SCAVENGE NEWSLETTER NO. 2

H2020 SCAVENGE (http://www.scavenge.eu/)

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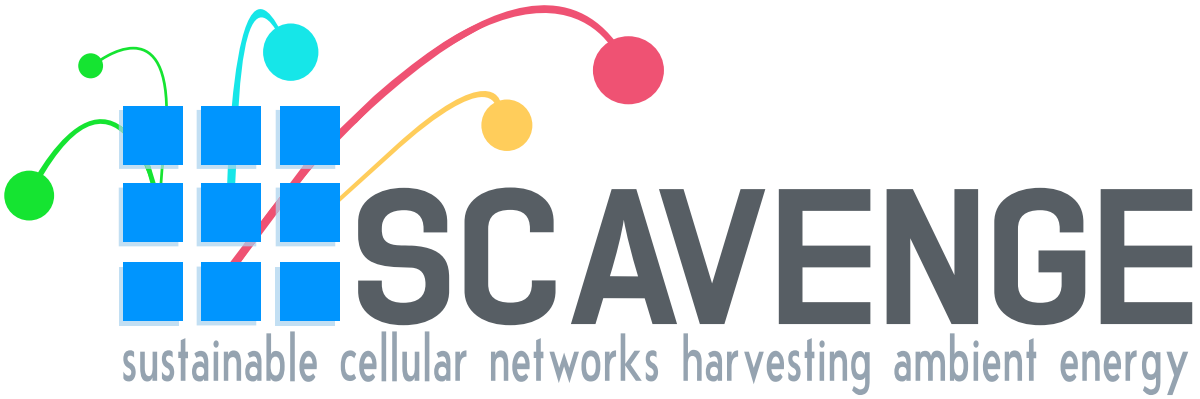
5. **Project Coordinator:** Paolo Dini - CTTC
6. **Project Officer:** Nina Poumpalova - REA



SCAVENGE
Newsletter No. 2

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Getting up to speed

With 2017, SCAVENGE has been getting up to speed. Our ESRs are growing stronger, they have started to publish their first research papers and many more are on the way. An updated list of papers is available through the following link: SCAVENGE publications.

The students also gave their first talks at international conferences such as ICC, WoWMoM, GLOBECOM, WCNC, PIMRC, etc. and developed some friendship among them, they are a team now and we are proud of them.

Training schools

In 2017, three training schools have been organized:

- **School 1**: 5G cellular networks and Internet of Things (March 27th, 30th, 2017, Imperial College, London, UK).
- **School 2**: Energy Generation and Storage: the case of Energy Harvesting in Mobile Networks (May 29th, June 2nd, 2017, University of Strathclyde, Glasgow, UK).
- **School 3**: New scenarios for 5G Mobile Networks: Smart City, Smart Grid, Public Protection and Disaster Relief (July 2nd - 7th, 2017, University of Padova, Bressanone/Brixen, Italy).

We believe the schools have all been very successful, in general featuring three types of lessons on: 1) *mobile communication systems*, 2) *energy management and smart grids*, 3) *fundamental theoretical tools* such as optimization, machine learning, convex programming, etc. All the schools have been very well received by our students, who provided excellent feedback in terms of organization and usefulness. Being open, and being their participation free of charge, we have also had the pleasure of teaching to (sometimes many) non-SCAVENGE students. A proof of that is provided by the picture below, which was taken during the school in Brixen :-)

Stay in touch with us

The perhaps easiest and most entertaining way to see what's going on is through our You Tube channel.

There, you can find the lessons from our first three schools and much more, including:

- Promo videos,
- Video lessons & tutorials,
- News from our students,
- Our technical achievements,
- Talks to public events, etc.

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News from the students

Ibrahim Fawaz (ESR01)

As the wireless mobile communications are witnessing unprecedented growth, the future 5G networks will have to satisfy the demands on high-volume data traffic and at the same time strong requirements on the latency, error rates and energy consumption. Focusing on resource scheduling algorithms, I proposed, as a first step, to minimize the consumed energy while taking into account a new constraint related to the latency. The idea is to introduce a strict delay constraint to guarantee that all the data packets are scheduled before an application-specific deadline. In this context, a power-efficient transmission strategy is designed to guarantee reliable and sustainable communications. As an extension to this work, I investigated an energy harvesting communication system meeting such strict delay constraint. In this case, the optimal policy should adapt the transmission rate to the randomness of the energy harvested from the surrounding environment in a way to prevent energy shortage. Then, offloading capabilities are added to the system, where the mobile terminal can choose to execute its tasks locally using his own processor, or remotely by offloading a part of the tasks to nearby servers or base stations with more energy and computation resources. Working within CEA premises and being a part of the LSC group (Communicating Systems Laboratory) offers me a unique opportunity to experience a professional research environment. It is also a great opportunity to understand theoretical and implementation aspects of mobile systems.

Filipe Conceição (ESR02)

With 5G, cellular connectivity will provide access to a great variety of network-enabled things which interact with one another. However, 5G applications will require much more from the network in terms of security/privacy, coverage availability, reliability and energy savings. This calls for clever cooperation strategies among end devices and my project at CEA aims at investigating approaches to do this. So far, I have proposed a new operating mode for Machine Type Communications that is characterized by human controlled devices connecting directly to IoT devices. I also provided a new secure method that can establish these connections without any prior trust relationships and under the supervision of the network, meeting all the requirements of current security and telecom standards. I then used the proposed method along with the ProSe standard and introduced a layout for coverage extension using D2D. This led to a conference paper entitled “Security Establishment for IoT Environments in 5G: Direct MTC-UE Communications” which was presented at PIMRC 2017, in Montreal, Canada, in October 2017. As direct connections have a great potential in energy efficiency, I am currently exploring areas where energy can be saved and energy efficiency can be improved. My current approach is to look at one IoT object and its energy consumption while interacting with its neighbor nodes. I am trying to quantify this energy and demonstrate that it can be saved if the devices are able to choose wisely with whom to cooperate.

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Outline

Our vision

- Energy sustainability is key to future mobile networks due to their foreseen capacity upsurge.
- SCAVENGE introduces the concept of *Sustainable 5G Mobile Network*.
- Environmental energy can be used to power the mobile system elements like base stations, mobile terminals, sensors and machines.

Our mission

- SCAVENGE’s objective is to create a training network for early-stage researchers (ESRs) who will contribute to the design and implementation of eco-friendly and sustainable next-generation 5G nets.
- SCAVENGE encompasses theory along with the optimisation and proof-of-concept implementation of base stations and mobile elements as well as their integration with the smart electrical grid.

Our team

- The attitude of SCAVENGE’s industrial partners towards the strong investment in R&D and their strategic vision are fully aligned with the mission of this project.
- The ESRs will have a unique opportunity towards professional growth in light of dedicated cross-partner training activities and through the interaction with the international Partner Organisations, which also include relevant stakeholders in the envisioned market.

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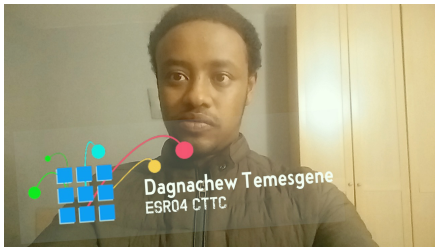
Hoang Duy Trinh (ESR03)

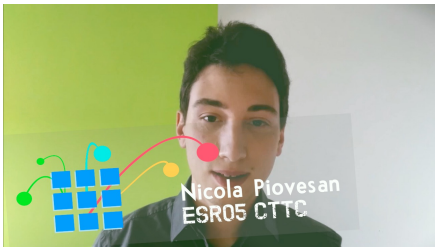
Understanding the huge amount of information that is exchanged in the mobile network, can help improve the system in terms of communication performance and energy efficiency. My project aims to deliver mobile network solutions studying datasets that come from the network and from the mobile users. The reason behind the focus on *data analytics* is motivated by the fact that, nowadays, the growth of most businesses is data-driven: thus, collection, manipulation and deep analysis of data are fundamental skills to be developed. Within the context of SCAVENGE, in 2017 we collected a huge amount of traffic datasets from mobile users, using a tool that is able to capture the control channel of LTE networks. We did this utilizing a software-defined radio and open-source algorithms. We analyzed the measurements, trying to understand how much efficiently the resources are allocated among the users. We are now able to identify recurrent patterns, but also unexpected traffic upsurges due to exceptional local events. Working with large chunks of data demands for fast and efficient algorithms. Underlying structures and hidden features can be discovered using artificial intelligence techniques and machine learning algorithms that show good abilities in solving these problems. Nevertheless, adapting existing machine learning algorithms, which are mostly applied to images and computer vision, to the telecommunication field, is a non-trivial endeavor. To help us dealing with this, the SCAVENGE network has organized schools and other training events, which provided me with a good set of skills. Likewise, the secondments are giving me the chance of growing technically with the help of other important institutions. In my case, the hosting period at University of Maryland, has given me the unique opportunity to work with Professor Ulukus. The scope of the work we carried out together is to combine different datasets and study the problem of network energy efficiency from a theoretical standpoint. Much work is still ahead of me, but I am very excited to continue and tackle data-driven learning challenges for 5G networks.

Dagnachew Temesgene (ESR04)



In 2017, my first main task has been to carry out a state-of-the-art review, exploring recent advancements in Software Defined Networking (SDN), Network Function Virtualization (NFV), Machine Learning, Network Slicing and Energy Harvesting. The application of these concepts and tools to the Radio Access Network and the resulting architectures were surveyed. Moreover, the training schools were also very helpful as they provided lectures and hands on experience on these topics. The findings from the literature survey have been published in an IEEE Access article entitled “Softwarization and Optimization for Sustainable Future Mobile Networks: A Survey”. This paper presents the interplay among softwarization, optimization and energy harvesting, as the pillars of sustainable mobile networks, and identifies open research challenges that require further investigation. Besides, based on the identified open issues, the study of optimal placement of functional split options for the scenario of energy harvesting virtual small cells is being carried out. I am currently formulating the related optimization problem and solving it by applying dynamic programming, shortest path search in particular. A paper with the description of the approach and simulation results has been submitted to IEEE ICC 2018. These results also served as a basis for our contribution to the WP4 deliverable 4.1. Additionally, a contribution on energy harvesting technologies, energy storage devices and base station power consumption has been made to the WP2 deliverable D2.1. In the future, I am planning to extend the current dynamic programming based solution to scenarios involving more energy harvesting virtual small cells and to compare the algorithm’s performance against static configurations. Finally, applying approximate optimization tools such as reinforcement learning for the same optimization problem is part of my future research plan.

Nicola Piovesan (ESR05)



I have begun my work in SCAVENGE by working on a survey paper about architectures and paradigms for future mobile networks. In this paper, we reviewed the literature about energy saving techniques, energy cooperation between base stations and energy trading with the smart electricity grid. This gave me the opportunity to study existent works and identify open issues. Currently, I am investigating the problem of the increased power consumption due to the augmented system capacity required by 5G networks. This requirement will be meet by deploying more network elements, in particular small cells, in a scenario that is usually referred to as “ultra-dense”. Specifically, I am focusing on the management of self-sustainable small cells that are only powered by renewable energy. The problem of minimizing the consumption of grid energy and maximizing the system performance can be solved by optimally switching ON-OFF the small cells. As a first step, I used graph theory and dynamic programming to find the performance bounds of this approach and published the algorithm and some results in a journal paper. Then, I have studied the impact of the energy harvesting and traffic profile on the optimal policies and submitted the results to the IEEE WCNC conference. In 2018, I plan to improve my knowledge about machine learn-

ing, also through my secondment, in order to exploit these techniques to design online algorithms for the load control of small cells. Furthermore, I plan to investigate energy sharing methods between network elements to further save grid energy and to reduce the carbon footprint of the whole network.

Angel Fernandez Gambin (ESR06)

In 2017, together with ESR05, I have analyzed the role of energy in the design of future mobile networks, advocating the use of energy harvesting hardware as a means to decrease the environmental footprint of 5G technology. A survey journal paper has been accepted, where we review existing energy sustainable paradigms and methods and identify several open issues ranging from the need for accurate data traffic and energy consumption models to the use of power transfer, energy cooperation and energy trading techniques. After this, we examined the tradeoffs involved in the process of wirelessly recharging mobile terminals as they get sufficiently close to base stations using Wireless Power Transfer (WPT) technology. Our performance evaluation revealed that WPT can increase the mobile terminal battery life, however transfer efficiencies are very low. This work led to a conference paper, that I presented to IEEE WoWMoM 2017. Then, I focused on small cell deployments where energy harvesting and packet power networks are combined to provide energy self-sustainability through the use of own-stored energy and carefully planned energy transfers among network elements. Numerical results revealed that my approach is capable of increasing the energy sustainability of the network, reducing the amount of energy purchased from the power grid, and preventing base stations to run out of service due to energy scarcity. A conference and a journal paper have emerged from this research. I presented the conference contribution to IEEE GLOBECOM 2017, whereas the journal is currently under review. My next steps involve the implementation of pattern recognition algorithms through machine learning techniques, to improve the effectiveness of energy cooperation and trading strategies. This is currently under investigation.

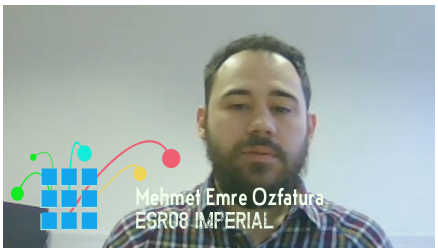
I am currently on leave at CTTC, working on the above topics and establishing collaborations with ESR03, in the design of data analytic techniques for 5G mobile traffic.

Elvina Gindullina (ESR07)

In 2017, I have been working on analyzing and developing a battery management system for mobile devices, in particular, considering non-idealities of batteries, such as leakage, charge recovery and deep discharge effects, which are caused by diffusion processes. By analyzing the outage probability, we demonstrated that these battery imperfections can have a dramatic impact on the operation policy of autonomous devices. A heuristic was devised, which is aimed at reducing events such as battery discharge and data losses for such systems. Results were published and presented at IEEE WCNC 2017 and IEEE ICC 2017. To analyze the management of mobile devices with inhomogeneous energy storage and energy harvesting capabilities, the system was represented as a Bayesian game with asymmetric players. Results were published at IEEE WoWMoM 2017 and demonstrate that knowledge about asymmetric properties provide more balanced performance for energy harvesting wireless networks.

I am currently on leave at Wordsensing in Barcelona, Spain, where I am studying orthogonal resource sharing in wireless networks. Resource sharing aims to enable distributed and dynamic discovery, negotiation and sharing of tasks and resources among nodes in heterogeneous and multi-tasked IoT-like networks. I am considering node-collaboration scenarios with three levels of knowledge about available resources. These activities encompass comparing the scenarios and extracting the best strategy as well as its implementation.

Mehmet Emre Ozfatura (ESR08)



In the last decade, on demand video streaming applications are responsible for most of the Internet traffic and many surveys predict that their share will increase further in the next few years. The boost in the size of the Internet video traffic and the densification process of heterogeneous cellular networks call for a paradigm shift in the design of future cellular networks. One of the most promising approaches to deal with the excessive video traffic is content caching; which entails moving the popular files to the network edge, closer to the final user in an attempt to improve the network performance such as reducing the transmission delay. In the literature, many papers deal with this problem, particularly focusing on cooperative caching, cooperative coded caching and coded delivery. However, we realize that there are only few works on mobility-aware content caching. Driven by these considerations, in 2017 we have started to work on mobility-aware coded storage and coded delivery techniques. Some of our results were published in the IEEE communication letters and some were presented at the ITG Workshop on Smart Antennas (WSA 2018). Moreover, we observed that user requests for the video files do no follow a uniform distribution. Hence, we steered our attention towards coded delivery schemes under non-uniform demand. Our results will be presented at the IEEE International Conference on Communications (ICC) 2018 and soon we will submit an extended journal pa-

per. At Imperial College of London, besides the aforementioned research activity, I am working as a co-advisor for graduation projects, to make undergraduate students familiar with the recent research areas on communication, while improving their research skills and enhancing my supervision abilities. We recently submitted the results of an ongoing graduation project to the IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) 2018. Our current research focuses on four main areas; coded distributed computation, decentralized coded caching schemes, cache replacement strategies for energy harvesting cells and smart transcoding strategies for video streaming in cellular networks. We are also seeking collaborations with other researchers to have a more complete design for future cellular networks.

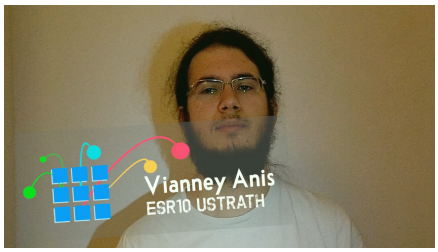
Nitish Mital (ESR09)

In 2017, I have researched literature on coded multicasting techniques for 5G networks, which have the potential to increase the overall efficiency and to reduce the power consumption and delivery latency. Coded caching is a novel method to utilize the memory capacities of devices on a network to supplement the spectrum constraints. There has been a long list of works in this area and industry considers it to be a very important technology for future networks. My work includes proposing a delivery scheme and study the performance of coded caching in a distributed small-cell based scenario.

My paper "Coded caching in a multi-server system with random topology" has been recently presented at IEEE WCNC 2018, where it has received the **best student paper award**. I feel that the environment I am getting from working in the SCAVENGE network and in Imperial College is optimal for my professional growth, because I am in the middle of people working on the best ideas in the area.

Currently, my work is directed towards studying and proposing distributed storage codes in a wireless setting, where files may be stored among multiple devices with dynamic memory management. The goal is to minimize the repair bandwidth (amount of communication among nodes to repair corrupted data) when stored data is disturbed during memory management.

Vianney Anis (ESR10)



In 2017, I continued experimentations on filter-bank multi-carrier systems, with further study of Wavelet based systems. In parallel, I carried out a preliminary study of heterogeneous network optimization problems for the reduction of base-station energy consumption, it included a listing of the involved variables, and various attempts at formulating the problem. This study is a first step towards the description of the considered heterogeneous network scenario as an optimization problem that can be solved using methods such as Bayesian networks and Dynamic programming. I also contributed to two SCAVENGE deliverables (within WP2 and WP4) and was amongst the main editors of one of the deliverables. These documents opened the discussions for future collaborations with other ESRs. My future research plans include further study and experimentations with filter-bank multi-carrier transceiver systems, which should soon lead to the implementation of a low-power TV white space base-station prototype on a software defined radio platform. This implementation work would mostly be carried out during my SCAVENGE secondment in *Toshiba Research Europe* in Bristol (9 months from April 2018). Using this radio system, we will extract a power consumption model which will be reused in the formulation of a heterogeneous network optimization problem.

Thembelihle Dlamini (ESR11)

Future cellular networks are required to be flexible with minimal infrastructure complexity, unlike current ones that rely on proprietary network elements to offer their services. Moreover, they are expected to make use of renewable energy to decrease their carbon footprint and of virtualization technologies for improved adaptability and flexibility, thus resulting in green and self-organized systems. In my project, I have focused on first understanding the core network management procedures, particularly the charging gateway function in order to develop guidelines for softwarizing it. From this work, I have observed that it is possible to visualize the extracted data over a Web dashboard and perform data analytics over the extracted data to identify traffic variation patterns. Thus, I have compared power consumption between virtualized computing platforms and "bare metal" using experimental power datasets and the server power consumption model, which considered the utilization of the CPU and other system components (memory, disk, network interface card). In this work, I have considered container- and hypervisor-based virtualized systems to better understand their power consumption in response to different applications. From my results, we have identified that each server will respond differently in response to the running application on the virtual machine or container, as the power consumption always varies. This makes it possible for the virtualized server to be power-aware, exploiting knowledge of the consumed power per time slot, and then mapping server utilization to the available energy stored, in renewable-powered networks. Also, I have observed the effects of CPU pinning, i.e., the lack of scheduling, in the virtualized servers,

and such insights can enable the development of auto-scaling policies (CPU and Memory utilization rules) since they guarantee latency for real time services demanded by users. The performance per watt ratings for the network function virtualized infrastructure (NFVI) shows a different response in relation to the benchmarks used. Lastly, we have worked on developing machine learning algorithms for edge workload prediction, using the long short term memory (LSTM) network for regression, using open source mobile traffic datasets, and then developed energy saving policies for virtualized systems for a remote site, thus enabling network coverage extension. From the obtained results, we have observed that we can use the past behavior of the network to project hour-ahead server workload estimates for a remote site, thus being able to provision edge network resources. My future work entails the development of mobility management procedures, for ultra-dense networks coexisting with virtualized computing platforms. A review journal paper has been accepted on softwarization technology for 5G networks, another journal paper is being prepared and conference paper will be submitted.

I am currently on leave at the Department of Information Engineering of the University of Padova.

Pavlos Triantaris (ESR12)

After completing my mandatory education (i.e., sixth-form equivalent, with mathematical/engineering foundation), I was accepted into the School of Engineering of the Aristotle University of Thessaloniki, Greece, in September of 2011, for a full-time M.Eng. course. Almost six years after initial enrollment, I completed my studies and acquired an M.Eng. degree in Electrical Engineering, with a GPA of 8.72/10, which is a First-Class Honors equivalent. During the course of the programme, I was involved in two projects with outlook towards research:

1) "ERPs-based Attention Analysis Using Continuous Wavelet Transform: The bottom-up and top-down paradigms". Written by a group of 8 students under the supervision of Prof. Leontios Hadjileontiadis and Chrysa Papadaniil. Submitted to the 14th Mediterranean Conference on Medical and Biological Engineering and Computing, qualified for the competitive phase of the conference.

2) "Accelerometer Data Processing for the Recognition of Hand Movements". Master's Thesis. Prepared under the supervision of Prof. Hadjileontiadis. Utilised hardware and developed software subsequently given to the Georgios Papanikolaou General Hospital of Thesaloniki for purposes of medical research.

In June, 2017, I was accepted into the SCAVENGE project as part of their team of Early Stage Researchers. In that, I also became a student of the Imperial College of London and an employee of Toshiba Research Europe Ltd. Having spent my first months as a PhD student in the facilities of Toshiba in Bristol, UK, I can only relay the best impressions about my employers, and I can state with confidence that the facilities and resources to which I have access thanks to them are most satisfactory in all respects. I believe that, thanks to the format of the SCAVENGE project for its ESRs, I shall gain invaluable experience in research and scientific work, in both academic and workplace scenarios.

An early-stage study of selected literature suggested that an interesting sub-area open to further research is the identification of the activity of specific devices within the context of a wireless system. As a result, the idea which was developed under this consideration is the development of an advanced algorithm which will leverage understanding of RF imperfections and Artificial Neural Networks in order to passively extract a fingerprint and identify each individual device which is active in the spectrum of a given access point or base station. The next phase of this study shall be a thorough attempt to understand the function and use of ANNs, as well as auxiliary signal processing techniques. As such, year 2018, during which my secondment at the Imperial College shall begin, shall be partly dedicated to the study of ANNs and partly to the development of new ANN-based models for device identification.

Ioana Suciu (ESR13)

This past year spent as a Scavenge Early Stage Researcher has been filled with opportunities, challenges and accomplishments: not only regarding the training but also regarding the way we, the ESRs, learned how to successfully collaborate inside the SCAVENGE project. The training schools organized by Scavenge represented great opportunities: not only for their invited speakers and the knowledge brought but also for the opportunity they gave us to share our training background experiences and to build real research teams. This, as well as working for the work packages thought us how to collaborate as research teams and it helped us broaden our knowledge outside our individual research projects. Regarding the challenges and accomplishments met during this past year, I significantly improved my technical and theoretical skills by following training activities in my host institution, Worldsensing. As Worldsensing is a well-known IoT pioneer company, training activities in embedded firmware development, energy consumption measurements, testings of wireless communication relia-

bility, etc, were carried out with the utmost professionalism. As a result, we recently submitted a paper analyzing the impact of packet fragmentation in Low Power Wide Area Networks and we are currently working on a new paper. Regarding future plans, I could only hope that the next year will bring me as many achievements as this one, and that I will be able to continuously improve as a researcher and as a person.

Soheil Rostami (ESR14)

Hello, I am Soheil Rostami, I have been hired by Huawei Finland to work as an Early Stage Researcher in the SCAVENGE training network. At Huawei, I am carrying out research on 5G networks, focusing on energy efficient transceiver architectures and on designs enabling low-energy operations for uplink and downlink communications. I am paying particular attention to energy efficient scheduling, which allocates resources in order to maximize the sleeping time for both mobile terminals and base stations, and to minimize their energy consumption through discontinuous and adaptive receiving / transmission scheduling (DRX/DTX). Furthermore, I am currently designing a wake-up scheme and the corresponding signaling for mobile devices to reduce the energy consumption of the devices when in power-saving mode. Different measurements show that current DRX techniques are not able to provide major energy savings, therefore a novel wake-up scheme is being investigated to tackle such a problem. For this, I have been designing the signal structure, a maximum-likelihood receiver, and have been assessing the corresponding implementation challenges. At Huawei, we hope to impact current 5G standardization activities, based on the promising results that we have recently obtained. Some papers are currently under submission and others in preparation.

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