Sub-THz Spectrum as Enabler for 6G Wireless Communications up to 1 Tbps

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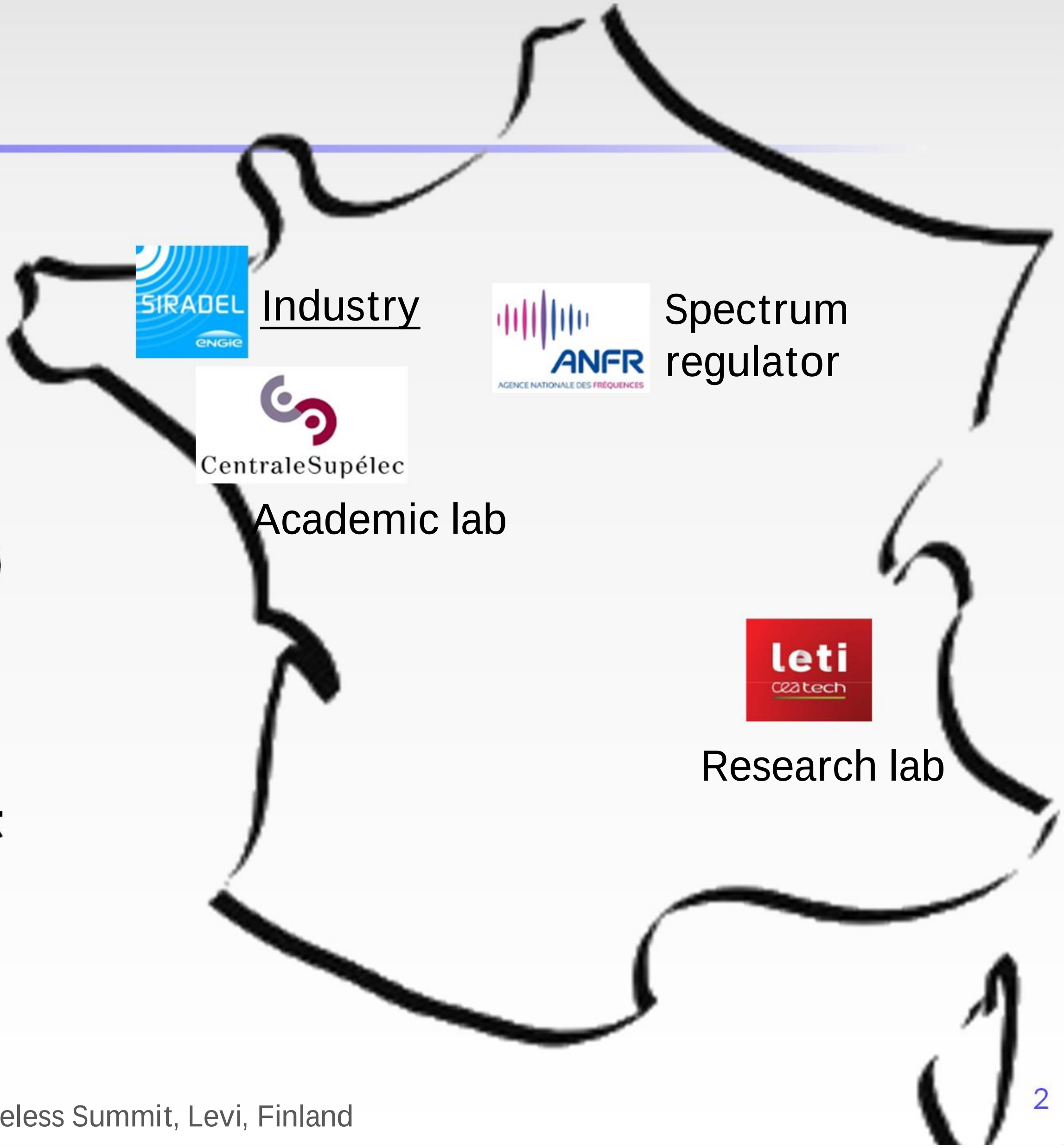
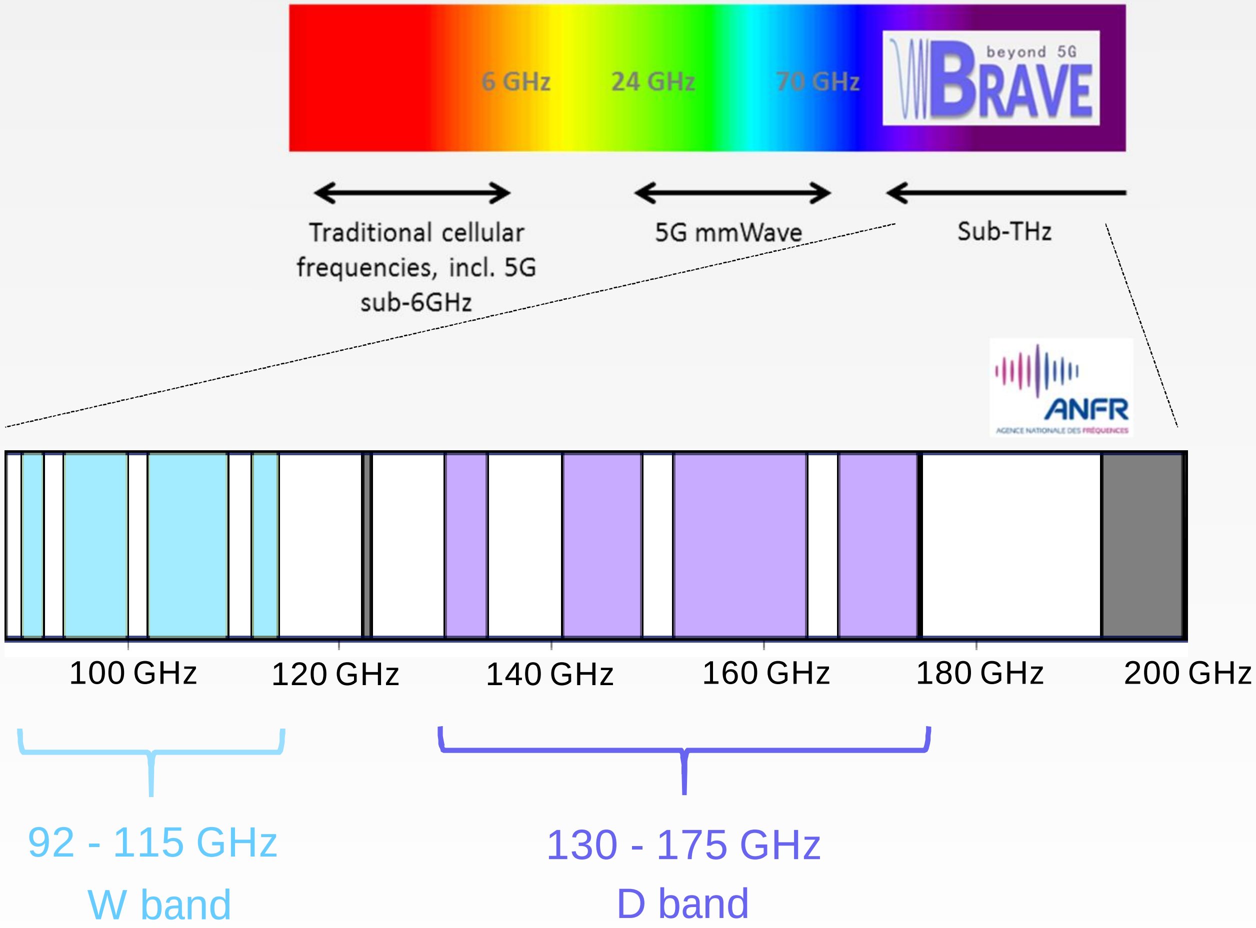
INTRODUCTION

- BRAVE project
  - Funded by French Research Agency (ANR)
  - 2018 - 2021
  - 1.5 M€
- Explore new radio technologies (waveform, topology, ...) to operate at frequencies above 5G spectrum



SPECTRUM OPPORTUNITIES

- Range of interest: [90 – 200] GHz
- Today: mainly scientific services
  - Astronomy observations, Earth exploration, Sat communications, Meteorology…
- Huge bandwidth potential
  - 58.6 GHz already allocated for fixed and mobile services by the Radio Regulation (RR)
  - W and D bands: Already some industrial interest, and CEPT recommendations released



beyond 5G BRAVE

EARLY VISION FOR B5G SUB-THZ COMMUNICATIONS

WORK IN PROGRESS

Sub-6GHz — 5G mmWave — V band → **Sub-THz** | THz | Infra Red | Visible

Spectrum

50+ GHz bandwidth in [90-200] GHz spectrum

Possibility for **light licensing regime**, along with adequate spectrum sharing mechanisms

No major coexistence issue with existing applications

Signal

Single-Carrier (SC)
Multi-Carrier (MC), but with large carrier BW

Channel bonding over several tens of GHz

Different regimes
1) High data rate
2) Low complexity

Radio

LoS
Near LoS
Canyoning (waveguiding)

From limited availability
→ Multi-connectivity
To high reliability
→ Protected fiber-like links

Antenna technology??

Applications

***1)* Ultra-high capacity xHaul**

***2)* Enhanced hotspot**

***3)* Ultra-fast short-range connectivity**

+ Unexpected uses

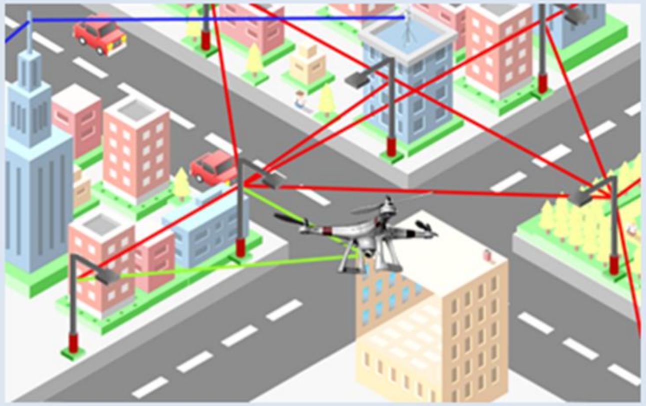
100's Gbps per node ... *up to 1 Tbps*

EARLY VISION FOR B5G SUB-THz COMMUNICATIONS

WORK IN PROGRESS

Ultra-high capacity xHaul

100's Gbps transport, for
- Dense massive MIMO networks
- Cell-free network architecture
- Massive cloud & edge computing (ubiquituous AI)
- Enhanced broadband fixed access
- Casual drone-based xHaul…

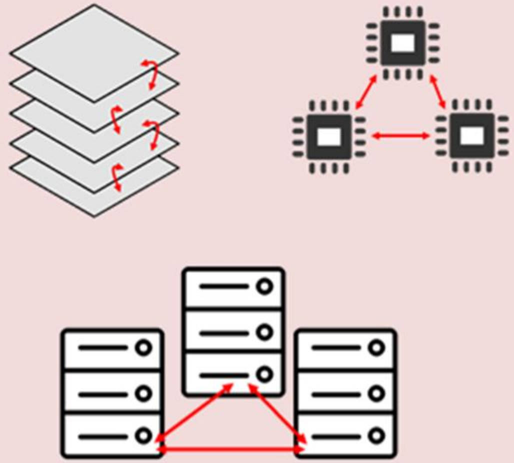


Enhanced hospot

100's Gbps per cell,
Multi-user access
Few meters range,
Low mobility, for
- Kiosk (high speed download)
- Enhanced immersive experience…

Ultra-fast short-range communications

100's Gbps P2P or P2MP, for
- Server farm
- Inter-chip
- Intra-chip…



DEFINITION OF SCENARIOS – ONE EXAMPLE: KIOSK

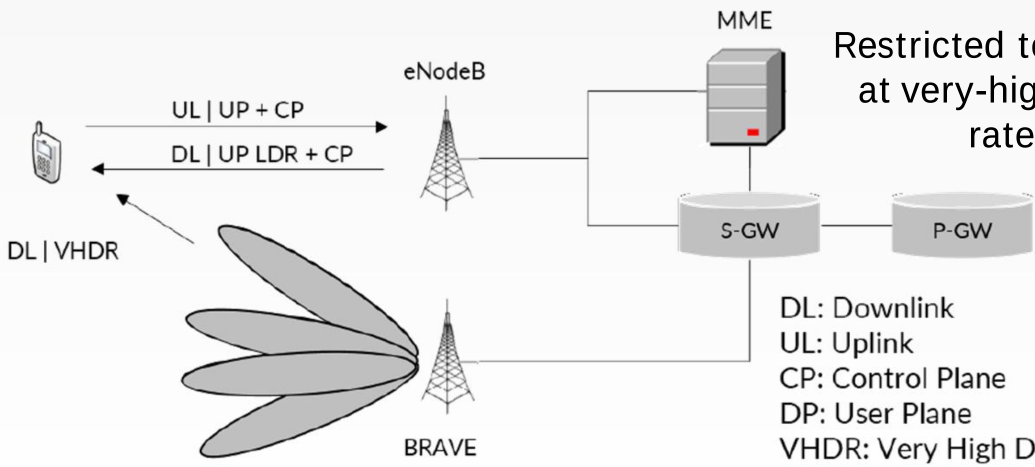
Scenario parameters

KPI	Value
Environment	Outdoor / Indoor
Coverage range	From 10 cm to 5 meters
Network Topology	P2P / P2MP
User Mobility	Low (Stationary/Pedestrian)
Link visibility	Mainly LOS, but possible crowd obstruction
Max. simultaneous connections	10
Constraints (size, power, etc) at user terminal	Low (e.g. car) High (e.g. handheld device)

System & performance requirements

KPI	Value
DL aggregated data rate	~1 Tbps per cell
DL peak user data rate	100-1000 Gbps
Latency	< 100 ms
Availability	Not guaranteed
DL kiosk Tx power	20-30 dBm
DL antenna gain (beamforming)	> 20 dBi
Bandwidth	Up to 40-50 GHz
Energy efficiency limit	~5 pJ/bit
Minimum Spectrum efficiency	25 b/s/Hz
UE Antenna Array	Up to 16
Data Kiosk Antenna Array	Up to 512
UE cost	500 $

All scenarios described in BRAVE D1.0



Restricted to DL DP at very-high data rate

DL: Downlink
UL: Uplink
CP: Control Plane
DP: User Plane
VHDR: Very High Data Rate
LDR: Low Data Rate

TECHNICAL CHALLENGES

Technical PHY related challenges that are adressed by the project

1. Model & simulate the radio propagation channel
2. Model & simulate RF impairments (typically: Phase noise, non-linearities)
3. Define & evaluate new appropriate waveforms
4. Define & evaluate efficient modulation and detection schemes
5. Assess the feasibility & performance of some applications
6. Demo

Exploration step → No hardware development

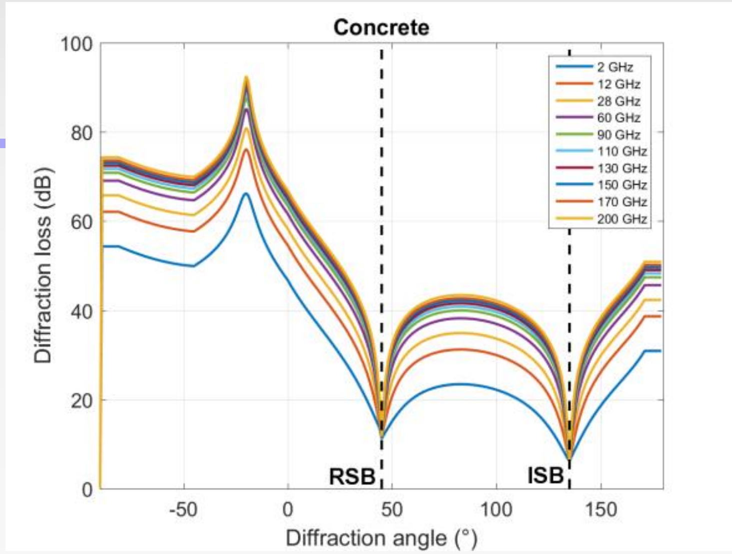
Evaluations are performed based on analytical studies & simulations

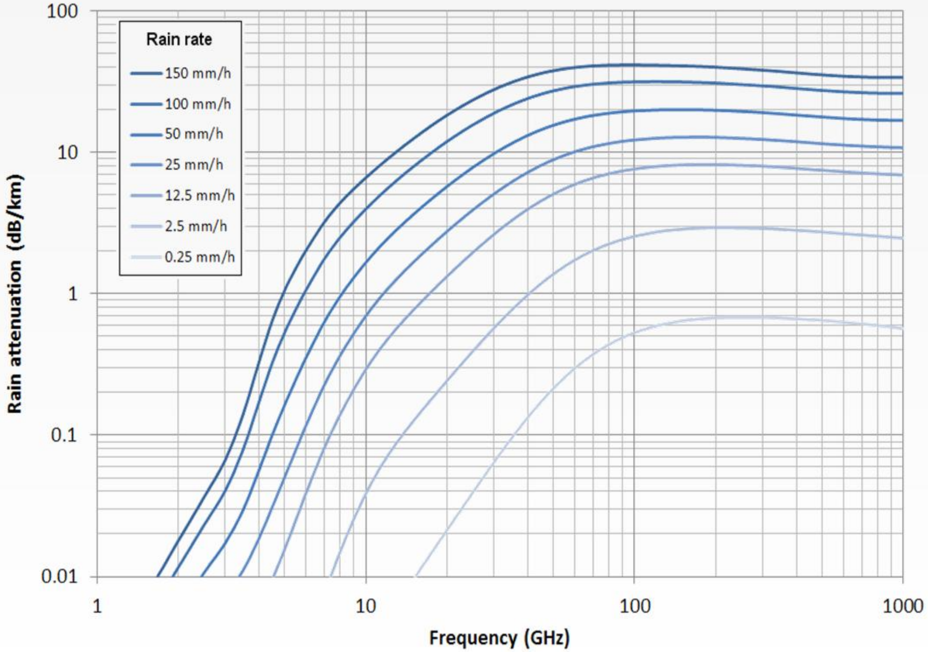
Propagation channel modelling

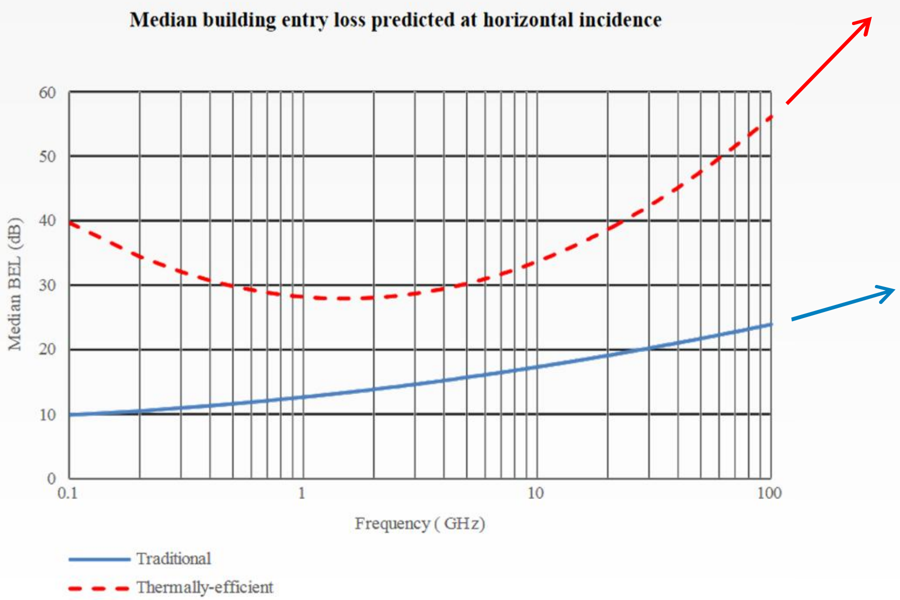
- Main channel properties (incl. MIMO)?
- Communication ranges?
- Isolation or Interference levels?
- Impact of antenna beamwidth, mis-alignment, body blockage…?
- Channel samples for design of new air interface

PROPAGATION CHANNEL MODELLING

- ITU models for atmospheric effect, rainfall loss, materials, building entry loss, and vegetation loss
- When needed: Frequency extrapolation used as a first approximation



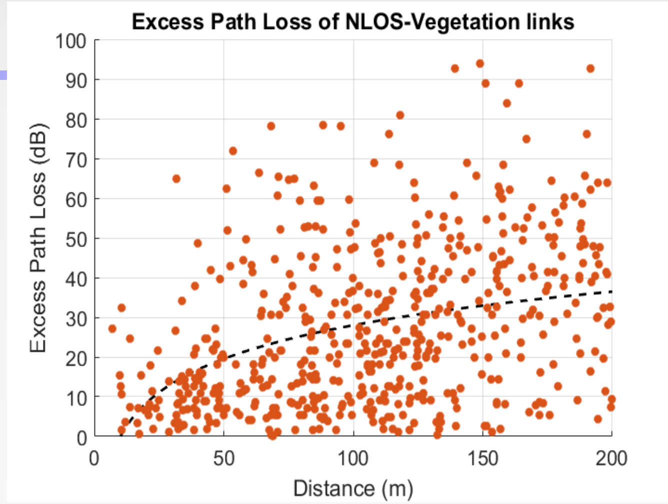


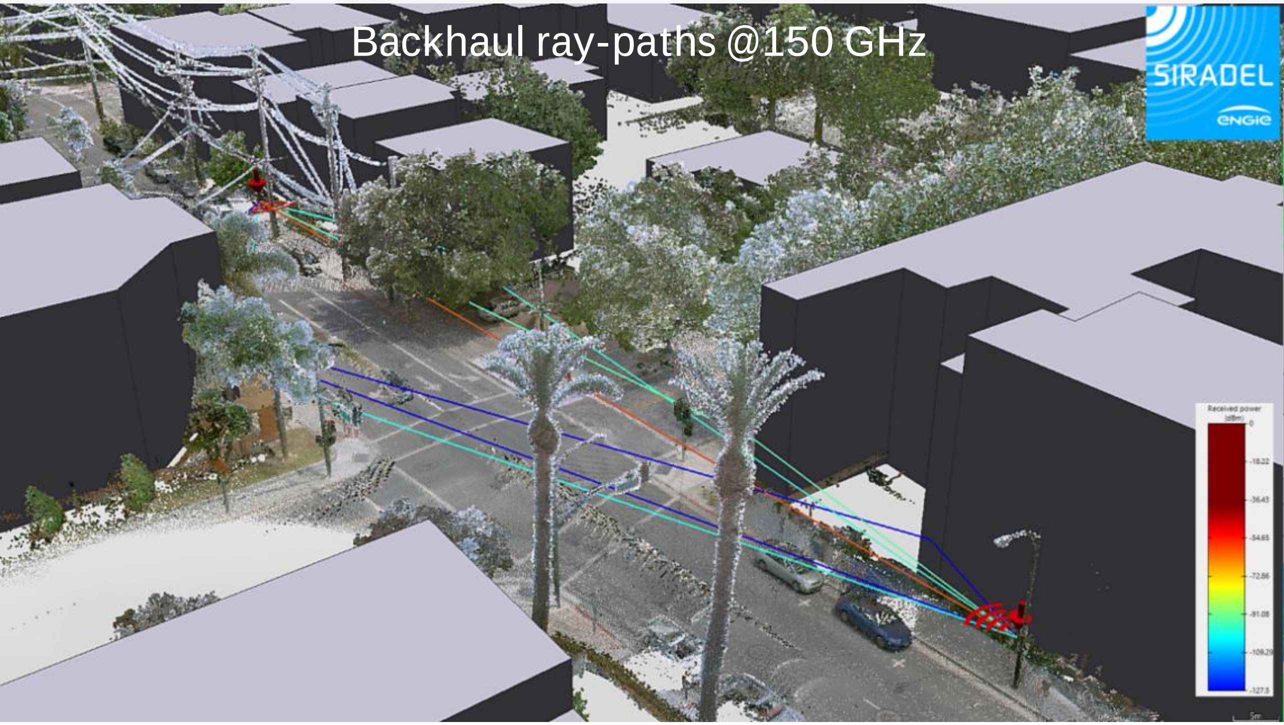


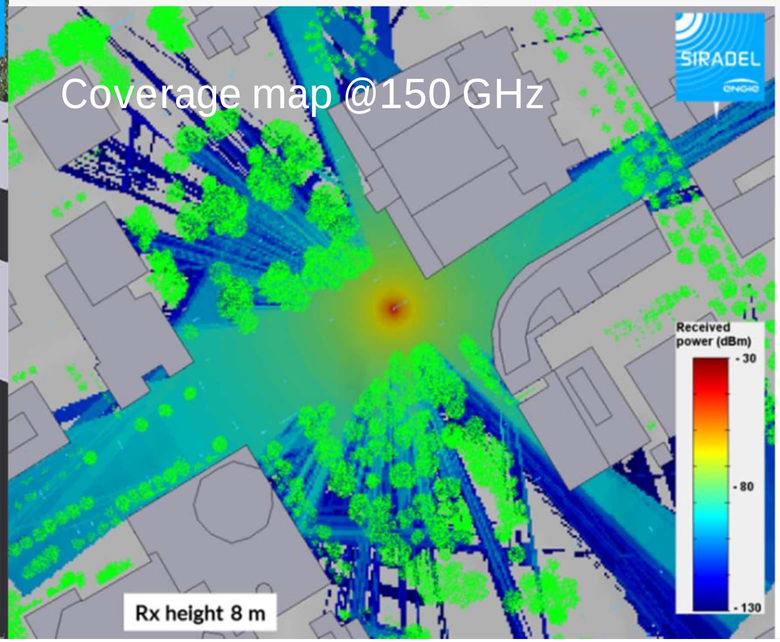
PROPAGATION CHANNEL MODELLING

- q Using Ray-based models
  - o Today tuned in 5G mmWave bands
- Ø Get channel statistics and samples

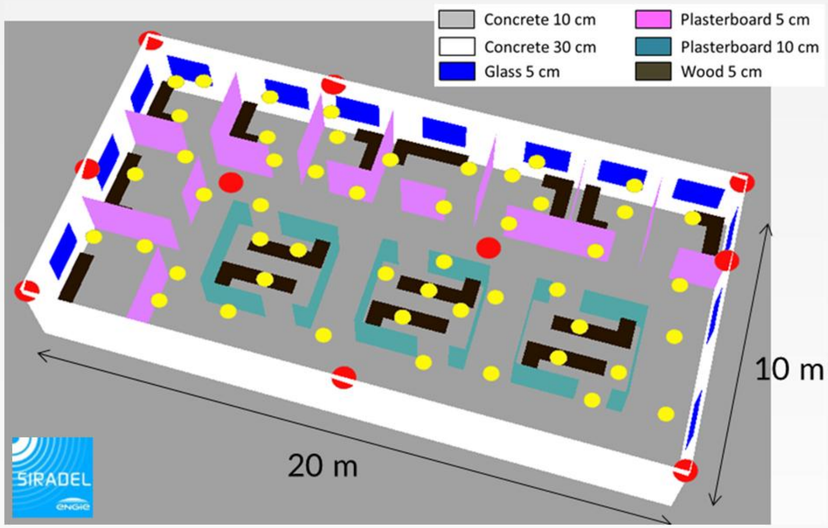
´ Many Links

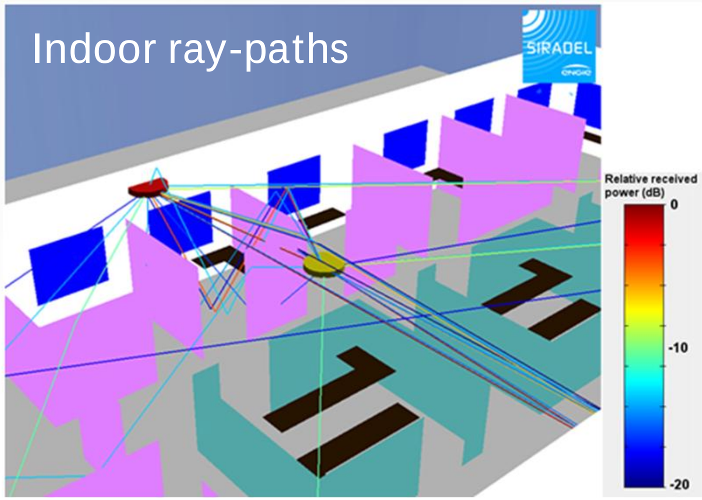


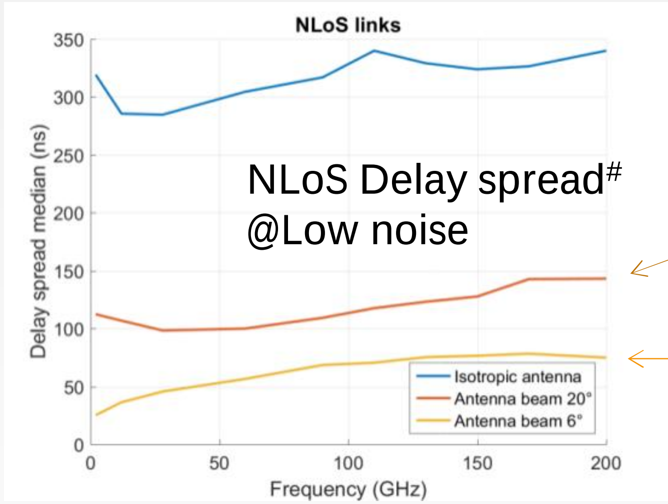




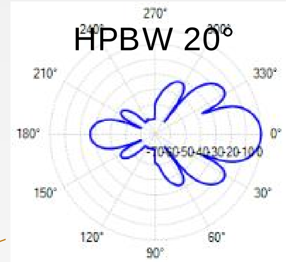
PROPAGATION CHANNEL MODELLING

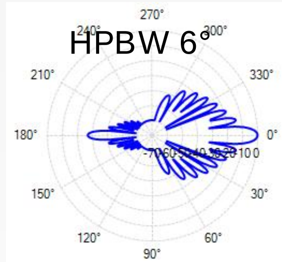


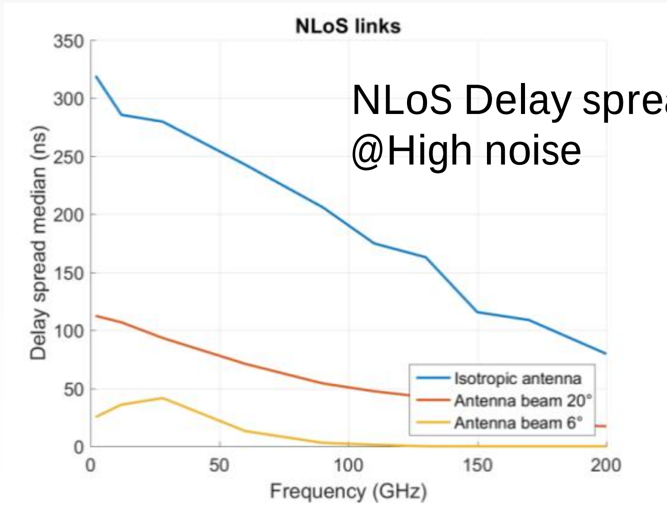




NLoS Delay spread#
@Low noise







NLoS Delay spread#
@High noise

Delay spread measured from 30-dB channel response range

SINGLE-CARRIER WAVEFORM

- Why BRAVE decided to look at single-carrier waveforms?
  1. Favorable propagation is expected (i.e. towards frequency flat)
  2. Lower PAPR (Peak to Average Power Ratio) can be achieved
  3. Modulations robust to Phase noise can be implemented
  4. Adequate sub-band division to be found

Channel sparsity.
Narrow antenna beam.

Multi-carrier OFDM suffers from non-linear distortion and poor efficiency at HPA.

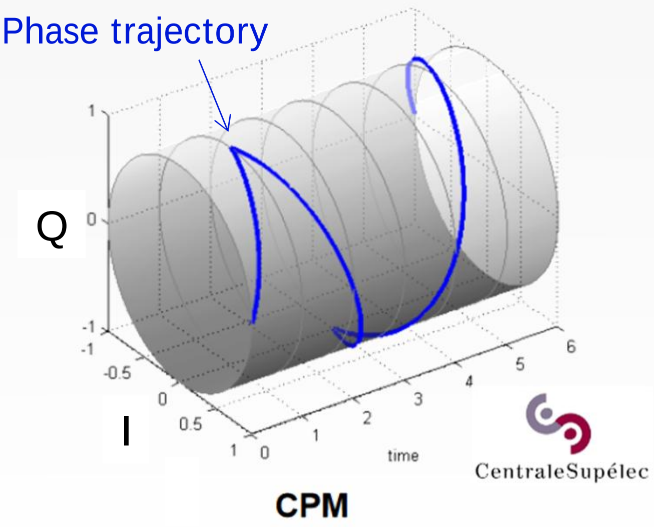
Efficiency of CMOS-based HPA decreases at higher frequencies.

Phase Noise is due to non-stationarity in the Local Oscillator (LO), and becomes a major limitation in sub-THz communications.

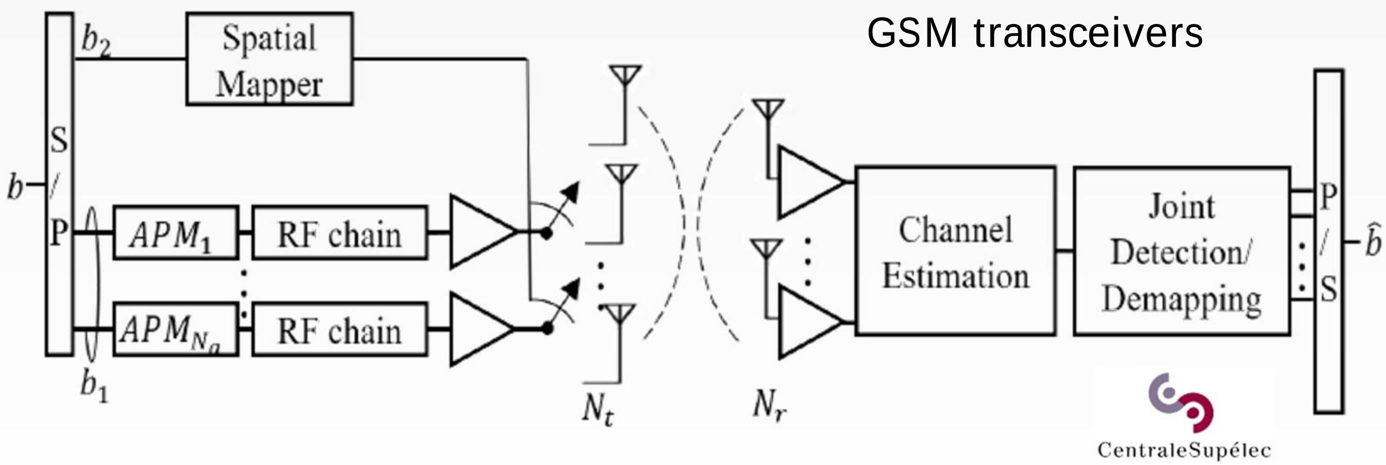
Band-limited A2D.

- Revisiting 5G NR waveform is mandatory!

- Constant or near-constant envelop modulations
  - For instance: CPM (Continuous Phase Modulation)
  - At the cost of lower spectral efficiency (SE)
  - But compensated by Index Modulation (IM) e.g. Generalized Spatial Modulation (GSM)
  - ➢ SC + CPM + IM waveform
  - ➢ Balance between SE, EE, HW cost and detection complexity



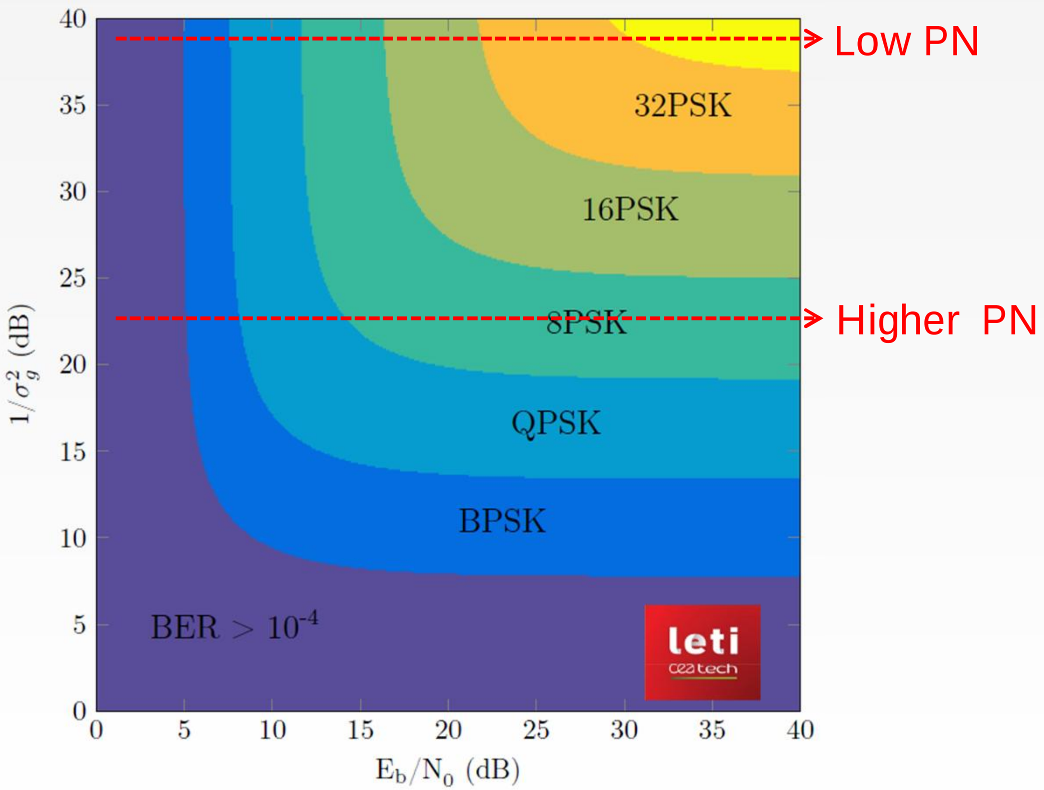
CPM



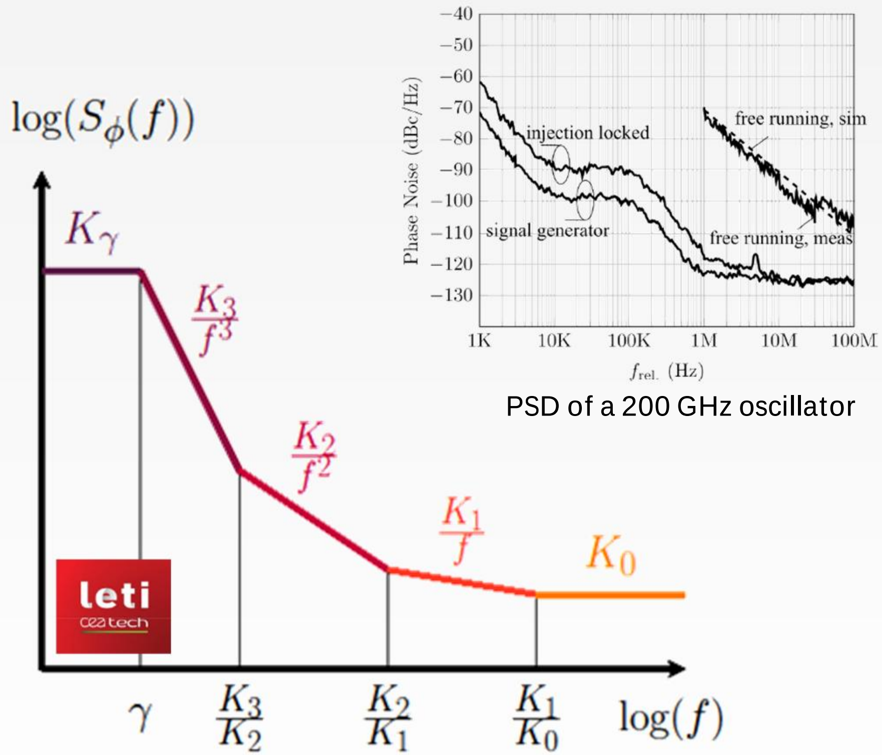
GSM transceivers

EFFECT OF THE PHASE NOISE (PN) VARIANCE

- M-PSK regions vs SNR and Phase Noise variance (σ_g^2)



- Accurate PN modelling

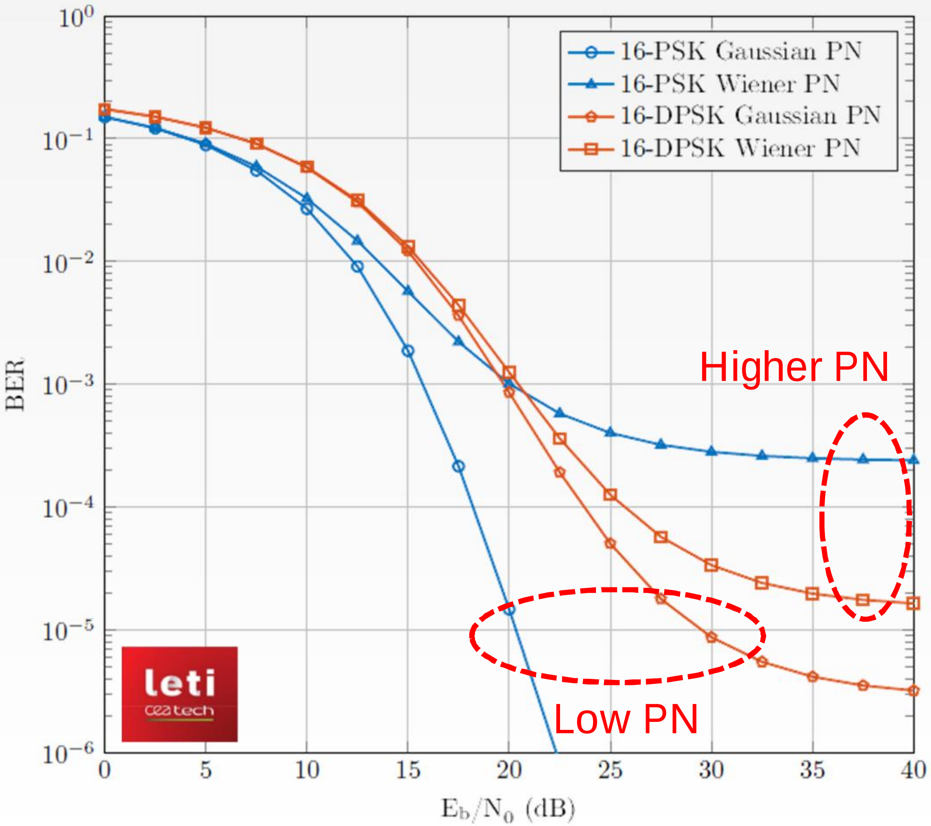


PSD of a 200 GHz oscillator

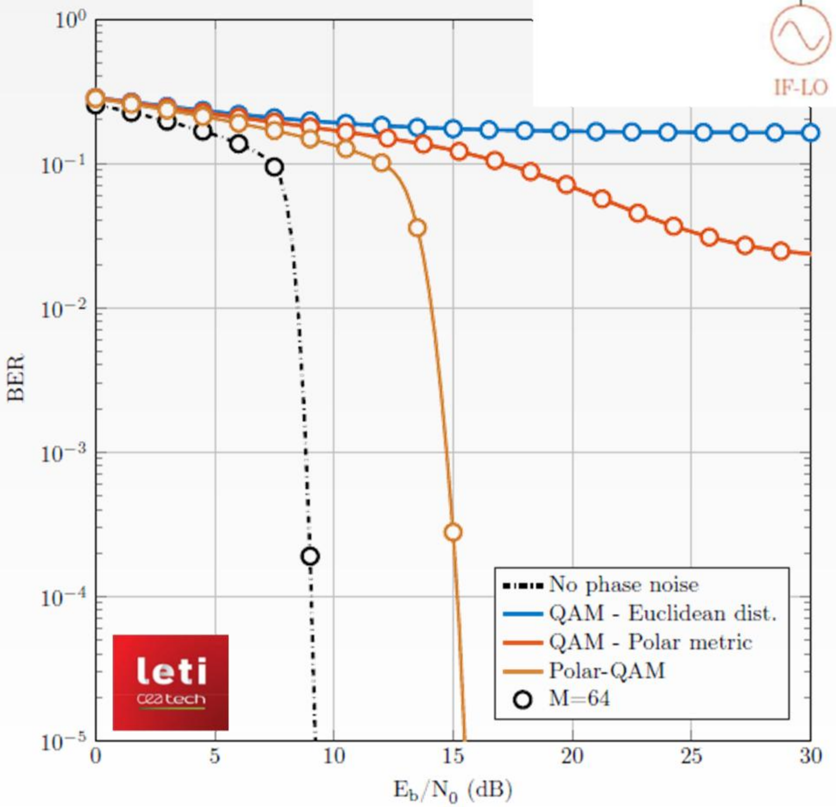
EFFECT OF THE PHASE NOISE (PN) VARIANCE

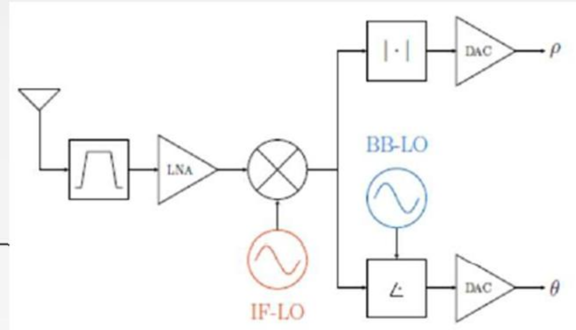
- Modulations tailored for PN channel

Coherent vs Non-coherent



Polar receiver





NEXT STEPS

- Continue PHY modelling work
- Consider realistic antenna capabilities
- Plug together the PHY models and the proposed waveform/modulation schemes
- Explore different operating modes
  - Ultra high data rate, at cost of complex architecture and heavy power consumption
  - Lower spectral efficiency, but compliant with low-cost low-power devices

- Propose 5GNR waveform amendments compatible with sub-THz channel constraints

Thank you for your attention

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