Millimeter-Wave Based Networking in 5G Communication Systems

IEEE 5G Thessaloniki Summit, 11.07.2017

Claudio Fiandrino,

IMDEA Networks, Madrid, Spain

Developing the Science of Networks

Research Projects @ IMDEA – WNG Group

Outline

- Introduction on mm-wave communications
- Localization system
- Hybrid beamforming
- Architectural design and optimizations

Move to Higher Frequencies

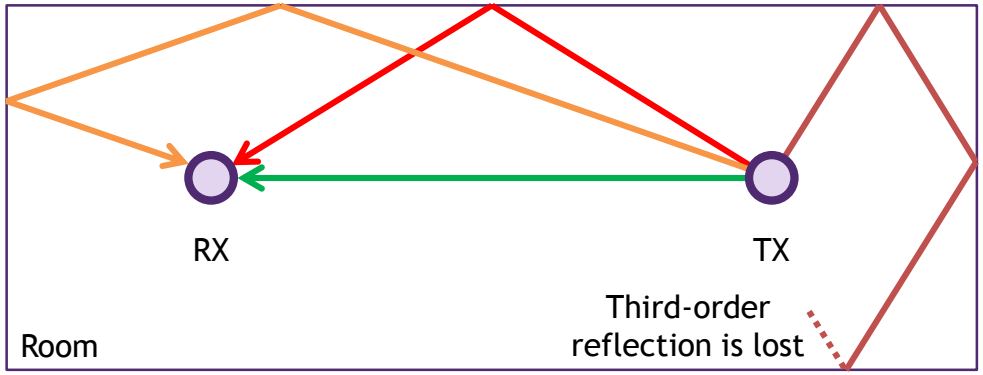
- Inevitable to achieve multi-Gbit/s data rates expected in 5G
  - Spectrum is very crowded at current frequencies up to ~6 GHz
  - GHz of spectrum available at mm-wave frequencies (> 24 GHz)
- **BUT:**
  - High frequency related path loss
  - Atmospheric absorption at very high frequencies
  - More noise due to very wide bandwidth
  - Most materials block the signal (also humans!)
  - Communication primarily line-of-sight
  - RF design much harder at these frequencies

Challenges at all Levels of the Protocol Stack

- Very directive signal → align the beams and keep alignment
- Short range → frequent handovers or multi-hop relaying
- Many access points → efficient network management and control, energy efficiency
- Blockage → fall back to lower frequency
- Little interference → encourage parallel transmissions
- No omni-directional control signals for coordination → new MAC paradigms
- High rate variations → requires flexible transport protocol
- Typical packet size too small for Gbit/s rates → extreme packet aggregation (100s of packets)
- … and many many more

mmWave Location System

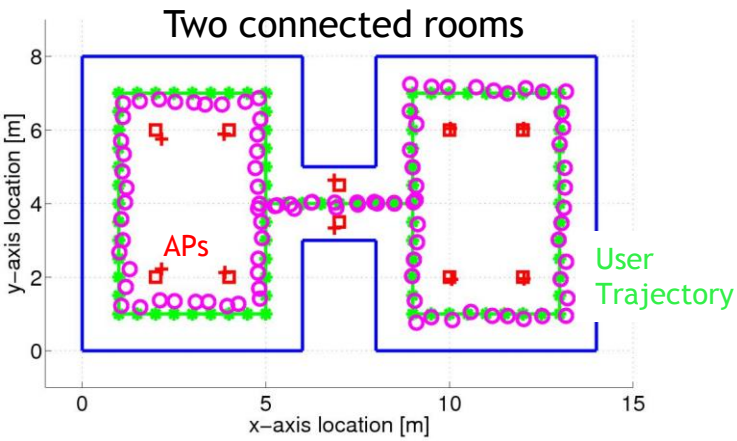
- Objectives: indoor localization and SLAM
- Additionally: network optimization
  - AP association, beam steering, handover, rate adaptation
- Angle of arrival/departure information from the beam-training can be used for surprisingly accurate location system
- Exploit multi-path scarcity in mm-Wave propagation
  - High attenuation allows only for first- or at most second-order reflections
  - Signals arriving at a receiver can be easily traced back to transmitter

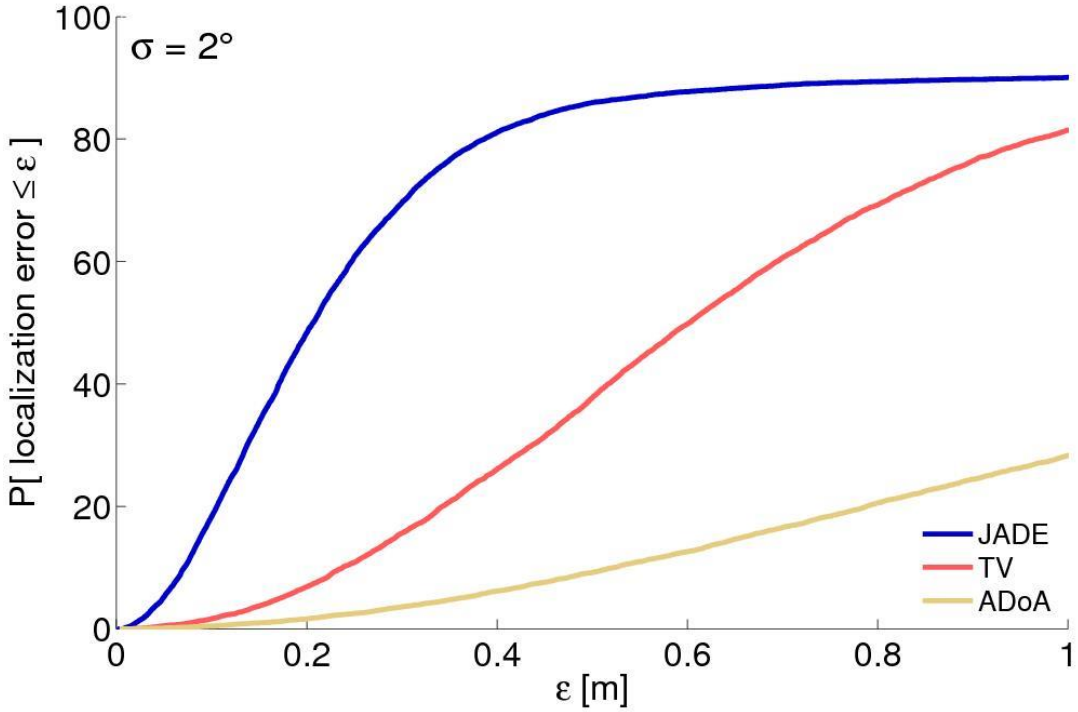


Joan Palacios, Paolo Casari, and Joerg Widmer. "Jade: Zero-knowledge device localization and environment mapping for millimeter wave systems." IEEE INFOCOM, Atlanta, GA, USA, May 2017.

Localization Results

- Joint Anchor and Device location Estimation (JADE)
- Unknown access point (AP) locations, unknown floor plan
- Learn: make use of history of locations for refinement
- Outperforms even algorithms that assume floor plan and APs are known!





mmMAGIC

Overall objective is to develop a **standard-ready mobile radio access technology (RAT)** operating in wide contiguous bandwidth above 6 GHz (including mm-wave frequencies)

Objectives

1. Investigate suitable frequency ranges (6-100 GHz) for extremely high capacity mobile broadband services
2. Conduct measurements and develop accurate channel models for identified candidate frequency ranges.
3. Develop novel mobile radio access technologies for 5G systems in frequency above 6 GHz

Consortium

6 vendors
Samsung (Coordinator), Ericsson(Technical Manager), Alcatel-Lucent, Huawei, Intel, Nokia

2 operators
Orange, Telefonica,

3 research institutes
HHI, CEA-Leti, IMDEA

4 universities
Aalto, Bristol, Chalmers, Dresden

1 SME
QAMCOM

2 test equipment suppliers
Keysight, Rhode & Schwarz

Facts

3 White Papers

17 Public Deliverables

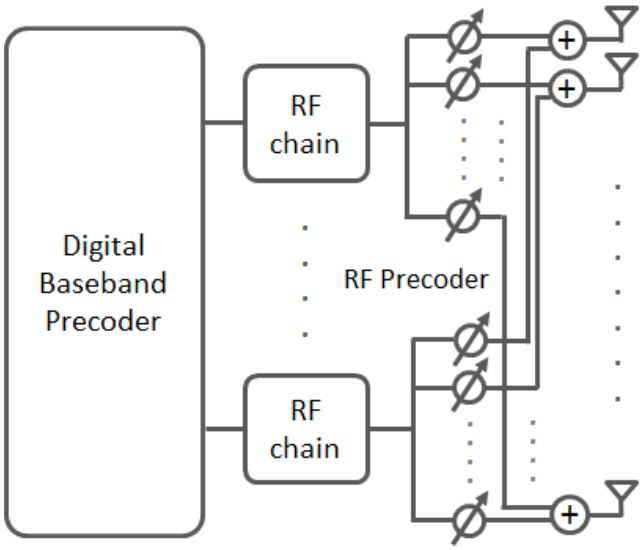
65+ Publications in top venues

http://5g-mmmagic.eu/

Website

Hybrid Beamforming

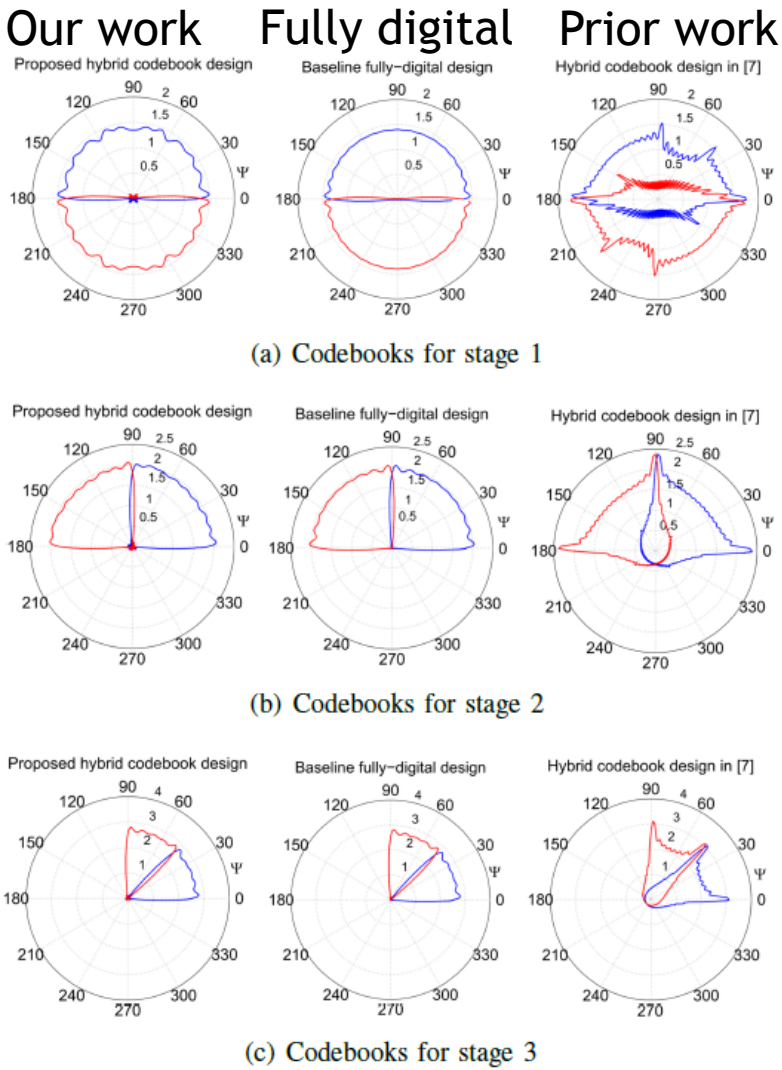
- Tradeoff between performance and complexity
- Capable of achieving multiplexing gains (multiple parallel streams) with low complexity hardware



Heath et al. "Channel estimation and hybrid precoding for mmwave wave cellular systems" IEEE Journal on Sel. Topics in Sig. Proc., Oct 2014

How to Design Beam Patterns?

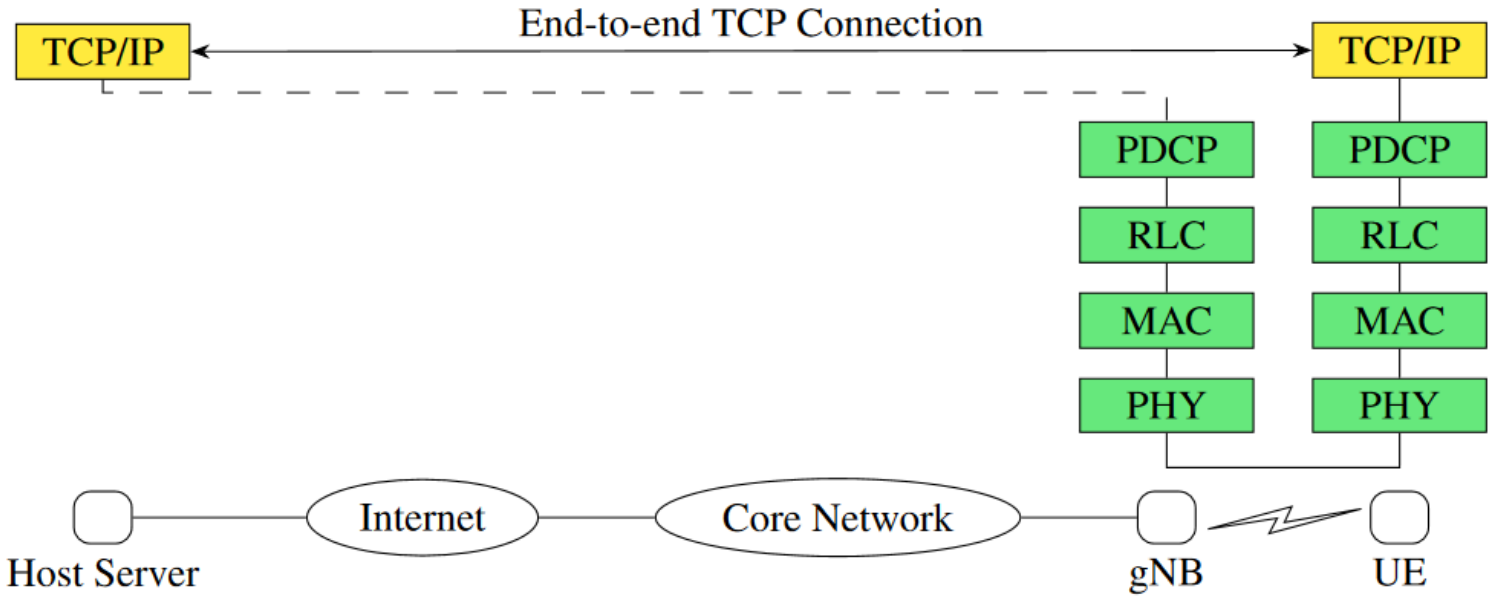
- Orthogonal Matching Pursuit (OMP) algorithm with dynamic dictionary learning mechanism
- Better beam shapes with lower complexity hardware
  - 64 antenna elements
  - Our work: design with 8 RF chains with 2-bit RF phase shifters
  - Prior work: 32 RF chains with 7-bit RF phase shifters



D. De Donno, J. Palacios and J. Widmer, "Millimeter-Wave Beam Training Acceleration Through Low-Complexity Hybrid Transceivers," in *IEEE Trans on Wireless Communications*, vol. 16, no. 6, pp. 3646-3660, June 2017. DOI: 10.1109/TWC.2017.2686402

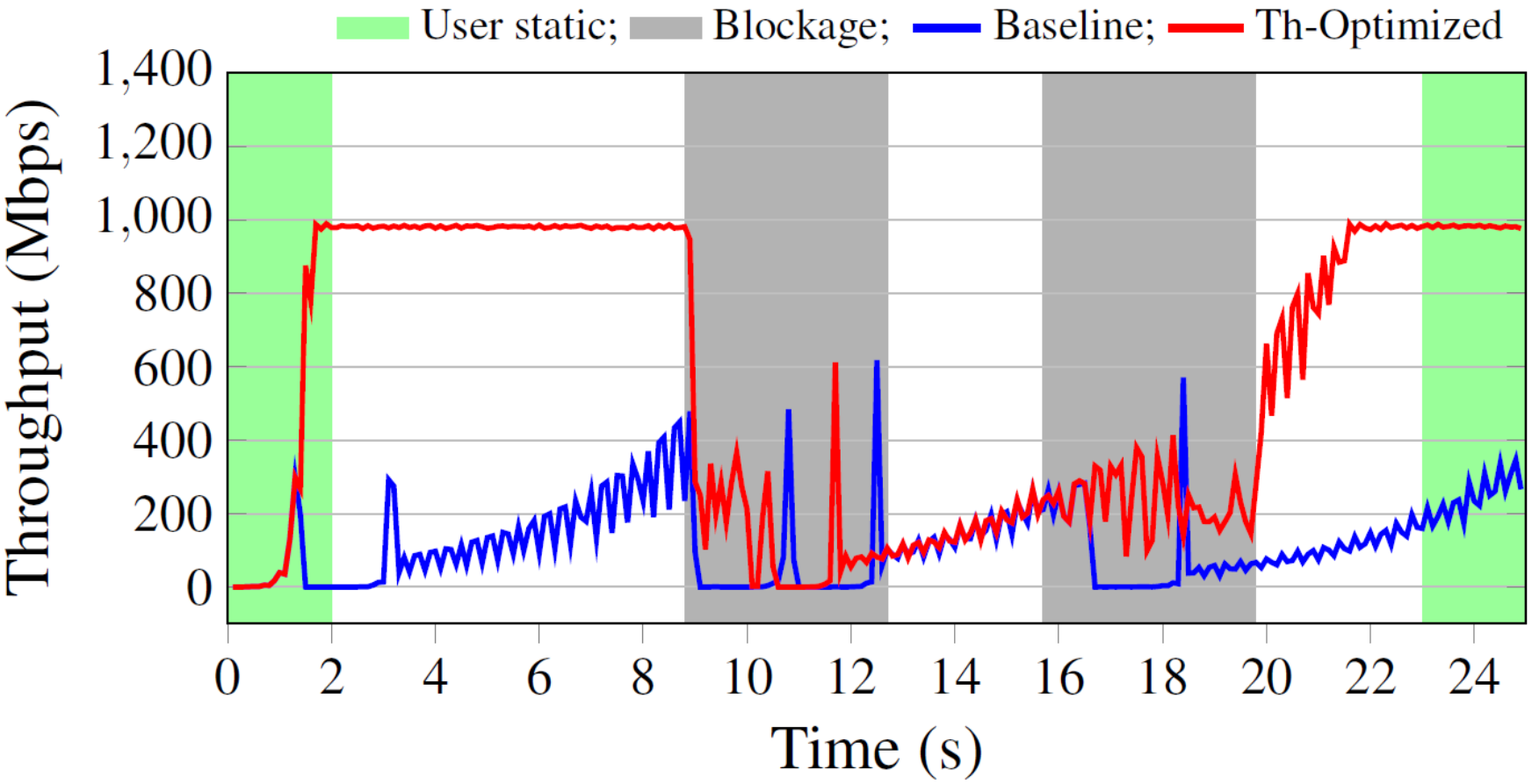
Transport Layer Optimization: an Example

- TCP performs poorly over wireless links
- Mm-wave link offer high capacity
  - In LOS the congestion window assumes high values
  - Sudden (short) NLOS can lead TCP to RTO and recover from SS
- Radio Link Control (RLC) & RTO timer



Transport Layer Optimization: an Example (II)

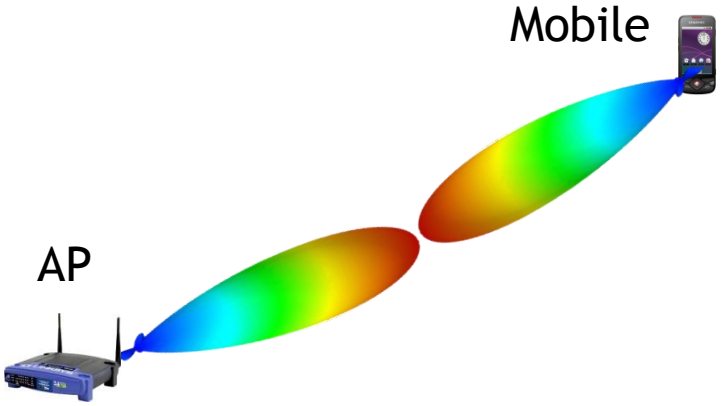
- Throughtput optimization:



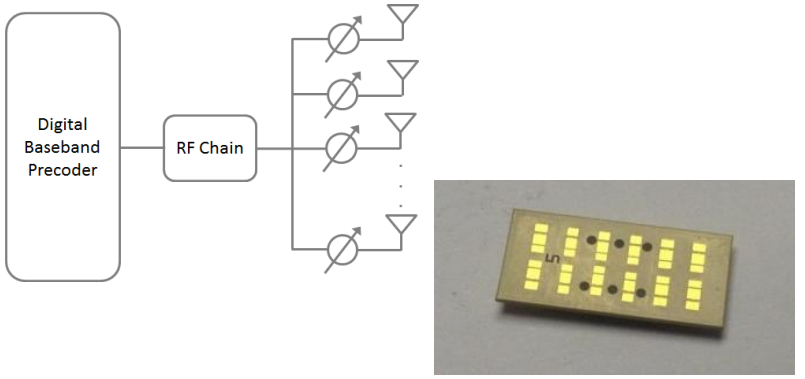
THANK YOU !

Mm-wave Communication

- Unacceptable propagation loss with omnidirectional antennas
- Use highly directional antennas
  - Increase gain at transmitter and receiver to overcome high path loss and absorption
- Antenna size directly related to wavelength → small form factor
- Typically: phased antenna arrays with analog phase shifters and *many* antenna elements
  - Inexpensive, simple design (but sub-optimal beam shapes)



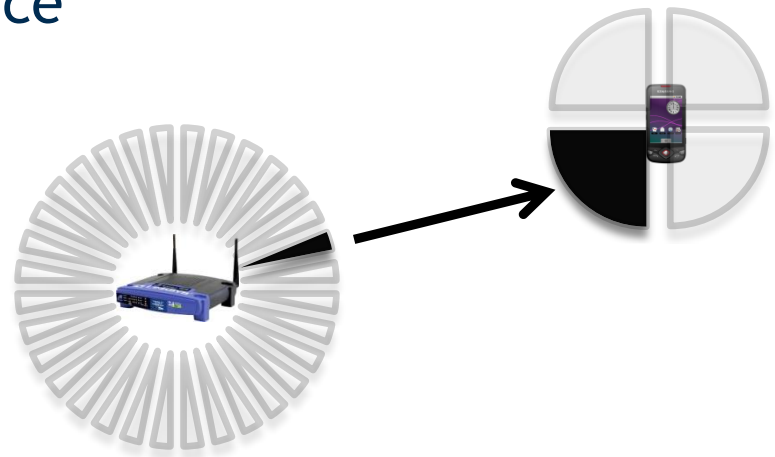
Standard: IEEE 802.11ad



Phased Antenna Array

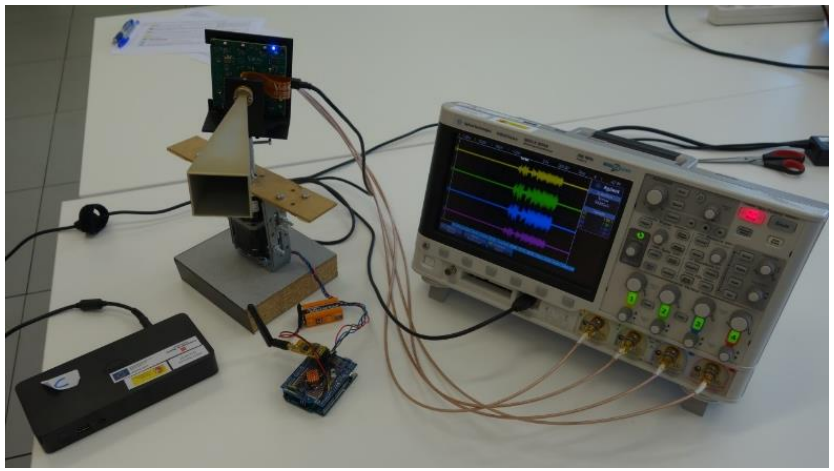
Beam Training

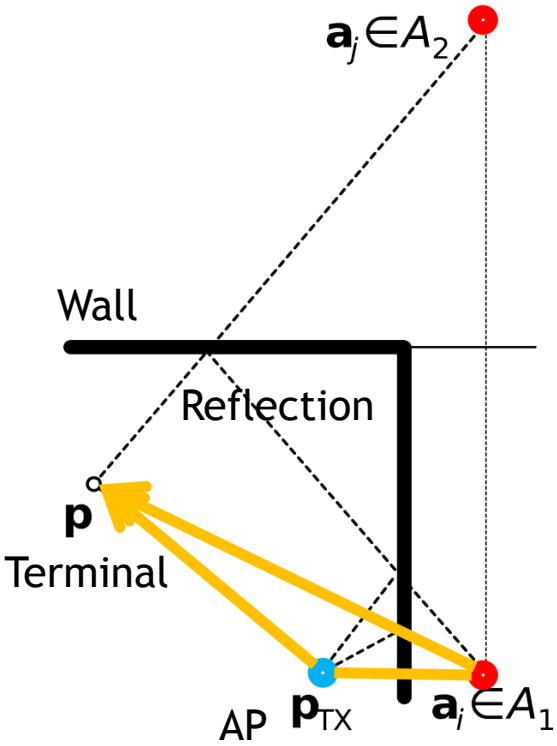
- Device discovery and beaconing become much more challenging compared to omni-directional communication
- Communicating devices need to precisely align their transmission and reception beams
- Beam training:
  - Transmitter transmits a beacon packet including a sector ID on each of its transmit sectors
  - “Brute force”



Localization Algorithm

- Joint Anchor and Device location Estimation (JADE)
- Several triangulation steps
  - Reflections are transformed into vectors departing from the position of the virtual anchor
  - Iterate over unknown position of terminal and unknown positions of anchors
  - Needs user mobility over time





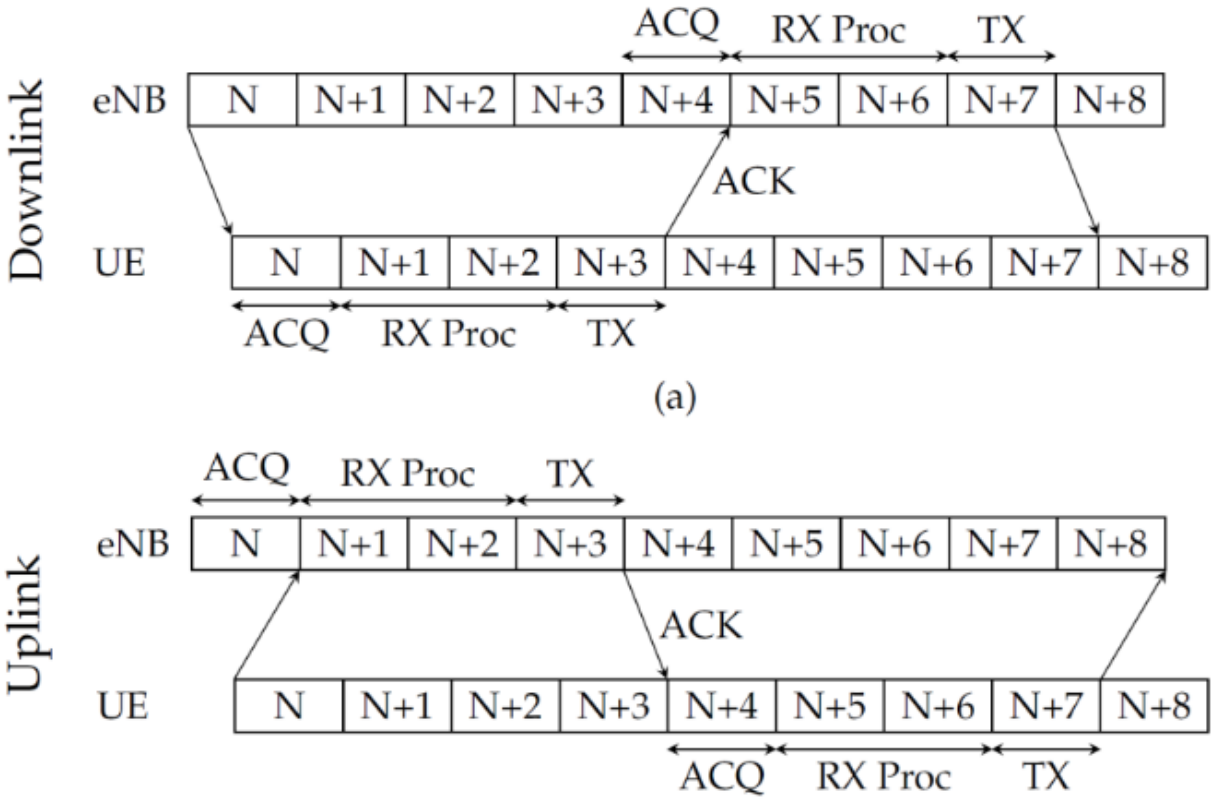
mmMAGIC: Architectural Enablers

- Definition of enabling concepts for new Radio Access Network (RAN)
  - Multi-connectivity and internetworking with LTE
  - RRC_INACTIVE state
  - Cell clustering
  - Network Slicing
  - Self-backhauling

5G PPP mmMAGIC, Architectural enablers and concepts for mm-wave RAN integration, White Paper, March 2017, Available at: https://5g-mmmagic.eu/

C-RAN Computational Complexity Challenges

- HARQ Process limiting factor...



- ... ACK within same TTI possible solution
- Or flexible HARQ