COMMUNICATIONS SIGNAL PROCESSING (CSP)

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Background and Mission

The mission of the Communications Signal Processing (CSP), Radio Frequency Engineering (RFE) and Wireless Medical Communications (WiMEC) Research Groups (RGs) operating within Centre for Wireless Communications (CWC) – Radio Technologies (RT) as well as Networks and Systems (NS) of Faculty of Information Technology and Electrical Engineering is to conduct world-class research, train world-class graduates, create new technology and IPRs, and support society by transferring technology to practical usage. CSP focuses on signal processing algorithm, architecture and device implementation technologies combined with appropriate electromagnetism based radio engineering and channel modelling tools with applications on 5G systems, internet of things (IoT) medical and health applications among others.

The scope of the activity covers signal processing for wireless and communications systems as well as related radio and medical engineering. The core applications for which the technology is developed include wireless access systems and related devices, wireless sensor networks, and medical diagnostic and treatment systems and devices. The main application areas and practical systems for which the developed technology and scientific knowledge are targeted include primarily wireless access systems and related devices, including 3GPP Long Term Evolution (LTE) – Advanced and the so-called 5G systems beyond it, internet of things (IoT), and IEEE802.11 WLAN evolution, and various industrial and other sensor and actuator systems, networks and related devices, IEEE802.15 standard family evolution with special emphasis on health care and medical WBANs.

Scientific Progress

The research in the CSP RG is realized under five main research areas: wireless algorithms and architectures, crosslayer statistical inference, radio engineering, wireless medical communications and nanoscale communications and networks.

Wireless Algorithms and Architectures

Radio Resource Allocation Algorithms

We have studied beamforming techniques for energy efficiency maximization (EEmax) in multiuser multiple-input single-output (MISO) downlink system. For this challenging nonconvex problem, we first derive an optimal solution using branch-and-reduce-and-bound (BRB) approach. We also propose two low-complexity approximate designs. The first one uses the well-known zero-forcing beamforming (ZFBF) to eliminate inter-user interference so that the EEmax problem reduces to a concave-convex fractional program. Particularly, the problem is then efficiently solved by closed-form expressions in combination with the Dinkelbach's approach. In the second design, we aim at finding a stationary point using the sequential convex approximation (SCA) method. By proper transformations, we arrive at a fast converging iterative algorithm where a convex program is solved in each iteration. We further show that the problem in each iteration can also be approximated as a second-order cone program (SOCP), allowing for exploiting computationally efficient state-of-the-art SOCP solvers. Numerical experiments demonstrate that the second design converges quickly and achieves a near-optimal performance. To further increase the energy efficiency, we also consider the joint beamforming and antenna selection (JBAS) problem for which two designs are proposed. In the first approach, we capitalize on the perspective reformulation in combination with continuous relaxation to solve the JBAS problem. In the second one, sparsity-inducing regularization is introduced to approximate the JBAS problem, which is then solved by the SCA method. Numerical results show that joint beamforming and antenna selection offers significant energy efficiency improvement for large numbers of transmit antennas.

Weighted sum rate maximization (WSRMax) with user specific quality-of-service (QoS) constraints and general convex transmit power constraints is considered in multi-cell multi-user multiple-input multiple-output system. The particular focus in the proposed joint transmitter-receiver design is on tractability in terms of implementation and moderately fast changing/time correlated channel conditions. The non-convex transmit precoder design problem is formulated as a difference of convex functions program, for which a locally optimal solution is achieved by successive convex approximation (SCA). To achieve practically realizable designs, two decentralized approaches with low signaling overhead are proposed. Primal decomposition based solution provides better compliance of the provided QoS constraints in slowly fading channel conditions. On the other hand, solution based on Lagrangian relaxation of the coupling rate constraints is proposed for relaxed feasibility conditions and improved convergence properties. As a special case, an iterative solution via the Karush–Kuhn–Tucker conditions of the precoder design problem with per base station transmit power constraints is also proposed. Finally, we propose a heuristic extension of the SCA method, which is shown to significantly improve the rate of convergence while achieving comparable sum rate with recently published methods.

We consider a downlink multi-cell multiple-input multiple-output (MIMO) interference broadcast channel (IBC) using orthogonal frequency division multiplexing (OFDM) with multiple users contending for space-frequency resources in a given scheduling instant. The problem is to design precoders efficiently to minimize the number of backlogged packets queuing in the coordinating base stations (BSs). Conventionally, the queue weighted sum rate maximization (Q-WSRM) formulation with the number of backlogged packets as the corresponding weights is used to design the precoders. In contrast, we propose joint space-frequency resource allocation (JSFRA) formulation, in which the precoders are designed jointly across the space-frequency resources for all users by minimizing the total number of backlogged packets in each transmission instant, thereby performing user scheduling implicitly. Since the problem is nonconvex, we use the combination of successive convex approximation (SCA) and alternating optimization (AO) to handle nonconvex constraints in the JSFRA formulation. In the first method, we approximate the signal-to-interference-plus-noise ratio (SINR) by convex relaxations, while in the second approach, the equivalence between the SINR and the mean squared error (MSE) is exploited. We then discuss the distributed approaches for the centralized algorithms using primal decomposition and alternating directions method of multipliers. Finally, we propose a more practical iterative precoder design by solving the Karush–Kuhn–Tucker expressions for the MSE reformulation that requires minimal information exchange for each update. Numerical results are used to compare the proposed algorithms to the existing solutions.

Transceiver Architectures

We consider application specific integrated circuit (ASIC) designs and performance comparison of linear minimum mean-square error (LMMSE) and K-best list sphere detector (LSD) algorithms for 4 × 4 and 8 × 8 multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) systems. Higher data rate and lower power consumption requirements set new challenges for implementation. An optimal detector would be able to change the detection algorithm to suit the channel conditions in order to minimize the power consumption. The detectors are designed for three different modulation schemes using 28 nm complementary metal oxide semiconductor (CMOS) technology. The communications performance is evaluated in 3GPP Long-Term Evolution (LTE) system. The impact of transmit precoding is considered. The ASIC designs aim at meeting the detection rate requirements in LTE, and complexity and power consumption results are found. Based on the implementation and communications performance results, we show the performance–energy efficiency and performance–complexity comparison. We also present the most suitable scenarios for a low-power detector and show how the transmit precoding impacts the detector selection.

Crosslayer Statistical Inference

We have considered lossy compressed sensing (CS) of a sparse source is studied. A lower bound to the best achievable compression performance in a finite-rate CS setup is established by providing support side information to the encoder and decoder. The rate-distortion problem is formulated via remote source coding and conditional rate-distortion theory. The best encoder separates into an estimation step and a rate-dependent transmission step. Numerical results illustrate the rate-distortion behavior of the scheme. We have further considered distributed finite-rate quantized compressed sensing (QCS) acquisition of correlated sparse sources in wireless sensor networks. We propose a distributed variable-rate QCS compression method with complexity-constrained encoding to minimize a weighted sum of the mean square error distortion of the signal reconstruction and the average encoding rate. The variable-rate coding is realized via entropy-constrained vector quantization, whereas the restrained encoding complexity is obtained via vector pre-quantization of CS measurements. We derive necessary optimality conditions for the system blocks for two-sensor case. Numerical results show that our proposed method efficiently exploits the signal correlation, and achieves superior distortion-rate compression performance.

We analysed the outage probability of 3-node lossy-forward (LF) relaying where line-of-sight (LOS) component is taken into account. The source-destination link suffers from block Rayleigh fading, whereas the source-relay and relay-destination links undergo independent block Rician fading. The outage probabilities of the LF relaying are derived on both the Gaussian codebook capacity and the constellation constrained capacity. It is found that regardless of the presence of the LOS component, LF can achieve superior performance compared to adaptive decode-and-forward (ADF) and compress-and-forward (CF). The ε-outage achievable rate is further investigated. It is shown that the ε-outage achievable rate is larger with LF than that with ADF. Moreover, the larger the LOS component ratio, the greater the ε-outage achievable rate. This paper also investigates the optimal location for the relay node in terms of the lowest outage probability. With LF, the optimal location of the relay is found to be closer to the destination than it is with ADF. The accuracies of the analytical results are verified by a series of Monte Carlo computer simulations.

Radio Engineering

Radio engineering is shaping it's scope at the moment. In addition to already strong antenna and propagation research RF transceivers and their implementation aspects will be strengthened in the research portfolio. For that professor nomination process is on-going and project planning started.

Antennas and Propagation

Antenna and propagation research has progressed under various topics. Antenna over-the-air measurements as well as 5G channel propagation measurements have been performed using developed measurement systems. Antenna structures have been developed both for wearable wireless medical and for infrastructure applications.

The advantages of a MIMO system have been under extensive research, and results show they are heavily dependent on the directional properties of the radio channel. To enable comparison between various MIMO terminals, they should be measured using comparable methods in realistic radio channel conditions. Signal throughput has been agreed in the CTIA forum to be the most significant figure of merit for testing LTE devices, because all the LTE services are digital and therefore the final performance of the LTE terminal can be quantified by its ability to transmit and receive digital data.

MIMOTA-2 research project started in June 2014 as a goal to study and compare different over-the-air (OTA) methods for MIMO terminal testing. Both experimental and simulation studies are used to evaluate the accuracy of the MIMO OTA test method. A goal of the simulations is to find cost effective and sufficiently accurate measurement configurations for different communication cases in different radio channel environments. The results are significant e.g. for CTIA standardization work for the MIMO terminal test methods.

A MIMO OTA measurement setup was built in the radio anechoic chamber and a measurement campaign was performed in autumn 2014. In the measurements, repeatable realistic MIMO radio channel conditions for urban environments are generated for mobile MIMO terminal throughput tests. The main goals of the campaign were to research minimum required radius of the measurement setup and to study human hand effects for MIMO terminals.

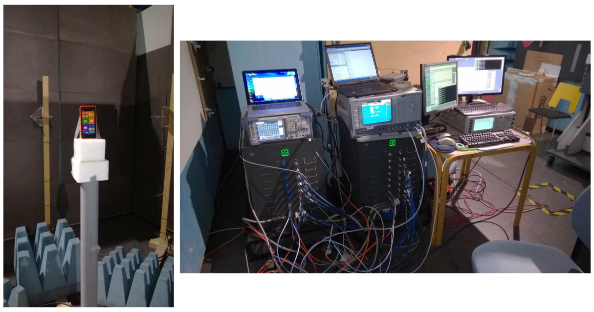

Figure 1. MIMO-OTA measurement system.

Antenna research in the field of wireless medical applications is focused on UWB on-body antennas. Instead of directly comparing the performance of the different types of antennas, the interaction between an antenna and a body is more interesting as well as radio wave propagation mechanism on a body. High-loss operation environment and the requirements for efficient antennas have led to the basic research in the electromagnetic field behavior close to the human body. The achieved theoretical results explain the antenna – human body interaction in wide frequency range and novel antenna structures based on this knowledge are developed. Further, theoretical findings are applied in 2.45 GHz frequency band and especially on the electromagnetic wave propagation around the human body, where significant improvements on received electric field strength are achieved. In addition, a new design method using artificial anisotropic material for controlling polarization properties has been developed. One application of this method is to decrease losses between planar antennas on a human body.

In a research oriented customer project a passive wideband antenna element was designed for active antenna system at 1.7-2.7 GHz bandwidth fulfilling targets of the research partner. The antenna structure was based on the dual-element dual-polarized sub-arrays.

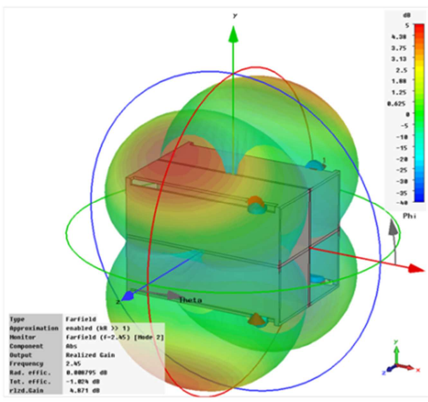

Figure 2. Example of antenna radiating pattern from [Sonkki et al,, "Four slot MIMO cube …," XXIX URSI National Symposium, Valencia, Spain].

A MIMO radio channel measurement system was developed during 2014. Instead of MIMO antenna arrays, virtual arrays were utilized in both the TX and RX ends. In a virtual array, a dual-polarized antenna is mechanically moved and rotated in freely selected grid. Typically antenna array is formed on a planar surface, but also conformal antennas, such as cylindrical or spherical, are easily achieved. Newly purchased PNA-X series four-port S-parameter analyzer serves as the TX/RX control, measurement and computing engine of the system. For 5G systems, radio channels have been measured and modelled in several campaigns at 10GHz range and initial results are reported for relevant 5G research activities. Channel modelling will continue during 2015.

Figure 3. Propagation measurement system.

RF Transceivers

Activity has been ramped up with very small volume in October 2014. RF system design to support 5G concept studies has been started. First focus will be in RF feasibility and requirement analysis for selected frequency band(s). Initial link budget calculations have been done for 5G system design. Based on these RF architecture for massive-MIMO and beamforming has been drafted.

Wireless Medical Communications

Wireless Medical Communications (WiMeC) team is investigating the concept and the problematic resulting from this requirement focusing on short range communication (up to tens of meters), wideband communication (in all the forms), channel modelling (crucial for system development), knowledge on antennas, and physical layer and medium access control (MAC). The wireless body area network (WBAN) is a key element of the research approach. In 2015, the central research topics included channel models for WBAN, performance evaluation of ultra wideband receivers, low-power MAC protocols for WBANs, and environmental challenges in medical WBANs. The team had also a major role in contributing to the ETSI SmartBAN standardization work. The results were presented in 1 Doctoral Thesis, 2 international journal papers, 14 international conference papers, 2 ETSI SmartBAN documents, and one tutorial. International relations were further developed in through the advisory Board membership of the Research Centre in the area of wireless medical technologies and applications in Macquarie University (Australia), and one three-month and two two-week visits to Yokohama National University, Japan. WiMeC also contributed to the scientific community by organising UWBAN 2015 (in conjunction with Bodynets 2015) in Sydney, serving as ISMICT2015 general co-chair and board members (International Steering Committee and Technical Program Committee). In 2016, the WiMeC team is focusing its research essentially on solutions of dual use in homes and institutions; receiver performance evaluation and new MAC protocols; dependable WSN networks (robustness, security and secrecy); close to body signal propagation; interference modelling; nanoscale communications; mobile clouds for medical ICT; and visible light communication for medical ICT.

Figure 4. Body area network measurement.

Nanoscale Communications and Networks

Time and frequency domain channel models are proposed for nanonetworks utilizing the terahertz band (0.1–10 THz) for wireless communication. Nanonetworks are formed by tiny nanodevices which consist of nanoscale (molecular scale) components. Channel models capturing the unique peculiarities of the THz band are needed for designing proper physical layer techniques and for accurate performance analysis. Existing channel models have included the free space path loss and the molecular absorption loss, which is significant in the THz band. This paper theoretically analyzes scattering including multiple scattering referring to a sequence of scattering events from small particles, such as aerosols. Both the frequency and the impulse responses are derived. It is shown that the small particle scattering can result into significant additional loss that needs to be taken into account with the loss depending on the density and size distribution of the particles. It is shown that multiple scattering leads to a long tail in the impulse response. As most of the physical layer proposals for nanonetworks are based on the on-off keying, the channel response to pulse waveforms is specifically considered.

Exploitation of Results

The CSP RG has proposed novel scientific information and results which are of interest to the global scientific community in general and our project partners in particular. Much of the work is done on simulator level but the ability to verify the usability of proposed algorithms with hardware implementations adds significant value to the results and helps the research community and the project partners to evaluate and further develop the ideas. Several invention reports and patent applications have been generated based on the research results. The cooperating companies also use the research results in wireless system standardization.

Future Goals

The major focus in the current research is to develop the basic enabling technologies and building blocks for the evolving IoT. The next major targets include optimized interplay of baseband and RF processing, which becomes increasingly critical with increasing carrier frequencies when cm and mm wave frequencies are introduced to practical use in the 5G system development.

Personnel

professors	4
senior research fellows	4
postdoctoral researchers	10
doctoral students	25
other research staff	3
total	46
person years for research	36

External Funding

Source	**EUR**
Academy of Finland	664 203
Tekes	778 638
other domestic public	0
domestic private	188 000
international	350 144
total	**1980 985**

Doctoral Theses

Karvonen, H (2015) Energy efficiency improvements for wireless sensor networks by using cross-layer analysis. Acta Universitatis Ouluensis, Technica C 520.

Lu, Pen-Shun (2015) Decoding and lossy forwarding based multiple access relaying. Acta Universitatis Ouluensis, Technica C 525.

Tervo, V (2015) Joint multiuser power allocation and iterative multi-antenna receiver design. Acta Universitatis Ouluensis, Technica C 517.

Selected Publications

J. Lehtomäki, M. Lopez-Benitez, K. Umebayashi & M. Juntti, "Improved channel occupancy rate estimation". IEEE Transactions on Communications, vol. 63, no. 3, pp. 643–654, March 2015.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7038215

J. Kokkoniemi, J. Lehtomäki, K. Umebayashi & M. Juntti, "Frequency and time domain channel models for nanonetworks in Terahertz band". IEEE Transactions on Antennas and Propagation, vol. 63, no. 2, pp. 678–691, February 2015.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6963344

M. Leinonen, M. Codreanu & M. Juntti "Sequential compressed sensing with progressive signal reconstruction in wireless sensor networks". IEEE Transactions on Wireless Communications, vol. 14, no. 3, pp. 1622–1635, March 2015.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6957562

K.-G. Nguyen, L.-N. Tran, O. Tervo, Q.-D. Vu & M. Juntti, "Achieving energy efficiency fairness in multicell MISO downlink". IEEE Communications Letters, vol. 19, no. 8, pp. 1426–1429, August 2015.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7111242

O. Tervo, L.-N. Tran & M. Juntti, "Optimal energy-efficient transmit beamforming for multi-user MISO downlink". IEEE Transactions on Signal Processing, vol. 63, no. 20, pp. 5574–5588, October 15 2015.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7150555

Q.-D. Vu, L.-N. Tran, M. Juntti & E.-K. Hong, ”Energy-efficient bandwidth and power allocation for multi-homing networks”. IEEE Transactions on Signal Processing, vol. 67, no. 7, pp. 1684–1699, April 1, 2015.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7029696

M. F. Bayramoglu & M. Juntti, ”A lower bound on the information rate of intersymbol interference channels based on the polyphase decomposition”. Proceedings of IEEE Global Telecommunications Conference (GLOBECOM 2015), San Diego, California, USA, December 6–10, 2015, 6 pages.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7417654

G. Destino, M. Juntti & S. Nagaraj, ”Leveraging sparsity into massive MIMO channel estimation with the adaptive-LASSO”. Proceedings of IEEE Global Conference on Signal and Information Processing (GlobalSIP 2015), Orlando, Florida, USA, December 14–16, 2015, pp. 166–170.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7418178

A. Ghazi, J. Boutellier, O. Silven, S. S. Bhattacharyya, S. S. Shahabuddin, M. Juntti & L. Anttila, ”Model-based design and implementation of an adaptive digital predistortion filter”. Proceedings of IEEE International Workshop on Signal Processing Systems (SiPS 2015), October 14-16, 2015, Hangzhou, China, 6 pages.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7345010

A. Ghazi, J. Boutellier, M. Juntti, L. Anttila & M. Valkama, “Data-parallel implementation of reconfigurable digital predistortion on a mobile GPU”. Proceedings of Asilomar Conference on Signals, Systems, and Computers (ACSSC 2015), Pacific Grove, California, USA, November 8–11, 2015, pp. 186-190.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7421110

X. He, X. Zhou, M. Juntti & T. Matsumoto “Data and Error Rate Bounds for Binary Data Gathering Wireless Sensor Networks”. Proceedings of IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC 2015), Stockholm, Sweden, June 28 – July 1, 2015, pp. 505–509.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7227089&tag=1

J. Huusko, J. Pyhtilä &, M. Juntti, “'Utilizing the statistical properties of a MIMO channel in transmission optimization”. Proceedings of ITG International Conference on Systems, Communication and Coding (SCC 2015), Hamburg, Germany, February 2–5, 2015, 6 pages.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7052133

J. Janhunen, J. Ketonen, A. Hulkkonen, J. Ylitalo, A. Roivainen & M. Juntti, ”Satellite uplink transmission with terrestrial network interference”. Proceedings of IEEE Global Telecommunications Conference (GLOBECOM 2015), San Diego, California, USA, December 6–10, 2015, 6 pages.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7417497

J. Kaleva, A. Tölli & M. Juntti, ”Rate Constrained decentralized beamforming for MIMO interfering broadcast channel”. Proceedings of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2015), Hong Kong, China, August 30 – September 2, 2015, pp. 376–380.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7343327

J. Kaleva, A. Tölli & M. Juntti, “Successive convex approximation for simultaneous linear TX/RX design in MIMO BC”. Proceedings of Asilomar Conference on Signals, Systems, and Computers (ACSSC 2015), Pacific Grove, California, USA, November 8–11, 2015, pp. 1227–1231.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7421337

J. Kaleva, A. Tölli, M. Juntti, R. Berry & M. Honig, ”Decentralized coherent coordinated multi-point transmission for weighted sum rate maximization”. Proceedings of IEEE Global Telecommunications Conference (GLOBECOM 2015), San Diego, California, USA, December 6–10, 2015, 6 pages.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7417345&tag=1

J. Kokkoniemi, J. Lehtomäki & M. Juntti, ”Frequency domain scattering loss in THz Band”. Proceedings of IEEE Global Symposium on Millimeter-Waves (GSMM 2015), Montreal, Quebec, Canada, May 25–27, 2015, 3 pages
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7175457.

M. Leinonen, M. Codreanu & M. Juntti, ”Channel-robust compressed sensing via vector pre-quantization in wireless sensor networks”. Proceedings of IEEE Global Conference on Signal and Information Processing (GlobalSIP 2015), Orlando, Florida, USA, December 14–16, 2015, pp. 383–387.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7418222

K. Li, A. Ghazi, M. Abdelaziz, L. Anttila, M. Juntti, M. Valkama, J. R. Cavallaro, ”Mobile GPU accelerated digital predistortion on a software-defined mobile transmitter”. Proceedings of IEEE Global Conference on Signal and Information Processing (GlobalSIP 2015), Orlando, Florida, USA, December 14–16, 2015, pp. 756–760
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7418298

O. Tervo, L.-N. Tran & M. Juntti, “Energy-efficient transmit beamforming for MISO downlink via sequential convex approximation”. Proceedings of IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC 2015), Stockholm, Sweden, June 28 – July 1, 2015, pp. 415–419.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7227071

I. Sugathapala, S. Glisic, M. Juntti, B. Lorenzo, L.-N. Tran &M. F. Hanif, ”Convexification approach for joint throughput maximization and user association in dynamic networks'”. Proceedings of IEEE International Conference on Communications (ICC 2015) – Workshop on MIMO and Cognitive Radio Technologies in Multihop Network (MIMOCR), London, UK, June 8–12, 2015, London, UK, June 8–12, 2015, pp. 573–578.

http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7247242

S. Qian, M. Juntti & T. Matsumoto, ”A comparative study on outage probabilities of decode-and-forward and lossy-forward relay techniques”. Proceedings of IEEE International Workshop on Computer Aided Modelling and Design of Communication Links and Networks (CAMAD 2015), September 7-9, 2015, Guildford, United Kingdom, pp. 278–282. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7390524

S. Shahabuddin, J. Janhunen, Z. Khan, M. Juntti & A. Ghazi, ”A customized lattice reduction multiprocessor for MIMO detection”. Proceedings of IEEE International Symposium on Circuits and Systems (ISCAS 2015), May 24-27, 2015, Lisbon, Portugal, pp. 2976–2979. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7169312

E. Suikkanen & M. Juntti, “ASIC implementation and performance comparison of adaptive detection for MIMO–OFDM system”. Proceedings of Asilomar Conference on Signals, Systems, and Computers (ACSSC 2015), Pacific Grove, California, USA, November 8–11, 2015, pp. 1632–1636. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7421424

O. Tervo, L.-N. Tran & M. Juntti, ”Decentralized coordinated beamforming for weighted sum energy efficiency maximization in multi-cell MISO downlink”. Proceedings of IEEE Global Conference on Signal and Information Processing (GlobalSIP 2015), Orlando, Florida, USA, December 14–16, 2015, pp. 1387–1391. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7418426

G. Venkatraman, J. Janhunen & M. Juntti, “Implementation of MU-MIMO schedulers on SoC”. Proceedings of Asilomar Conference on Signals, Systems, and Computers (ACSSC 2015), Pacific Grove, California, USA, November 8–11, 2015, pp. 1637–1641. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7421425

G. Venkatraman, J. Janhunen & M. Juntti, ”Exploiting multicore SoC architecture for MU-MIMO schedulers”. Proceedings of IEEE Global Conference on Signal and Information Processing (GlobalSIP 2015), Orlando, Florida, USA, December 14–16, 2015, pp. 761–766. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7418299

X. Zhou, X. He, M. Juntti & T. Matsumoto, “Outage probability of correlated binary source transmission over fading multiple access channels”. Proceedings of IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC 2015), Stockholm, Sweden, June 28 – July 1, 2015, pp. 96–100 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7227007

J. Petäjäjärvi, H. Karvonen, K. Mikhaylov, A. Pärssinen, M. Hämäläinen, J. Iinatti: WBAN Energy Efficiency and Dependability Improvement Utilizing Wake-up Receiver. IEICE Transactions on Communications 04/2015; E98-B(4):535-542. DOI:10.1587/transcom.E98.B.535.

V. Niemelä, T. Kumpuniemi, M. Hämäläinen, J. Iinatti, “Impulse radio UWB receiver analysis of non-coherently detected orthogonal signal”, IET Electronics Letters, Volume 51, No. 24, November 19, 2015. pp. 2061-2062. DOI: 10.1049/el.2015.2234, Print ISSN 0013-5194, Online ISSN 1350-911X, 2015.

T. Kumpuniemi, M. Hämäläinen, K. Yekeh Yazdandoost, J. Iinatti, Dynamic On-Body UWB Radio Channel Modeling. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

L. Mucchi, A. Carpini, T. D’Anna, M. H. Virk, M. Hamalainen, J. Iinatti, Threshold Setting for the Evaluation of the Aggregate Interference in ISM Band in Hospital Environments. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

J. Petäjäjärvi, K. Mikhaylov, H. Karvonen, R. Vuohtoniemi, M. Hämäläinen, Loose Synchronization Method for Low-power Superregenerative Wake-up Receiver. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

M. Hämäläinen, T. Paso, L. Mucchi, M. Girod-Genet, J. Farserotu, H. Tanaka, W.H. Chin, L. Nachabe, ETSI TC SmartBAN: Overview of the Wireless Body Area Network Standard. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

H. Viittala, M. Hämäläinen, J. Iinatti, Zone-Based Fuzzy Routing for WBANs. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

T. Paso, H. Tanaka, M. Hämäläinen, W.H. Chin, J. Haapola, R. Matsuo, S. Subramani, An Overview of ETSI TC SmartBAN MAC Protocol. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

K. Nakanishi, V. Niemelä, M. Hämäläinen, J. Iinatti, S. Hara, On IEEE 802.15.6 IR-UWB ED Receiver Performance in the Presence of Multiuser Interference. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

W.H. Chin, H. Tanaka, T. Nakanishi, T. Paso, M. Hämäläinen, An Overview of ETSI TC SmartBAN's Ultra Lower Power Physical Layer. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

M. H. Virk, R. Vuohtoniemi, M. Hämäläinen, J. Iinatti, J-P. Mäkelä, Stochastic Spectral Occupancy Modeling: A Body Area Network Perspective in ISM Band. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

M. H. Virk, R. Vuohtoniemi, M. Hämäläinen, J. Iinatti, J-P. Mäkelä, On Spectrum Occupancy Evaluations From the Standpoint of Body Area Networks in ISM Band. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

T. Tuovinen, M. Berg, M. Hämäläinen, J. Iinatti, Towards High On-Body Sensor Node Performance with the 3D Antennas for IR-UWB WBANs. The 9th International Symposium on Medical Information and Communication Technology (ISMICT2015), 24-26.3.2015, Kamakura, Japan.

T. Kumpuniemi, M. Hämäläinen, K. Yekeh Yazdandoost, J. Iinatti, Measurements for Body-to-Body UWB WBAN Radio Channels. The 9th European Conference on Antennas and Propagation (EuCAP2015), 12-17.4.2015, Lisbon, Portugal.

T. Paso, V. Niemelä, J. Haapola, M. Hämäläinen, J. Iinatti, ”Performance Evaluation of IEEE 802.15.4-2011 IR-UWB System with Enhanced Modulation Scheme”, the 10th International Conference on Body Area Networks (BodyNets-2015), Sep 28 – Sep 30, 2015, Sydney, Australia.

K. Takabayashi, H. Karvonen, T. Paso, H. Tanaka, C. Sugimoto, R. Kohno, “Energy Efficiency Evaluation of ECC Scheme Utilizing Decomposable Codes in IEEE Std 802.15.6 Based WBANs”. The 10th International Conference on Body Area Networks (BodyNets-2015), Sep 28 – Sep 30, 2015, Sydney, Australia.