Short-Range Optical Wireless Communication

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KIVI Engineering Society

Webinar 30 November 2021 on "Recent Advances in Optical Communications"

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Outline

Optical Wireless Communication in The Netherlands

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Ton Koonen

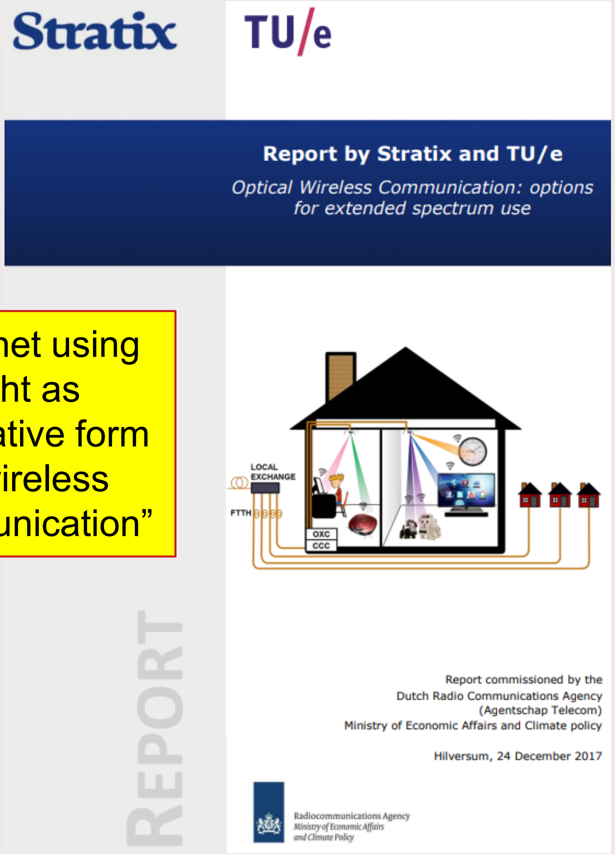
Eduward Tangdiongga

Stratix

Sitse van der Gaast

Henny Xu

"Internet using light as alternative form of wireless communication"



https://www.agentschaptelecom.nl/documenten/rapporten/2018/02/07/onderzoek-lifi

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Motivation

Two major drivers in the telecommunication business

- Wireless traffic has grown faster than Moore's law since 1904
- Spectrum crunch is imminent, telecom growth cannot be accommodated unless
  1. We apply very **dense** spectral reuse in small cells without interference
  2. We find ways to accommodate very **high speeds**

Optical wireless is in an excellent position to solve both due to light <u>small footprints</u> and <u>huge available spectrum.</u>

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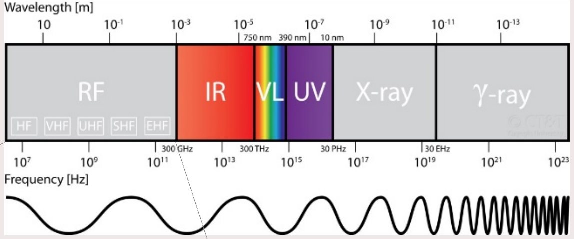
History of Visual-based Communication

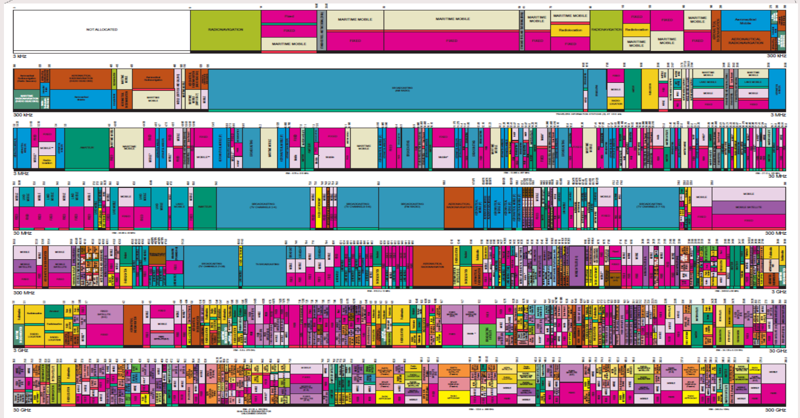
- The use of sunlight:
  Heliograph: information delivery using reflecting mirrors of sunlight

- The use of fire or lamp:
  - Beacon fire
  - Lighthouse
  - Signal lamp for ship-to-ship communication

- OWC or FSO: the use of LEDs and lasers (since 1960) for increasing capacity and ranges, including LiDAR
  - Disappear in 1970's due to introduction of fiber-optics technology
  - Reappear in 2000's for various reasons: higher capacity, lower costs, lower power consumption etc

OWC Advantages and Standardization

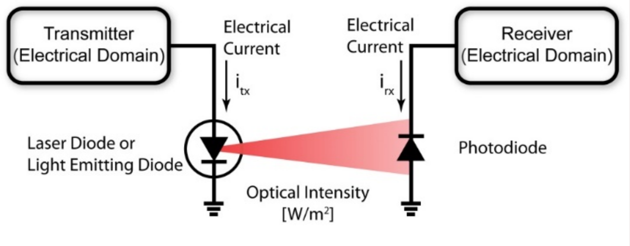




- Large bandwidth capacity per wavelength
- Unregulated spectrum (100’s THz)
- High-degree of spatial confinement
  - High re-use factor
  - Inherent security
- Robustness to EM Interference → can be safely used in RF restricted areas (hospitals, airplanes, spacecraft, industrial areas etc)

- Standardization:
  - ITU-T G.9991: OWC for Home Networking
  - IEEE 802.15.13: Multi-Gbps OWC

OWC Basics

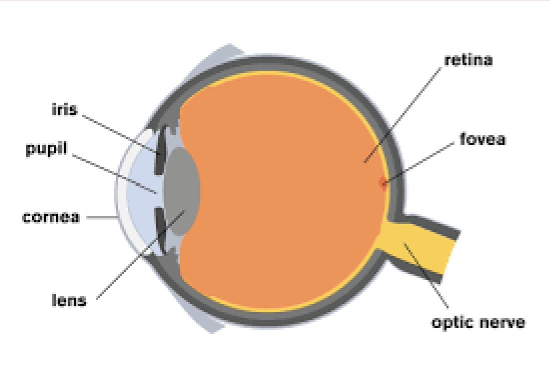


- Transmitter:
  - Baseband processing in electrical domain
  - Electrical-to-Optical Conversion
    - Laser: small Field-of-View (FoV) and restricted to Line of Sight (LoS)
    - LED (large FoV and LoS / non-LoS)

- Receiver
  - Optical-to-Electrical Conversion (Photodetector, Image Sensor or Camera)
  - Baseband processing in electrical domain

- Amplitude constraints
  - Non-negativity of optical signal
  - Eye-safety regulation for light source

Eye Safety and Link Budget



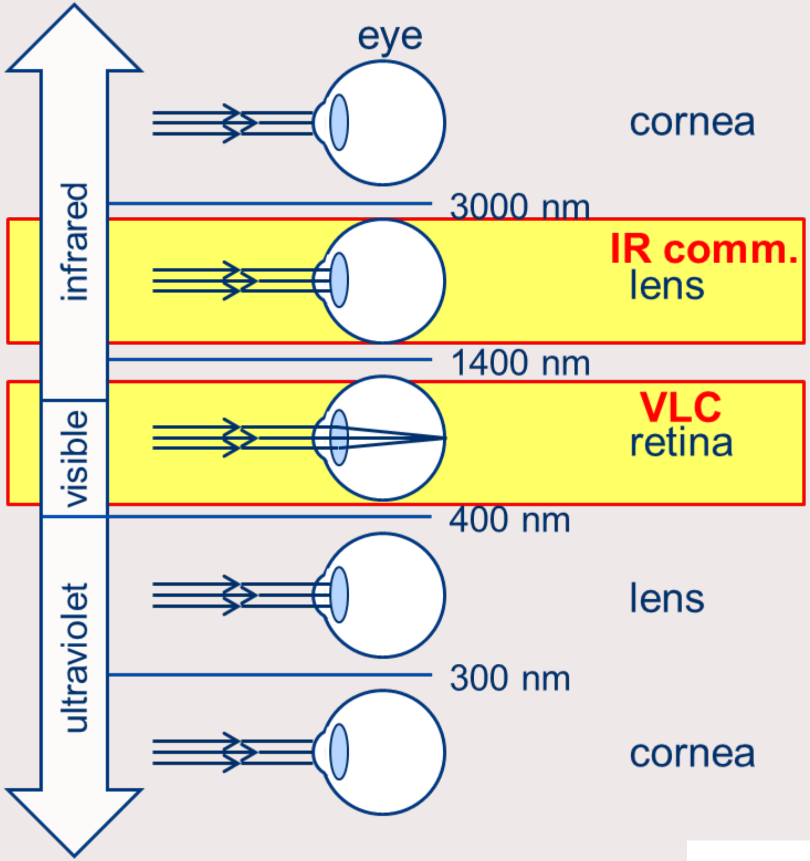
eye safety (ANSI Z-136 series and IEC 825 series)

	max. power @ λ=880nm	max. power @ λ=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 sensitivity
- less interference from ambient light

} Higher Link Budget



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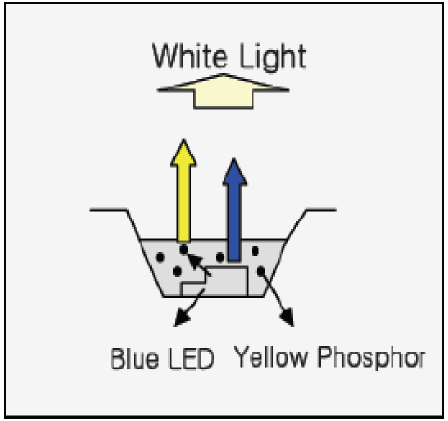
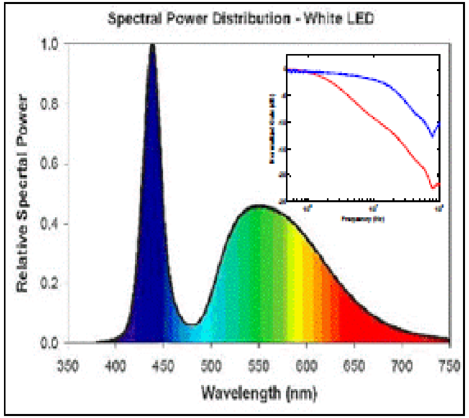
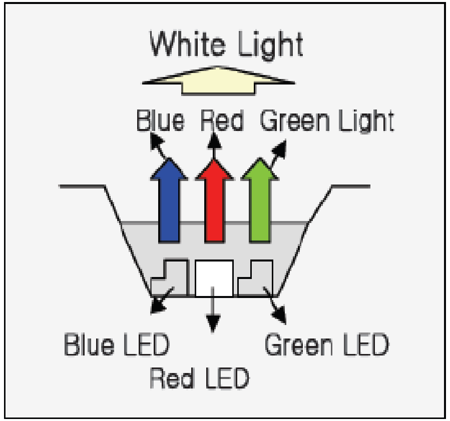
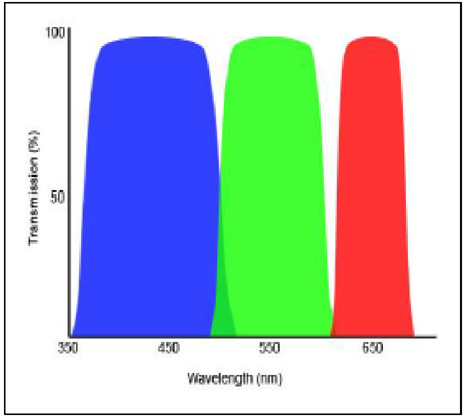
Visible Light Communication / LiFi: LED types









Blue LED + phosphor

- Blue LED is fast (BW≈ 20MHz, EQ 100MHz)
- Phosphor is slow (BW ≈ 2MHz)
- Low cost
- Simple driver
- Use blue filter at Rx
- Lab results <2 Gbps w/ advanced modulation

R+G+B+(Y) LED

- 4x data speed by wavelength multiplexing
- BW ≈ 20MHz per colour
- Higher cost
- More complex driver
- One Rx per colour
- Lab results < 8 Gbps w/ advanced modulation

Jungnickel, IPS Summer Topicals 2016

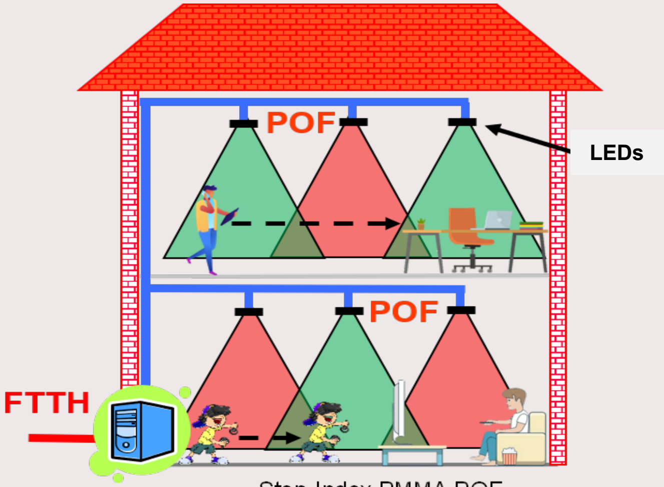
Commercial LiFi Products

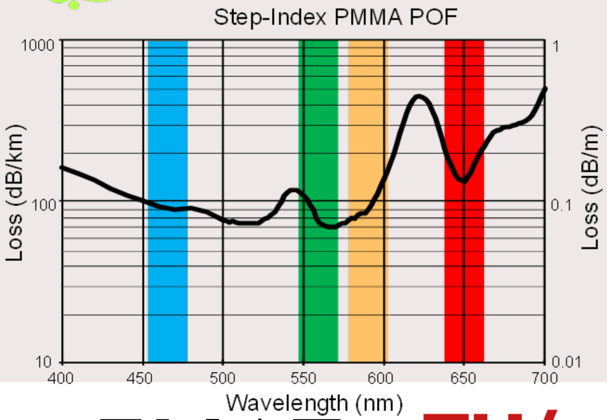
Bidirectional Down- and Upstream <3m
Data rates 250 Mbps – 1 Gbps

WDM-over-POF as front-haul for LiFi

Wavelength Division Multiplexing technique:

- Increase POF throughput: sum of data rate per wavelength
- Create multiple services: different wavelength for different services
- Route services to rooms inside buildings
- Enable Multiple Input Multiple Output (MIMO) technology by assigning each MIMO channel per wavelength for
  - Avoiding blocking and extend coverage areas (**spatial diversity**)
  - Increasing link capacity per user (**spatial multiplexing**)
  - Enabling smooth handover between coverage areas





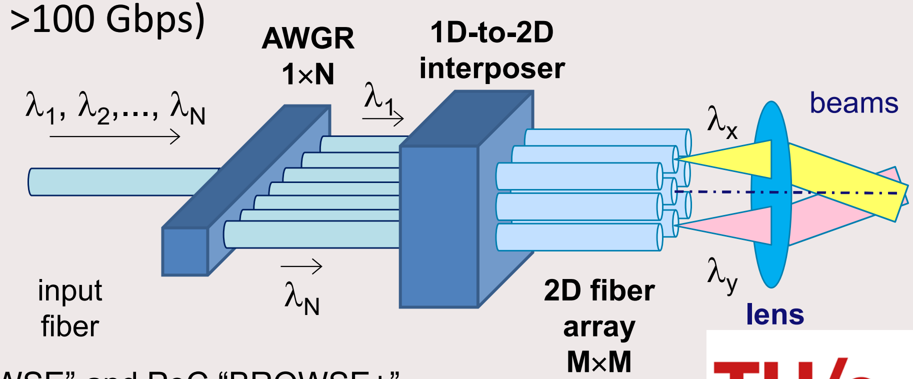
Current LiFi system uses PLC, TP or CAT-5 as front-haul → limited capacity

Next Generation LiFi

Using narrow but steerable optical beams

- Pencil beams from lasers, thus no LEDs
- Each user gets a beam
- Infrared, telecom wavelengths (1400-1700nm)
- Steering: a tunable wavelength laser + gratings
- → each user gets a wavelength channel
- → easy scalable to many beams, just add λs
- Ultra-high throughputs >10 Gbps / beam (Labs shown >100 Gbps)
- Fast and accurate localization technique
- Large aperture and large field-of-view receiver

2D beam steerer @ room's ceiling



European Research Council

Ton Koonen 2012-2019, ERC AdG "BROWSE" and PoC "BROWSE+"

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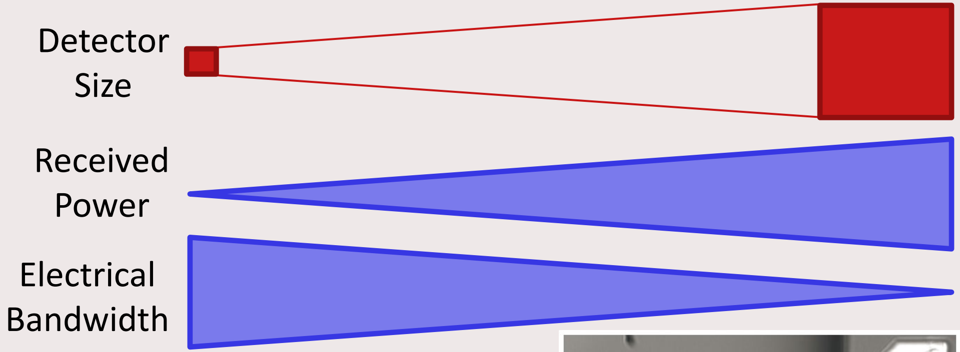
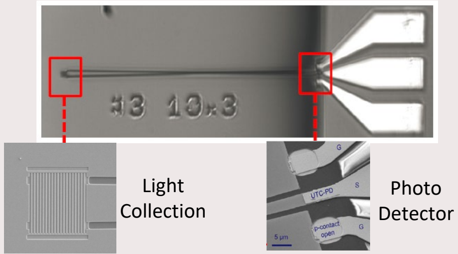
Wireless Receivers

Desired properties: sensitivity, bandwidth, and large Field of View

- Simple form of optical wireless receiver is camera, but limited by frame rate and sensitivity
- Combination between lenses and semiconductor detector forms an optimal solution
  - Lenses for capturing light as much as possible
  - Semiconductor for increasing bandwidth and sensitivity
- Relation between detector size, RF bandwidth and receiver power

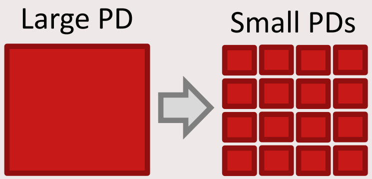


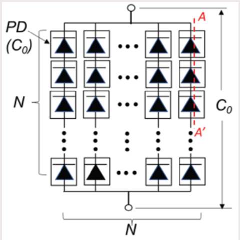
BW 67GHz, full FoV 10°

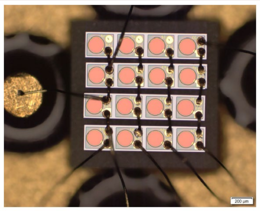


Cao et al, OFC 2017, PDP Th5A.6

Array of PDs in series and parallel connection







- 4×4 Small PDs, each ∅150 µm
- Fresnel lens on top
- Full FoV 20°
- BW 1 GHz, extendable to 10 GHz

Koonen et al, ECOC 2020, Tu2G-6

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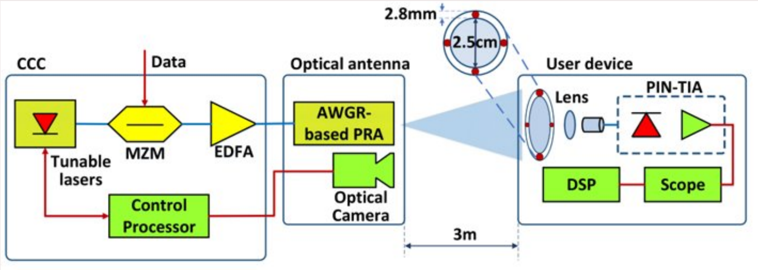
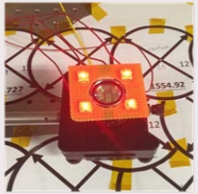
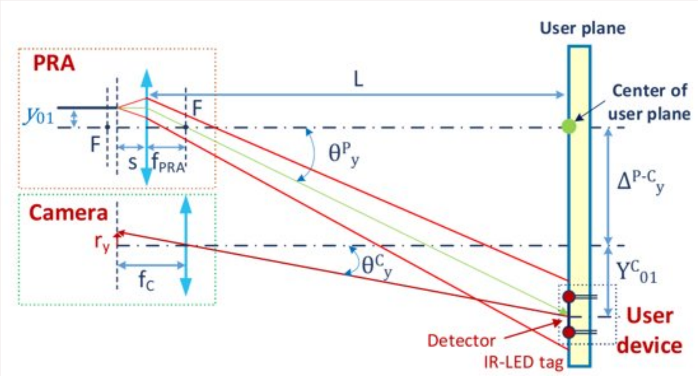
Localization and Tracking Techniques



Tx with camera



Rx with LED tags



$$\theta_y^P = \tan^{-1}\left(\frac{r_y}{f_c} + sign(r_y)\frac{\Delta_y^{P-C}}{L} - \frac{f_{PRA}.r_y}{f_c.L}\right)$$

A camera allows for localization and tracking of multiple users

- Red/Near-IR LED beacon with 4-LEDs tag and a high-speed camera (200 fps)
- Fast localization with the updated rate of 5ms – real-time user localization
- Localization accuracy of 0.02° (<1mm deviation at 3m)
- Upstream signaling of 12 bits/frame (24 kbps) for channel status information

Pham et al, IEEE PTL (33), 11, June 2021

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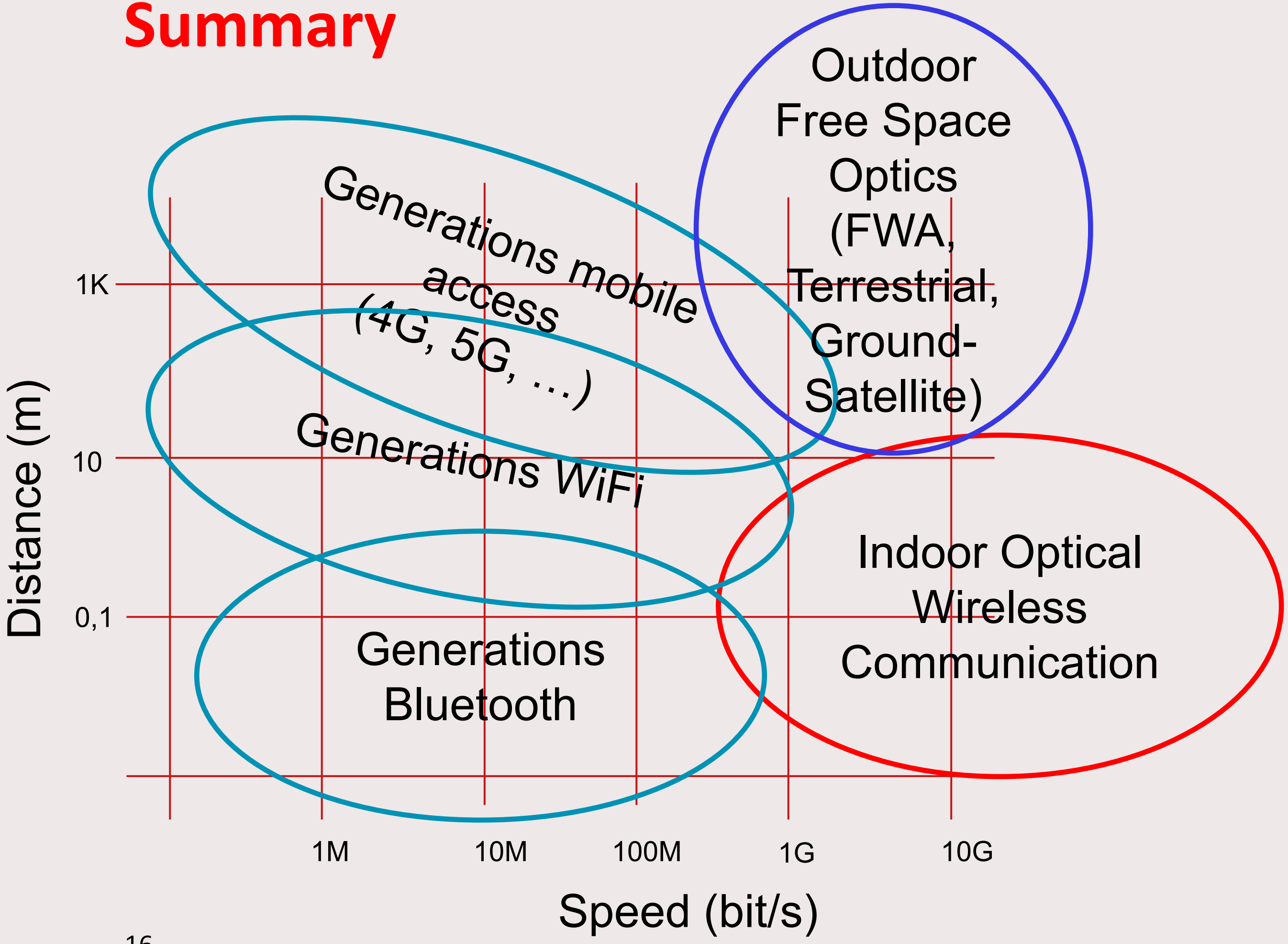
Summary



- OWC is a powerful technology to relieve growing demand for bandwidth
- Labs work has shown >100 Gbps
- OWC can become a valuable addition to existing wireless technologies such as WiFi and Bluetooth in offloading heavy traffic

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Ongoing Works

- KPN SMART Program
- EU H2020 ELIOT “Enhance Lighting for Intenet of Things”
- NWO Perspectief Program (2021-2026)

Optical Wireless Superhighways

Free photons (at home and in space) (P19-13)

Thank you!