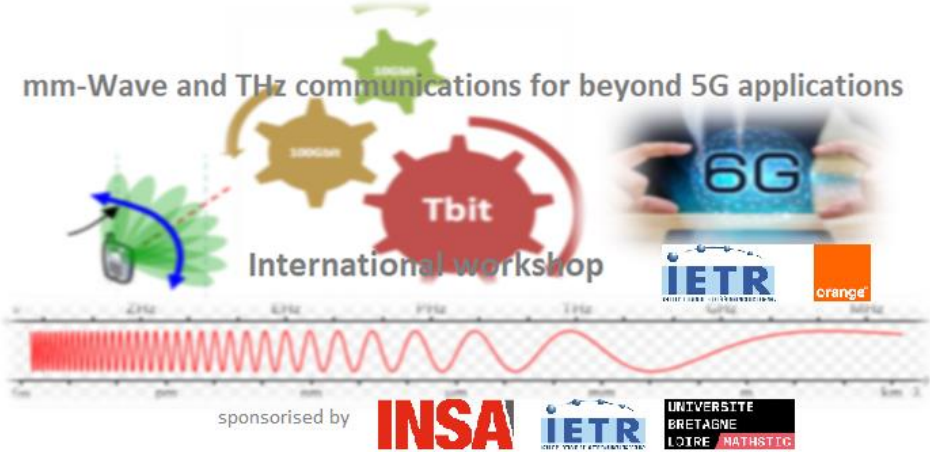


This workshop addresses mm-waves and THz communications status for Beyond 5G and 6 G applications. Mm-wave communications resulting from national and international project achievements as CominLabs M5-HESTIA, FP7-ICT EU/JP MiWEBA, FP7-ICT MiWaves, 5G PPP mm-MAGIC and other collaborative projects shall provide solid solutions for mm-wave deployments. Advanced beam management over moving hot-spots mixing digital processing and RF components dived in mobile cellular communications still discloses research domains to explore for optimization issues. THz communications, as an implicit evolution of mm-wave, raise new opportunities and horizons making communicate optical, physics of materials and radio communities to address the THz gap. The objective of the workshop is to highlight research statements in the mm-wave and THz domains and sketch emerging technical challenges for 6G applications. State of the art and results will be shown through technical presentations. Exhibitions and posters will illustrate Proof of Concepts and dedicated realizations.

Program

8.45 **Welcome to participants**

9.00 **Workshop opening,** ***M. Hélard - I. Siaud - AM Ulmer Moll***

Session 1 - M5HESTIA Project

Chair: Dr. Isabelle Siaud

9.10 **Project presentation,** ***M. Hélard***

9.25 **A 60GHZ RX front-end for MU-MIMO application,** ***F. Gallée***

9.50 **Beamforming Strategies for Efficient mmWave Communications,** ***M. Cruissière***

10.15 **High throughput beamsteering mm-Waves HW platform,** ***R. Legouable***

10.25 **Coffee Break with Demos and Posters**

Session 2 - 5G mm-Wave

Chair: Pr. Ronan Sauleau

10.55 **New key PHY/MAC techniques for coverage increase, collision avoidance and network interference reduction in the upcoming millimeter-wave IEEE 802.11ay standard,** ***A. Maltsev***

11.25 **Millimeter-Wave massive-MIMO antennas: Which use cases?,** ***A. Doll***

11.55 **Hybrid beamforming: A System Level Modelling approach,** ***G. Albertini***

12.15 **Lunch**

13.15 **Coffee with Demos and Posters**

Session 3 - Beyond 5G and 6G

Chair: Pr. Maryline Hélard

13.45 **THz Communications: an overview and challenges,** ***I. Siaud***

14.15 **Power-efficient architectures towards THz communications,** ***C. Desset***

14.45 **Single Carrier with Index Modulation for Low Power Terabit Systems,** ***C. Bader***

15.15 **Realizing Next-Generation Backhaul/Fronthaul and Fixed-Wireless Access Networks Through Reconfigurable Intelligent Surfaces, K. Ntontin**

15.45 **Wrap-up Workshop**

Abstracts

Session 1 - M5HESTIA Project

Project presentation *presented by Maryline Hélard*

M5HESTIA, that stands for "mmW Multi-user Massive MIMO Hybrid Equipments for Sounding, Transmissions and HW ImplementAtion" is a research project funded by the Labex Comin Labs. A specificity of this Comin Labs project is that it involves academic partners (IETR and Lab_STICC) but also two industrial partners (Orange and IRT b<>com). M5HESTIA project aimed at designing advanced M-MIMO antennas, characterizing / modelling the outdoor mm-Wave channel and proposing innovative algorithms in order to demonstrate, a full M-MIMO hardware (HW) platform operating in the 60-GHz band.

A 60GHZ RX front-end for MU-MIMO application *presented by Francois Gallée*

M5HESTIA project aims at designing advanced MU-MIMO antennas, characterizing / modelling the outdoor mmW channel and proposing innovative algorithms in order to demonstrate, a full M-MIMO hardware (HW) platform operating in the 60-GHz band. The presentation will focus on the design of a 60GHz front-end RF compatible with a digital beamforming or a mix analog/digital beamforming.

Beamforming Strategies for Efficient mmWave Communications
presented by Matthieu Crussière

Millimeter Wave Communications are considered as a key technology for future wireless communication systems and networks. Yet, many challenges still remain before making such technology come to the reality of practical deployments, among which complexity, cost and power consumption. The works conducted during the MHESTIA project tend to give answers and solutions to these challenges. In this talk, the aim is to review the main results obtained at the level of signal processing and theoretical performance point of view. In that perspective, hybrid beamforming (HBF) strategies are considered as the baseline for efficient communications at mmWave frequencies. After a review on the HBF principles, we study how HBF performs compared to full digital beamforming (DBF) and show in which extend both strategies become equivalent in terms of achievable spectral efficiency at mmWave frequencies and using large-scale antenna structures. We then investigate on the robustness of such systems in presence of blockage and multipath channels, and propose efficient beamforming strategies and multi-user management algorithms in that context. In addition to theoretical performance expressions, validations of our results using measured channel response are provided.

High throughput beamsteering mm-Waves HW platform
presented by Rodolphe Legouable

One of the main objectives of the M5HESTIA project is to implement a high data rate video service transmission. This presentation presents the powerful hardware platform that integrates the digital baseband processing in one hand and the 60 GHz RF analog front-end in the other hand; this front-end integrates the beamsteering antenna arrays that are developed in the project allowing to focus the data stream in the right user's direction.

Session 2 – 5G mm-Wave

New key PHY/MAC techniques for coverage increase, collision avoidance and network interference reduction in the upcoming millimeter-wave IEEE 802.11ay standard

presented by Alexander Maltsev

To realize the full potential of the millimeter-wave systems as part of 5G, two important problems should be solved. Firstly, the millimeter-wave coverage should be increased up to several hundred meters – and this is possible only with implementation of high-gain steerable antennas and special beamforming algorithms. Secondly, the MU-MIMO should be introduced in the mmWave standards, but that leads to significant increase of simultaneously served stations and therefore, require proper collision avoidance and association algorithms.
A brief review of the new key "intelligent" techniques in the upcoming millimeter-wave IEEE 802.11ay standard is the main subject of this presentation.

Millimeter-Wave massive-MIMO antennas: Which use cases?

presented by André Doll

The key difference in terms of equipment of the sites and even of some of the UE's between 5G and the previous generations of mobile communication is the use of massive-MIMO antennas. This is the case below 6GHz but also in the mm-Wave frequency bands as they are also considered for the deployment of the 5G ecosystem.
Using massive-MIMO technologies in mm-Wave brings for instance the benefit of generating "pencil" beams, therefore it allows to focus the beam where it needs to be pointed, but at the cost of an extra antenna design complexity. The use-cases that can be considered both from a technical and market standpoint will be discussed.

Hybrid beamforming: A System Level Modelling approach
presented by Gerald Albertini

During this presentation, we will illustrate a methodology for system-level modeling and simulation of a 66 GHz QPSK RF transmit and receive system with a 32-element hybrid beamforming antenna.
The system includes RF imperfections, transmit array radiation effects, a narrowband receive array and a baseband receiver with corrections for system impairments and message decoding. The antenna beamforming direction is defined using azimuth and elevation angles and it is estimated in the RF receive antenna using a Root Music DOA algorithm.
We will detail the steps required to model the complete system, composed of the following building blocks:

- A QPSK baseband transmitter encodes the message "Hello World ###".
- An RF transmitter with IQ modulation, mixing, amplification and hybrid beamforming with control circuitry. The RF transmitter model includes RF imperfections such as noise, non-linear effects and antenna element coupling.
- An ideal channel attenuating the transmitted signal with a free space path loss model.
- An RF receiver with two narrowband receive array antennas, receiver gain and SNR, 12-bit ADC with finite dynamic range, and two root MUSIC algorithms for angle of arrival estimation along azimuth and elevation.
- A QPSK receiver, including carrier and frame synchronization, demodulation and data decoding.

Session 3 – Beyond 5G and 6G

THz Communications: an overview and challenges
presented by Isabelle Siaud

Orange is looking at beyond 5G and 6G applications for new emerging services enabling extremely high speed communications and large distance ranges from intra-device communications to large backhaul scenarios completing 5G scenarios requirements. For that purpose, exploring new spectrum bands in mm-wave bands and above would bring new opportunities and new services related to proper spectrum signature. For that purpose, THz communications would get underway promising solutions for dedicated use cases, handling throughput up to several hundred Gbit/s that bridge macro/micro/nano applications. THz band interests started 1897 with Ruben's research work. Today, with the discovery of the Graphene material in 2010, THz wave generation is processed using SPP waves transported through Graphene material enabling EM waves radiation in the THz band with extremely high speeds, ultra-low-power, miniaturized and low-complexity schemes.

This presentation aims at providing an overview on the current status of THz Communication systems focusing on ongoing research activities thorough Academia, European Horizon 2020 framework and standardization activities turned towards ETSI ISG mWT, ITU-R and IEEE802 standardization bodies. Another key challenge of the presentation is to identify in a second step, new opportunities for 6G applications that telecom operator would advocate and delve. Throughout this work statement, it has reached a level of relative maturity to develop first technological solutions enabling the set-up of hardware demonstrators and emerging system design and services.

Power-efficient architectures towards THz communications
presented by Claude Desset

With the ever-increasing throughput requirements of communication systems and thanks to advances in deep-scaled semiconductor technology, carrier frequencies above 100 GHz are being investigated for applications such as advanced gaming, high-speed access hot-spots and point-to-point network links. Those frequencies offer very wide bandwidths and will exploit large antenna arrays. The corresponding architectures will significantly differ from traditional systems.
This presentation first reviews the link budget corresponding to different scenarios, taking into account the specific propagation at those frequencies. In a second part, the analysis is extended in order to estimate the overall power consumption of the different system components. Based on a flexible power estimation tool, we can compare different architecture types and identify the most power-efficient solutions. More especially, trade-offs between full-analog and full-digital approaches are investigated, with a special focus on hybrid MIMO architectures. Hybrid MIMO solutions offer the combined benefits of wide bandwidth and spatial multiplexing, while keeping the complexity under control.

Single Carrier with Index Modulation for Low Power Terabit Systems
presented by Carlos Bader

Wireless terabit-per-second (Tb/s) links will become an urgent requirement within the next 10 years. However, current focuses for high data rate wireless communication that keep increasing the M-ary modulation schemes and the order of MIMO spatial multiplexing cannot reach Tb/s with low power consumption. Thus, a new approach is required with a large bandwidth in the millimeter-wave (mm-Wave) and sub-Terahertz (sub-THz) bands above 90GHz. In addition, it must be able to provide an extremely high spectral efficiency with low energy consumption. This talk suggests a new way of looking at how to reach 1 Tb/s with low power consumption by combining power efficient single carrier with Index Modulation (IM).

Realizing Next-Generation Backhaul/Fronthaul and Fixed-Wireless Access Networks Through Reconfigurable Intelligent Surfaces

presented by Konstantinos Ntontin

Due to the continuous increase in data-rate demands, millimeter-wave (mmWave) backhaul/fronthaul and fixed-wireless access (FWA) networks operating in the 30-100 GHz range are already a reality. Such an increase though is going to necessitate the migration to the beyond 100 GHz mmWave spectrum for the corresponding 5G and beyond networks, as several trials from vendors indicate. Furthermore, the foreseen high densification is going to inevitably result in several backhaul/fronthaul and FWA links being non line-of-sight (NLOS). Although NLOS communication is feasible in the 30-100 GHz range, it is highly questionable for the beyond 100 GHz spectrum.

In this talk, we are going to discuss a disruptive and low-complexity way to circumvent the aforementioned bottleneck that is based on the use of the novel paradigm of reconfigurable intelligent surfaces.

Moreover, simulation results will showcase the substantial gain, in terms of performance, that can be achieved by their deployment over the conventional relaying approach in a next-generation fronthaul scenario.

Finally, key open areas of research will be identified.

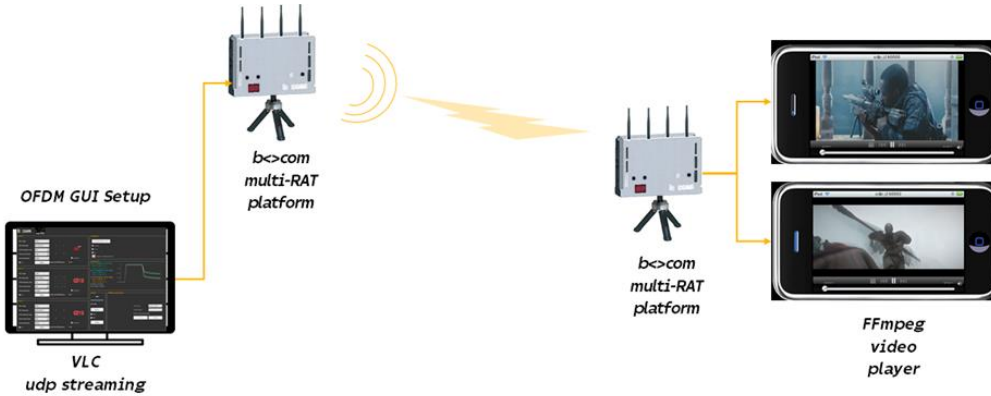
Demos

MATLAB Innovations for Antenna Array Design and RF Propagation *[Mathworks]*

Discover the latest MATLAB innovations for antenna array analysis and RF propagation and learn how to model your communications systems, baseband to RF, antenna arrays and electromagnetic propagation.

Contact: galberti@mathworks.com

High throughput HW Platform *[b<>com]*



The objective of the demonstration is to transmit simultaneously 2 video services with high data throughput. The set-up aims at showing the main baseband components of the Physical layer that are implementing in FPGA. The transmitter and receiver are separated on 2 different boards and the transmission is directly carried out in baseband. Next step is to plug the RF Mm waves board on our digital board (board under progress) to transmit the video service over 2 separate beams with antenna arrays developed by IMT Atlantique within the M5HESTIA project framework.

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Posters

WORTECS
Wireless Optical/Radio TErabit CommunicationS

Introduction

WORTECS explores the terabyte capabilities of above 90GHz spectrum, combining radio and wireless optical technologies

Achievement

Within Information and Communication Technology (ICT) H2020 framework, the European research project **WORTECS** (**W**ireless **O**ptical/**R**adio **TE**rabit **C**ommunication**S**) has been accepted and labeled despite high competition.

Use case

Wortecs project: Wireless terabyte communication with Virtual Reality use case.

Offer

WORTECS aims to offer:

- **Optical Wireless Communication** (OWC), **Fiber Wireless Fiber** (FWF) and **radio over 90 GHz** Proof of Concept (PoC) with several Gigabit per second (Gbps) throughput: innovation on antenna, coding and other PHY/MAC improvements.
- **Heterogeneous wireless Network** architecture (HetNet) studies with new architectures and protocols for routing, latency and caching.

Last but not least, the **customer views** will be taken into account through interviews, questionnaires and **field tests**. The purpose is to provide a Virtual Reality **user-friendly** interface with a homogeneous solution including several Gbps data rate, reduced latency and multi-user environment associated with an accurate tracking.

With a **3 million euro** budget, WORTECS consortium brings together several European industrial and institutes players in this market (Orange, Oledcomm and B-Com from France, IHP Microelectronics from Germany and pureLiFi from the UK) as well as universities recognized in this area (University of Oxford from United Kingdom and University of Las Palmas from Spain).

Next step

WORTECS was launched in September 2017 for a three years period. The aim is to propose scientific and technological enablers for new spectrum bandwidth availability, especially at frequencies above 90 GHz up to THz allowing communications backed by innovative usage scenarios; for instance, **Virtual Reality (VR).** It will also address visible light communications and develop radically new approaches for spectrum efficiency.

WORTECS project website: https://wortecs.eurestools.eu/ *Contact WORTECS:* olivier.bouchet@orange.com

Acknowledgement : The project WORTECS is funded by European Commission ICT-09 2017 H2020 Program.

Contact: olivier.bouchet@orange.com

International workshop

M⁵HESTIA

mmW **M**ulti-user **M**assive **M**IMO **H**ybrid **E**quipment for **S**ounding, **T**ransmissions and HW **I**mplement**A**tion

2016—2019

https://project.inria.fr/m5hstia/

Academic partners
- INSA Rennes
- Université Rennes 1
- IMT Atlantique

Industrial partners
- IRT b<>com
- Orange Labs

***Abstract**: **Exploiting millimeter-wave** (mmWave) radio spectrum will unlock ultra-large bandwidths for **future 5th generation (5G)**– wireless systems. Development of both **innovative cost-effective antenna / beamforming architectures** (by increasing the number of radiating elements) and **new processing techniques** play a key role in those frequency bands, in order to allow massive deployment of consumer products in the coming years. The studies were carried out in 2 projects in parallel on mmWave transmissions at 60 GHz: the CominLabs M⁵HESTIA project and the IRT b<>com 5M project.*

Main challenges

Improve the link budget in mmWave transmissions
- High path losses: directive and high gain antennas to ensure sufficient Signal To Noise Ratio (SNR)
- Critical HW implementation: calibration, interference, integration losses…

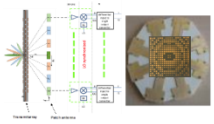
Increase of the number of antennas
- Hybrid massive MIMO: trade-off between the number of RF chains and radiating elements

Model the mmWave Channel
- Need of measurements and channel models
  Sparse channel and LOS dominated channel, blockage effect…
- Need of tracking position and orientation algorithm studies

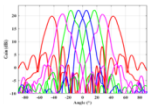
Develop antennas, front-ends and proofs of concept

Antenna design and RF architecture

Antenna system with 60 GHz front-end Rx



Beam scanning of the system



Developping a modular approach for lens-based antennas
- Easy duplication for other sounding and transmission antennas and other frequencies

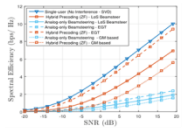
Providing a 60 GHz MIMO channel sounding antenna
- Used by Orange and IMT-A for measurement campaigns

Design of different systems
- A wide scan angle transmit array antenna
- Different multibeam 60 GHz systems
  - for channel sounding with analog or digital beamforming
  - for wireless communication: until 8 IQ links and 2 users

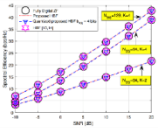
Results in accordance with:
- 802.11 ad norms (beamsteering)
- 802.11 ay standardization standards (multi-user multibeams)

Baseband Signal Processing

Hybrid beamforming with path blockage



Equivalence between Hybrid and Full Digital Beamforming



Theoretical performance of large-scale MIMO systems
- with spatially clustered and ray-based channel representations (WP3)
- with spare and LOS dominated channels

Hybrid beamforming
- New efficient and low complexity beamforming strategies
- Resource allocation algorithms

Application to spatial modulations
- Design of new index modulation strategies and related theoretical results

Aims of the project

- Develop **advanced massive MIMO antennas** and Tx Rx **front-ends**
- Characterize and model **indoor/outdoor mmWave MIMO channels**
- Propose innovative **Multi-user massive-MIMO algorithms**
- Demonstrate **a full Multi-user massive MIMO** hardware platform operating in the 60 GHz band

Propagation, sounding and channel modeling

Analysis and use of the measurements campaigns from Altoo University
- Better modeling of small scatterers in the outdoor channel
- Integration in our PyLayers channel model

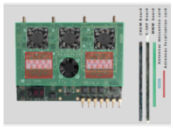
Theoretical contributions for location and tracking in 5G systems
- A new joint heuristic beam selection and user position and orientation **tracking** approach

HW baseband implementation & platform

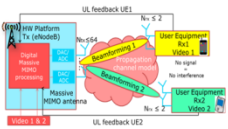
Integration of the WP2 antennas in the b<>com platform
- Beamsteering allowing 2 parallel beams in a **2 GHz bandwidth**
- Real time video services transmission
- Validation of the analog and digital parts of the powerful b<>com platform
- Platform that can be used to test new digital enablers in real environments
- High throughput (5 Gbps), OFDM and LDPC, 2 GHz bandwidth, 256-QAM, indoor/outdoor transmissions, beam scanning/tracking

Further developments in 5M
- Testing new MU-MIMO precoding schemes
- Virtual Reality use-case wireless transmission

Developped board



Beamsteering: 2 independent spatial streams



And after M⁵HESTIA?

At the beginning of the project
- Mostly MIMO systems **below** 6 GHz (5G system)
- Mu-MIMO in mmWave for **indoor** systems: IEEE 802.11ad (WiGig) – 4.6 Gbps max
- WRC'19: first frequency bands identification 57 – 64 GHz as potential candidate

Now
- 5G proposes 26 GHz (over up to **400 MHz**) for **outdoor** transmission (mgNodeB)
- **Hybrid** M-MIMO system up to 256 antenna array (with lens) -> Identical direction as M⁵HESTIA

Action « Innovation » of CominLabs: mmWSounder project
- **A full and dynamic 3D channel sounder** based on Software Defined Radio equipment
  - to integrate M⁵HESTIA antennas into a dynamic channel sounder
  - to carry out channel measurements in indoor and outdoor scenarios
  - to contribute to the improvement of channel modelling
  - to check theoretical simulation results with "measured channels"
  - to integrate practical channel estimation algorithms and user tracking in mobility scenarios

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NOTES

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