THz Communications

Enabling Wireless Systems Beyond 5G

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Broadband Communication Systems Group

- **Established** in 2010 by Prof. Angeliki Alexiou (leveraging cutting-edge **industrial research expertise** in advanced wireless technologies since 1999)
- **Undergraduate and postgraduate courses**: Stochastic Processes, Broadband Communications, Wireless Access Technologies, Short Range Communications, SDR
- **Research vision**: Densification, proximal communications, ultra high spectral efficiency technologies and THz communications will drive evolution beyond 5G
- **Research focus**: MIMO (massive, distributed, network), UDN (small cells, hetnets, 'cell-less' architectures, cloud-based design, multi-operator competition/sharing), D2D (overlay/underlay, optimal resource allocation), M2M (random vs scheduled access, aggregation, M2M over cellular design challenges), THz Comms (info theory, pencil-BF, MAC/RRM design)
- **Expertise/skills**: fundamental information theoretic analysis, signal processing for advanced physical layer procedures, resource and interference management algorithms, system level simulation platform and experimental HW/software-defined platform development.
- **Tools**: analytical (e.g. stochastic geometry, game theory), link level simulator(OFDM, MIMO), system level simulator, large network optimization tools, SDR prototyping
- **Wireless standards**: LTE, LTE-ADV, NR, WiFi (evolution), NB-IoT
- **Funded projects**: EXALTED(FP7) [M2M], ARTCOMP(national) [MIMO, UDN], FLEX(FIRE) [D2D], TERRANOVA(H2020) [THz Comms], (1million of funding raised since 2011)
- **Dissemination/exploitation/leadership**: WWRF (Chairing Radio Tech and HF WGs), ITU-R WP5D (invited speaker at IMT-2020 workshops, leader of the WWRF IMT-2020 Evaluation Group)
- For further info: https://sites.google.com/site/bcsgunipi/

BCSG recent research contributions

- Architectural design concepts: Cloud-RAN, Ultra-Dense Small-Cell Networking, Machine-Type (M2M) / Paired (D2D) Communications, etc…
- Fundamental performance limits analytical assessment of densification performance gains and cross-mode interference characterization
- Analytical modeling of multi-operator competition/resources sharing gains
- Optimization of large dense wireless networks
- Radio resources management algorithms in massive MIMO and distributed MIMO networks considering signaling and backhaul overhead
- Joint optimization of access and backhaul over shared radio resources
- Enabling and optimizing M2M communications over cellular radio access
- Coordination and interference management of hybrid cellular - D2D networks
- **Analytical Performance Assessment of THz Wireless Systems**
- **Distance- and Bandwidth-Dependent Adaptive Modulation Scheme for THz Communications**
- **Pencil-Beamforming and Tracking for THz Wireless Access**

Recent Funded Research Highlights (completed)

ICT EXALTED (09/2010 - 02/2013)

Framework: FP7-ICT-2009-5, Objective ICT-2009.1.1: Network of the future

Objective: To develop a cost, spectrum and energy efficient radio access technology for M2M applications, adapted to coexist within a high capacity LTE network.

BCSG Roles:

- Work-Package Leader (WP2: Business Models, Use Cases and Technical Requirements);
- Member of the Project Management Technical committee;
- One of the main contributors of the project objectives formulation in the conceptual (proposal) phase

Technical Achievements:

- Contributed to the System Architecture Definition
- Devised novel M2M Scheduling Algorithms and Protocols for LTE and Capillary Networks

NSRF ART-COMP (09/2012 - 02/2015)

Framework/Action: Supporting Postdoctoral Researchers", National Operational Programme "Education and Lifelong Learning. Accepted after Open-Call (~rate<5%)

Objective: To design, analyze and experimentally asses advanced cellular access concepts, architectures, as well as PHY and MAC algorithms for managing interference and achieving high quality-of-service experience in beyond 4G ultra-dense radio access networks.

Technical Achievements:

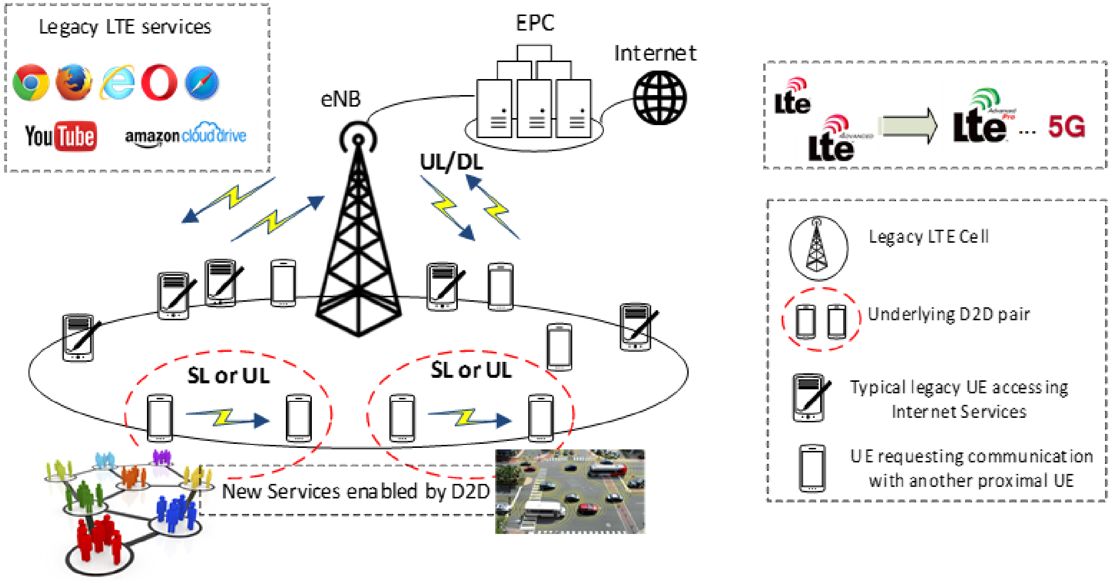
- Development of a unified radio resources management framework and exemplary algorithms for dealing with complex interference scenarios in future UDNs
- Development of an experimental proof-of-concept hardware/software test-bed and demonstration of a series of potential interference coordination policies in baseline LTE-compliant multi-user multi-cell networks

Recent Funded Research Highlights (completed)

FIRE

FLEx – D

FIRE LTE TESTBEDS FOR OPEN EXPERIMENTATION



ICT FP7 FIRE FLEX-D

(01/04/2016 – 31/03/2017)

Framework: FLEX (FIRE LTE testbeds for open experimentation) FIRE Project, 2nd Open Call

Objective: To develop a set of D2D enabling innovative components towards enabling flexible device-centric experimentation within legacy LTE network deployments.

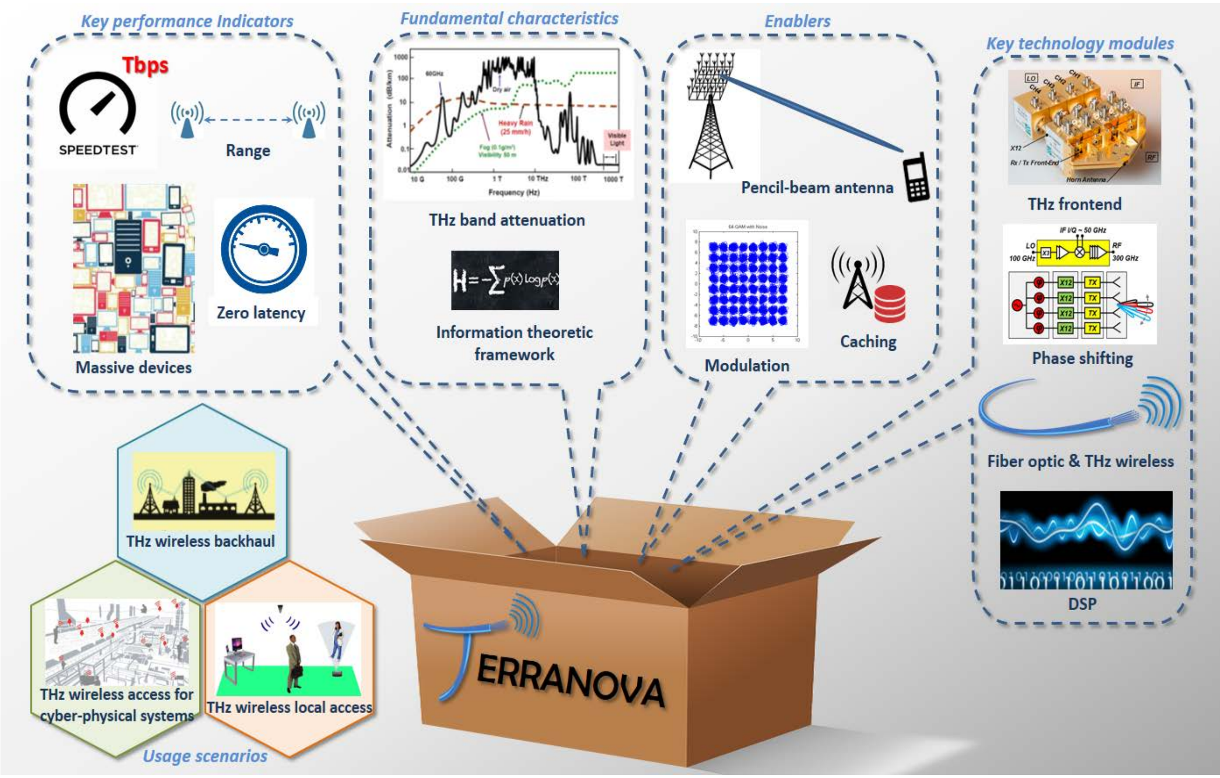
BSCG Role:

- Development of LTE-D2D co-existence methods and performance evaluation through analysis and simulation.

Achievements:

- A framework for optimized D2D operation in a LTE-controlled access environment
- A test-bed platform allowing to perform D2D discovery and communication experiments in real-world conditions, using softwarized protocol stacks and SDR equipment.

Recent Funded Research Highlights (in progress)



TERRANOVA (H2020, ICT-09) (01/07/2017 – 31/12/2019)

Framework: H2020, ICT-09, B5G

Objective: To take advantage of breakthrough novel technology concepts, namely the joint design of baseband signal processing for the complete optical and wireless link, the development of broadband and spectrally highly efficient RF-frontends for frequencies >275 GHz, as well as channel modelling, waveforms, antenna array and multiple-access schemes design and development tailored to the particularities of the THz regime and the associated extremely large bandwidth.

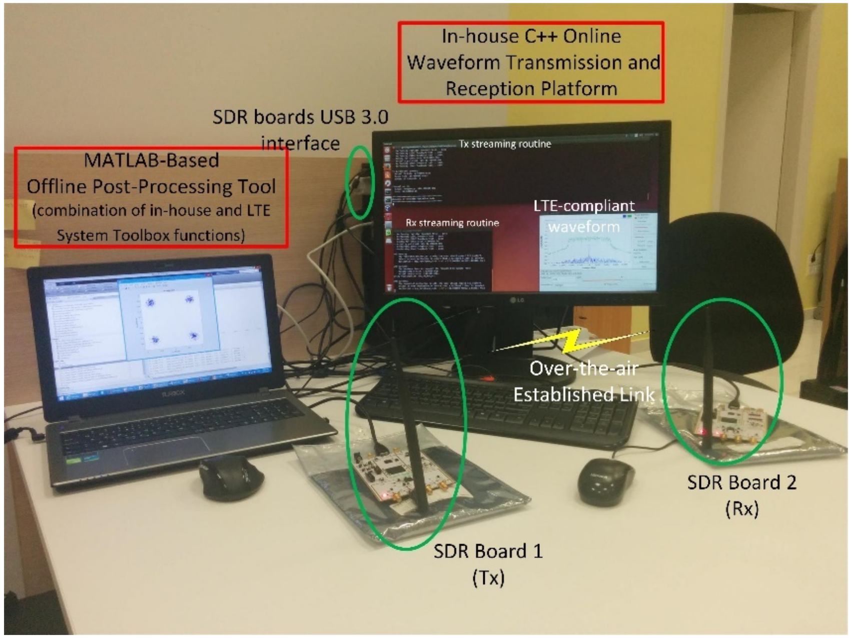
BSCG Role:

- Project coordinator
- Task leader for Information Theory in THz Comms
- WP leader for MAC and RRM
- Contributions to pencil-BF and channel and interference modelling

Experimental Facilities

Hardware

A software-defined platform for evaluating wireless links performance over-the-air.



Software

Baseband implementations, L1/L2 stacks, simulation models for LTE, LTE-A, 802.11x, 802.16 protocols and various cellular, ad-hoc, vehicular setups.

Dissemination/Exploitation channels

WIRELESS WORLD RESEARCH FORUM

mi·cluster coralllia

International Telecommunication Union

ITU Radiocommunication Sector

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

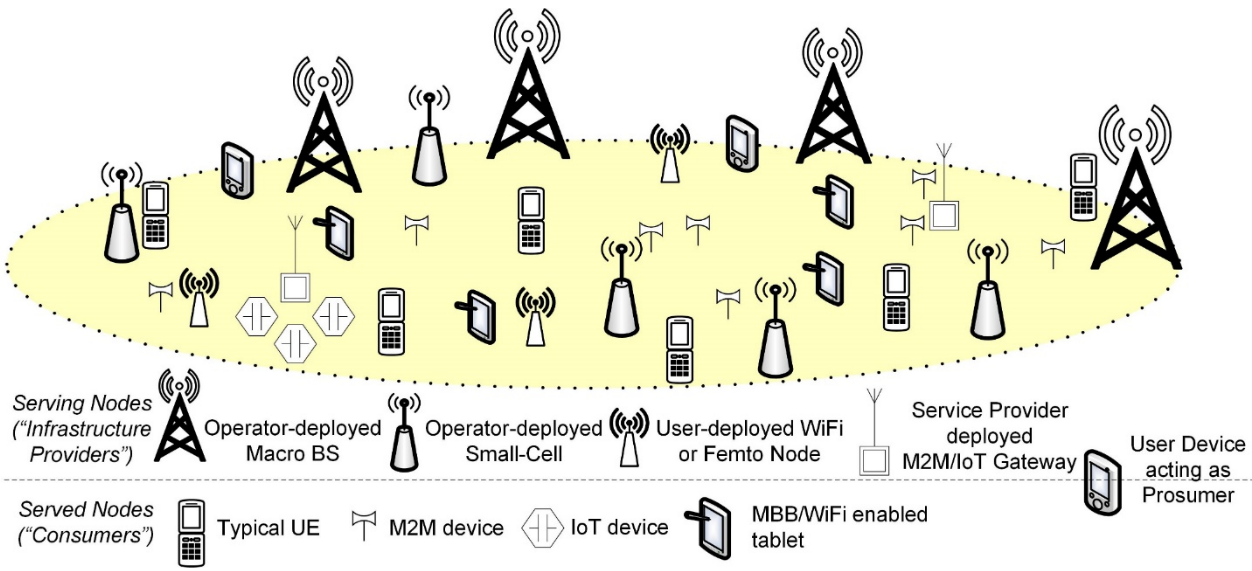
CA COST Action CA15104
Inclusive Radio Communication Networks for 5G and beyond (IRACON)

- WWRF: chairing/driving new radio and high frequencies activities
- ITU-R WP5D: invited speaker at IMT-2020 workshops and leader of the WWRF IMT-2020 (registered) Evaluation Group
- Recent presentations: https://sites.google.com/site/bcsgunipi/recent-talks
- Recent dissemination activities: https://sites.google.com/site/bcsgunipi/home

A THz Vision for Systems Beyond 5G

Beyond 5G Design and Architecture Principle

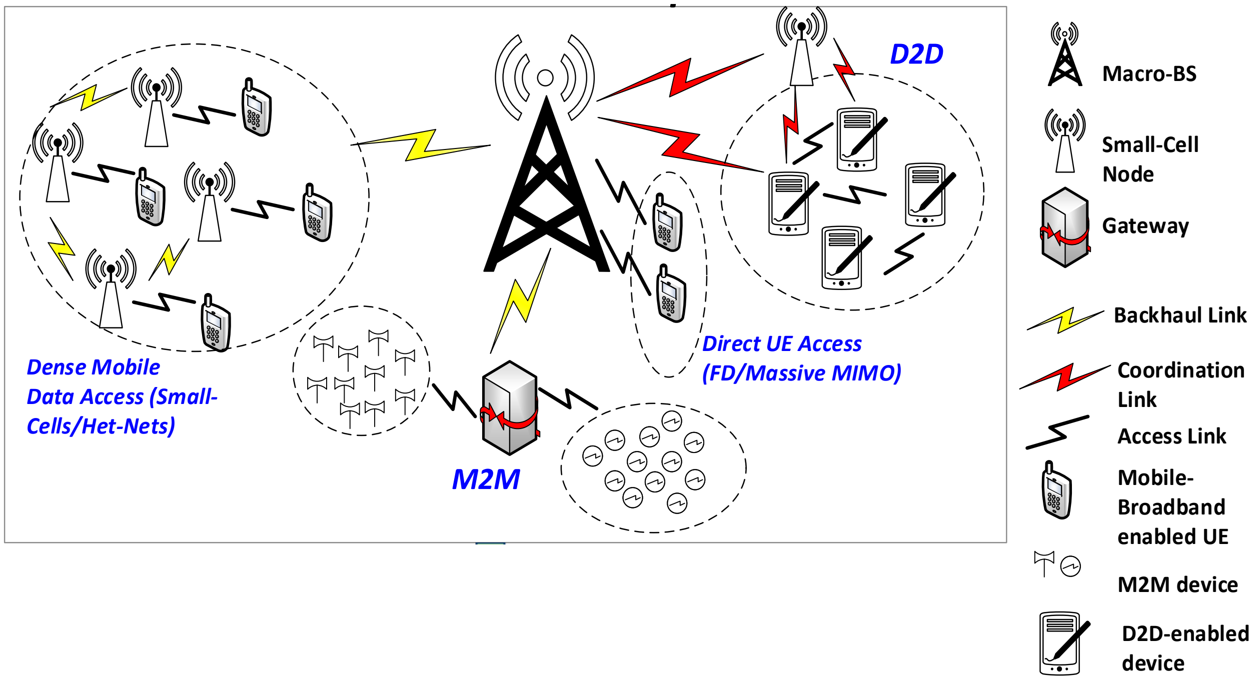
Extreme Network Densification



- The UDN concept introduces a paradigm shift from the well-known small-cell to a cell-less wireless future, by integrating:
  - Operator-driven hyper-dense small-cell deployments, bringing a multiple orders of magnitude increase in the number of available infrastructure elements per user;
  - Complementary radio access networks (e.g. WiFi) operated by alternative providers (stadiums, airports, shopping malls);
  - User-deployed home infrastructure, such as wireless routers for internet access, femto-cells, M2M gateways;
  - "Crowdsourced" high-end user devices equipped with various wireless interfaces, and acting as adhoc providers.

Beyond 5G novel system concept

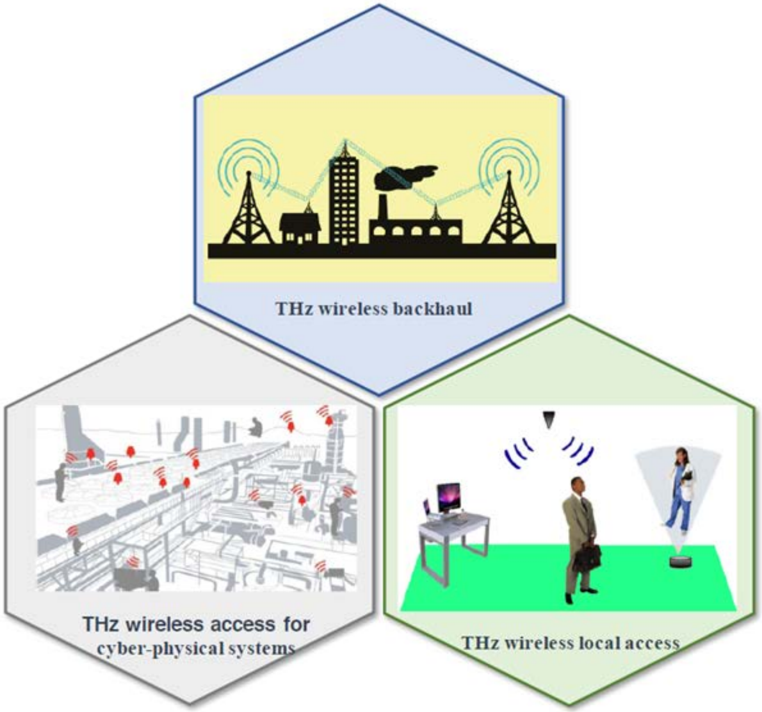
Proximal communications with ‘2-layer’ access



- Basic concept: exploit massive UE densification to access the network via a proximal link (M2M, D2D, SCN, WiFi, ..)
- Main challenge: ‘2-layer’ multiple access, access/fronthaul/backhaul, overlay/underlay, cashing…

Beyond 5G expectations

Tbps



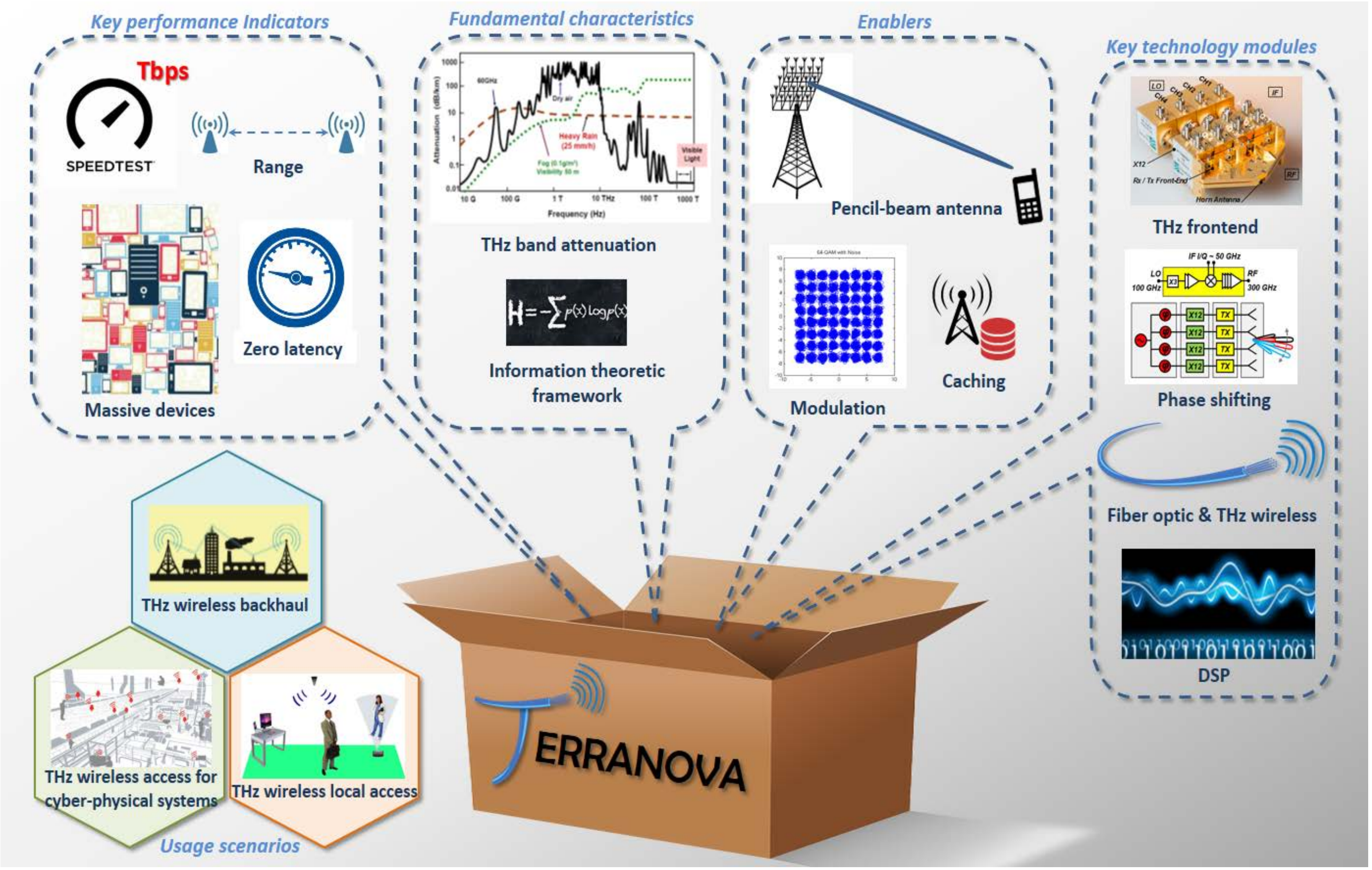
- Inherently support a large dynamic range of novel usage scenarios that combine extreme data rates with agility, reliability, zero response time and AI
- Cost-efficient and flexible provision of high-speed data connections guaranteed, zeroing the 'digital divide'
- Extend the fibre optic systems QoE and performance reliability to wireless

THz Opportunity and its unique Challenges

- Bridge the THz ‘gap’
- Tackle the THz propagation characteristics
  - Ultra wideband and extremely directional wireless links
  - Absorption Loss
  - Attenuation with distance

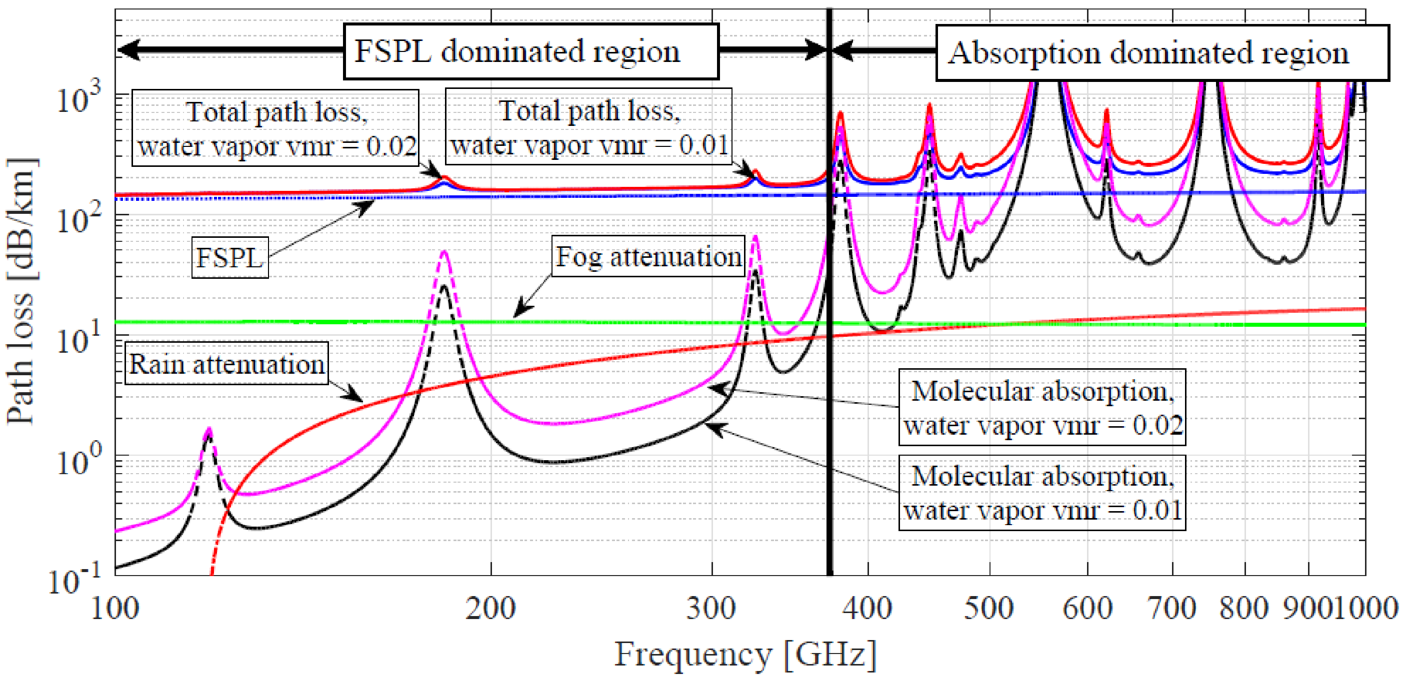
- **Devise a new network information theoretic framework imposed by the new disruptive characteristics of the channel**
- **Design appropriate wireless access technologies, i.e. pencil-beamforming, space synchronization, beam tracking, ..**
- **Design MAC protocols tailored to ‘pencil-beam’ access: challenging initial access/discovery and tracking w.r.t. complexity/delay/reliability/..**

TERRANOVA System Concept



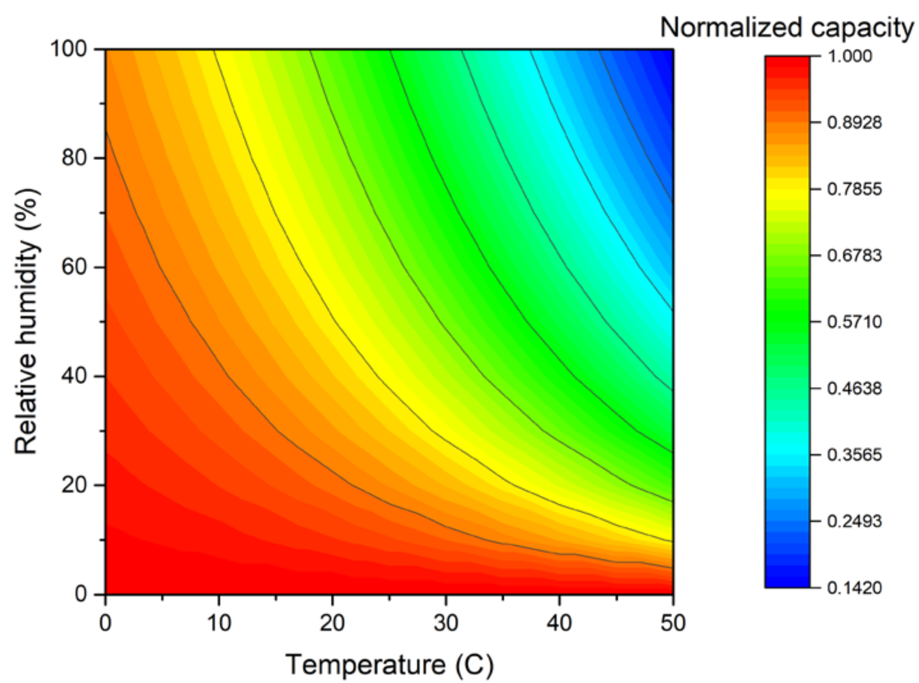
ict-terranova.eu

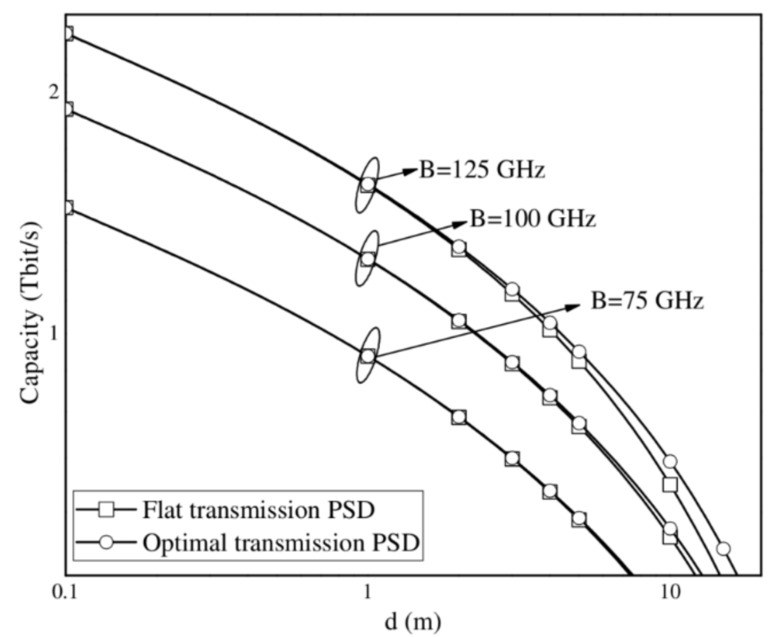
THz Channel Modelling



Alexandros-Apostolos A. Boulogeorgos, Angeliki Alexiou, Thomas Merkle, Colja Schubert, Robert Elschner, Alexandros Katsiotis, Panagiotis Stavrianos, Dimitrios Kritharidis, Panteleimon-Konstantinos Chartsias, Joonas Kokkoniemi, Markku Juntti, Janne Lehtomaki, Antonio Teixeira, and Francisco Rodrigues, "Terahertz Technologies to Deliver Optical Network Quality of Experience in Wireless, Systems Beyond 5G, IEEE Communications Magazine, vol. 56, no. 6, pp. 144–151, Jun. 2018.

Fundamental Performance Evaluation of THz Wireless Links





SNR and capacity depend on:

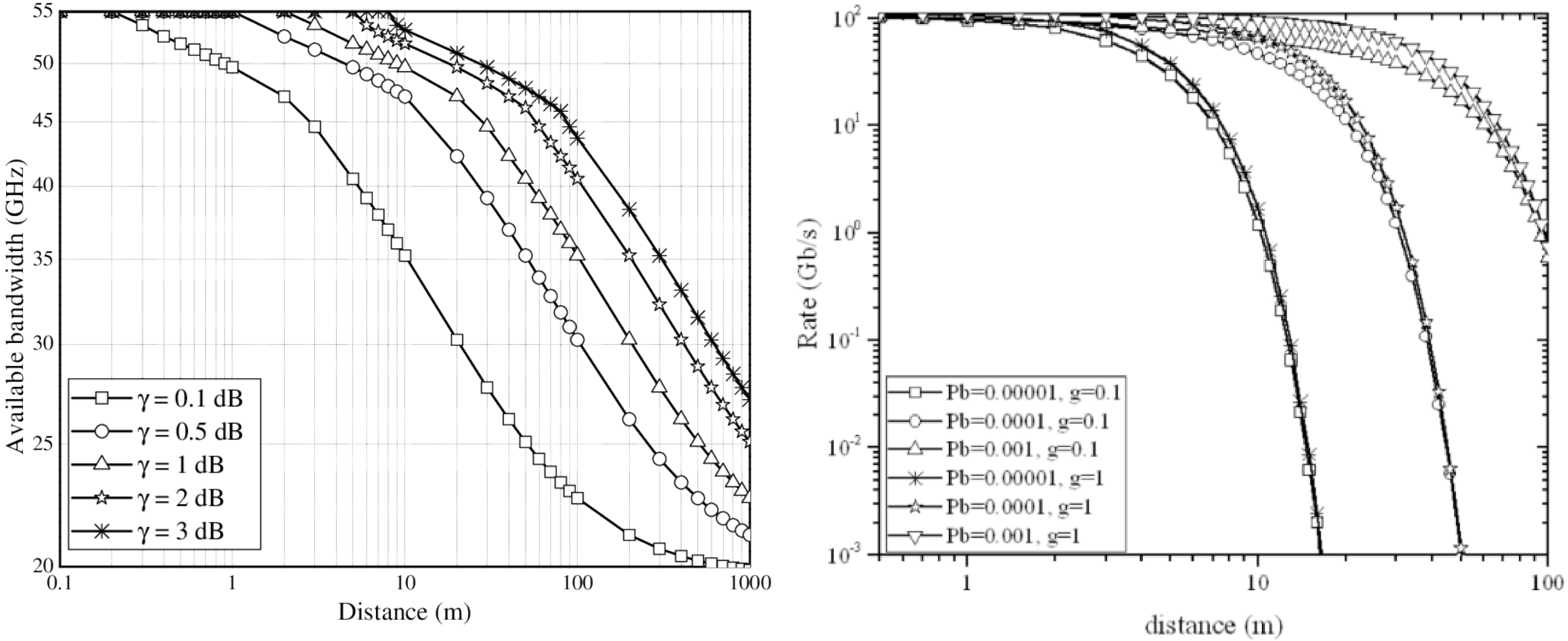
- transmission central frequency;
- transmission power allocation;
- antenna gains;
- distance between the TX and RX;
- transmission bandwidth; and
- atmospheric conditions

Assumptions and considerations

•Assume flat transmission PSD, $S(f)=S_o$
•g=100 dB
•B=125 GHz
•Standard atmospheric conditions

Alexandros-Apostolos A. Boulogeorgos, Evangelos N. Papasotiriou, Joonas Kokkoniemi, Janne Lehtomaki, Angeliki Alexiou, and Markku Juntti, "Performance Evaluation of THz Wireless Systems Operating in 275−400 GHz Band ", VTC Spring 2018, Porto, June 2018

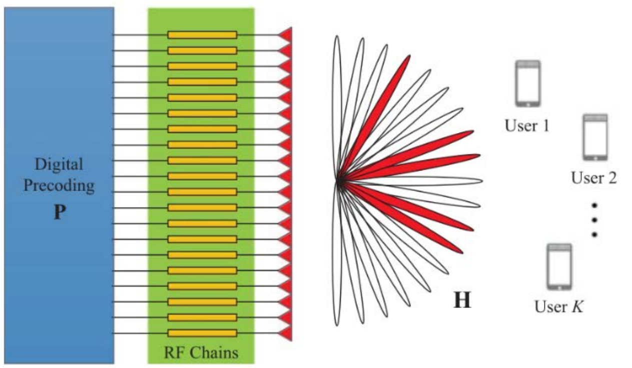
A distance and bandwidth dependent adaptive modulation scheme for THz communications

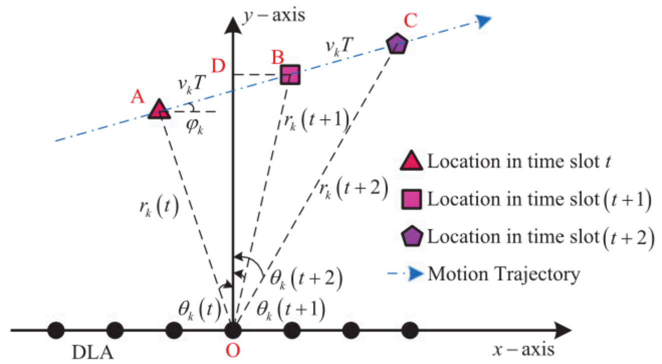


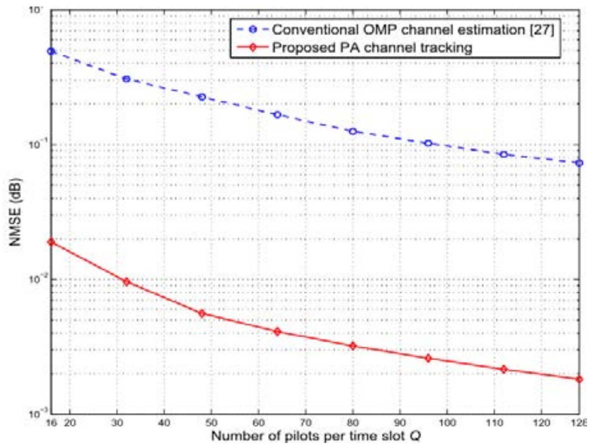
- For a given γ, as the transmission distance increases, the used bandwidth will be constrained.
- For a given d, as γ increases, the available bandwidth also increases
- For given P_b and γ, as the distance increases, the achievable rate decreases.
- For given P_b and d, as γ increases, the achievable rate increases.

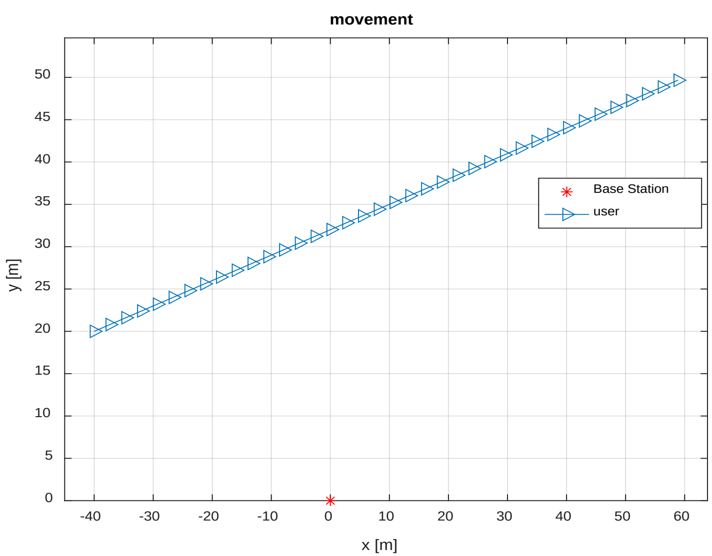
Alexandros-Apostolos A. Boulogeorgos, Evangelos N. Papasotiriou, Angeliki Alexiou, "A distance and bandwidth dependent adaptive modulation scheme for THz communications", SPAWC 2018, Kalamata, Greece

Fast Beam-Tracking algorithm

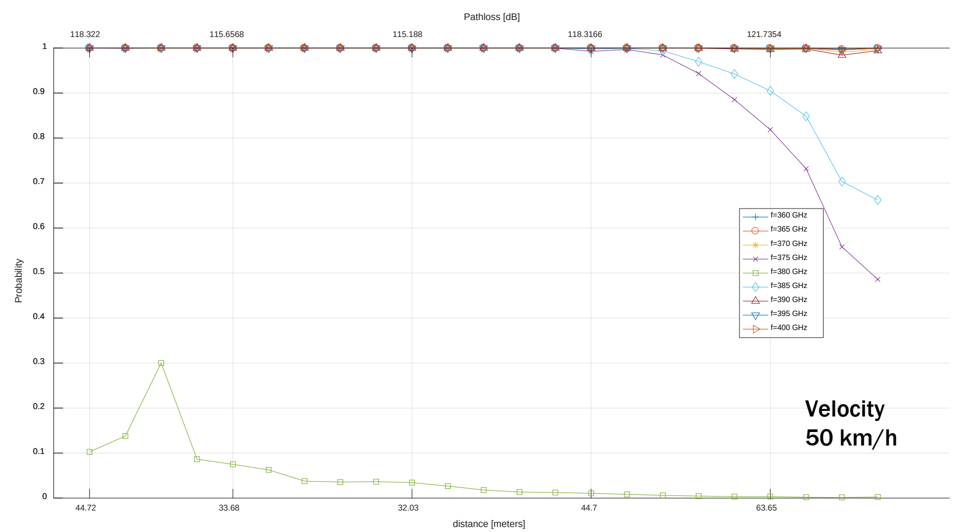






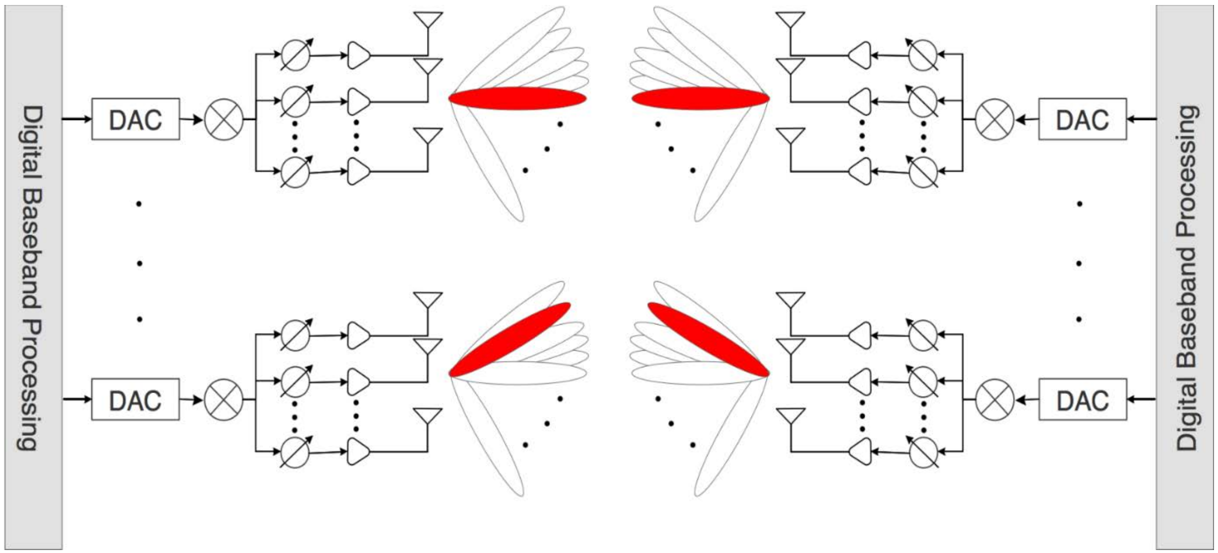


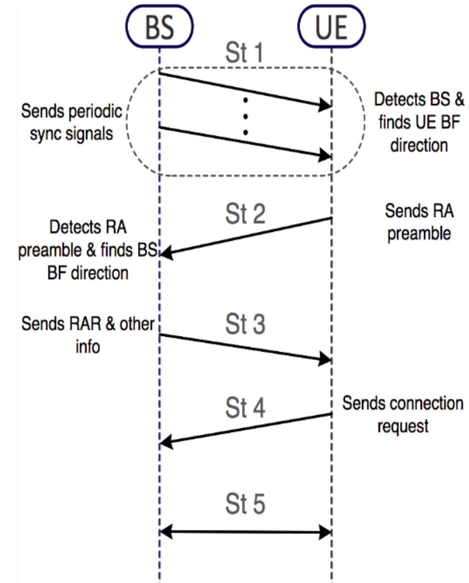
Probability of correct estimation in each timeslot



MAC and RRM

Beam-Space Access





- Step 1: Synchronization and Signal Detection
- Step 2: Random Access Preamble Tx
- Step 3: RA response (RAR)
- Step 4: Connection Request
- Step 5: Scheduled Communication

- Critical parameters: Beamwidth, number of beamspace channels, number of pilots, distance, mobility
- Important metrics/challenges: detection probability, space synchronization (misalignment)