TACTILENet

Towards Agile, effiCient, auTonomous and massIvely LargE Network of things

WP3- Development of Course Material

D3.3 D15 Final Version of MOOC

Public
Due date: Jan 31, 2019
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Leading: Sabanci University

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1 Introduction

Tactilenet project provided the material for the first steps in a Massively Online Open Course (MOOC) on 5G technologies. The project identified important modules of the course that can provide researchers and practitioners knowledge into several aspects of 5G networks. MOOC is an evolving course with material added during and after the project according to new developments and findings. Almost all modules are partially covered and completed, and also additional material will be added even after the project comes to an end. This deliverable highlights all the tasks and objectives of the WP3 and provides the relevant links and information. Please note that the main reason for the delay is due to Unforeseen Risk U1, i.e., Imperial College made an exclusive agreement with edX and coursera ((https://www.edx.org/school/imperialx and https://www.coursera.org/imperial) which does not allow us to post Imperial College courses outside these platforms. The other beneficiaries were unable to take any corrective action due to the lack of resources and short time left in the project. We are still working together with Imperial to find a partial solution, where only the course material related to the project can be published over Tactilenet website.

In this report, we address several modules related to Tasks 3.1, 3.2, and 3.3. In particular, new material on sub-tasks 3.1 (c), (d), 3.2 (b), and 3.3 (c), (d) are reported.

In particular, the partners have setup a Youtube channel (https://www.youtube.com/channel/UCJj_a663VRKppfUSOddajRA) and several parts of the course material is available on this Youtube channel. Additionally, research presentations related to the course modules are also added on the website. We have added explanations to Youtube videos to describe the contributions of each video.

The structure of the course is divided into several modules: 1. Traffic modeling and access protocols for 5G, 2. Wireless Access for massive Machine-type communication, 3. Designing Intelligent Energy Harvesting Communications, and 4. Caching in mobile communication networks. The videos of courses on the parts of Modules 1, 2 and 3 are added on the project Youtube channel. These videos are different in the topic that they discuss and each video highlights specific subject included in modules 1-4. Moreover, the currently uploaded videos to the Youtube channel are the last version of these videos. Additionally, all presentation materials generated in WP2 and related to the Modules are uploaded on the project website (http://tactilenet.sabanciuniv.edu). Since it sometimes takes long time for an educational video which is focused on a specific new topic, to get popular and grab attentions in YouTube, we have not yet received a large number of feedbacks from users; hence, currently our method to promote the material courses is to regularly re-check and discuss them and then perform any possible update or upgrade. This procedure is done by the partners led by Sabanci University.

2 Overview and Structure of the Course

At the end of the project, we aim to have sufficient material for an introductory course titled "Fundamentals and Theory for 5G and Beyond Wireless Networks." We expect that the material provides information to mini-courses of duration of 2-3 weeks each with 2-3 hours of lectures per week that can be integrated in the senior level undergraduate or first year graduate course on communications networks courses. These undergraduate or graduate courses are offered at each

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institute approximately every year attended by on the average 20 ESRs. At the end of the project, it has been noticed that the aforementioned goals are successfully achieved, as demonstrated by the use of the material in several courses at the partners. In particular, Dr. Deniz Gunduz incorporated some of the knowledge developed throughout the TactileNet project, particularly those on the development of machine learning tools for wireless communication networks, into his new course module "Introduction to Machine Learning", which he taught for the first time in Fall 2018. This mainly involved using some of the communication network problems arising in the implementation of a tactile Internet as examples for deep learning and reinforcement learning topics.

Additionally, Dr. Deniz Gunduz prepared a short course on the use of machine learning tools in communication networks, titled "Learn to Communicate - Communicate to Learn", which he has/ will present at various universities worldwide (University of Padova, KTH, MIT, Stanford, Berkeley). He also gave a version of the course at training schools such as the 6th IRACON Training School (in March 2019 in Spain) and at the European School of Information Theory (in April 2019 in France). The duration of each of these courses were approximately two hours.

The course material is going to be kept up-to-date by all partners even after the project. However, the maintenance of Youtube channel will be the responsibility of Sabanci University. The material is going to be updated with the availability of a new material, but at the latest every 6 months (i.e., every academic semester). In order to maintain the update of the course material and YouTube channel, the research group of Prof. Ercetin (Researcher no: 2, ER) at Sabanci University will regularly keep the track of any new updates and changes, and accordingly, will update the course materials and videos. In particular, we aim to pursue the possibility of including lectures of Dr. Gunduz by obtaining permission from Imperial College until 01.05.2019. If this permission is granted, all new videos will be added to Youtube channel by 15.05.2019. Otherwise, we will investigate the possibility of adding new material by securing new funds to prepare the remaining modules. In particular, Prof. Ercetin will investigate the possibility to obtain internal funds from Sabanci University for this purpose through an existing Internal Activities Funding Programme at the same university. This programme can provide up to 10000TL per activity which should be sufficient for recording of the modules. The application will be made by 01.06.2019, and if the support is granted the recording will start by 01.09.2019.

The partners have developed a course structure that will address the following modules. Note that for some sub-courses online links are not provided yet and they will be added as soon as partners prepare the corresponding materials which may take longer even after the project comes to an end.

Module 1. *Traffic Modeling and Access Protocols for 5G.*

a. Traffic Modeling and performance requirements for IoT and D2D traffic.[link]
b. Emerging radio access protocols for IoT such as Sigfox, LoRa and 802.11ah. [link1] [link2]
c. Recent 3GPP activities for cellular IoT, Low-cost LTE and D2D.
d. D2D proximity discovery with different degrees of network support.
e. Analysis and modeling of D2D communications using stochastic geometry tools.
f. Resource allocation, interference cancellation and power control for D2D communications.

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Module 2. *Wireless access for massive Machine-Type Communication (mMTC) [link]*

a. MTC and its position in 5G.
b. The access problem and architectures for massive access. [link]
c. Communication models.[link]
d. Access principles and coded random access. [link]
e. Technologies for mMTC wireless access.
f. Traffic models.

Module 3. *Designing Intelligent Energy Harvesting Communication Networks. [link]*

a. Introduction.
b. Offline optimization framework.
c. Online optimization framework.
d. Design of energy management policies based on data priority/importance.
e. Design of energy management policies for minimum delay.
f. Distributed and centralized optimization of EH networks.
g. Learning theory framework [link].
h. Concluding remarks.

Module 4. *Caching in mobile communication networks.*

a. Content Delivery and Distribution in Traditional Networks.
b. Network architecture and protocols.
c. Theoretical framework of wireless caching for 5G.
d. Performance limits and bounds of caching in wireless networks.
e. Wireless Caching-enabled HetNet[link].
f. Coded Caching in Wireless Networks.
g. Edge Caching techniques for 5G Wireless Content Caching for D2D Networks[link].
h. Energy Efficiency of Wireless Caching Networks.
i. Resource allocation in Wireless Caching Networks.
j. Interference management in cache-aided wireless interference networks.

3 Status of Mooc

Prof. Yanikomeroglu (Fellow no.18, ER) gave a tutorial titled "5G and Beyond Wireless Networks: Emerging Concepts and Technologies." The tutorial can be reached at http://www.magnetmail.net/actions/email_web_version.cfm?ep=Qfqs2iYSCyGwCzB5v7o3NjeX8bd4e5VM2GkTbKtjx3eiZpu8fGgTyqmZe5Y4cTj-GBG5i-KzmcNXPJuXGT05GBD6GP4w41tjP84dP-BNyfvldCIfMdCP2xzCCKUmaqOW

The research group of Prof. P. Popovski (Researcher no: 32, ER) prepared a Phd level course titled "Wireless Communication for the Internet of Things (IoT)". For the purpose of creating an online material for a MOOC within TactileNet, this course was recorded and the videos have been uploaded to the Tactilenet YouTube channel https://www.youtube.com/channel/UCJj_a663VRKppfUSOddajRA

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The material in this course is to be used for Modules 1 and 2 as defined above. The description of the course is given below.

Course title: Wireless Communication for the Internet of Things (IoT)
Organizer: Prof. Petar Popovski, e-mail: petarp@es.aau.dk
Lecturer: Prof. Petar Popovski, Assoc. Prof. Cedomir Stefanovic, Dr. Dong Min Kim, Assoc. Prof. Jimmy Nielsen

Description:
Techno-economic forecasts indicate that in the coming years wireless Internet-of-Things (IoT) will become massive, connecting tens of billions of devices. Wireless chips have grown in capability and power efficiency, while shrinking in size and cost. Wireless IoT networks are instrumental to manage the complexity of tracking, fleet, and asset management. The industrial sector can widely apply IoT in monitoring and control of processes and equipment. The IoT showcase is the smart grid: the evolved power grid where a rich information flow is used to balance the electricity production (e. g. windmills), distribution, storage, and consumption (e. g. large industrial capacities). In this regard, wireless IoT is at the moment one of the hottest topics for the 5G networks. Yet, the requirements posed by IoT require revision of conventional wisdom of wireless protocol design, leading to new research challenges. This course focuses on the emergent research challenges in wireless communication for the IoT. This is an area of immense interest of the wireless research and development community, and the course topics aim to attract attendants from abroad as well as from the industry.

The course covers the following topics:

- IoT and its position in 5G
- The access problem and architectures for massive access
- Communication models
- Short packet transmission
- System requirements and architectures for IoT communication.
- Information theoretic models of uplink cellular access
- Reservation based vs grant-free access
- Design of advanced random-access algorithms for IoT cellular access
- Performance assessment: latency, reliability, energy efficiency
- 3GPP and non-3GPP IoT systems for low power wide area network
- Analytical model for cellular IoT network
- Traffic models and characteristics of the IoT traffic

Prerequisites:
Fundamentals of networking and protocols, digital communications, stochastic processes, and queueing theory.

Course schedule:
The course is scheduled as follows:

Lecture 1: Introduction and communication-theoretic models for IoT (Petar Popovski)

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Session 1	IoT and 5G, the problem of massive access
Session 2	Communication models and short packet transmissions
Lecture 2: Uplink cellular communications and random access algorithms (Cedomir Stefanovic)	
Session 1	Information theoretic models of uplink cellular access
Session 2	Design of enhanced random-access algorithms
Lecture 3: LPWAN and NB-IoT (Dong Min Kim)	
Session 1	Low Power Wide Area Network: LPWA and NB-IoT
Session 2	Low Power Wide Area Network: LoRa and SigFox
Session 3	Analytical Model for Cellular IoT
Lecture 4: Smart Grid Communications (Jimmy J. Nielsen)	
Session 1	Introduction to Smart Grid and Communication Architectures
Session 2	Communication technologies for smart grid
Session 3	Case study: smart grid using cellular networks

Related reading materials:

[1] M. Chiang and T. Zhang, "Fog and IoT: An Overview of Research Opportunities", IEEE Internet of Things Journal, vol. 3, no. 6, pp. 854-864, Dec. 2016.
[2] J. Granjal, E. Monteiro and J. Sá Silva, "Security for the Internet of Things: A Survey of Existing Protocols and Open Research Issues", IEEE Communications Surveys & Tutorials, vol. 17, no. 3, pp. 1294-1312, third quarter 2015.
[3] B. Lee, S. Park, D. J. Love, H. Ji and B. Shim, "Packet Structure and Receiver Design for Low Latency Wireless Communications with Ultra-Short Packets," in IEEE Transactions on Communications, to appear.
[4] K. F. Trillingsgaard and P. Popovski, "Downlink Transmission of Short Packets: Framing and Control Information Revisited," in IEEE Transactions on Communications, vol. 65, no. 5, pp. 2048-2061, May 2017.
[5] Z. Li et al, "2D time-frequency interference modelling using stochastic geometry for performance evaluation in Low-Power Wide-Area Networks", IEEE ICC 2017.
[6] Abdul Wachid Syamroni - J. Granjal, E. Monteiro and J. Sá Silva, "Security for the Internet of Things: A Survey of Existing Protocols and Open Research Issues", IEEE Communications Surveys & Tutorials, vol. 17, no. 3, pp. 1294-1312, third quarter 2015.
[7] M. Centenaro et al, "Long-Range Communications in Unlicensed Bands: The Rising Stars in the IoT and Smart City Scenarios", IEEE Wireless Communications, October 2016.
[8] A. Meloni and L. Atzori, "The Role of Satellite Communications in the Smart Grid", IEEE Wireless Communication Letters, to appear.
[9] I. Al-Anbagi, M. Erol-Kantarci, and H. T. Mouftah, "Priority- and Delay-Aware Medium Access for Wireless Sensor Networks in the Smart Grid", IEEE Systems Journal, 2013.
[10] V. C. Gungor, B. Lu, and G. P. Hancke, "Opportunities and Challenges of Wireless Sensor Networks in Smart Grid", IEEE Transactions on Industrial Electronics, vol. 57, no. 10, October 2010.
[11] D. Danyev, B. Laczay, and M. Ruszinko, "Multiple Access Adder Channel", In E. Biglieri, and L. Gyorfy (eds), Multiple Access Channels. IOS press, 2007
[12] X. Chen, T. Y. Chen, and D. Guo, "Capacity of Gaussian Many-Access Channels", IEEE Transactions on Information Theory, vol. 63, no. 6, pp. 3516-3539, June 2017
[13] Y. Polyanskiy, "A perspective on massive random-access", Proc. of IEEE International Symposium on Information Theory (ISIT) 2017
[14] E. Paolini, G. Liva, and M. Chiani, "Coded Slotted ALOHA: A Graph-Based Method for Uncoordinated Multiple Access", IEEE Transactions on Information Theory, vol. 61, no. 12, pp. 6815-6832, December 2015
[15] J. Goseling, C. Stefanovic, C., and P. Popovski, "Sign-Compute-Resolve for Random Access", Proc. of 52nd Annual Allerton Conference, 2014
[16] C. Stefanovic, E. Paolini, and G. Liva, "Asymptotic Performance of Coded Slotted ALOHA with Multi Packet Reception", IEEE Communications Letters, to appear

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[17] F. Clazzer, E. Paolini, I. Mambelli, and C. Stefanovic, "Irregular repetition slotted ALOHA over the Rayleigh block fading channel with capture", Proc. of IEEE International Conference on Commununications (ICC), 2017
[18] G. Durisi, T. Koch, and P. Popovski, "Towards massive, ultra-reliable, and low-latency wireless communication with short packets", Proceedings of the IEEE, vol. 104, no. 9, pp. 1711-1726, 2016

The following are the list of activities categorized with respect to the tasks under WP3.

Task 3.1 5G Machine-type Communications

(a) The research group of Prof. P. Popovski (Researcher no: 32, ER) prepared a Phd level course titled "Wireless Communication for the Internet of Things (IoT)".[link]

(b) Prof. Simeone (Researcher no:9, ER) from New Jersey Institute of Technology presented a work related to the project on fog networking at Aalborg University on 08.06.2016 (M6) attended by 20 people including ESRs and ERs.

(c) Prof. Yanikomeroglu (Fellow no.18, ER) gave a tutorial titled "5G and Beyond Wireless Networks: Emerging Concepts and Technologies". The tutorial can be reached at http://www.magnetmail.net/actions/email_web_version.cfm?ep=Qfqs2iYSCyGwCzB5v7o3NjeX8bd4e5VM2GkTbKtjx3eiZpu8fGgTyqmZe5Y4cTj-GBG5i-KzmcNXPJuXGT05GBD6GP4w41tjP84dP-BNyfvldCIfMdCP2xzCCKUmaqOW

(d) Dr. Gunduz (Fellow no 8) gave the following at several universities in Italy.
https://tactilenet.sabanciuniv.edu/sites/tactilenet.sabanciuniv.edu/files/learn_to_communicate_communicate_to_learn.pdf

Task 3.2 5G Green communications

Prepared video presentations on Energy Harvesting Networks. The videos are currently available online at Tactilenet YouTube channel.

(a) Communication over a Time-Correlated Channel with an Energy Harvesting Transmitter. This presentation is result of the research activities performed under Task 2.2. The presenter is Mehdi Salehi Heyder Abad (Researcher no: 18, ESR) from Sabanci University.[link]

(b) Energy Harvesting Wireless Networks with Correlated Energy Sources. This presentation is result of the research activities performed under Task 2.2. The presenter is Mehdi Salehi Heyder Abad (Researcher no: 18, ESR) from Sabanci University.[link]

Task 3.3 5G Spectrum Allocation and identification and optimization of relevant QoE measures

(a) Dr. Deniz Gunduz (Researcher no: 8, ER) is currently teaching the Communication Systems course, which is an introductory course covering fundamental concepts in communications and information theory. This 25-hour course is currently being recorded with a special software tool, and made available to local students for remote access. By the

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end of the semester, subject to necessary approvals from Imperial College London, we are planning to make these online lectures available to the project partners as a pilot MOOC project. The course has supplementary material including homeworks, quizzes, short informative videos, which will also be available to MOOC students. Currently we do not have the necessary resources to provide additional assistance to remote students in parallel to the lectures, such as homework evaluation, online problem sessions, etc., but these may also be considered in the future stages.

(b) Prof. Koksal (Researcher no: 3, ER) from Ohio State University gave a talk on Massive MIMO Security at Imperial College London on 16.03.2016 (M2) attended by 25 people including ESRs and ERs http://talks.ee.ic.ac.uk/talk/index/833 The talk incorporated in part ongoing research by Prof Koksal and Prof Gunduz,. The ongoing work investigates the risks and benefits of using massive MIMO technology in ultra-dense communications networks.

(c) Fellow no 21 Sreejith Sreekumar gave the following talk in Texas A&M on 14th September, 2018 to an audience of 20-30 people.

https://tactilenet.sabanciuniv.edu/sites/tactilenet.sabanciuniv.edu/files/distributed_binary_hypothesis_testing_over_noisy_channels.pdf

(d) Fellow no 21 Sreejith Sreekumar gave the following talk in Rice University on 18th September 2018 to an audience of 20-30 people.

https://tactilenet.sabanciuniv.edu/sites/tactilenet.sabanciuniv.edu/files/distributed_hypothesis_testing_with_a_privacy_constraint.pdf

4 Resources

The work reported in the previous sections is the result of research activities performed by the following researchers. The following table provides the names, and the corresponding person-months.

Table 1: List of researchers involved

Researcher ID	First Name	Last Name	Sending Organisation	Seconded To	Person-months
2	Ozgur	Ercetin	SU	--	--[1]
8	Deniz	Gunduz	IC	--	--[1]
17	Mehdi	Heyder Abad	SU	--	--[1]
22	Amin	Farajzadeh	SU	--	--[1]
32	Petar	Popovski	AAU	--	--[1]

[1] Note that the person-months of effort for this researcher is not reported, since the work is done outside the period of secondment for this researcher.

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3	Can Emre	Koksal	OSU	SU	1.03
21	Sreejith	Sreekumar	IC	UTA	1
18	Halim	Yanikomeroglu	Carleton	SU	0.8

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