Engineering Tripos Part IIB, 4B27: Internet of everything, 2024-25

Module Leader

Prof O B Akan [1]

Lecturers

Prof O B Akan

Timing and Structure

Lent term. 16 timetabled lecture slots, including lectures and time for coursework. Assessment: 100% coursework.

Aims

The aims of the course are to:

- Introduce the history and definition of Internet of Things (IoT), concepts of the Internet of Everything (IoE), the relation and differences between IoT and IoE by drawing on the established theories regarding the relation
- Outline the challenges of the IoE focusing on ubiquitous connectivity, energy efficiency, miniaturization, and interoperability.
- Introduce and discuss the Internet of Bio-Nano Things (IoBNT), its major role at the core of the IoE, its emerging applications, enabling technologies, challenges and proposed solutions.
- Explore IoBNT-related concepts, such as biosensors, wearables, drug delivery systems, microfluidic systems, bioelectronics, bio-cyber and neural interfaces, molecular and nanomachines.
- Explore natural IoBNT systems, such as human-body nanonetworks, bacterial nanonetworks, plant networks.
- Explore artificial nanoscale communication networking techniques, such as molecular communications, THz-band EM, nano-mechanical communications, acoustic nanocommunications, and FRET-based nanocommunications.
- Discuss current and future IoBNT applications, such as smart drug delivery, continuous health monitoring, smart agriculture.
- Review the fundamentals of molecular information and communication technologies. Introduce modelling, analysis and simulation techniques for molecular nanonetworks.

Objectives

As specific objectives, by the end of the course students should be able to:

- Understand IoT and IoE concepts, key components, enabling technologies and applications, and understand the role and position of IoBNT in the IoE framework.
- Carry out technological investigation on IoBNT-related fields, such as molecular communications, bio-cyber interfaces, neural interfaces, microfluidics, nanobiosensing, intrabody nanonetworks.
- Be familiar with the tools for targeting IoBNT challenges and developing novel IoBNT applications through facilitating communication between heterogeneous bio-nano things.
- Perform communication theoretical analysis and simulation of molecular nanonetworks.
- Explore practical tools available for the implementation of IoBNT systems.

Content

Internet of Everything (2L)

- **The universe as the natural IoE:** Review of governing rules/dynamics of natural Internets.
- **Key components of IoE:** People, things, data, and processes.
- **Internet of Things (IoT) vs. Internet of Everything (IoE):** Comparison and the main differences between these two paradigms.
- **Major IoE challenges:** Connectivity, scarcity of bandwidth, energy-efficiency, miniaturization, application-driven networking, interoperability.
- **Universal transceivers for IoE:** From smart IoT gateways to multi-modal IoE transceivers with hybrid energy harvesting capabilities.

Current Practice in Commercial IoXs (1L)

- **Overview/Applications of main IoXs:** Industrial Internet of Things (IIoT), Internet of Agricultural Things (IoAT), Internet of Energy (IoEn), Internet of Vehicles (IoV), Internet of Money (IoM), Internet of Space (IoSp), Internet of Digital Twins/Metaverse.

Internet of Bio-Nano Things (IoBNT) (3L)

- **Introduction to IoBNT:** Framework, network architecture and fundamental components.
- **Bio-Nano Things (BNTs):** Nanobiosensors, nano-stimulators, engineered cell-based BNT designs, functional biomolecules as BNT.
- **IoBNT applications:** Medical applications (detection and mitigation of infectious diseases, intrabody continuous health monitoring, theranostic systems, smart drug delivery), organ-on-a-chip, smart agriculture, biocomputing, food safety, environmental applications.
- **Nanoscale communication methods for IoBNT:** Bio-inspired molecular communications, electromagnetic (THz-band), optical, acoustic, nanomechanical, magneto-inductive nanocommunications.
- **IoBNT challenges:** Co-existence and biocompatibility, energy harvesting, privacy and security.

Bio-cyber interfaces for IoBNT (2L)

- **Overview of brain-machine interfaces.**
- **Bioelectronics and micro/nanoscale neural interfaces.**
- **Wearable bio-cyber interfaces,** and enabling technologies, e.g., organic electrochemical transistors, and electrophoretic drug delivery, biosensing.

Molecular Communications (MC) (4L)

- **MC-based Natural IoBNT**: IoBNT inside us (nervous and hormonal nanonetworks, immune system, gut-brain axis, molecular networks of cancer metastasis), bacterial nanonetworks, plant communications, odour transduction networks.
- **Artificial MC:** Diffusion-based MC, microfluidic MC, FRET-based MC, DNA-based MC, microfluidic lab-on-chip/organ-on-a-chip, human-body as MC network infrastructure, bacteria-mediated MC, olfactory (smell) MC.
- **Communication techniques for MC:** Modulation, coding, synchronization, detection and channel estimation techniques.
- **Modelling and analysis of MC networks:** Information and communication theoretical modelling of MC networks. Analytical and numerical approaches to obtain MC channel response, channel capacity, received signal statistics.
- **Simulation tools for MC networks:** Particle-based spatial stochastic simulation techniques, and deterministic finite-element simulation techniques for MC. MC simulators (e.g., N4Sim, NanoNS, AcCoRD, nanoNS3).
- **Transmitter and receiver architectures for MC:** Nanomaterial-based (e.g., graphene biosensor-based MC receiver, stimuli-responsive hydrogel-based MC transmitter) and biosynthetic design approaches.
- **Practical MC testbeds:** Microfluidic, magnetic nanoparticle-based, and light-responsive bacteria-based testbeds for MC.

Coursework

Activity 1: Stochastic Simulations of Molecular Communications

In this coursework, you will simulate diffusion-based molecular communications in 3d fluidic environment by using Smoldyn (an open-source particle-based stochastic simulation software). You will analyse propagation delay, diffusion noise, binding noise for different channel, transmitter and receiver designs, and experiment with several MC modulation and detection techniques to see their impact on the communication performance.

Learning objectives:

- Gain knowledge of common MC models
- Gain skills in particle-based spatial simulation of stochastic systems
- Implement simple modulation and detection techniques for an MC system
- Gain knowledge of common ICT performance metrics

Activity 2: From IoX to IoE (research report — max 8-pages)

Choose an IoX (either from the ones covered during the lectures or another one from the literature) and:

(a) Study it by abstracting with a layered communication network architecture and identifying the role of Xs (i.e., people/things), data, and processes in the operation of the IoX

(b) Investigate the communication channels and the transmitter/receiver architectures utilised in the IoX, propose/devise new approaches if needed

(c) Analyse and discuss its energy characteristics (power requirements, corresponding available energy sources, harvesting possibilities), communication capabilities, and potential applications

(d) Describe the role of this IoX within the broader IoE framework. More specifically, identify the potential interaction pathways of the IoX of interest with the other IoXs. Discuss the potential applications enabled by the IoE synergy between the IoX of interest and others, together with the interoperability challenges to maintain these interactions

(e) Identify and discuss potential open research/engineering challenges for the realisation of the IoX of interest

Optional (Recommended but not mandatory): The students can earn extra points if their report includes analytical, numerical and/or simulation-based analyses to justify their discussion. If the selected IoX involves molecular communications in its framework, students can incorporate Smoldyn simulations. Otherwise, the use of any other mathematical analysis (learned in previous modules) and simulation tools (including MATLAB) will be welcome.

Learning objectives:

- Identify existing IoT applications (IoXs), map out their architectures with key components and technologies involved
- Identify the existing and potential interaction pathways between different IoXs and analyse the potential value added through facilitating the existing interactions or creating new interaction pathways
- Map existing IoXs onto the IoE framework according to their existing or potential interactions and identify the open challenges for their realisation

Examination Guidelines

Please refer to Form & conduct of the examinations [2].

Last modified: 31/05/2024 10:01

Links
[1] mailto:oba21@cam.ac.uk
[2] https://teaching26-27.eng.cam.ac.uk/content/form-conduct-examinations