# High-Speed Optical Wireless Communication by Narrow Infrared Beams

**Ton Koonen, Ketemaw Mekonnen, Zizheng Cao, Frans Huijskens, Ngoc-Quan Pham, Eduward Tangdiongga**

*IPI, ECO group*
*Eindhoven University of Technology*

**OWCC2020, Eindhoven, Mon. Oct. 5, 2020**
**Invited paper**

Institute for Photonic Integration
Materials · Devices · Systems

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

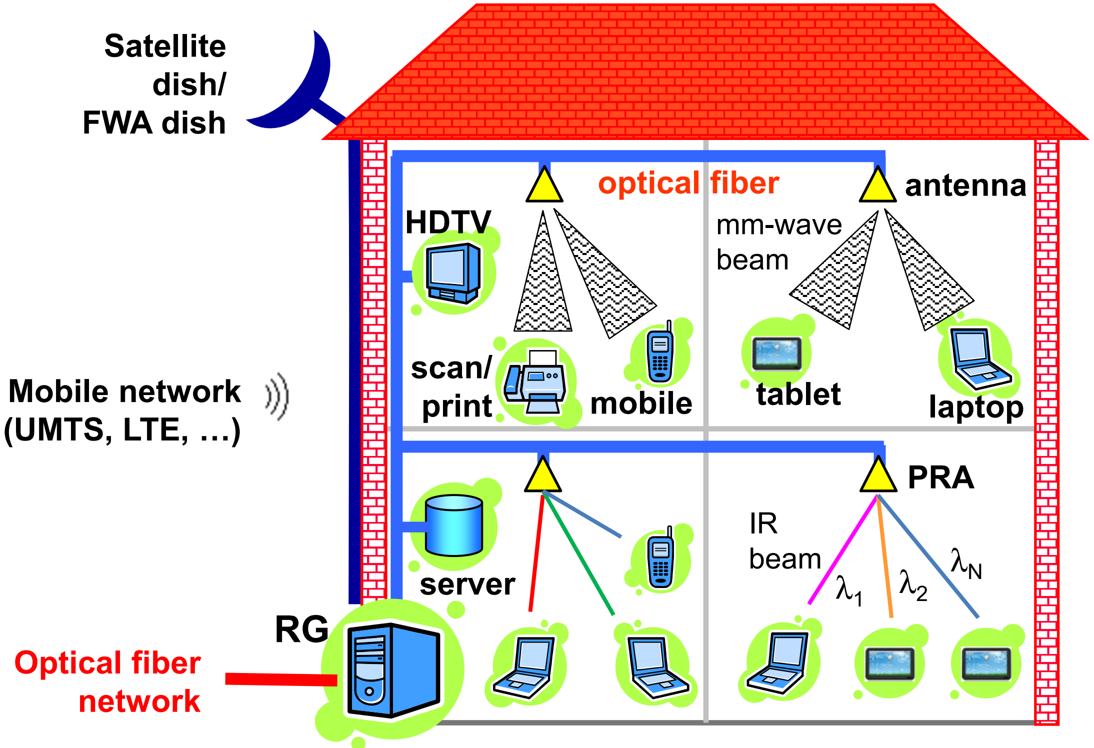
# Outline



- **Introduction**
  - picocell indoor wireless networks
  - the BROWSE system concept
- **Optical wireless communication with narrow IR beams**
  - $\lambda$-controlled diffractive 2D beam steering
  - user localization using passive retro-reflection
- **Laboratory system demonstrator**
- **Concluding remarks**

# Indoor wireless BB services by steerable beams

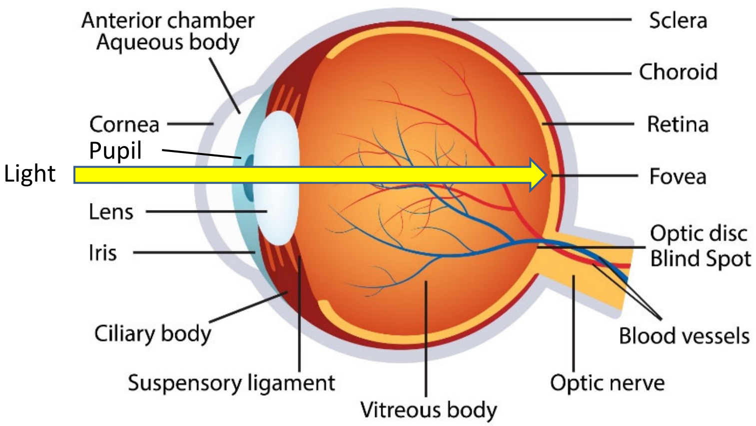
*The most powerful way to increase capacity in a network is by creating smaller cells* [Cooper's Law]




- **narrow beams** → higher user density, higher link budget, better power efficiency, improved privacy/security
- **mm-wave beams:** by phased array antennas
- **narrow optical beams:** by lens collimator
- **optically-controlled steering:** by wavelength tuning

# Eye safety

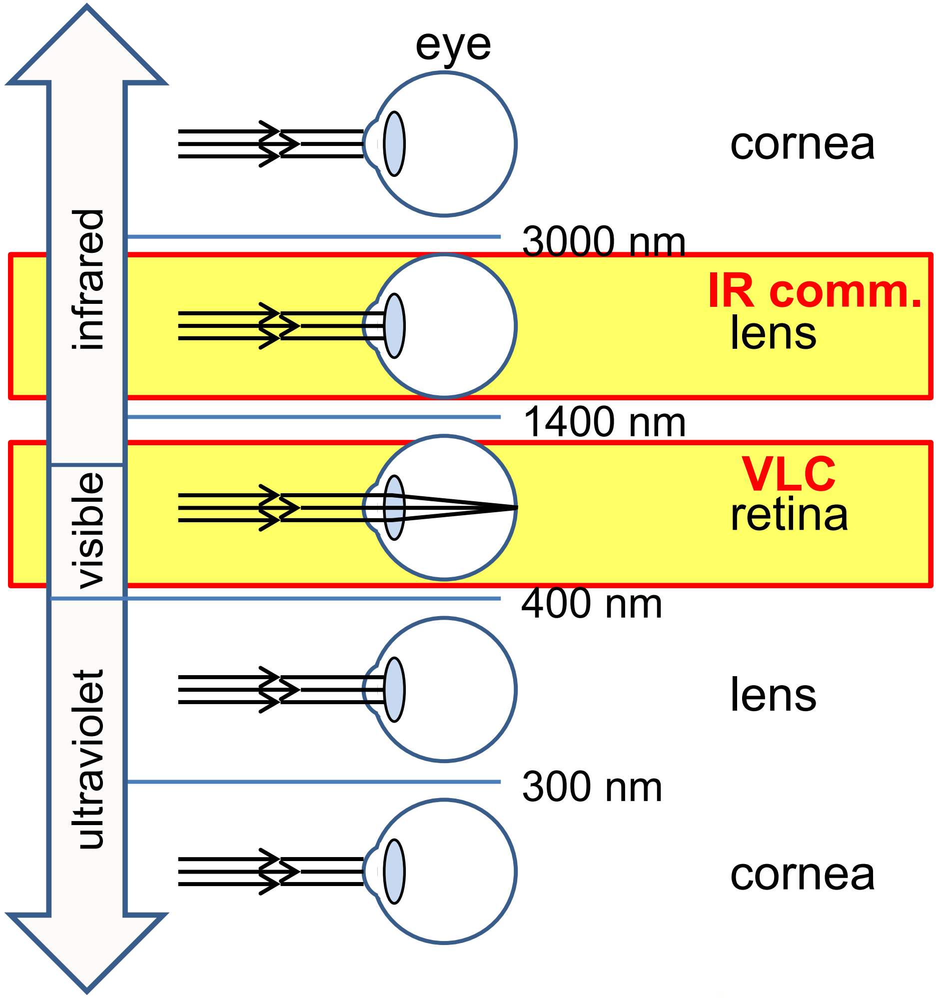





**Eye safety (ANSI Z-136 series and IEC 825 series)**

| | *max. power @ $\lambda$=880nm* | *max. power @ $\lambda$=1550nm* |
|---|---|---|
| Class 1 | <0.5mW | <10mW |
| Class 1M | <2.5mW | <150mW |
| Class 3R | <500mW | <500mW |

**IR Communication vs. VLC:**
- allows higher optical transmit power
- higher photodiode responsitivity (R∝λ)
- less interference from visible light

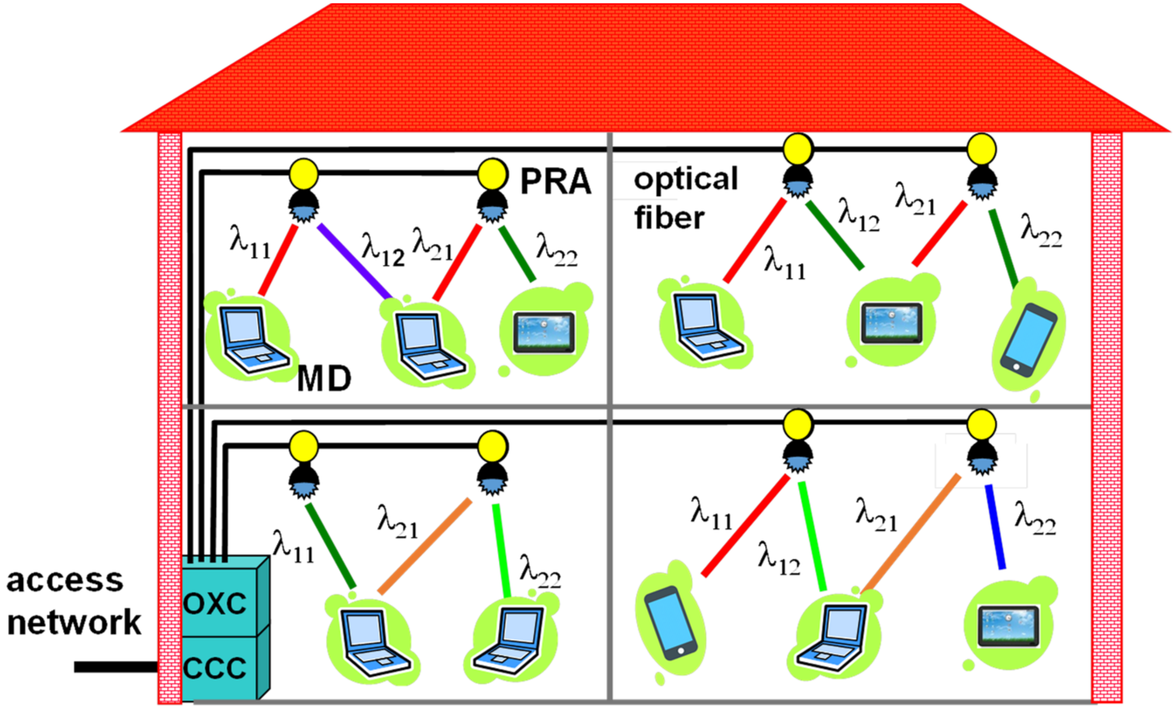



Institute for Photonic Integration

# Breaking wireless barriers: free-space beam-steered optical communication

## BROWSE's system concept:

- **pencil beams** →
  no capacity sharing,
  long reach
- **IR λ>1400nm** →
  $P_{beam}$ up to 10mW
- **passive diffractive beam steerer** →
  no local powering, easily scalable
- **λ-controlled 2D steering** →
  embedded control channel
- **easily scalable** to many beams, just add λ-s
- *target*:
  **≥10Gbit/s per beam**



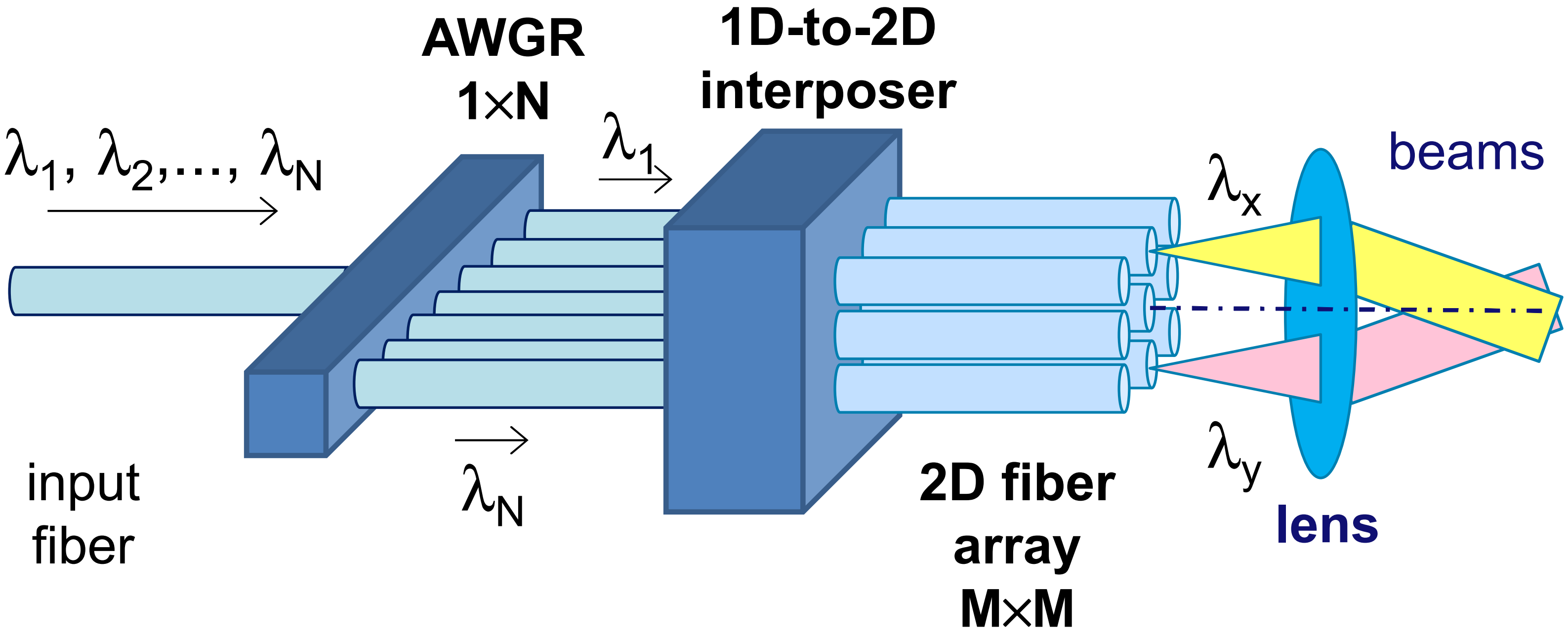

OXC = Optical Crossconnect
CCC = Central Communication Controller
MD = Mobile Device
PRA = Pencil-Radiating Antenna

[Koonen et al, MWP2014]
[Koonen et al., JLT Oct. 2016, JLT May 2018, JLT Oct. 2018, Phil. Trans. Royal Soc. A Mar. 2020]

Institute for Photonic Integration

# 2D steering with high port count Arrayed Waveguide Grating Router

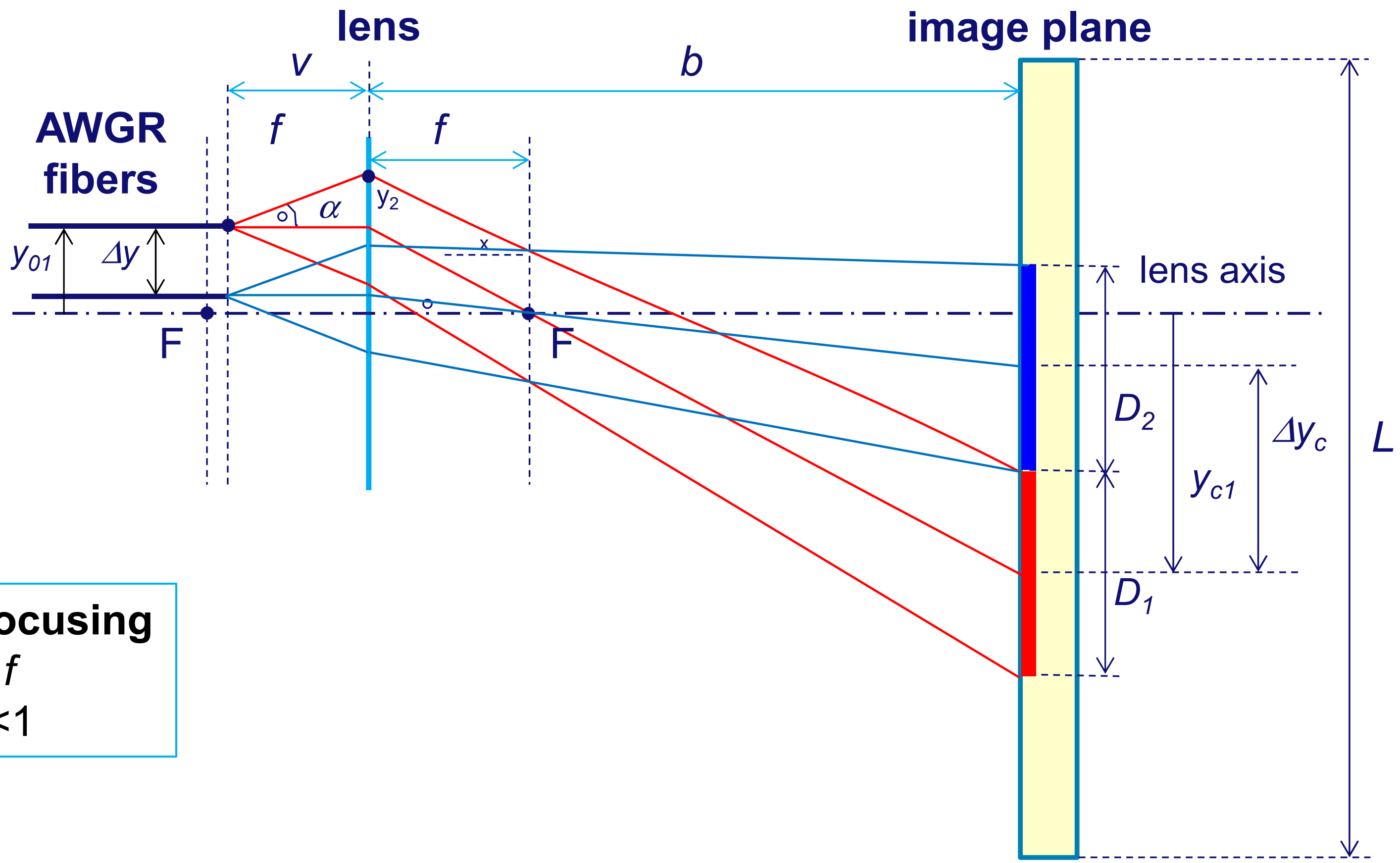





[Koonen et al, Sum. Top. 2016, JLT Oct. 2018]

Institute for Photonic Integration

# Generation of adjacent spots, with defocusing




**Relative defocusing**

$p = 1 - v / f$

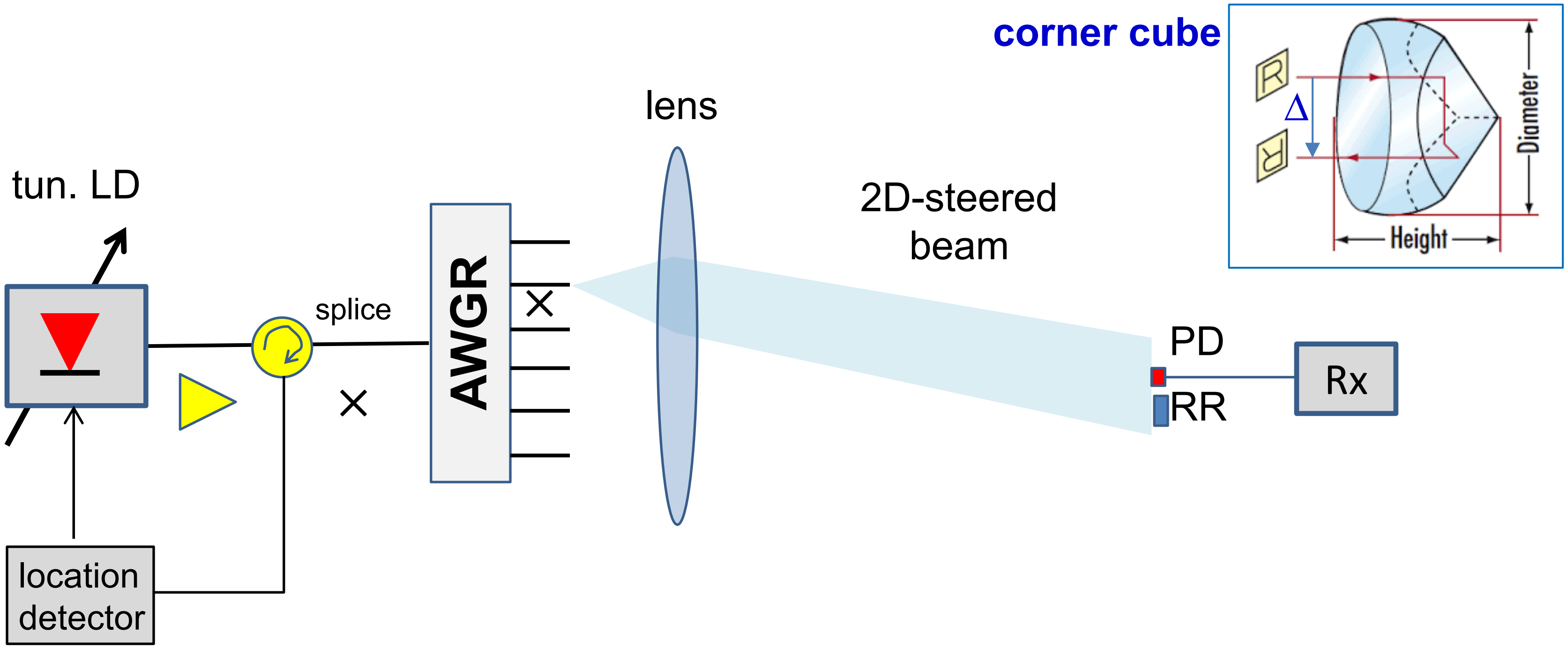
where $0 \leq p < 1$

For given spot diameter, by *defocusing* the required lens' focal length and fiber pitch are reduced → reduces beam steerer size

Institute for Photonic Integration

# Localisation by passive retro-reflector at user device





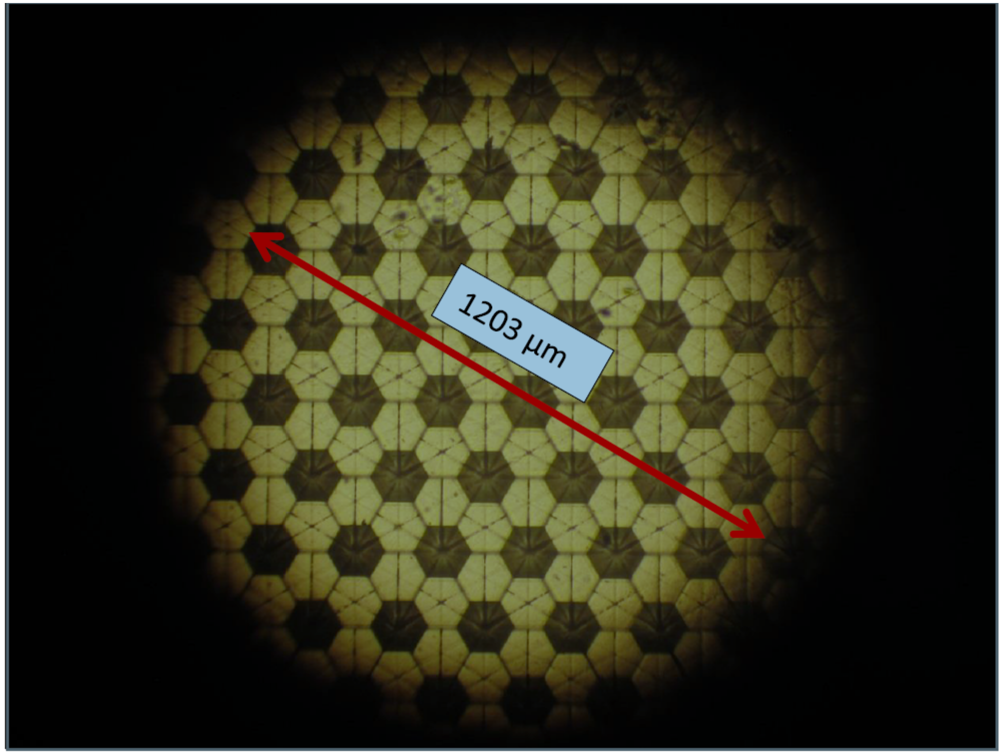

- **RR (e.g. corner cube)** next to PD, such that both are within footprint of same beam
- **Fully passive localisation** means at the user
- Tuning the laser yields scanning the user area with a beam; hitting the device is signalled by detecting the power of the beam returned by the RR

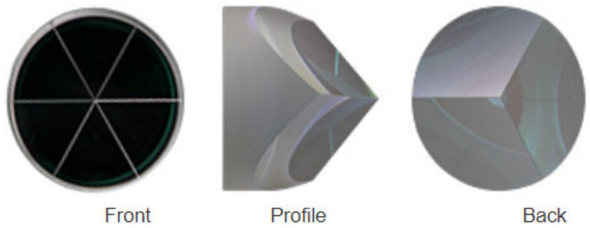
➔ Directly determines the wavelength which corresponds with the lateral position of user's device, **auto-calibrates** position to wavelength.
*Note*: does not determine angular orientation of user device.

[Koonen et al, ECOC 2019, JLT May 2020]

# Array of miniature CC-s, each with aperture *D* =100µm

- miniature CC-s molded in retro-reflecting foil
- cheap, robust
- widely used commercially for e.g. road signage



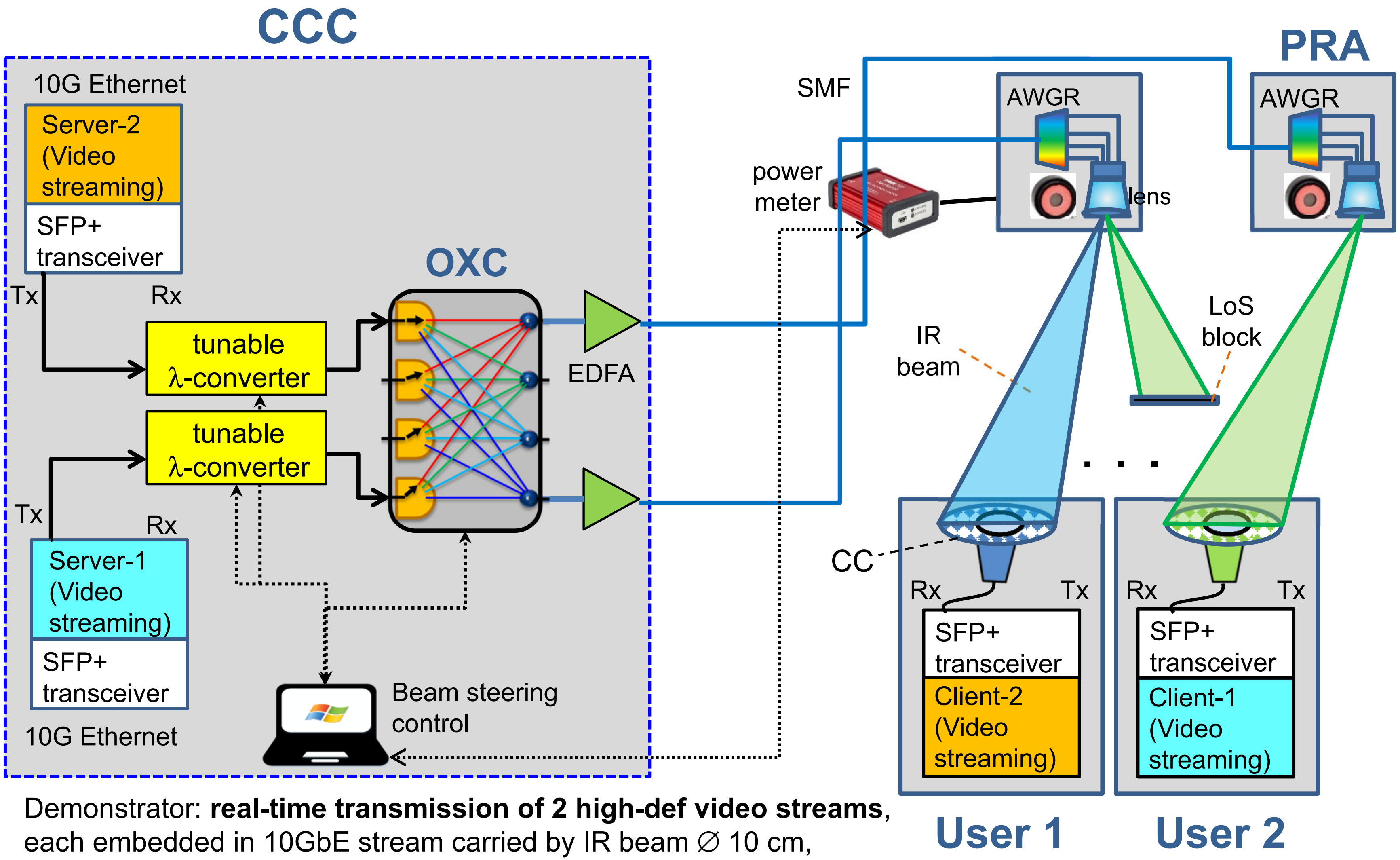




[Thorlabs]

CC retroreflecting foil
(from Orafol)

Institute for Photonic Integration

# Laboratory system demonstrator

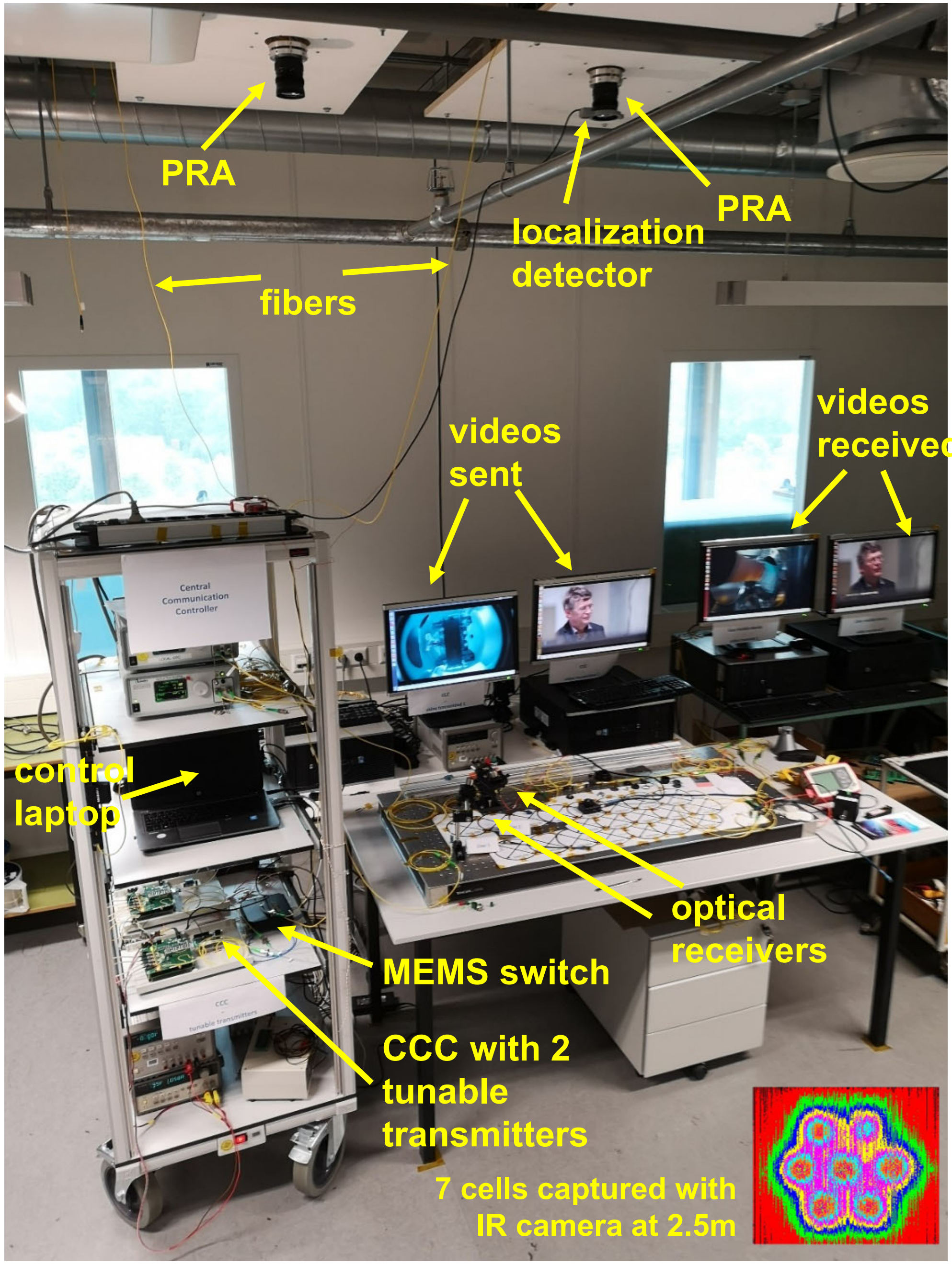



- Demonstrator: **real-time transmission of 2 high-def video streams**, each embedded in 10GbE stream carried by IR beam ∅ 10 cm, beam power ~ 6dBm; reach 2.5m, coverage area per PRA ca. ∅ 1.3 m
- **MEMS OXC**, to extend coverage area, and to circumvent LoS blocking
- **Circular CC foil at user device**, diameter 4 to 5 cm
- Internal reflections inside PRA → use ∅1 cm power detector near PRA's lens

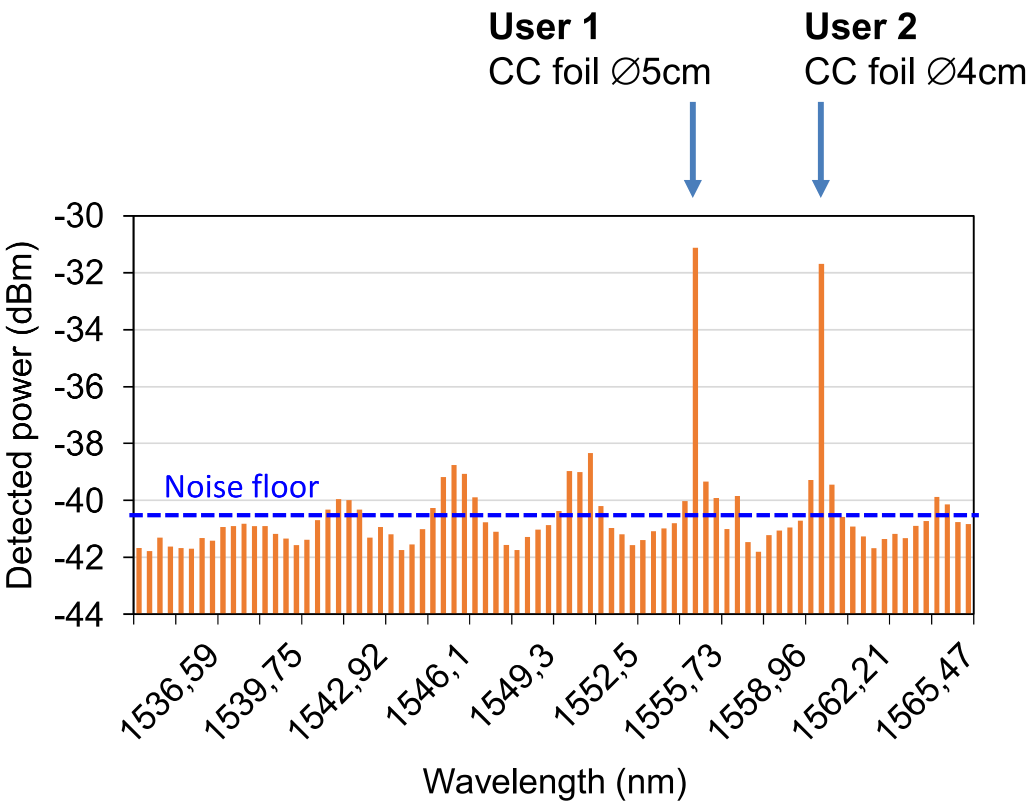
# Lab demonstrator

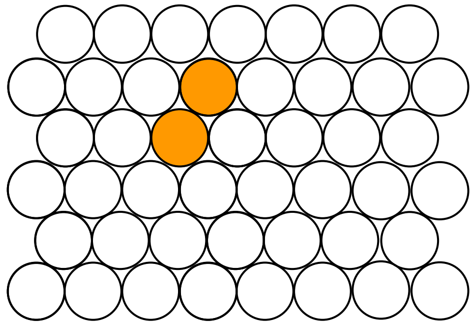
- Transfer of two high-def video streams
  - Real-time
  - Embedded in two 10GbE streams
- Two PRA-s
  - 2D array with 128 fibres
- MEMS switch enabling path diversity for avoiding LoS blocking

European Research Council erc



# Localizing the user device by λ-scanning



scanned cells
with 2 user devices

- Peaks indicate positions of user device, mapped to wavelength
- Scanning whole user area takes 15 sec. (largely consumed by Labview's control software and detected signal acquisition; 115ms/cell × 128 cells)

# Concluding remarks



- Optical technologies greatly support the pico-cell wireless network architectures needed for BB service delivery
- Narrow infrared beams are optimally suited for ultra-high-capacity wireless service delivery
- Wavelength-tuned 2D beam steering and localization for indoor enables multi-Gbit/s service delivery to multiple users individually
- Feasibility of high-def video delivery by10GbE streams featuring path-diversity for LoS blocking avoidance has been demonstrated in our labs

Funding by the European Research Council in the Advanced Grant project BROWSE and Proof-of-Concept project BROWSE+ is gratefully acknowledged, as well as funding by KPN in the Dutch Smart-One program.
Orafol is gratefully acknowledged for providing the miniature corner cube foil.

European Research Council erc

Institute for Photonic Integration

Thank you for your attention!
Any questions?