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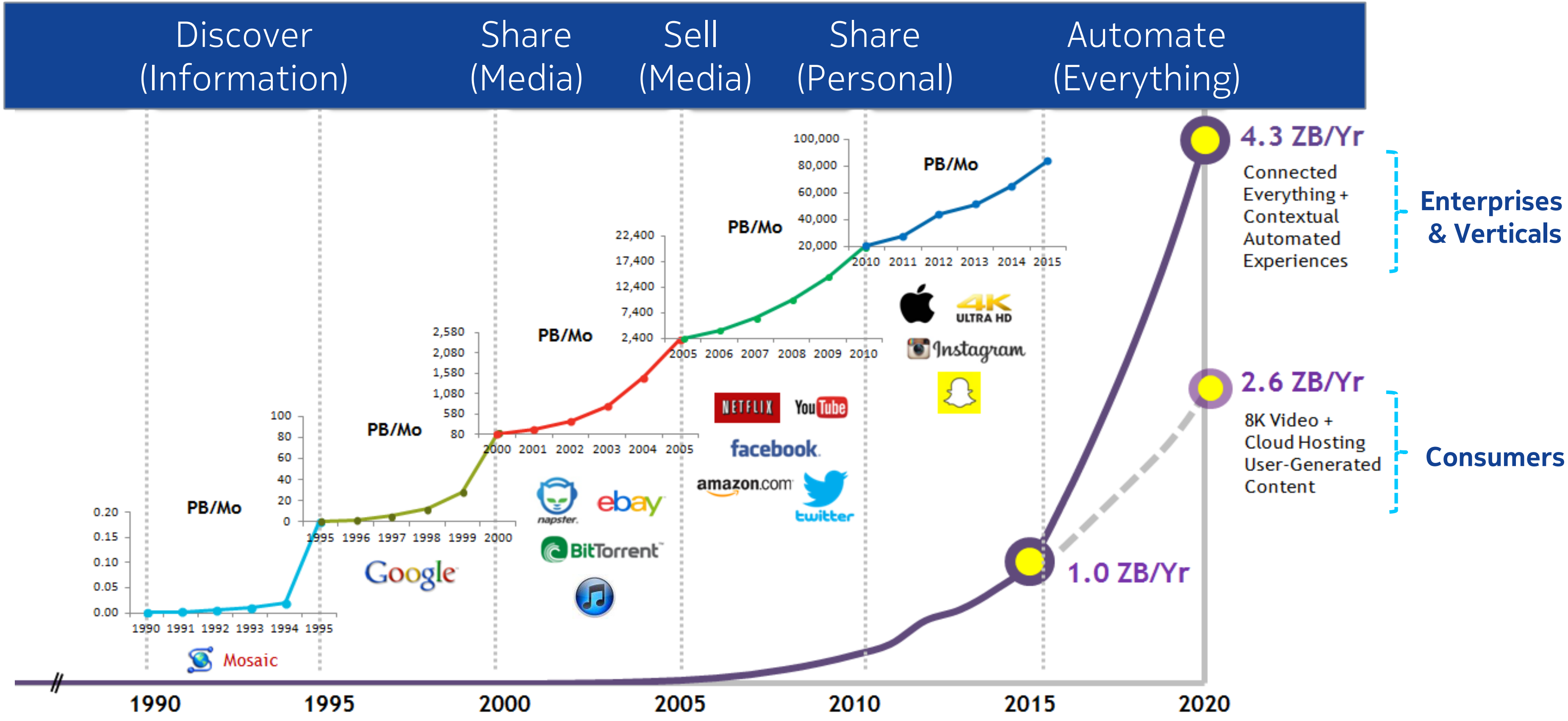
Opening the THz-Spectrum for Communication in 5G and Beyond

- Wolfgang Templ

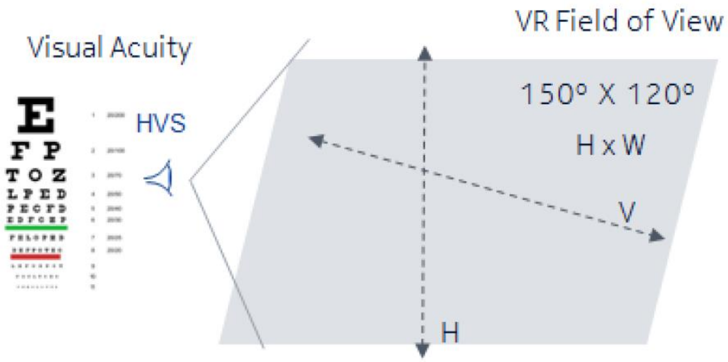
- ‘Towards TeraHertz Communications Workshop’, 07/03/2019

A New Networking & Connectivity Era



VR and AR generate huge amounts of data traffic

- Immersive ‘field of view’ for Virtual Reality → ‘virtual screen’ is much larger (e.g. 20x)
  - 150º x 120º vs. 30º for HDTV
  - With head + body motion, FoV can be 360º x 180º



Example:

- Visual Acuity (1 arc min); Frame Rate 60/sec; H265 Encoding (.08 - .125 bits/pixel)

→ **VR Bandwidth ~0.4 – 0.7 Gbps**

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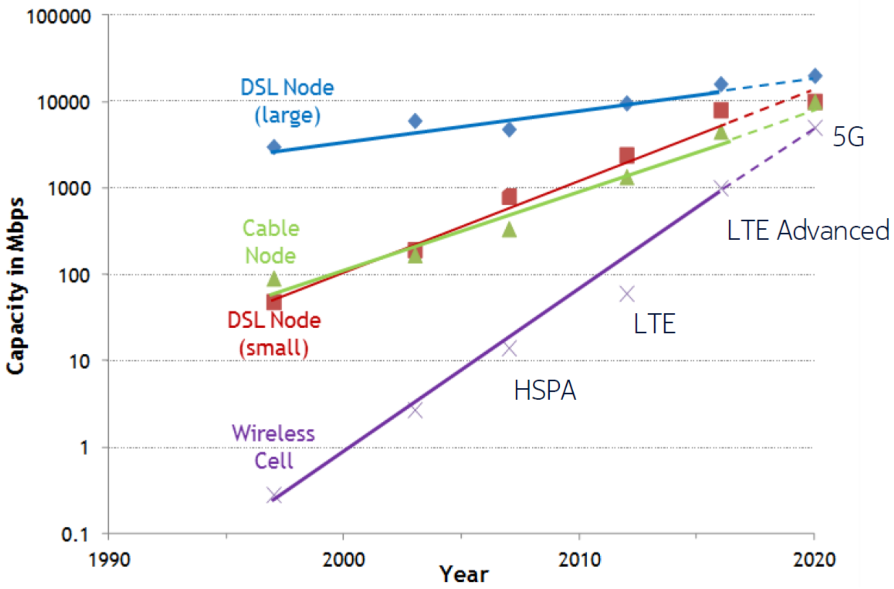
Access Technologies

Convergence at 10Gbps by 2020 time frame

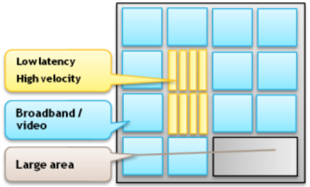


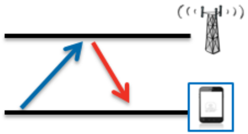
- ~1 Gbps peak rates per household
- ~100 Mbps sustained data rates per household
- Self-installable CPE

5G mmWave

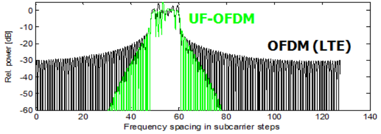
The Six Essential 5G Technologies

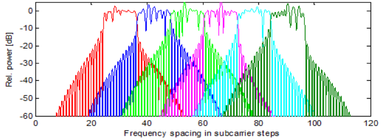
Modular Framing Structure for ultra-broadband, ultra-narrowband and ultra-low latency support



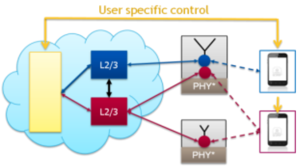


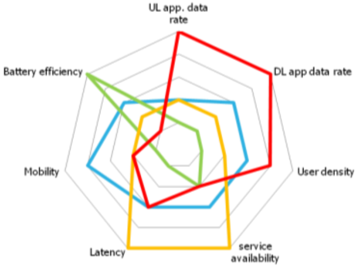
New Air Interface: New Waveform and control for flexible multi-service interface
- ~2X battery life
- ~5X lower latency

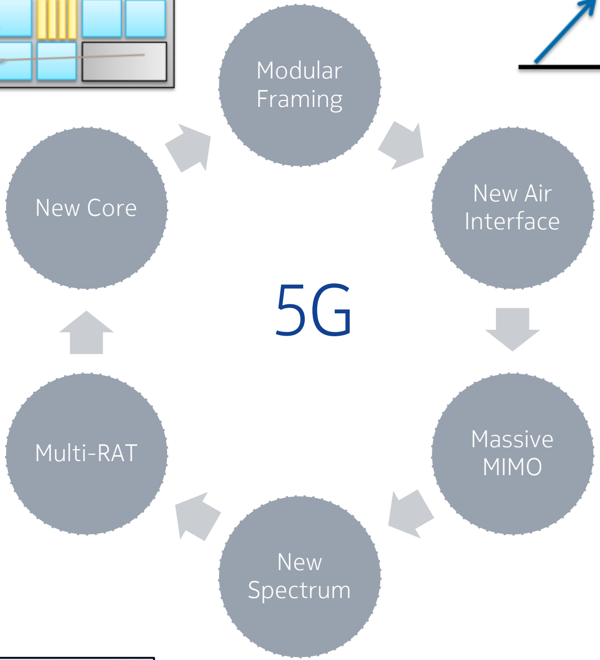




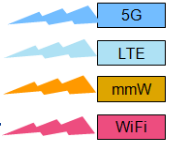
New Virtualized + Software-Defined Core for flexible routing through centralized, distributed, gateways optimized for any service mix

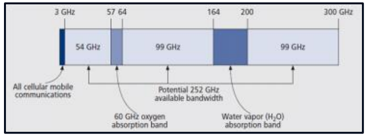




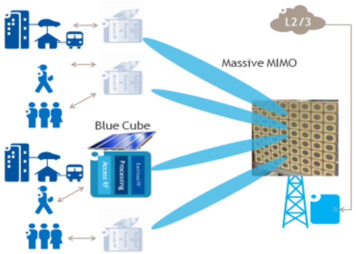


Multi-RAT with network controlled traffic steering and cell-less architecture
- ~2X increase data rate
- Guaranteed user/service experien





Massive MIMO
Higher spectral efficiency through spatial multiplexing (beamforming)
- ~5X increase in spectral efficiency



New "mmWave" spectrum small cells
- ~10X bandwidth

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An abundance of bandwidth becomes available for wireless communication …

FCC voted unanimously in July 2016 on the historic Spectrum Frontiers plan to free up *vast amounts of spectrum* for 5G.
The move *effectively quadrupled the amount of radio bandwidth ever made available to the mobile industry*.

“A historic moment, a turning point, as the Renaissance of wireless begins."
(T. Rappaport, NYU Wireless)

"There is no doubt that giant new businesses and applications that exploit this unprecedented spectrum will change our world in amazing ways over the next decade."

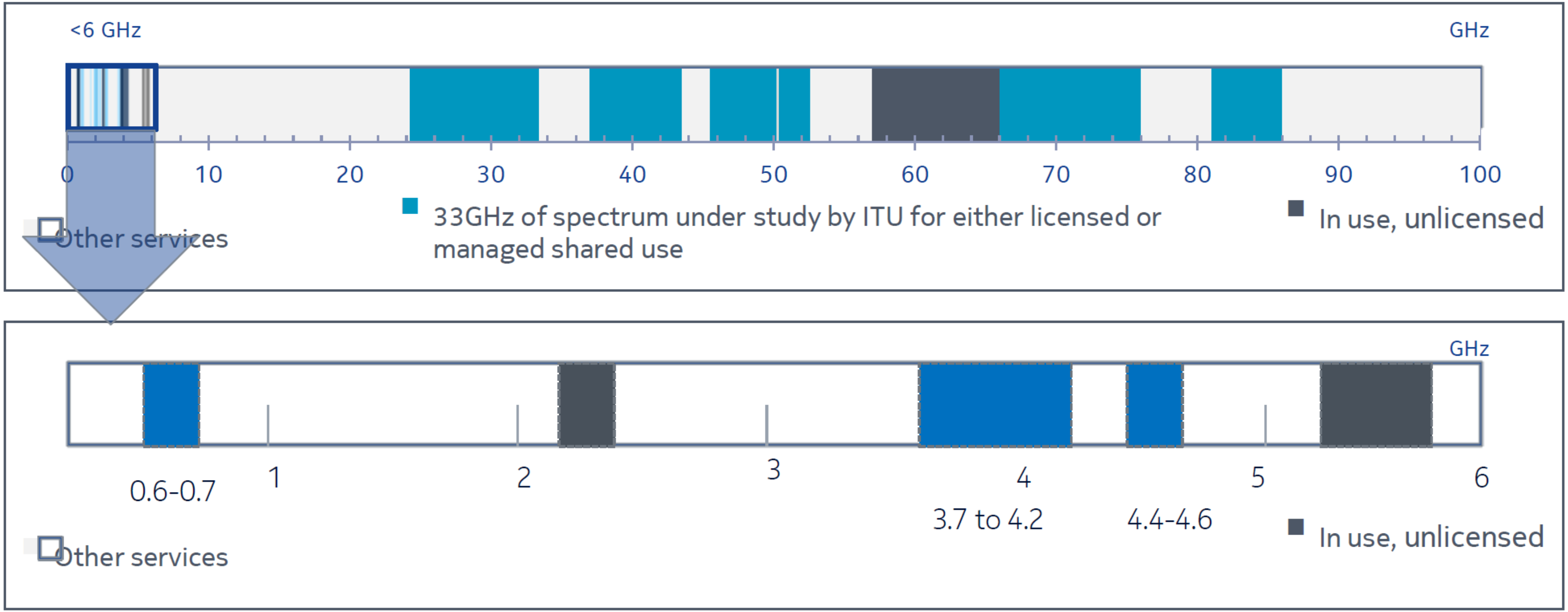
“The next wireless evolution promises to fundamentally change the way we live, interact and engage with our communities. … There is seemingly no limit on how what we refer to as 5G could impact our everyday existence.“
(Mignon Clyburn, FCC Commissioner)

Facebook already built a sizable 60 GHz network in San Jose, California; the 60 GHz ecosystem is growing.

… a lot of spectrum bands are in play at the FCC. Commissioner Jessica Rosenworcel has identified open dockets in the 3.5 GHz, 3.7-4.2 GHz, 6 GHz, 24 GHz, 28 GHz, 32 GHz, 37 GHz, 39 GHz, 42 GHz, 47 GHz, 50 GHz, 70 GHz and 80 GHz, among others
(fiercewireless.com)

“the commission is seeking to unleash new *spectrum in frequencies above 95 GHz –*
‘way, way up there’ spectrum that some see as going overboard”

5G New Frequency Bands



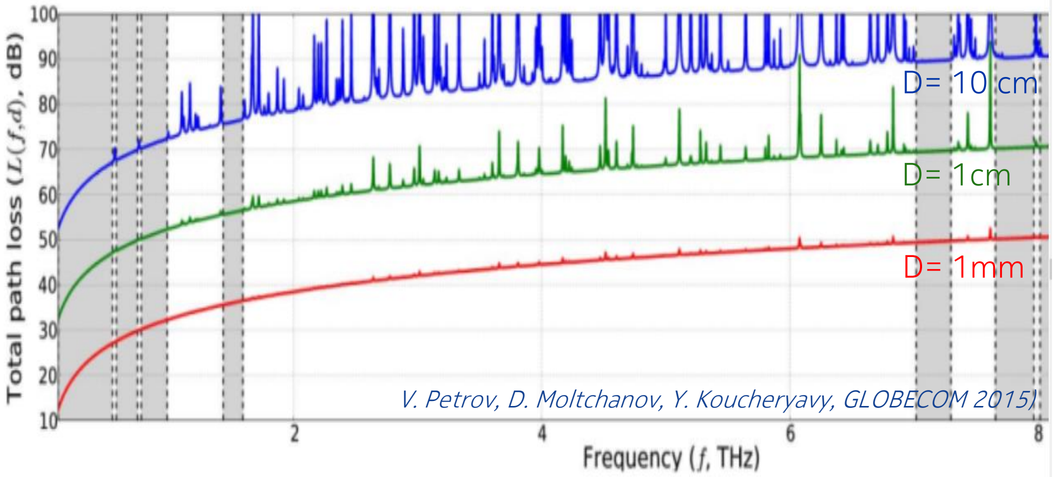
Going Beyond 5G …

Beyond 5G: Exploring THz Communication

- ***THz Bands (0.1-10 THz) promise BW in Abundance***

Challenging THz-Communication

- The “THz-Gap” -> Suitable Signal Sources ?
  - Cost efficient, Robust, Reproducible, Ease of Application, Mass Production
- Propagation Properties (LoS, Absorption)
  - *Boon* (Spatial Channel Reuse, Security, …) *and Bane* (Short Reach, Directivity, …)
- Complex THz Channel Modelling (In-door, absorption spectra)
  - Short wave length scattering profiles
  - Directivity of antennas



- Coverage Requires Dense Network (High Antenna Count) -> Challenging MAC
- Mobility is Challenging (Beam Tracking,100s of Antennas)
- Network Planning (3D models of environment)

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The THz Gap

Challenging Generation and Detection of THz Radiation

Electronic

- Inefficient up-conversion of oscillator signals
- Small antenna aperture
- Signal sources
  - Hi bandwidth transistor
    - SiGe HBT (ft/fmax<500GHz) ~ 300GHz
    - GaN, InP metamorphic materials (fmax <1200 GHz)
  - Resonant Tunnelling Diodes (RTDs) (1.92THz, 0.4µW)
    - Coherent Arrays?
  - Low Output Power

Optical/Photonic

- At room temperature and f ~ 6 THz: kT ~ ħω -> photon energy in range of thermal excitation
- Quantum Cascade Laser (3.2THz , T=200K)
- Optical signal generation w. down-conversion
- Optical mixing/heterodyning

Plasmonics

- E.g. Graphene research
  - Nano-antenna: Surface Plasmon Polariton (SPP) waves in semi-finite size Graphene Nanoribbons (GNRs
  - Smith-Purcell Based THz-emitter
    - ~0.1–30 THz , *P*/*A* ~ 0.5 W/cm2

Propagation of THz Signals
Challenges

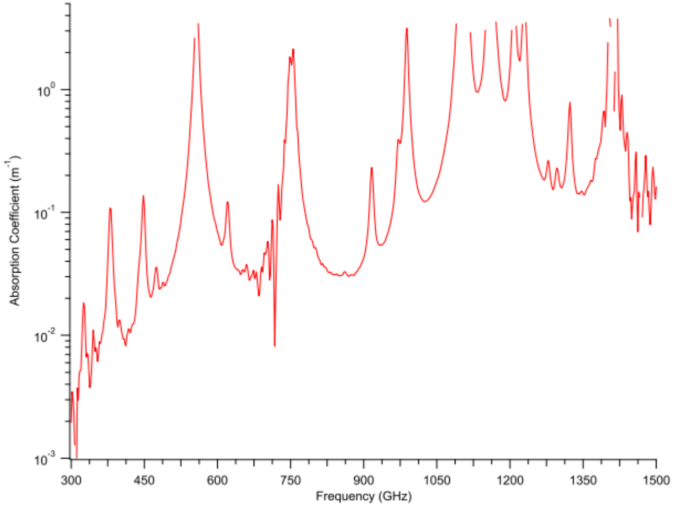
- Line of Sight propagation path

- Effective Area of isotropic antenna:

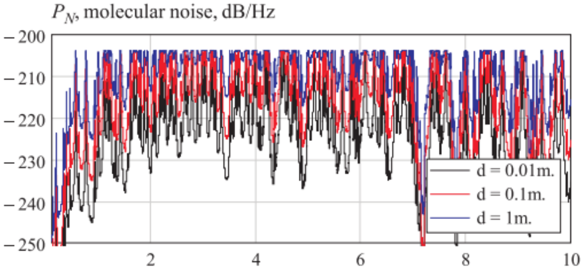
$\frac{\lambda^2}{4\pi}$ → Free Space Loss: $\left(\frac{4\pi R}{\lambda}\right)^2$

- Smaller antenna aperture results in significant
  λ/2 (1THz) = 0.15mm !!
  higher attenuation FSL[THz]/FSL[GHz] ~ 1E6 ~ 60db
- Need for high gain antennas
- Thermal challenges (heat dissipation)
- -> Need to go for antenna arrays (-> MMIMO?)

- Molecular absorption loss dominated by water vapor
  - Frequency dependency (features "Windows")
  - Exponential characteristic (Lambert-Beer law) $\frac{I}{I_0} \sim e^{-c\varepsilon R}$
  - Molecular absorption noise
- Rain attenuation up to 30db/km (Nagatsuma)
- Small wavelengths lead to significant scattering effects



D.M. Slocum et al., Atmospheric absorption of terahertz radiation and water vapor continuum effects, J. of Quantitative Spectroscopy and Radiative Transfer, 127, 2013, pp 49-63



P. Boronin et al. / Nano Communication Networks 5 (2014) 72–82

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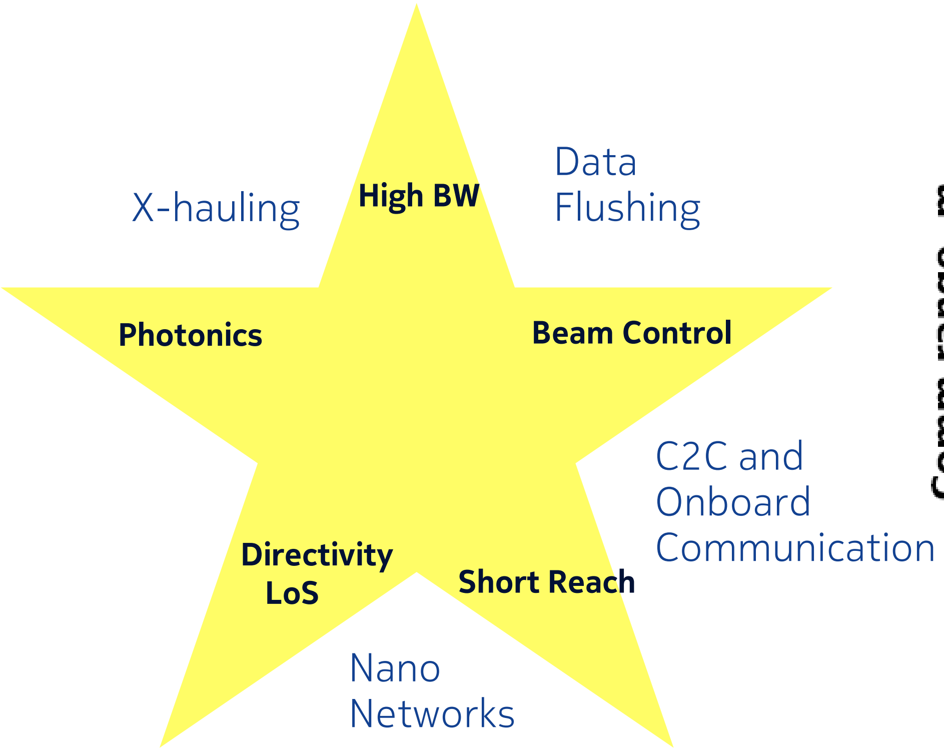
Interlude

So … after all this it seems THz-communication faces similar challenges like free space optical communication.

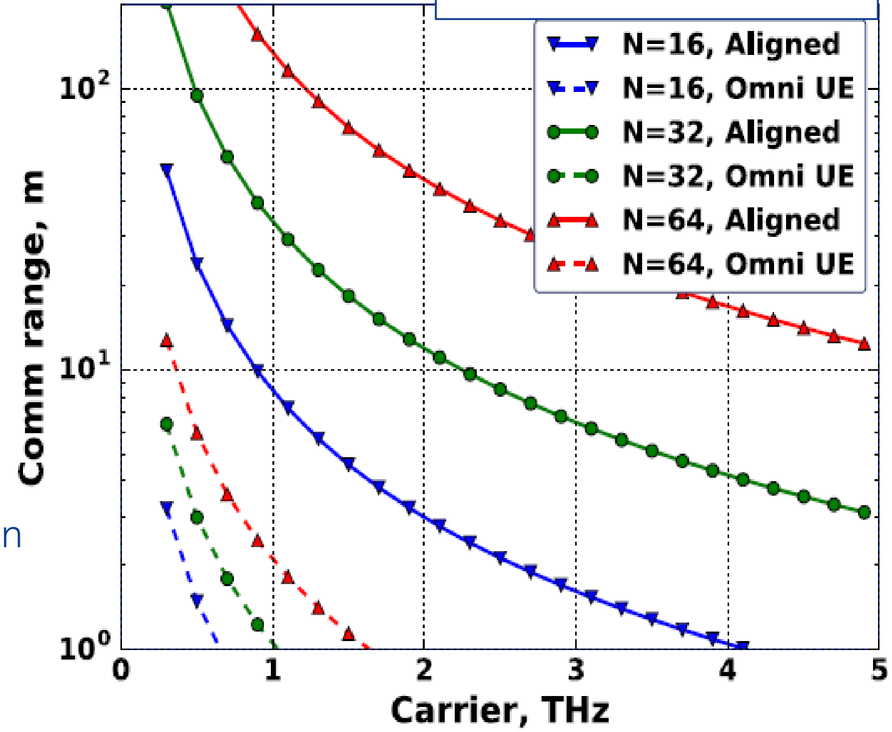
….. *but it offers smaller bandwidth*

Why do we go for it?

Applications



By Vitaly Petrov, Tampere Univ.



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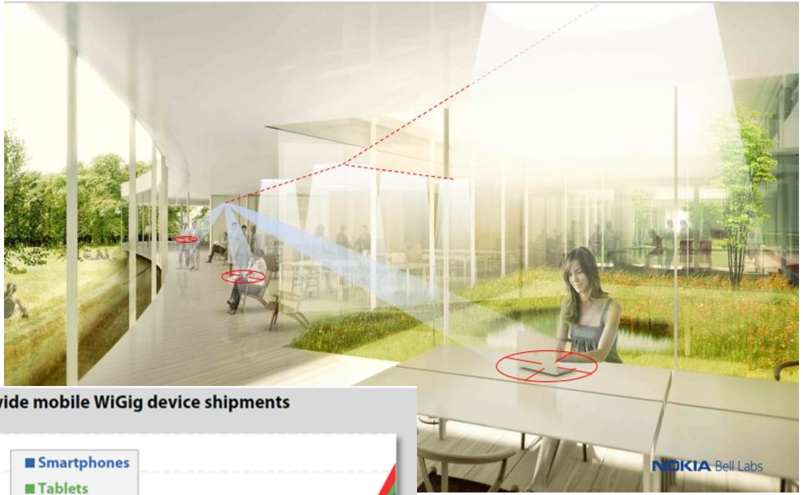
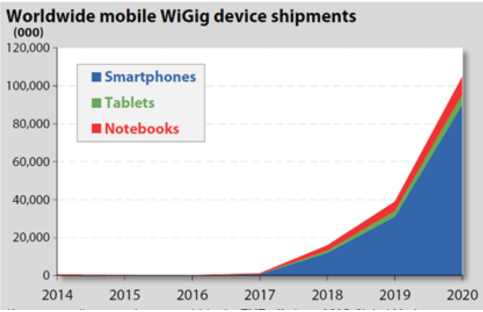
Indoor Communication
A Future Vision

- Highly Integrated components (active electronics, antenna and filter systems) for low cost mm-wave and THz- applications
- Use of new manufacturing methods
- Integration of beam steering mm-wave TRX frontends
- Integration with fiber infrastructure
  - Light -> THz conversion
- MMIMO approaches

→ Realize highly flexible and self-adapting Gbps indoor network nodes for mm-wave access and backhaul solutions



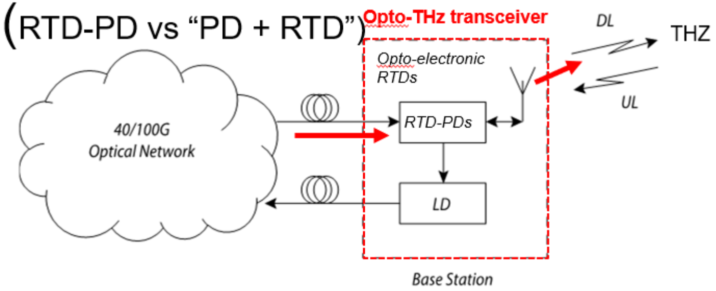


H2020-Project iBROW

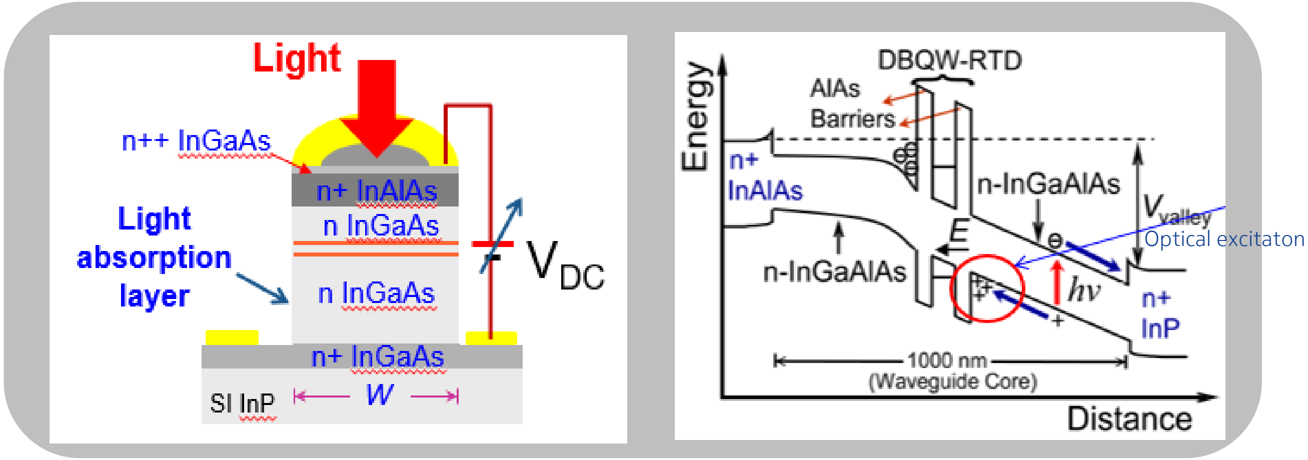
Exploring RTD based THz communication

Some Results:

- High performing RTDs, a.o.:
  - 2mW @ 84GHz , 1mW @ 307 GHz
- Integrated antenna designs
  - Fc=280GHz, BW 40GHz, 5dbi
- Models for THz propagation in Indoor environment
- **RTD Photodetector**
  - DC Response 5A/W @ 1310nm
  - III/V direct growth on Si
- Transmission experiments
  - 15Gbit/s @ 84GHz
- Amendment f. IEEE 802.15.3-2016
  - OOK Phys. Layer Mode
- Concept for integrated mmW/photonic backhauling



Partners:
Univ. Glasgow, IQE, Univ. Lisbon, Vivid Components, INESC TEC, CST Global, Optocap, III-V Lab, CEA-LETI, TU Braunschweig, Nokia Bell-Labs



Looking ahead: iBROW+
The next step

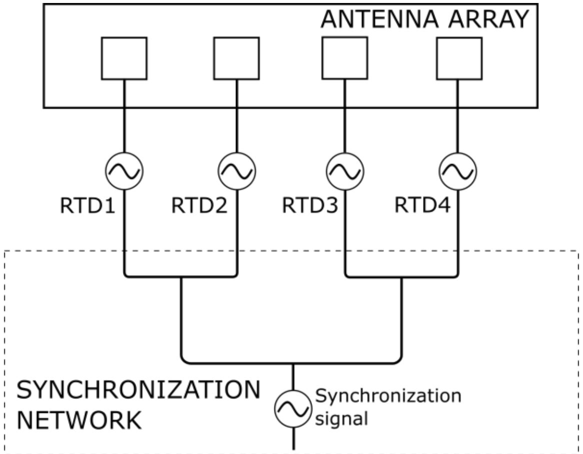
- Open Questions to address
  - Are RTDs a suitable solution?
    - Evolution of TRX technologies to higher frequency, bandwidth and output power
      - After first experiences below 100GHz, targeting Fc > 300GHz, 100Gbit/s , Pout > 2.5mW
    - Feasibility of low cost mass production
    - (m)MIMO technologies and coherent RTD Arrays (4*2.5 mW)
    - Phased array solutions with beam steering
    - Support moving terminals
    - Communication methods, modulation formats and signal processing supporting THz communication to mobile terminals and for backhauling
    - Benchmarking vs. conventional approaches for electronic THz-signal generation (InP HBT)

Mm-wave and THz novel transceiver technology

Future Research – coherent RTD array

- Main drawback of RTD-based sources is the limited output power (P_{OUT}): P_{OUT} < 2mW
- Alternative to increase the power and cope with limited aperture: coherent RTD array

  e.g. 4-elem RTD array: P_{OUT}>10mW
- Coherent operation can be achieved through injection-locking by means of an external reference/synchronization signal



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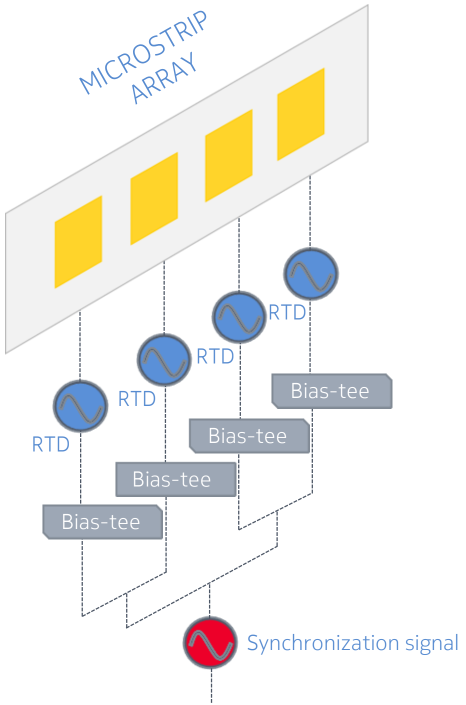
Mm-wave and THz novel transceiver technology

Future Research – coherent RTD array

Variant 1 - microstrip patch-based antenna array:

- Bias tees for simultaneous DC-biasing and synchronization
- coherent operation by injection locking free-running RTD oscillators



Array feeding:

A. Probe-feeding:

- ☹ cannot maintain $\lambda/2$ separation between array elements using standard SMA connectors:

  $\lambda/2_{free\text{-}space} = 5mm$

  SMA plug = 7,67mm; SMA jack= 6,19mm

B. In-line feeding:

- ☺ $\lambda/2$ separation can be maintained through the use of meandered in-line feeding technique
- ☹ frequency response of the system sensitive to fabrication tolerances

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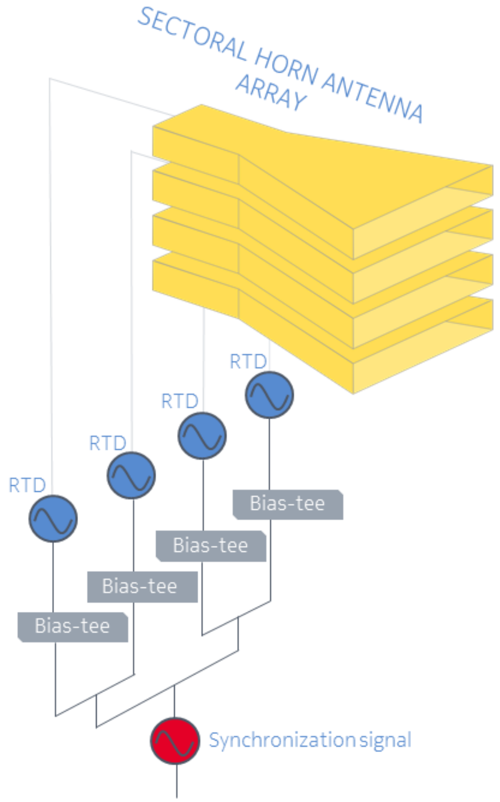
Mm-wave and THz novel transceiver technology

Future Research – coherent RTD array

Variant 2 – sectoral horn antenna array:

- Provides wide-band operation and high gain(+++)

- λ/2 separation between the radiating elements can be maintained through the use of sectoral horn antennas



<u>However:</u>

interconnection between RTD output and array input must be realized through waveguide-to-coax adapters

⇩

Due to the physical dimensions of the transition, λ/2 separation cannot be maintained using standard waveguide-to-coax adapters.

e.g. WR28 waveguide-to-coax adapter: 19mm x 19mm)

coax-to-waveguide transition needs to be tuned (how?)

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