Technische Universiteit Eindhoven University of Technology

5G New Radio System Research at the TU/e

CWTe Research Retreat 2017

Dr. Ulf Johannsen

What is 5G New Radio?

3 Classes of Use Cases for 5G[1]:

- Ultra-Reliable and Low Latency Communications (URLLC)
- Massive Machine Type Communications (mMTC)
- Enhanced/Extreme Mobile Broadband (eMBB)
  - Use of Millimetre-Wave Spectrum à **5G New Radio**

[1] 5G PPP Architecture Working Group, "View on 5G Architecture (Version 2.0)," July 2017 , www.5g-ppp.eu

NGMN Key Performance Indicators[1]:

Broadband access in dense areas:	Broadband access in a crowd:
• 200-2500 connections/km² DL: 750 Gbps / km² UL: 125 Gbps / km²	• 30,000 / stadium DL: 0.75 Tbps / stadium UL: 1.5 Tbps / stadium

Up to **1 Gb/s** should be supported!

[1] Next Generation Mobile Networks Alliance, "NGMN 5G White Paper," February 2015, www.ngmn.org

5G PPP Vision[1]:

- Up to **10 Tbps/km²**
- Peak data-rate of **10 Gbps/user**

Current Status of 3GPP Standardisation[2]:

- **1 Gbps** DL and **500 Mbps** UL up to **10 km/h** (average)
- **10 Gbps** up to **10 km/h** (peak)

[1] 5G-PPP, "5G Vision," February 2015, www.5g-ppp.eu
[2] 3GPP Technical Report (TR) 22.863, Version 14.1.0 (2016-09)

http://silika-project.eu/

“Silicon-Based Ka-Band Massive MIMO Systems for New Telecommunication Services”

- EU Marie Sklodowska-Curie programme
- Research started on 1st January 2017
- 12 PhD students
  - distributed over 3 countries
  - working on 12 individual sub-projects
  - Topics ranging from
    - System design
    - Antenna systems
    - Millimetre-wave electronics
    - Signal processing

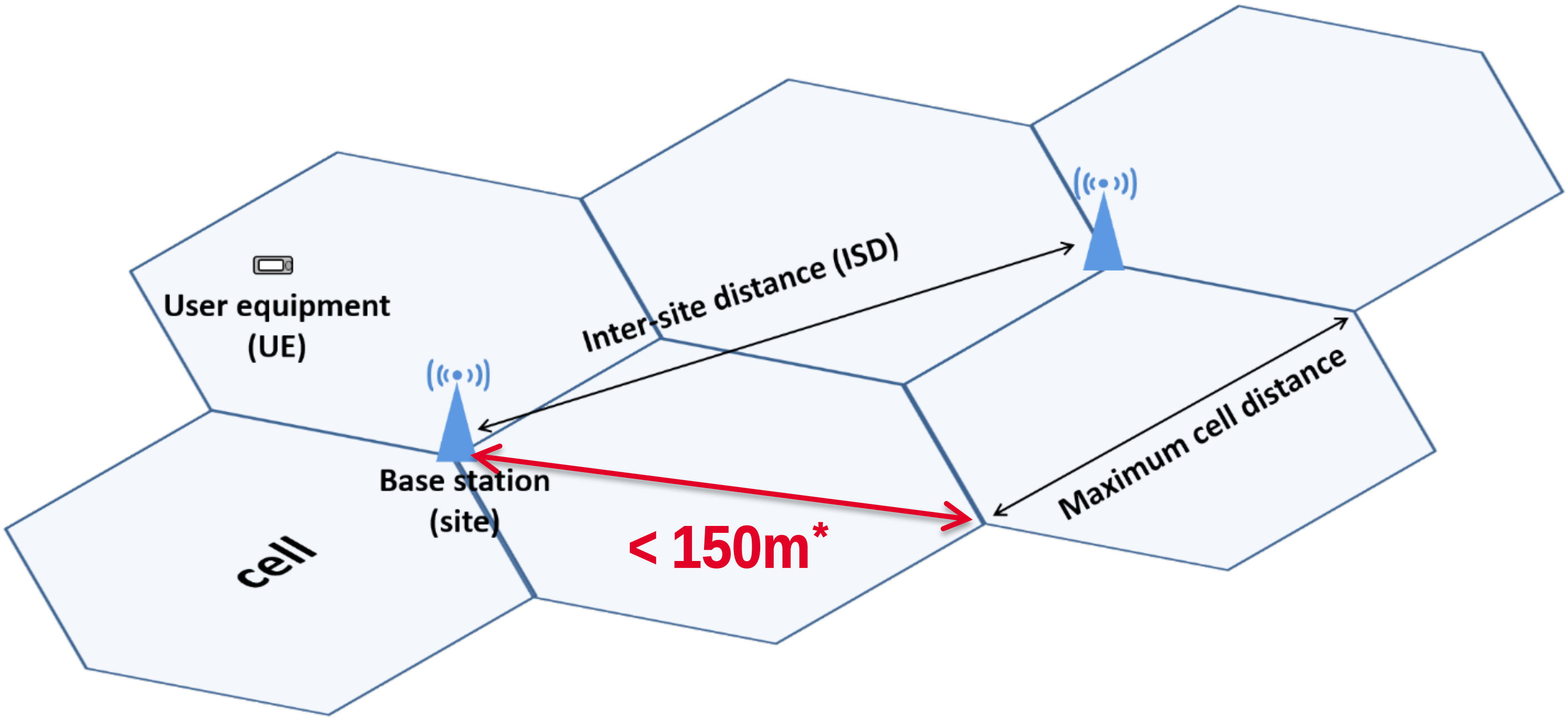
Objectives:

- Development of innovative **integrated antenna systems** for future **5G base stations** operating at **mm-wave** frequencies utilizing highly-integrated and cost-effective **(Bi-)CMOS** technologies.

- These antenna systems will rely on the use of multi-antenna **massive MIMO** concepts in which the number of individual antenna elements in the base station is much larger than the number of users ($M>>K$)

- **Training of 12 PhD students** in the domain of mm-wave massive MIMO systems

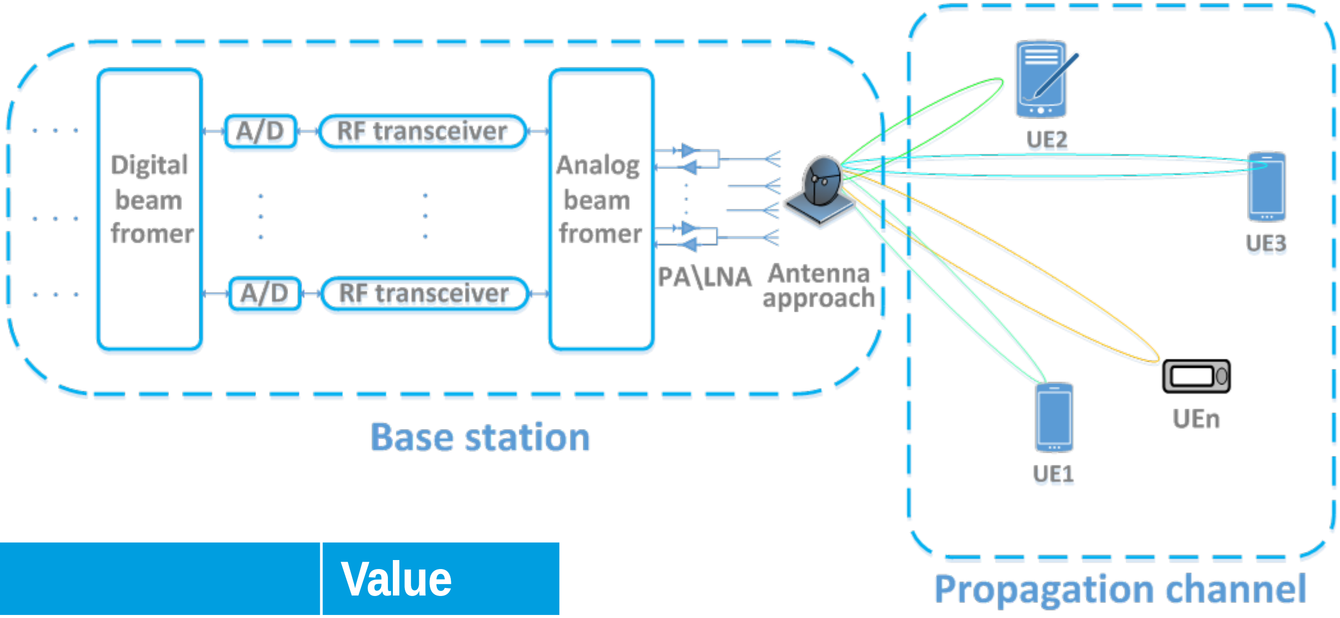
Re-Use of Existing Base-Station Sites



* For Urban Micro Cell

Picture Courtesy of Thomas Bressner

Overview



Parameter	Value
Frequency	~ 30 GHz
Number of users per cell	64
Communication distance (max. cell size)	< 150 m
PA output power (average)	8 dBm
Average Data Rate per User	1 Gbps

Picture Courtesy of Thomas Bressner

Feasibility Study

More possible at mm-waves

75 dBm*

max. EIRP:
62 dBm/100 MHz
(FCC limit)

UE antenna gain:
0 dBi

< 132 dB
attenuation
(NLOS)[1]

Sensitivity:
-75 dBm

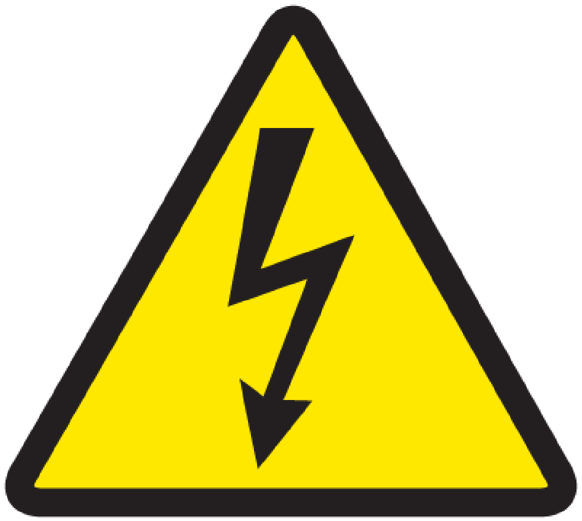
P_{Rx} = EIRP – PL + $G_{ant.}$
= (62 – 132 + 0) dBm
= -70 dBm

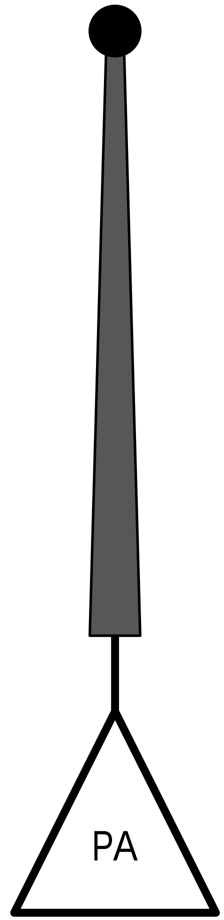
* FCC "Fact Sheet: Spectrum Frontiers Proposal to Identify, Open Up Vast Amounts of New High- Band Spectrum for Next Generation (5G) Wireless Broadband," June 2016.

[1] Based on "White paper: 5G Channel Model for bands up to 100 GHz (Annex)," Dept. of Computer Science, Michigan State University, September 2016

How to achieve 62 dBm EIRP?

- **Option 1**:





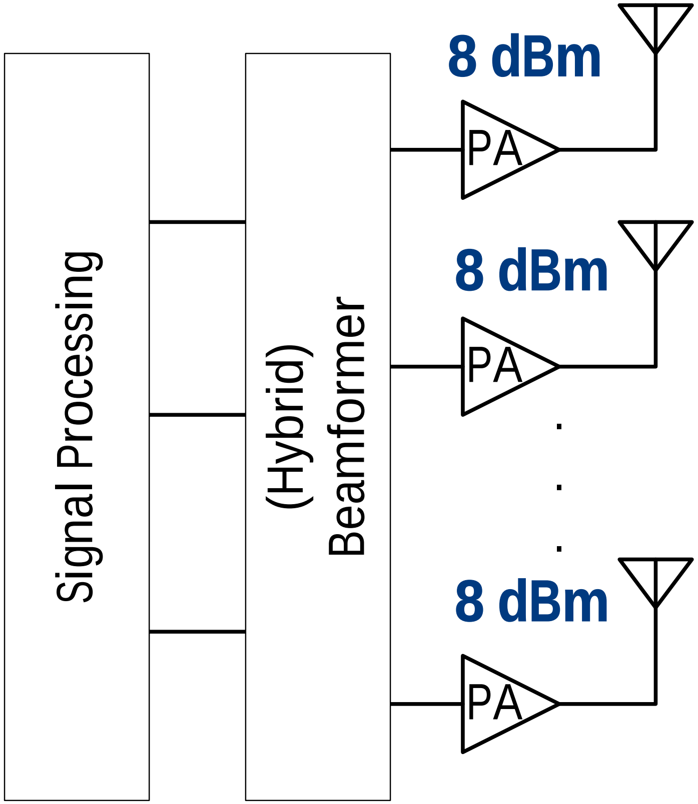
0 dBi

P_{Tx} > 1500W

- **Not possible with BiCMOS**
- **No massive MIMO**

How to achieve 62 dBm EIRP?

- <u>Option 2</u>:



N ≈ 500 elements

è 35 dBm Tx Power

- OK for Downlink
- OK for single user
- Not enough Tx power for Uplink!

How to achieve 62 dBm EIRP?

- <u>Option 2</u>:

Why?

35 dBm ≈ 3.2 W

Reduce UL speed to extend battery lifetime?

How to achieve a balance between UL and DL data rates?

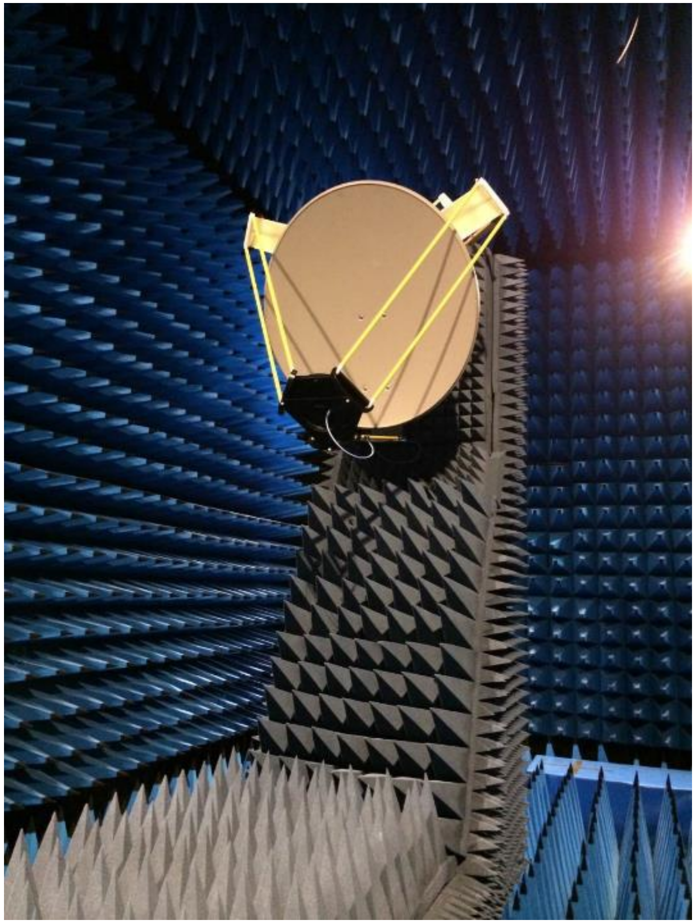
Limited

$$P_{Rx} = \left(\frac{\lambda}{4\pi R}\right)^2 G_{Rx} G_{Tx} P_{Tx}$$

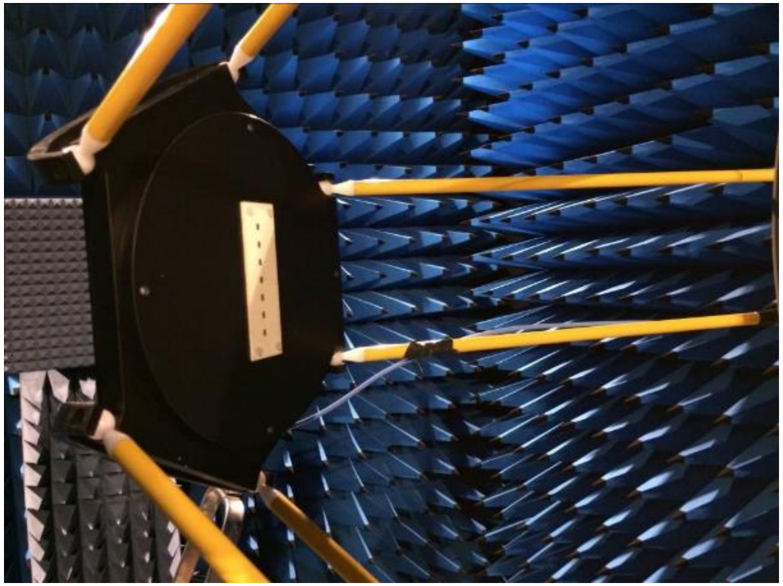
Required

Maximise Base-Station Antenna Gain!

Antenna Technology Proposed within SILIKA:



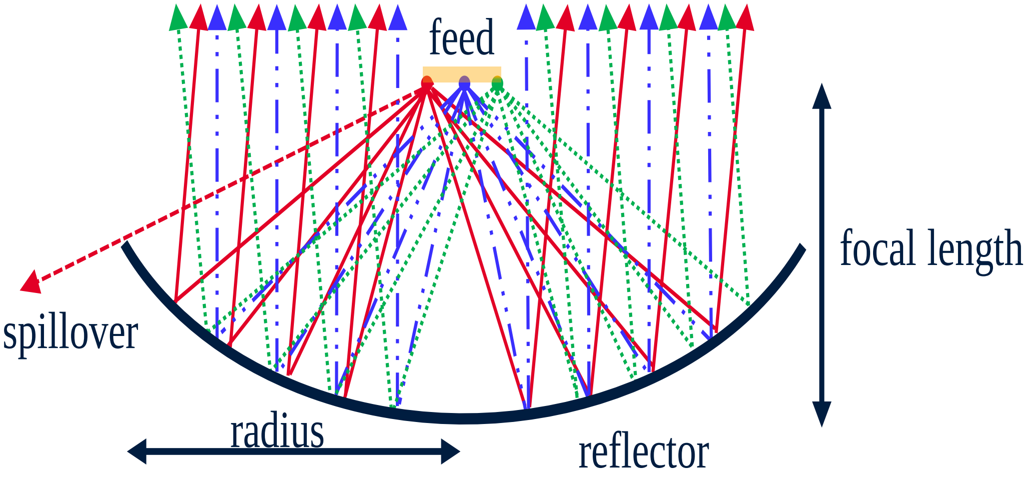
- **Large antenna gain possible**
- **Beam-steering by focal plane array**



A. Zamanifekri, A.B. Smolders, "Beam squint compensation in circularly-polarized offset reflector antennas using a sequentially-rotated focal-plane array," IEEE Antennas and Wireless Propagation Letters, 2015

Beam-Steering Using Phased-Array-Fed Reflector Antennas:

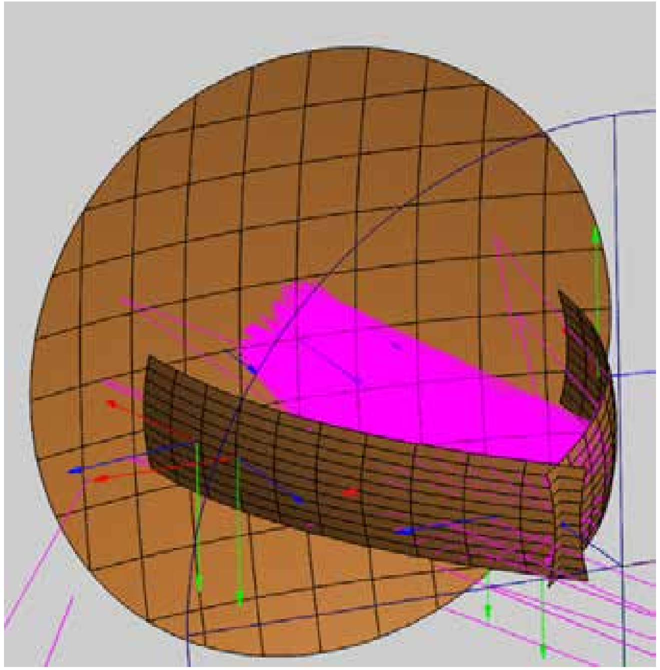
base station



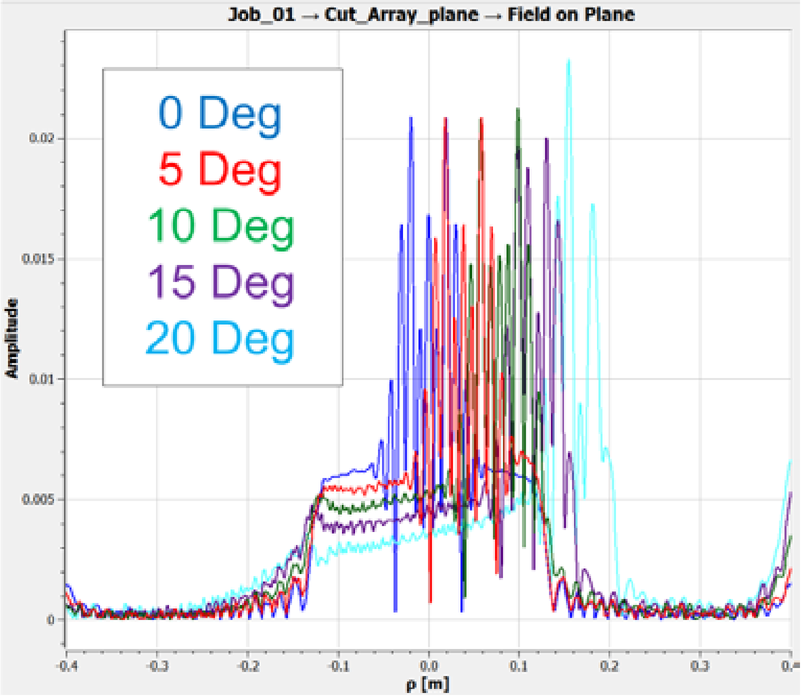
Double Reflector Configuration

Idea of complex sub-reflector with shaped main reflector for wide-angle scanning

Symmetrical sub-reflector configuration



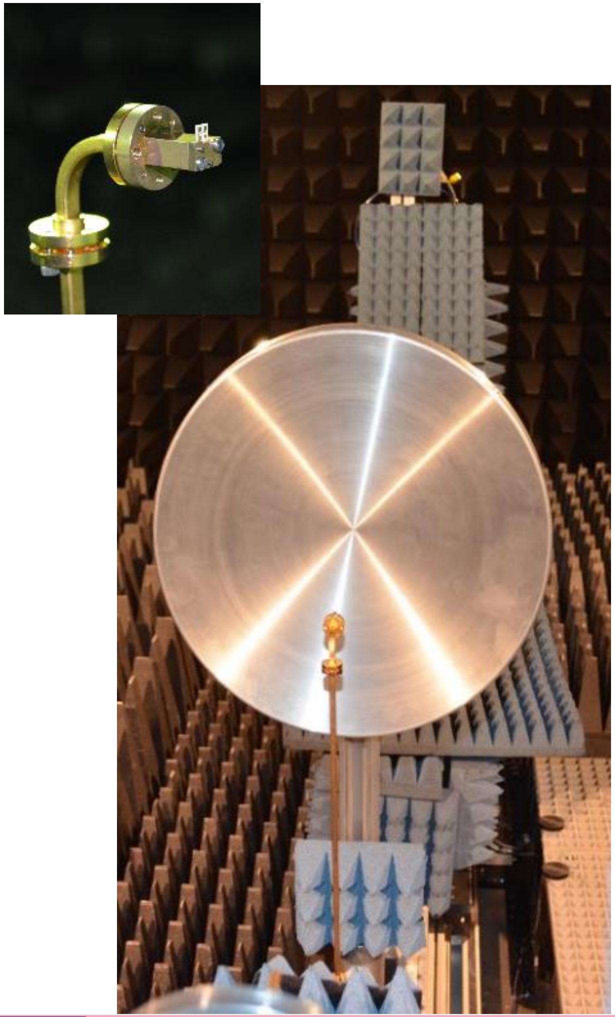
Electric field cuts in array plane for different angles incidents:

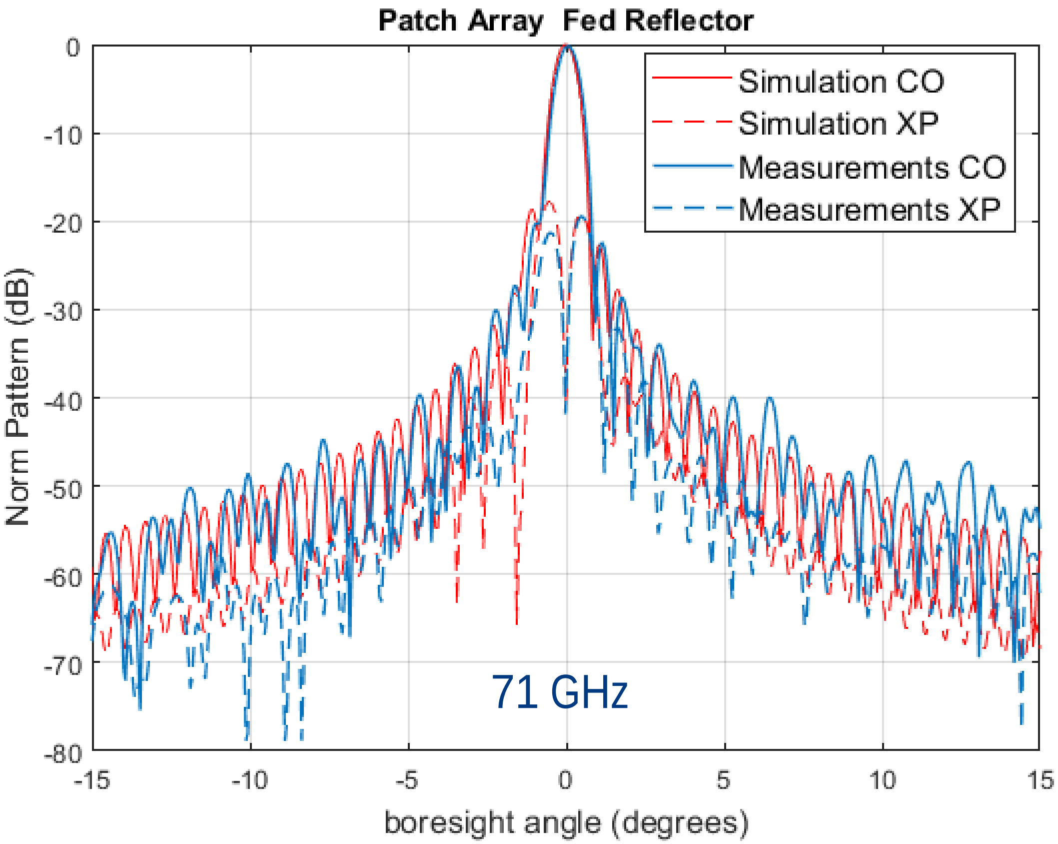


Research ongoing!!

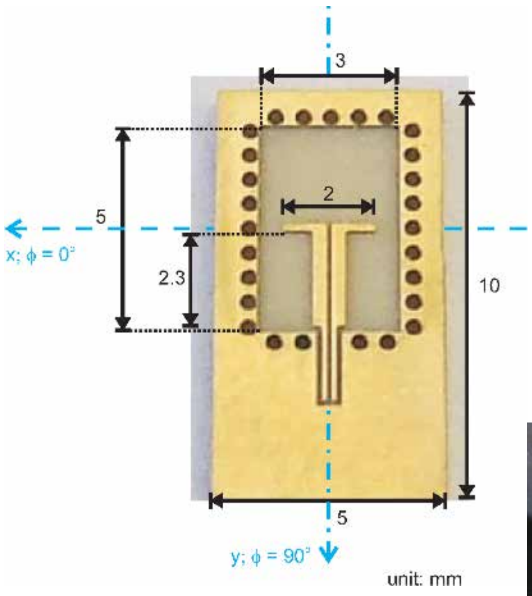
BiCMOS-Based E-Band Backhauling

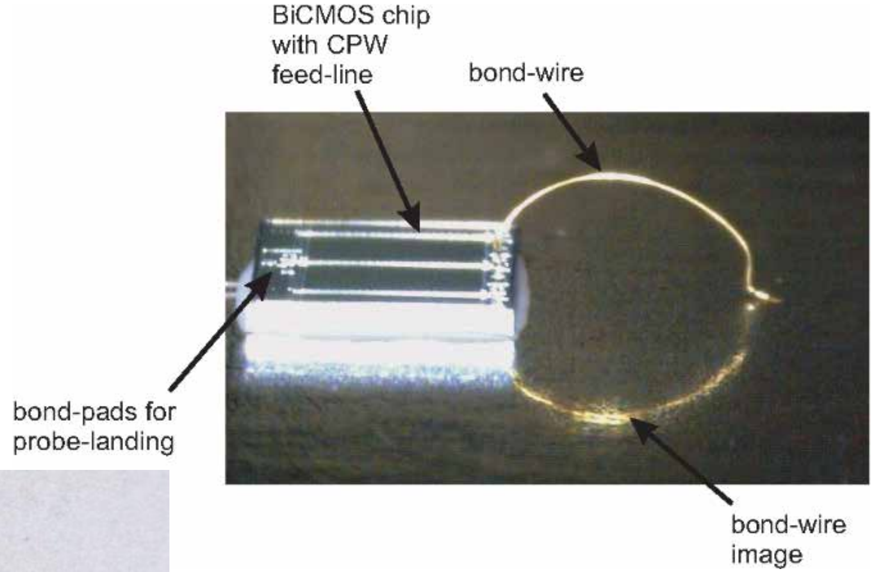
Proof of Concept

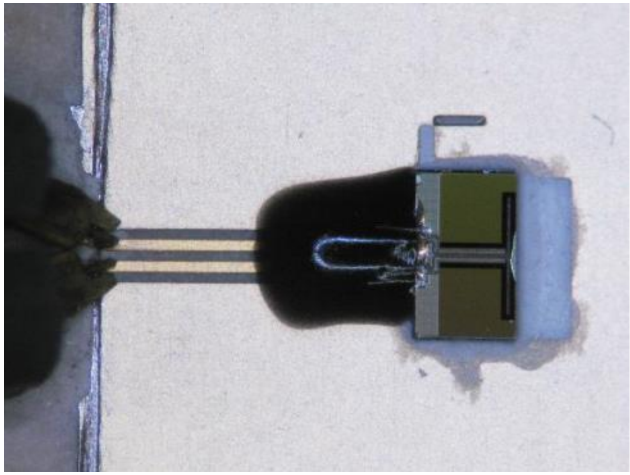




Integrated Millimetre-Wave Antenna Concepts

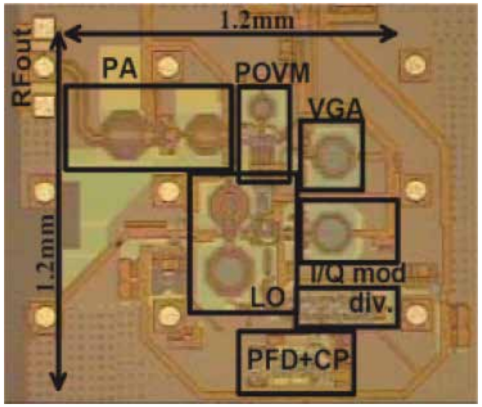


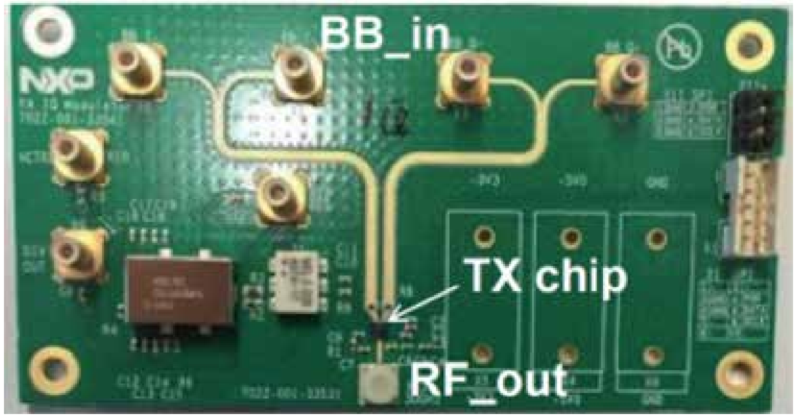




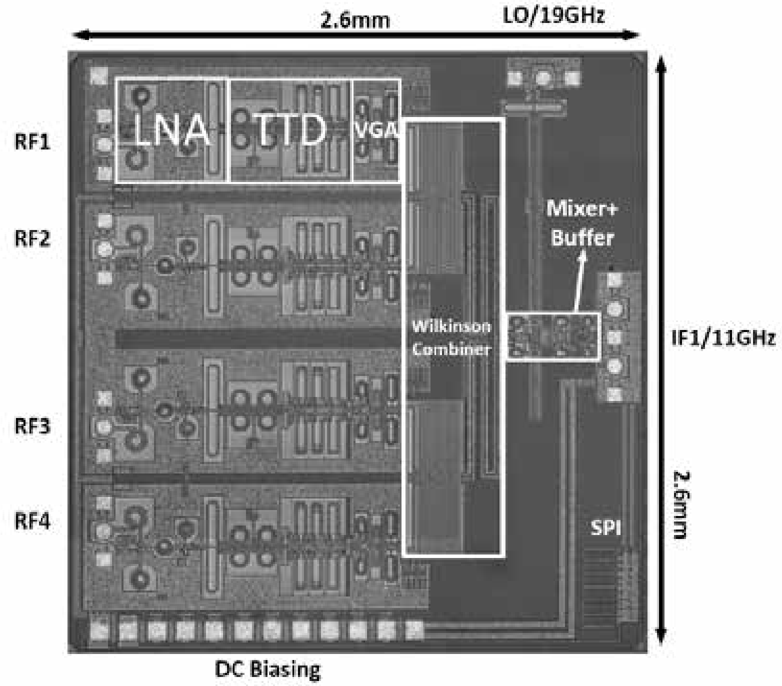
Ka-Band Electronics

Transmitter

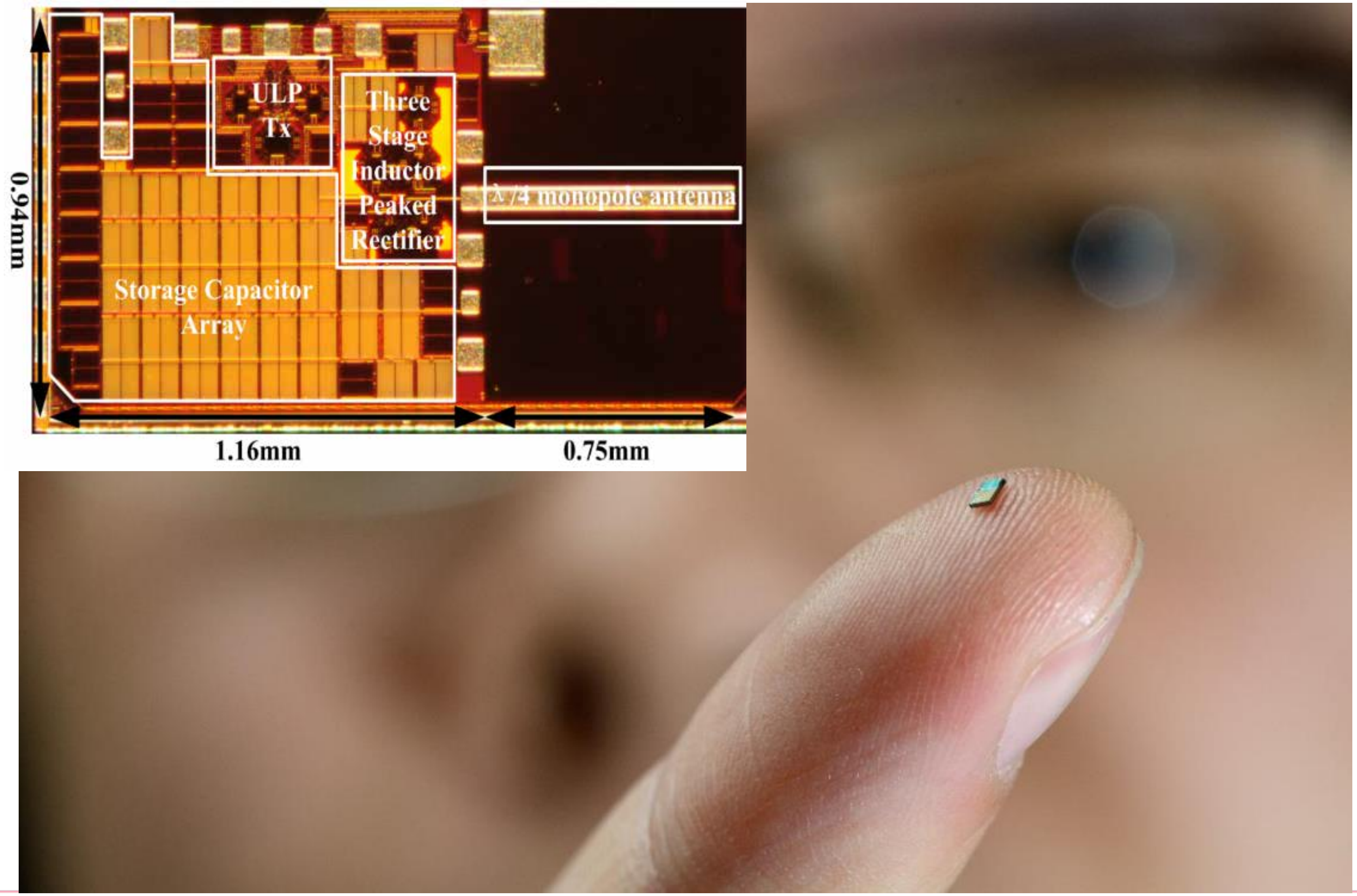




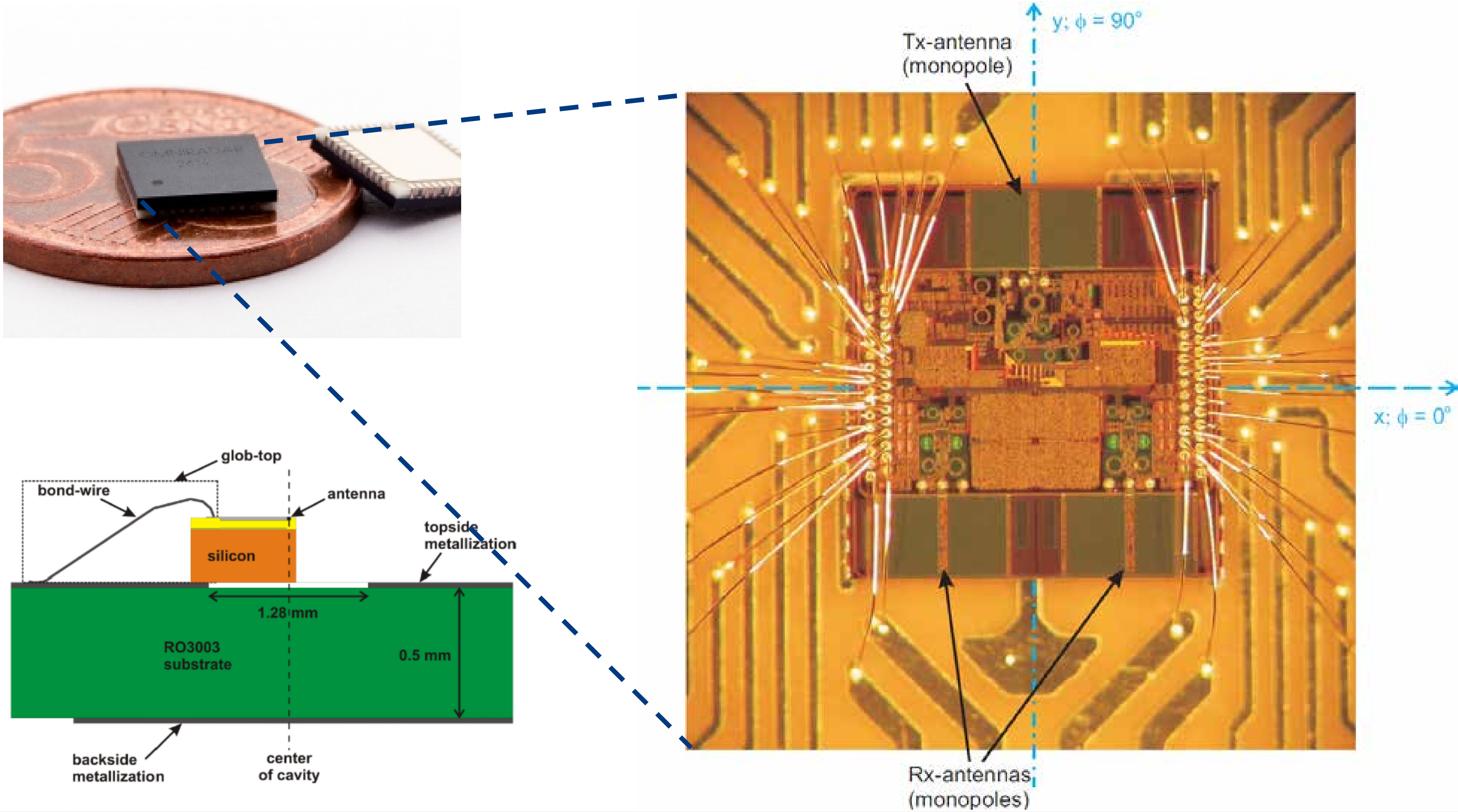
Receiver



Complete 60 GHz System On-Chip

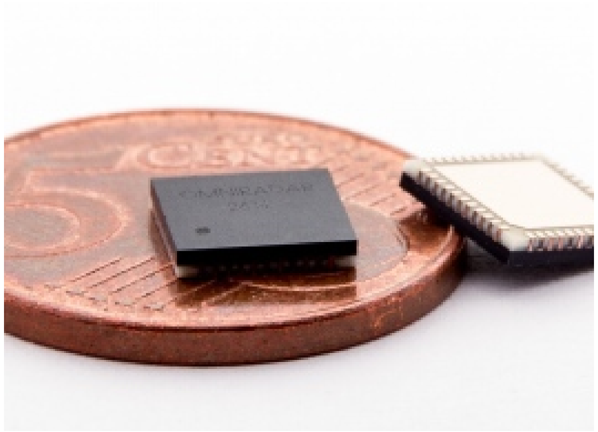


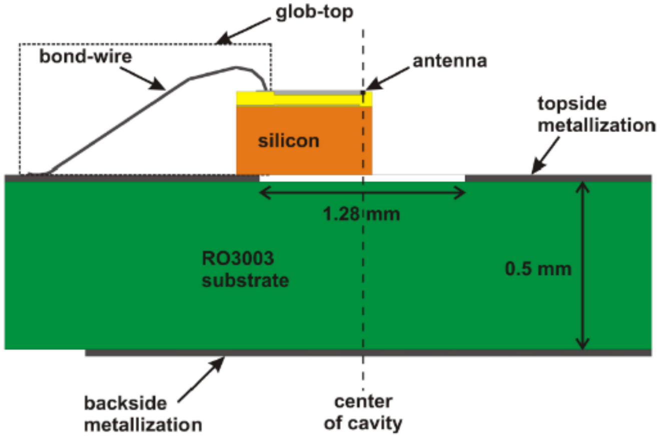
Single-Chip 60 GHz Radar in BiCMOS

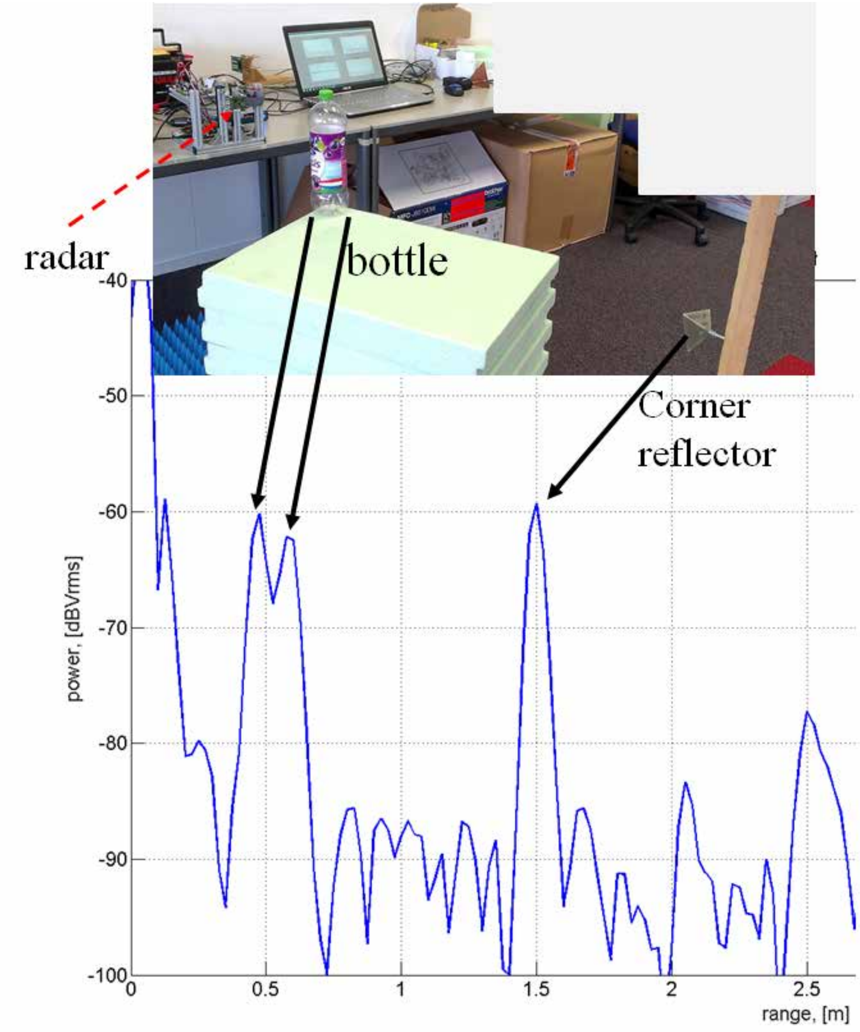


B. Adela; P.van Zeijl; U. Johannsen; A. B. Smolders “On-chip Antenna Integration for Millimeter-wave Single-chip FMCW Radar, Providing High Efficiency and Isolation” IEEE Transactions on Antennas and Propagation Year: 2016, Volume: PP,

Single-Chip 60 GHz Radar in BiCMOS







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Challenges within SILIKA:

- Design reflector antenna with
  - sufficient gain
  - steering range
  - feed array with suitable feed network
- Design of BiCMOS mm-wave receiver with
  - low system noise figure
  - integrated antenna(s)
- Calibration procedure
- Massive MIMO waveforms and algorithms

Related Activities with CWTe

(past and ongoing)

5G integrated Fiber-Wireless networks exploiting existing photonic technologies for high-density SDN-programmable network architectures

TU/e: Prof. Idelfonso Tafur Monroy

1 postdoc (open position)

Prof. Nikos Pleros, Coordinator

TU Tessaloniki

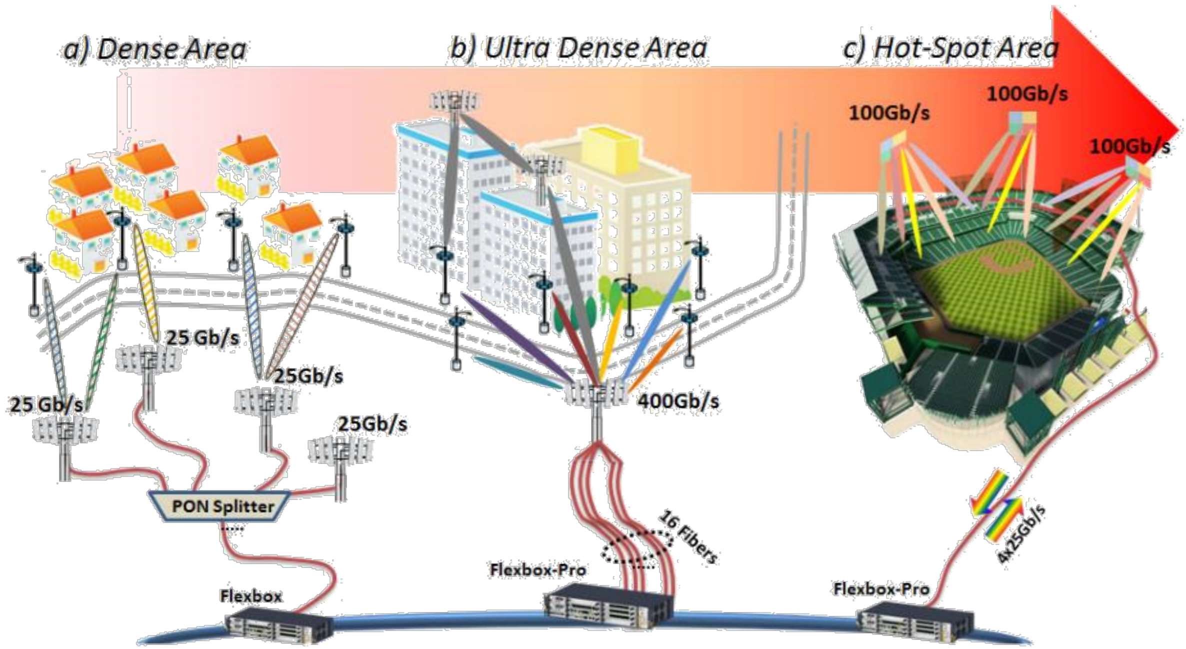
EU contribution: EUR 7 848 540

Topic(s): ICT-08-2017 - 5G PPP Convergent Technologies

Call for proposal: H2020-ICT-2016-2I

Funding scheme: IA - Innovation action

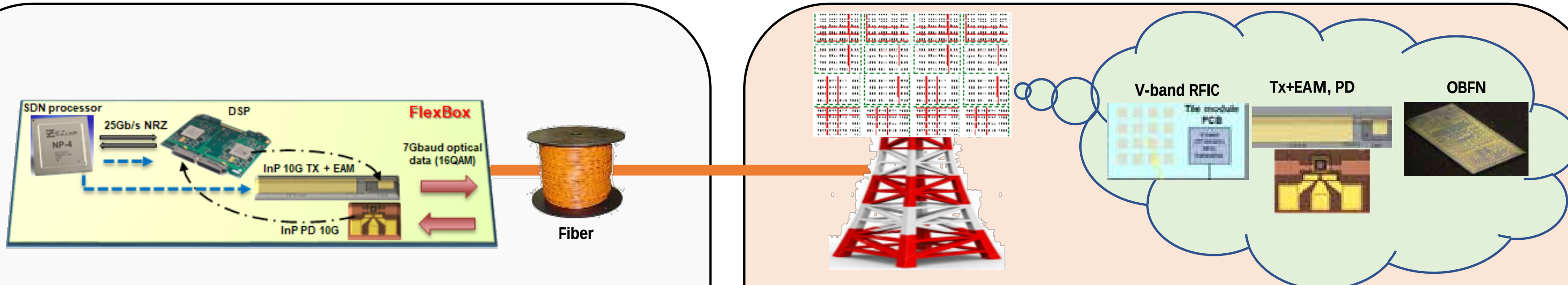
Pilot field-trial demonstrations 25 Gb/s -100 Gbps – 400 Gbps



TU/e Main contribution: Testbed Configuration and Evaluation

Complete FlexBox and 25 Gb/s RRH evaluation (individually & jointly) to initiate the pilot lab-scale demonstrator

4 x 4 x(16x16) MIMO Tails



FlexBox evaluation at TUE's testbed

ü ***BER & SNR measurements***
ü ***Various modulation formats/schemes***
ü ***Different fiber link lengths***

25 Gb/s RRH evaluation at TUE's testbed

ü ***Channel power & path loss measurements***
ü ***EVM & BER performance***
ü ***Different wireless LOS transmission distances***
ü ***Tunability, beamsteering & sweep angle tests***

FlexBox-RRH link performance evaluation
(latency, maximum distance coverage, BER/EVM measurements, etc.)

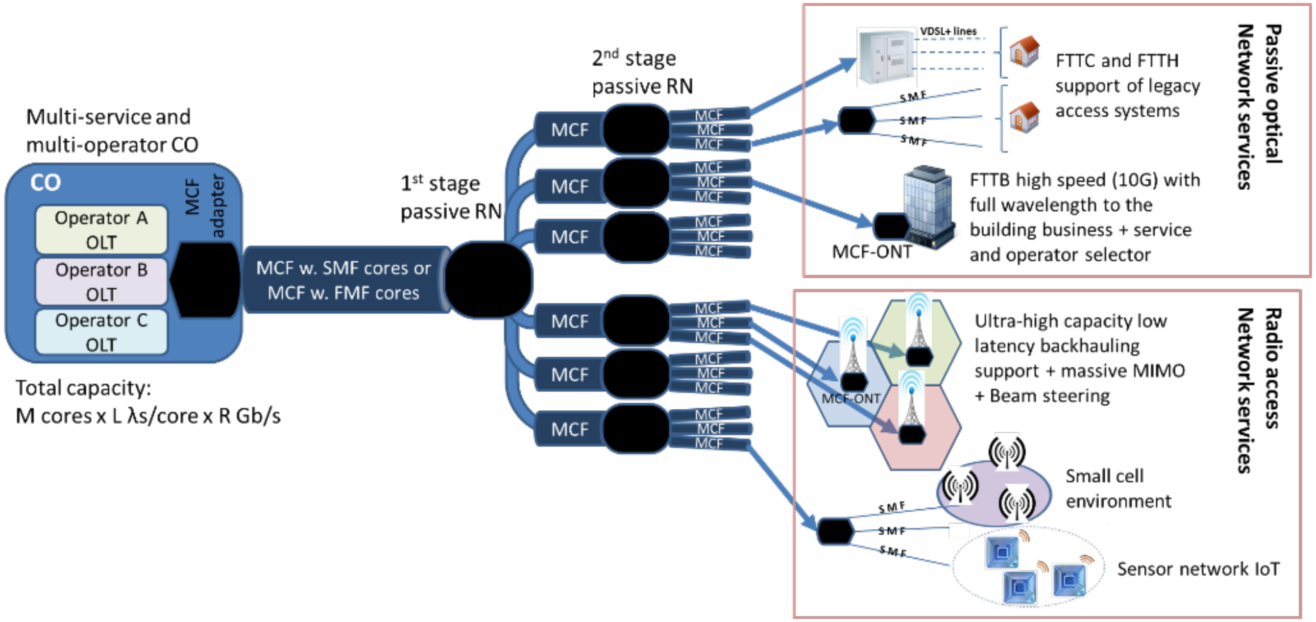
Building on the use of Spatial Multiplexing 5G Network Infrastructures and Showcasing Advanced Technology and Networking Capabilities

BLUESPACE concept: Ka-band wireless 5G network over multicore optical fiber infracstructure

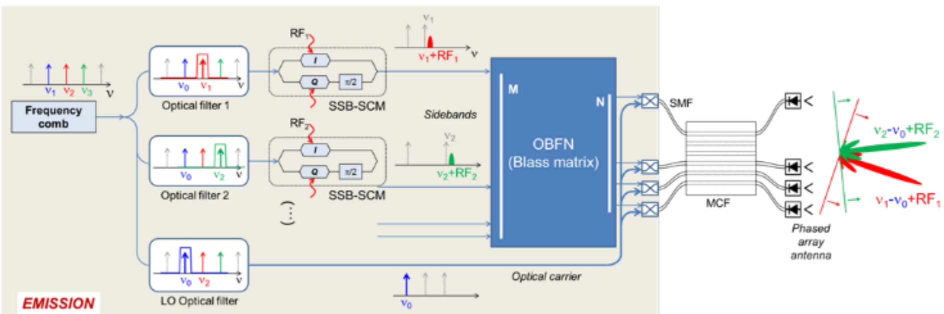
Coordinator:
Prof. Idelfonso Tafur Monroy

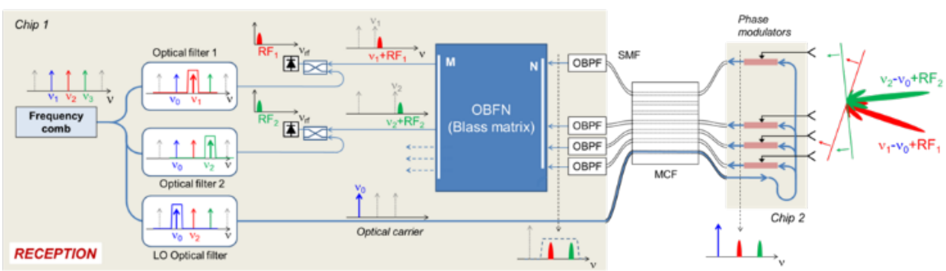
EU contribution: EUR 6 655 127,50
Topic(s): ICT-07-2017 - 5G PPP Research and Validation of critical technologies and systems

H2020-ICT-2016-2
Funding scheme: RIA - Research and Innovation action

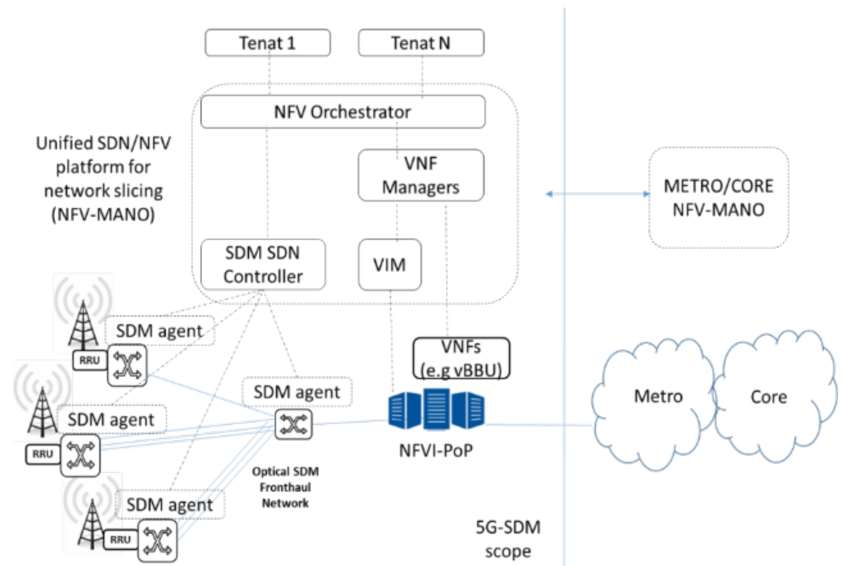


TU/e contributions: Overall Integration (spatial division multiplexing, analog & digital RoF, and SDN)





Beamforming



Demonstrator, SDN control, user cases

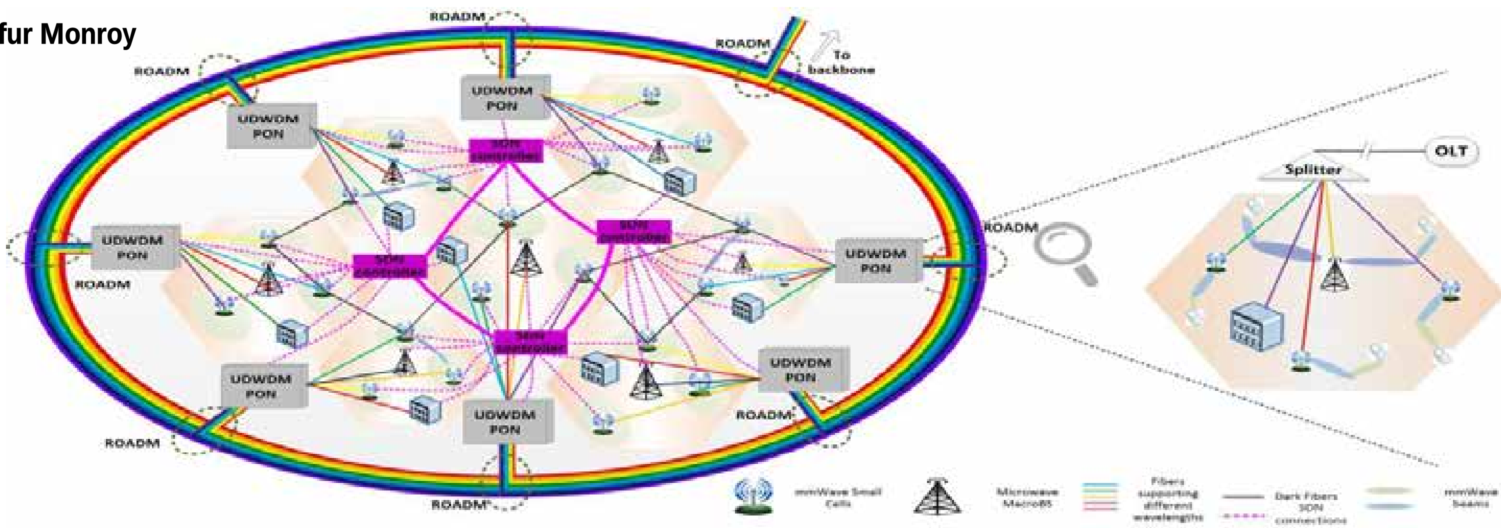
5G System Technological Enhancements Provided by Fiber Wireless Deployments

STEPFWD

TU/e: Prof. Idelfonso Tafur Monroy

2 ESRs

Prof. C Verikoukos



EU contribution: EUR 7 848 540

H2020-MSCA-ITN-2016

MSCA-ITN-ETN - European Training Network

15 PhD students on mmw 5G networks over ultra-dense WDM access networks

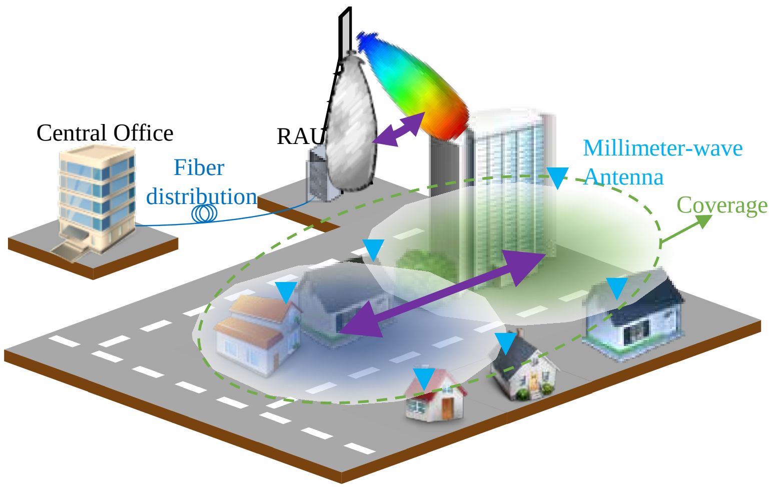
Focus on deployment

TU/e contributions: 2 ESRs and Scientific coordination (Prof. Tafur Monroy)

PhD student Dimitrios Konstantinou

ESR 11: i) design and optimization of a converged mm wave-over Ultra dense WDM Passive optical networks:

ii) design and test the Central Office for the converged network, and
iii) generic research in 5G and beyond fiber-wireless convergence.



PhD student Toms Salgals

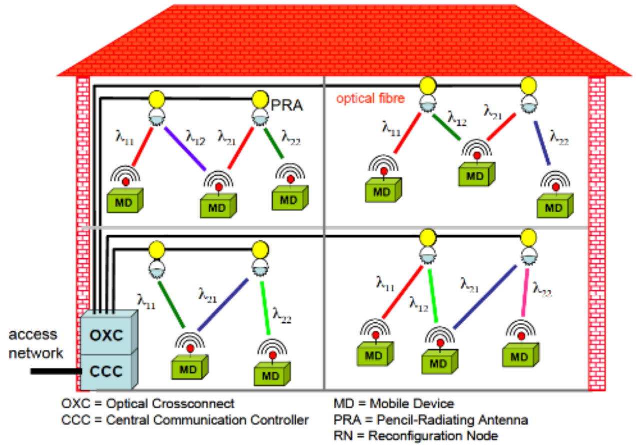
ESR 12: on i) new modulation/demodulation techniques for the transmission of mm wave signals through optical networks that incorporates ultra-dense wavelength spacing:

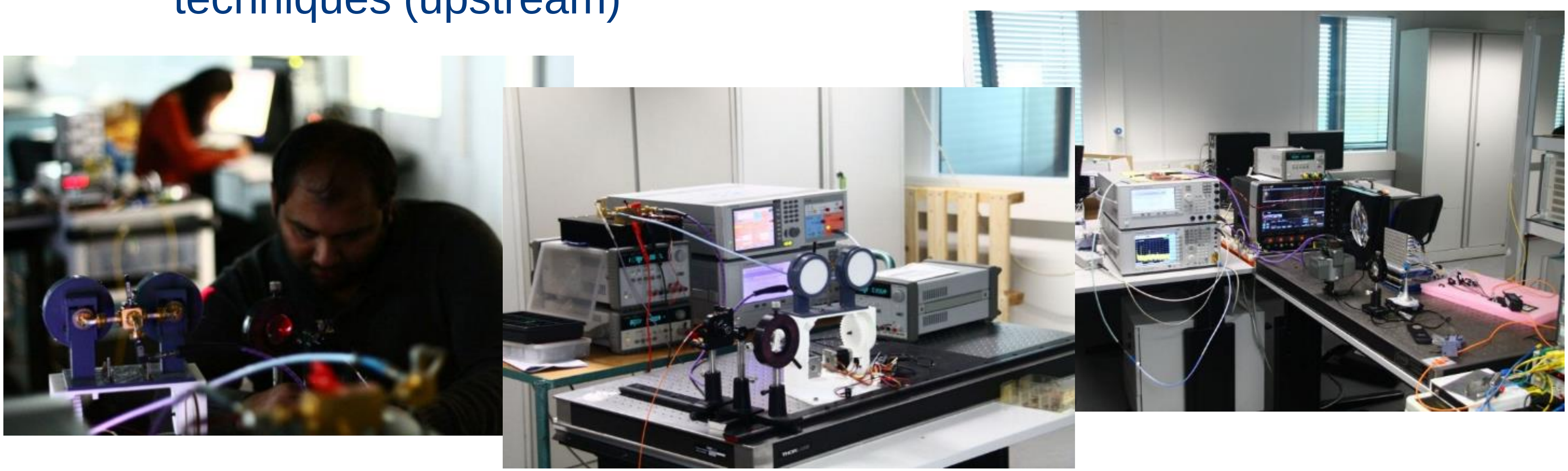
ii) design the interface between the optical network unit (ONU) and the small-cell antenna

iii) generic research in 5G and beyond fiber-wireless convergence.

Optical technologies

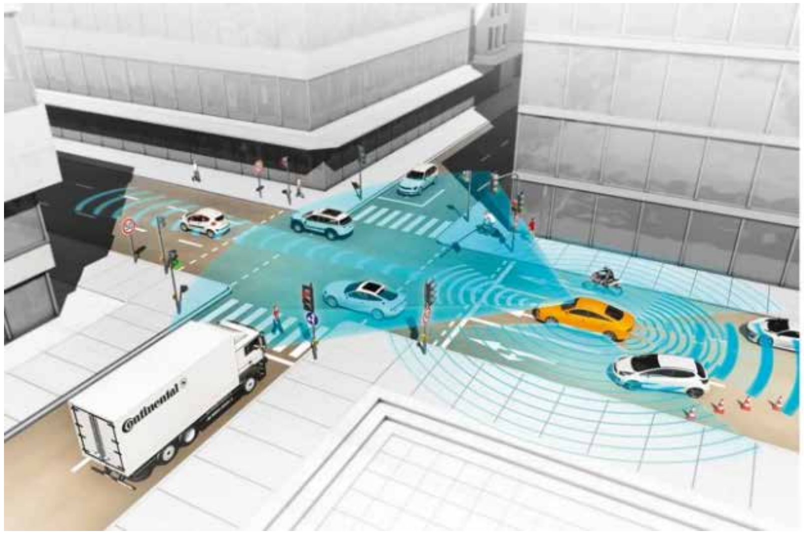
- Browse project
  (Prof. Koonen, Prof. Baltus)
  - Multiple dynamically-steered free-space optical beams (downstream)
  - flexible mm-wave radio communication techniques (upstream)





https://www.tue.nl/en/university/departments/electrical-engineering/research/research-groups/electro-optical-communications-eco/research/projects/browse/

i-CAVE – Advanced radar-based communication networks (RADCOM)



Prof. Willems (SPS group)

- Cooperative awareness
- Radar and communication devices are jointly used in a cooperative way to realize a more robust and synergetic approach to sensing and communication for ITS and platooning.

Expected project outcomes

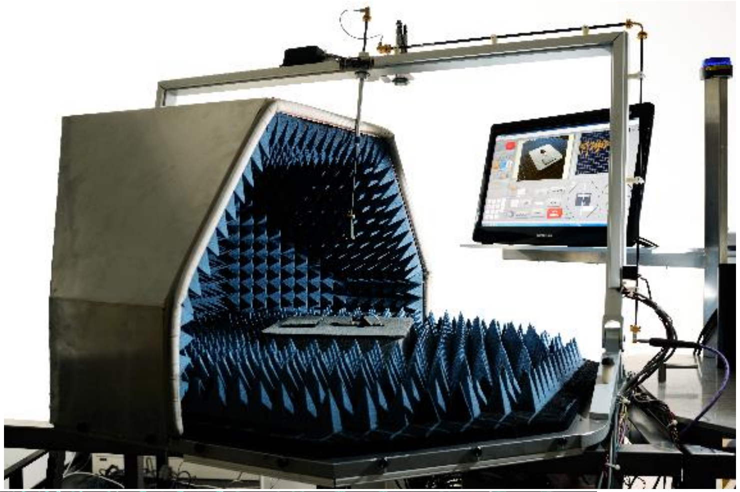
- Advanced design methods for a new generation of Software defined RADCOM platforms (architectures unification).
- Definition of new waveform, access protocol and DSP schemes to address radar/communication functionalities simultaneously.
- Functional reconfiguration and fusion methods.

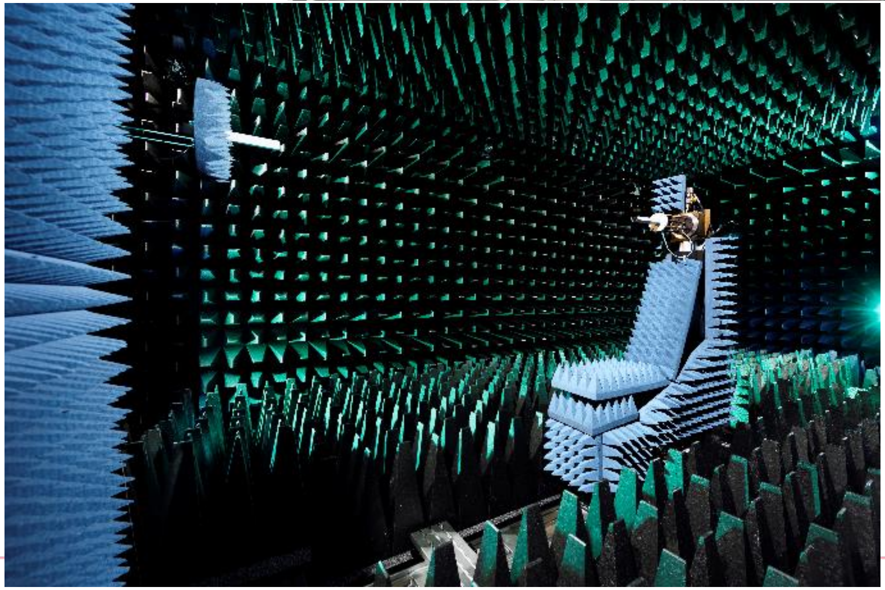
Impuls - 5G in Future Intelligent Transportation Systems

- Luis Abanto Leon
- Enhancements for ultra-low latency, high reliability, and high mobility
- Increasing data rates
- Heterogeneous architectures for optimal hybrid operation of WAVE + 5G

Thank you very much!

Measurement Facilities

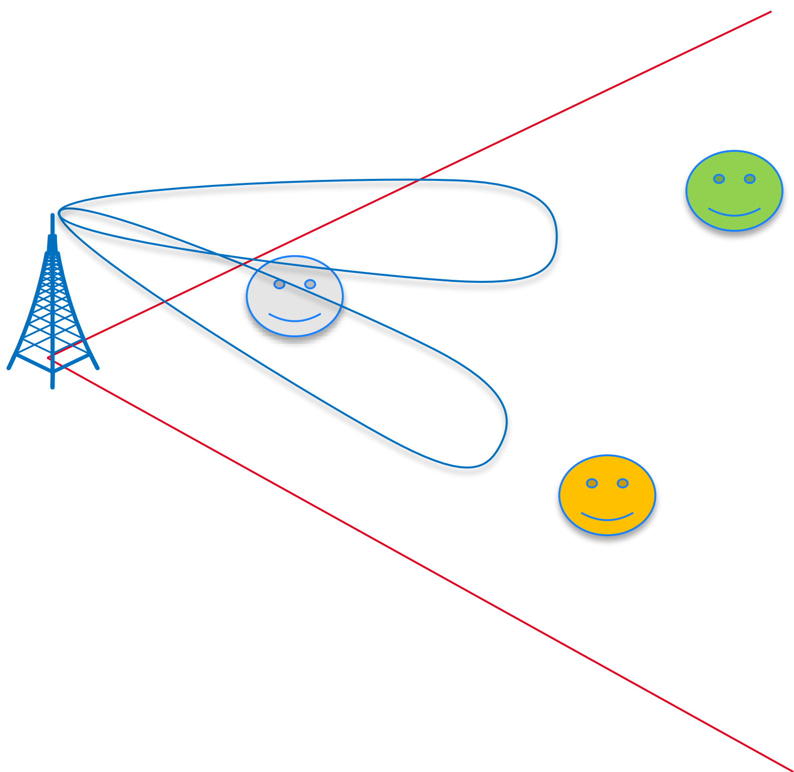




Pictures by
Bart van Overbeke

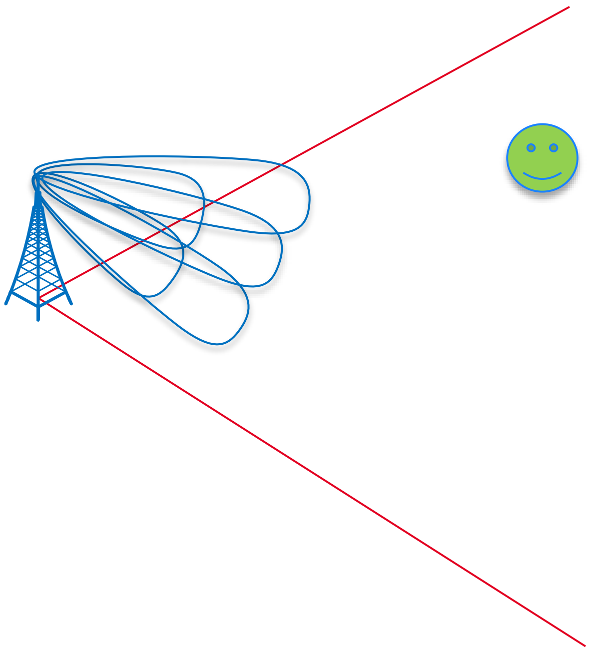
Direction of Arrival Estimation:

- Highly focused beams
  - High EIRP @ low transmit power
  - Finding and tracking users difficult



DoA Challenge

Assumption: Users are synchronized
System is calibrated



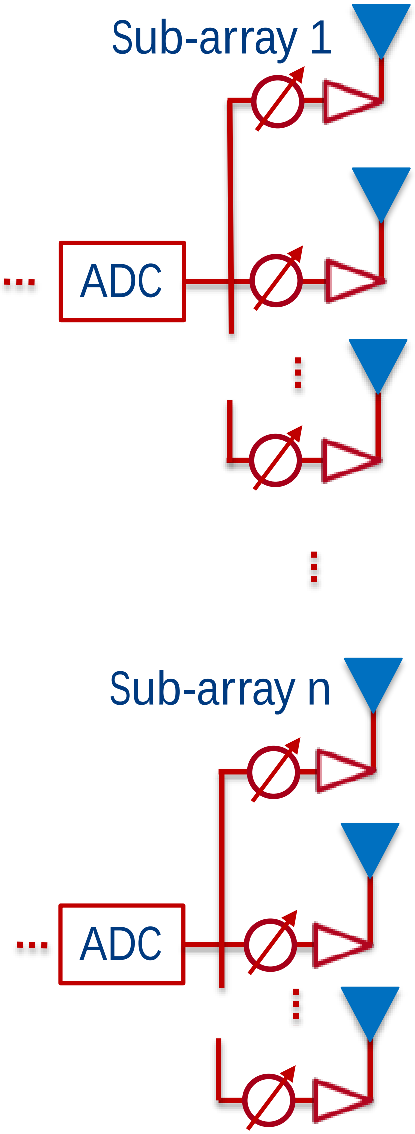
Channel estimation

mmWave: Difficult to have high SNR for user far away
Reflector: Small surveillance area
Massive MIMO: High computational effort

Beam training

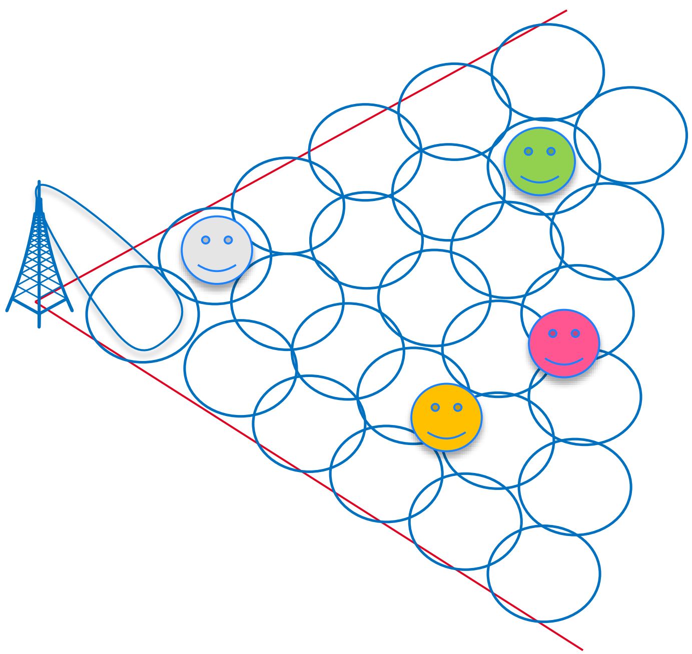
Small beam due to the reflector
-> Needs a good initial guess
Iterative approach lowers system throughput

Single Shot DoA



+ DAC per sub-array
+ Sufficient antenna gain due to
    Phased sub-arrays
    Reflector (not shown)

Assumptions: Users is synchronized
System is calibrated



Gain and EIRP

- Desired data rates requires EIRP and gains as defined in Tables I and II

Range [m]	NLOS path loss [dB] UMi/UMa	Required EIRP [dBm] UMi/UMa
25-50	116/111	41/36
50-100	126/121	51/46
100-150	132/127	57/52
150-200	137/131	- /56
200-250	140/134	- /59
250-300	143/137	- /62
300-350	145/139	- /64

Table I

# amps	Average transmit power [dBm]	Antenna gain at 100-150m [dBi] (UMi)	Antenna gain 300-350m [dBi] (UMa)
1	8	49	56
2	11	46	53
4	14	43	50
8	17	40	47
16	20	37	44
32	23	34	41
64	26	31	48
128	29	28	35

Table II

Gain Vs HPBW

- UMi Scenario (150m cell radius)
- For a parabolic dish with 70% aperture efficiency
- The table below shows the gain and HPBW for the minimum and maximum distances way from the base station.

Diameter [m]	Number of Amplifiers	Gain [dBi]	HPBW [Deg]	Beam footprint at 25m (radius[m])	Beam footprint at 150m (radius[m])
0.29	16	37	2.34	1.7	31.5
0.41	8	40	1.65	1.2	25.4
0.58	4	43	1.17	0.7	20
0.82	2	46	0.83	0.6	15.5