tuition Revenue @ current rates	Total Expenses (current & new funds) exclude Tuition remission	Total Projected Tuition Remission Expenses	Projected Revenue Less Projected Expenses

One								
Two								
Three								
Four								
Five								

Notes

c. *Will new funds for this program, including tuition remission be required? If so, how much?*

Year	Total New Tuition Remission Required (including ongoing new funds from prior year)	Total Other New Funds Required (including ongoing new funds from prior year)	Total New Funds Required - tuition remission and other (including ongoingnew funds from prior year)
One			
Two			
Three			
Four			
Five			

d. *Include any additional information for consideration.*

Appendix 1: Elective Courses for the MS in IoT Program

Courses offered by ECE

EECE 5360. Combinatorial Optimization.
EECE 5550. Mobile Robotics.
EECE 5606. Micro- and Nanofabrication.
EECE 5638. Compilers for Modern Computer Architectures.
EECE 5639. Computer Vision.
EECE 5640. High-Performance Computing.
EECE 5641. Introduction to Software Security.
EECE 5642. Data Visualization.
EECE 5643. Simulation and Performance Evaluation.
EECE 5645. Parallel Processing for Data Analytics.
EECE 5649. Design of Analog Integrated Circuits with CMOS
EECE 5652. Microwave Circuits and Networks.
EECE 5666. Digital Signal Processing.
EECE 5693. Electromagnetic Devices for RF and Wireless Communications.
EECE 5697. Acoustics and Sensing.
EECE 5698. ST GNSS Signal Processing
EECE 5698. ST Network Programming
EECE 5699. Computer Hardware and System Security.
EECE 7150. Autonomous Field Robotics.
EECE 7200. Linear Systems Analysis.
EECE 7201. Solid State Devices.
EECE 7202. Electromagnetic Theory 1.
EECE 7204. Applied Probability and Stochastic Processes.
EECE 7205. Fundamentals of Computer Engineering.
EECE 7240. Analog Integrated Circuit Design.
EECE 7242. Integrated Circuits for Mixed Signals and Data Communication.
EECE 7245. Microwave Circuit Design for Wireless Communication …
EECE 7275. Antennas and Radiation.
EECE 7310. Modern Signal Processing.
EECE 7323. Numerical Optimization Methods.
EECE 7336. Digital Communications.
EECE 7337. Information Theory.
EECE 7345. Big Data and Sparsity in Control, Machine Learning, and Optimization.
EECE 7346. Probabilistic System Modeling and Analysis.
EECE 7370. Advanced Computer Vision.
EECE 7374. Fundamentals of Computer Networks.
EECE 7390. Computer Hardware Security.
EECE 7397. Advanced Machine Learning.
EECE 7398 ST Wireless Network Systems and Applications
EECE 7398 ST An Experimental Approach to Wireless Communications
EECE 7398 ST Terahertz Communications

Courses offered in other COE Departments

Mechanical and Industrial Engineering
IE 7270. Intelligent Manufacturing.

Bioengineering
BIOE 5250. Design, Manufacture, and Evaluation of Medical Devices.

Civil Engineering
CIVE 7150. Data-Driven Decision Support for Civil and Environmental Engineering.
CIVE 7380. Performance Models and Simulation of Transportation Networks.
OR 7245. Network Analysis and Advanced Optimization.
CIVE 5280. Remote Sensing of the Environment.
CIVE 7150. Data-Driven Decision Support for Civil and Environmental Engineering.
CIVE 7151. Urban Informatics and Processing.

Courses offered outside of COE

Khoury College of Computer Sciences
CY 5120 Applied Cryptography
CY 6740 Network Security
CY 5240 Cyberlaw: Privacy, Ethics, and Digital Rights
CY 5150 Network Security Practices
CY 6750 Cryptography and Communications Security
CY 6720 Machine Learning in Cybersecurity and Privacy
CS 5700 Fundamentals of Computer Networking

D'Amore McKim School of Business
ENTR 6222. Competing in Dynamic, Innovation-Driven Markets.
MGMT 6280. Innovation for Next-Generation Products and Systems.
TECE 6222. Emerging and Disruptive Technologies.
TECE 6300. Managing a Technology-Based Business.
TECE 6340. The Technical Entrepreneur as Leader.
ENTR 6230. Intro to Platform Business Models
MGMT 6280. Innovation for Next-Generation Products and Systems

Bouve College of Health Sciences
Health Informatics:
HINF 5101. Introduction to Health Informatics and Health Information Systems.
HINF 5200. Theoretical Foundations in Personal Health Informatics.
HINF 5300. Personal Health Interface Design and Development.
HINF 5301. Evaluating Health Technologies.
HINF 6400. Introduction to Health Data Analytics.

Nursing:
NRSG 6306. Health Informatics.

College of Arts, Media and Design

Communication Studies
COMM 6605. Youth and Communication Technology.

School of Law
LAW 7002. Intellectual Property.
LAW 7009. Intellectual Property and Technology Law.
LAW 7640. Information Security Law.
LAW 7669. Law and Technology.
LAW 7672. Data Privacy Compliance in the 21st Century.
LAW 7675. Information Privacy Law.
LPSC 7312 Cities, Sustainability, and Climate Change

College of Sciences
Physics
PHYS 5116. Complex Networks and Applications.
PHYS 5126. Contagion on Networks.
PHYS 7331. Network Science Data.

College of Social Sciences and Humanities
Public Policy and Urban Affairs
PPUA 5262. Big Data for Cities.

Political Science/Urban Affairs
POLS 7341 Security and Resilience Policy
POLS 7441 Cyberconflict
POLS 7346 Resilient Cities

Philosophy
PHIL 5005 Information Ethics