**BESTCOM meeting**

KU Leuven, December 15, 2017

**Venue:** KU Leuven Faculty Club
Groot Begijnhof 14
B-3000 Leuven

**Program**

- 08h45-09h15: Welcome coffee

- 09h15-09h30: Opening by L. Vandendorpe (BESTCOM coordinator)

- 09h30-10h30: Keynote presentation

**Title:**
Open-Source in Telecoms – New Opportunities in Times of Change
**Author:**
Irfan Ghauri
www.openairinterface.org ,
5G software alliance for democratising wireless innovation
**Abstract:**
Open Source over Commercial-Off-The-Shelf (COTS) is a native of the IT world. A shining example there is Linux by virtue of which several innovations have successfully been marketed in recent times. In Telecoms, on the other hand, proprietary hardware and software until now stay the norm, with only a few major players in a position to commercialize solutions. Open-Source over COTS hardware is now in the process of challenging the oligopoly in place, a testimony of which is the entrance of many small companies in the fray. So while disruption is underway, Open Source in Telecoms is still at an embryonic stage and needs surmounting several challenges, the greatest and foremost of which is the need to come up with suitable business models.

This keynote will address some of the main challenges and recent wins in Open Source for Telecoms ranging from an overview of ongoing endeavours to commercialize solutions, licensing mechanisms, vendor perspective, service providers' view and that of new-entrants, as well as some of the doubts and fears around the Open Source business models raising their heads. Finally, we shall introduce OpenAirInterface.org, its structure, its technology offering in both 4G space and 5G research, ambitions as well as it utility to different communities in the telecoms space.

-10h30-11h00: Coffee break

- 11h00-11h30: Oral presentation 1

**Title:**
Aligned Frequency Reuse with D2D Communication

**Authors:**
Rodolfo Torrea-Duran, Máximo Morales-Céspedes, Jorge Plata-Chaves, Luc Vandendorpe, Marc Moonen

**Abstract:**
Dealing with inter-cell interference is a main challenge in wireless networks, especially for cell edge users. Resource orthogonalization approaches have been typically used to deal with this problem by assigning disjoint resources to users served by different base stations (BSs). However, these approaches can achieve at most 1/2 degrees of freedom (DoF) per cell. Blind interference alignment (BIA) has emerged as a means to achieve higher data rates by aligning all the interference in one dimension to facilitate its cancellation using reconfigurable antennas. A simple form of BIA without such antennas can be realized through aligned frequency reuse (AFR). For a cell with N neighboring cells, AFR can achieve N/(N+1) DoF per cell. However, most BIA-based approaches lack spatial diversity. Therefore, we propose an approach that increases the spatial diversity and the spectral efficiency by allowing device-to-device (D2D) communication among cell edge users during the time-slots in which they are not receiving their intended signal from their serving BS. We develop the proposed approach for different cellular topologies and extend it to the scenario with multiple cell edge users per cell edge.

-11h30-12h00: Oral presentation 2

**Title**:
Stochastic geometry-based analysis of wireless communication networks

**Authors:**
Charles Wiame, Luc Vandendorpe, Claude Oestges

**Abstract:**
The presentation is dedicated to two hot topics in the modelling of wireless communication networks. First, the propagation environment which significantly impacts the network coverage : we here focus on an urban environment and propose a model including both building penetration and corner diffraction. In the second part of the talk, we compare different access point distributions and coordination strategies for massive MIMO networks (beamforming, clustering, etc). Both topics are analyzed by means of stochastic geometry, enabling to obtain analytical results that are spatially averaged over all possible locations of the network nodes.

- 12h00-12h30: Poster spotlight presentation: each poster presenter will have one minute to introduce his/her poster by means of a single slide

-12h30-13h30: Lunch

- 13h30-14h00: BESTCOM PI meeting

- 13h30-15h00: Poster session (all posters)

-15h00-15h30 Coffee break

-15h30-16h00: Oral presentation 3

**Title:**
Distributing Massive MIMO: why and how
**Authors:**
C.-M. Chen, A. Guevara, S. Pollin,
**Abstract:**
Massive MIMO (MaMIMO) is a technology of primary interest for sub-6 GHz operation in the next generation cellular systems. While MaMIMO is most often linked to macrocell scenarios, where a single cell serves many users distributed over a large area, network densification will also result in scenarios where many users are served by a MaMIMO base station (BS) that is nearby. A key question is how to scale up MaMIMO: should we add more antennas to a given cell, or create multiple smaller and distributed cells that can cooperate?
This paper documents the measured performance of a very dense MaMIMO system for an indoor-to-outdoor propagation environment. The impact of the number of antennas, and the distribution of the antenna elements is experimentally verified for a simplified linear deployment of the BSs. Concretely, we serve 12 closely located users with 16, 32 or 64 antennas. We compare a centrally positioned collocated array and two distributed arrays with their uplink throughput in a licensed 2.6 GHz band. The experimental results show that 12 users can be served with only 32 antennas for the distributed topology, which is effectively only 16 antennas per MaMIMO BS. For the specific case analyzed in our measurement campaign, with the centralized deployment, 64 antennas are needed to obtain good performance, while distributing the antenna elements in two sub-arrays improves total performance and fairness between the users.

-16h00-16h30 Oral presentation 4

**Title:**
A new coding configuration for a combined fiber and twisted-pair multi-Gbps link
**Authors:**
Adriaan Suls, Yannick Lefevre, Mamoun Guenach en Marc Moeneclaey
**Abstract:**
In this contribution we consider a communication system consisting of a cascade of a passive optical network (PON) link with on/off keying, and a short twisted pair (TP) link with discrete multitone modulation (DMT). Three coding configurations are investigated. In the first configuration (C1), the PON link and the TP link are protected by a Reed-Solomon (RS) code and trellis-coded modulation (TCM), respectively. In the second configuration (C2), the PON link is the same as with C1, but the TP link is now protected by the concatenation of an outer RS code and inner TCM. We compare these conventional coding configurations C1 and C2 with an alternative configuration (C3), in which an outer RS code protects the cascade of the uncoded PON and the TCM-encoded TP. Whereas the configuration C3 has the same complexity as the configuration C1, we show that the former is able to achieve approximately the same information bitrate as the (more complex) configuration C2, at the expense of a slightly (about 1 dB) higher optical power. Our numerical results for a typical setting indicate that the configurations C2 and C3 can provide information bitrates beyond 10 Gbps, which are about 20-25% larger than for configuration C1.

-16h30-17h00 Oral presentation 5

**Title:**
Experimental analysis of specular and dense multipath components in industrial environments
**Authors:**
Emmeric Tanghe, Wout Joseph, Luc Martens, Davy Gaillot, Martine Liénard
**Abstract:**
This work presents two radio channel sounding campaigns performed in indoor industrial environments. Specular and dense multipath components were estimated from the channel sounding data with the RiMAX maximum-likelihood algorithm. The statistics of multipath component parameters such as their polarization behavior and reverberation characteristics are discussed and compared to other types of indoor environments.

-17h00 End

## Posters

**(P1) Title:**
Construction Methods of Reed-Muller Subcodes
**Authors:**
Johannes Van Wonterghem, Joseph J. Boutros, Marc Moeneclaey
**Abstract:**
In this work, subcodes constructed from Reed-Muller codes by removal of generator matrix rows are considered. A greedy algorithm based on the overlap of generator matrix rows is developed. This heuristic algorithm does not generate a unique solution, determining the number of minimum weight codewords allows selection of the best subcode generated by the greedy algorithm. Computer simulations confirm that the greedy algorithm outperforms three other considered construction methods, generating the best codes among all presented subcodes.

**(P2) Title:**
Sparse-UCA-Root-Music Direction of Arrival Estimation: Effect of Random Antenna Element Displacements for Different Values of the Signal-to-Noise Ratio
**Authors:**
Veronique Inghelbrecht, Jo Verhaevert, Tanja Van Hecke, Dries Vande Ginste, Hendrik Rogier, Marc Moeneclaey, Herwig Bruneel
**Abstract:**
A lot of algorithms for direction-of-arrival (DOA) estimation for circular antenna arrays (UCAs) exploit the circular symmetry. If there are random antenna position errors, which break the symmetry, these algorithms experience a significant performance loss. In this letter we use the stochastic collocation method (SCM) to obtain the mean square error of the DOA estimates for different values of the Signal-to-Noise Ratio.
The procedure is illustrated by relying on the Sparse UCA Root-MUSIC DOA estimation algorithm. This method can compensate for mutual coupling by incorporate all relevant phase modes of the active elements pattern. Comparison of the SCM to the Monte-Carlo method demonstrates that the SCM method accurately predicts the mean square errors, for a reduction in CPU time of about 40.

**(P3) Title:**
Power Allocation for Energy Efficient Multiple Antenna Systems with Joint Total and Per-Antenna Power Constraints
**Authors:**
Zijian Wang, Luc Vandendorpe
**Abstract:**
An energy Efficiency (EE) maximization problem with multiple transmit antennas (multiple-input-single-output (MISO) or distributed antennas setups) is considered in this paper. Besides the constraint on the total transmit power, per-antenna transmit power constraints and a total weighted power constraint are jointly considered. Both linear and nonlinear high power amplifier (HPA) cases are studied. Because the original problem for the linear HPA case is a fractional convex problem, Dinkelbach's algorithm is implemented to reformulate the problem. By investigating the Karush-Kuhn-Tucker (KKT) conditions, the mathematical properties of the globally optimal solution are studied and proved, which provides a deeper understanding of the structure of power allocation among antennas. These properties also

lead to a reduction of the complexity of the algorithms proposed to find the global optimum. For the nonlinear HPA cases, the reformulated problem after successive convex approximation (SCA) is shown to be exactly in the same form as that of the previous problem with linear HPA with different weights of power consumption at each antenna. Numerical results are reported to show a performance comparison for various schemes of EE maximization.

**(P4) Title:**
Modeling the Power Angular Profile of Dense Multipath Components Using Multiple Clusters
**Authors:**
Brecht Hanssens, Kentaro Saito, Emmeric Tanghe, Luc Martens, Claude Oestges, Wout Joseph, Jun-ichi Takada
**Abstract:**
In this work, we will discuss the modeling of the Power Angular Profile (PAP) of the Dense Multipath Components (DMC), taking into account multiple angular clusters. We have extended the maximum likelihood estimation of the angular DMC parameters in the RiMAX framework, so that the PAP of the DMC can be modeled with a multimodal von Mises distribution. This allows us to better characterize the diffuse scattering between transmitter and receiver, originating from multiple reflections in an environment. We have validated our proposed method with synthetic radio channel data based on Monte Carlo simulations, and have shown the importance of applying a multimodal assumption over a unimodal one.

**(P5) Title**:
Vectoring-Based Dynamic Spectrum Management for G.fast Multi-User Full-Duplex Transmission
**Authors**:
Wouter Lanneer, Jeroen Verdyck, Paschalis Tsiaflakis, Jochen Maes, and Marc Moonen
**Abstract**:
Full-duplex (FDX) transmission is a promising technique emerging in DSL networks that theoretically may double the spectral efficiency by simultaneously transmitting in the downstream (DS) and upstream (US) on the same frequency band. Unfortunately, this may lead to severe near-end crosstalk (NEXT) interference in addition to the usual far-end crosstalk (FEXT) among the lines within a cable binder. To limit the NEXT impact by balancing the user transmit powers, tailored vectoring-based dynamic spectrum management (DSM) techniques are vital. In this paper, we develop a DSM algorithm for the specific case of perfect NEXT cancellation at the access node. This assumption in combination with US-DS duality theory allows to reformulate the DS-US structure of the non-convex weighted sum-rate maximization problem into an easier US-US structure, which can be solved with low-complexity iterative fixed-point power updates. Simulations of G.fast multi-user FDX transmission demonstrate significant improvements over time division duplex transmission.

**(P6) Title:**
Asymptotically fair delay differentiation
**Authors:**
Michiel De Muynck, Herwig Bruneel, Sabine Wittevrongel
**Abstract:**

In this poster, we present a scheduling mechanism where certain places in the queue are reserved for future high-priority data packets, allowing those packets to enter the queue at those reserved places and to therefore undergo a shorter delay.
Contrary to most commonly-used scheduling mechanisms, such as absolute priority or generalized processor sharing, this scheduling mechanism offers asymptotic delay fairness. This means that the distributions of the delay of all traffic classes have the same exponential decay rate. The asymptotic tails of these delay distributions differ from each other only by a constant factor. We show how the parameters of the scheduling mechanism, namely the number of reservation places assigned to each of the traffic classes, influence this constant factor, and how these parameters can be chosen to achieve a desired asymptotically fair delay differentiation.

**(P7) Title:**
Modeling data backups as a batch-service queue with vacations and exhaustive policy
**Authors:**
Apoorv Saxena, Dieter Claeys, Herwig Bruneel, Joris Walraevens
**Abstract:**
For data backup processes to cloud infrastructure, there is a clean trade off between backing up frequently (improving data safety) and reducing resource usage (power consumption and communication cost). With rapid growth of data storage requirements in recent years, we need to find the right balance between both objectives. To explicitly address this trade off, we model data backup processes as a general batch service queueing model with multiple vacations, exhaustive service and probabilistic restarts.
We study this queueing model and establish expressions for general performance measures such as system content and queue content distributions. This analysis aids in computing Quality of Service measures of the data backup process such as the probability the backup server is busy, and the probability that a new connection is made. We also compute the maximum age of the data in this queueing model.
These measures are useful to quickly examine exact dependence of performance on the model parameters as well as to compute the optimal parameters in the backup process. We illustrate the latter by defining a particular utility function of a user and by framing an optimization problem.

**(P8) Title**:
Application of Polynomial Chaos Expansions for Uncertainty Estimation in Angle-of-Arrival based Localization
**Authors**:
Thomas Van der Vorst, Mathieu Van Eeckhaute, Aziz Benlarbi-Delaï, Julien Sarrazin, François Quitin, François Horlin, Philippe De Doncker
**Abstract**:
In the context of localization of Internet-of-Things nodes, angle-of-arrival based estimation is considered. By using a polynomial chaos expansion on a least squares estimator, a new positioning method is designed. Simulation results show that the proposed method returns precise information about the statistical distribution of the position.

**(P9) Title:**
Body-Worn Channel Characterization Unit for the 868 MHz Band

**Authors:**
Thomas Ameloot, Patrick Van Torre, Sam Agneessens, Jo Verhaevert, Hendrik Rogier
**Abstract:**
With the development of the Internet of Things, wireless sensor networks are constantly being deployed over larger and larger areas. Compared to higher radio frequencies, sub-GHz frequency bands possess superior radio propagation properties for long-range wireless connections. However, as frequency decreases, efficient antennas become larger. The highest sub-GHz band at 868 MHz enables good radio propagation and provides the possibility to design efficient body-worn antennas by means of substrate-integrated waveguide technology. A number of standards, such as LoRa, Sigfox and Dash7 can be employed for communication in this band. Commercial transceivers for these standards often do not allow accurate measurement of the received signal strength. For off-body radio propagation research, a wearable measurement node for 868 MHz is proposed, exploiting an accurate logarithmic power detector. A prototype of the node was implemented and tested, yielding accurate channel measurements for this band. Recorded signal levels are documented in an indoor environment for Line of Sight as well as Non Line of Sight propagation paths. Different features caused by various radio propagation phenomena are clearly visible in the measurement results and illustrate the correct operation of the system.

**(P10) Title:**
Substrate-Independent Microwave Components in SIW Technology for Smart Surface Applications
**Authors:**
Kamil Yavuz Kapusuz, Sam Lemey and Hendrik Rogier
**Abstract:**
Although all existing air-filled substrate integrated waveguide (AFSIW) topologies yield substrate-independent electrical performance, they all rely on dedicated, expensive, laminates to form the air-filled regions that contain the electromagnetic fields. In this paper, a novel substrate-independent AFSIW manufacturing technology is proposed that enables straight-forward integration of high-performance microwave components in a wide range of general-purpose commercially-available surface materials by means of standard additive (3D-printing) or subtractive (CNC milling/laser cutting) manufacturing processes. Several microwave components were fabricated and integrated to validate our novel AFSIW manufacturing technology. After characterizing diverse traditional surface materials in terms of electrical properties, they were adopted as a microwave substrate for a coaxial-to-air-filled SIW transition, a waveguide and a four-way power divider/combiner. Measurements prove that this novel approach yields microwave components that allow direct integration into everyday surfaces without influencing their matching, loss, and isolation within the entire [5.15-5.85] GHz band. Hence, this novel approach paves the way for a new generation of cost-effective, high-performance and invisibly-integrated smart surface systems that efficiently exploits the area and materials available in everyday objects.

**(P11) Title:**
Human Positioning by Using Absorption Cross Section & Double-Directional Spatial Power Spectrum
**Authors:**
Yang Miao, Pierre Laly, Davy Gaillot, Emmeric Tanghe, Wout Joseph, Luc Martens

**Abstract:**
This work aims at conceiving a positioning algorithm utilizing the variations of the power delay profile (PDP) and the power angular profile (PAP) of the double-directional channel when with and without person presenting in room. The judgement on the existence of person is explored by using the absorption cross section estimated from the variations of reverberation time. The person is positioned by using PDP and PAP in combination. The variations of PDP at the first peak indicates that the person locates in the first Fresnel zone between transmit and receive antennas. The variations of PAP, together with room configuration, can further estimate the person's position.

**(P12) Title:**
Measurement Uncertainty Propagation in Transistor Model Parameters via Polynomial Chaos Expansion
**Authors:**
A. Petrocchi, A. Kaintura, G. Avolio, D. Spina, T. Dhaene, A. Raffo and D. M. M. P. Schreurs
**Abstract:**
We present an analysis of the propagation of measurement uncertainty in microwave transistor nonlinear models. As a case study, we focus on residual calibration uncertainty and its effect on modeled nonlinear capacitances extracted from small-signal microwave measurements. We evaluate the uncertainty by means of the polynomial chaos expansion (PCE) method and compare the results with the NIST Microwave Uncertainty Framework, which enables both sensitivity and Monte Carlo (MC) analysis for uncertainty quantification in microwave measurements. We demonstrate that, for the considered application, PCE provides results in agreement with classical MC simulations but with a significant reduction of the computational effort.

**(P13) Title:**
A Comprehensive and Modular Stochastic Modeling Framework for the Variability-Aware Assessment of Signal Integrity in High-Speed Links
**Authors:**
Y. Ye, D. Spina, P. Manfredi, D. Vande Ginste and T. Dhaene
**Abstract:**
We present a comprehensive and modular modeling framework for stochastic signal integrity analysis of complex high-speed links. Such systems are typically composed of passive linear networks and nonlinear, usually active, devices. The key idea of the proposed technique is to express the signals at the ports of each of such system elements or subnetworks as a polynomial chaos expansion. This allows one to compute, for each block, equivalent deterministic models describing the stochastic variations of the network voltages and currents. Such models are synthesized into SPICE-compatible circuit equivalents, which are readily connected together and simulated in standard circuit simulators. Only a single circuit simulation of such an equivalent network is required to compute the pertinent statistical information of the entire system, without the need of running a large number of time-consuming electromagnetic circuit cosimulations. The accuracy and efficiency of the proposed approach, which is applicable to a large class of complex circuits, are verified by performing signal integrity investigations of a suitable example.

**(P14) Title:**
WSN MAC Optimization in Dynamic Environments using Cloud Repositories
**Authors:**
Michael Tetemke Mehari and Ingrid Moerman
**Abstract:**
Wireless Sensor Networks (WSNs) are a special class of Internet of Things (IoT) networks where constrained devices are used to monitor large areas of buildings, farmlands, nature environments or industrial areas. To cope with the diverse number of use cases, a number of WSN medium access control (MAC) protocols exist in literature each with a wide set of configurable parameters. Furthermore, generic optimization solutions exist to automatically optimize the configurable parameters of WSN protocols towards domain-specific applications and deployment requirements. However, these solutions assume static network, and as such they can not cope with changes over time caused by deployment changes, environmental dynamics or evolving application requirements. To remedy this, a novel optimization approach is proposed that supports network optimization in slow-changing environments. First, MAC protocols are optimized using state-of-the-art model-based optimization methods. The resulting models are stored in a cloud repository, with each model representing an optimized instance of the MAC protocol for a specific static environment. Whenever environmental, application or deployment conditions change, the most representative models from the cloud repository are retrieved to quickly reconfigure the MAC protocols to better support the new conditions, thereby avoiding the time-consuming model creation and optimization phase that would otherwise be required.

**(P15) Title:**
A PAPR-aware transmission strategy for SWIPT over fading channels
**Authors:**
N. Pan, M. Rajabi, S. Claessens, D. Schreurs, S. Pollin
**Abstract:**
A peak to average power ratio (PAPR)-aware transmission strategy considering a realistic rectifier model is proposed for simultaneous wireless information and power transfer (SWIPT). This work analyses how the PAPR of signals impacts harvested direct current (DC) power. Pre-equalizers maximizing the signal to noise ratio (SNR) of each tone, the PAPR of the received signal and the channel capacity are designed for a SWIPT system, which experiences frequency-selective channel fading. Finally, a balanced pre-equalizer is proposed to improve the wireless power conversion efficiency (PCE), trading-off between the received signal to noise ratio (SNR), capacity, and signal PAPR. The balanced pre-equalizer can improve the wireless PCE up to 60%within 5 % channel capacity loss compared to pre-equalizers only maximizing the SNR or PAPR of the received signal.

**(P16) Title:**
Human Body Communications: a video streaming demonstration
**Authors:**
Luca Petrillo, Hugues Libotte, François Horlin and Philippe De Doncker
**Abstract:**
In the field of wireless networks of wearable devices, Human Body Communication (HBC) is a technology that uses the human body as transmission medium. For this reason, the communication is confined in the very close vicinity of the user. In this poster presentation we

will show how using software defined radios it is possible to conceive a system that allows a user to stream a video signal by using HBC.

**(P17) Title:**
Optimal Resource Allocation in Ultra-low Power Fog-computing SWIPT-based Networks
**Authors:**
Nafiseh Janatian, Ivan Stupia and Luc Vandendorpe
**Abstract:**
In this paper, we consider a fog computing system consisting of a multi-antenna access point (AP), an ultra-low power (ULP) single antenna device and a fog server. The ULP device is assumed to be capable of both energy harvesting (EH) and information decoding (ID) using a time-switching simultaneous wireless information and power transfer (SWIPT) scheme. The ULP device deploys the harvested energy for ID and either local computing or offloading the computations to the fog server depending on which strategy is most energy efficient. In this scenario, we optimize the time slots devoted to EH, ID and local computation as well as the time slot and power required for the offloading to minimize the energy cost of the ULP device. Numerical results are provided to study the effectiveness of the optimized fog computing system and the relevant challenges.

**(P18) Title:**
On the effect of blockage objects in dense MIMO SWIPT networks
**Authors:**
Ayse Ipek Akin, Ivan Stupia, Luc Vandendorpe
**Abstract:**
Simultaneous information and power transfer (SWIPT) is characterized by the ambiguous role of multi-user interference. In short, the beneficial effect of multi-user interference on RF energy harvesting is obtained at the price of a reduced link capacity, thus originating nontrivial trade-offs between the achievable information rate and the harvestable energy. Arguably, in indoor environments, this trade-off may be highly affected by the attenuation due to blockage objects like walls. In addition to this, the technological limitations associated with the electronics of the RF energy harvesters make the entire wireless power transfer process very sensitive to the strength of the received signals. According to the literature, the harvesting devices can efficiently work at the condition that the received power lies in the microwatt region. Consequently, SWIPT can become a reality only if an ultra dense deployment of energy transmitters (also referred to as power heads) is contemplated in the system design. In this scenario, a couple of fundamental questions arise. How much the network elements must be densified to counteract the blockage attenuation? Is blockage always detrimental on the achievable rate-energy trade-off? In this paper, we analyze the performance of indoor multiple-input multiple-output (MIMO) SWIPT-enabled networks in the attempt to shed a light of those questions. The effects of the obstacles are examined with the help of a stochastic approach. Power heads are located by using a Poisson Point Process and walls are generated through a Manhattan Poisson Line Process. Maximum Ratio Transmission (MRT) and Maximum Ratio Combining (MRC) are considered at the transmitter and the receiver side, respectively. The stochastic behaviors of the signal attenuation and the multi-user interference are studied to obtain the Joint Complementary Cumulative Distribution Function (J-CCDF) for the information rate and the harvested power. Theoretical results are validated through Monte Carlo simulations. Eventually, the rate-energy trade-off is presented as a

function of the frequency of walls showing how the conflicting behaviour of information and power transfer may be influenced by the topology of the venue.

**(P19) Title:**
Optimal Dynamic Spectrum Management for Full Duplex Digital Subscriber Line Networks
**Authors:**
Jeroen Verdyck, Paschalis Tsiaflakis, Wouter Lanneer, Marc Moonen
**Abstract:**
In DSL networks, the dense packing of twisted pair cables into a single cable binder results in an electromagnetic coupling, which in turn gives rise to crosstalk or interference. The distinction is often made between far-end crosstalk (FEXT) and near-end crosstalk (NEXT). On the one hand, FEXT has typically been dealt with by dynamic spectrum management (DSM) techniques. On the other hand, the influence of NEXT has mostly been avoided by dividing resources between upstream (US) and downstream (DS) using FDD or TDD. Recently however, interest has risen in full-duplex (FDX) operation for DSL, in which US and DS transmission occur at the same time and in the same frequency band. In this FDX setting, NEXT is no longer avoided and should be dealt with using DSM techniques. In our work, we developed an algorithm, referred to as FDX-OSB, which finds the globally optimal DSM operating point for FDX DSL systems. FDX-OSB provides a basis for the development of suboptimal but more efficient algorithms, the performance of which can be objectively assessed using the results yielded by FDX-OSB as a benchmark.

**(P20) Title:**
Numerical Assessment of Human Electromagnetic Exposure in ATTO-cell Wireless Networks
**Authors:**
Sergei Shikhantsov, Arno Thielens, Günter Vermeeren, Guy Torfs, Piet Demeester, Luc Martens, Wout Joseph
**Abstract:**
We present a numerical method for assessment of human exposure to EMF in the ATTO-cell floor, a future ultra-dense wireless networking technology of the future. In the ATTO-floor humans are exposed to the radiation of multiple uncorrelated transmitters. We propose a statistical approach, based on a set of FDTD simulations, which, for the first time, allows to estimate human EM-exposure in the ATTO-cell network. We applied the presented approach to assess the localized absorption in terms of peak-spatial SAR in 10 grams. We obtained an average exposure level of around 4.9 mW/kg, reaching 7.6 mW/kg in 5% of cases.