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OCRG

# Optical Wireless Communication – Part I – Introduction


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- Why the need for new wireless technologies
- 5G & 6G
  - Applications
- Wireless technologies
- How to overcome spectrum congestion
- Optical wireless communications
  - Innovation timeline
  - Systems in the market
  - Future applications
- Final comments

# Why the need for

New *Wireless*?


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## Context:

SUSTAINABLE DEVELOPMENT GOALS


**The role of ICT**

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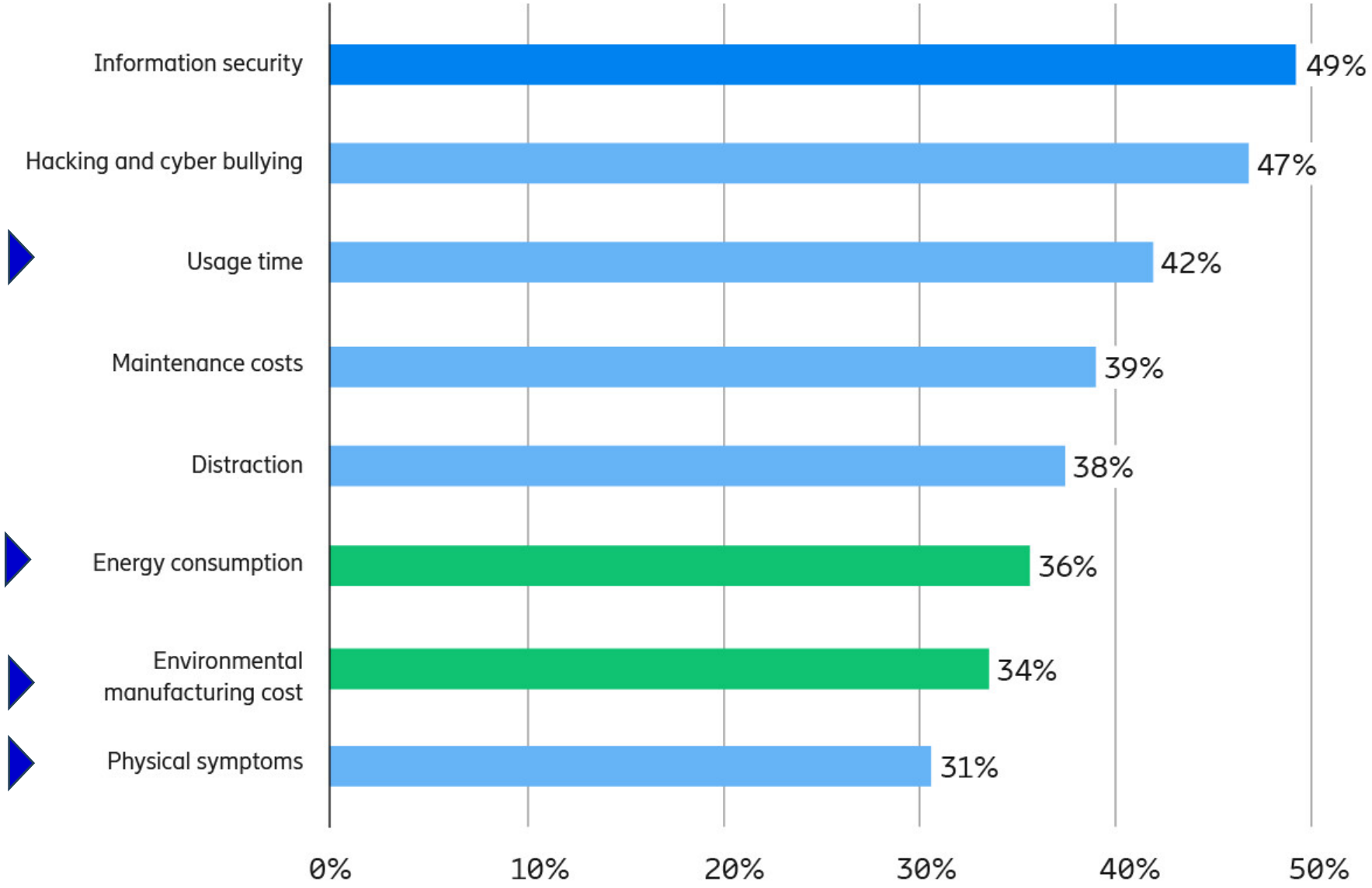
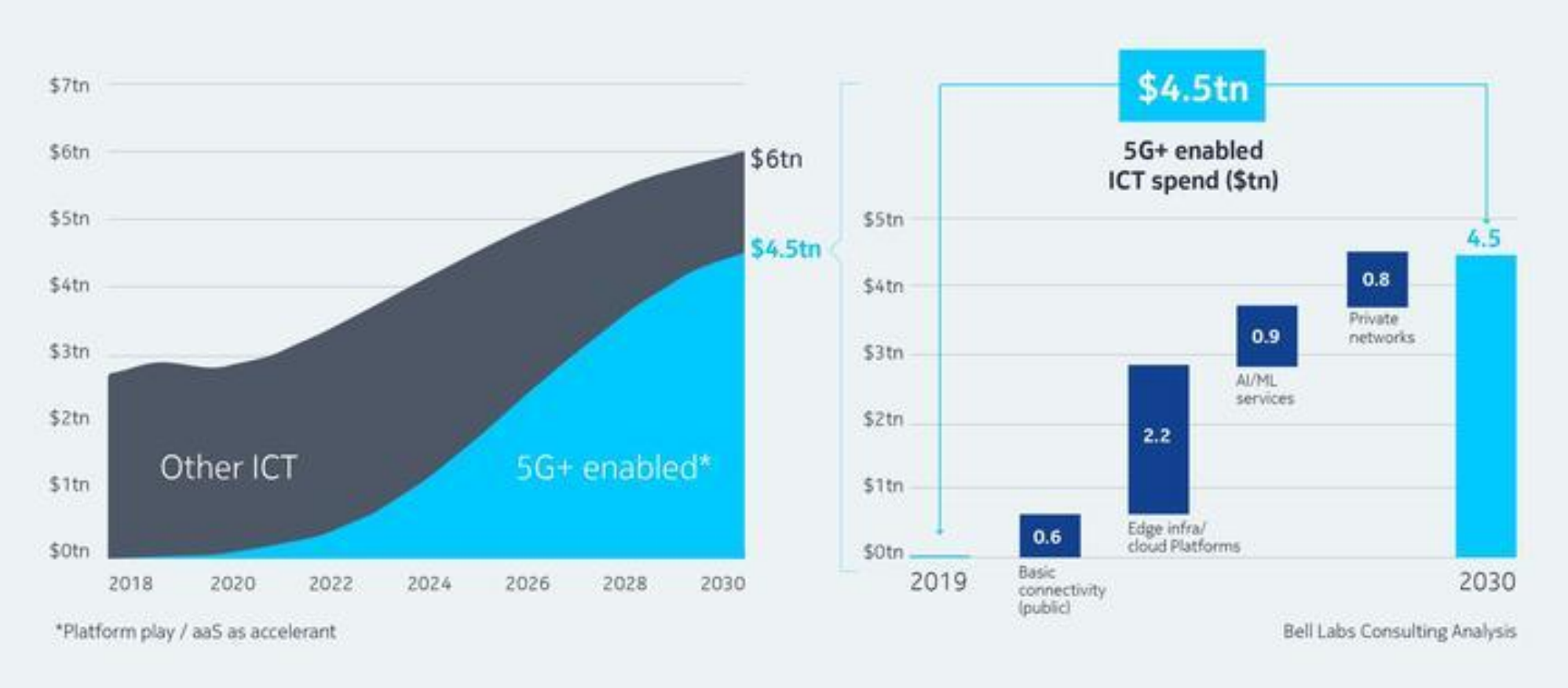
# Context - ICT Sustainability




**Percentage of consumers who express concern for different aspects of their ICT devices**

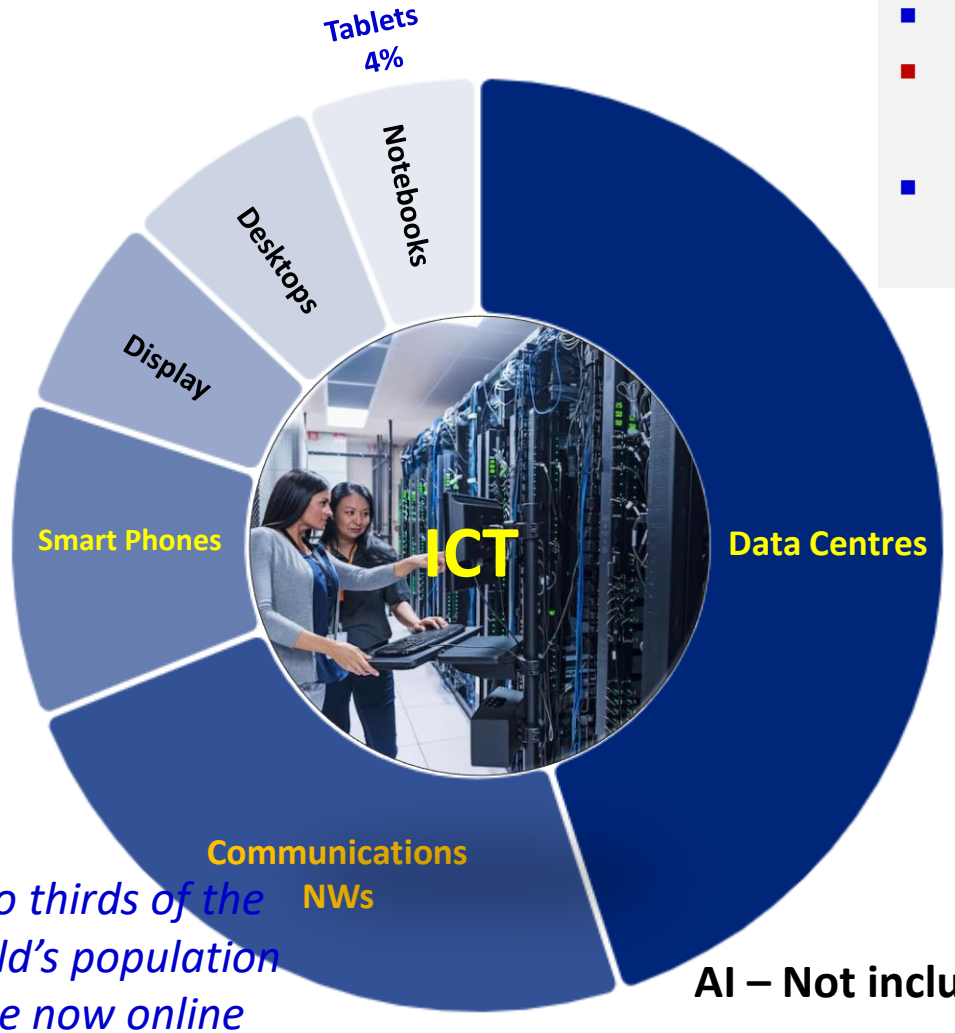
https://www.ericsson.com/en/reports-and-papers/consumerlab/reports/consumers-sustainability-and-ict

# A $4.5 Trillion Industry by 2030




https://www.nokia.com/networks/5g/how-to-monetize-5g-enterprise-markets/?gclid=Cj0KCQiAtJeNBhCVARIsANJUJ2HjRAsylnAd4ca6GOQFCtvzFd3uHK3hIjuDp13uPiqPuxNYVavFmkIaAhraEALw_wcB

# Context - Global data - Carbon Emission

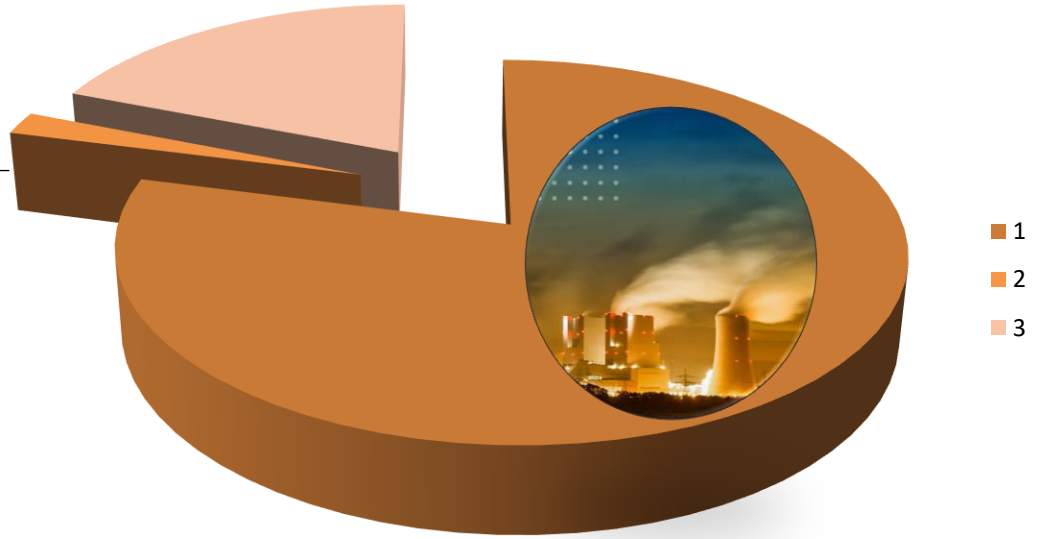



*Two thirds of the world's population are now online*

- **Rising energy consumption by ICT is a growing global concern**
- **E-Waste is the one of, if not the fastest growing waste stream on the planet**
- **Global Energy use from ICT projected to grow from 6% today to around 25% by 2050**

**According to International Telecommunication Union**

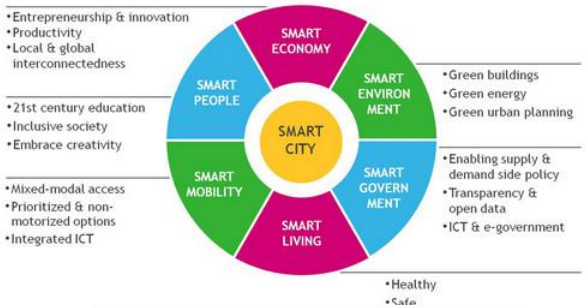
**ICT (4-10%) > aviation industry**

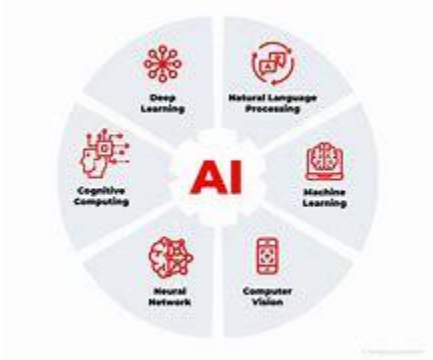



**AI – Not included**

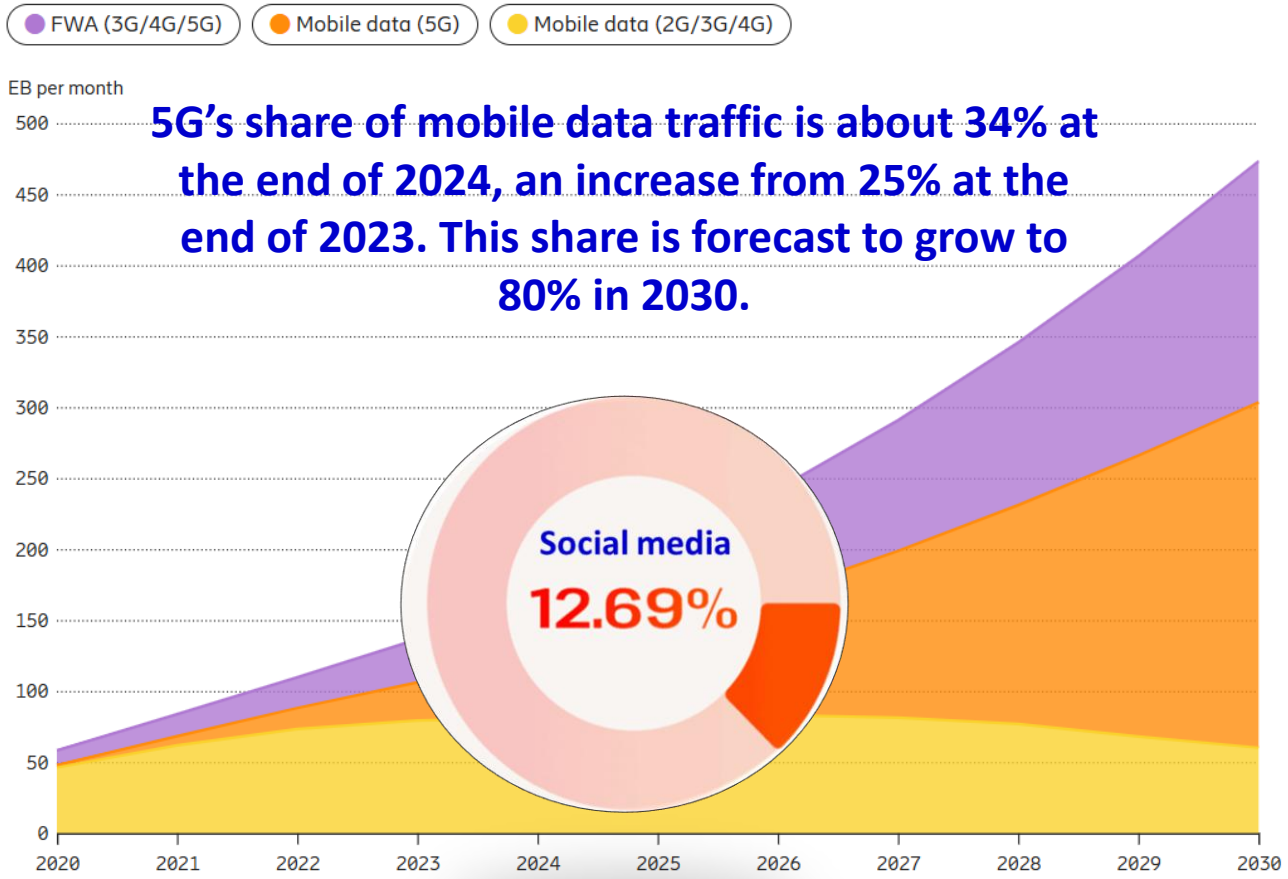
https://public.flourish.studio/visualisation/3038679/?utm_source=showcase&utm_campaign=visualisation/3038679
https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099121223165540890/p17859702a98880540a4b70d57876048abb
https://sustainableict.blog.gov.uk/2023/04/27/why-sustainable-ict-is-vital/

# Context - Global Data








https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/mobile-traffic-forecast





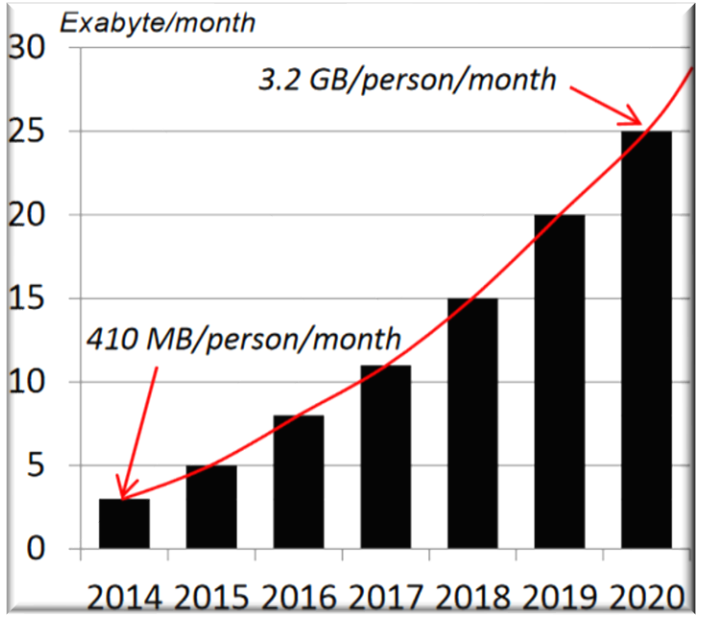
https://www.researchgate.net/figure/Spectral-efficiency-B-90-versus-SNR-considering-PSK-transmit-symbols_fig4_324706796

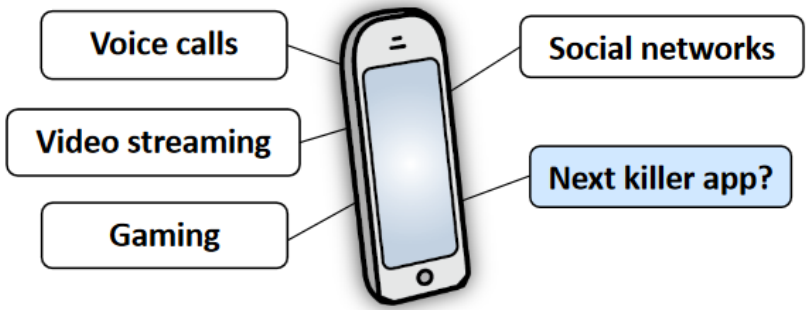
# Success of Wireless Communications

## Martin Cooper's law

*The number of simultaneous voice/data connections has **doubled** every **2.5 years (+32% per year)** since the beginning of wireless*


*Inventor of handheld cellular phones*

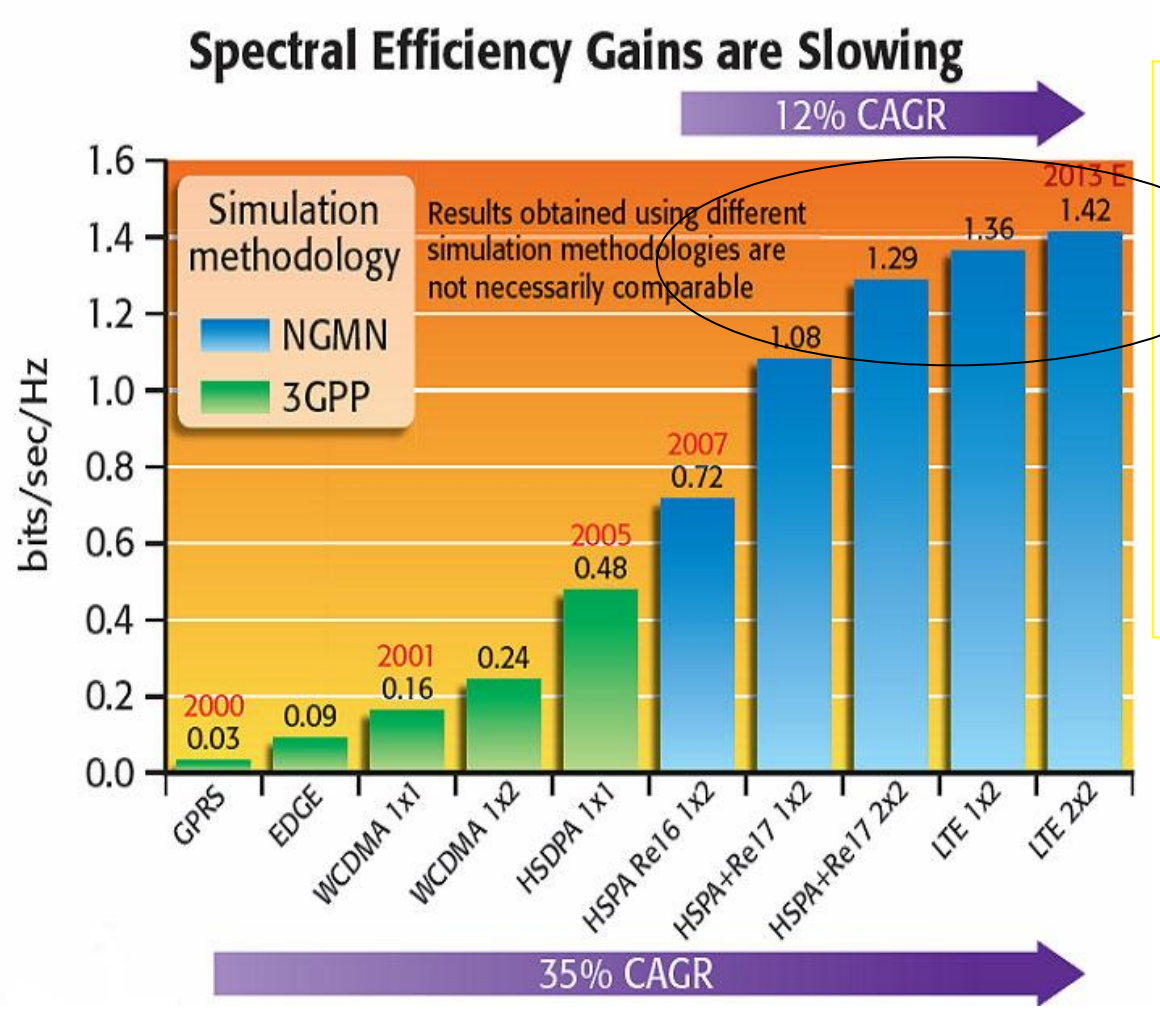


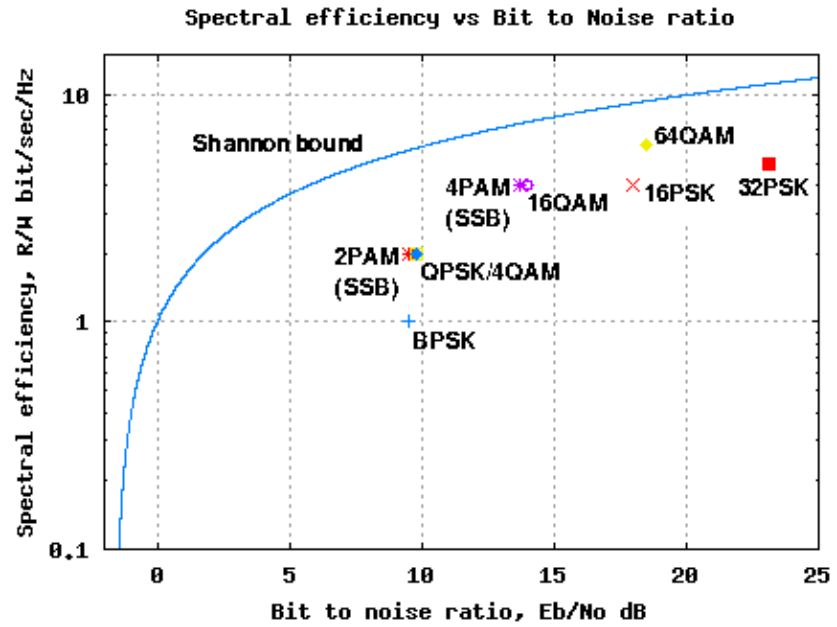

**Network Throughput = Cell density × Available spectrum × Spectrum efficiency**

(bit/s in area) (Cell/area) (Hz) (bits/s/Hz/Cell)

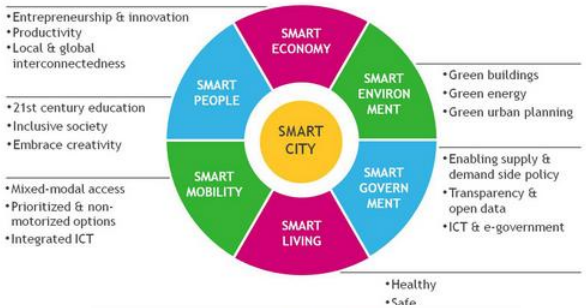
# Spectral Efficiency Slowing Down

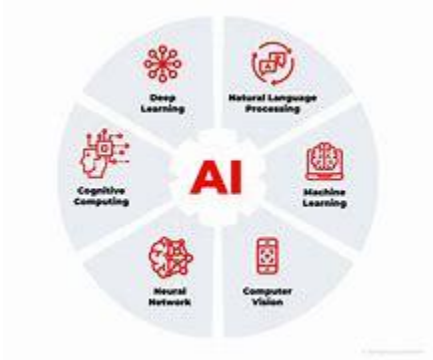



**Saturation of The spectrum efficiency gains of cellular systems**

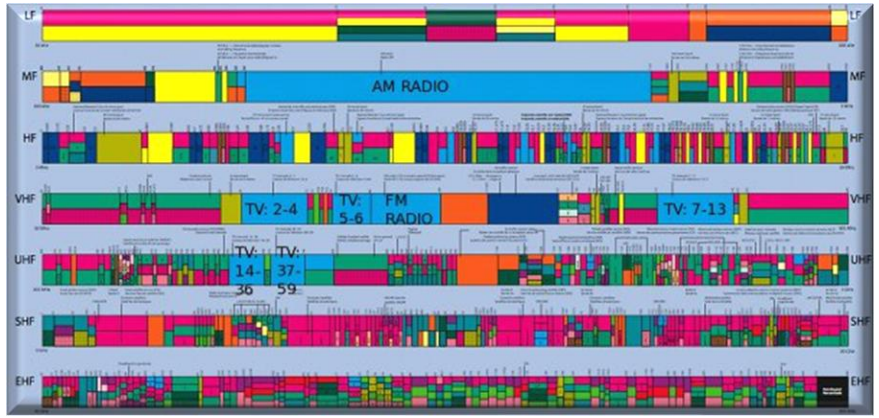


# Global Data Traffic - So What Is the Real Problem?



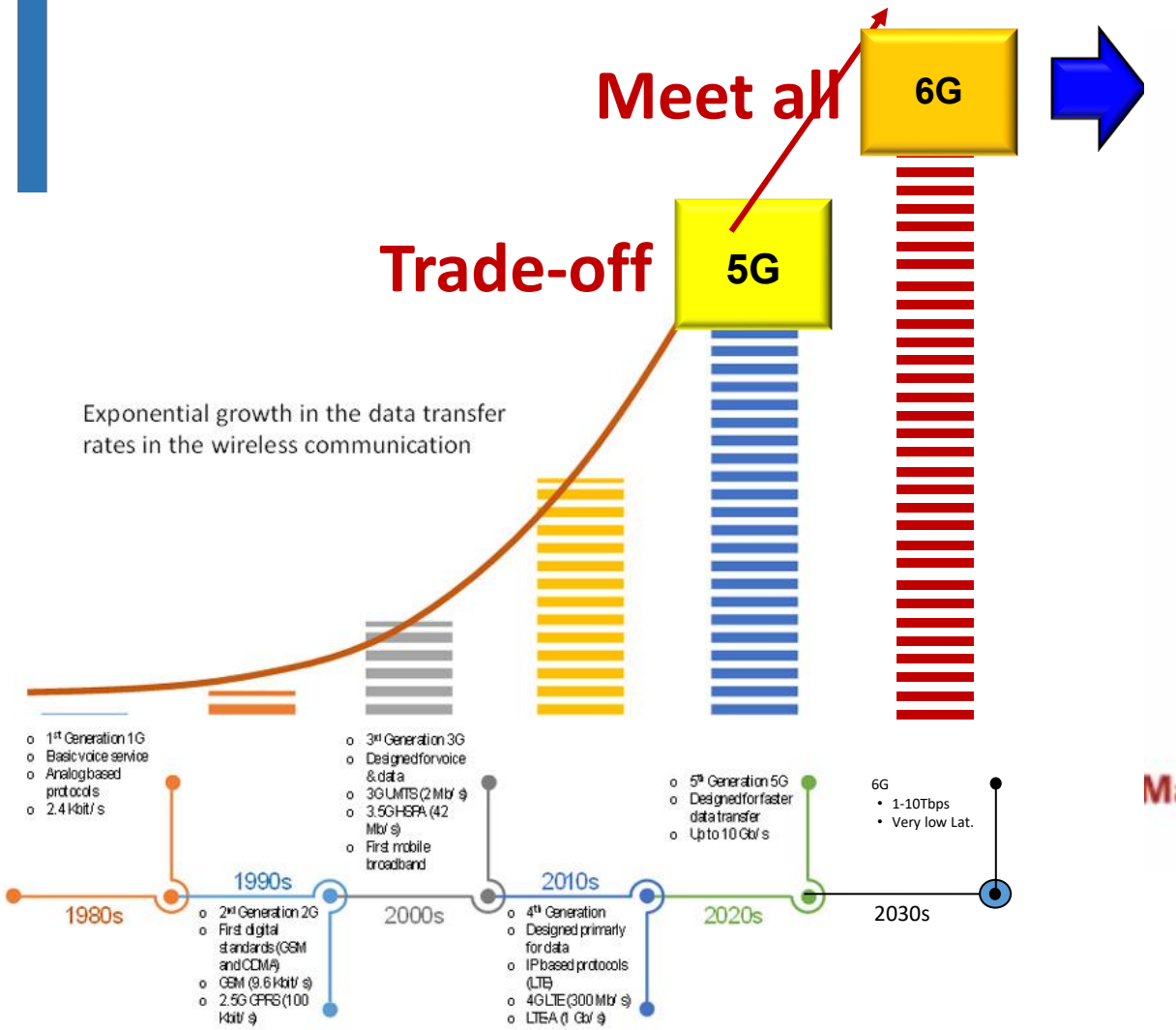



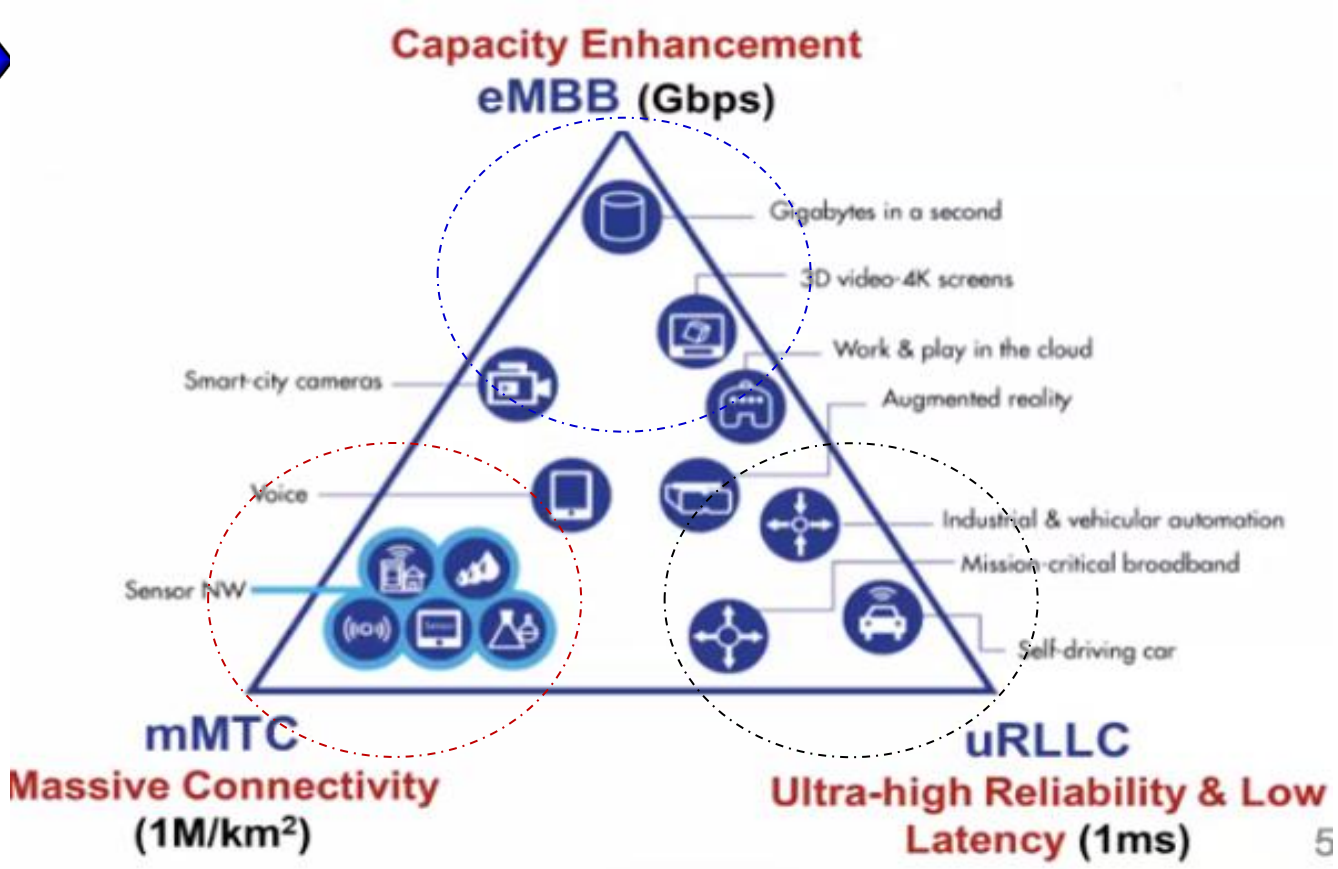



Spectrum (frequency) congestion in RF domain

# Context - Wireless Networks – Beyond 2030 - Applications




**Key wireless technologies?**

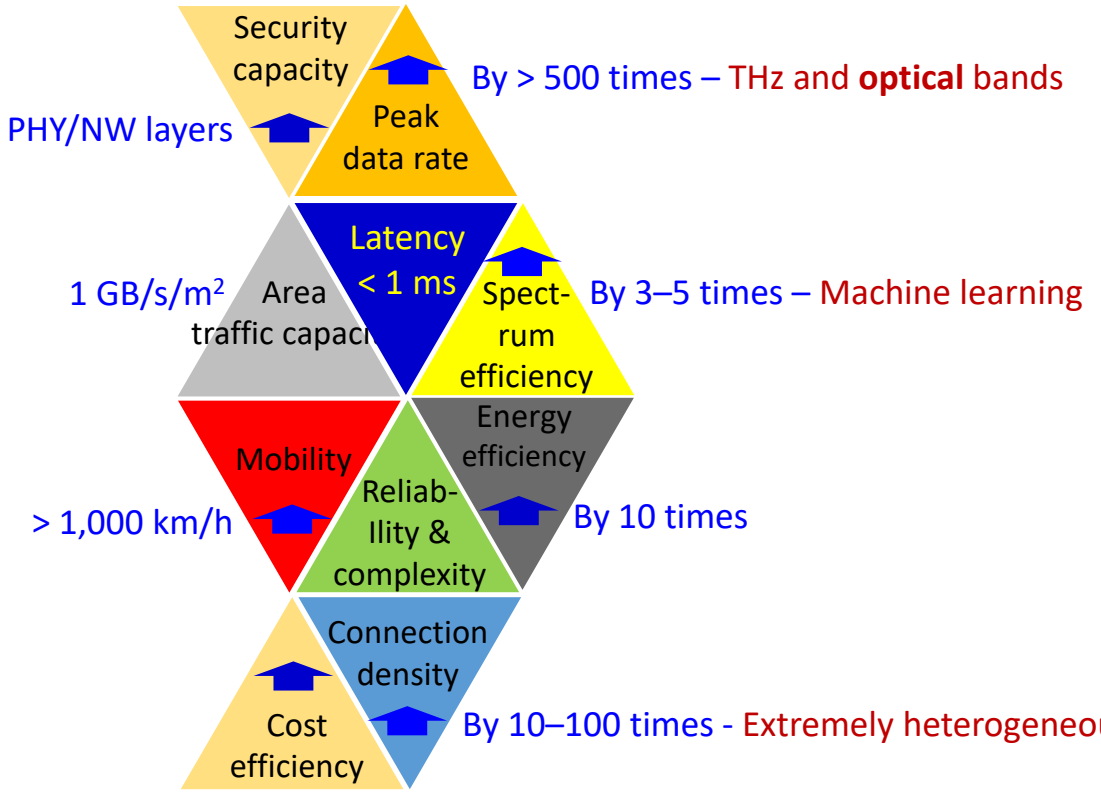

Z. Zhang et al., "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," IEEE Vehic. Tech. Mag., vol. 14, no. 3, Sept. 2019, pp. 28–41.; W. Saad, M. Bennis, and M. Chen, "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems," IEEE Network (Early Access), 2019; NTT DOCOMO 6G White Paper, [Online]. Available: https: //www.docomo.ne.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_v5.0.pdf.; 5G PPP, "European vision for the 6G network ecosystem," [Online]. Available: https://5g-ppp.eu/European-vision-for-the-6g-networkecosystem/; - L. Hanzo, et al, "Wireless myths, realities, and futures: From 3g/4g to optical and quantum wireless," Proceedings of the IEEE , vol. 100, pp. 1853–1888, May 2012.

- Wu S, Wang H, Youn C H. Visible light communications for 5G wireless networking systems: from fixed to mobile communications. IEEE Network, 2014, 28(6): 41

# Wireless Networks – Beyond 2030

**Resilient networks** – Avoiding failure and resuming service as quickly as possible

**5G – Trade-off**




**6G – Meet all**

**E.g.,**

- **NTT – Outlined the expectations for 6G [1] –** Requiring extreme coverage by integrating the space, air, terrestrial and underwater networks.
- **European - vision for the 6G network i.e., 5G PPP [2] -** Supporting higher capacity, higher data rates, higher device density, and less latency, as illustrated



1- NTT DOCOMO 6G White Paper, [Online]. Available: https: //www.docomo.ne.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_v5.0.pdf.
2- 5G PPP, "European vision for the 6G network ecosystem," [Online]. Available: https://5g-ppp.eu/European-vision-for-the-6g-networkecosystem/

# 5G and Beyond …

**5G is fundamental to achieving a European gigabit society by 2025**

**But, can 5G meet all of the requirements of future networks?**

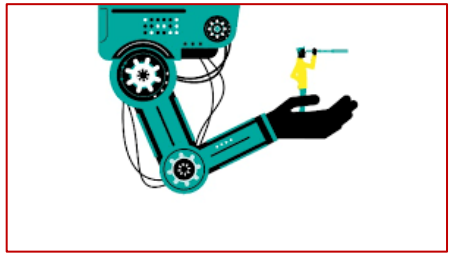
- https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/646172/EPRS_BRI%282020%29646172_EN.pdf

# 6G - Applications - Multi-agent Systems

Various robots, rovers, drones, and other agents of mass-produced products are expected to encounter scenes, where they will intersect and collaborate.

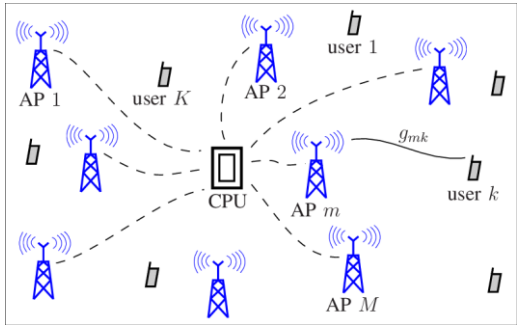
Individual identification and communication play crucial roles.

Generally, agents with identical appearances in mass-produced products are visually indistinguishable when using conventional CMOS cameras. **Therefore, linking visual information with information acquired through conventional radio communication is challenging.**



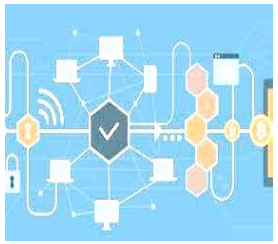
# 6G - Applications

**Internet of Nano-thing**



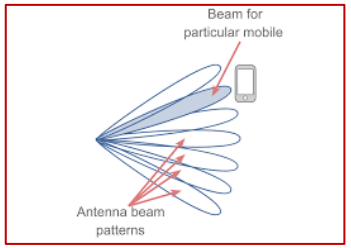

**Cell-free Communications** - Unmanned Aerial Vehicles - not using a specific cell

**Extended Reality** - Audios, videos, GPS for creating an interactive environment



## Blockchain Technology

- Large data represented as distributed blocks connected to each other and cryptographically secured
- Spectrum sharing – Secure, low cost, smart and efficient spectrum utilization
- + Machine learning - Improve QoS and smatterer resources sharing
- **Challenges: Latency and scalability**




## Beamforming

- Better coverage and throughput
- Higher SINR
- Track users
- Holographic beamforming via **Software-Defined Antenna**

M.Giordani, M. Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Towards 6G Networks: Use Cases and Technologies," arXiv: 1903.12216, 2019.; H. Elayan, O. Amin, R. M. Shubair, and M.-S. Alouini, "Terahertz communication: The opportunities of wireless technology beyond 5G," in International Conf. on Advanced Communication Technologies and Networking (CommNet). IEEE, pp. 1–5, 2018.; NTT DOCOMO 6G White Paper, [Online]. Available: https://www.docomo.ne.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_v5.0.pdf.; 5G PPP, "European vision for the 6G network ecosystem," [Online]. Available: https://5g-ppp.eu/European-vision-for-the-6g-networkecosystem/; M. Piran, D. Suh, "Learning-driven wireless communications, towards 6G," arXiv: 1908.07335, August 2019; S. Elmeadawy and R. M. Shubair, "6G Wireless Communications: Future Technologies and Research Challenges," *2019 Intern. Conf. on Electrical and Computing Technologies and Applications (ICECTA)*, Ras Al Khaimah, United Arab Emirates, 2019, pp. 1-5, doi: 10.1109/ICECTA48151.2019.8959607; Y. Dai, D. Xu, S. Maharjan, Z. Chen, Q. He and Y. Zhang, "Blockchain and deep reinforcement learning empowered intelligent 5G beyond," in IEEE Network, 33 (3), pp. 10-17, May/June 2019.; B. Fei and Y. Zhang, "UAV communications for 5G and beyond: recent advances and future trends," IEEE Internet of Things Journal, vol. 6, no. 2, pp.2241-2263, April 2019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# 6G – Applications - IoT



## IoT Technology - Trends for Businesses in the Future

**Artificial Intelligence & IoT Technology -** AI is benefitted by IoT with distributed data, and IoT is benefitted by AI with advanced management.

**IoT Connectivity — 5G, WiFi 6 & 7, Low-power wide-area network, and Satellites**

**Wi-Fi 6 -** A new networking standard. Unlike past wireless upgrades, Wi-Fi 6 will focus not on speed but rather on efficiency by sharing bandwidth across many devices.

**LPWAN -** Allowing devices to communicate with each other over long distances using very little power in a non-cellular configuration.

**Edge Computing – Low Latency & Security -** Real time applications depend on edge computing. Instead of calculating everything at a central source, edge networks process information closer to the user and lighten the load of the entire network for all users.

**Software Defined Radio/Optics/Newtorks + ML/AI**

# 6G – Applications - IoT



## IoT Technology - Trends for Businesses in the Future

**Private 5G Cellular -** Private cellular, which effectively takes cellular technology and repurposes it for use on your enterprise local area network.

**Wearable IoT Technology -** While sensors and edge devices are important for many IoT technology solutions, wearable IoT devices shouldn't be overlooked.

**Wi-Fi Sensing -** The ability of devices to detect the presence of Wi-Fi networks and to gather information about them. This information can be used to determine the location of Wi-Fi networks, to identify the type of network, and to estimate the number of devices

Software Defined Radio/Optics/Newtorks + ML/AI

# 6G – Applications - IoT



## IoT Technology - Trends for Businesses in the Future

- **Smart Homes and Cities – mmW, THz and optical**
  - **Data communications, Sensing, positioning**
- **IoT Technology in Healthcare**
- **Connected Networks Aid Manufacturers**
- **Contextual Wireless Networs**
  - Require contextual knowledge, environmental awareness, and the ability to make projections of future scenarios.
  - Using hyper-aware Wi-Fi/Li-Fi access points as hubs for an array of sensors

**Software Defined Radio/Optics/Newtorks + ML/AI**

# Wireless Technologies - Innovations

- Dynamic Spectrum Management
- Advanced Interference Mitigation Techniques
- Propagation Prediction Techniques for Dynamic Spectrum Sharing
- Artificial Intelligence/Machine Learning for Radios/Optics
- Flexible, Extensible, and Secure Transportation Communication Framework, Architecture, and Management
- Receiver Performance Interference Thresholds

# Wireless Technologies - Innovations

- Low Cost Wide Spectral Range RF Front-End (Multi-decade; Contiguous) (Tx,Rx)
- Efficient Techniques to Minimize Power Amplifier Spectral Regrowth in Non-contiguous Spectral Environment
- Network Management of Mobile Ad-hoc Networks (MANET)
- Integrated Development and Debug Environment to Create Portable SW-Based Applications on Embedded Heterogeneous Platforms

# Wireless Networks – Beyond 2030 - Issues

**Societal performance MUST have the same importance as system performance!**

**Energy efficiency and sustainability – Will be much better than 5G using AI/ML, but**

- Massive MIMO in 5G and 6G
  - **Consume too much power** than (i.e., 3 times more) traditional 4G antenna
  - Offers beam forming
- DSP - Great in energy per bit compared with the noise

**EMI awareness**

**Ideal device** - Life time needs to be long

**Intelligent networks**

- Assessing network users, services, and environments
- Decision making, and dynamic adjustment of the network
- Network self-evolution mechanism

**But. AI is not totally secure!**

**Asymmetrical security**

**Digital inclusion** - People must have access to the technology, which is simple and user friendly

# RF Wireless Technologies – Issues

**Cost - More complexity** - Many base stations in a small area.

- According to European Commission estimates, to reach the target, including urban areas, the cost is estimated at **€500 billion by 2025** [1].

## Impacts on human health and environment [2, 3]

- **Massive MIMO**
- **Possible ranges** - 20-150 m with smaller coverage areas/small cell
  - A cell radius of 20 m would imply **about 800 base stations/km²**
    - This contrasts with 3/4G which use large or 'macro' cells, ranges of 2-15 km or more.

**Compact cell antennas deployment**

**Constant exposure of people to mmW and THz radiations.**

World Health Organization

**Reaching the EMI limit (World Health Organisation recommended regulations)!**

**Already reached!**

[1] https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/646172/EPRS_BRI%282020%29646172_EN.pdf; [2] See '5G Deployment: State of Play in Europe, USA and Asia', European Parliament, June 2019; [3] R. M. Powell. See also similar opinions from experts such as T. Schoechle and P. Héroux, 'Fiber is safer, faster, more reliable, and far more cyber secure and energy efficient than wireless; Cheng-Xiang Wang, et al, 6G WIRELESS CHANNEL MEASUREMENTS AND MODELS Trends and Challenges, IEEE VEHICULAR TECHNOLOGY MAGAZINE | DECEMBER 2020; J. Huang, et al, "5G millimeter wave channel sounders, measurements, and models: Recent developments and future challenges," IEEE Commun. Mag., 57 (1), pp. 138–145, Jan. 2019.; T. S. Rappaport et al., "Wireless communications and applications above 100 GHz: Opportunities and challenges for 6G and beyond," IEEE Access, vol. 7, pp. 78,729–78,757, June 2019; K. M. S. Huq, S. A. Busari, J. Rodriguez, V. Frascolla, W. Bazzi, and D. C. Sicker, "Terahertz-enabled wireless system for beyond-5G ultrafast networks: A brief survey," IEEE Netw., vol. 33, no. 4, pp. 89–95, July/Aug. 2019. doi: 10.1109/MNET.2019.1800430.

# 6G – Spectrum Efficiency Gain

$$\eta_{sp} = \frac{R/B}{k}$$ Bit/s/Hz/site (i.e. cluster size)

**Shannon capacities** of different types of channels over HetNets with **interference**.

**Seamless global network coverage:**
(Space-air-ground-sea integrated network)
- Satellite communication
- UAV communication
- Terrestrial communication (UDN)
- Maritime communication
- Underwater acoustic communication

**More bandwidth:**
- mmWave, THz, optical wireless
- Unlicensed access/cognitive radio network (CRN)
- Full-duplex
- Multi-standard systems

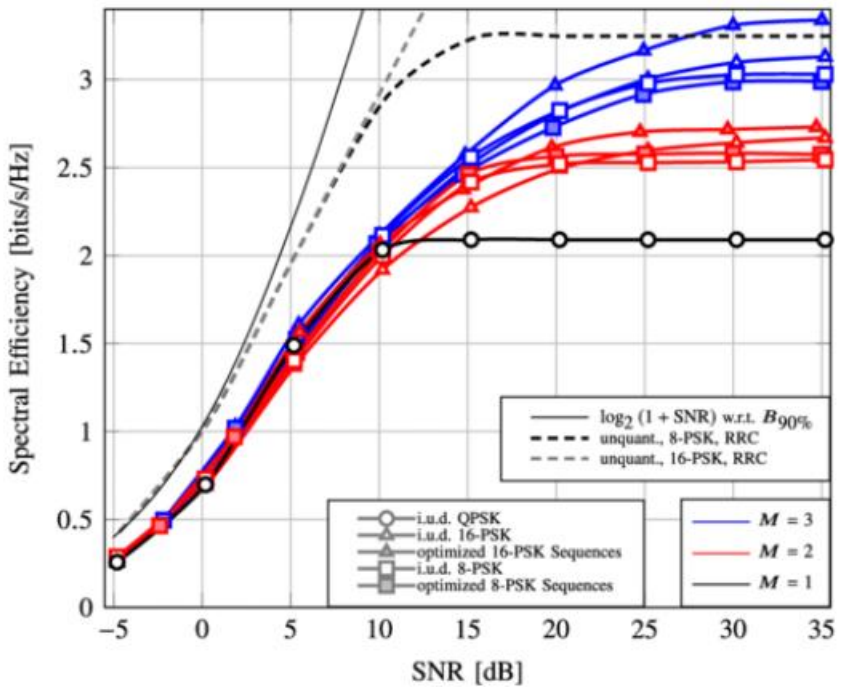
**Less noise:**
(filtering)

$$C_{sum} \approx \sum_{HetNets} \sum_{Channels} B_{n,i} \log_2[1 + P_{n,i}/(N_{n,i} + I_{n,i})]$$

**More channels:**
- Ultra-massive MIMO, spatial modulation
- Orbital angular momentum (OAM)
- New waveforms: F-OFDM/UFMC/FBMC
- HST/V2V/D2D, multiple access
- New devices: industry IoT, VR/AR/MR, wearable displays, mobile robots and drones

**More power (efficiency):**
- Small cells
- Green communications
- Advanced modulation and coding: network coding, polar code, LDPC, …

**Less interference:**
- Interference randomization
- Interference coordination
- Interference cancellation
- Interference alignment



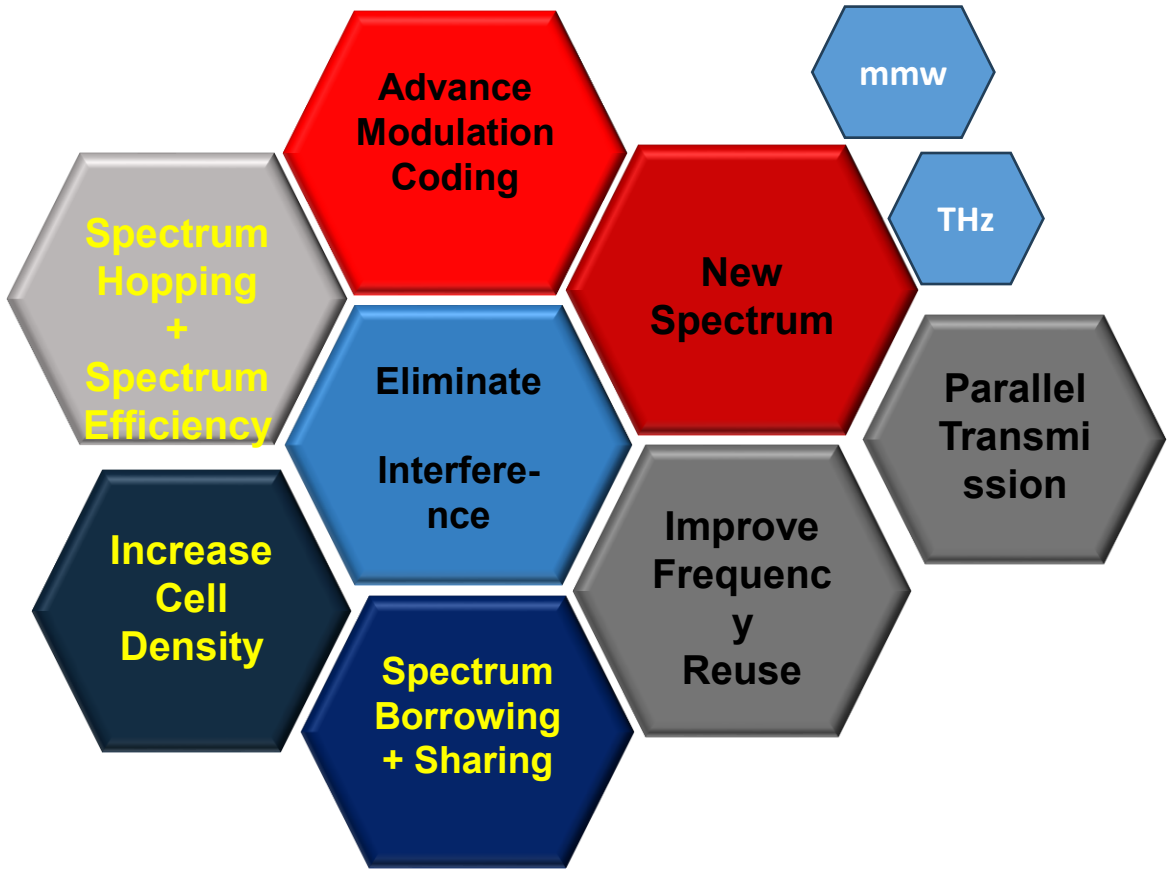

C. -X. Wang, J. Huang, H. Wang, X. Gao, X. You and Y. Hao, "6G Wireless Channel Measurements and Models: Trends and Challenges," in IEEE Vehicular Technology Magazine, vol. 15, no. 4, pp. 22-32, Dec. 2020, doi: 10.1109/MVT.2020.3018436.

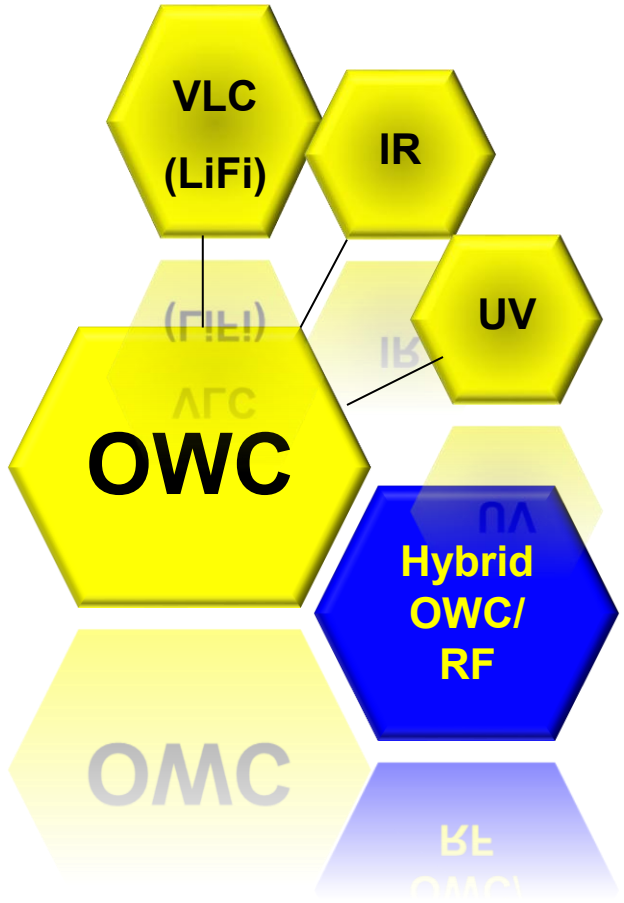
# So What Next?

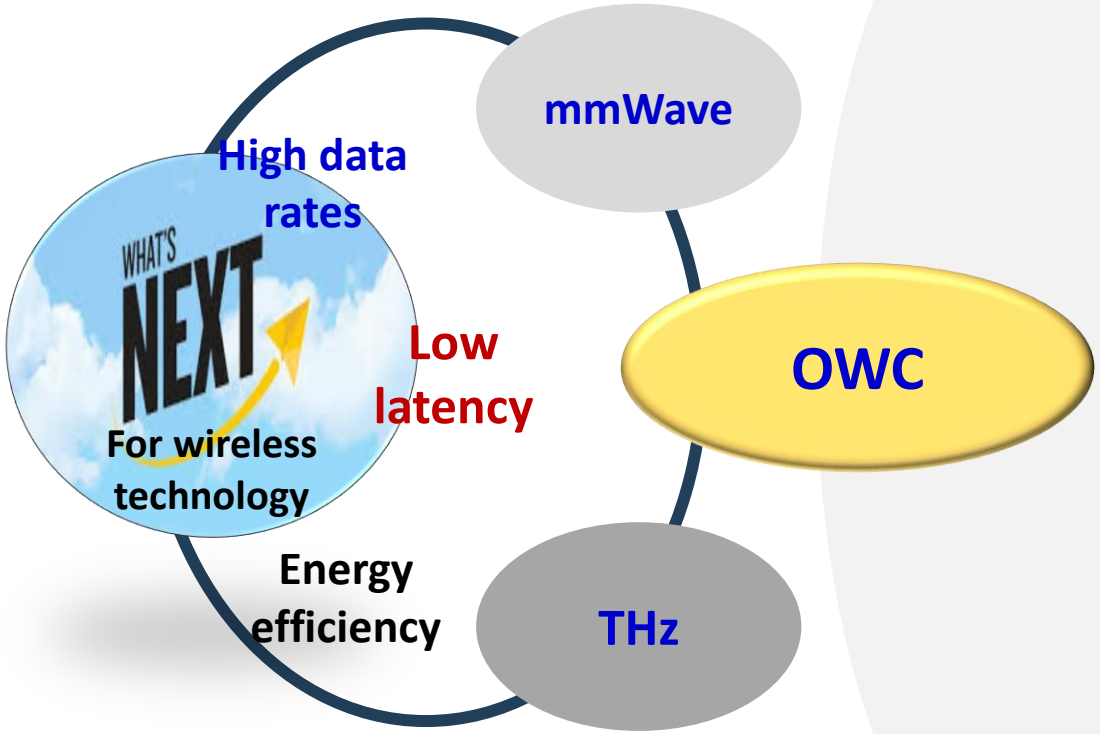
WiFi, WiGig, **LiFi/VLC**:

- High data rates
- Low latency
- Energy efficiency

# How to Overcome the Spectrum Congestion?






**Is there a need for optical wireless technology?**

**Will WiFi 6 and 7 block the use of OWC?**

**Do we need high-speed wireless links for all cases?**

**Should we be driven by industry or by curiosity or both?**

**What are the killer applications in OWC?**

**Complexity and cost of OWC?**

**Hybrid RF-OWC-THz?**

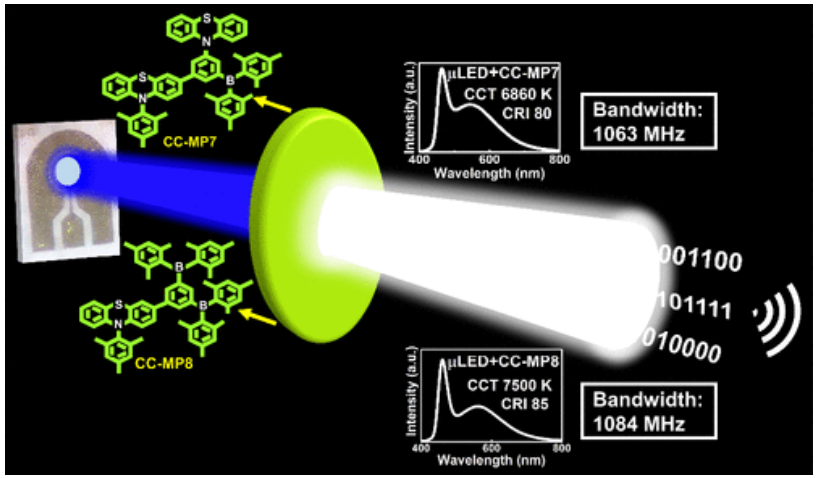
**Light flickering**

**Has VLC a future?**

**……..?** ***What do you think?***

# Optical Wireless

*A disruptive technology offering a free spectrum, security and high data rate!*




https://pubs.acs.org/doi/10.1021/acsphotonics.3c01332

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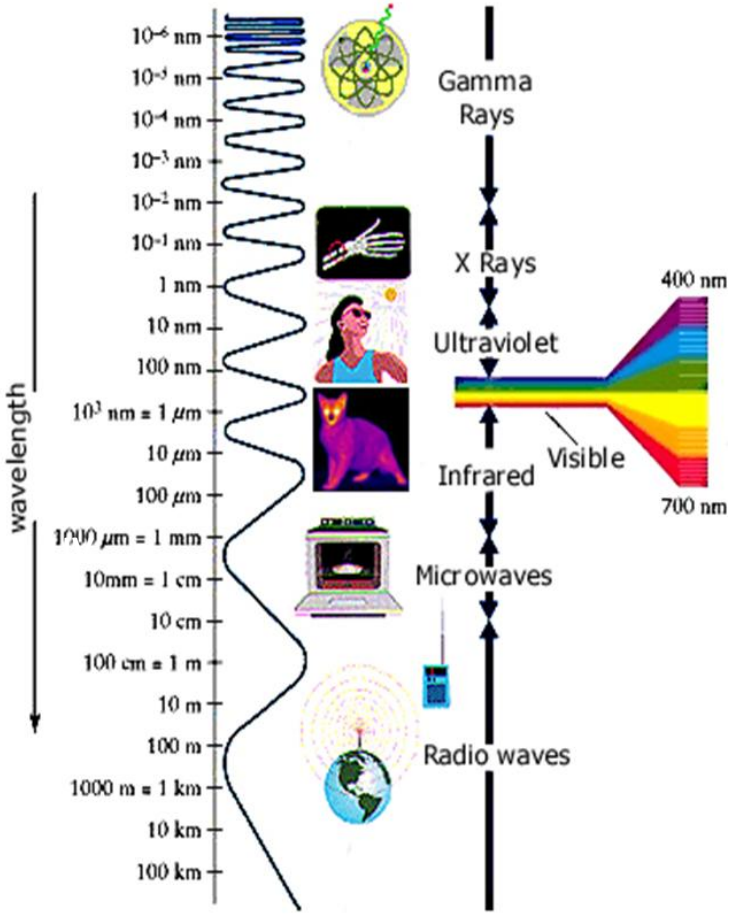
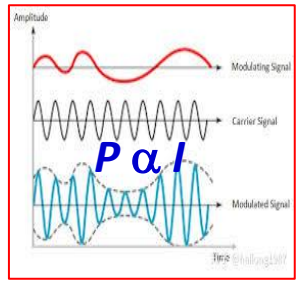
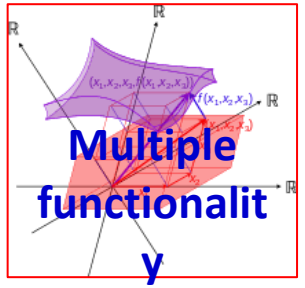
# OWC – KPIs Important for 6G



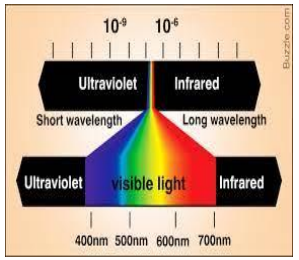


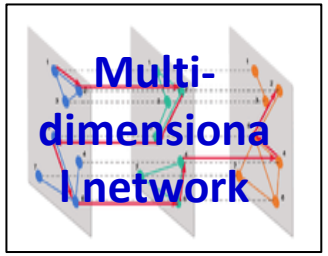







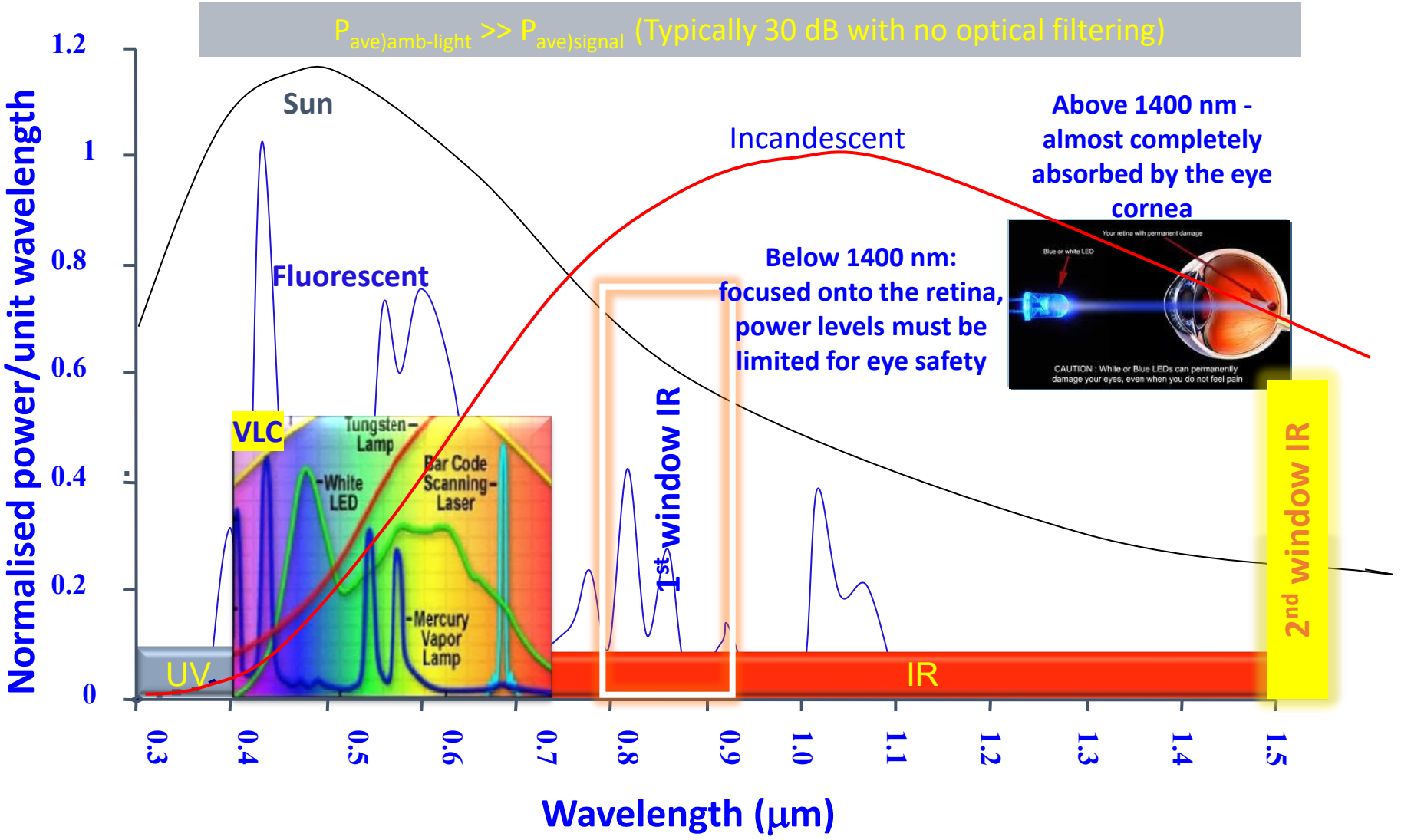




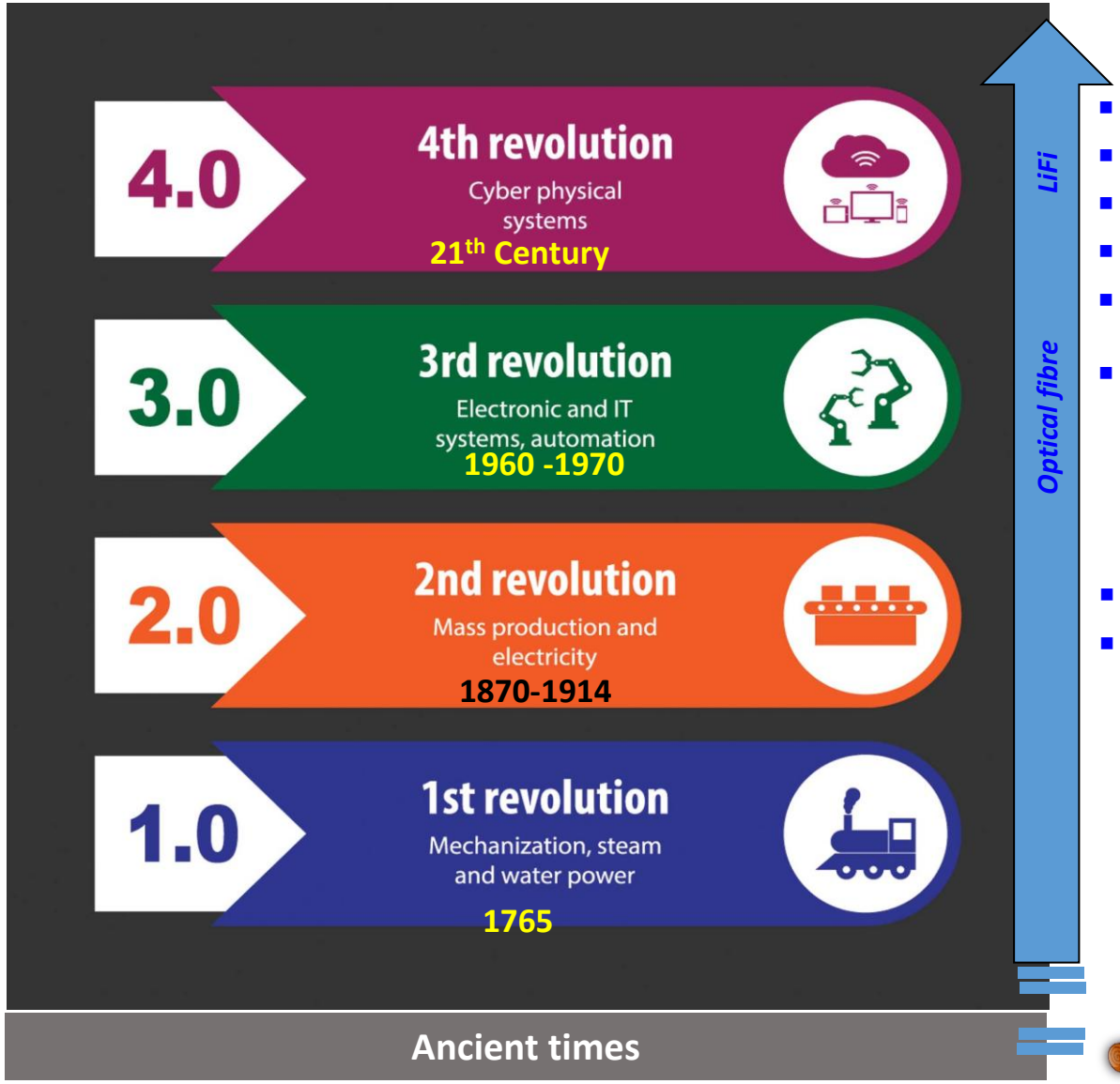



1- HR. Ji, S. Wang, Q. Liu, and W. Lu, High-speed visible light communications: Enabling technologies and state of the art, in Applied Sciences, vol. 8, no. 4, Art. no. 589, 2018, doi: 10.3390/app8040589.
2- C. Rohner, S. Raza, D. Puccinelli, and T. Voigt, Security in visible light communication: Novel challenges and opportunities, in Sensors Transducers vol. 192, no. 9, pp. 915, 2015.
3- D. Karunatilaka, F. Zafar, V. Kalavally, and R. Parthiban, LED based indoor visible light communications: State of the art, IEEE Commun. Surv. Tut., vol. 17, no. 3, pp. 16491678, 2015, doi: 10.1109/COMST.2015.2417576.

# OWC - Transmission Windows



# Industrial Revolutions – Light Revo.




- Massive MIMO
- Blue LED
- VR/AR
- IoT/IoE
- Wearable

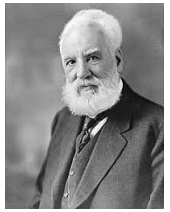
- Laser (1960)
  Theodore Maiman

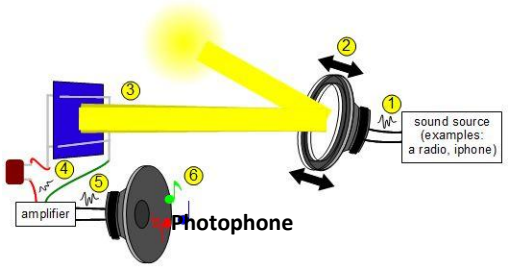
- Space Comm. MIMO
- AI/ML

United Nations Educational, Scientific and Cultural Organization

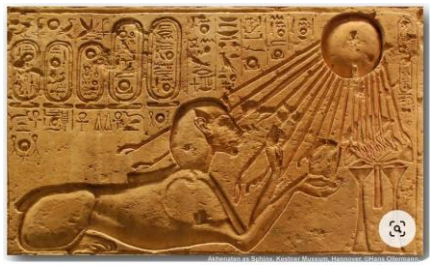
International Day of Light 16 May

- Photophone
- Light bulbs





# Light Technologies – Innovation Timeline



**~1340 BC.**

Dynasty 18.

Akhenaten as Sphinx.

Kestner Museum, Hannover, Germany.

**1810**

William Murdoch

Oil gas lamp.

**~1934**

The first practical fluorescent tube.

**1960**

Laser development

Theodore Maiman

**~1976**

Compact Florescent Light (CFL) lamp

**2006**

Shuji Nakamura wins the

Millennium Technology Prize for the development of a white LED

**2019**

Many countries do not have any incandescent light bulb phase out policy currently in place

Ancient Egyptians

Candle.

**1800**

The first incandescent light bulb was invented by Thomas Edison.

**1879**

First practical light-emitting diode (LED) was developed.

**1962**

Blue LEDs were discovered by Shuji Nakamura of Nichia.

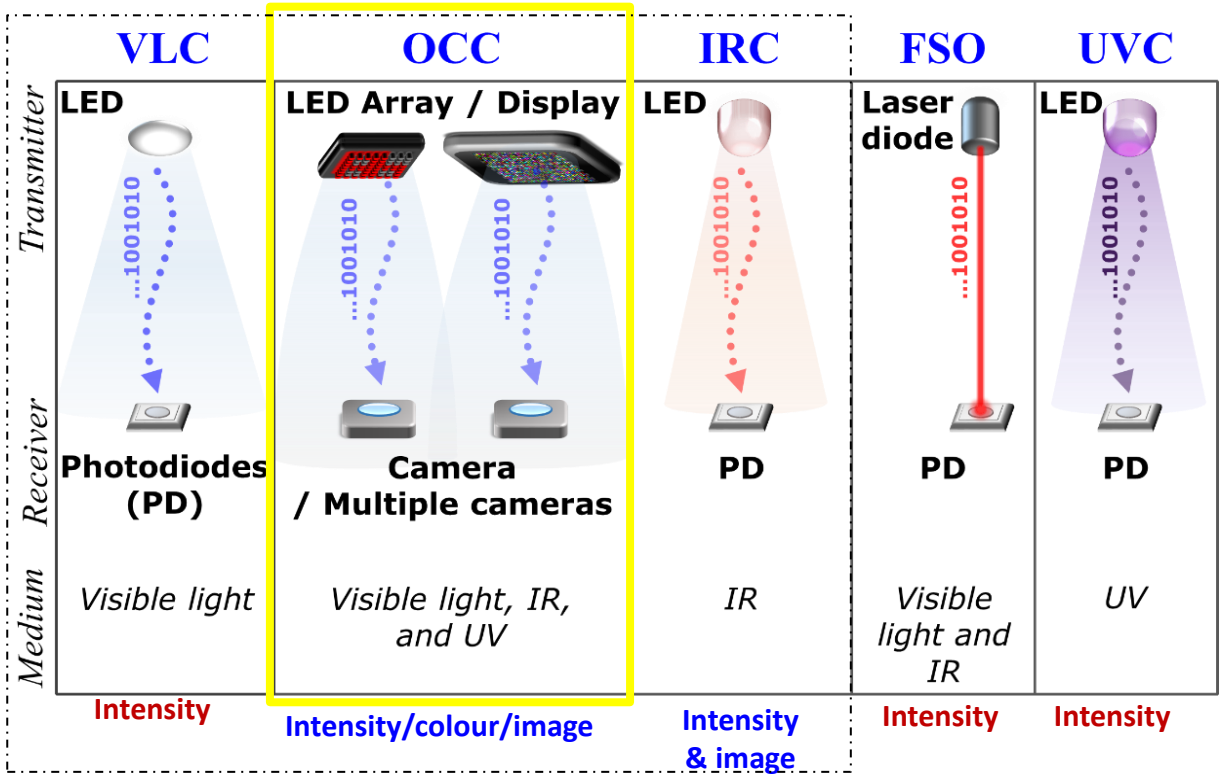
**1993**

- Torraca becomes the first township to convert its entire illumination system to LED

- The first car to use fully LED headlamps

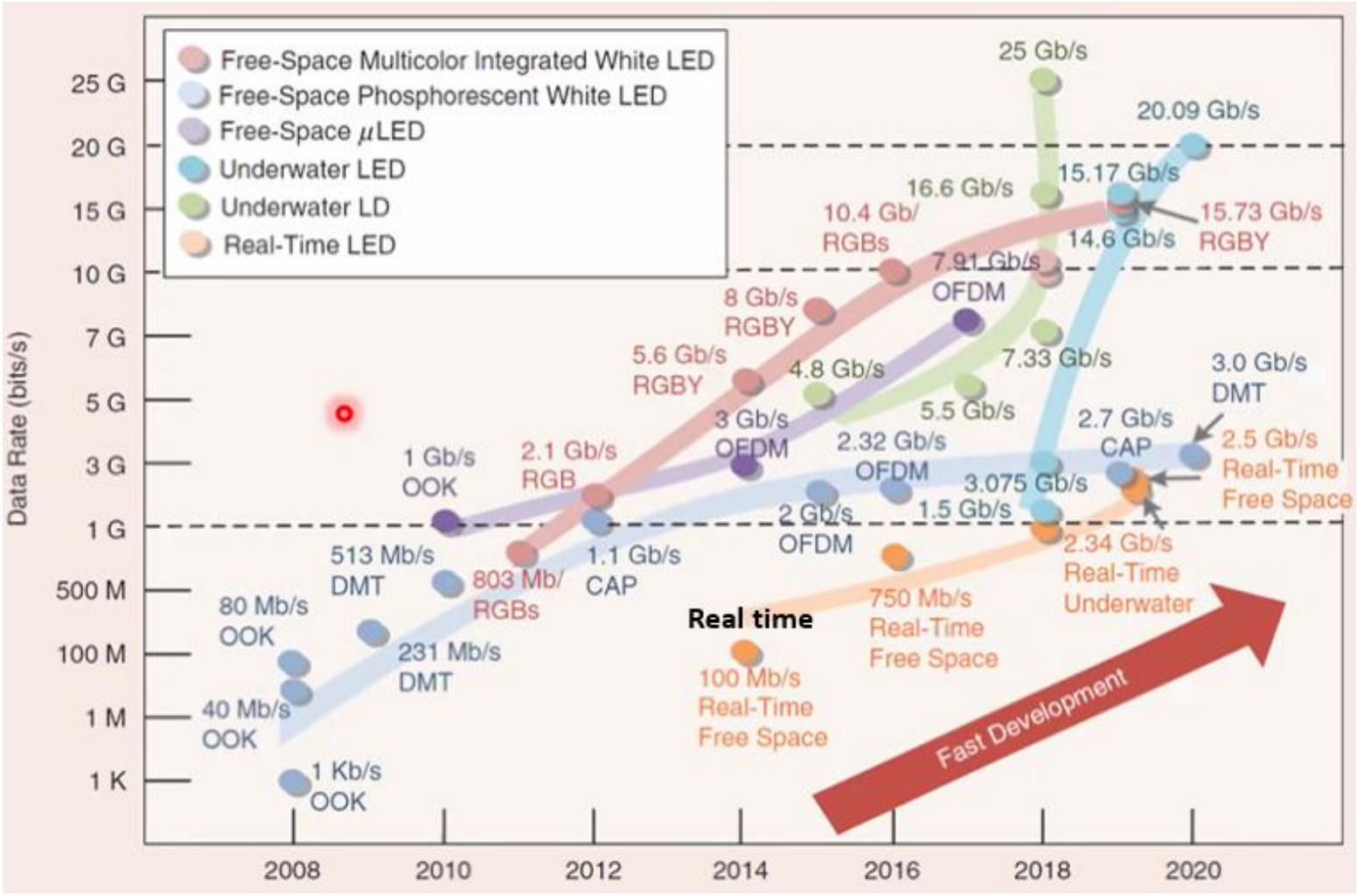
**2007**

# OWC - Technology




- Is there the need for high-speed VLC systems?
- Has VLC got a future?
- Do we need to focus more on:
  - IR, IR/VLC
  - IR Optical Camera Communications (OCC)
  - VLC/OCC
  - IR/VLC/OCC?

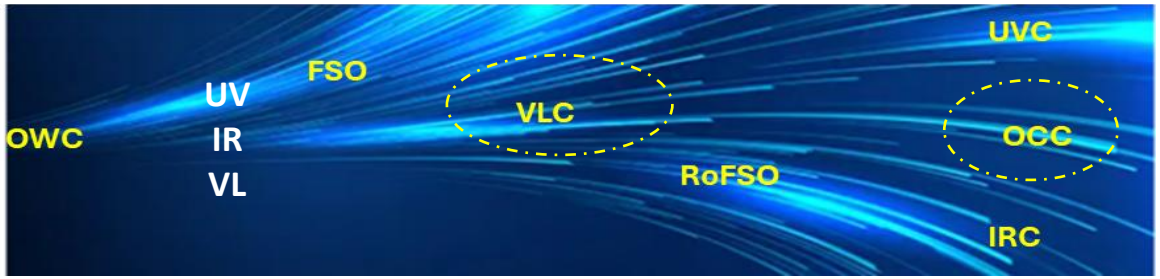
# OWC - Technology

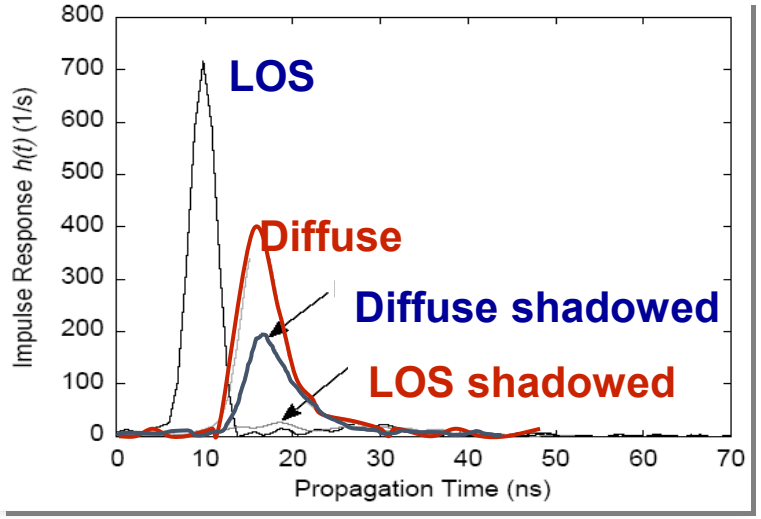



Z. Ghassemlooy

N. Chi, Y. Zhou, Y. Wei and F. Hu, "Visible Light Communication in 6G: Advances, Challenges, and Prospects," in *IEEE Vehicular Technology Magazine*, vol. 15, no. 4, pp. 93-

# OWC – Types

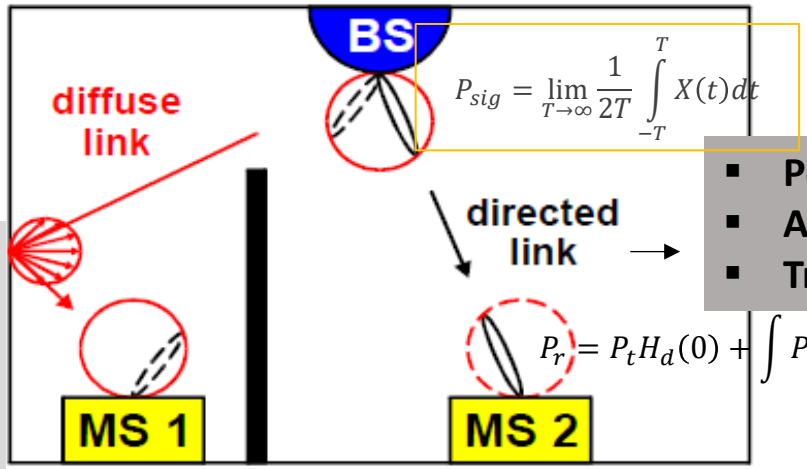



- **Optical beam-steering:**
  - Mechanical; MEMS
  - Optical phase arrays; Liquid crystal-based spatial light modulators
- **Reconfigurable intelligent surface**

**VLC - Transmission link**

BS: base station, MS: mobile station




- **Pointing**
- **Acquisition**
- **Tracking**

**Ceiling bounce model (Carruther)**

$$h(t) = G_0 \frac{6a^6}{(t+7)^7} u(t) \qquad a = \frac{2H}{c} \qquad G_0 = \frac{\rho A}{3\pi H^2}$$

$u(t)$ - unit step response, $H$ - height of ceiling above transmitter & receiver, $\rho$ - plane reflectivity, $A$-receiver photo diode area, $c$ - velocity of Light

**Received Signal** $$r_e = \eta[(h_d h_p h_a h_t) I_s + I_a] + n$$

H. Chun et al., "A wide-area coverage 35 Gb/s visible light communications link for indoor wireless applications," Sci. Rep., vol. 9, 2019, Art. no. 4952; P. C. Kuo et al., "Actively steerable integrated optical phased array (OPA) for optical wireless communication (OWC)," in Proc. Opt. Fiber Commun. Conf. Exhib., 2022, paper M1C.7; Y. H. Jian et al., "Optical beam steerable orthogonal frequency division multiplexing (OFDM) non-orthogonal multiple access (NOMA) visible light communication using spatial-light modulator based reconfigurable intelligent surface," IEEE Photon. J., vol. 15, no. 4, Aug. 2023, Art. no. 7303408.; A. Trichili, M. A. Cox, B. S. Ooi, and M. S. Alouini, "Roadmap to free space optics," J. Opt. Soc. Amer. B, vol. 37, pp. A184–A201, 2020.

# VLC – Systems in the Market

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signify *Netherland*

**Trulifi - A USB access key**

- **USB-based Tx and Rx**
- **250 Mbps DL IR**
- **160 Mbps UP IR**

PHILIPS


iOS, Android SDK, and cloud services

pureLiFi *UK*

**LiFi Xc**

- **DL 43 Mbps Visible; UL IR; 1 sec handover; 802.11**

Fraunhofer *Germany*

- **Standard high-power IR LEDs**
- **Optical bidirectional**
- **Dynamic rate adaptation**
- **Adaptable optics Peak DL data rate 1 Gbit/s**
- **Latency < 2 ms**

# VLC – Systems in the Market

vlncomm *Netherlands*


- LumiNex- LED LiFi Access Point
- DL 70 Mbps; UL 60 Mbps IR; Latency of 0.4 ms; No. of simultaneous users 15

oledcomm *France*


DL 100 Mbps IR; DL 1Gbps IR; UL 40 Mbps IR; AP < 5 W; Dongle 2.5 W

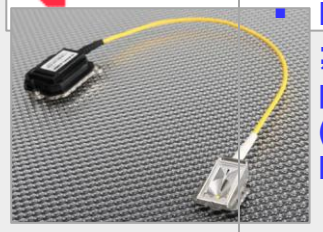
- 38 W; 100 lm/W; Windows, macOS, Linux with type A USB port; Android & iOS

iNET® &/or GEOLiFi® Street Lighting with RAGNI

HYDROMEA *Switzerland*

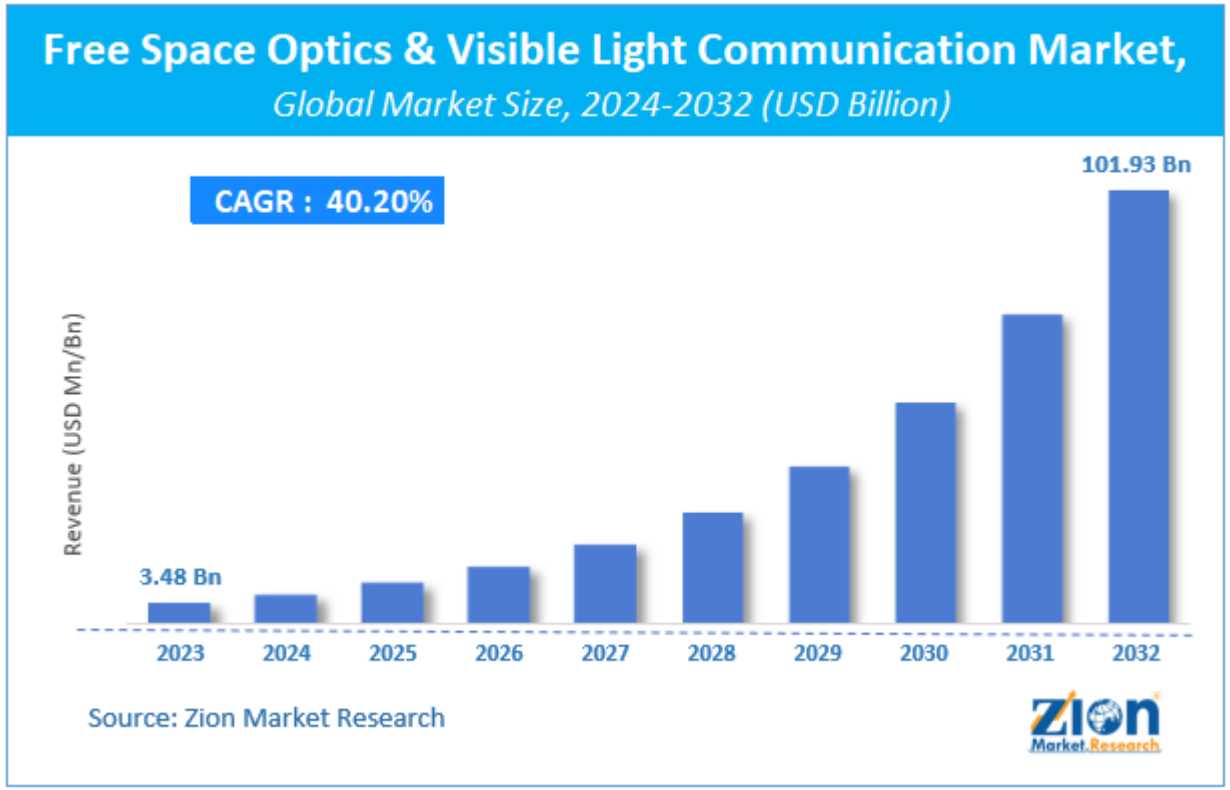
- **LiFi optical modem for underwater**
- Range down to 6 km ; Collecting data over 50 m; Data rate – 10 Mbps

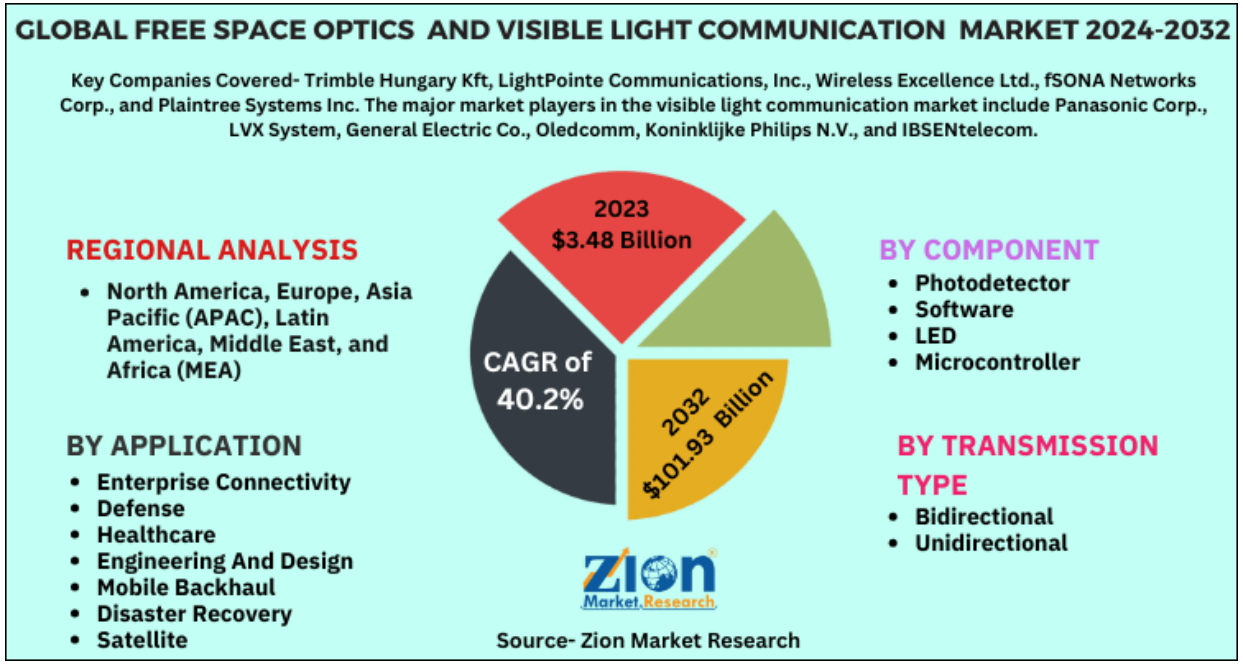
KYOCERA




- **Laser light fibre – White light ; High power; Illuminating phosphor; Brightness (lm/unit area: 50x – 100x the brightness of a LED.**

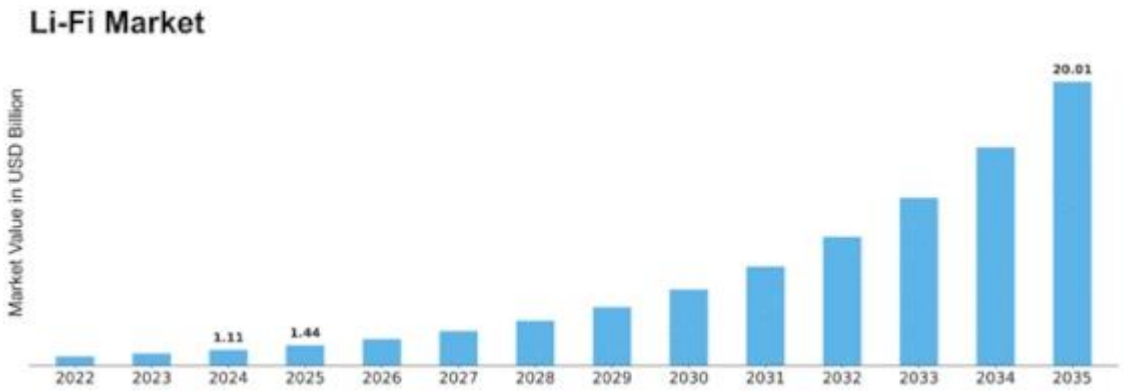
# OWC - The Global Market Size



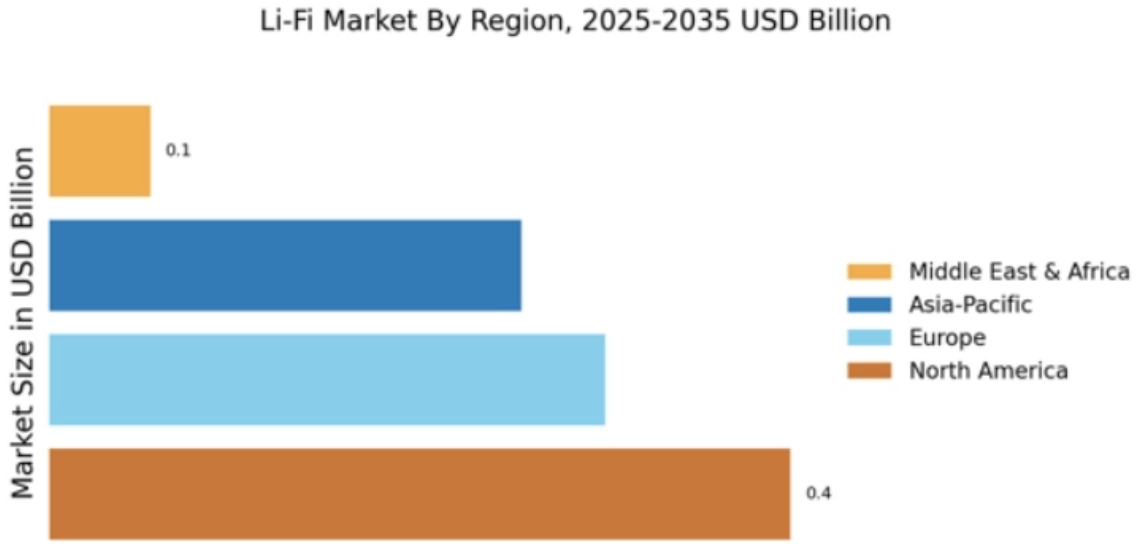




https://www.zionmarketresearch.com/report/free-space-optics-visible-light-communication-market

# VLC - The Global Market Size




https://www.marketresearchfuture.com/reports/visible-light-communication-li-fi-market-3561



# OWC [VLC, IRC, and FSO] – Commercial Players

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Lucibel S.A.

LiFi Labs

Fizyr

Ayla Networks

Fraunhofer IPMS

CVLC 中国可见光通信产业技术创新战略联盟 China Visible Light Communications Alliance

IST Integrated System Technologies

intel

Disney

CASIO

LIGHTPOINTE

EG ELECTRONICS

SONA Optical Wireless

GE Lighting

SIEMENS

Supreme Architecture

TAIYO YUDEN

VLC Ltd

MostCom

Artolink®

PLAINTREE

infsoft smart connected locations

LiFi Consortium

Color Kinetics

Mitsubishi Electric Changes for the Better

optical connections

EC SYSTEM

CableFree Wireless Excellence

THORLABS

PAV free space optical solution

cailabs

SAMSUNG

Nakagawa Laboratories, Inc.

pureVLC

HYDROMEA

TRANSCELESTIAL

SDFSO 六博光电

Trimble

NEC Corporation

VLCC Visible Light Communications Consortium

LVX System

IBSENtelecom optical telecom designed with people in mind

eldoLED your product | our drive

ACPTIX TECHNOLOGIES

SA Photonics

TOYO ELECTRIC CORPORATION

RENESAS

SHIMADZU Excellence in Science

Panasonic

AXIOM OPTICS

comnet Communication Networks

VLCA Visible Light Communications Association 一般社団法人可視光通信協会

nextLiFi visible | light | communications

FIREFLY WIRELESS NETWORKS

BROADCOM

Optelix WIRELESS

LEO SPACE Leading edge Optical Solutions

Canon

Outstanding Technology Co., Ltd.

LiFi Photonics

GLOBAL LIFI TECH

InfinityTechnology 無際科技股份有限公司

ByteLight

sonaBeam

Media Lario

artLink TECHNOLOGY

PAV free space optical solutions

TAIYO YUDEN

oledcomm

qbeam

Newport

L3 Technologies

PHILIPS

MAXLINEAR

LASERBIT WIRELESS CABLES

pureLiFi

axiom OPTICS

LASERBIT WIRELESS CABLES

TNO innovation for life

PhotonFi Inc.

ams OSRAM AG

ZERO1 Pte. Ltd.

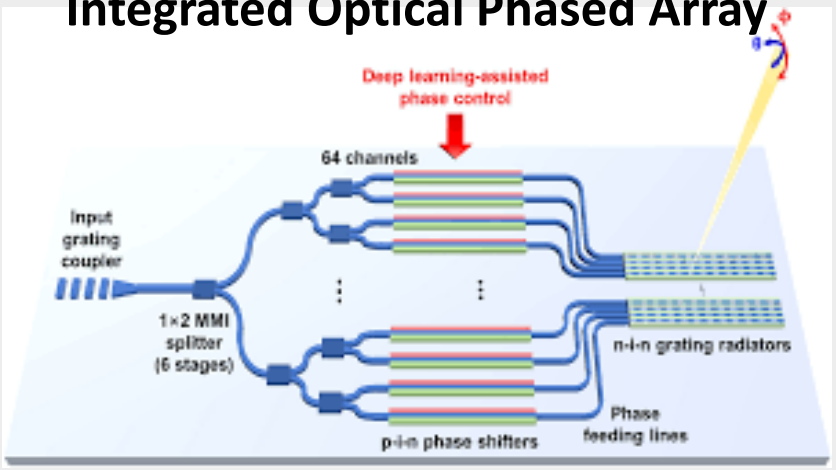
IBSENtelecom Ltd.

Z. Ghassemlooy

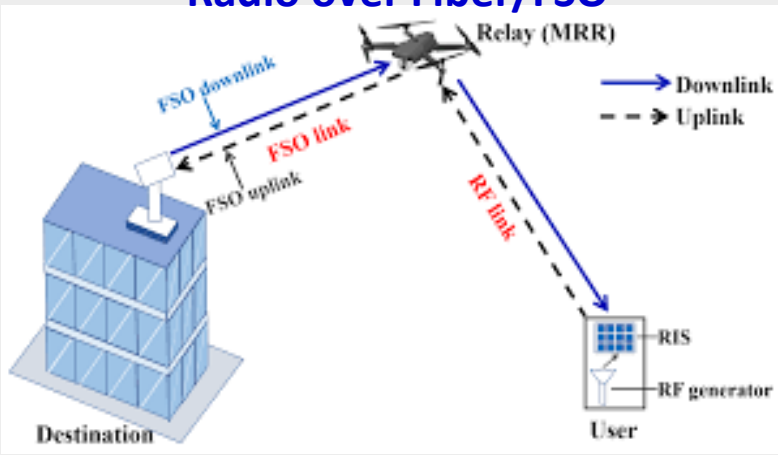
# OWC – Future applications



## Integrated Optical Phased Array




## Radio over Fiber/FSO



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UK Research and Innovation

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cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

NEWFOCUS

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# OWC – Future applications





## Current OWC activities:

Theoretical

Simulation

Experimental

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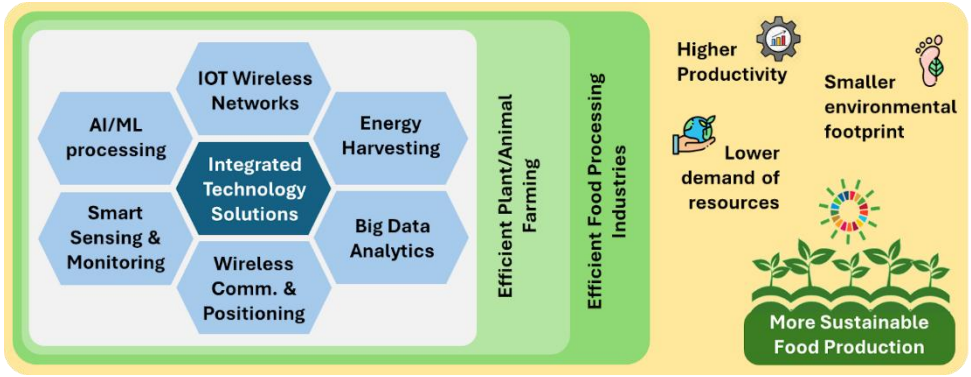
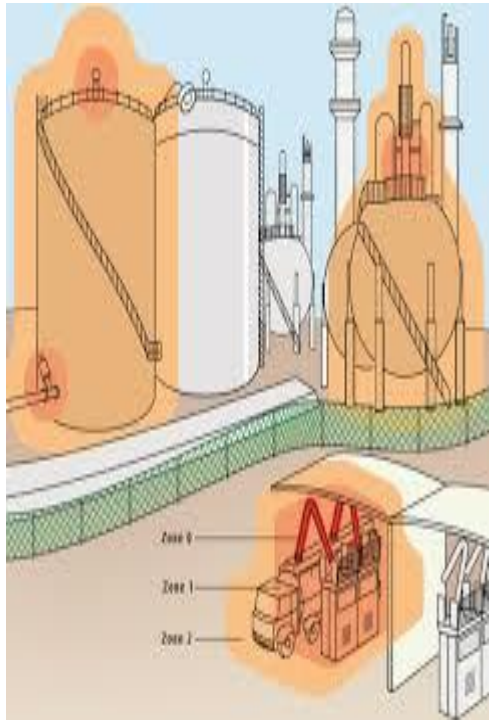
# OWC – Future applications

Vertical Farming

# WC



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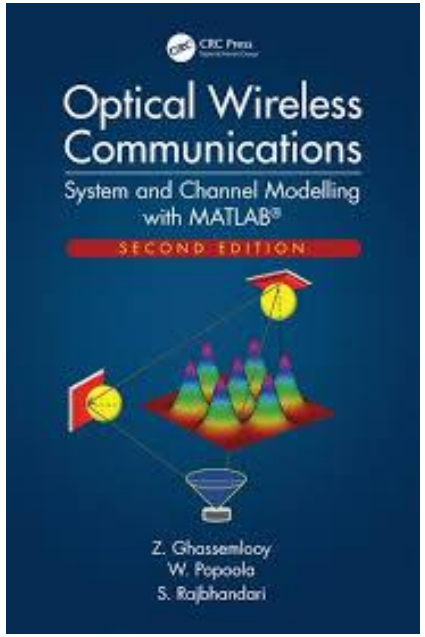
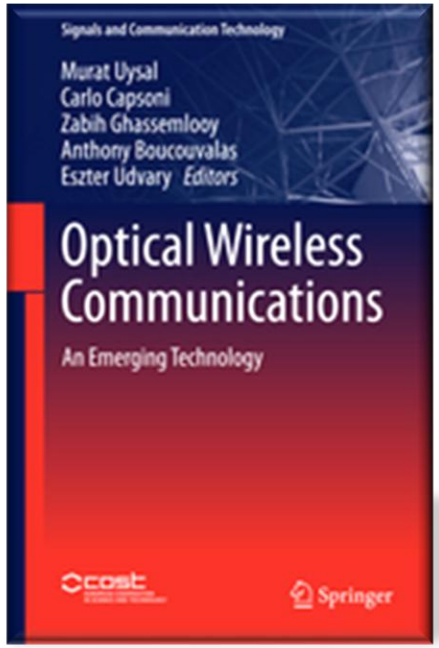
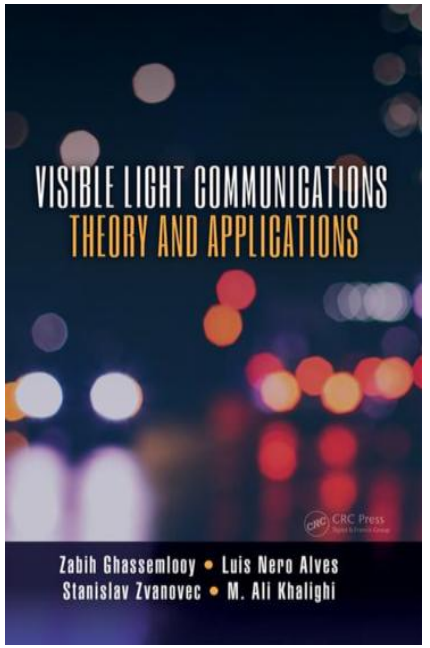
# Further Reading

## Our Contributions:








+

+ A large number of papers.

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# Final Comments

- A complementary wireless technology to RF.
- The OWC will continue to grow driven by technological advancements and increasing demand for high-speed connectivity.
- Enhanced security features especially in outdoor point-to-point and indoor networking is highly attractive.
- Energy efficiency – Continue to remains a key focal point.
- Integrated with various applications and wired/wireless networks.
- Key drivers pushing market expansion are demand for high-speed internet and the integration with Internet of Things.

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UK Research and Innovation
instituto de telecomunicações
E C R N European Collaborative Research Network
O C R G

## Acknowledgment:


- **All our research students and colleagues**
- All funding bodies


# Thank You!