FUTURE TECHNOLOGIES FOR FIBER-TO-THE-ROOM

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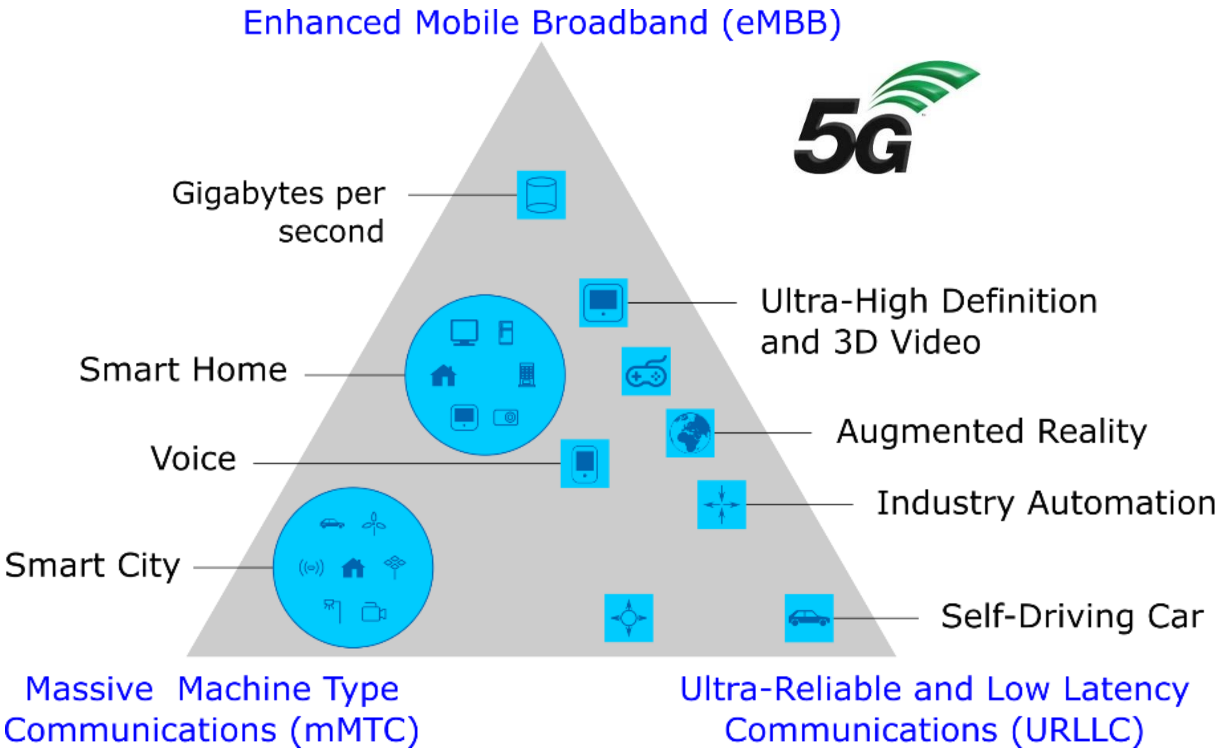
OVERVIEW

1. **Introduction**
   - Next-generation wireless communication systems
   - Multi-antenna systems : opportunities and challenges
   - Optically-enabled multi-antenna systems
2. **Passive Remote Antenna Units (RAUs) for Sub-6 GHz Radio-over-Fiber**
   I. Cost-effective downlink RAU (3.5 GHz) through impedance matching to 50 Ω
   II. Cost-effective and compact downlink RAU (5 GHz) through conjugate matching
3. **Distributed Antenna Systems based on mmWave-over-Fiber (28 GHz)**
4. **Conclusion**

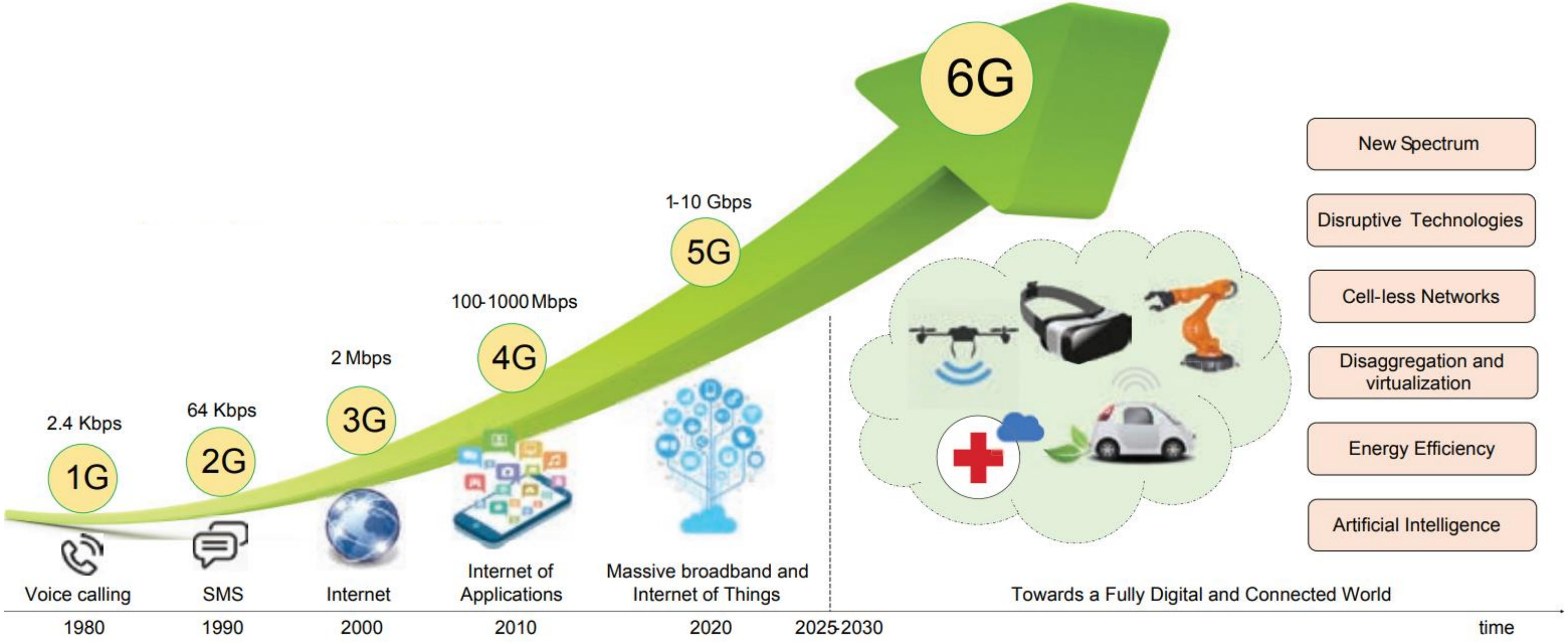
INTRODUCTION

NEXT-GENERATION WIRELESS COMMUNICATION SYSTEMS



Recommendation ITU-R M.2083-0, "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond," 2015.

NEXT-GENERATION WIRELESS COMMUNICATION SYSTEMS



M. Giordani *et al.*, ``Toward 6G Networks: Use Cases and Technologies,” *IEEE Communications Magazine*.

Jointly meet strict rate, reliability, latency, efficiency and connectivity requirements

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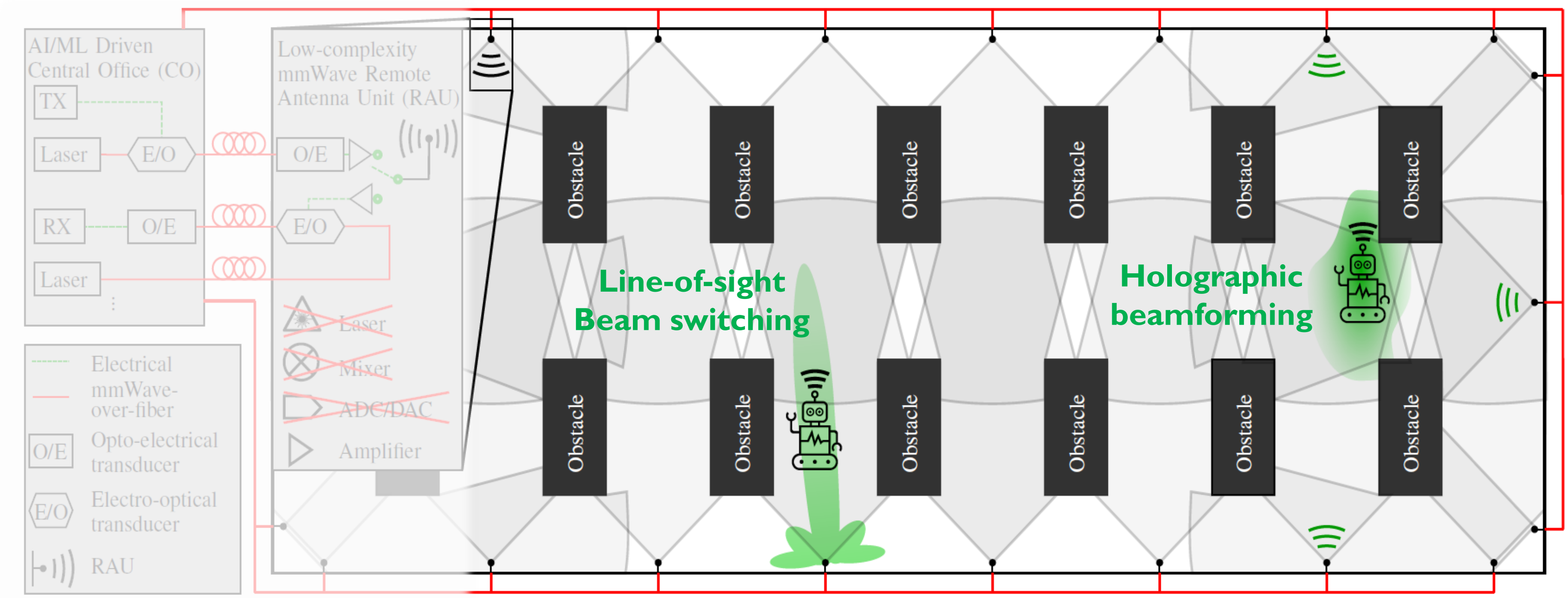
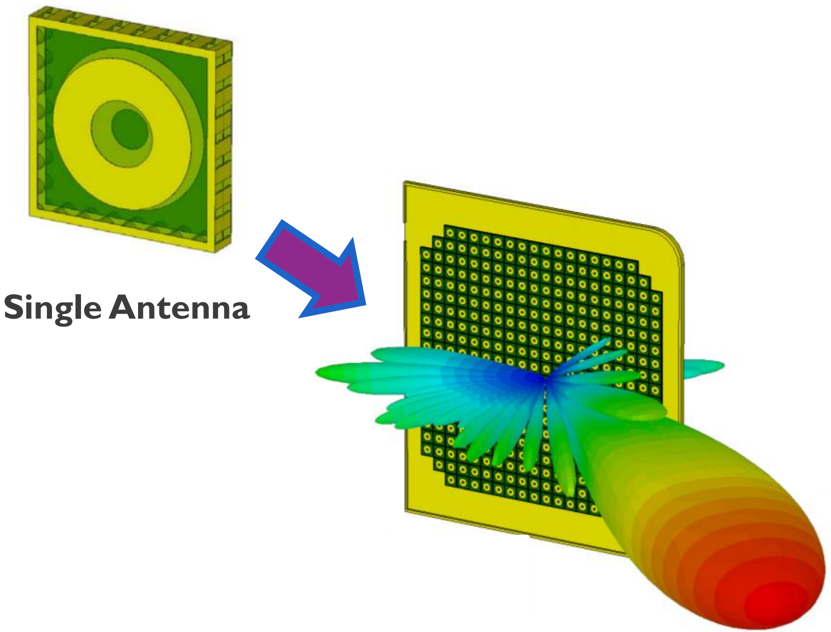


Jointly meet strict rate, reliability, latency, efficiency and connectivity requirements

Examples : Extremely Immersive AR/VR, Holographic Telepresence, Factory-of-the-Future, …

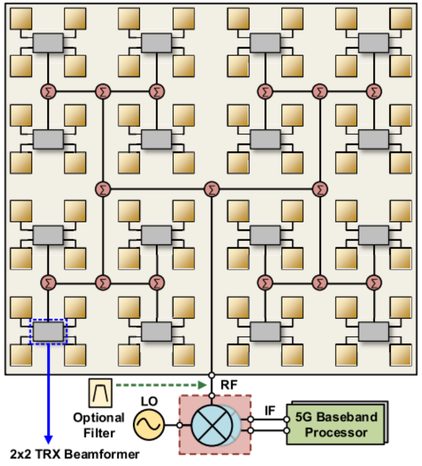
MULTI-ANTENNA SYSTEMS : SIGNAL DISTRIBUTION

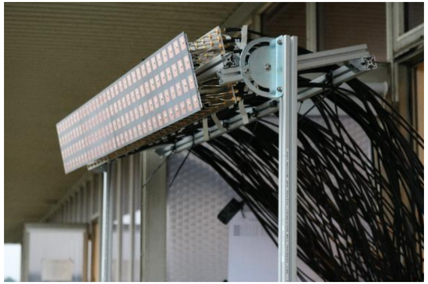


Multi-antenna system

- ✓ Adaptive beam forming
- ✓ (Massive) MIMO technology

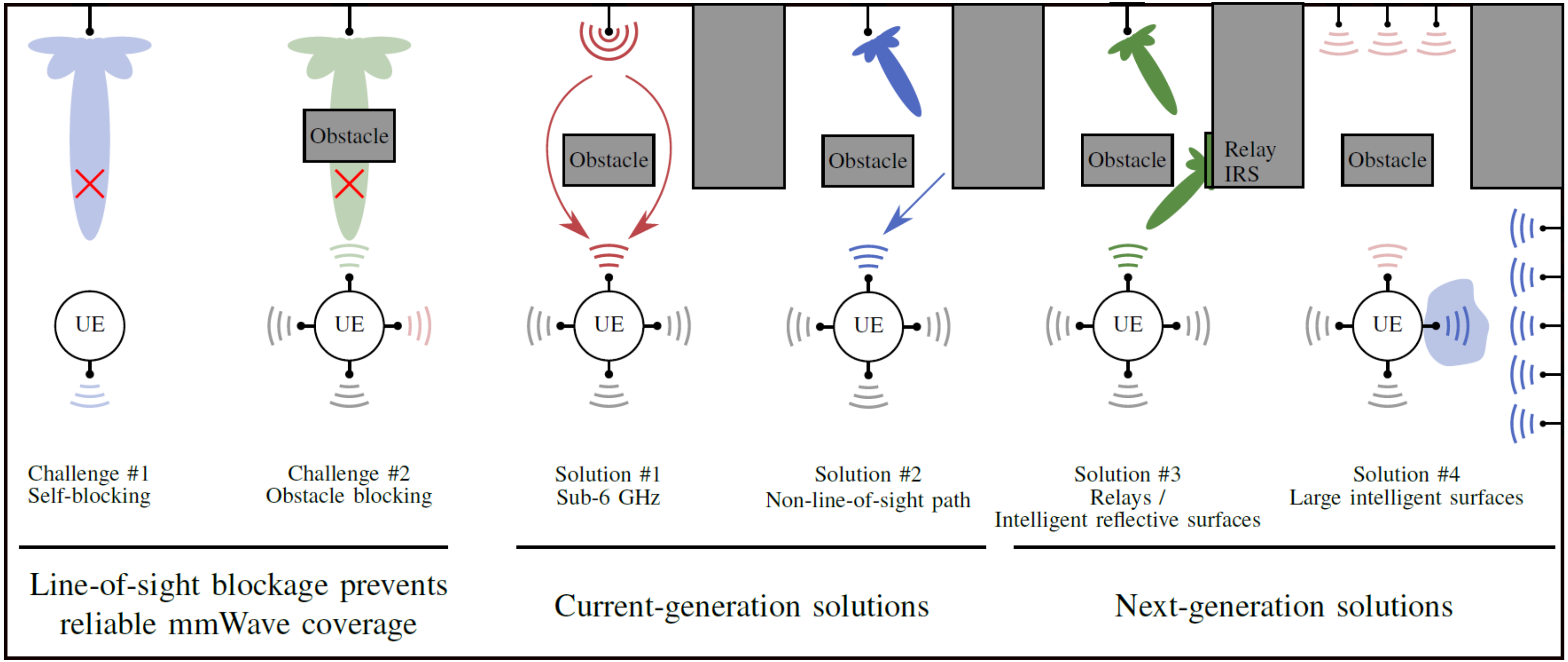
All-electric multi-antenna feed





- ☒ Lossy, expensive routing
- ☒ Bandwidth constraints
- ☒ EMI/EMC-issues

MULTI-ANTENNA SYSTEMS : CO-LOCATED VS. DISTRIBUTED

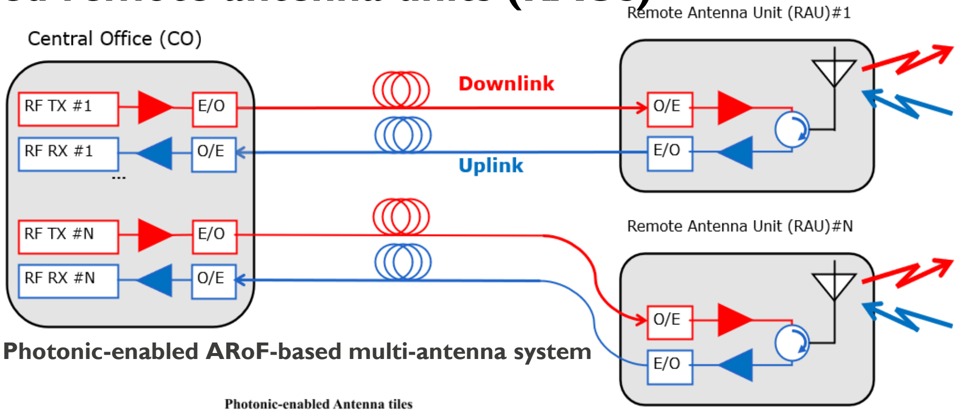


mmWave : More bandwidth ⇔ Unfavorable propagation conditions

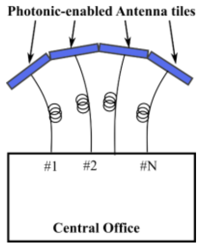
OPTICALLY-ENABLED MULTI-ANTENNA SYSTEMS

Exploit radio-over-fiber techniques to efficiently distribute wideband signals to co-located and/or distributed photonic-enabled remote antenna units (RAUs)

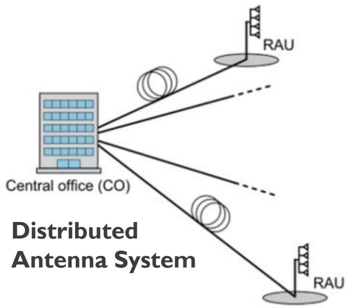
- **Optical routing**
  - ✓ Low loss
  - ✓ Large bandwidth
  - ✓ No EMI/EMC issues
- **Potential**
  - ✓ Support of very high bandwidth signals
  - ✓ Scalable **co-located** and **distributed** multi-antenna systems
  - ✓ Cost-effective and tightly-synchronized RAUs



Photonic-enabled ARoF-based multi-antenna system



Co-located Conformal Multi-antenna system



Distributed Antenna System

G. Torfs et *al.*, "ATTO: Wireless Networking at Fiber Speed," in *IEEE Journal of Lightwave Technology*.

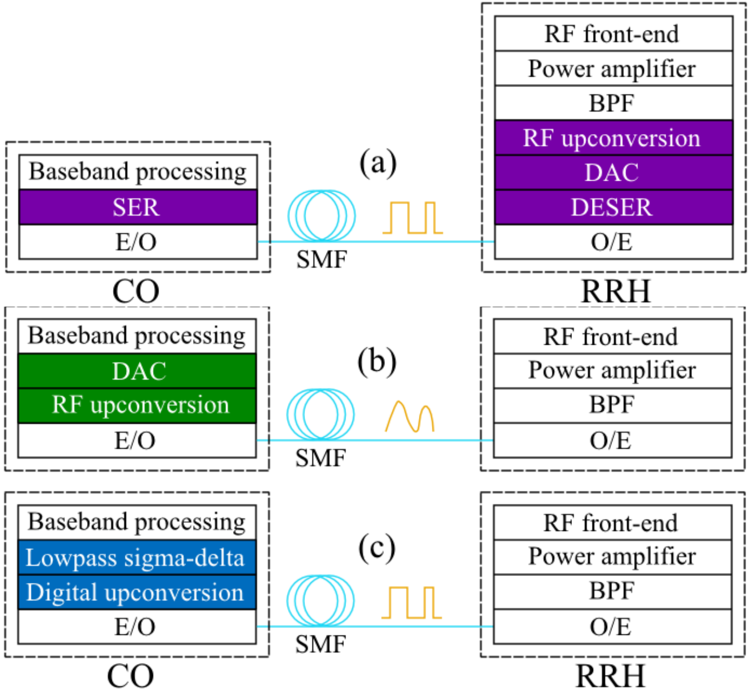
A. Moerman *et al.*, "Beyond 5G Without Obstacles: mmWave-over-Fiber Distributed Antenna Systems," in *IEEE Communications Magazine*.

RADIO-OVER-FIBER (RoF) TECHNOLOGY

(a) Digitized RoF (DRoF)
- Low-cost telecom components
- Low spectral efficiency
- Complex RAU

(b) Analog RoF (ARoF)
- High spectral efficiency
- Low-complexity RAU
- Highly linear optics required

(c) Sigma-Delta RoF (SDRoF)
- Low-cost telecom components
- Low-complexity RAU (sub-6 GHz)
- Moderate-complexity RAU (mmWave)



L. Breyne *et al.*, "Comparison Between Analog Radio-Over-Fiber and Sigma Delta Modulated Radio-Over-Fiber," in *IEEE Photonics Technology Letters*.
H. Li *et al.*, "A 21-GS/s Single-Bit Second-Order Delta–Sigma Modulator for FPGAs," in *IEEE Transactions on Circuits and Systems II: Express Briefs*.

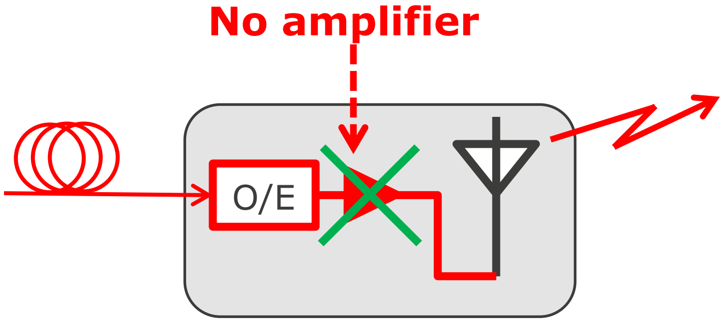
PASSIVE REMOTE ANTENNA UNITS FOR SUB-6 GHZ RADIO-OVER-FIBER

PASSIVE DOWNLINK RAUs : DESIGN CONSTRAINTS

- **Fully passive opto-electric conversion**
  - No additional active components (amplifiers)
- **Wideband and efficient opto-electric conversion**
  - Optimized for operation in specified frequency band
  - Lossless impedance matching
- **Low-profile and highly efficient antenna**
- **Cost-effective unit**
  - 850 nm multi-mode fiber
  - Vertical-cavity surface-emitting laser (VCSEL)
  - Standard PCB fabrication process

ERC Grant 695495 "ATTO: A new concept for ultrahigh capacity wireless networks." (https://atto.ugent.be)

***atto*-cell served by optoelectronic RAUs**



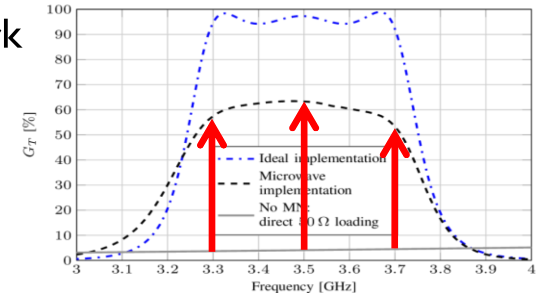
Fully-Passive Downlink Photonic-Enabled RAU

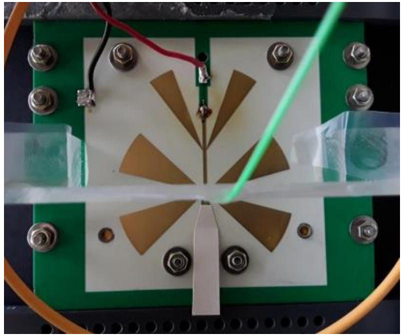
- **Concepts extendable towards more conventional 5G applications**

G. Torfs *et al.*, "ATTO: Wireless Networking at Fiber Speed," in *IEEE Journal of Lightwave Technology*.

PASSIVE DOWNLINK RAUs : DESIGN DETAILS

- Design I
  - Wideband air-filled cavity-backed slot antenna with nearly 100 % efficiency
  - Zero-volt biased photodetector
  - Bulky lumped/distributed matching network





> 10 x extracted power as compared to direct loading

- Design II
  - Similar antenna topology
  - Ultra-compact matching network through dedicated co-design
  - Similar performance

	Footprint (A) [$\lambda \times \lambda$]	-3 dB Gain Bandwidth [GHz]	Boresight gain at f_c* [dBi] (*normalized w.r.t. SE as in [4])	E/H-Plane HPBW at f_c [°]
Design I	1.19×0.66	3.27–3.75 (3.25–3.74)	10.8 (10.2)	150/55 (105/56)
Design II	0.84×0.41	4.98–6.00 (5.07–5.91)	10.5 (10.3)	117/62 (102/68)

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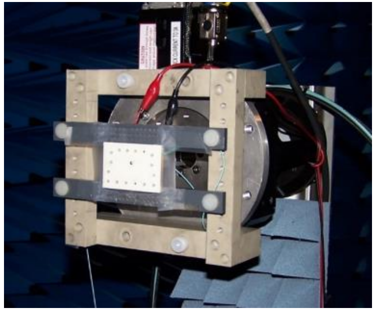

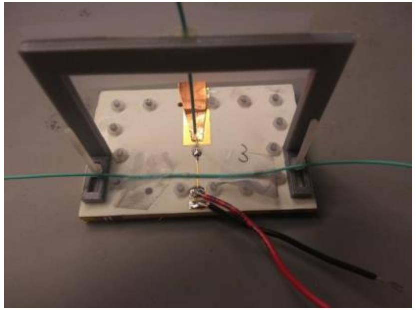

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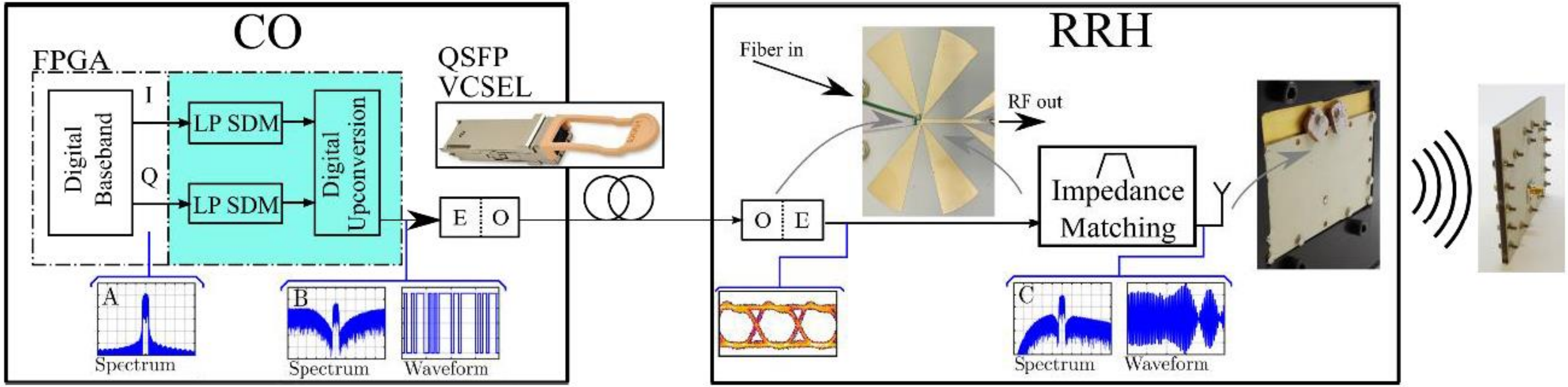
RAU DESIGN 1 : SHORT-RANGE >1 Gb/s SDROF-BASED WIRELESS LINK



RAU Design 1

- FPGA-based sigma-delta modulator
- Fully passive optoelectronic conversion
- Matching network & antenna filter quantization noise
- Sigma-delta modulator robust to non-linear distortion of zero-bias photodiode

H. Li *et al.*, "Sigma-delta radio-over-fiber with passive opto-antenna for low-power short-reach optical-wireless downlink," 2018 Symposium IEEE Photonics Society Benelux, Brussels, Belgium, 2018, pp. 120–123.
H. Li *et al.*, "A 21-GS/s Single-Bit Second-Order Delta–Sigma Modulator for FPGAs," in *IEEE Transactions on Circuits and Systems II: Express Briefs.*

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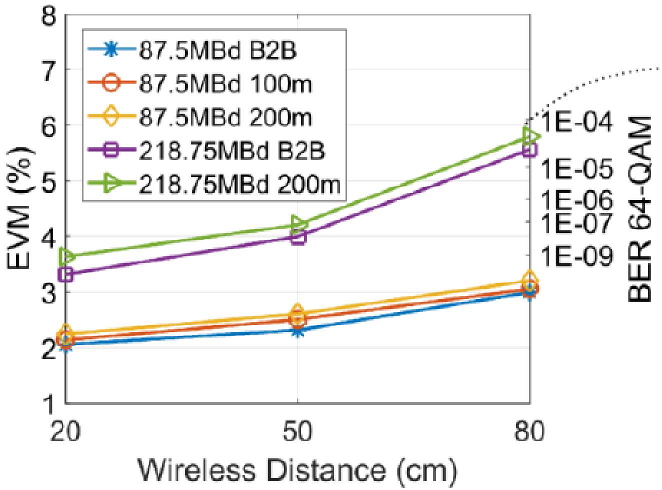

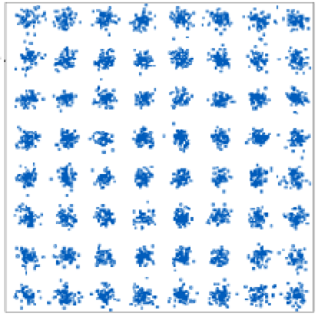

200 m OM4 MMF
80 cm wireless
218.75 MBd 5.8% EVM

- Data rate of 1.3 Gb/s over 80 cm of wireless propagation / 200 m of multi-mode fiber

→ Ultra-low cost, low-power solution for short-reach wireless applications

H. Li *et al.*, "Sigma-delta radio-over-fiber with passive opto-antenna for low-power short-reach optical-wireless downlink," 2018 Symposium IEEE Photonics Society Benelux, Brussels, Belgium, 2018, pp. 120–123.
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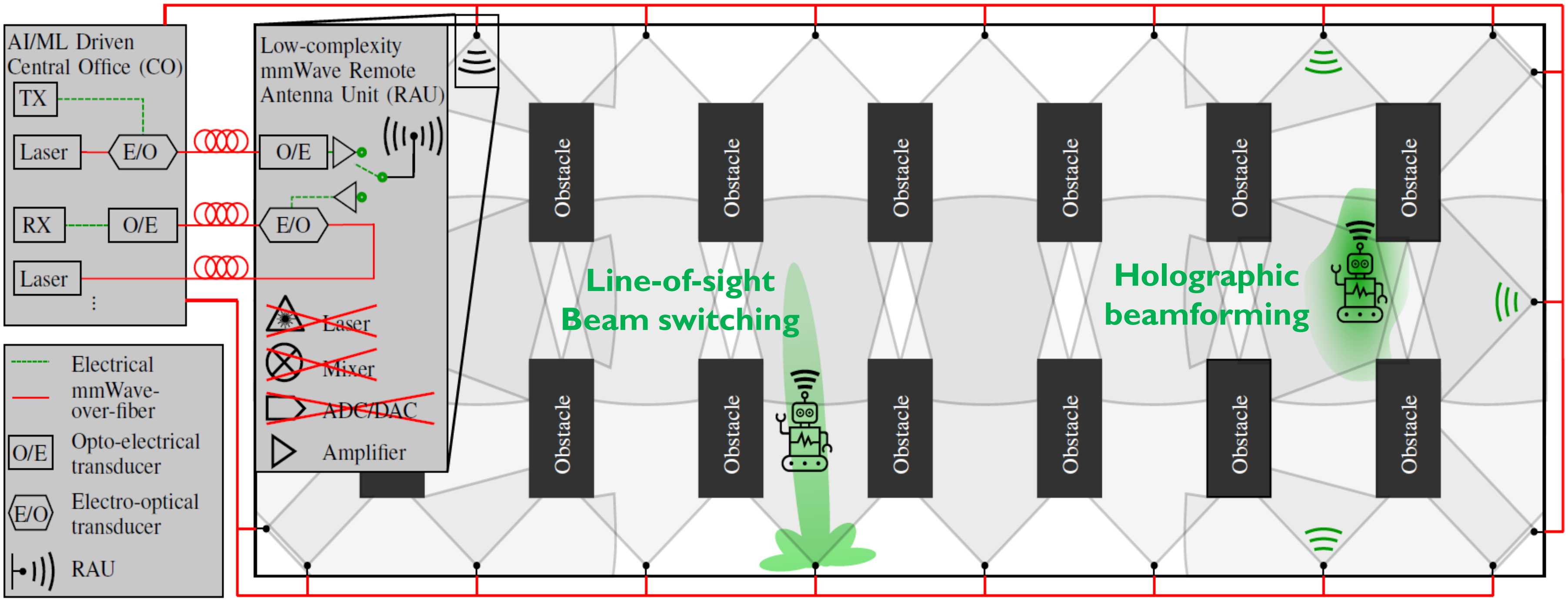
DISTRIBUTED ANTENNA SYSTEMS BASED ON MMWAVE-OVER-FIBER

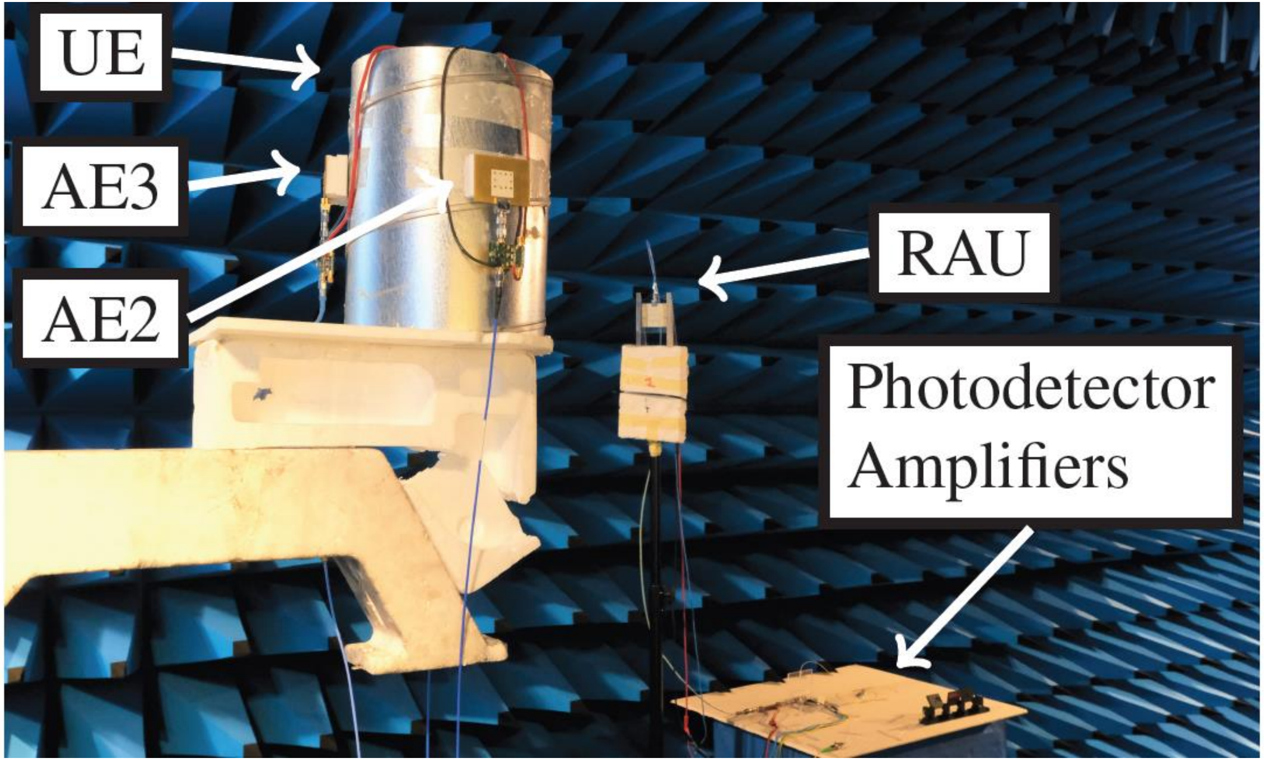
MMWAVE-OVER-FIBER DISTRIBUTED ANTENNA SYSTEM (DAS)



Methusalem Grant "SHAPE: Next Generation Wireless Networks,"
(https://www.ugent.be/ea/idlab/en/news-events/news/piet-demeester-methusalem-funding-shape.htm)

A. Moerman *et al.*, "Beyond 5G Without Obstacles: mmWave-over-Fiber Distributed Antenna Systems," in *IEEE Communications Magazine.*

LINK EXPERIMENTS IN ANECHOIC CHAMBER

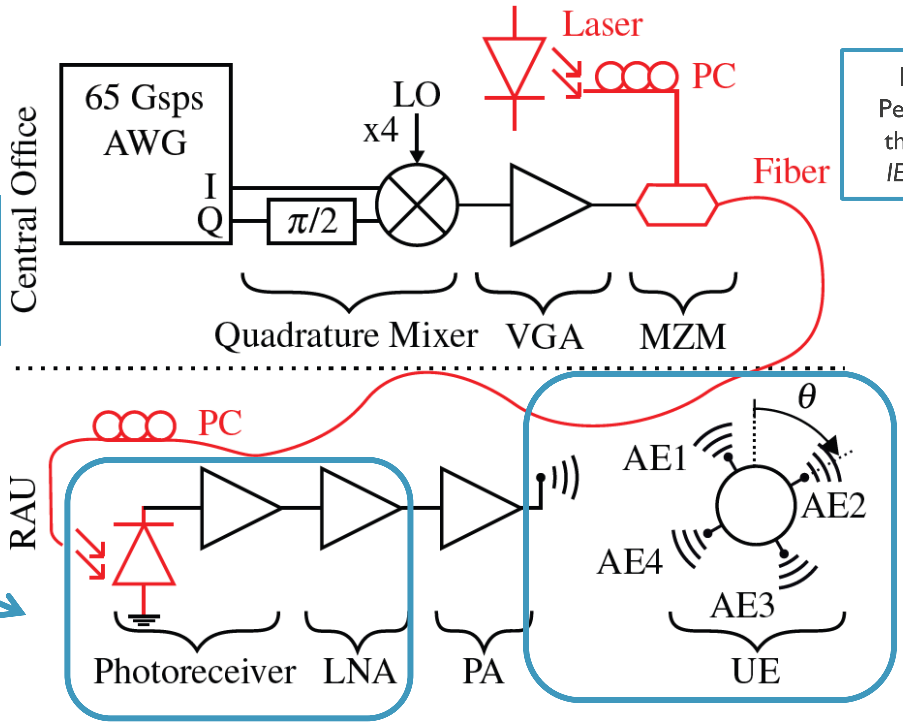


Rotating metallic robot with 4 x 90° spaced antenna elements (AEs) and strategically positioned RAUs

A. Moerman *et al.*, "Beyond 5G Without Obstacles: mmWave-over-Fiber Distributed Antenna Systems," in *IEEE Communications Magazine.*

LINK EXPERIMENTS IN ANECHOIC CHAMBER

L. Bogaert *et al.*, "36 Gb/s Narrowband photoreceiver for mmWave analog radio-over-fiber," in *IEEE Journal of Lightwave Technology*.



I. Lima de Paula *et al.*, "Cost-Effective High-Performance Air-Filled SIW Antenna Array for the Global 5G 26 GHz and 28 GHz Bands," in *IEEE Antennas and Wireless Propagation Letters.*

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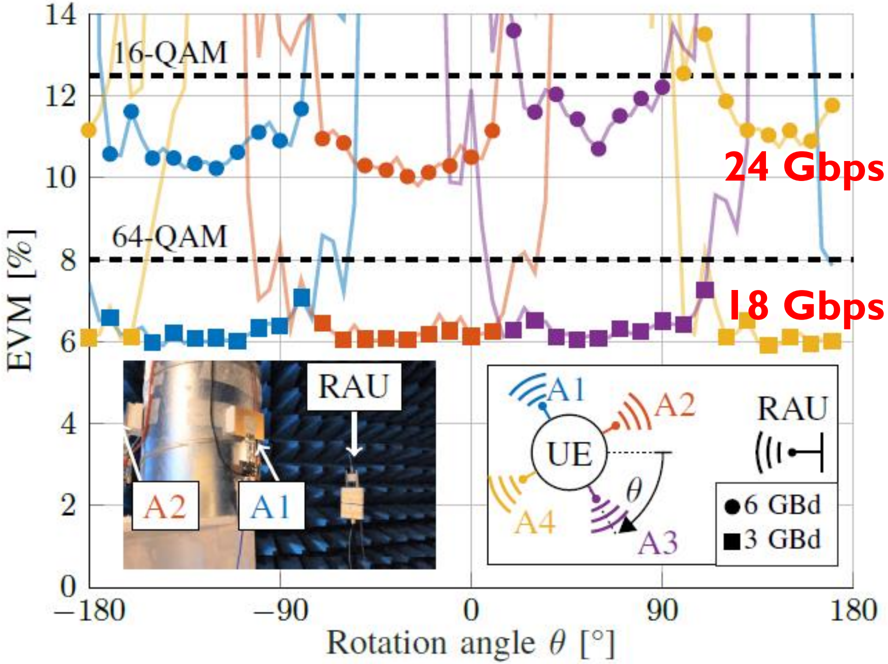
LINK EXPERIMENTS IN ANECHOIC CHAMBER

- Main conclusions
  1. Self-blocking solved by
     - user equipment (UE) spatial diversity
     - distributed antenna system (DAS)
  2. Line-of-sight blockage solved by DAS
  3. Data rate boosted by DAS



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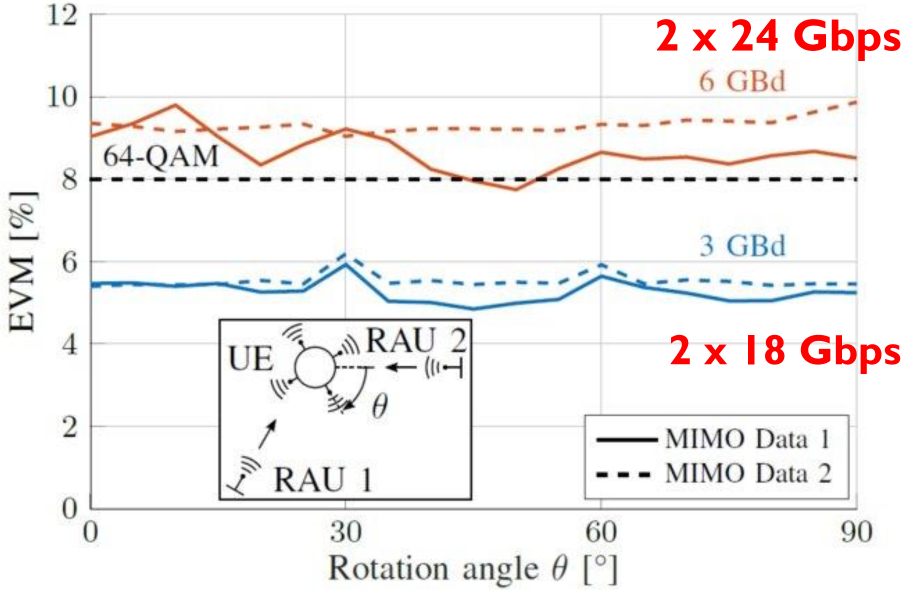
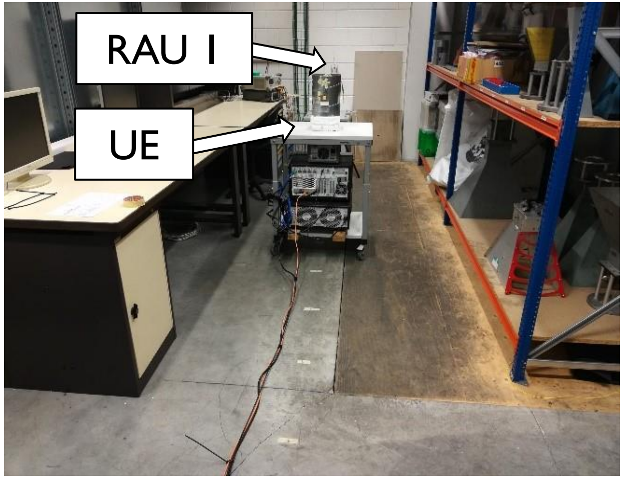
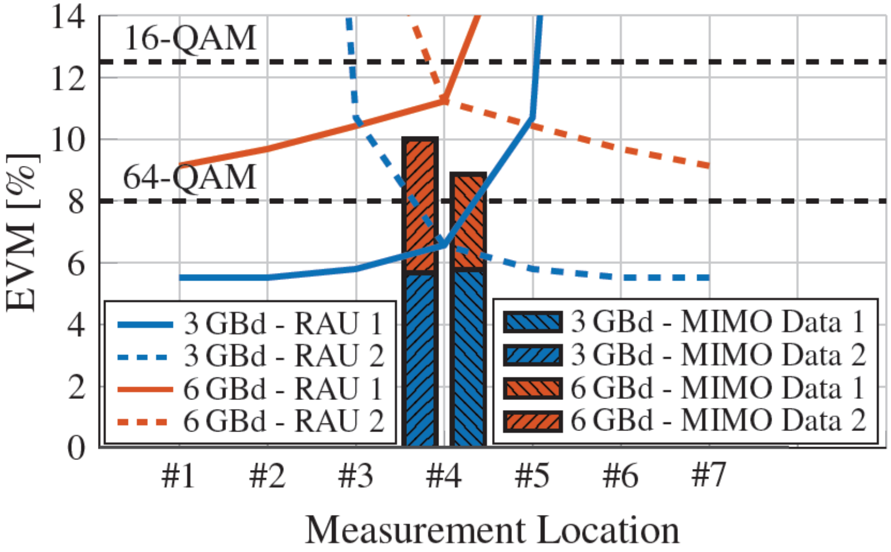


LINK EXPERIMENTS IN REALISTIC ENVIRONMENT

- Two fixed RAUs
- UE placed on 7 locations
- Metal racks obstruct LoS

1. Line-of-sight blockage solved by DAS
2. Data rate boosted to 36/48 Gbps by DAS at location #4





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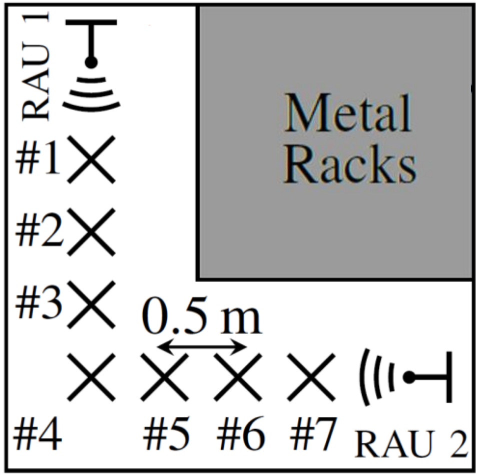

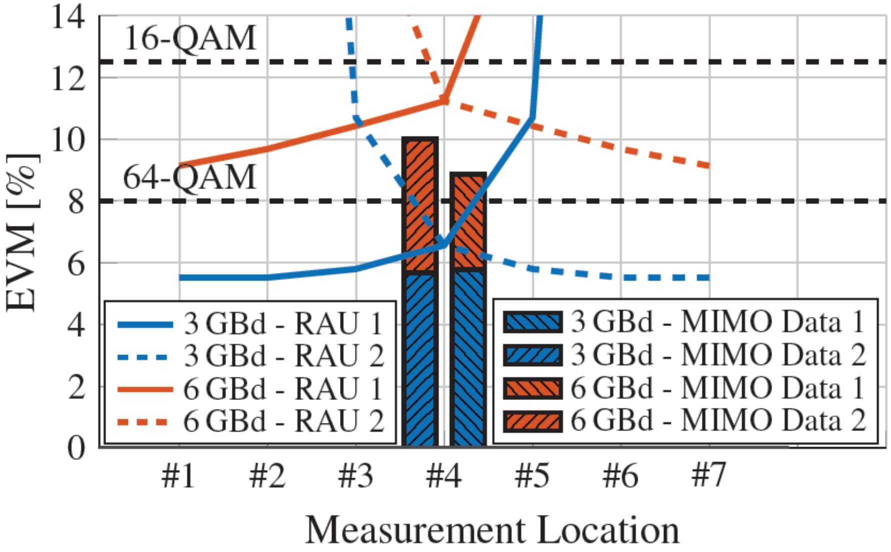

CONCLUSION

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- Radio-over-Fiber : key technology for (beyond-)5G
  - → Efficient routing of wideband signals to realize large-scale multi-antenna systems
  - → mmWave distributed antenna systems
  - → Analog and Sigma-Delta types
- Ultra-low cost, low-power RAUs for short-reach wireless applications
- mmWave-over-fiber DAS unlocks reliable mmWave coverage

embracing a better life

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