NETWORKING (NET)

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Background and Mission

The mission of the Networking Group (NET) is to conduct high level research and provide leading solutions in the field of wireless networks as well as the high level graduate and postgraduate education in this filed. NET is internationally perceived as a forerunner in its field, and a valued partner for research.

Its success is due to the capability to react fast to the changes taking place in the operational environment, as well as to the needs expressed by its research partners. As a provider of high-quality university training, NET aims at producing theses and dissertations, and peer-reviewed publications of the highest rank and extensive set of postgraduate courses within the PhD program for networking.

Scientific Progress

Sociality-aided new adaptive infection recovery schemes for multicast DTNs

Delay-tolerant networks (DTNs) consist of nodes moving around and occasionally coming into each other's proximity. During the limited proximity time, nodes can exchange data; this can result in a very slow data dissemination process that is usually governed by a replication-based mechanism. However, due to the long propagation delay and the large overhead associated with the replication approach, DTN delivery performance is neither efficient nor effective. To reduce the overhead, which becomes a critical aspect particularly when addressing a multicast scenario, infection recovery mechanisms have been proposed to control and reduce the number of copies of a packet circulating through the network. This, however, has the cost of decreasing the chances of delivering packets to all destinations. In this paper, adaptivity in infection recovery is addressed. This represents a viable solution to make transmission more reliable, hence delaying the activation of the infection recovery procedure, depending on the number of nodes, destinations, and the time. Moreover, we also propose to exploit an additional feature in data multicasting, i.e., socially aided data dissemination, where the packet dissemination procedure is not trivially epidemic, but rather exploits the intrinsic sociality of users and their interests to reduce the delivery overhead and speed up the multicast process. More specifically, we consider a procedure where users are not regarded as individual members of the network but can be aggregated into groups sharing interests, and their sociality helps the data dissemination procedure. Results of our analysis show that new sociality-aided adaptive recovery schemes can speed up the delivery process. The system operation in infection phase is illustrated in Figure 1 and in recovery phase in Figure 2.

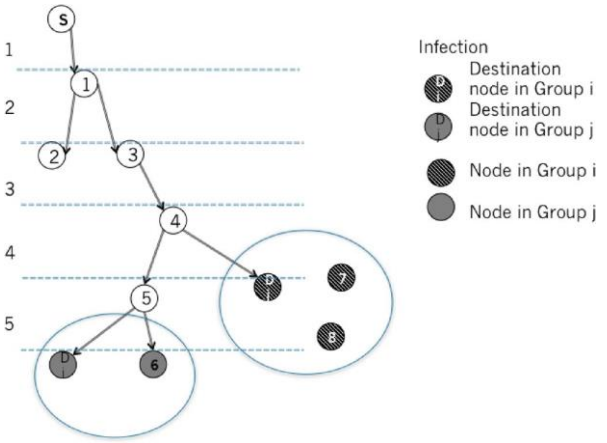

Figure 1. Example of system functioning: infection phase.

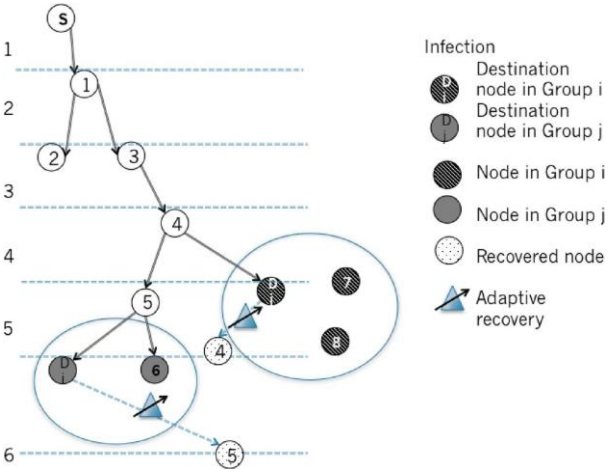

Figure 2. Example of system functioning in recovery phase.

Framework for Dynamic Network Architecture and Topology Optimization

A new paradigm in wireless network access is presented and analyzed. In this concept, certain classes of wireless terminals can be turned temporarily into an

access point any time while connected to the Internet. This creates a Dynamic Network Architecture (DNA) since the number and location of these APs vary in time. In this paper, we present a framework to optimize different aspects of this architecture. First, the dynamic AP association problem is addressed with the aim to optimize the network by choosing the most convenient APs to provide the QoS levels demanded by the users with the minimum cost. Then, an economic model is developed to compensate the users for serving as APs and thus, augmenting the network resources. The users' security investment is also taken into account in the AP selection. A pre-clustering process of the DNA is proposed to keep the optimization process feasible in a high dense network. To dynamically reconfigure the optimum topology and adjust it to the traffic variations, a new specific encoding of genetic algorithm (GA) is presented. Numerical results show that GA can provide the optimum topology up to two orders of magnitude faster than exhaustive search for network clusters and the improvement significantly increases with the cluster size. The concept of the network is presented in Figure 3.

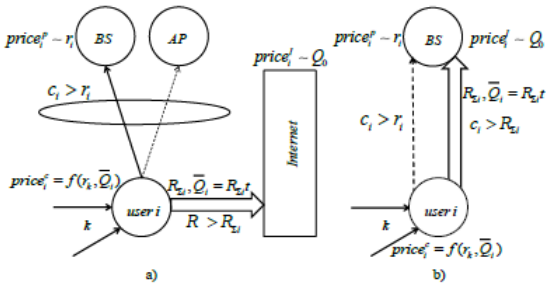

Figure 3. DNA network model with T/W(r)/I(Q) contract with: a) wired Internet and b) wireless Internet.

Optimal Scheduling for Multi-radio Multi-channel Multi-hop Cognitive Cellular Networks

Due to the emerging various data services, current cellular networks have been experiencing a surge of data traffic and already overloaded, thus not able to meet the ever exploding traffic demand. In this study, we first employ a Multi-radio Multi-channel Multi-hop Cognitive Cellular Network (M3C2N) architecture to enhance network throughput. Under the proposed architecture, we then investigate the minimum length scheduling problem by exploring joint frequency allocation, link scheduling, and routing. In particular, we first formulate a maximum independent set based joint scheduling and routing optimization problem called OOP. It is a Mixed Integer Non-Linear Programming (MINLP) and generally NP-hard problem. Then, employing a column generation based approach: we develop an ϱ-bounded approximation algorithm which can obtain an ϱ-bounded approximate result of OOP. Noticeably, in fact we do not need to find the maximum independent sets in the proposed algorithm, which are usually assumed to be given in previous works although finding all of them is NP-complete. We also revisit the minimum length scheduling problem by considering uncertain channel availability. Simulation results show that we can efficiently find the ϱ-bounded approximate results and the optimal result as well, i.e., when ϱ = 0% in the algorithm.

Quantifying Benefits in a Business Portfolio for Multi-Operator Spectrum Sharing

Multi-operator spectrum sharing in wireless networks has recently become the subject of intensive research. It heavily depends on the traffic misbalance in the networks belonging to different operators. In this paper, we study the likelihood that such misbalance occurs in networks with high traffic dynamics. An extensive business portfolio for heterogeneous networks is presented to analyse the benefits due to the multi-operator cooperation for spectrum sharing. Pricing models are developed to dynamically facilitate the price adaptation to the system state. By using queuing theory, we quantify the operators' gains in cooperative arrangements as opposed to non-cooperative independent operation. Under the condition that there is a traffic underflow in one band, it has been shown that with capacity aggregation model, the operator operating in other band can take advantage of additional channels with probability close to 1. Quantitative results are provided for those gains as a function of the number of cooperating operators. In capacity borrowing/leasing model, this advantage is not unconditional, and there is a risk that the operator leasing the spectra will suffer temporary packet losses. When cognitive models are used in a network with high traffic dynamics, 50-70% of the spectra may be lost due to channel corruptions caused by the return of primary users. The gains from traffic offloading from a cellular network to a WLAN are quantified by an equivalent increase in opportunistic capacity proportional to the ratio of aggregate coverage of cellular networks and WLANs.

An example of the business model is illustrated in Figure 4 and probability distribution function for the spectra occupancy by operator 1 and two (n_1,n_2) in Figure 5.

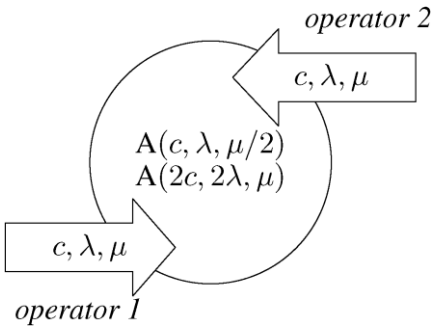

Figure 4.1. Capacity aggregation - A model.

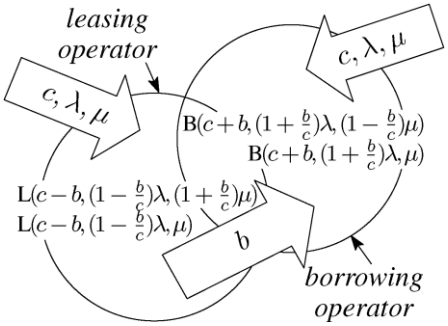

Figure 4.2. Capacity borrowing/leasing - BL model.

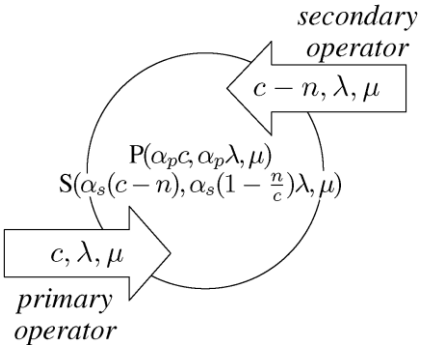

Figure 4.3. Cognitive networks - C model.

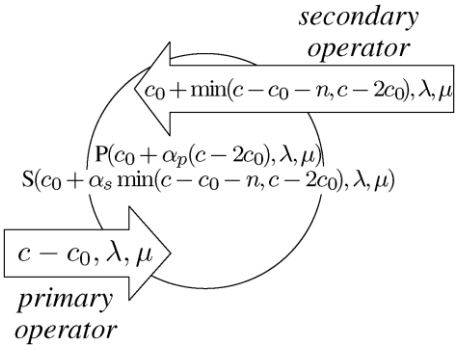

Figure 4.4. Partial cognitive networks - PC model.

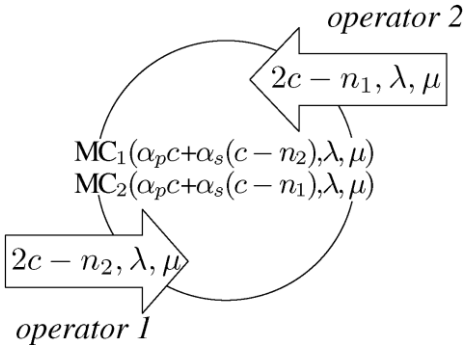

Figure 4.5. Mutually cognitive networks - MC model.

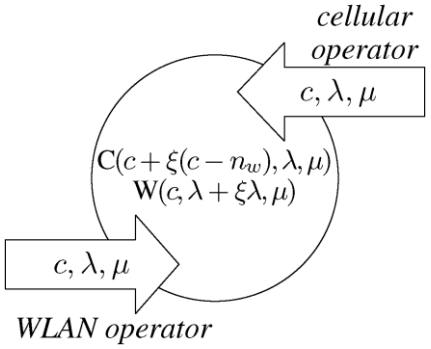

Figure 4.6. Spectra aggregation in heterogeneous network - CW mode.

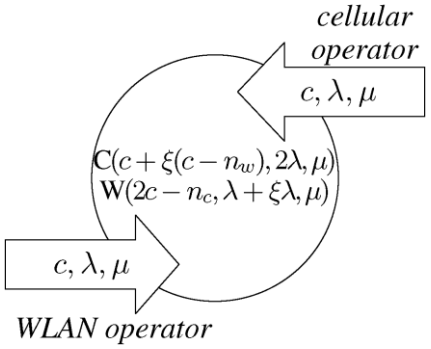

Figure 4.7. Spectra aggregation in heterogeneous network - CWC mode.

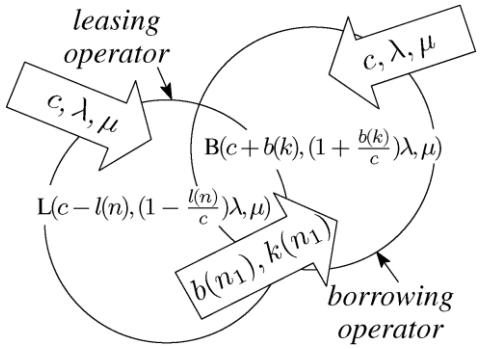

Figure 4.8. Channel lending with pricing.

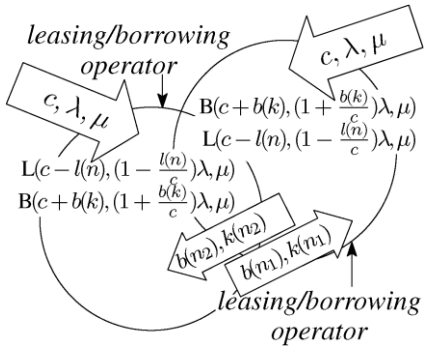

Figure 4.9. Mutual channel leasing with pricing.

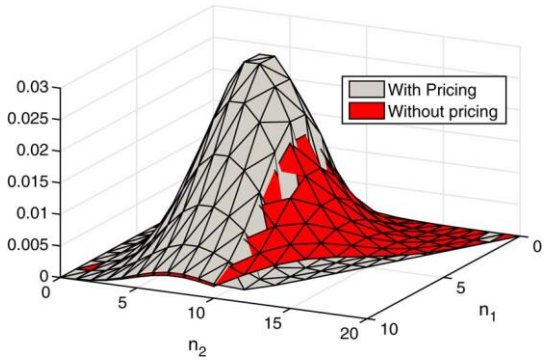

Figure 5. Pn_1n_2 for BL system with pricing, λ_1=5, λ_2=8, μ=1 and c=10.

Resource Harvesting in Cognitive Wireless Computing Networks with Mobile Clouds and Virtualized Distributed Data Centers: Performance Limits

We consider a virtualized data center (computing cloud) illustrated in Figure 6, consisting of a set of servers hosting a number of mobile terminals forming a mobile cloud, and study the problem of optimal resource allocation in the presence of time varying workloads and uncertain channels. The channel uncertainty may be either due to fading and/or uncertain link availability and reliability in cognitive wireless networks. The servers are processing certain applications delegated to them by the terminals, for either energy saving or due to the lack of necessary software at the terminal to process the applications. The control problem is to dynamically adjust resources in reaction to channel and workload fluctuations in order to maximize a joint utility of the long-term average application processing throughput and to minimize the energy cost of the overall system while maintaining the network stability. We have carried out a unified stability analysis and illustrated joint stability regions for both cognitive and conventional wireless networks. Dynamic programming is used to design a dynamic policy that is shown to support every point on the network stability region without using the information of arrival statistics. The policy also mitigates the mutual impact of primary and secondary service providers on each other.

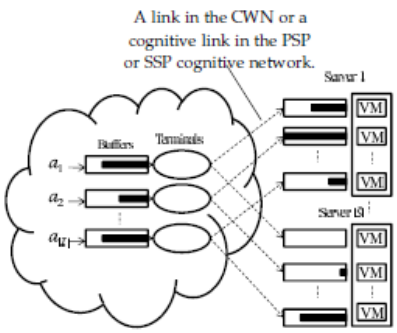

Figure 6. Virtualized distributed data centres.

Power Efficient Resource Allocation in a Heterogeneous Network with Cellular and D2D Capabilities

This work focuses on a heterogeneous scenario, illustrated in Figure 7, where cellular and wireless local area technologies coexist and where User Equipments (UEs) are enabled with device-to-device communication capabilities. In this context, this paper assumes a network architecture in which a given UE can receive a mobile service either by connecting directly to a cellular base station or by connecting through another UE that acts as access point and relays the traffic to/from a cellular base station. The paper investigates the optimization of the connectivity of the different UEs with the target to minimize the total transmission power in the scenario. An optimization framework is presented and a distributed strategy based on Q-learning and *softmax* decision making is proposed as a means to solve the considered problem with reduced complexity. The proposed strategy is evaluated under different conditions, and it is shown that it is able to achieve a performance very close to the optimum one provided that the temperature parameter of the *softmax* decision making is properly set by means of a cooling function. Moreover, significant transmission power reductions in the order of 40% are obtained with respect to the classical approach in which all users are connected to the cellular infrastructure.

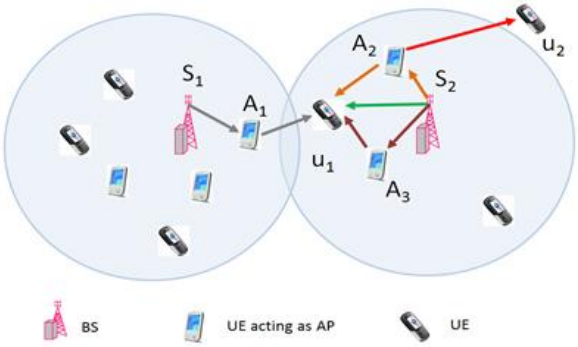

Figure 7. Considered scenario: heterogeneous network with D2D capabilities.

The Naked Approach (The Naked User Approach – Nordic Perspective to Gadget-free Hyperconnected Environments)

The Naked Approach project will start a research and development path towards a significant paradigm shift changing the digital world from gadget-centric to user-centric, gadget free ("naked") environment.

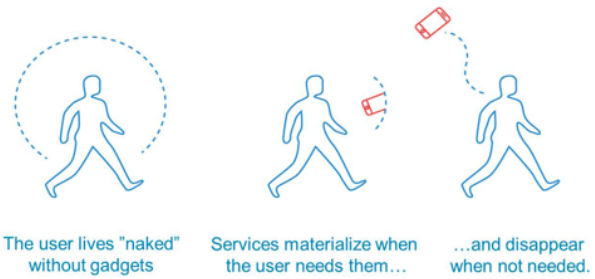

Figure 8. Gadget-free hyperconnected environments.

The Naked Approach project is seeking and developing alternative, human-centric ways of producing and consuming digital services. The driving vision is digital paradise, where users can live "naked" without carry-on gadgets. The digital services appear to the user from the texture of the environment when needed and then completely disappear when not needed anymore.

NET is leading "the Surrounding as a service" work package. We are working on developing the new communication architecture as well as studying the rising security and privacy issues in order to realize new digital interaction paradigms. While developing the new security and communication architecture, the Nordic values – respectful co-living and trust – are emphasized as a part of new services and products – on our way towards the hyperconnected world of the future.

SIGMONA (SDN Concept in Generalized Mobile Network Architectures)

The SIGMONA project aims at evaluation, specification and validation of a Software Defined Mobile Network concept designed onto the software defined networking (SDN), network virtualization and cloud computing principles. The project will provide an insight into the feasibility and opportunities of such network concepts, as well as evaluate the limits of performance and scalability of the new technologies applied on mobile broadband networks.

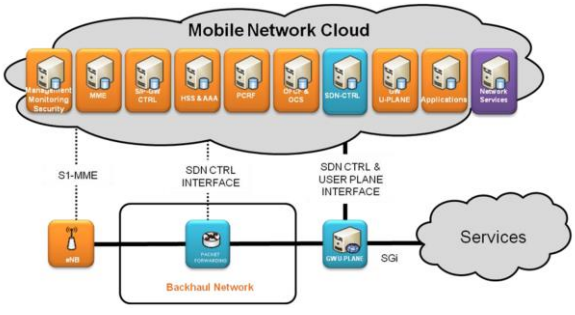

Figure 9. SIGMONA SDN concept.

NET is leading Security work package. We address the security aspects for future mobile networks while adapting SDN, virtualization and cloud computing concepts into telecommunication networks. We design a consolidate security architecture and evaluate performance limits and scalability by using Proof-of-concept demonstrations. We also contribute to 3GPP in terms of corrections or new contributions for security management in (virtualized) mobile networks.

CONVINcE (Consumption Optimization in Video Networks)

CONVINcE is an Eureka Celtic Plus research project that focuses on reducing power consumption of IP-based video networking with an end-to-end approach. The power consumption characteristics of video networking is studied and optimized along the media path from the Head End, where content is encoded, to the terminals, where the content is consumed, embracing the CDN and the core access networks between them. The effort concentrates on architectures, hardware and software design, protocols and basic technologies in the devices, as well as software best practices and power measurements.

University of Oulu leads the biggest work package of the project, concerning terminal side energy consumption. The primary research focus is on the energy-efficiency of multimedia sensing and delivery mechanisms, lightweight security mechanisms and power consumption estimation algorithms in the context of constrained devices and networks.

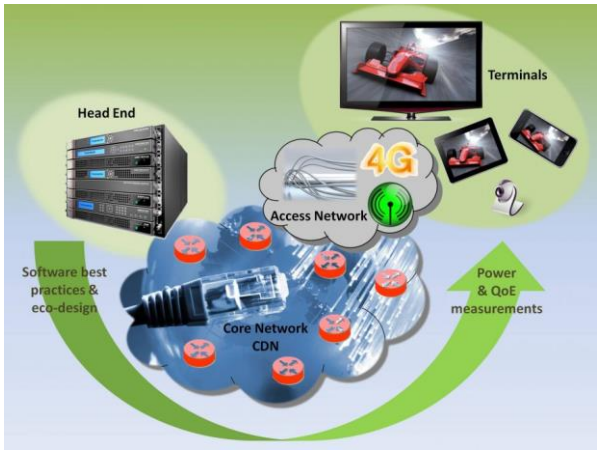

Figure 10. Consumption optimization in video networks.

Smart Water Measurements: Applications, Communication technologies, and Challenges

After the big popularity gained in the smart grid, there has been a desire to develop a similar technology for the water system. The limited availability of fresh water and the increasing water demand globally have been critical issues that smart water management systems have to be employed to match the user needs and to avoid unnecessary wasting. From this perspective, a smart water measurement system is one viable solution envisaged to perform automatic water measurements. It applies smart water meters, communication networks,

and advanced IT systems to get access to real-time or near real-time data about hydraulic and water quality, water consumption, leakage, and its related water problems thereby providing intelligence to water utilities and customers. A survey of smart water measurements for drinking water systems in urban areas is conducted with a focus on some applications with special interest in wireless smart water metering and water quality monitoring. As communications is a key element between the smart water meters and the utility servers, the most promising communication technologies and protocols for this application are reviewed. Challenges and open research issues that smart water metering networks must address to realize the technology are also addressed.

Resilient Smart Grid Communications in LTE Network using Ad Hoc mode

LTE network is a good choice for delivering smart grid demand-response traffic. However, a base station may be malfunctioning due to natural phenomena, hardware abrasion, or software errors. A solution is proposed to overcome a problem that a directly reachable LTE base station is not available for a smart meter. The solution is to develop an ad hoc mode for LTE-Advanced user equipment. The ad hoc mode is applied to reach a relay node that is the nearest user equipment with base station connection. Demand-response traffic is delivered between clusters of user equipment and the relay node using multihop communications. Analytical Markov process models and a Riverbed Modeler network simulation model are implemented to illustrate the functionalities and the performance of the system when demand-response traffic is delivered with multiple transmission power values. A detailed physical layer propagation model for device-to-device communications, a static resource allocation in time domain, hybrid automatic repeat request retransmissions, and a capability for user equipment to receive uplink transmissions are modeled. All packets are successfully delivered at most with the fourth transmission attempt and the average network delay is low enough to support most of the smart grid demand-response applications.

Personnel

professors	2
postdoctoral researchers	2
doctoral students	13
other research staff	2
total	**19**
person years for research	16

External Funding

Source	**EUR**
Tekes	723 000
domestic private	100 000
international	250 000
total	**1 073 000**

Selected Publications

L. Galluccio, B. Lorenzo and S. Glisic , Sociality-aided new adaptive infection recovery schemes for multicast DTNs, IEEE Transactions on Vehicular Technology, May 2015

Alireza S. Shafigh, Beatriz Lorenzo, Savo Glisic, Jordi Pérez-Romero, Luiz A. DaSilva, Allen B. MacKenzie and Juha Röning-A Framework for Dynamic Network Architecture and Topology Optimization-IEEE/ACM Transactions on Networking, January 2015

Ming Li, Sergio Salinas, Pan Li, Xiaoxia Huang, Yuguang Fang, and Savo Glisic, Optimal Scheduling for Multi-radio Multi-channel Multi-hop Cognitive Cellular Networks, IEEE Transactions on Mobile Computing, January 2015

I. Sugathapala, I. Kovacevic, B. Lorenzo, S. Glisic, Y. Fang. Quantifying Benefits in Business Portfolio for Multi-Operator Spectrum Sharing. IEEE Transactions on Wireless Communications, vol. 14, no. 12, pp. 6635 - 6649, July 2015.

Maria Kangas, Savo Glisic, Yuguang Fang and Li Pan, "Resource Harvesting in Cognitive Wireless Computing Networks with Mobile Clouds and Virtualized Distributed Data Centers: Performance Limits, accepted to IEEE transactions on Cognitive Communications and Networking, December 2015.

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Madhusanka Liyanage, Ijaz Ahmed, Mika Ylianttila, et al, Security for Future Software Defined Mobile Networks , in Proc. of 9th International Conference on Next Generation Mobile Applications, Services and Technologies (NGMAST,2015), Cambridge, UK. September 2015. Best Paper Award

P. Porambage, A. Braeken, C. Schmitt, A. Gurtov, M. Ylianttila, B. Stiller, Group Key Establishment for Enabling Secure Multicast Communication in Wireless Sensor Networks Deployed for IoT Applications, IEEE Access, vol 3, pages 1503-1511, September 2015.

P. Porambage, A. Braeken, P. Kumar, A. Gurtov, M. Ylianttila, Efficient Key Establishment for Constrained IoT Devices with Collaborative HIP-based Approach, Proc. of IEEE Globecom, December 2015.

A. Heikkinen, T.Koskela, M. Ylianttila, “Performance Evaluation of Distributed Data Delivery on Mobile Devices Using WebRTC”, Proc. International Wireless Communications & Mobile Computing Conference (IWCMC’15), August 2015.

B.G. Gebremedhin, J. Haapola and J. Iinatti. Performance Evaluation of IEEE 802.15.4k Priority Channel Access with DSSS PHY, European Wireless 2015, Budapest, Hungary, 20-22 May 2015.

J. Markkula, J. Haapola. Resilient Smart Grid Communications in LTE Network Utilising Ad Hoc Mode. IEEE Transactions on smart grid. (Submitted).