INTERNATIONAL TELECOMMUNICATION UNION

REPORT ON THE IOT TRAINING PROGRAMME (IOT TP)

HUMAN CAPACITY BUILDING DIVISION

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report describes the structure and content of a proposed Training Programme (TP) on the Internet of Things (IoT) to be made available to the ITU membership for training and educational purposes. The beneficiaries of the TP are expected to be academia, industry, regulatory bodies, government organisations and telecom providers.

The TP has a modular structure and each module takes between 4 and 5 weeks for the student to complete, including the final assessment per module. The option of an MSc Thesis is also offered.

The modules described cover the entire area of the Internet of Things pertinent to the ITU. Notably, the TP deals with IoT standards, architectures, protocols, interoperability, devices, wireless connectivity technologies, cloud, security, privacy, trust, artificial intelligence, big data, ethical issues, business models and case studies; as well as IoT entrepreneurship.

The eight Foundation Modules introduce above topics whilst providing students with a sufficient level of technical detail. Out of these eight modules, at least six have to be taken and the first five are compulsory. Upon a successful completion of the Foundation Modules, verified by means of a test at the end of each of the taken modules, an **ITU Foundational IoT Certificate** will be issued to the student.

Seven Advanced Modules provide the student with a much greater depth of understanding and more practical experience in each subject area. To obtain the **ITU Advanced IoT Certificate**, students needs to take at least four Advanced Modules and have successfully passed the respective module tests.

The Master Thesis can only be started after a successful completion of the Advanced IoT Certificate. The thesis ought to be assessed by an external body accredited to offer degrees at MSc level. A successful completion of such an assessment yields the **Internet of Things MSc.**

The Advanced IoT Certificate course should ideally be taken after completion of the Foundational IoT Certificate; however, for those skilled in the arts, an entry test will be offered which is modular in design and allowing the student to only take those modules in the foundational course which the student failed.

The designed TP would complement the existing professional training options and promote common education and design approaches. Due to the resources held by the ITU and partner institutions, and the constant updating that should be possible due to on-going activities in the three ITU sectors, the TP should be able to establish itself as the “gold standard” of training in the IoT arena.

Note: To ensure viability, the format of this report was based on the successful ITU Spectrum Management Training Programme.

1 BACKGROUND AND JUSTIFICATION

1.1 THE ROLE OF AN IOT TRAINING PROGRAMME

Connecting devices to the Internet is not a new idea: a toaster was connected to the network in 1990 and users could interact with it via a web interface. Since then, industry, utilities and trucking and logistics companies have all begun connecting their machines and assets to various systems and to each other. The actual phrase "The Internet of Things (IoT)" has been coined in 1999 by Kevin Ashton of MIT in a presentation to Procter & Gamble. In the last couple of years ubiquitous connectivity, widespread adoption of IP, miniaturization, the rise of cloud computing and advances of data analytics have created the conditions for a dramatic growth of IoT. Cisco predicts that there will be billions connected devices by 2020.

In 2012 the ITU defined IoT in Recommendation ITU-T Y.2060 as:

"*A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies. A device is a piece of equipment with the mandatory capabilities of communication and optional capabilities of sensing, actuation, data capture, data storage and data processing. The devices collect various kinds of information and provide it to the information and communication networks for further processing. Some devices also execute operations based on information received from the information and communication networks.*"

This new technology has the potential to change the world, just as the Internet did; maybe even more so. IoT is based on Next Generation Networks to communicate the huge amount of data gathered from the physical world. Furthermore, the availability of Big Data can be leveraged to make inferences about many phenomena and take corrective actions to mitigate unwanted effects. In addition to applications in cities and in industries, IoT can greatly benefit populations in Developing Countries: food safety can be checked, water quality can be monitored, air quality can be measured, landslides can be detected and mosquitoes can be counted in cities in real time.

The standardization activities for IoT is being conducted through the ITU-T Study Group 20 on Internet of Things and smart cities and communities. This study group was created in June 2015 and develops international standards aimed at implementing IoT and smart cities and communities and promoting interoperability and transparency. The foundations of this Study Group are provided by ITU-T's experience in the development of IoT standards and the findings of the ITU-T Focus Group on Smart Sustainable Cities (FG-SSC), which concluded its activities in May 2015 with the release of 21 technical reports and specifications.

The role of IoT in smart cities is also explored within the global initiative United for Smart Sustainable Cities, launched by ITU and UNECE in May 2016. This initiative is supported by 16 United Nations agencies and programmes.

The proposed Training Programme on Internet of Things aims at developing experts that are able to plan, design and maintain IoT systems with a special focus on applications, and adopting a problem-solving methodology.

Formal academic certification in collaboration with Centres of Excellence and other ITU Academy partners in IoT worldwide would increase the appeal of this Training Programme. If the Programme provided an equivalent qualification to a Master's (MSc) degree, it would offer to employers a clear benchmark reference, simplifying the process of recruitment while at the same time facilitating the mobility of IoT professionals.

1.2 OVERVIEW OF EXISTING STUDY RESOURCES AND COURSES ON IOT

1.2.1 Written Sources

Written texts in the form of online and offline sources can be used by participants to augment the training material contents. The following are examples from ITU and from other sources (as retrieved on 27 March 2017), and should be extensively used within all modules:

Published by ITU-T:

Recommendation ITU-T Y.2060: Overview of the Internet of things (IoT), 2012, http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=y.2060

Unleashing the potential of the Internet of Things, 2016, https://www.itu.int/pub/T-TUT-SMARTCITY-2016-2

Recommendation ITU-T Y.2063, Framework of the web of things, 2012, https://www.itu.int/rec/T-REC-Y.2063/en

Internet of Things Global Standards Initiative, 2015, http://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx

Shaping smarter and more sustainable cities: Striving for sustainable development goals, 2016, http://wftp3.itu.int/pub/epub_shared/TSB/ITUT-Tech-Report-Specs/2016/en/flipviewerxpress.html

WTSA Resolution 98 – Enhancing the standardization of Internet of things and smart cities and communities for global development, 2016, https://www.itu.int/dms_pub/itu-t/opb/res/T-RES-T.98-2016-PDF-E.pdf

Implementing ITU-T International Standards to Shape Smart Sustainable Cities: The Case of Dubai, 2016, http://www.itu.int/en/publications/Documents/tsb/2016-DubaiCase/index.html

I**United for Smart Sustainable Cities: Striving for Sustainable Development Goals,** 2016, http://wftp3.itu.int/pub/epub_shared/TSB/2016-ITUT-SSC-Brochure/en/index.html#p=1

Joint Coordination Activity on Internet of Things and Smart Cities and Communities (JCA-IoT and SC&C), available online: http://www.itu.int/en/ITU-T/jca/iot/Pages/default.aspx

ITU-T SG20: IoT and smart cities and communities (SC&C), available online: https://www.itu.int/en/ITU-T/studygroups/2017-2020/20/Pages/default.aspx

Published by ITU-R:

Resolution ITU-R 66: Studies related to wireless systems and applications for the development of the Internet of Things, 2015, http://www.itu.int/pub/R-RES-R.66-2015

Resolution ITU-R 54-2: Studies to achieve harmonization for short-range devices, 2015, http://www.itu.int/pub/R-RES-R.54-2-2015

Published by ITU-D:

The Internet of Things: data for development. In Measuring the Information Society Report 2015, 2015, pp. 147-171. http://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2015.aspx

Published by ITU General Secretariat:

ITU Internet Reports 2005: The Internet of Things, 2005, http://www.itu.int/pub/S-POL-IR.IT-2005/e

Harnessing the Internet of Things for Global Development, 2016, https://www.itu.int/en/action/broadband/Documents/Harnessing-IoT-Global-Development.pdf

Published outside ITU:

Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J. and Aharon, D., 2015. **The Internet of Things: Mapping the Value Beyond the Hype**. McKinsey Global Institute.

Evans, D., 2011. **The Internet of Things. How the Next Evolution of the Internet Is Changing Everything**. CISCO I.B.S.G. http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf. Accessed 7 Apr. 2017.

Goldman Sachs, 2014. **IoT primer. The Internet of Things: Making sense of the next mega-trend**. http://www.goldmansachs.com/our-thinking/outlook/internet-of-things/iot-report.pdf. Accessed 7 Apr. 2017.

Walport, M., 2014. **The Internet of Things: making the most of the Second Digital Revolution**. London: UK Government Office for Science. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/409774/14-1230-internet-of-things-review.pdf. Accessed 7 Apr. 2017.

Rose, K., Eldridge, S. and Chapin, L., 2015. **The internet of things: An overview**. The Internet Society (ISOC), pp.1-50. http://www.internetsociety.org/doc/iot-overview. Accessed 7 Apr. 2017.

ETSI, 2017. **Connecting Things.** http://www.etsi.org/technologies-clusters/clusters/connecting-things. Accessed 30 Mar. 2017.

Eclipse.org, 2016. **Eclipse IoT Working Group.** https://iot.eclipse.org/working-group/. Accessed 30 Mar. 2017.

GSMA, 2016. **GSMA: the impact of the Internet of Things. The Connected Home.** http://www.gsma.com/newsroom/wp-content/uploads/15625-Connected-Living-Report.pdf. Accessed 30 Mar. 2017.

IEEE.org, 2017. **IEEE Internet of Things.** http://iot.ieee.org/. Accessed 30 Mar. 2017.

1.2.2 IoT Courses

ITU Asia-Pacific CoE Program:

Developing the ICT ecosystem to harness Internet of Things, 13-15 December 2016, Bangkok, Thailand
http://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Pages/Events/2016/Dec-2016-IoT/IoTtraining.aspx

Online training courses:

Fog Networks and the Internet of Things
Princeton University via Coursera, available online:
https://www.class-central.com/mooc/2731/coursera-fog-networks-and-the-internet-of-things

The Internet of Things
King's College London, available online:
https://www.class-central.com/mooc/3820/futurelearn-the-internet-of-things

Internet of Things: How did we get here?
University of California, San Diego via Coursera, available online:
https://www.class-central.com/mooc/4276/coursera-internet-of-things-how-did-we-get-here

How the Internet of Things and Smart Services Will Change Society
via openSAP, available online:
https://open.sap.com/courses/iot1

Internet of Things: Communication Technologies
University of California, San Diego via Coursera, available online:
https://www.class-central.com/mooc/4173/coursera-internet-of-things-communication-technologies

Internet of Things: *Roadmap to a Connected World*
MIT Professional Education, available online:
http://web.mit.edu/professional/digital-programs/courses/IoT/

IoT for Executives
Expertfy, available online:
https://www.experfy.com/training/courses/iot-for-executives

University Courses:

Malmo University, Sweden
Computer Science: Internet of Things, Master's Course, available online:
http://edu.mah.se/en/Course/DA650A

University of Salamanca, Spain
Master in the Internet of Things, available online:
http://iot.usal.es/

University of Oxford, UK
Data Science for the Internet of Things (IoT), available online:
https://www.conted.ox.ac.uk/courses/data-science-for-the-internet-of-things-iot

Queen Mary University of London, UK
MSc in Internet of Things, available online:
http://www.qmul.ac.uk/postgraduate/taught/coursefinder/courses/173148.html

CIFF Business School, Spain
Master in Internet of Things (IoT), available online:
http://www.ciff.net/master-en-internet-of-things.html

Royal Holloway, University of London, UK
Masters in The Internet of Things, available online:
https://www.royalholloway.ac.uk/computerscience/prospectivestudents/postgraduatetaught/internet-of-things/iot.aspx

University of the West of Scotland, UK
MSc Internet of Things (IoT), available online:
http://www.uws.ac.uk/postgraduate/internet_of_things_(iot)/

Waterford Institute of Technology, Ireland
BSc (Hons) in the Internet of Things, available online:
https://www.wit.ie/courses/type/science/department_of_computing_maths_physics/bsc-hons-in-the-internet-of-things

1.3 CONCLUSIONS FROM ANALYSING EXISTING TRAINING AND CERTIFICATION OPTIONS

Although several Universities already offer courses (at MSc and BSc levels) on subjects related to the IoT, a training programme organised by the ITU specifically on IoT would complement

the existing professional training options and promote common approaches. The IoT TP should meet the following criteria:

- Important is to scout for tutors who have a proven track record in the respective field of teaching; the reason this is not so easy is because the IoT is a fairly new area (thus shortage of skills) and very hyped area (thus exaggeration of skills).
- The program should not be focused on a national agenda (e.g. only US or only UK) but be truly international in scoping, case studies, applications, etc; it is important to highlight the global capabilities of the IoT whilst also highlighting the national particularities.
- It should be based on the latest IoT standards and regulations as defined by ITU and by other international and industrial organizations. While other programs cover IoT in general, few focus their attention on regulations which we believe could be a massive differentiator for the ITU TP.
- The case studies and applications should also be geared towards Developing Countries where the potential of the IoT is very large.
- The IoT TP, when fully completed, should aim at being recognized as an equivalent to a Master's degree.
- The TP should offer a broader and deeper professional knowledge with stronger engagement than possible through exclusively online courses.
- As the TP is organised by the ITU, particular attention should be given to regulation, standards and technical planning pertaining to the IoT.
- The topic of ethical issues, including data privacy laws, related to IoT should be included in the TP, as this aspect is gaining more and more attention.

1.4 CHOICE OF IMMERSION LEVELS AND PROFESSIONAL SPECIALIZATION FOR THE IOT TP

It is likely that an ITU training programme on IoT would interest people with different academic and professional backgrounds and with different work experience. Two entry levels to the IoT TP are therefore proposed:

1. **Foundation level**, for participants with little or no prior work experience in or knowledge about IoT. Foundation level modules will provide the basic concepts about IoT and related technologies. Successful completion of a set of foundation modules would lead to a certificate but not a full diploma equivalent to an MSc.

2. **Advanced level**. For admission at this level the participant would need to have passed the Foundation level successfully or, alternatively, demonstrate an equivalent understanding of the principles by means of an entry level examination/project.

2 THE IOT TP CONCEPT AND PROGRAMME OUTLINE

The IoT TP is designed to fit within the European Credit Transfer and Accumulation System (ECTS). ECTS is a standard for comparing the study attainment and performance of students of higher education across the European Union (EU) and other European countries. ECTS credits are awarded for successfully completed studies. One academic year corresponds to 60 ECTS credits that are equivalent to 1500–1800 hours of study in all countries irrespective of qualification type, and so can facilitate transfer and progression throughout the EU. The objective will be to extend this globally for the IoT TP. Formal (external) assessment would be needed for the qualification to be recognised externally, as described later.

The IoT TP is designed to be modular, with each successfully completed module requiring around 125 hours of study and generating 5 ECTS credits. 10 modules and a Master Thesis would therefore be required to complete a course of 60 ECTS credits and receive a Master's degree. The duration is designed to be around one calendar year for participants aiming to take the complete course, but this can be extended to allow part time study.

2.1 TARGET AUDIENCES

The IoT TP could be taken by any professional who has previously graduated with a first-level university degree (e.g. BSc). Students entering the IoT TP could be from different institutional levels, from technical to managerial, and from different backgrounds (engineering, legal, regulatory, economic, etc.). Students wishing to join at the Advanced Level would need to have at least one year of professional experience in the field of IoT and pass an entrance examination and/or submit a project or essay to assess their level of knowledge. A committee would be in charge of evaluating the examination/essay, taking into account cultural differences.

The IoT TP is designed for anyone wishing to enhance their professional knowledge in the field of IoT, for example:

- Electronical engineers
- Telecommunications engineers
- Computer scientists
- Policy makers and Regulators
- Telecom Operators
- Networks Operators

2.2 COURSE STRUCTURE

As the IoT TP is mainly addressed to working professionals, it should consist of a sequence of modules spread over a calendar year. A modular structure would allow new modules to be added or existing modules to be changed readily. A modular structure also has the following benefits:

1. They are a convenient way to combine study options with daily work commitments, as students would only need to focus on one study topic at a time;

2. They simplify the logistics by minimizing the coordination needed between different partner institutions: only the organization managing a particular study module would be responsible for daily operations in any given time period;
3. Time commitments are more predictable for teaching staff (assuming each tutor is assigned the same module(s) in successive years and each module is offered annually in the same time-frame);

Module durations of four/five weeks have been used throughout, which are short enough for focused study of one topic but long enough to give instructors flexibility in planning their syllabuses. This also allows for a succession of different modules to fit within one year. Periods of self-directed study may fit in with holidays, major industry events, work-related travel, etc.

As per Figure 1, there are Foundation Modules underpinning the **Foundational IoT Certificate** at **30 ECTS credits** which are described in great depth in Section 4; and there are Advanced Modules underpinning the **Advanced IoT Certificate** at **20 ECTS credits** which are described in Section 5. Finally, in Section 6, the **Master Thesis** at **10 ECTS credits** is detailed which can be taken by those with an Advanced Certificate and yields the **Internet of Things MSc.**

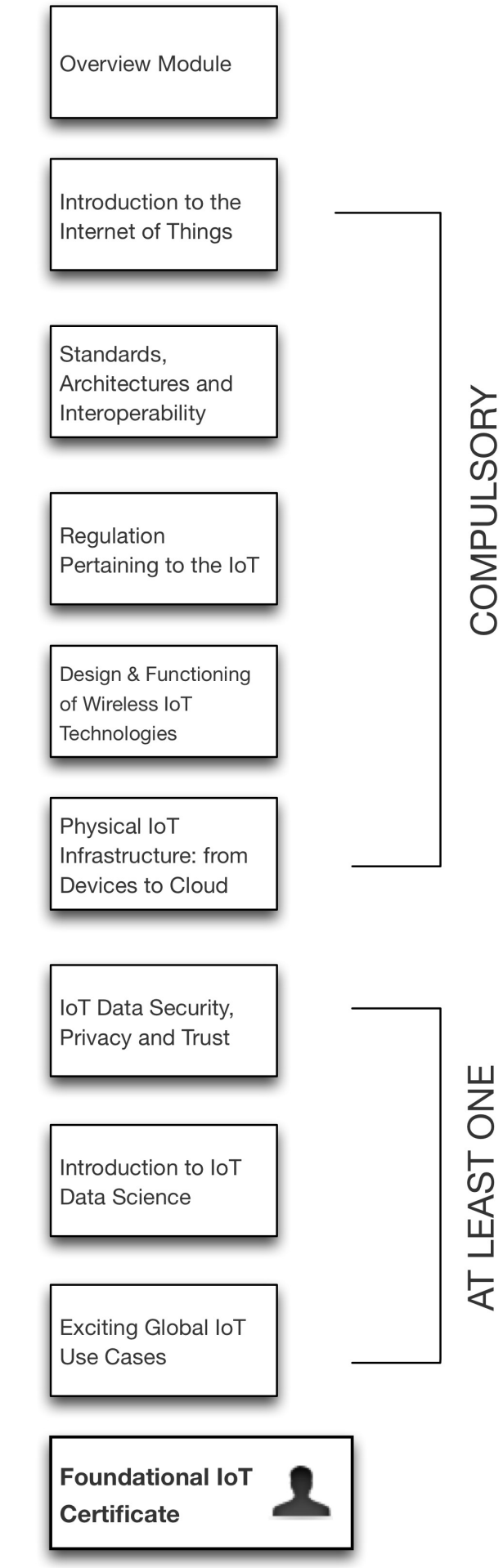
Only taking the Fundamental Modules yields a Foundational IoT Certificate. Out of the 8 modules, at least 6 have to be taken with 5 ECTS credits each. The first 5 are compulsory, whilst the student can choose at least 1 from FM6-FM8 which are optional.

To obtain the Advanced IoT Certificate, one needs to take at least 4 Advanced Modules at 5 ECTS credits each. All of the offered 7 Advanced Modules are optional, and only loosely related allowing a completely independent choice of modules.

The Internet of Things MSc can only be started after the Advanced IoT Certificate. The Advanced IoT Certificate course should ideally be taken after completion of the Foundational IoT Certificate; however, for those skilled in the subject area, an entry test will be offered which is modular in design and allowing the student to only take those modules in the foundational course which the student failed.

The proposed composition of the IoT TP modules is discussed in greater details in subsequent Sections 3-5.

Foundation IoT Certificate



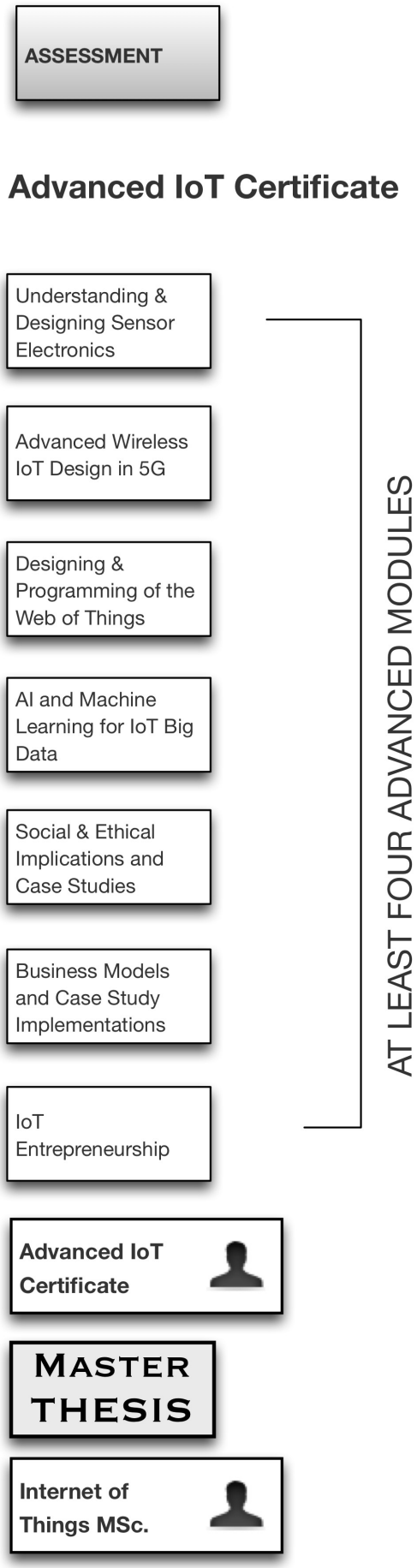


Figure 1. IoT Training Programme Scheme.

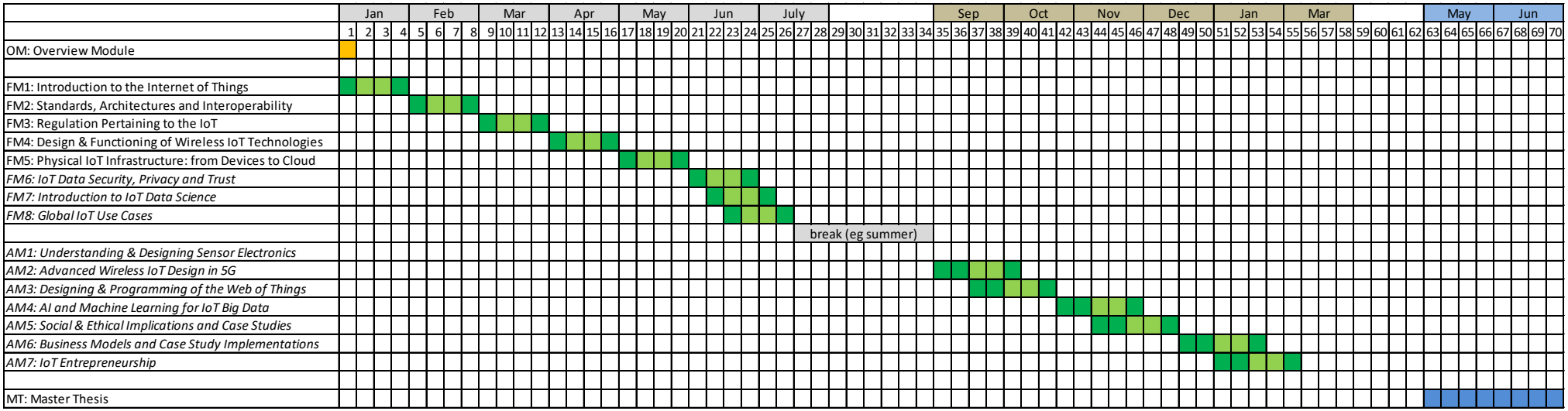


Figure 2. Approximate Gantt chart of the IoT TP. Important to note is that the first and last weeks of each module generally require physical presence and/or some form of increased interaction where likely many agendas need to be aligned. It is therefore important to keep these weeks orthogonal and not double schedule them. In the Gantt they are marked in dark green and at any week only 1 dark green should be present. The light green are self study and the students should be able to study in parallel at their own pace.

2.3 COURSE DELIVERY OPTIONS

The IoT TP structure is presented in Figure 1 and a suggestion on the timing Gantt in Figure 2. It is based on the assumption that Foundation modules will be primarily classroom driven, with face-to-face tuition, whereas Advanced modules could rely primarily on e-learning including some real-time, web-based seminars with experienced tutors to introduce the subjects, set a structure for the module, present best-practice case studies and set challenges for the students. The emphasis would be on actively teaching the well-established general subjects (Foundation modules) in classroom situations, drawing on pre-prepared presentations and reference materials, while the Advanced modules could rely more on self-paced e-learning, including in-depth research and study of specialized literature sources (albeit some instructor-led teaching is required due to the depth of the topic). The flexibility of Advanced modules oriented toward instructor-led self-study would be especially useful if the student's organization requires some special type of knowledge in a given subject.

Consequently, all modules might benefit from exploiting different delivery modes adapted by the tutor. For example, the time allocated to a module might be divided between:

- Classroom teaching and physically attended seminars and workshops.
- Case studies and practical exercises which should be included in all modules.
- Instructor-led remote lectures (live or pre-recorded).
- Self-study of textbooks and reference material.

Classroom instruction could be coordinated by the ITU Academy and conducted at ITU Centres of Excellence or other partner institutions.

2.4 PARTNER INSTITUTIONS

The ITU Academy should become a convenient coordinating point for devising and then implementing the IoT TP. International partners would be involved in preparing teaching content, decide how and what to test for in the certification procedure, design entry-level examinations that could confer academic credit for work experience, and eventually determine how to staff, deliver and manage the training programme.

Suitable institutional partners could be found among the following categories:

- ITU BDT, together with the ITU Academy, as coordinator;
- ITU-T and its study groups (e.g. those dealing with relevant technological standards);
- Organizations participating in the running of the ITU Centres of Excellence (CoEs) in various regions;
- Centres of Excellence in IoT worldwide (such as the CoE in IoT in Rwanda, the CoE in IoT in Colombia, etc);
- Academic members of the ITU; and
- Universities and Research Centres.

All potential partners should be consulted in order to gauge their interest in an IoT TP, both with regard to the possibility of their participating in training and with regard to the potential demand for certified specialists. The level of demand will influence the number of students

accepted onto the programme, which will in turn influence the budget and staffing requirements. These consultations will provide a better understanding of the types of institution that are interested in participating and their level of engagement, as well as the overall scale of the undertaking, which will help in forming a consortium.

Another important consideration in terms of support and participation should be the establishment of a pool of well-qualified IoT experts. These experts may be involved first of all in the process of developing the teaching content and assessment exams; some may continue their engagement in the delivery of the classroom-based modules and remote tutoring of students, as well as supervision of their progress and eventual Master's thesis.

3 OVERVIEW MODULE

The Overview Module that precedes the course structure shown in Figure 1 is described in this section. This introductory Overview Module would expose the structure of the overall IoT Training Programme along with a detailed description of the modules, their content, their rational as well as their assembly to yield the two degree options. This is a mandatory module which explains the structure and the content of each of the subsequent modules of the three development stages. It is important for students to take this module to understand the background and rational of the choice of modules.

Notably, the rational which needs to be conveyed is due to an underlying learning process. The module composition and structure, which will be introduced and discussed during the opening overview module, is as follows:

- OM: Overview Module

- FM1: Introduction to the Internet of Things
- FM2: Standards, Architectures and Interoperability
- FM3: Policies and Regulations Pertaining to the IoT
- FM4: Design & Functioning of Wireless IoT Technologies
- FM5: Physical IoT Infrastructure and Network Planning: from Devices to Cloud
- *FM6*: IoT Data Security, Privacy and Trust
- *FM7*: Introduction to IoT Data Science
- *FM8*: Global IoT Use Cases

- *AM1*: Understanding & Designing Sensor Electronics
- *AM2*: Advanced Wireless IoT Design in 5G
- *AM3*: Designing & Programming of the Web of Things
- *AM4*: AI and Machine Learning for IoT Big Data
- *AM5*: Social & Ethical Implications and Case Studies
- *AM6*: Business Models and Case Study Implementations
- *AM7*: IoT Entrepreneurship

- MT: Master Thesis

PROPOSED DELIVERY MODE AND DURATION

This module is a “warm-up” for the overall TP on IoT. It ought to be be implemented as a 1-day training course or taken by the student as an on-line web-based training course with examination via an automatically marked questionnaire. The overall duration of this session should be rather short (e.g. 1-2h) and delivered by an enthusiastic teacher who can set the tone for the entire IoT TP.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should demonstrate an understanding of the overall structure of the course. They should be able to make a knowledgeable choice between the

two study options. They ought to understand the flow of the modules in each option, and the expected learning outcomes.
The test at the end of this module does not have to be compulsory and it should pertain to questions addressing the structure and thereby underpin that students have reflected on the actual choice of modules. This may prove vital to avoid future misunderstandings regarding content, workload and outcomes.

STUDY RESOURCES

There is no mandatory study list but prospective students are encouraged to read documents which underpin the importance of the emerging Internet of Things, and the underlying technical components as well as major challenges. Examples of such a list are:

- Morgan, J., 2014. **A simple explanation of 'the internet of things'.** Forbes**.**
- Postscapes.com, 2017. **An Internet of Things. Some example applications**. http://www.postscapes.com/internet-of-things-examples. Accessed 30 Mar. 2017.
- Cohodas, M., 2014. **The Internet of Things: 7 Scary Security Scenarios**. http://ubm.io/1xXSju0. Accessed 30 Mar. 2017.

4 FOUNDATION MODULES

The Foundation Modules that fit into the course structure shown in Figure 1 are described in this section. These modules would cover the basics of the Internet of Things and lay the foundation for the Advanced Modules and the subsequent Master Thesis. The level of detail is such that the students will be familiar with all the relevant concepts, even though they may not yet be able to carry out a full IoT systems design. Note that FM1-FM5 are compulsory and only one (at least one) from FM6-FM8 needs to be taken so that a credit of at least 30 ECTS is obtained.

4.1 FOUNDATION MODULE 1: INTRODUCTION TO THE INTERNET OF THINGS

This is the first of five obligatory modules in the IoT TP as it introduces the whole area of the Internet of Things and explains its relevance and importance. This background will be instrumental for the student to undertake the other modules successfully, and attendance is thus mandatory.

This foundational module should cover the following subjects and concepts:

- What is the history of the Internet of Things?
- Why is it a concept more than 30 years old but only starts growing now?
- Understand the IoT, the Industrial IoT (IIoT) and the 4th Industrial Revolution
- What are the massive opportunities IoT offers?
- What is the likely societal impact, pros and cons?
- Important challenges which need to be addressed
- The role of the regulator and policy makers
- Selected use cases
- Importance of the right choice of technology
- Exercise to participate in an IoT related international event or similar.

PROPOSED DELIVERY MODE AND DURATION

This module will set the stage and context for the rest of the IoT TP teaching. It is therefore important to start it on a high note with carefully orchestrated instructor-led teaching, e.g. as a full-time, five-days a week, lecture-based classroom presentation. This could be followed by three weeks of instructor-led e-learning with self-study of reference materials (primary documents whenever possible). At the end of the final week, an interactive seminar should be held to enable students to strengthen their knowledge and understanding by discussing and resolving problems based on real-life situations.

It would also be useful if students were required as part of completing this module to attend in person some IoT-related international events (seminar, workshop or policy-making conference) of which several are organised by the ITU Centres of Excellence. Students ought to choose a suitable event themselves, in consultation with their employer organization, subject to approval by the module instructor or course coordinator. They should then feedback in the interactive session about the event and how it correlates to the learning material provided in this first module.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should demonstrate an understanding of the overall scope and objectives of the Internet of Things. They ought to understand the challenges, opportunities, mistakes made, and value chain as well as the truly complex stakeholder system. The learners ought to understand how policy makers and regulators can make a difference– topics which will be covered in the more advanced modules.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test, 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module include selected parts of the documents outlined in Section 1.2.1, as well as the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters should be given for read given the sheer amount of material.
- Rose, K., Eldridge, S. and Chapin, L., 2015. **The internet of things: An overview**. The Internet Society (ISOC), pp.1-50.
- ITU, 2012. **Recommendation Y.2060: Overview of the Internet of Things.** https://www.itu.int/rec/T-REC-Y.2060-201206-I. Accessed 7 Apr. 2017.
- Accenture, 2015. **Accenture's View on the IoT and the Industrial Internet of Things (IIoT).** http://www.accenture.com/iot. Accessed 30 Mar. 2017.

- World Economic Forum, 2015. **Industrial Internet of Things: Unleashing the Potential of Connected Products and Services.** http://reports.weforum.org/industrial-internet-of-things/. Accessed 30 Mar. 2017.
- Oro, D., 2016. **10 Case Studies for the Industrial Internet of Things.** http://www.iotcentral.io/blog/10-case-studies-for-the-industrial-internet-of-things. Accessed 30 Mar. 2017.
- Cisco, 2013. **Internet of Things. White Papers and Case Studies.** http://www.cisco.com/c/en/us/solutions/internet-of-things/resources/case-studies.html. Accessed 30 Mar. 2017.
- Bahga, A. and Madisetti, V., 2014. **Internet of Things: A Hands-On Approach.** VPT.
- ITU, 2016. **Shaping smarter and more sustainable cities: Striving for sustainable development goals.** http://wftp3.itu.int/pub/epub_shared/TSB/ITUT-Tech-Report-Specs/2016/en/flipviewerxpress.html. Accessed 7 Apr. 2017.
- ITU, 2016. **Implementing ITU-T International Standards to Shape Smart Sustainable Cities: The Case of Dubai.** http://www.itu.int/en/publications/Documents/tsb/2016-DubaiCase/index.html. Accessed 7 Apr. 2017.
- ITU and UNECE, 2016. **United for Smart Sustainable Cities: Striving for Sustainable Development Goals.** http://wftp3.itu.int/pub/epub_shared/TSB/2016-ITUT-SSC-Brochure/en/index.html#p=1**.** Accessed 7 Apr. 2017.

In addition, students may be required to review some actual documents on IoT being prepared by the respective ITU study groups at the time of study.

4.2 FOUNDATION MODULE 2: STANDARDS, ARCHITECTURES AND INTEROPERABILITY

This is the second of the compulsory modules in the IoT TP. It deals with the important topic of interoperability, standardised architectures and important standards defining organisations. It is instrumental in understanding the core technical functioning of the Internet of Things as it enables the much needed data horizontality. This module is thus instrumental for the student to undertake the other modules successfully and understand the overall technical concept of the IoT; attendance is thus mandatory.

This foundational module should cover the following subjects and concepts:

- Role of standards and standards defining organisations (SDOs)
- Short & long-term pros and cons of standards and SDOs
- Most important SDOs pertinent to the IoT
- Inter-relation between these SDOs and possible gap analysis
- Deep-dive into IEEE, IETF, 3GPP, ITU and other important SDOs
- Resulting communications and data architectures, based on SDOs
- Most important architecture elements, such as the communications architecture
- Sufficiently detailed understanding of the architecture element functionalities
- Deep-dive into the importance of the Internet Protocol (IPv6)
- Exploring interoperability within SDO-proposed architectures
- Exploring interoperability between architectures of different SDOs

- Deep-dive on interoperability, notably the required protocols
- Develop and explore scenario where the IoT would not be standardised, and contrast to a standardised IoT ecosystem

PROPOSED DELIVERY MODE AND DURATION

This module ought to start with instructor-led teaching, i.e. as a full-time, five days a week lecture-based class. This is then followed by three weeks of instructor-supported e-learning and self-study of reference materials. During the self-study period the students should also be given one individual/group assignment to prepare a module project exploring a scenario in their respective country assuming the IoT is not standardised and contrast it to the enabling opportunities of a standardised IoT ecosystem.

In the final of the four weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their projects on the standardisation issues for discussion with their instructor and peers.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should demonstrate an understanding of standards and standards defining organisations. They ought to understand the SDO landscape and how they inter-relate, as well as part of their recent development history. The learners ought to understand basic notions of architecture design and related inter-operability challenges and opportunities.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to the standardisation of the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters related to standardisation should be given for read given the sheer amount of material.
- Rs Components, 2015. **11 Internet of Things (IoT) Protocols You Need to Know About.** https://www.rs-online.com/designspark/eleven-internet-of-things-iot-protocols-you-need-to-know-about. Accessed 30 Mar. 2017.
- IEEE.org, 2017. **IEEE Internet of Things**. http://iot.ieee.org/. Accessed 30 Mar. 2017.

- Anton-Haro, C. and Dohler, M. eds., 2014. **Machine-to-machine (M2M) communications: architecture, performance and applications**. Elsevier.
- Postscapes.com, 2017. **IoT Standards and Protocols.** http://www.postscapes.com/internet-of-things-protocols/. Accessed 30 Mar. 2017.
- Keränen, A. and Bormann, C., 2016. **Internet of Things: Standards and Guidance from the IETF.** IETF Journal, 11 (3).
- ITU, 2016. **Shaping smarter and more sustainable cities: Striving for sustainable development goals.** http://wftp3.itu.int/pub/epub_shared/TSB/ITUT-Tech-Report-Specs/2016/en/flipviewerxpress.html. Accessed 7 Apr. 2017.
- ITU, 2016. **Implementing ITU-T International Standards to Shape Smart Sustainable Cities: The Case of Dubai.** http://www.itu.int/en/publications/Documents/tsb/2016-DubaiCase/index.html. Accessed 7 Apr. 2017.
- ITU and UNECE, 2016. **United for Smart Sustainable Cities: Striving for Sustainable Development Goals.** http://wftp3.itu.int/pub/epub_shared/TSB/2016-ITUT-SSC-Brochure/en/index.html#p=1. Accessed 7 Apr. 2017.
- ITU and WTSA, 2016. **Resolution 98 – Enhancing the standardization of Internet of things and smart cities and communities for global development.** https://www.itu.int/dms_pub/itu-t/opb/res/T-RES-T.98-2016-PDF-E.pdf Accessed 7 Apr. 2017.

In addition, students may be required to review some actual documents on IoT being prepared by the respective ITU study groups at the time of study.

4.3 FOUNDATION MODULE 3: POLICIES AND REGULATIONS PERTAINING TO THE IOT

This is the third of the compulsory modules in the IoT TP which focuses on the important topic of regulation in the context of the Internet of Things. Notably, focus here is on spectrum, wireless communications and data regulations. It is important to the work of the ITU and in understanding the wider context of the Internet of Things. This module is therefore also instrumental for the student to undertake and attendance is thus mandatory.

This foundational module should cover the following subjects and concepts:

- Importance of national and international regulation, with pros and cons
- Policy frameworks to enable IoTs
- National and international legislations impacting IoT
- ITU organization and its regulatory processes
- How does regulation work operationally, and how is it imposed?
- IoT spectrum regulation, with emphasis on spectrum availability internationally
- IoT spectrum, with emphasis on spectrum usage
- Near-term and future developments on spectrum at international level, including discussions on WRC
- Regulation related to wireless communications and electronic devices in general, and how they impact the usage of the IoT
- Regulation on street furniture usage where IoT devices are typically mounted
- General regulatory issues around data, depending on the regions of Europe, Americas, Asia, etc

- Data regulation and data protection laws specifically pertinent to the Internet of Things
- Important regulatory issues when designing end-to-end IoT systems which include devices in the field, wireless, storage and processing of data
- Cross-sectoral coordination amongst policy makers and regulators
- IoT numbering and addressing
- Roaming in IoT

PROPOSED DELIVERY MODE AND DURATION

This module ought to start with instructor-led teaching, i.e. as a full-time, five days a week lecture-based class. This is then followed by three weeks of instructor-supported e-learning and self-study of reference materials. During the self-study period the students should also be given one group assignment to prepare a module project related to regulation of the respective country they are in. Students should also become familiar with ITU's study groups. This is to maximise the learning experience and also make the work pertinent to the national role of the student.

Again, in the last of the four weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their projects on regulation for discussion with their instructor and peers.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should demonstrate an understanding of the importance and functioning of regulation; and why it is particularly important in the context of wireless systems. They also ought to comprehend the specific regulatory issues pertaining to the use of electronic IoT devices, communicating over a wireless spectrum, and storing/ processing data in a cloud. Important current and upcoming regulatory laws ought to be learned and understood by the student.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. Again, the latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to regulation in the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters related to regulation should be given for read given the sheer amount of material.

- Brown, I., 2015. **GSR Discussion Paper: Regulation and the Internet of Things**. https://www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2015/Discussion_papers_and_Presentations/GSR_DiscussionPaper_IoT.pdf. Accessed 7 Apr. 2017.
- Sengul, C., 2016. **Privacy in the Internet of Things: Regulation vs Innovation.** http://iot.ieee.org/newsletter/september-2016/privacy-in-the-internet-of-things-regulation-vs-innovation.html. Accessed 30 Mar. 2017.
- Scl.org, 2016. **Regulation of the Internet of Things.** http://www.scl.org/site.aspx?i=ed47967. Accessed 30 Mar. 2017.
- Mazar, H., 2009. **An analysis of regulatory frameworks for wireless communications, societal concerns and risk: the case of Radio Frequency (RF) allocation and licensing**. Universal-Publishers.
- Loy, M., Karingattil, R. and Williams, L., 2005. **ISM-band and short range device regulatory compliance overview**. Texas Instruments.
- ITU, 2016. **Internet of Things: Policy and Regulatory Enablers.** https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2016/Dec-2016-IoT/IoTtraining/IoT%20Enabling%20Environment.pdf. Accessed 7 Apr. 2017.
- Internet Society, 2016. **The Internet of Things. An Internet Society Public Policy Briefing**. http://www.internetsociety.org/policybriefs/iot. Accessed 30 Mar. 2017.
- European Commission, 2017. **IoT Privacy, Data Protection, Security.** http://ec.europa.eu/information_society/newsroom/cf/document.cfm?action=display&doc_id=1753. Accessed 30 Mar. 2017.
- ITU, 2016. **Shaping smarter and more sustainable cities: Striving for sustainable development goals.** http://wftp3.itu.int/pub/epub_shared/TSB/ITUT-Tech-Report-Specs/2016/en/flipviewerxpress.html. Accessed 7 Apr. 2017.
- ITU, 2016. **Implementing ITU-T International Standards to Shape Smart Sustainable Cities: The Case of Dubai.** http://www.itu.int/en/publications/Documents/tsb/2016-DubaiCase/index.html. Accessed 7 Apr. 2017.
- ITU and UNECE, 2016. **United for Smart Sustainable Cities: Striving for Sustainable Development Goals.** http://wftp3.itu.int/pub/epub_shared/TSB/2016-ITUT-SSC-Brochure/en/index.html#p=1. Accessed 7 Apr. 2017.

4.4 FOUNDATION MODULE 4: DESIGN, PLANNING & FUNCTIONING OF WIRELESS IOT TECHNOLOGIES

This is the fourth of the compulsory modules in the IoT TP which focuses the design of wireless IoT technologies. It is an important topic in that tethered IoT systems would not scale but wireless designs proved to be extremely difficult. The focus of the module will be on short range wireless IoT systems, as well as emerging low power wide area networks (LPWANs) and cellular narrowband IoT (NB-IoT) technologies. Again, this module is mandatory for all students.

This foundational module should cover the following subjects and concepts:

- Basic principles of wireless, including the importance of wireless IP, which underpins the functioning of discussed systems

- Overview of the different connectivity families (Zigbee, Wifi, LPWANs, 4G, etc) and a detailed discussion on their pros and cons, as well as responsible SDOs
- Detailed discussion on Zigbee and derivatives; explore reasons why technology has not delivered as promised
- Detailed discussion on the emerging low-power Wifi (LP-Wifi) technology
- Detailed discussion on emerging LPWANs, such as Sigfox, LoRa, etc
- Detailed discussion on cellular 3GPP technologies, such as EC-GSM, LTE-M and NB-IoT
- Exposure of the future roadmap of these technologies
- Network planning for IoTs
- Students should do one example where different technologies are used, e.g. instrumenting a Smart City with 10,000 IoT sensors

PROPOSED DELIVERY MODE AND DURATION

This module ought to start with instructor-led teaching, i.e. as a full-time, five days a week lecture-based class. This is then followed by three weeks of instructor-supported e-learning and self-study of reference materials. During the self-study period the students should also be given one group assignment to prepare a module project comparing the costs and capabilities of the different technologies in the context of e.g. a Smart City. This is to maximise the learning experience and also make the work pertinent to the national role of the student.

Again, in the last of the four weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their learnings on the technology dimensioning of a specific usecase for discussion with their instructor and peers.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should be familiar with the landscape of available wireless IoT connectivity technologies. They also ought to comprehend the pros and cons of each technology family, and appreciate the different capabilities of short-range/long-range as well as cellular technology families. Importantly, related to the latter, students should have a sufficient understanding of the emerging cellular IoT connectivity solutions, such as enhanced coverage GSM (EC-GSM), LTE-M and NB-IoT as they will play an important role in the future IoT connectivity landscape globally (note that a very detailed exposure of this specific topic is done in the Advanced Module #2).

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. Again, the latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to wireless systems underpinning the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters related to wireless systems should be given for read given the sheer amount of material.
- Palattella, M.R., Dohler, M., Grieco, A., Rizzo, G., Torsner, J., Engel, T. and Ladid, L., 2016. **Internet of things in the 5G era: Enablers, architecture, and business models**. IEEE Journal on Selected Areas in Communications, 34(3), pp.510-527.
- Palattella, M.R., Accettura, N., Vilajosana, X., Watteyne, T., Grieco, L.A., Boggia, G. and Dohler, M., 2013. **Standardized protocol stack for the internet of (important) things**. IEEE Communications Surveys & Tutorials, 15(3), pp.1389-1406.
- Bachir, A., Dohler, M., Watteyne, T. and Leung, K.K., 2010. **MAC Essentials for Wireless Sensor Networks**. IEEE Communications Surveys & Tutorials, 12 (2), pp. 222-248. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5451759 Accessed 7 Apr. 2017.
- Anton-Haro, C. and Dohler, M. eds., 2015. **Machine-to-machine (M2M) communications: architecture, performance and applications**. Elsevier.
- Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M. and Ayyash, M., 2015. **Internet of things: A survey on enabling technologies, protocols, and applications**. IEEE Communications Surveys & Tutorials, 17(4), pp.2347-2376.
- Sheng, Z., Yang, S., Yu, Y., Vasilakos, A., Mccann, J. and Leung, K., 2013. **A survey on the ietf protocol suite for the internet of things: Standards, challenges, and opportunities**. IEEE Wireless Communications, 20(6), pp. 91-98.
- Gupta, A. and Jha, R.K., 2015. **A survey of 5G network: Architecture and emerging technologies**. IEEE access, 3, pp.1206-1232.
- ITU, 2016. **Shaping smarter and more sustainable cities: Striving for sustainable development goals.** http://wftp3.itu.int/pub/epub_shared/TSB/ITUT-Tech-Report-Specs/2016/en/flipviewerxpress.html. Accessed 7 Apr. 2017.
- ITU, 2016. **Implementing ITU-T International Standards to Shape Smart Sustainable Cities: The Case of Dubai.** http://www.itu.int/en/publications/Documents/tsb/2016-DubaiCase/index.html. Accessed 7 Apr. 2017.

4.5 FOUNDATION MODULE 5: PHYSICAL IOT INFRASTRUCTURE: FROM DEVICE TO CLOUD

This is the fifth of the compulsory modules in the IoT TP which focuses the design of the physical entities of an end-to-end IoT system. It includes devices (sensors, etc), repeaters/gateways, connectivity networks and cloud infrastructures. Given the importance of the design of an end-to-end system, this module is mandatory for all students.

This foundational module should cover the following subjects and concepts:

- Different type of IoT devices, such as sensors, actuators, drones and robots
- Specialised IoT devices, such as smart thermostats, autonomous cars, etc

- Usage of repeaters/gateways to connect these devices; pros & cons, and lessons learnt from existing deployments
- IP networks and how to ensure secure end-to-end connectivity from devices to the cloud
- Detailed discussions on cloud infrastructures and the various available embodiments
- Understand difference between private servers, centralised cloud, distributed cloud, edge-processing infrastructure, and hybrid embodiments
- Challenges and opportunities of designing systems end-to-end
- Dimensioning example comparing cloud-only versus edge-processing + cloud solution, ideally applied to a real-world scenario such as prior Smart City example

PROPOSED DELIVERY MODE AND DURATION

This module also ought to start with instructor-led teaching, i.e. as a full-time, five days a week lecture-based class. This is then followed by three weeks of instructor-supported e-learning and self-study of reference materials. During the self-study period the students should also be given one group assignment to prepare a module project dimensioning and infrastructure project with emphasis of cloud-only versus edge-processing & cloud approaches. This is to maximise the learning experience of the student.

Again, in the last of the four weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their learnings on the cloud/edge-cloud technology dimensioning of a specific, and ideally national, usecase for discussion with their instructor and peers.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should be familiar with the end-to-end technology composition ranging from devices in the field to the cloud infrastructure needed to handle the IoT data. Students should obtain a detailed understanding of the challenges of designing end-to-end systems. Of importance is to understand the possibilities and advantages of emerging edge-cloud approaches which are of particular importance to IoT systems.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. Again, the latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to IoT devices and clouds,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific

chapters related to IoT end-to-end infrastructure should be given for read given the sheer amount of material.

- Buyya, R. and Dastjerdi, A.V. eds., 2016. **Internet of Things: Principles and paradigms**. Elsevier.
- Vasseur, J.P. and Dunkels, A., 2010. **Interconnecting smart objects with ip: The next internet**. Morgan Kaufmann.

4.6 FOUNDATION MODULE 6: IOT DATA SECURITY, PRIVACY AND TRUST

This is the sixth module, and one of the three optional modules in the IoT TP. This module focuses on the important issues IoT data & systems security; data privacy and system trust. It underpins more ethical and societal issues an IoT designer is likely to encounter. Since it is optional, the module ought to be taken by students who are interested in security, privacy and trust in the context of the Internet of Things.

This foundational module should cover the following subjects and concepts:

- Relationship and inter-dependencies between security, privacy and trust
- High-level security concepts and approaches, including the generally used security taxonomy
- Discussion of IoT usecases where security is absolutely instrumental; include examples of securing downstream communications such as for drones/robots/actuators
- Overview of cryptography, ciphers, hashes, etc adapted to embedded systems, such as the Internet of Things
- System security design aspects, such as key refresh, secure device management, etc
- End-to-end data security approaches, and how they work with cloud-based systems
- Detailed discussion on the socially accepted notion of privacy, and how it may differ between countries/cultures
- Most important privacy laws as well as national/international regulations on privacy
- Why privacy is particularly challenging in the context of the IoT?
- Discussion around trust in IoT systems
- How privacy and security enable trust in IoT, and thus the uptake thereof
- Give students a specific usecase and ask them to dimension security and discuss privacy and trust implications

PROPOSED DELIVERY MODE AND DURATION

This module also ought to start with instructor-led teaching, i.e. as a full-time, five days a week lecture-based class. This is then followed by three weeks of instructor-supported e-learning and self-study of reference materials. During the self-study period the students should also be given one group assignment to prepare a module project with focus on a specific usecase and ask the student(s) to dimension security and discuss privacy and trust implications (in the national context). This is to maximise the learning experience of the student, and also position the design with regards to national privacy regulations.

Again, in the last of the four weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their learnings on the security/privacy/trust trade-offs in their national settings, for discussion with their instructor and peers.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should be familiar with the complex interplay between security, privacy and trust in the context of the IoT. Students should obtain a detailed understanding of security design approaches and why they matter particularly in the context of the IoT. Privacy laws and regulations ought to be appreciated, particularly the upcoming European laws on data protection which comes into force in May 2018.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. Again, the latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to IoT security/privacy/trust,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters related to security/privacy/trust in IoT should be given for read given the sheer amount of material.
- Barki, A., Bouabdallah, A., Gharout, S. and Traoré, J., 2016. **M2M security: challenges and solutions**. IEEE Communications Surveys & Tutorials, 18(2), pp.1241-1254.
- Zhang, K., Liang, X., Lu, R. and Shen, X., 2014. **Sybil attacks and their defenses in the internet of things**. IEEE Internet of Things Journal, 1(5), pp.372-383.
- Russell, B. and Van Duren, D., 2016. **Practical Internet of Things Security**. Packt Publishing Ltd.

- Hu, F., 2016. **Security and Privacy in Internet of Things (IoTs): Models, Algorithms, and Implementations**. CRC Press.
- Balte, A., Kashid, A. and Patil, B., 2015. **Security Issues in Internet of Things (IoT): A Survey**. International Journal of Advanced Research in Computer Science and Software Engineering, 5(4).

4.7 FOUNDATION MODULE 7: INTRODUCTION TO IOT DATA SCIENCE

This is the seventh module, and another of the three optional modules in the IoT TP. This module focuses on the issues of IoT data science, notably, Big Data analytics approaches and typical signal processing as well as programing packages used. Since it is optional, the module ought to be taken by students who are interested in big data analytics and data science in the context of the Internet of Things.

This foundational module should cover the following subjects and concepts:

- Taxonomy on the types of data generally available, and the type of data pertinent to the IoT
- Introduction to data science, what it involves and what not
- Fundamentals and basics of underlying signal processing enablers
- Data cleaning and data conditioning approaches
- Linear data science methods, such as linear regression analysis, etc
- Application of linear methods to IoT data examples
- Fundamentals of machine learning and other non-linear approaches
- Application of machine learning to IoT data examples
- Introduction to deep-learning, and discussion of pros and cons
- Future applications of deep learning in the context of the IoT
- Overview of available data science platforms, open source solutions, etc
- Application of knowledge to real-world IoT case studies with real IoT data

PROPOSED DELIVERY MODE AND DURATION

This module also ought to start with instructor-led teaching, i.e. as a full-time, five days a week lecture-based class. This is then followed by three weeks of instructor-supported e-learning and self-study of reference materials. During the self-study period the students should also be given one group assignment to prepare a module project dealing with data science analysis of IoT data from a real-world IoT case study, ideally from or within the context of the country the student is based. One could envisage that the student ought to obtain that data by reaching out locally to IoT companies, cities, etc. This is to maximise the learning experience of the student, and also position the design with regards to national IoT ecosystem.

Again, in the last of the four weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their learnings on the data science project in their national settings, for discussion with their instructor and peers.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should be familiar with the exciting and growing field of data science and know how to apply it to IoT usecases. Students should obtain a detailed understanding of the different data science approaches, including linear and non-linear algorithms as well as deep-learning approaches. The student should also have an appreciation of available open-source data science platforms and algorithms, allowing to address future usecases with these available toolboxes.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. Again, the latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to IoT data and data analytics,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters related to data in IoT should be given for read given the sheer amount of material.
- Shan, C., H. Wang, M. Song and W. Chen, 2017. **The Data Science Handbook: Advice and Insights from 25 Amazing Data Scientists.** http://www.thedatasciencehandbook.com/. Accessed 30 Mar. 2017.

- Schutt, R. and O'Neil, C., 2013. **Doing data science: Straight talk from the frontline**. O'Reilly Media, Inc.
- Haider, M., 2015. **Getting Started with Data Science: Making Sense of Data with Analytics**. IBM Press.

4.8 FOUNDATION MODULE 8: GLOBAL IOT USE CASES

This is the eighth and last foundation module, and the third of the three optional modules in the IoT TP. This module introduces the student to some of the most pertinent use cases. It will also discuss real-world case studies, along with the lessons learned. Since it is optional, the module ought to be taken by students who are interested in more practical and business issues of the Internet of Things.

This foundational module should cover the following subjects and concepts:

- Business models in the IoT
- Return of investment (ROI) calculus for typical IoT applications
- IoT market & usecase taxonomy
- most important IoT industry usecases
- emerging IoT consumer usecases
- discussion on the timing of industrial vs consumer deployments
- overview of real-world case studies, such as Smart City deployments
- summary of most important lessons learnt from these rollouts
- societal and ethical impact of these projects
- student project on important national IoT project

PROPOSED DELIVERY MODE AND DURATION

This module could be a little shorter from a teaching point of view but should definitely start with instructor-led teaching, i.e. as a full-time, e.g. three days a week lecture-based class. This is then followed by two weeks of instructor-supported e-learning and self-study of reference materials.

In the fourth week, the students should be given one group assignment to prepare a module project dealing with a national rollout of IoT projects (either industrial or successful consumer deployments). One could envisage that the student ought to obtain that data by reaching out locally to IoT companies, cities, etc. This is to maximise the learning experience of the student, and also position the design with regards to national IoT ecosystem. Students should then present their learnings on the project for discussion with their instructor and peers.

Total duration: four weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should be familiar with the market and business potential of the IoT, notably business models and ROI calculus. Based on that, the most important use cases ought to be appreciated by the student, both from an industrial as well as consumer point of view. It is also instrumental that the students appreciate current real-world rollouts, particularly in their national settings.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. Again, the latter is very important to assess their independent thinking in the space.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to IoT usecases and rollouts,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters related to IoT usecases and rollouts should be given for read given the sheer amount of material.
- Zanella, A., Bui, N., Castellani, A., Vangelista, L. and Zorzi, M., 2014. **Internet of things for smart cities**. IEEE Internet of Things journal, 1(1), pp.22-32.
- Gea, T., Paradells, J., Lamarca, M. and Roldan, D., 2013, July. **Smart cities as an application of internet of things: Experiences and lessons learnt in Barcelona**. In Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2013 Seventh International Conference on (pp. 552-557). IEEE.
- Cheng, B., Longo, S., Cirillo, F., Bauer, M. and Kovacs, E., 2015. **Building a big data platform for smart cities: Experience and lessons from Santander**. In Big Data (BigData Congress), 2015 IEEE International Congress on (pp. 592-599). IEEE.
- ITU, Study Group 2, Question 1/2 (Creating the smart society: Social and economic development through ICT applications). https://www.itu.int/net4/ITU-D/CDS/sg/blkmeetings.asp?lg=1&sp=2014&blk=14211 Accessed on 14 Jun. 2017, case studies based on contributions from ITU members are presented.

5 ADVANCED MODULES

The Advanced Modules that fit into the course structure shown in Figure 1 are described in this section. These modules cover more advanced topics of the Internet of Things and lay the foundation for an in-depth knowledge as well as strong Master project in the area. The level of detail is such that the students will become experts or near-experts in all the relevant concepts, allowing them to carry out a full IoT systems design. It is important to note that at least four of the seven modules AM1-AM7 need to be taken so that a credit of at least 30 ECTS is obtained. Only with the attained credits in the advanced level can the student proceed to the Master Thesis.

5.1 ADVANCED MODULE 1: UNDERSTANDING & DESIGNING SENSOR ELECTRONICS

This is the first optional module in the advanced series in the IoT TP. It deals with the challenging topic of sensor electronics and embedded design. The topics covered here range from the actual sensing design (including MEMS) to the design of an entire transducer system able to sense, process and transmit data. The course will also deal with the advanced topics of actuators, robots and drones. This module ought to be taken by students interested in hardware, embedded designs and actuators.

This advanced module should cover the following subjects and concepts:

- overview of the components of a modern IoT device, including:
  - various transducer approaches
  - electronic components
  - mechanical components
  - batteries
  - radios
- very detailed examination of available transducers today, i.e. electronic, mechanical, chemical and many other sensing approaches
- mechanisms of how sensed signals are translated to electronic signals, and how they are calibrated
- in-depth exposure on MEMS and high-level introduction to NEMS
- discussion on other classes of actuators, including drones and robots
- detailed examination of micro-controllers, i.e. history, functioning and design
- introduction to embedded memory and data storage in IoT devices
- enabling hardware security and other advanced security designs
- embedded battery design, and control electronics for batteries
- revisit of radio technologies and impact on battery lifetime/management
- open hardware and open source electronic design tools
- students ought to do a high level design for one specific IoT application

PROPOSED DELIVERY MODE AND DURATION

For the advanced modules, a more in-depth and lengthier mentoring is required. We envisage a carefully orchestrated instructor-led teaching which is full-time, five-days a week, lecture-based classroom presentation, and over the duration of 1.5-2 weeks. This ought to be followed by 2.5-3 weeks of instructor-led e-learning with self-study of reference materials.

During that self-study period the students should also be given one group assignment to prepare a module project with focus on the design of an IoT device for an application which is pertinent to their national setting. This is to maximise the learning experience of the student, and also position the design with regards to national ecosystems.

In the last of the five weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their learnings on the design of their IoT device, for discussion with their instructor and peers.

Total duration: five weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students should be experts in the understanding of the functioning of IoT devices from an embedded hardware and software point of view, and be able to reflect on the requirements for a viable design. Students should have a strong knowledge of MEMS and a good understanding of the potential of NEMS. Students should be able to design IoT devices given a certain set of application requirements.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space. Both tests should be substantially more in-depth than the tests designed for the foundational modules.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to devices and device design in the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters on IoT devices should be given for read given the sheer amount of material.
- ITRS, 2015. **ITRS Report: International Technology Roadmap for Semiconductors.** http://www.itrs2.net/itrs-reports.html Accessed 30 Mar. 2017.
- Fisher, R., Ledwaba, L., Hancke, G. and Kruger, C., 2015. **Open hardware: A role to play in wireless sensor networks?**. Sensors, 15(3), pp. 6818-6844.

5.2 ADVANCED MODULE 2: ADVANCED WIRELESS IOT DESIGN IN 5G

This is the second optional module in the advanced series in the IoT TP. It deals with the design of wireless IoT systems in the context of 5G; and is substantially more in-depth than the Foundational Module 4. Focus of this advanced module is truly on cellular 3GPP technologies, history, opportunities and challenges. It lays open the fundamental design challenges of enabling a low complexity and embedded IoT system through the latest 4G+ and 5G 3GPP

technologies. This module ought to be taken by students interested in cellular technologies and 5G.

This advanced module should cover the following subjects and concepts:

- in-depth discussion on the history and functioning of 3GPP, including working groups, working items and releases
- history of telemetry and connected devices (not humans) in 3GPP, and the inflection point of the emergence of IP in telecoms
- introduction to machine-to-machine (M2M) and Machine-Type Communications (MTC), and their relation to the IoT
- detailed exposure of fundamentals of wireless communications, including important difference between energy and power
- in-depth discussion on the suitability of 2G, 3G, 4G, post 4G and emerging 5G systems to the connectivity of low-complexity IoT devices
- technical exposure of Enhanced Coverage GSM (EC-GSM), and latest features of R13
- in-depth technical exposure of Long Term Evolution for M2M (LTE-M), including latest features of R13
- in-depth technical exposure of Narrowband LTE (NB-LTE) in R13, and discussion on the future roadmap of that specific technology
- detailed discussions on the architecture design suitable for the IoT, including latest concepts of up/downlink decoupling
- discussion of the 5G roadmap pertinent to the Internet of Things, and the industrial IoT; possibly with application to use cases like Smart Cities
- introduction to interoperability approaches with other systems, such as Wifi or Zigbee
- one very detailed design exercise determining the optimum choice and configuration from the 3GPP radio technology families

PROPOSED DELIVERY MODE AND DURATION

For the advanced modules, a more in-depth and lengthier mentoring is required. Again, we envisage a carefully orchestrated instructor-led teaching which is full-time, five-days a week, lecture-based classroom presentation, and over the duration of 1.5-2 weeks. This ought to be followed by 2.5-3 weeks of instructor-led e-learning with self-study of reference materials.

During that self-study period the students should also be given one group assignment to prepare a module project with focus on the design of a cellular IoT system, which includes the correct choice from the given technology families, and the correct configuration of the technology.

In the last of the five weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their learnings on the design of their IoT 3GPP interface, for discussion with their instructor and peers.

Total duration: five weeks.

STUDY OBJECTIVES AND ASSESSMENT

*On completing this module, students will have gained advanced knowledge i*n the understanding of the functioning of cellular connectivity technologies geared towards low-complexity and embedded IoT devices, and be able to reflect on the requirements for analysis and design. Students should have a strong knowledge of EC-GSM, LTE-M and NB-IoT; as well as their pros & cons. The students should also have a very good understanding of the 5G development roadmap in terms of 3GPP releases.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space. Both tests should be substantially more in-depth than the tests designed for the foundational modules.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to 5G in the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters on cellular IoT should be given for read given the sheer amount of material.
- Boccardi, F., Heath, R.W., Lozano, A., Marzetta, T.L. and Popovski, P., 2014. **Five disruptive technology directions for 5G**. IEEE Communications Magazine, 52(2), pp.74-80.
- Yilmaz, T., Gokkoca, G. and Akan, O.B., 2016. **Millimetre Wave Communication for 5G IoT Applications. In Internet of Things (IoT).** In 5G Mobile Technologies, pp. 37-53. Springer International Publishing.
- Biral, A., Centenaro, M., Zanella, A., Vangelista, L. and Zorzi, M., 2015. **The challenges of M2M massive access in wireless cellular networks**. Digital Communications and Networks, 1(1), pp.1-19.

5.3 ADVANCED MODULE 3: DESIGNING & PROGRAMMING OF THE WEB OF THINGS

This is the third optional module in the advanced series in the IoT TP. It deals with the advanced topic of designing and programming IoT devices such that they are usable from the Internet and web applications. This module ought to be taken by students interested in application software design for the Internet of Things.

This advanced module should cover the following subjects and concepts:

- introduction to web programming: history, concepts and programming languages
- biggest challenges in translating web programming from typical Internet devices (computers, laptops) to very constrained IoT devices
- introduction to the most prominent IoT platform and web programming concepts and approaches
- in-depth discussion on popular IoT data formats such as JSON, XML, etc
- in-depth discussion on RESTful and related IETF protocols
- in-depth discussion on CoAP and what it means to the IoT ecosystem
- IoT system management approaches with e.g. SNMP/Netconf/Yang
- introduction to logical design languages, such as Python (data structures, control flow, classes, Django, etc)
- exposure to data analytics approaches in the IoT, such as Hadoop and others
- students should then execute specific programming examples and write IoT web applications using above-gained knowledge

PROPOSED DELIVERY MODE AND DURATION

For the advanced modules, a more in-depth and lengthier mentoring is required. Again, we envisage a carefully orchestrated instructor-led teaching which is full-time, five-days a week, lecture-based classroom presentation, and over the duration of 1.5-2 weeks. This ought to be followed by 2.5-3 weeks of instructor-led e-learning with self-study of reference materials.

During that self-study period the students should also be given one group assignment to prepare a module project with focus on programming an interesting and viable IoT web application. This is to maximise the learning experience of the student.

In the last of the five weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their programming code, web applications and discuss with their instructor and peers.

Total duration: five weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students will have gained advanced knowledge in the application design and programming for the Internet of Things, and be able to reflect on the requirements for application design. They should have an in-depth knowledge on IoT data structures (such as JSON) and IoT APIs (such as RESTful), as well as embedded application protocols (such as CoAP). They should be able to write web applications give certain design guidelines.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space. The former may include coding snippets to choose from. Both tests should be substantially more in-depth than the tests designed for the foundational modules.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to Big Data in the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters on IoT Big Data should be given for read given the sheer amount of material.
- Bahga, A. and Madisetti, V., 2014. **Internet of Things: A Hands-On Approach**. VPT.
- Shelby, Z., 2010. **Embedded web services**. IEEE Wireless Communications, 17(6).
- Bormann, C., Castellani, A.P. and Shelby, Z., 2012. **Coap: An application protocol for billions of tiny internet nodes**. IEEE Internet Computing, 16(2), pp.62-67.
- Szilagyi, I. and Wira, P., 2016, October**. Ontologies and Semantic Web for the Internet of Things-a survey**. In Industrial Electronics Society, IECON 2016-42nd Annual Conference of the IEEE, pp. 6949-6954. IEEE.
- Yassein, M.B. and Shatnawi, M.Q., 2016, September. **Application layer protocols for the Internet of Things: A survey**. In Engineering & MIS (ICEMIS), International Conference on (pp. 1-4). IEEE.
- W3.org, 2017. **Web of Things at W3C**. https://www.w3.org/WoT/. Accessed 30 Mar. 2017.
- Guinard, D. and Trifa, V., 2016. **Building the Web of Things: With examples in Node.js and Raspberry Pi**.

5.4 ADVANCED MODULE 4: AI AND MACHINE LEARNING FOR IOT BIG DATA

This is the fourth optional module in the advanced series in the IoT TP. It deals with the topic of artificial intelligence (AI) and machine learning in the context of the Internet of Things. This module ought to be taken by students interested in Big Data and underlying signal processing concepts.

This advanced module should cover the following subjects and concepts:

- overview of Big Data, it's main opportunities and challenges
- expose synergies between the IoT and Big Data
- taxonomy of the Big Data processing stream (cleaning/calibrating of data, storage, processing, displaying, etc)
- introduction to basic and more advanced signal processing algorithms which underpin Big Data algorithms

- in-depth treatment of linear big data and statistical analysis approaches, such as regression algorithms
- in-depth treatment of non-linear machine learning algorithms for e.g. clustering purposes; an example of such an algorithm is model-free reinforcement learning (Q-Learning, SARSA, etc)
- sufficiently deep treatment of modern AI approaches, such as Planning (over a large but finite state space), Deep Learning, among others
- introduction to graphical representation methodologies of Big Data
- available software packages for Big Data, AI and visualisation
- student is asked to acquire or generate large IoT data and then demonstrate the learned abilities by developing an analytical processing algorithm with an attractive visualisation; example case studies could be from national Smart Cities

PROPOSED DELIVERY MODE AND DURATION

For the advanced modules, a more in-depth and lengthier mentoring is required. Again, we envisage a carefully orchestrated instructor-led teaching which is full-time, five-days a week, lecture-based classroom presentation, and over the duration of 1.5-2 weeks. This ought to be followed by 2.5-3 weeks of instructor-led e-learning with self-study of reference materials.

During that self-study period the students should also be given one group assignment to prepare a module project with focus on IoT data acquisition, big data processing algorithm and attractive visualisation. This is to maximise the learning experience of the student; ideally, nationally available IoT data ought to be procured.

In the last of the five weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their Big Data algorithm and visualisation program and discuss with their instructor and peers.

Total duration: five weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students will have gained advanced knowledge in Big Data approaches for the Internet of Things, and be able to reflect on the requirements for system designs. They should have an in-depth knowledge on the different Big Data signal processing approaches, including linear, non-linear and advanced AI frameworks. The students ought to be able to design an end-to-end Big Data processing framework, including the cleaning of data, processing of data and visualisation.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space. Both tests should be substantially more in-depth than the tests designed for the foundational modules.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to AI and Machine Learning in the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters on IoT analysis frameworks should be given for read given the sheer amount of material.
- Alsheikh, M.A., Lin, S., Niyato, D. and Tan, H.P., 2014. **Machine learning in wireless sensor networks: Algorithms, strategies, and applications**. IEEE Communications Surveys & Tutorials, 16(4), pp.1996-2018.
- Nilsson, N.J., 2015**. Introduction to Machine Learning.** http://ai.stanford.edu/~nilsson/mlbook.html. Accessed 30 Mar. 2017.
- R2D3, 2016. **A Visual Introduction to Machine Learning.** http://www.r2d3.us/visual-intro-to-machine-learning-part-1/. Accessed 30 Mar. 2017.

5.5 ADVANCED MODULE 5: SOCIAL & ETHICAL IMPLICATIONS AND CASE STUDIES

This is the fifth optional module in the advanced series in the IoT TP. It deals with the topic of social and ethical implications of deploying and using the Internet of Things. Indeed, a huge amount of potentially very personal data is being accumulated by the IoT which will have strong repercussions on people's lives. On the other hand, it will enable a huge amount of truly interesting and empowering applications. How to balance this ethically is the focus of this module. This module ought to be taken by students interested in societal potentials and societal issues of the IoT.

This advanced module should cover the following subjects and concepts:

- overview of most promising IoT usecases, differentiating between industry vs consumer as well as developed vs developing countries
- in-depth discussion on which data is collected (and how); and what large societal benefits these usecases can potentially give
- in-depth discussion on how the collected data could facilitate abuse and what are the resulting ethical implications
- in-depth introduction to ethics, including the historic transformation over past decades
- law and regulation related to ethics, also highlighting major differences between countries/regions
- in-depth discussion on privacy, and the available regulation on a per country/region basis
- calibration of above with some very specific case studies of IoT deployment in industrial and consumer settings (such as Smart Cities), again with focus on data, the problem it solves as well as its potential abuse
- essay on ethical tradeoffs and associated law/regulation with focus on national use cases and/or case studies

PROPOSED DELIVERY MODE AND DURATION

For the advanced modules, a more in-depth and lengthier mentoring is required. Again, we envisage a carefully orchestrated instructor-led teaching which is full-time, five-days a week, lecture-based classroom presentation, and over the duration of 1.5-2 weeks. This ought to be followed by 2.5-3 weeks of instructor-led e-learning with self-study of reference materials.

During that self-study period the students should also be given one group assignment to prepare a module project with focus on national IoT use cases and/or case studies for which they ought to write an essay discussing the ethical issues arising in that context. This is to maximise the learning experience of the student; ideally, nationally available IoT projects ought to be procured.

In the last of the five weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present the major findings of their ethical analysis in the national context and discuss with their instructor and peers.

Total duration: five weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students will have gained advanced knowledge in ethics and privacy, associated tradeoffs, laws and regulations. Of importance here is that the student understands that IoT data is not only a threat but also a huge potential, whilst being very skilled in understanding the potential risks associated with IoT data collection and actuation.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space. Both tests should be substantially more in-depth than the tests designed for the foundational modules.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to ethics and privacy in the IoT,
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters on IoT ethics/privacy should be given for read given the sheer amount of material.
- ITU, 2016. **Harnessing the Internet of Things for Global Development.** https://www.itu.int/en/action/broadband/.../Harnessing-IoT-Global-Development.pdf. Accessed 7 Apr. 2017.
- Scherf, T., 2016. **Internet of Things – hype or hope for developing countries?** https://www.kfw-entwicklungsbank.de/PDF/Download-Center/PDF-Dokumente-

Development-Research/Internet-of-Things-%E2%80%93-hype-or-hope-for-developing-countries.pdf. Accessed 30 Mar. 2017.
- Popescul, D. and Georgescu, M., 2013. **Internet of Things–some ethical issues**. The USV Annals of Economics and Public Administration, 13(2), p.18.

5.6 ADVANCED MODULE 6: BUSINESS MODELS & CASE STUDY IMPLICATIONS

This is the sixth optional module in the advanced series in the IoT TP. It deals with the topic of business modelling, return of investment approaches, risk assessment in the business context, and some very specific use cases. This module ought to be taken by students interested in business and entrepreneurship.

This advanced module should cover the following subjects and concepts:

- in-depth overview of IoT use cases with specific emphasis on the potential business case
- introduction to return of investment, and application of that knowledge to the discussed IoT use cases
- in-depth exposure on business models and business modelling, including the Lean Canvas approach
- in-depth exposure of Porter's and related frameworks
- in-depth analysis of risk and risk assessment, and how it applies to the IoT
- in-depth analysis of development, production and sales cycles, and what is unique about these cycles in the context of the IoT
- based on above, understand investment, growth, returns, timings, and all important to a successful business case
- overview of failed and successful IoT case studies globally, and tailored to a specific region where the student is based
- student ought to perform a business analysis for one failed and one successful IoT deployment, ideally in national context

PROPOSED DELIVERY MODE AND DURATION

For the advanced modules, a more in-depth and lengthier mentoring is required. Again, we envisage a carefully orchestrated instructor-led teaching which is full-time, five-days a week, lecture-based classroom presentation, and over the duration of 1.5-2 weeks. This ought to be followed by 2.5-3 weeks of instructor-led e-learning with self-study of reference materials.

During that self-study period the students should also be given one group assignment to perform a business analysis for one failed and one successful IoT deployment, ideally in national context. This is to maximise the learning experience of the student.

In the last of the five weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present the major findings of their ethical analysis in the national context and discuss with their instructor and peers.

Total duration: five weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students will have gained advanced knowledge in all aspects business with specific focus on the Internet of Things, and be able to reflect on the requirements for application analysis and design. Notably, students must be skilled in the notions of business case and business modelling, investment, return of investment, impact of development/sales cycles, as well as risk and risk assessment. Student should be able to take an IoT use case and carry out a business modelling analysis; they should also be able to pinpoint the reasons of a failed or successful IoT case study from a business point of view.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space. Both tests should be substantially more in-depth than the tests designed for the foundational modules.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to business cases in the IoT.
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters on IoT business opportunities/cases should be given for read given the sheer amount of material.
- Westerlund, M., Leminen, S. and Rajahonka, M., 2014. **Designing business models for the internet of things**. Technology Innovation Management Review, 4(7), p.5.
- Capone, M.J., 2016. **Thirty Measurable Business Cases for IoT with Connected Services.** https://www.capgemini.com/resources/thirty-measurable-business-cases-for-iot-with-connected-services. Accessed 30 Mar. 2017.

5.7 ADVANCED MODULE 7: IOT ENTREPRENEURSHIP

This is the seventh optional module in the advanced series in the IoT TP. It deals with the exciting topic of entrepreneurship. It covers first some basics on entrepreneurship and then dives into the particularities of starting and growing a company in the settings of the Internet of Things. This module ought to be taken by students interested in entrepreneurship and start-up business.

This advanced module should cover the following subjects and concepts:

- discussion on entrepreneurial versus corporate working trajectory, what it implies from a daily routine, sacrifice and potential return point of view
- in-depth discussion on the notion of opportunity cost and how it allows one to make the right decision between corporate & entrepreneurial worlds, as well as the right decisions when growing one's own company
- basics of entrepreneurship, including business models, market assessments, how to get started, hiring strategies, growth milestones, product development, production, etc
- in-depth discussion on the entrepreneurial differences of IoT ventures
- exposure on differences between industrial and consumer IoT markets and products
- understanding the stark differences between need and demand in the emerging Internet of Things
- deep-dive on how to overcome long sales cycles in the IoT
- deep-dive on business models and business modelling for the IoT
- introduction on securing investment for IoT ventures, and discussion on specific exit strategies
- in-depth analysis of the 3-4 milestones which need to be met and what they entail from a company transformation point of view
- important entrepreneurial laws and deep-dive on taxation
- discussion on the most typical mistakes made by IoT entrepreneurs, and how to avoid them
- student should do a business plan and company life cycle development plan for a specific IoT company he/she would like to start (even if only fictional)

PROPOSED DELIVERY MODE AND DURATION

For the advanced modules, a more in-depth and lengthier mentoring is required. Again, we envisage a carefully orchestrated instructor-led teaching which is full-time, five-days a week, lecture-based classroom presentation, and over the duration of 1.5-2 weeks. This ought to be followed by 2.5-3 weeks of instructor-led e-learning with self-study of reference materials.

During that self-study period the students should also be given one group assignment to prepare a business plan and company life cycle development plan for a specific IoT company he/she would like to start (even if only fictional). This is to maximise the learning experience of the student; ideally, the startup should have a national focus.

In the last of the five weeks, a series of interactive seminars could also be held to review the results of the module (in parallel and in support to their own studies). Students would present their company idea along with a detailed planning which each can defend to their instructor and peers.

Total duration: five weeks.

STUDY OBJECTIVES AND ASSESSMENT

On completing this module, students will have gained advanced knowledge in everything related to entrepreneurship. This includes a very detailed understanding on how a business is started, what are the legal implications, which mistakes must be avoided and how. The student should also understand the intricate differences between an IoT and non-IoT business, as well as between an industrial IoT and consumer IoT business.

As a part of the overall module assessment, students will be required to substantiate the results of their distance learning by completing 1 multiple-choice test and 1 test containing several open questions related to the learning content of this module. The latter is very important to assess their independent thinking in the space. Both tests should be substantially more in-depth than the tests designed for the foundational modules.

STUDY RESOURCES

The reference sources for this module ought to include documents outlined in Section 1.2.1, as well as the entire or selected parts of the following:

- ITU, 2017. **Internet of Things** http://www.itu.int/en/ITU-T/techwatch/Pages/internetofthings.aspx. Accessed 30 Mar. 2017, consolidating all activities conducted within the ITU which are related to IoT case studies and applications.
- ITU, 2016. **Unleashing the Potential of the IoT.** https://www.itu.int/en/publications/Documents/tsb/2016-InternetOfThings/index.html. Accessed 30 Mar. 2017; note that only specific chapters on IoT business opportunities should be given for read given the sheer amount of material.
- harvard.edu, 2016. **Engineering and Entrepreneurship: The Internet of Things**. http://crcs.seas.harvard.edu/engineering-and-entrepreneurship-internet-things. Accessed 7 Apr. 2017.
- S.Case, 2016. **The Third Wave: An Entrepreneur's Vision of the Future.** New York: Simon & Schuster**.**
- ITU, 2016. **Shaping smarter and more sustainable cities: Striving for sustainable development goals.** http://wftp3.itu.int/pub/epub_shared/TSB/ITUT-Tech-Report-Specs/2016/en/flipviewerxpress.html. Accessed 7 Apr. 2017.

- ITU, 2016. **Implementing ITU-T International Standards to Shape Smart Sustainable Cities: The Case of Dubai.** http://www.itu.int/en/publications/Documents/tsb/2016-DubaiCase/index.html. Accessed 7 Apr. 2017.
- ITU and UNECE, 2016. **United for Smart Sustainable Cities: Striving for Sustainable Development Goals.** http://wftp3.itu.int/pub/epub_shared/TSB/2016-ITUT-SSC-Brochure/en/index.html#p=1. Accessed 7 Apr. 2017.

6 MASTER THESIS

To qualify for an MSc, the student must have completed the Advanced Certificate and also complete a Master Thesis based on undertaking a project related to the Internet of Things. The scope and objectives of such a Master ought to have been agreed in advance with the course tutor responsible for the theses.

The content of the thesis could pertain to any of the taken modules and/or a subset of discussion items of these modules and/or a mix of several modules. The thesis cannot be the same as any of the prior assessment works; however, a significantly expanded work is acceptable. The thesis must be individual, i.e. this is not a group project. The thesis ought to contain substantially novel content/findings, and be at least 50 pages long (with size 12 font and single line spacing).

This thesis should be assessed (but not awarded!) by an external professional institution accredited to provide degrees at MSc level. The criteria of assessment should reflect above requirements, and should be agreed upon prior to any master work between the responsible tutor, the ITU and the evaluating institution. Evaluation should not only be done remotely on paper but ideally also include a short Master presentation which the student could give remotely over a video link.

Upon successful completion, the Master Thesis counts for 10 ECTS credits and yields the **Internet of Things MSc.**

7 SETTING UP THE COURSE AND PREPARING SYLLABUSES

7.1 POSSIBLE CONTRIBUTING INSTITUTIONS AND EXPERTS

7.1.1 Universities

If the idea of conferring a university degree upon completion of the IoT Training Programme is adopted, partnerships will need to be established with suitable academic partners. The academic partners may offer to teach some particular module(s) and/or grant certificates/credits for completion of a given module. Depending on the ultimate composition of the consortia and the overall teaching and examination arrangements, the other partnering universities could even consider joining as co-sponsoring institutions for the diploma granted at the end of the course.

It will be important to find one or more Universities willing to act as the MSc diploma-issuing institutions. Choosing a Western European university or a University adopting the ECTS system as the lead diploma-issuing institution would simplify the process as they are accustomed to the ECTS framework and to multi-university courses. The selection process should consider multi-lingual issues and should not limit the suitable candidates to Western Europe only.

We suggest contacting the ITU Academic members to identify Universities interested in becoming IoT MSc. diploma-issuing institutions.

7.1.2 Experts to develop the programme syllabuses

In order to ensure high pedagogical quality of different modules and relevant, up-to-date technical content, a team of international experts in different sub-fields will be appointed.

The experts will develop:

• Syllabuses for the Foundation and Advanced modules:

- the list of topics that should be covered by each module, with the number of hours to be devoted to each topic,
- apportionment of the instructor-led/self-study time needed to complete the topics, from the overall time (ECTS credit-based) allocated to a given module,
- complete list of study materials including ITU reports and documents, international reports, textbooks and similar references to be used by tutors and students. The material should be sufficient to complete the projects and exercises.

• Associated sets of module completion/examination requirements:

- minimum set of knowledge and skills to be obtained on completion of the module,
- proposal for formal assessment of knowledge/skills acquired, through a combination of examination and practical tests.

The experts responsible for developing module syllabuses should be selected from existing BDT experts and ITU study group leaders, rapporteurs and editors in the topics related to IoT. It is recommended that the team responsible for developing the syllabuses of the IoT TP modules should consist of at least 5 experts from different sub-fields of IoT taking into account:

- the initial complement of the IoT TP consists of around 15 Foundation and Advanced modules;
- the list of Advanced modules may be expanded with additional specialized modules;
- the topics of some modules are sufficiently close to allow some experts to cover at least two related topics.

7.2 REMAINING TIME REQUIRED TO SET UP THE IOT TP

The remaining steps required to set up an IoT Training Programme include:

a) Completing and agreeing the structure of the IoT TP.
b) Recruiting the Experts to develop the modules.
c) Experts to draft the full set of modules.
d) Development of training material on ITU Academy platform.
e) Testing of a representative set of modules by ITU Centres of Excellence Network / IoT training activities organized by ITU member institutions.
f) Reviewing the results of the training activities that used the modules.
g) Amending the TP based on this review.

It is expected that once appropriate and knowledgeable experts have been appointed it will take around 8 weeks to draft and agree the presentation slides and other materials for each module.

8 PRINCIPLES OF STUDENT ASSESSMENT AND GRADING

Student assessment must ensure that diplomas are only awarded for work that merits it. It must not be possible for the student to copy large amounts of text from the Internet or from other students in order to complete their projects or assignments. Therefore, a mixture of assessment methods should be used:

• Multiple choice questionnaire.
These are simple to administer and should ideally be used to check understanding part way through a module so that a student can go back a repeat any parts that they have not assimilated. They should not be used as the only way used to assess a complete module.

• Examination.
An examination could be used to assess a complete module, especially the Foundation modules where students are either physically present face-to-face or electronic (on-line) tools can be used. However, this method may not be flexible enough to cover Advanced modules, where understanding demonstrated through projects and exercises will be much more important.

• Essays.
An essay can be used to demonstrate a student's understanding of the content of a particular module. This would demonstrate a student's ability to assimilate a subject in depth and objectively analyse the material that has been provided. However, marking of essays can be time consuming for the course tutor and lead to a degree of subjective assessment which depends, for example, on the student's knowledge of English rather than on their level of knowledge of the subject.

• Projects.
A project can be set which requires the student (or a group of students) to research a subject in more depth than has been provided on the course. The thoroughness with which a project has been completed and the adequacy of the results obtained could be an excellent way to assess whether a student has fully understood the concepts and methods used in the module. Ideally, around 50% of the marks for a particular module should be based on the results of projects or interactive exercises if these can be set in the required context and timescale.

• Seminars.
This involves grading of the student's active participation in seminars. However, note that this should not be used as an assessment method on its own, as some students may be reluctant to put forward their ideas in a competitive classroom (either virtual or face-to-face) situation. This could be due to cultural, gender or English language competency issues.

• Interactive exercises.
These can be a fun way of quickly allocating marks to a student or a group of students. A problem can be outlined and the student or group of students asked to work out the best way of solving it (e.g. how to design an IoT regulation in a national context). Enough scope should be given to allow the student to come up with innovative ways of solving the problem.

The following is an example of an assessment scheme that uses a combination of assessment methods, with the maximum marks that can be obtained by a student from this method given in brackets:

- Attendance (10%)
- Interactive exercises and class participation (20%)
- Examination through on-line multiple choice questionnaires (30%)
- Longer (1 week) project (40%)

9 CONCLUSIONS

This report has scoped out the structure of an Internet of Things Training Programme that could be offered to the ITU membership including academia, industry, regulators, government organisations and telecom providers. The Programme has a modular structure so that the content of existing modules can be changed and new modules can be added as required.

Each module should take 4/5 weeks for the student to complete including final assessment. The student will be required to pass Foundation and Advanced modules in order to receive Foundation and Advanced IoT Certificates. To qualify for an MSc in IoT the student must also complete a Master Thesis based on undertaking a project whose scope and objectives have been agreed in advance with the course tutor. This thesis should be assessed by an external professional institution accredited to provide degrees at MSc level.