Module Title: 5C7 Complex Systems Science for Communication Networks

Code: EE5C07

Level: MAI (Optional module)

Credits: 5

Lecturers: Prof. Nicola Marchetti (nicola.marchetti@tcd.ie)

Module Organisation

<table>
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<tr>
<th>Semester</th>
<th>Start Week</th>
<th>End Week</th>
<th>Associated Practical Hours</th>
<th>Lectures</th>
<th>Tutorials</th>
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<td></td>
<td>Per week</td>
<td>Total</td>
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<tr>
<td>2</td>
<td>1</td>
<td>12</td>
<td>8</td>
<td>3</td>
<td>33</td>
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Total Contact Hours: 52

Module Description
Modern communications research is tending towards a dynamical description of networks. These dynamics, which include movement, growth, competition and adaptation, add complexity to the networks.

The above sets the scene for this module, which will introduce the students to the emerging scientific field of complexity. The module will focus on different aspects of relevance to complex systems, including nonlinearity and adaptivity and how complex systems science differs compared to the traditional study of systems.

Information theoretical aspects of complex systems will be considered, in terms of specific quantities that characterize to what degree and in what sense a system can be defined as complex, and the relation to other aspects such as regularity and randomness in network abstractions. The module will then introduce students to the network science aspects such as the classification of networks into random, small world, scale free, and regular, based on graph theoretical quantities. The time evolution of complex systems, encompassing dynamical systems, chaos theory and fractal geometry aspects, will then be studied.

Game theory is a mathematical framework that can be applied to model complex interactions in a communication network. In particular, it can help predict the outcomes of autonomous decisions by rational decision makers. In the second part of the course, we will introduce fundamental concepts in cooperative and non-cooperative game theory and illustrate how they can be applied to model resource management in current and future networks. Further, we will use also optimization and machine learning to model wireless communication and networking problems.

The course will relate the introduced complex systems science aspects to communication networks throughout its duration. Such applications will include cellular network frequency planning, Internet-of-Things protocols, communication networks functional topology, and social networks.

Learning Outcomes
On completion of this module the student will be able to:
1. Understand the limitations and applicability of complex systems science, in particular with respect to communication networks.
2. Model the information theoretical, dynamical, network science aspects of modern communication networks.
4. Use software tools to solve relevant network engineering problems by using complex systems science.
5. Study the constraints related to environmental and sustainability limitations in terms of energy consumption of modern networks.
6. Design and conduct software based experiments working in a project team, demonstrating understanding of group dynamics and related leadership aspects.
7. Present the relevant technical aspects in a written form, in a way that is both concise and precise.

Module Syllabus
1. Introduction to complex systems; complexity, nonlinearity, adaptivity.
2. Information theoretical aspects; measures of entropy and complexity, and application to self-organizing cellular and IoT networks.
3. Dynamical systems, chaos theory and fractal geometry aspects; application to telecom traffic modelling, circuit and antenna design.
4. Network science aspects; random networks, small world and scale free networks, regular networks; application to cellular, IoT and social networks.
5. Fundamentals of game theory; cooperative and non-cooperative games.

Associated Laboratory/Project Programme
Four software-based lab sessions will demonstrate some of the concepts covered in class. In particular, students will be required to complete a software-based project focusing on the application of complex systems science to emerging topics in wireless networks, such as 5G networks, Internet of Things systems, self-organizing densely deployed networks.

Prerequisites
EE4C04 Next Generation Networks.

Recommended Text(s)
- *Information Theory for Complex Systems*, K. Lindgren, Chalmers University of Technology, 2014 (available online)

Teaching Strategies
The module is taught using a combination of lectures and tutorials. Every week one lecture is allocated to tutorials. There will also be four lab lectures to introduce the students to software tools relevant to the study of complex systems.

Assessment
Continuous assessment will be adopted. The final marks for the module will be calculated according to:
- A lab project (10%);
- Two in-class quizzes (20% each);
- End-of-year formal written two-hour examination (50%).