ComInLabs

M^{5}HESTIA

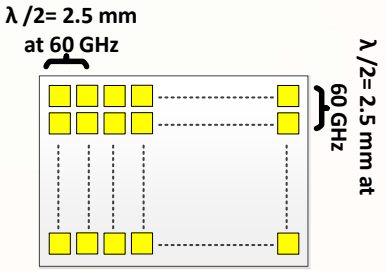
mmW **M**ulti-user **M**assive **M**IMO **H**ybrid **E**quipments for **S**ounding, **T**ransmissions and HW **I**mplement**A**tion

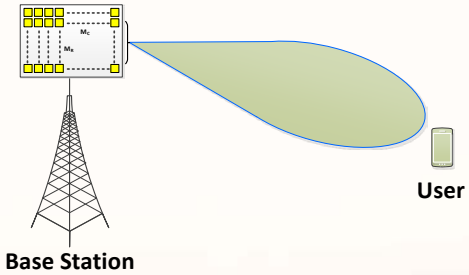
https://project.inria.fr/m5hstia/

2016—2019

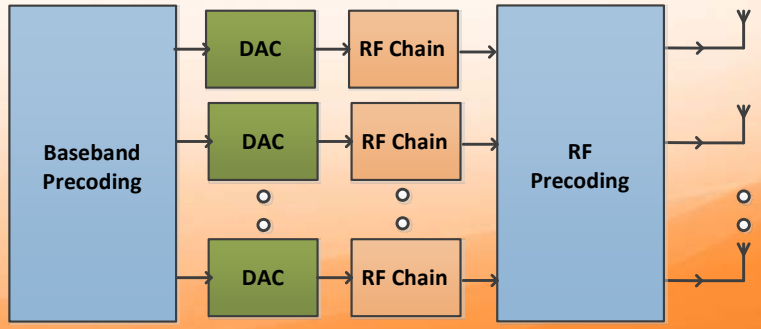
Massive MIMO and mmWave

Massive MIMO	mmWave
Large Physical Dimension (limits practical deployment)	Small Wavelength (small antenna size)
High Antenna Array Gain	Severe Pathloss
High Hardware Complexity (large number of RF chains and DACs)	Sparse Channel and LOS Dominated





Link Budget



Hybrid Beamforming

M5HESTIA consortium

- *Academic partners*
  - INSA Rennes
  - Rennes 1 University
  - IMT – Atlantique

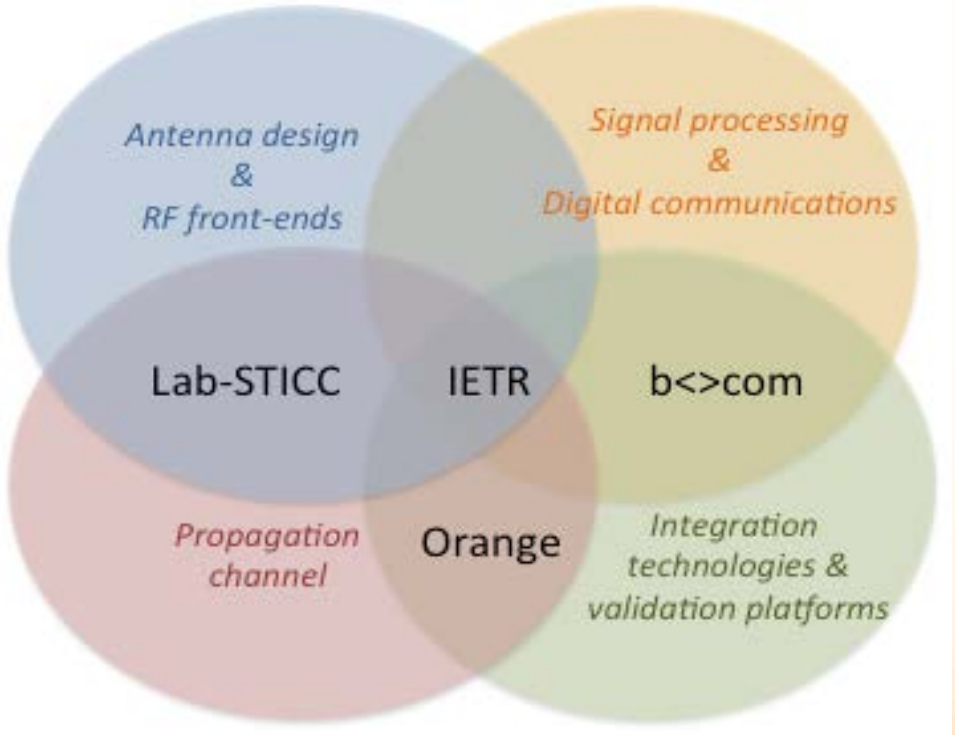
  - CominLabs
    - 2 PhD students (T. Pham, M. Shehata)
    - 2 post docs (A. Shahmansoori, J. Weng)
- *Industrial partners*
  - Orange Labs
  - IRT b<>com

People involved in M^{5}HESTIA

- INSA, **IETR** : M. Hélard, M. Crussière,
- IMT A, **Lab-STICC**: F. Gallée, P. Pajusco, C. Karnfelt, D. Bourreau, **J.i Weng (post Doc)**
- Rennes 1, **IETR** : R. Sauleau, B. Uguen, **A. Shahmansoori (Post Doc)**
- **b<>com:** R. Legouable, J. Dion, S. Paquelet, M. Lanoiselée, L. Lemagoarou
- **Orange Labs**: C. Gallard, N. Malhouroux, P. Ratajczak, J.-P. Rossi

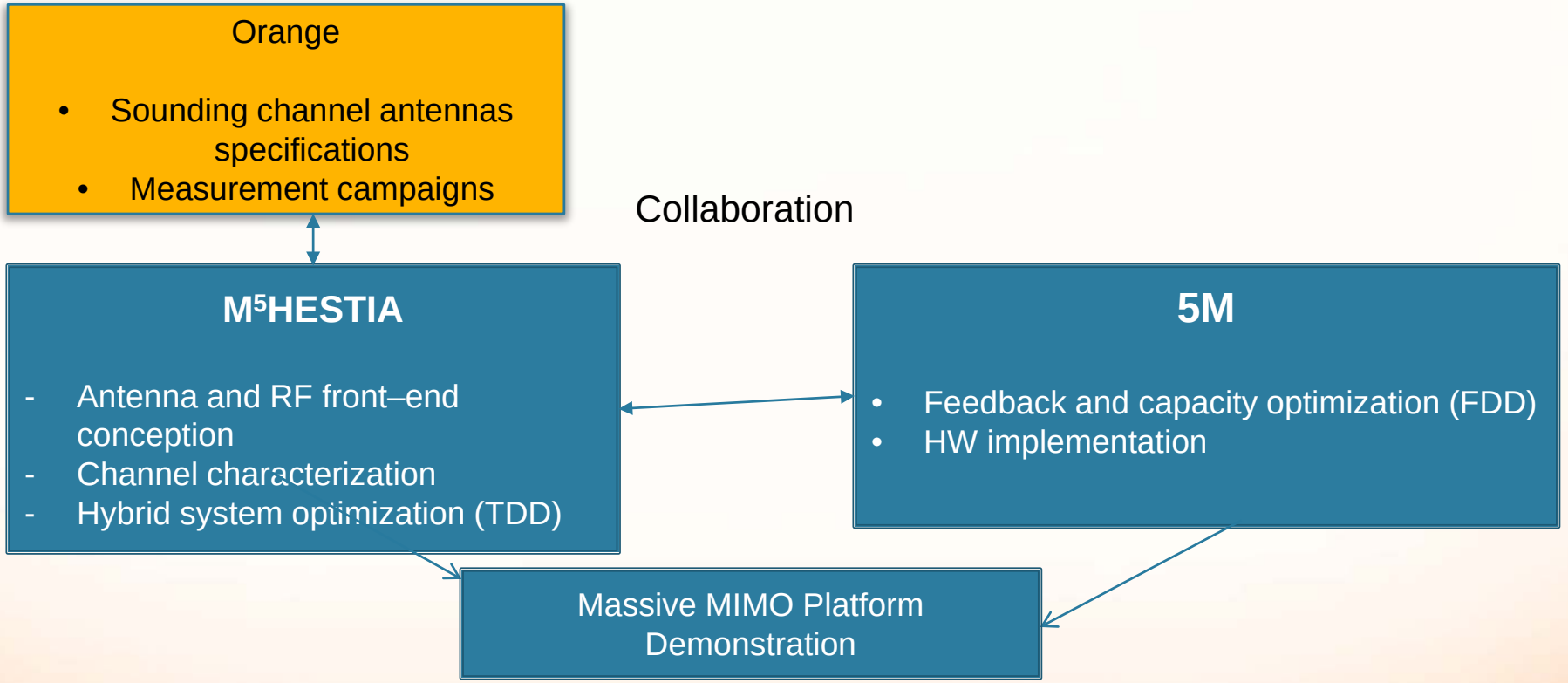
- + PhD students: **T. Pham** (IMT-A & IETR) and **M. Shehata** (IETR & IMT-A)

Complementary of expertises



- *Hybrid techniques*
  - antennas
  - propagation
  - signal processing
- *Rich parternship*
  - IRT b<>com: platform
  - Orange: identification of industrial needs and standards

2 projects in parallel: CominLabs M5HESTIA & b<>com 5M



Common objectives:

- Comparison of Mu massive-MIMO hybrid techniques
- Development of antennas: channel sounding and transmissions
- Measurement campaigns and channel modelling
- Integration of M5HESTIA antennas and RF front-ends in the bcom platform

State of the Art

- **At the beginning of the project**
  - **Some 5G challenges in 2015**
    - New frequencies: Higher frequencies and larger bandwidths
      - mmWave transmissions for both indoor and outdoor
      - since the beginning of the project: 26-GHz and 72- GHz bands have been defined
    - Improvment of the spectral efficiency
      - by increasing the number of antennas: massive MIMO
  - Mostly MIMO systems **below** 6 GHz (5G system)
  - Very few measurments, no channel model for massive MIMO
  - 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 M^{5}HESTIA

Main challenges for M5HESTIA

- **Improve the link budget in mmWave transmissions**
  - directive and high gain antennas
  - critical HW implementation: calibration, interference, integration losses…
- **Increase of the number of antennas**
  - Hybrid massive MIMO
- **Channel modelling**
  - Measurements and channel models for theoretical studies
- **Develop proofs of concept** by designing one **HW platform**

WP2: Antenna design and RF architectures

Current state of the art:

- Tokyo Institute of Technology 2019: Chip 802.11.ay without beamforming
- No complete front-end RF with simultaneous beams

Provided by M[5]HESTIA: antennas for channel sounding at 60GHz, antenna for M-MIMO (8 RF chains in parallel) [Pham19a,19b,19c, Guer19]

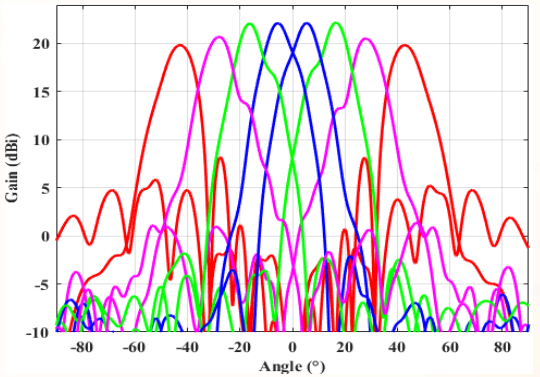
a) Development of a modular approach for lens-based antennas
- Easy duplication for other sounding and transmission antennas and other frequencies

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

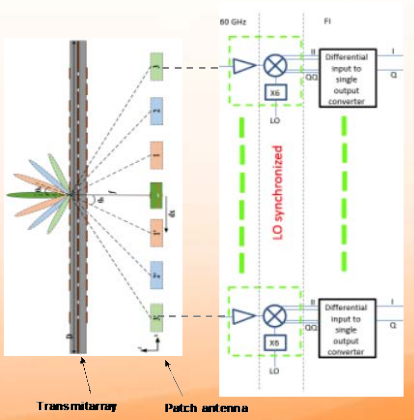
c) Design of different systems
- A wide scan angle transmit array antenna
- Different multibeam 60 GHz systems
  for channel sounding with analogue or digital beamforming
  for wireless communication: until 8 IQ links and 2 users (used by IRT)

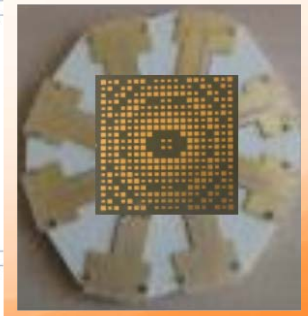
d) Results in accordance with:
- 802.11 ad norms (beamsteering)
- 802.11 ay standardization (multi-user multibeams)

Beam scanning of the system



Antenna system with 60 GHz front-end Rx





WP3: Propagation, sounding and channel modeling

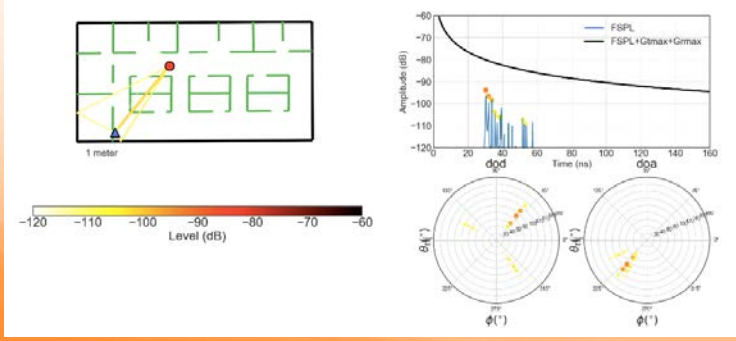
Current state of the art:

- Still few channel measurements and modelling with large antenna arrays
- No model for massive MIMO

Provided by M^{5}HESTIA: improvement of the existing channel modelling (PyLayer) and contribution to mobility scenarios [Shah19, Bald19]

a) 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

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



indoor METIS model used in *M. D. Baldé, B. Uguen, A. Karttunen and K. Haneda, "Identification of Wave Scatterers in an Urban MicroCellular Environment at 32 GHz," 2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Bologna,* ***2018****,*

WP4: Baseband Signal Processing

Current state of the art:

- Hybrid architectures widely assumed for communicating systems based on large-scale antenna arrays,
- Various theoretical results relying on the today's common assumption of (sparse) ray and cluster based channel representations
- Confirmation of the interest for a 2-stage beamforming strategy: analogue and digital precodings (5G)

Provided by M^{5}HESTIA: New results in terms of theoretical performance and algorithms for M-MIMO systems taking into account mmWave propagation characteristics and relying on hybrid precoding and/or index modulation [Sheh17, 18a, 18b, 18c, 19a, 19b, 19c, Mokh19]

a) Theoretical performance of large-scale MIMO systems

- with spatially clustered and ray-based channel representations (from WP3)
- with spare and LOS dominated channels
    - Under Los dominant channel: performance of hybrid beamforming with number of RF chains equals to the number of users are the same than with a full digital beamforming system

b) Hybrid beamforming

- New efficient and low complexity beamforming strategies proposed
    - Analogue Los beamsteering + digital interference cancellation (ZF)
        - Simple and optimal solution in pure LoS scenarios
        - Remains robust in sparse channels
    - Simple and efficient : ZF + EGT-based beamforming
        - Remains robust if some paths are blocked or shadowed

c) Application to spatial modulations

- Design of new index modulation strategies and related theoretical results

WP5: HW baseband implementation & platform

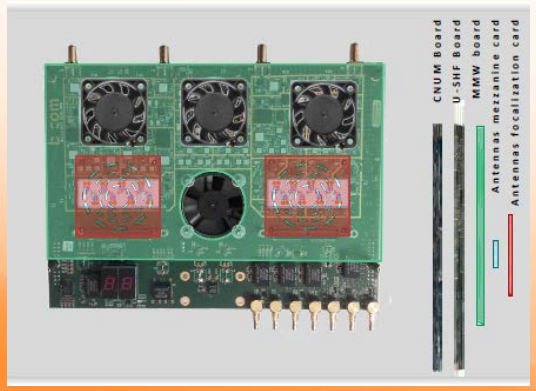
Current state of the art:

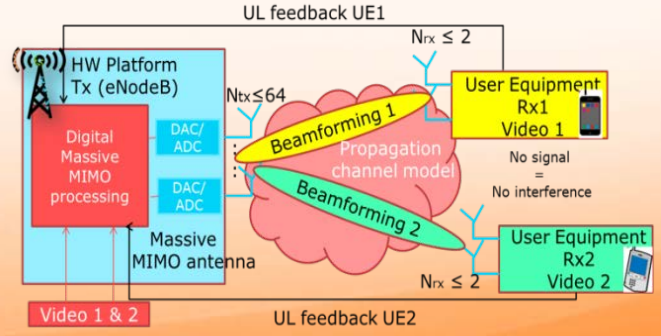
- 5G proposes 26 GHz (over up to **400 MHz**) for **outdoor** transmission (gNodeB)
- **Hybrid** M-MIMO system up to 256 antenna array (with lens) -> Identical direction as M5HESTIA

Provided by M^{5}HESTIA: integration of the antennas in the b<>com platform for beamsteering allowing 2 parallel and different beams in a 2 GHz bandwidth leading to high data rate transmission (more than 5 Gbps per spatial stream)

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





Future works

- **Antennas**
  - Orange & IMT-A: in channel sounders
  - b<>com: in its platform
  - IETR: in its NI MIMO platform
- **Dynamic channel sounder** based on SDR: CominLabs, Innovation action “mmWSounder”, same partners
  - to integrate antennas provided by M^{5}HESTIA into a dynamic channel sounder
  - to carry out additional channel measurements (indoor and outdoor)
  - to go on improving channel modelling
  - to check theoretical simulation results with “measured channels”
- During the “mmWave and Thz communication workshop” 8/11/2019
  - Dedicated session to M^{5}HESTIA
  - Contacts with: IMEC, INTEL, NOKIA, RFS…

Questions

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

WP1: project management & dissemination

- 8th November 2019, International Workshop on “mm-Wave and THz communications for beyond 5G applications”, with a session dedicated to M5HESTIA. https://wave-and-thz-com-66.webself.net/home

WP2: antenna design and RF architecture

- **T. Pham,** J. Weng, K. Pham, F. Gallée, R.Sauleau, *V-Band Beam-Switching Transmitarray Antenna for 5G MIMO Channel Sounding*, 13th European Conference on Antennas and Propagation (EuCAP), Krakow, Poland, 2019
- R. Guerrero, F. Gallée, C. Kärnfelt, *Novel 60 GHz DRA topology adapted to the LTCC technology process*,13th European Conference on Antennas and Propagation (EuCAP), Krakow, Poland, 2019
- **T. Pham**, F. Gallée, R. Sauleau, *A Beam-Steering Transmitarray Antenna for 5G MIMO Channel Sounding in V-band*, EuMW 2019, Paris, France
- **T. Pham**, K. T. Pham, F. Gallée, and R. Sauleau, *A Wide-Angle Beam-Steering Bifocal Transmitarray Antenna for 5G Channel Sounding at V-ban*d, IEEE Transactions on Antennas and Propagation (submitted)

WP3: channel modelling

- **Ar. Shahmansoori**, B. Uguen, G. Destino, G. Seco-Granados, H. Wymeersch, "Tracking Position and Orientation through Millimeter ave Lens MIMO in 5G Systems, "IEEE Signal Processing Letters, Vol 26, N°8, August 2019
- Di. Balde, B. Uguen ; A. Karttunen and K. Haneda, Identification of Wave Scatterers in an Urban MicroCellular Environment at 32 GHz", PIMRC 2018, Bologna, **2018**

WP4: baseband signal processing

- **M. Shehata**, M. Crussière, M. Hélard, P. Pajusco, *Hybrid Analog and Digital Precoding in Millimeter Wave Massive MIMO Systems with Realistic Hardware and Channel Constraints*, 2017 IEEE SPS Summer School on Signal Processing for 5G Wireless Access, Gothenburg, Sweden : 2017
- **M. Shehata**, M. Hélard, M. Crussière, A. Rozé, C. Langlais, *Angular Based Beamforming and Power Allocation Framework in a Multi-User Millimeter-Wave Massive MIMO System,* 87th Vehicular Technology Conference: VTC2018-Spring: 2018
- **M. Shehata**, M. Crussiere, M. Hélard, Hybrid Beamforming for Multi-User MISO Channels with Equal Gain Transmission: A Robust and Spectral Efficient Approach, ICT 2018 | 25th International Conference on Telecommunication : 2018
- **M. Shehata**, M. Crussiere, M. Hélard, P. Pajusco, *Leakage Based Users Selection for Hybrid Beamforming in MillimeterWave MIMO*, 2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) : 2018
- **M. Shehata**, A. Mokh, M. Crussière, M. Hélard, P. Pajusco*, On The Equivalence between Hybrid and Full Digital Beamforming in mmWave communications,* IEEE ICT 2019,26th Hanoi, Vietnam
- **M. Shehata**, M. Crussière, M. Hélard, On the Theoretical Limits of Beam Steering in mmWave Massive MIMO Channels, IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) : 2019
- A. Mokh, **M. Shehata,** M. Crussière, M. Di Renzo, M. Hélard, "Hybrid Beamforming for Receive Spatial Modulation" , To be submitted to IEEE Tr. on Wireless Communication
- **M. Shehata,** A. Mokh, M. Crussière, M. Hélard, "Analytical Performance of Hybrid Beam Index Modulation", Submitted at IEEE Wireless Communication Letters