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Visible Light Communications & Optical Camera Communications *for Medical and Businesses*

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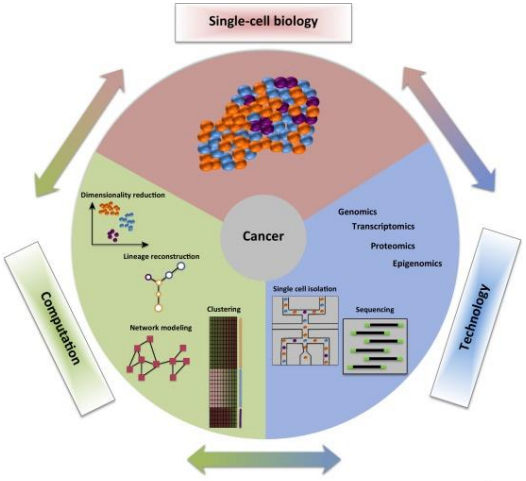
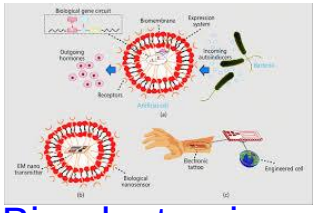
OCRG

Emerging Technologies

- Constantly being developed to meet the needs of companies a people.



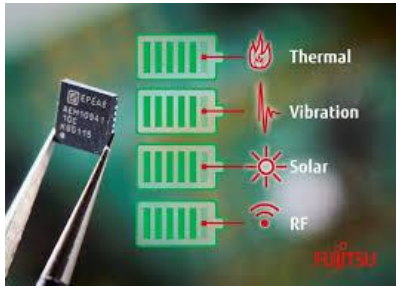


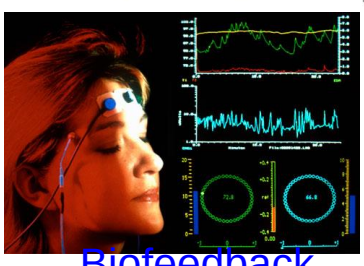
Bio-electronics

Battery technologies

Thought control of electronics

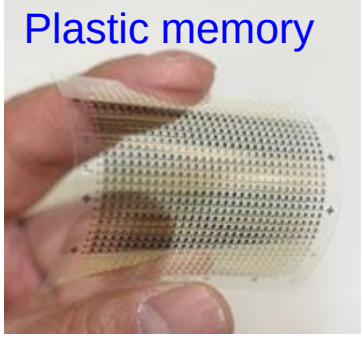
Energy harvesting





Biofeedback

Printed electronics



Plastic memory

Why

Visible Light Communications + Optical Camera Communications

Technology?

Medical

Healthcare of the future (HoF) and the requirements for its wireless connectivity as part of Interner of Medical Things (IoMT)

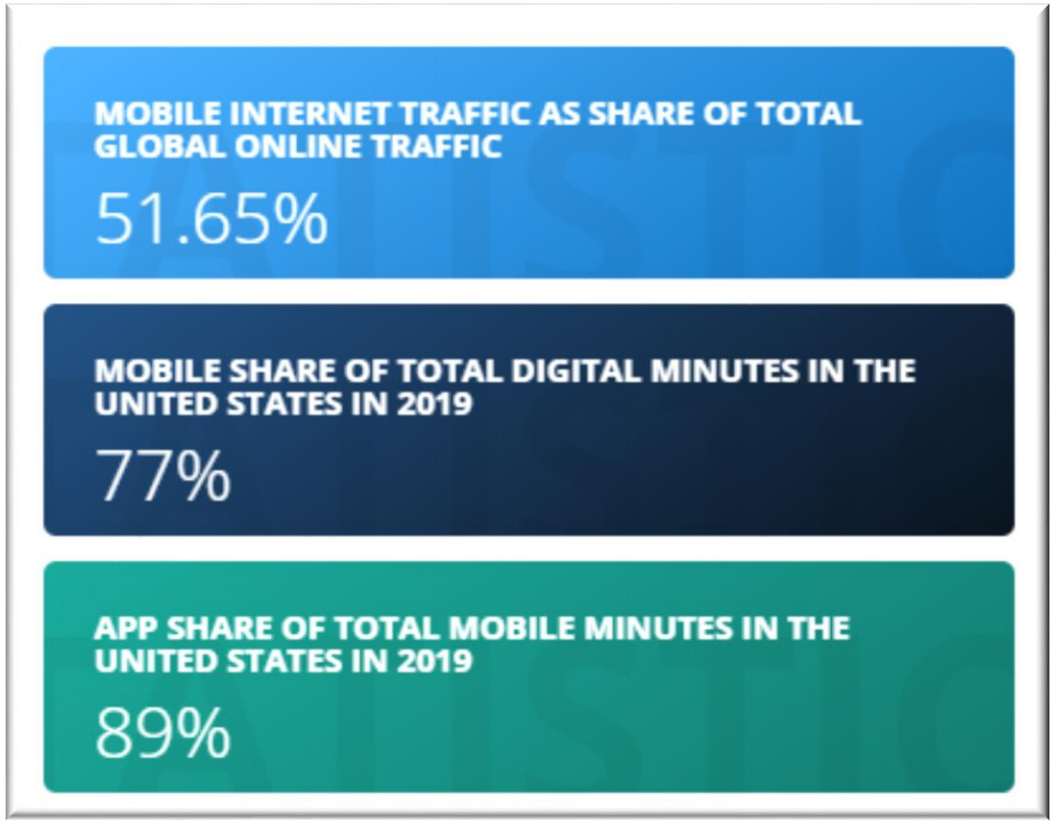
HoF - Will be Mostly

- Digital and wireless
- Exploit widely **artificial intelligence and big data**
- Connecting patients
  - Healthcare professionals
  - Management and operational staff
  - Patients
  - Visitors
  - Sensors and wearable devices
  - Computers and medical devices
  - Public spaces
- Home or remote healthcare
- Real-time monitoring of patients, remote control of robots, implants or actuators, etc.

1- J. Ehrich, E. Molloy, R. Kerbl, M. Pettoello-Mantovani and A. Gerber-Grote, Conceptual design of future children's hospitals in Europe. The role of public and private stakeholders as transferors of new concepts from theory into practice, *Journal of Pediatrics*, Vol. 183, pp. 1–2, 2017.
2. J. D. Zajac, The public hospital of the future, Medical Journal of Australia, Vol. 179, No. 5, pp. 250–252, 2003.
3. M. Hensher, N. Edwards and R. Stokes, International trends in the provision and utilisation of hospital care, BMJ, Vol. 319, No. 7213, pp. 845–848, 1999.
4. A. M. Mokhtar, The future hospital: a business architecture view, The Malaysian Journal of Medical Sciences: MJMS, Vol. 24, No. 5, p. 1, 2017
6. S. Landers, E. Madigan, B. Leff, R. J. Rosati, B. A. McCann, R. Hornbake and T. Lee, The future of home health care: a strategic framework for optimizing value, Home Health Care Management & Practice, Vol. 28, No. 4, pp. 262–278, 2016.
7. G. López, V. Custodio and J. I. Moreno, LOBIN: E-textile and wireless-sensor-network-based platform for healthcare monitoring in future hospital environments, IEEE Transactions on Information Technology in Biomedicine, Vol. 14, No. 6, pp. 1446–1458, 2010.
8. W. Noonpakdee, Adaptive wireless optical transmission scheme for health monitoring system, in 2013 IEEE Third International Conference on Consumer Electronics? Berlin (ICCE-Berlin), IEEE, pp. 161–64, 2013.
9. R. Murai, T. Sakai, H. Kawano, Y. Matsukawa, Y. Kitano, Y. Honda, and K. C. Campbell, A novel visible light communication system for enhanced control of autonomous delivery robots in a hospital, in 2012 IEEE/SICE International Symposium on System Integration (SII), IEEE, pp. 510–6, 2012

Business – The Needs

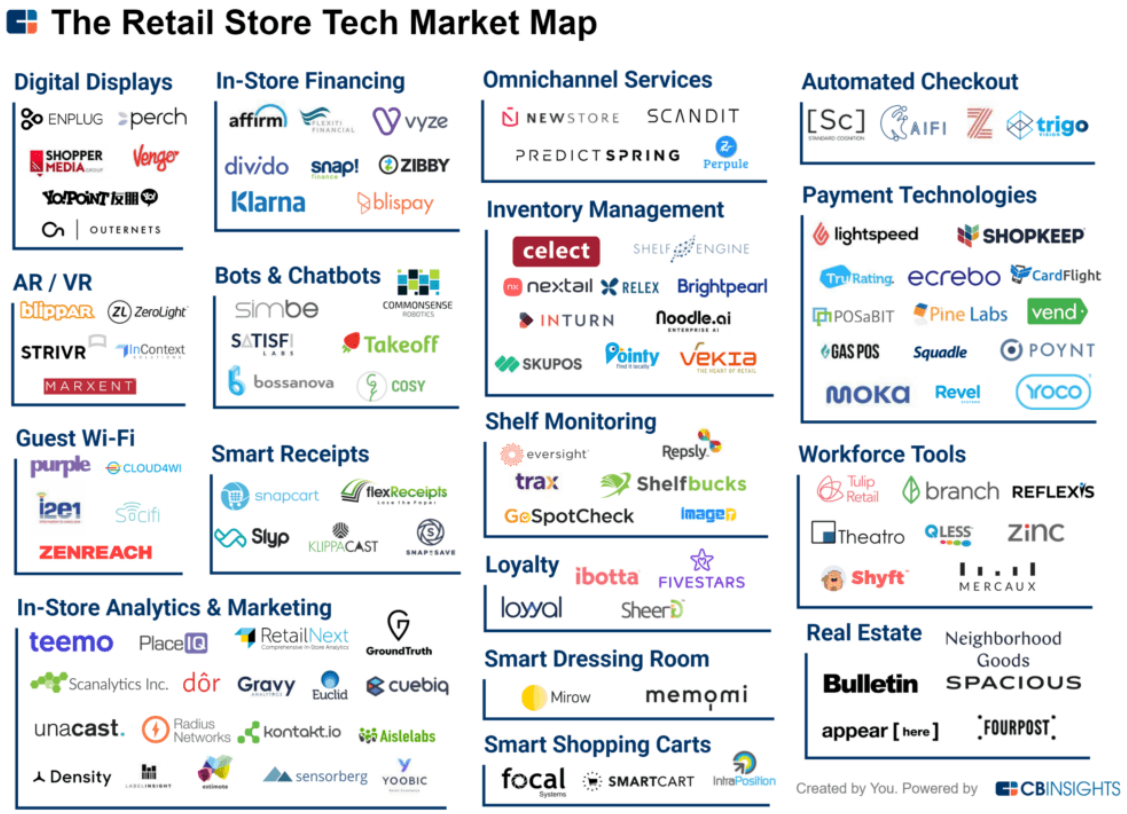
- **Improved efficiency** – Higher data throughput within businesses and between partners and customers.
- **Better coverage and flexibility** – Working without sitting at dedicated computers and working away from the office. BYOD (Bring Your Own Device)
- **Cost savings and improve productivity**
- **Virtual try-on technology** - to help in-store customers see what a particular makeup would look like on them before they buy
- **Free wireless** - Access to the Internet on the go



https://www.statista.com/topics/779/mobile-internet/

Business – The Needs

- **Smart shelves**
- **An augmented reality application on the smartphone** - that triggers when one enter a store and guiding him/her directly to the shelf where the items are.



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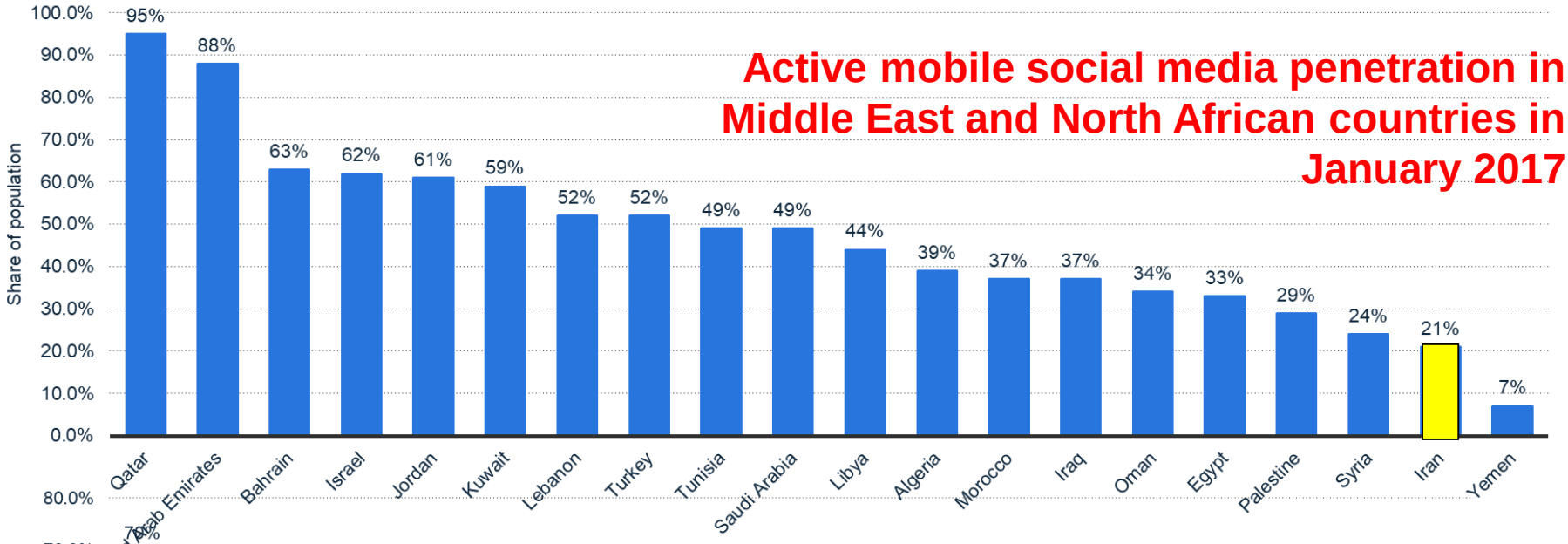
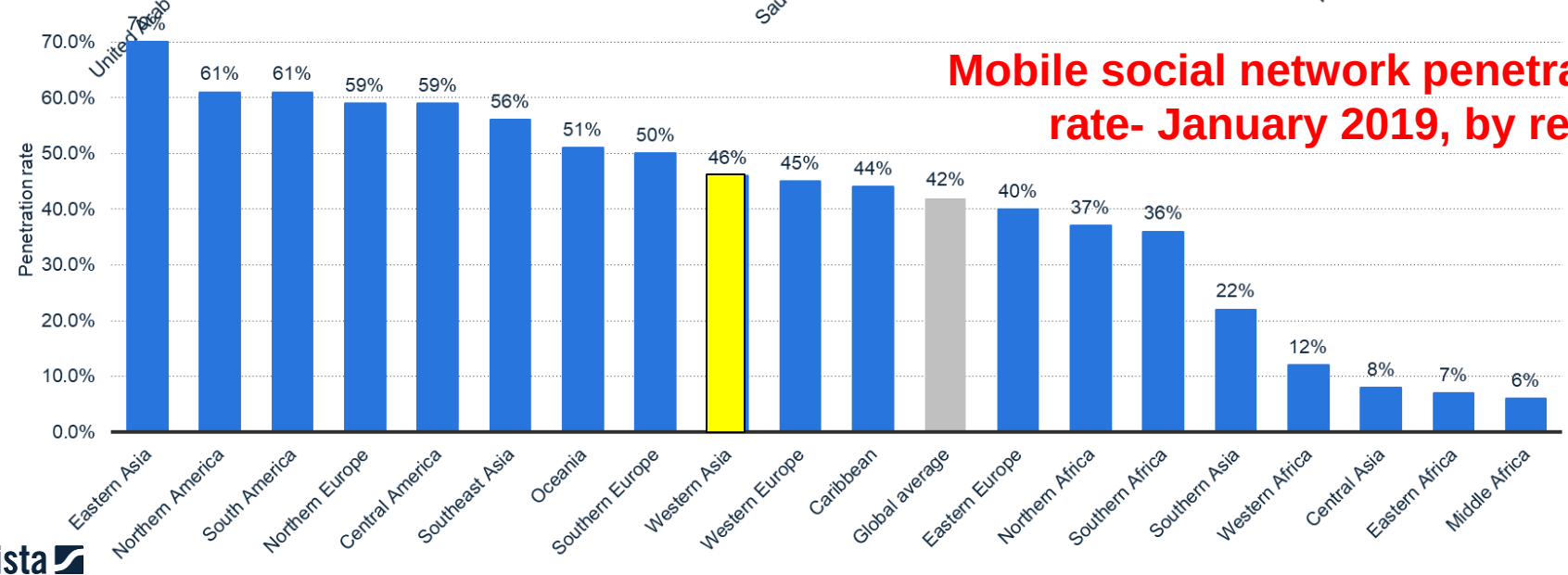
Global Data

Active mobile social media penetration in Middle East and North African countries in January 2017



Mobile social network penetration rate- January 2019, by region



statista

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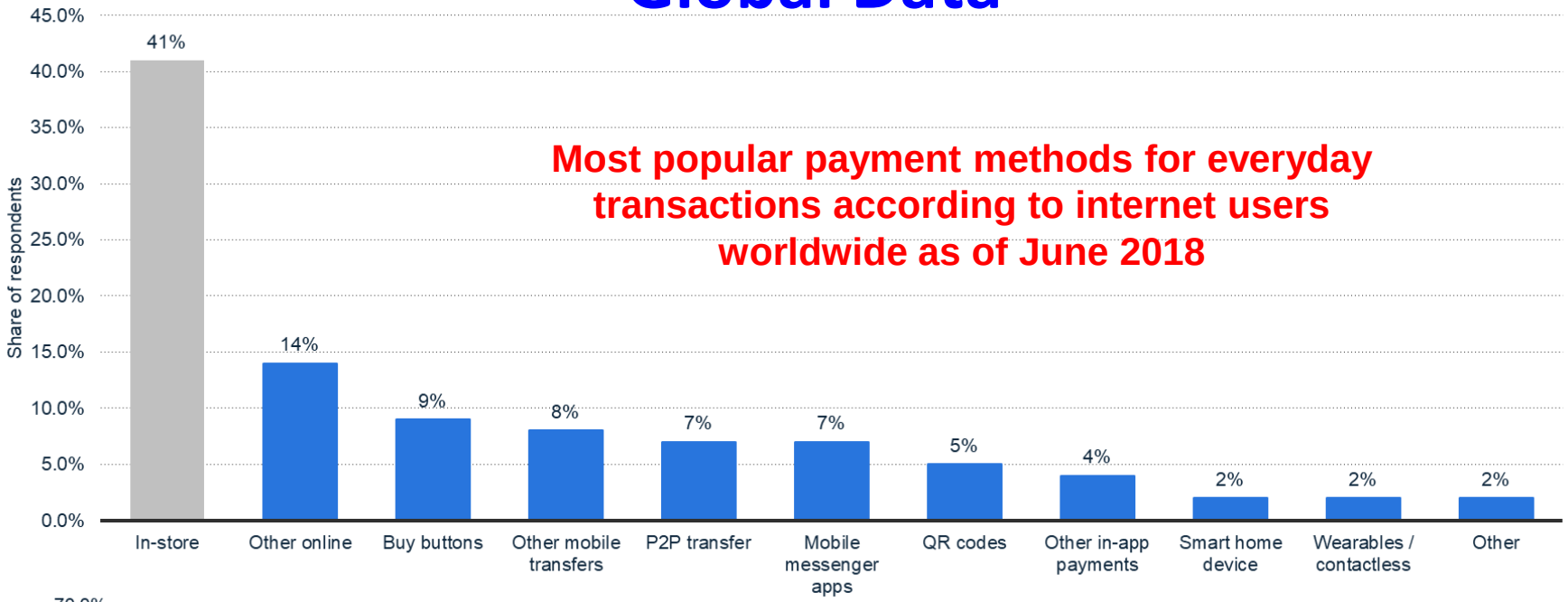
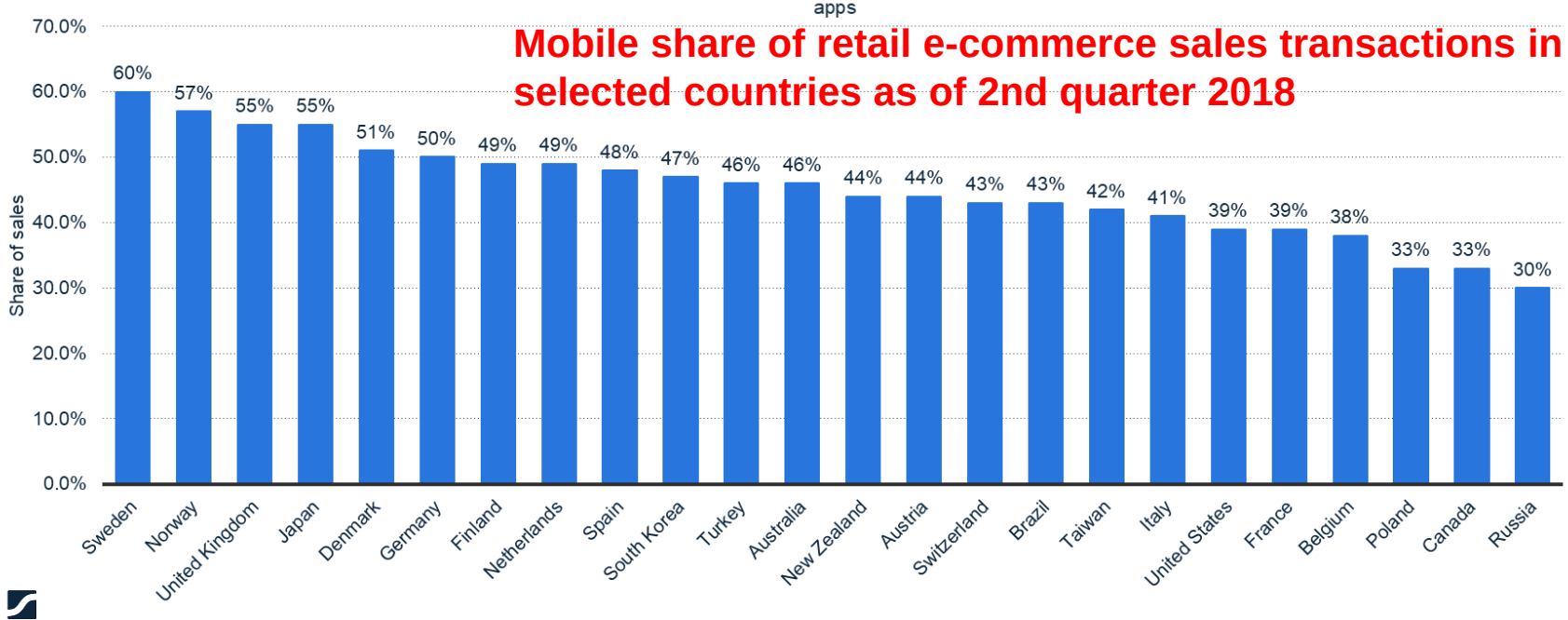
Global Data





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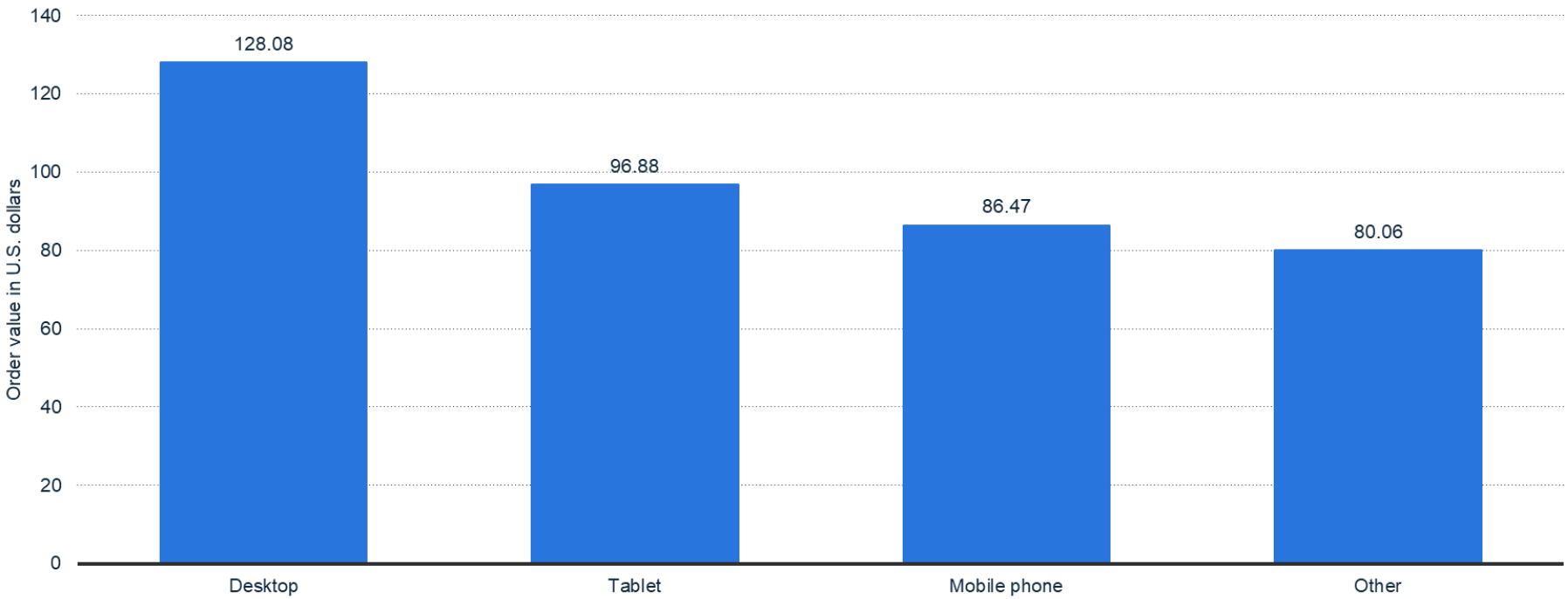
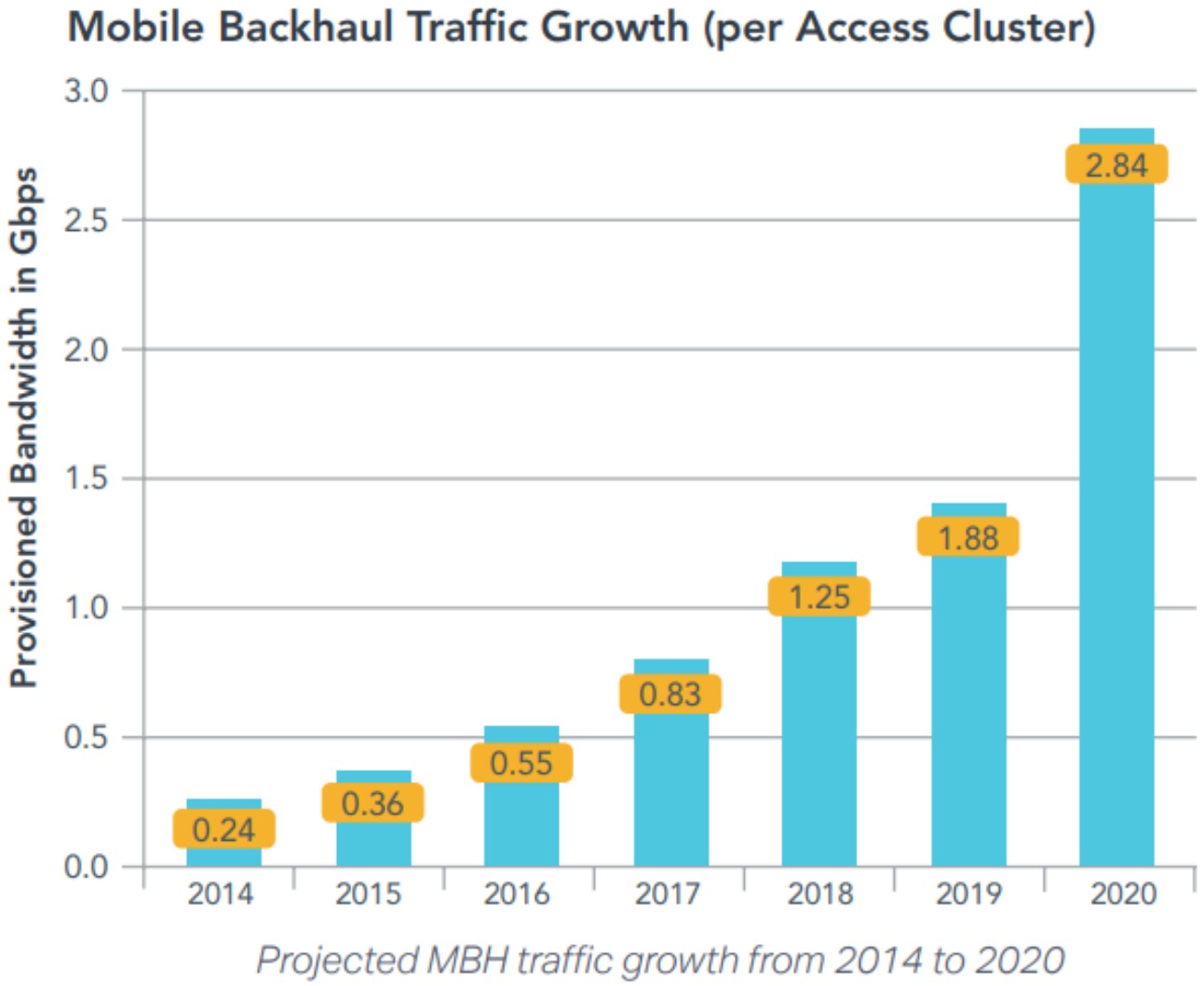
Global Data



Average value of global online shopping orders as of 2nd quarter 2019, by device (in U.S. dollars)

statista

Global Data



https://www.ciena.com/insights/articles/5G-wireless-needs-fiber-and-lots-of-it_prx.html

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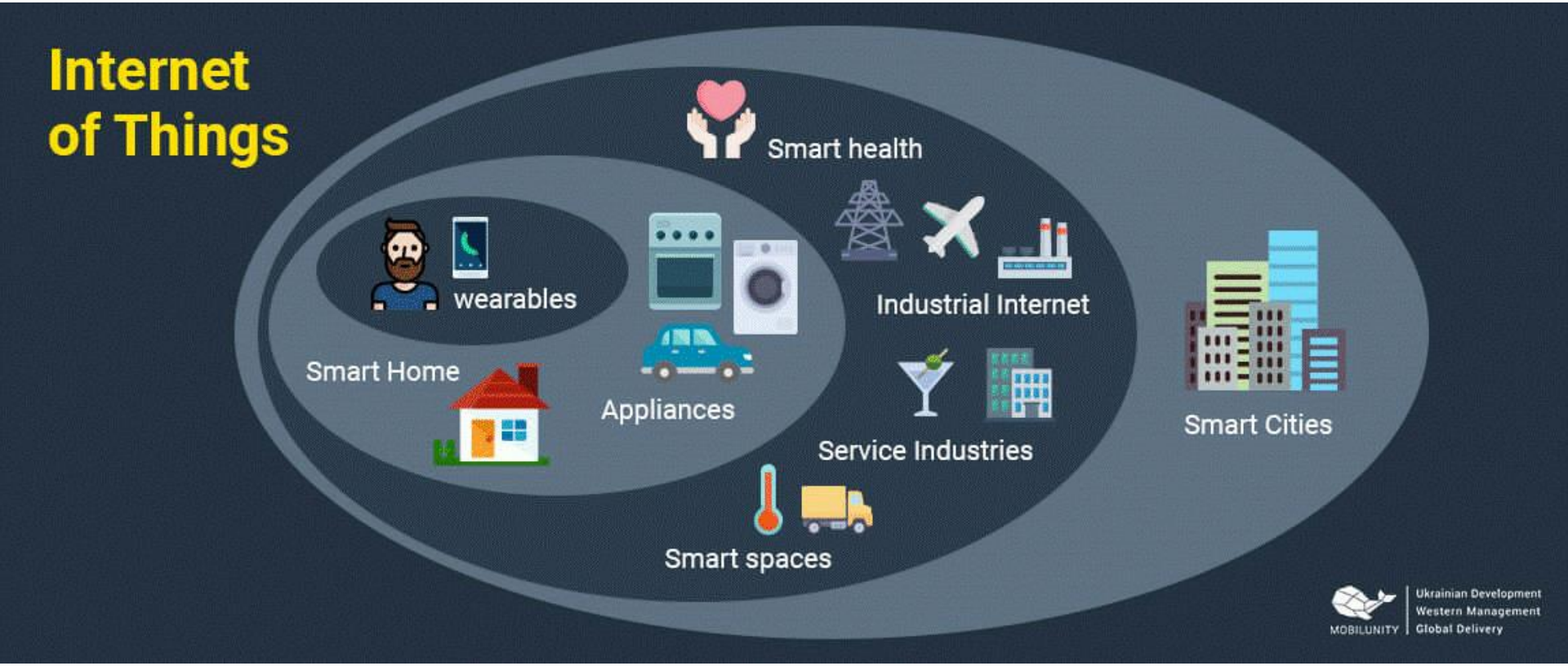
Internet of Things



More device → More Data → Higher channel bandwidth → More problems

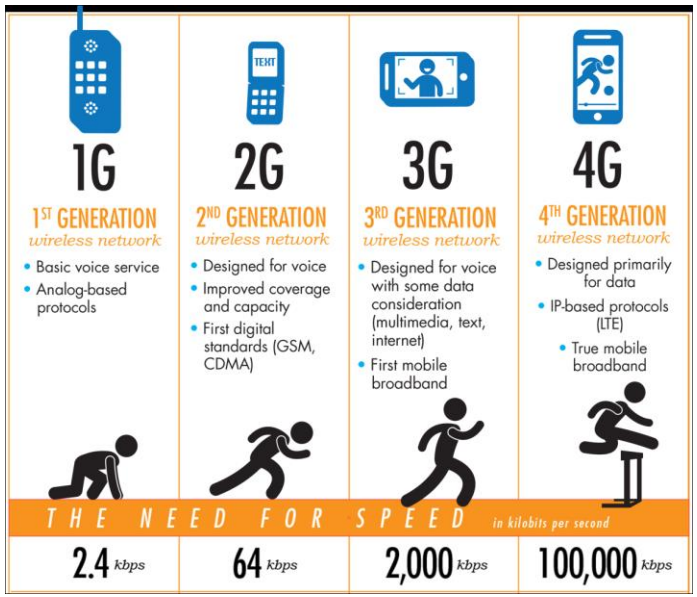
Wireless Communications – Current Status

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*

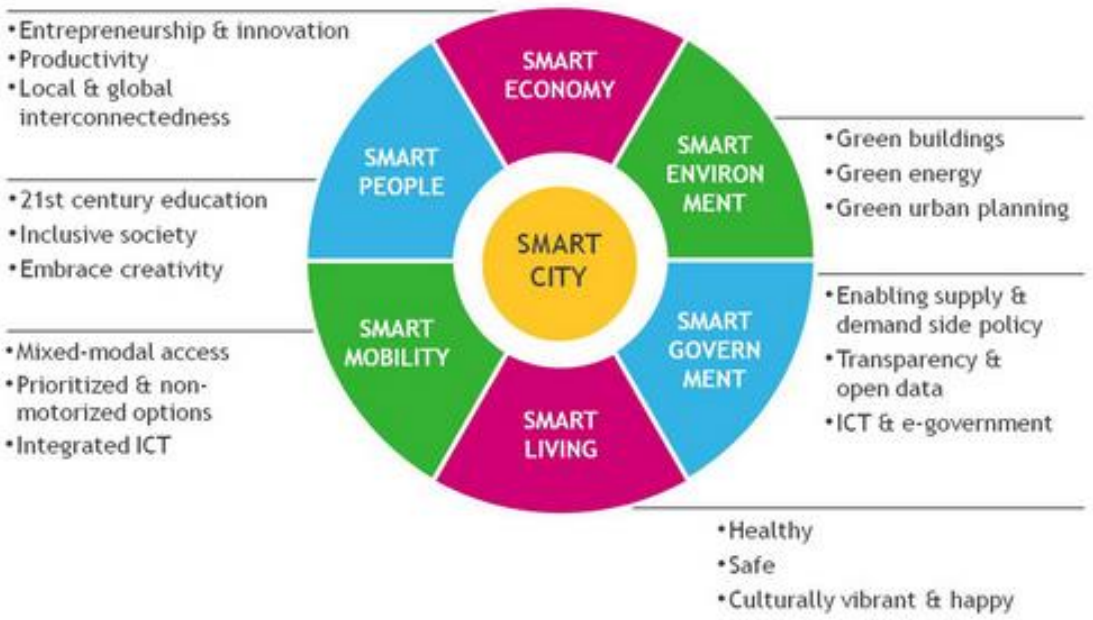
Network Throughput = Cell density × Available spectrum × Spectrum efficiency

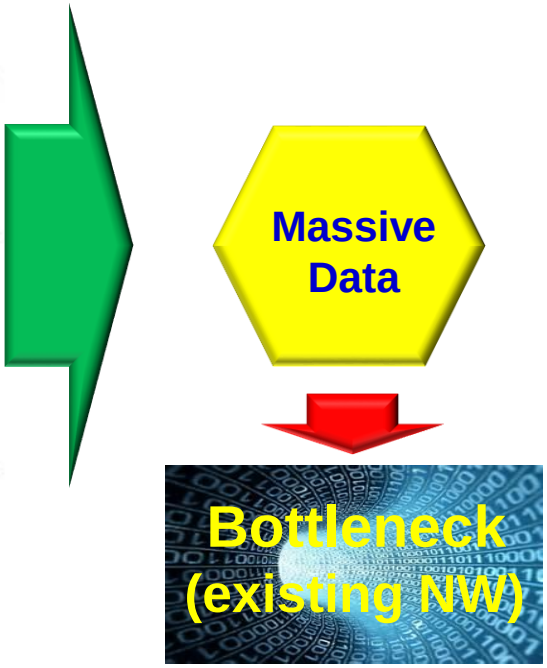
(bit/s in area) (Cell/area) (Hz) (bits/s/Hz/Cell)



- All Radio Frequency based technologies
- Limited data rates
- As the world continues to move, so does the improvement of technology.

Global Data Traffic - So What Is the Real Problem?



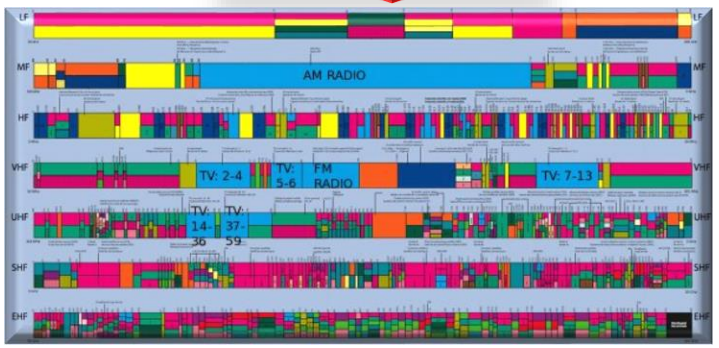


Smart Cities - promote the interaction between the human and the environment, enhance the reliability, resilience, operational efficiency, and energy efficiency.

- **2015** – 1.1 billion connected things
- **2020** – 9.7 billion[1]

[1] Gartner Inc.

https://techzine.alcatel-lucent.com/smart-cities-are-built-smart-networks

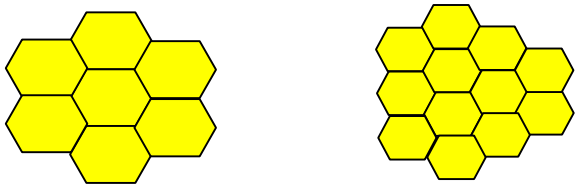


Spectrum (frequency) congestion

How to Overcome the Spectrum Congestion? [1/2]

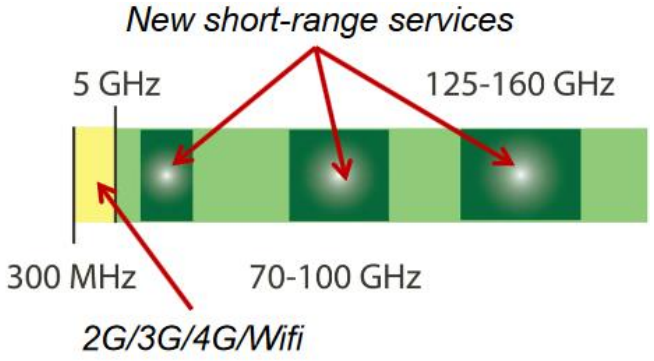
Increased Cell Density

- Divide cell radius by x →x^2 more cells
- Expensive: Rent and deployment cost



Higher Frequencies

- Above 5 GHz: High propagation losses
  - Mainly short range WiFi?

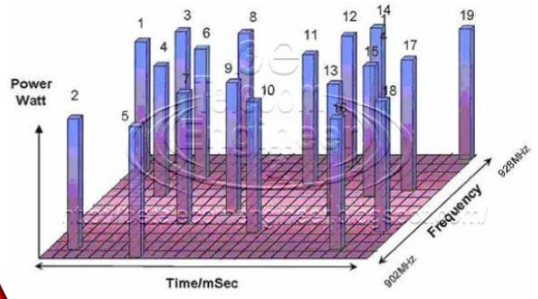


Higher Spectral Efficiency

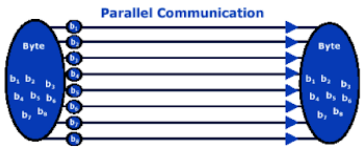
- No big improvements in the past
- **Can it be the driving force in future networks?**

Sharing Resources

- Spectrum hopping
- Spectrum borrowing



Advance Modulation Coding



More Efficient Protocols

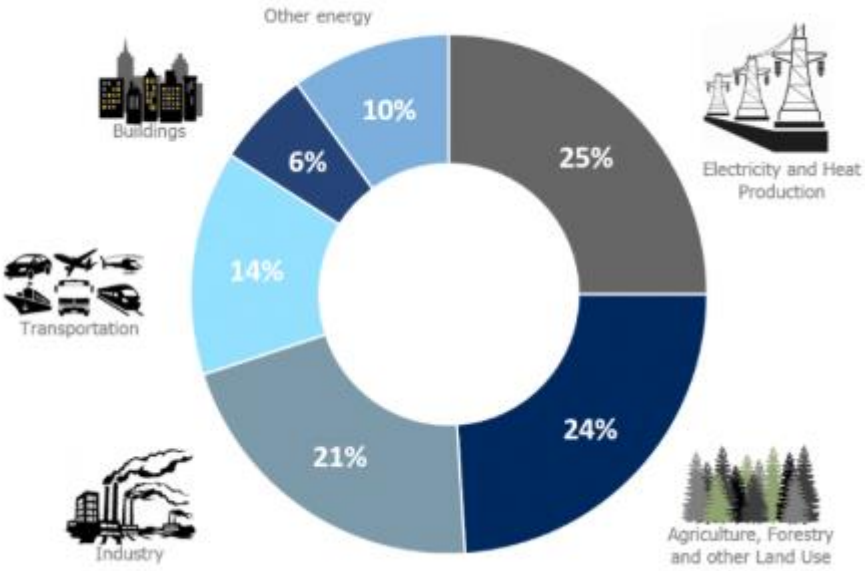
How to Overcome the Spectrum Congestion? [2/2]

Target:
- Very high dense deployment
- Very high capacity: 10-100 Gb/s
- Very low latency; Distributed access; Scalability

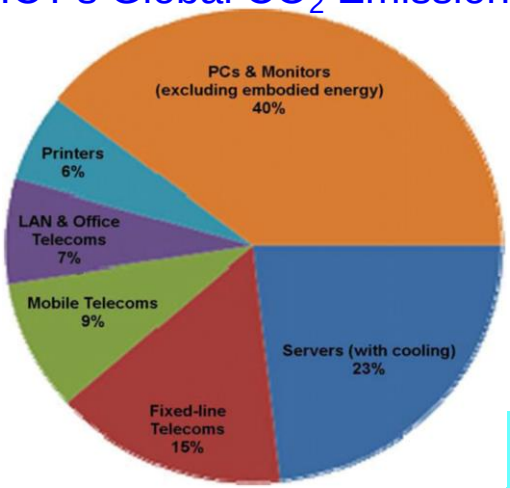
Not be based on a single access technology, but a number of different complementary and disruptive enabling technologies when confronting the ever-serious challenge of the balance of spectrum- and energy-efficiency:
- **Massive MIMO**
- **Super-dense meshed cells/macro-assisted small cells**
- **Enhanced VoIP**
- **New modulation/coding**
- **mmWave – 15 GHz; 28 GHz; 60 GHz; > 70 GHz, etc.**
- **VLC?**

- 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

Global Carbon Emissions – ITC Contributions

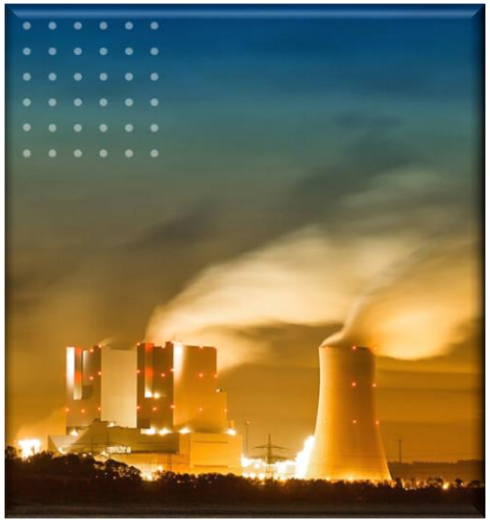


ICT's Global CO_2 Emissions



3.3% World-wide Energy

III



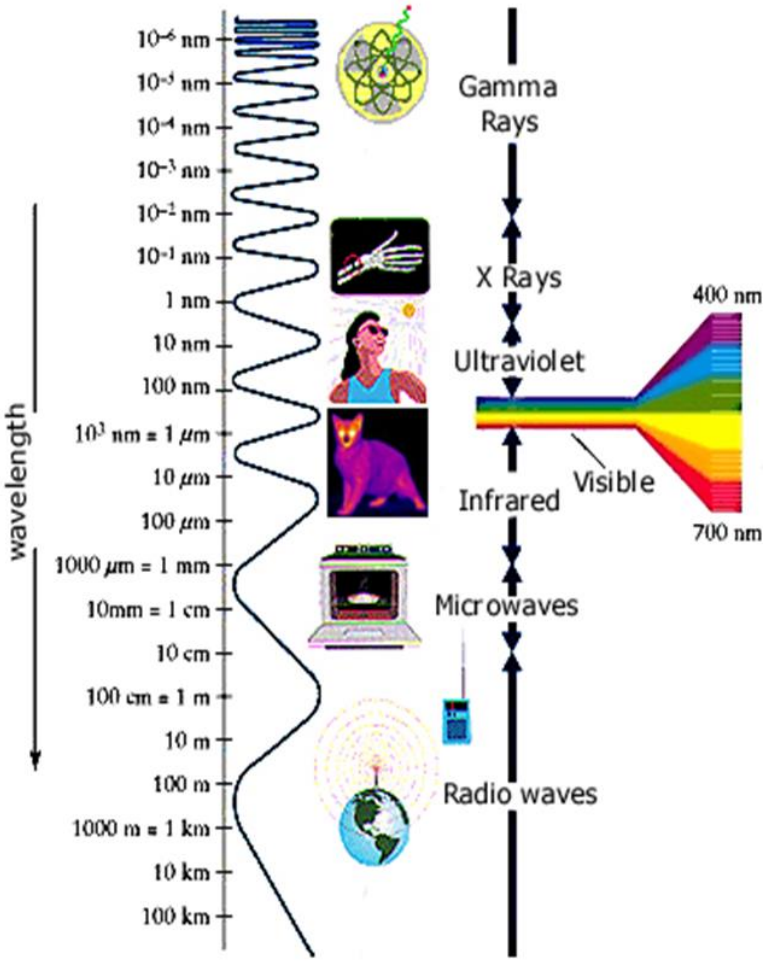
All commercial

http://climatechange-theneweconomy.com/green-chemistry-braskem/

https://solarimpulse.com/energy-crisis-solutions

Visible Light Communications – Optical Camera Communications

- Concept
- Typical Applications
- Our contributions
- Others contributions
- Concluding Remarks



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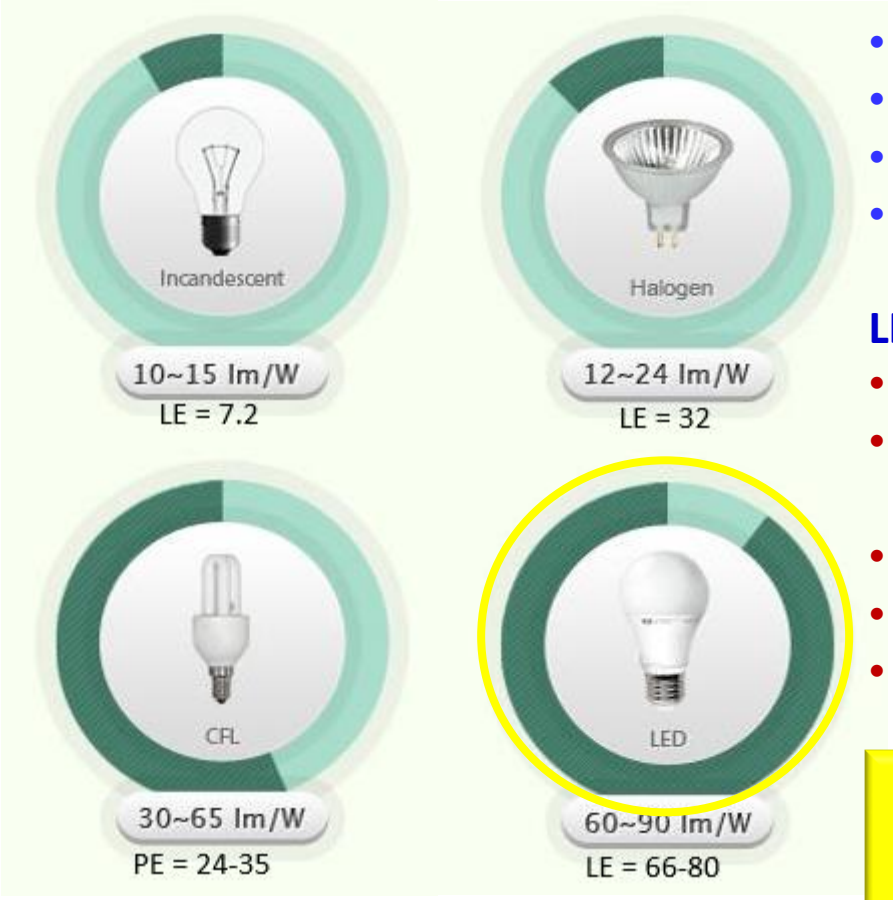
General Lighting Sources



- **LEDs** - 30,000 to 100,000 hours - **6 to 30 years**
- **Incandescent bulbs** - 1000 to 5000 hours
- **CFLs** - 8,000 to 10,000 hours
- **Fluorescent tubes** - 20,000 to 50,000 hours

LED Benefits by 2025[1]

- Lower electricity demands for lighting by **62%**.
- Reduce carbon emissions by **258 million metric tons**.
- Diminish amount of materials in landfills.
- Prevent construction of **133 new power plants**.
- Save **$280 billion**.

Market: Expected to grow 30.8% compound annual growth rate (CAGR) from $13 billion (2012) to $ 86.08 billion (2019).

PE: Power efficiency
LE: Luminous efficiency

[1]The U.S. Department of Energy

LEDs offer much faster SWITCHING speed!

What To Do With LED Switching?

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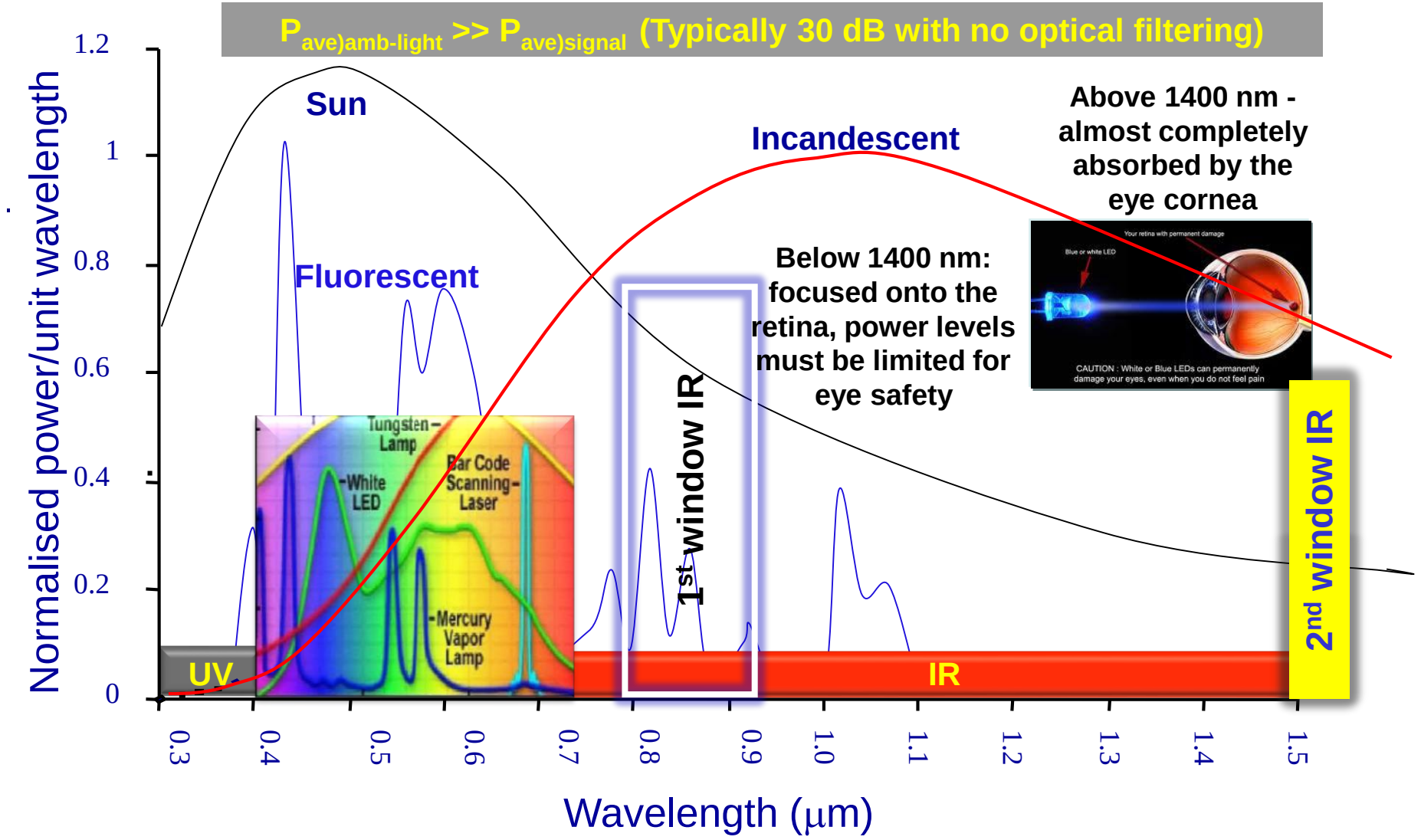
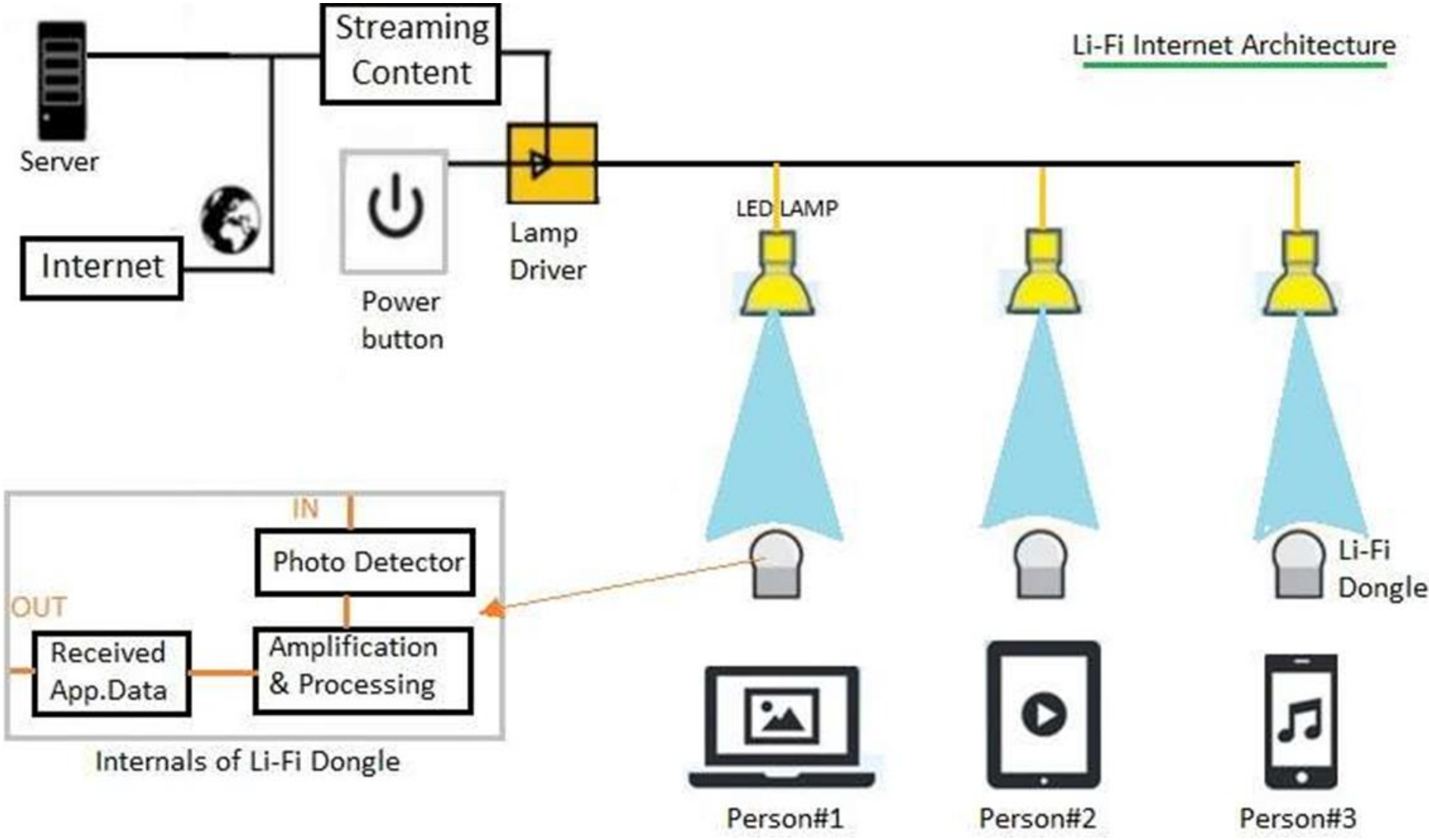
OWC - Transmission Windows & Power Spectra of Ambient Light Sources

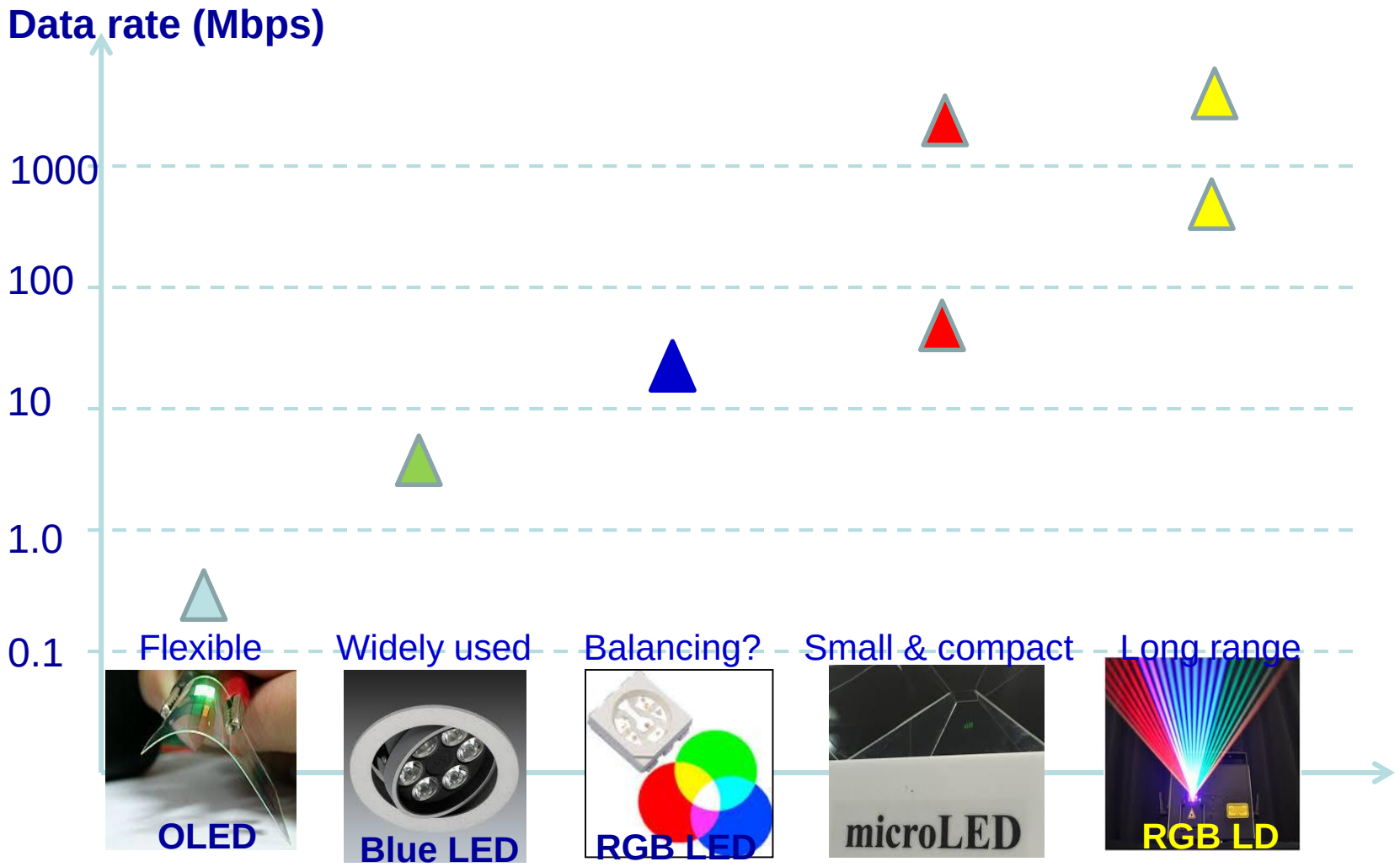


VLC – The Concept

IEEE 802.15.7 and 802.15.7r1



VLC – Light Sources



1- Grubor, Jelena, et.al, 33rd European Conf. and Exhibition of , vol., no., pp.1-2, 16-20 Sept. 2007.
2- D. Tsonev, H. et al, A 3-Gb/s single-LED OFDM based wireless VLC link using a gallium nitride LED, IEEE Photonics Technology Letters, vol. 36, pp. 637640, Apr. 2014.
3- P. A. Haigh, Z. Ghassemlooy, et al , Visible light communications using organic light emitting diodes, IEEE Communications Mag., 51, 8, pp. 148154, 2013
4- P. A. Haigh *et al*., "Hybrid Super-Nyquist CAP Modulation based VLC with Low Bandwidth Polymer LEDs," *2019 IEEE 30th PIMRC*, Istanbul, Turkey, 2019, pp. 1-6.

Light Source – OLED

- Next generation luminary

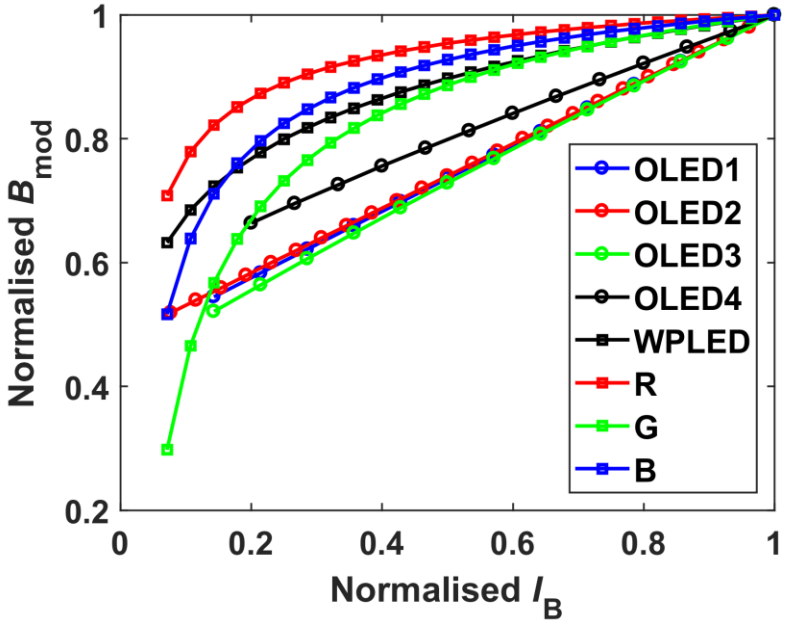
Display technology

Safety clothing

Home and office lighting

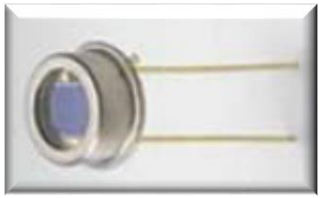
Home entertainment

Vehicular technology



- LEDs tested - Reached 80% B_{mod} within 17-35 % of I_B.
- OLEDs tested - Reached 80% B_{mod} within 47-61 % of I_B.

VLC – Detectors



PIN photodiode

- low cost, large area
- limited sensitivity

Avalanche photodiode (APD)

- higher sensitivity
- smaller area
- high reverse bias → higher cost

Issue with a single-element PD
- cannot be used effectively in direct sunlight.

Image sensors

- **CCD type**: low cost, slow due to serial read-out
- **array type**: pixels are operated like parallel photodiodes → fast but high price, mass market would be revolutionary for optical wireless
- ability to **separate sources spatially**

J. Rufo et al.: Experimental Evaluation of Video Transmission Through LED Illumination Devices, 2013
N. Bani Hassan *et al*., "Non-Line-of-Sight MIMO Space-Time Division Multiplexing Visible Light Optical Camera Communications," in *Journal of Lightwave Technology*, vol. 37, no. 10, pp. 2409-2417, 15 May15, 2019.

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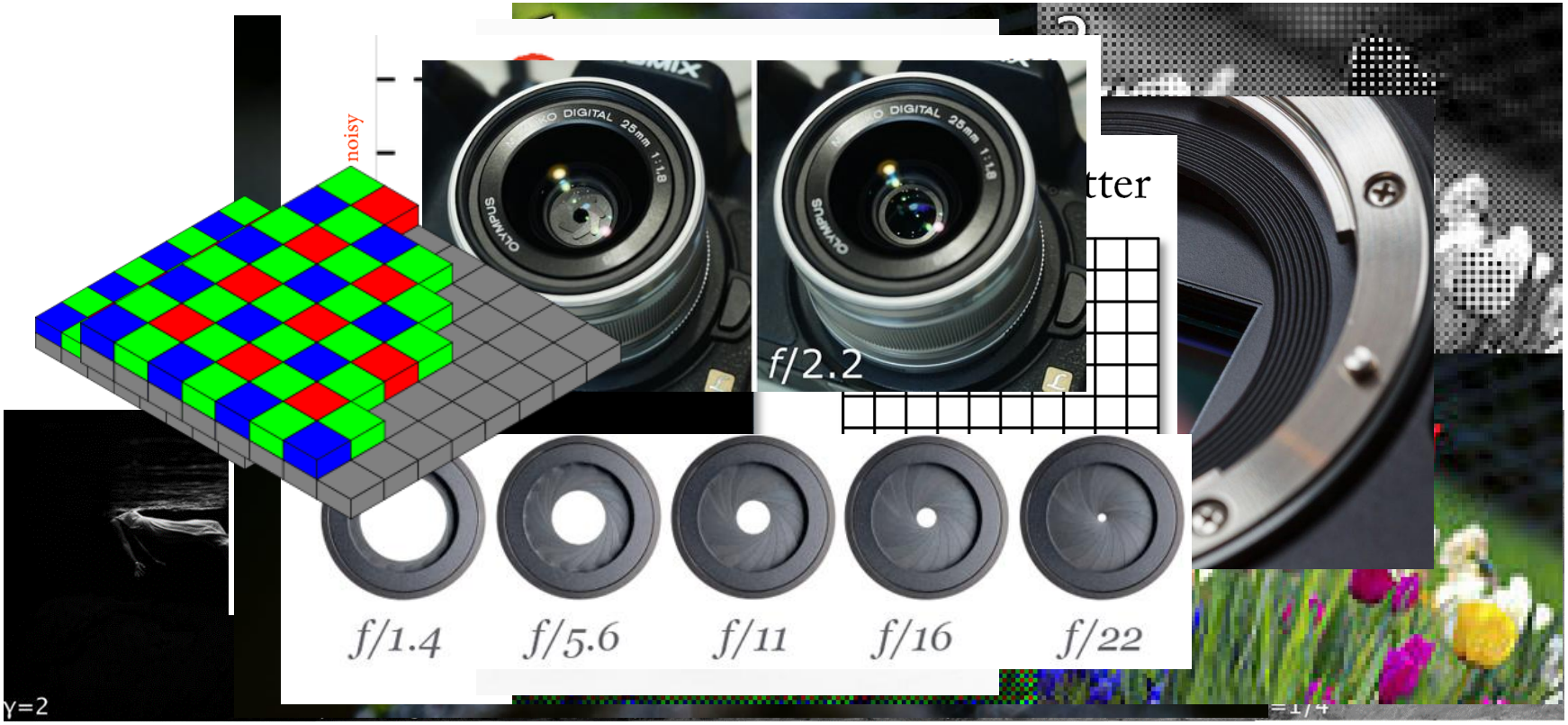
Optical Camera Communications – A Camera (IS)

Lens System	Aperture	Shutter	Sensor	ISO	Quant-ization	DeBayering	Gamma Correction



B. Lin, Z. Ghassemlooy, C. Lin, X. Tang, Y. Li, and S. Zhang, "An indoor visible light positioning system based on optical camera communications," *IEEE Photonics Technology Letters*, vol. 29, no. 7, pp. 579-582, 2017.

Optical Camera Communications – Why?

Massive MIMO Mobility Available

Data Rate

Diversity

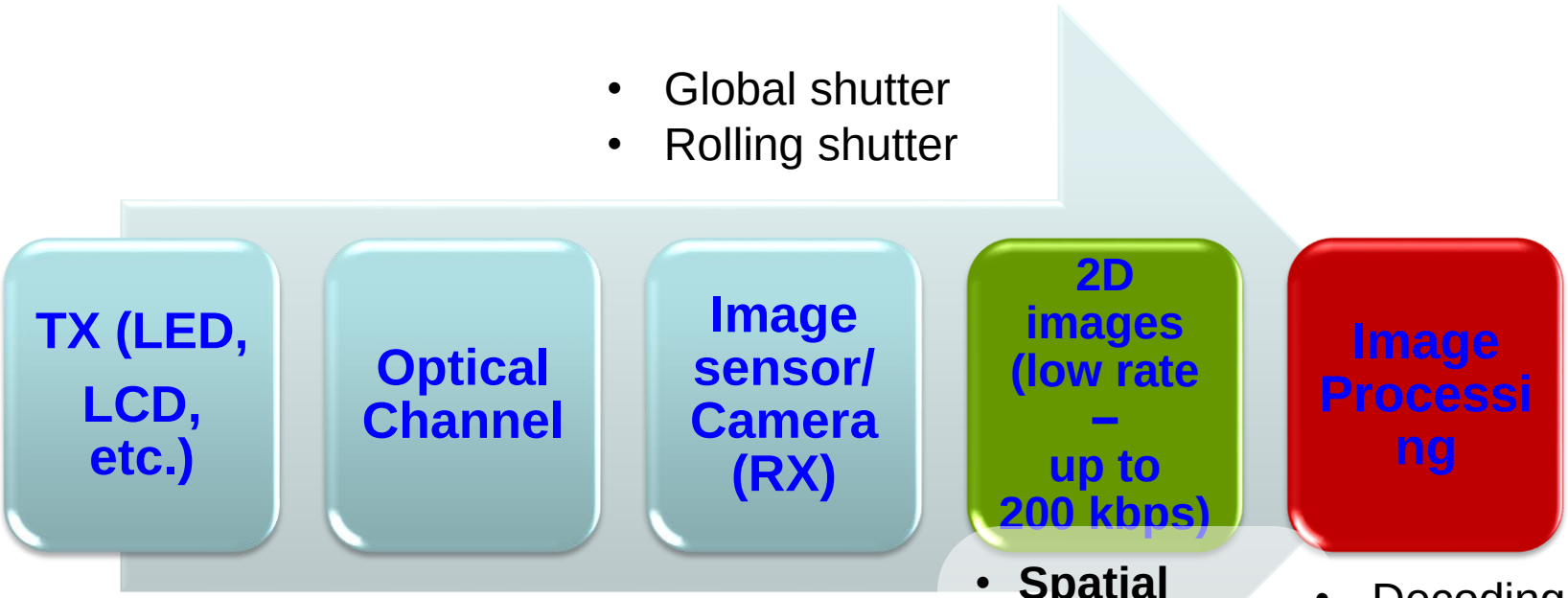
Spatial Division

N. Bani Hassan, Z. Ghassemlooy, S. Zvanovec, M. Biagi, A. M. Vegni, M. Zhang, and P. Luo, "Non-Line-of-Sight MIMO Space-Time Division Multiplexing Visible Light Optical Camera Communications," IEEE/OSA J. Lightwave Technol. 37, 2409-2417, 2019.
Chowdhury, M.Z.; Hossan, M.T.; Islam, A.; Jang, Y.M. A comparative survey of optical wireless technologies: Architectures and applications. IEEE Access 2018, 6, 9819–9840.

OCC – Concept

IEEE 802.15.7r1

Dare rates: A few kbps



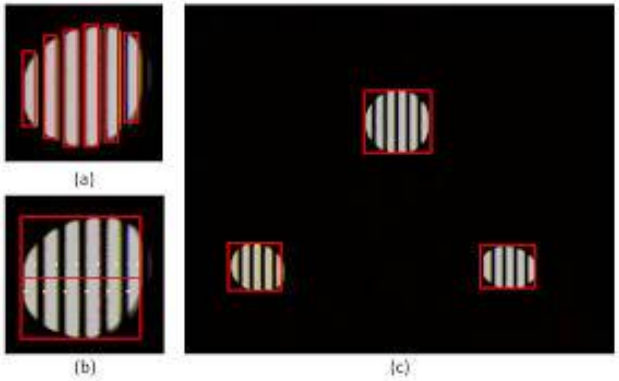
N. B. Hassan, Y. Huang ; Z. Shou ; Z. Ghassemlooy; A. Sturniolo; S. Zvanovec; P. Luo; and H.-Minh, "Impact of Camera Lens Aperture and the Light Source Size on Optical Camera Communications," 2018 11th Intern. Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP), Budapest, Hungary, 2018, pp. 1-5
Luo, P.; Zhang, M.; Ghassemlooy, Z.; Le Minh, H.; Tsai, H.M.; Tang, X.; Png, L.C.; Han, D. Experimental demonstration of RGB LED-based optical camera communications. IEEE Photonics J. 2015, 7, 1–12.

OCC – Concept

Global shutter cameras - The entire frame is exposed at one time; therefore, it captures either the ON or OFF state of an LED.

Rolling shutter cameras

- The image is captured using row-by-row exposure.
- Demodulation – Is done by measuring the widths and thresholding of strips.



For a fixed frame rate:

- The camera **exposure time** needs adjusting to deal with LED's ON-OFF status and capture a black and white striped image.
- However, the **widths of these strips** depend on the frequency of modulation.

Issues:

- **Low frame rates**
- **Focusing**
- **Real time processing in smartphone**

Lee, H.Y.; Lin, H.M.; Wei, Y.L.; Wu, H.I.; Tsai, H.M.; Lin, K.C. RollingLight: Enabling line-of-sight light-to-camera communications. In Proceedings of the Thirteenth Annual International Conference on Mobile Systems (ACM MobiSys), Florence, Italy, 18–22 May 2015.

N. B. Hassan, Y. Huang ; Z. Shou ; Z. Ghassemlooy; A. Sturniolo; S. Zvanovec; P. Luo; and H.-Minh, "Impact of Camera Lens Aperture and the Light Source Size on Optical Camera Communications," 2018 11th Intern. Symp. on Communication Systems, Networks & Digital Signal Processing (CSNDSP), Budapest, Hungary, 2018, pp. 1-5

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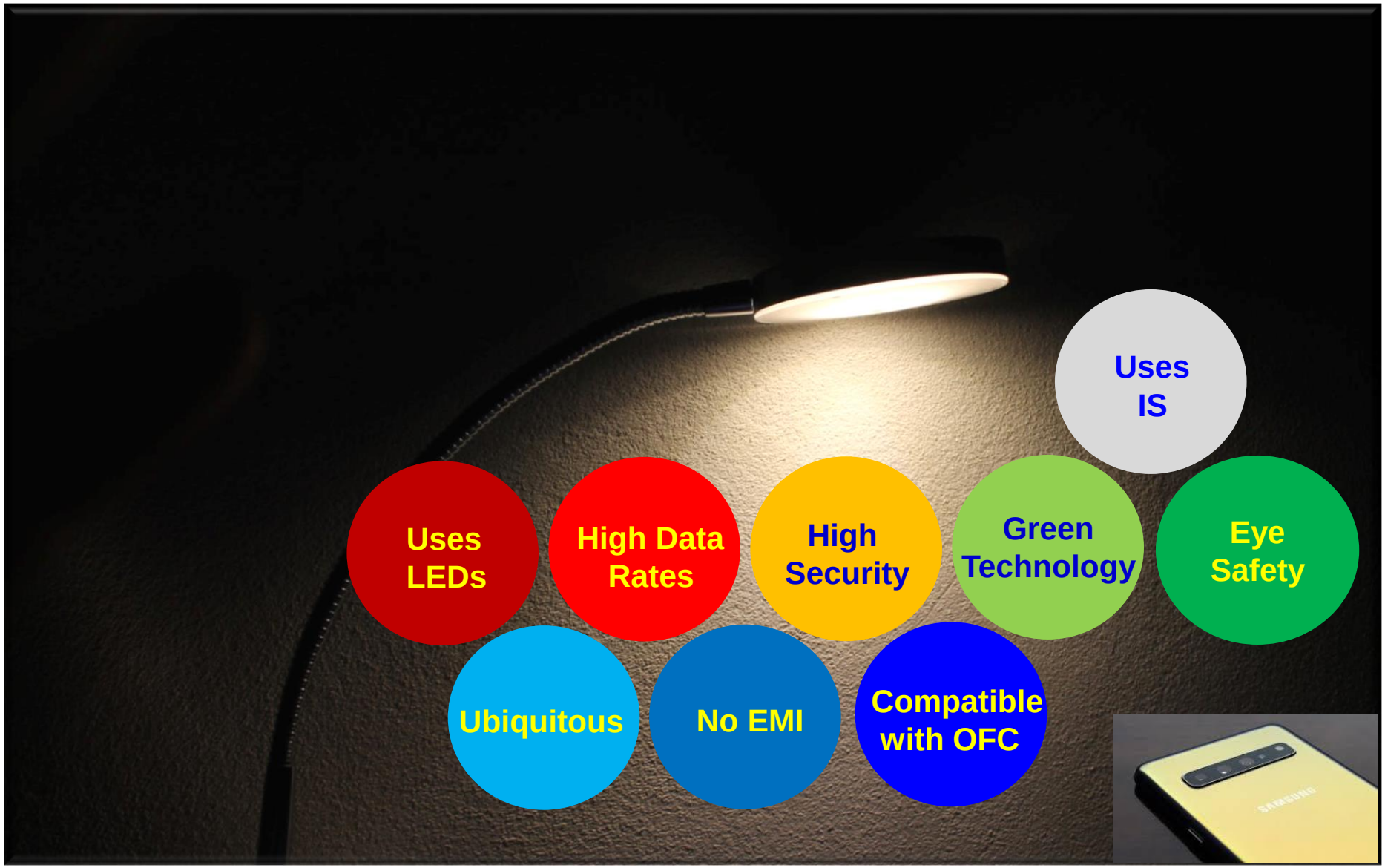
VLC-OCC – Features



VLC – OCC – Applications

Where LED and IS are used for illumination and vision can be employed in:

Inter- and Intar-Chip

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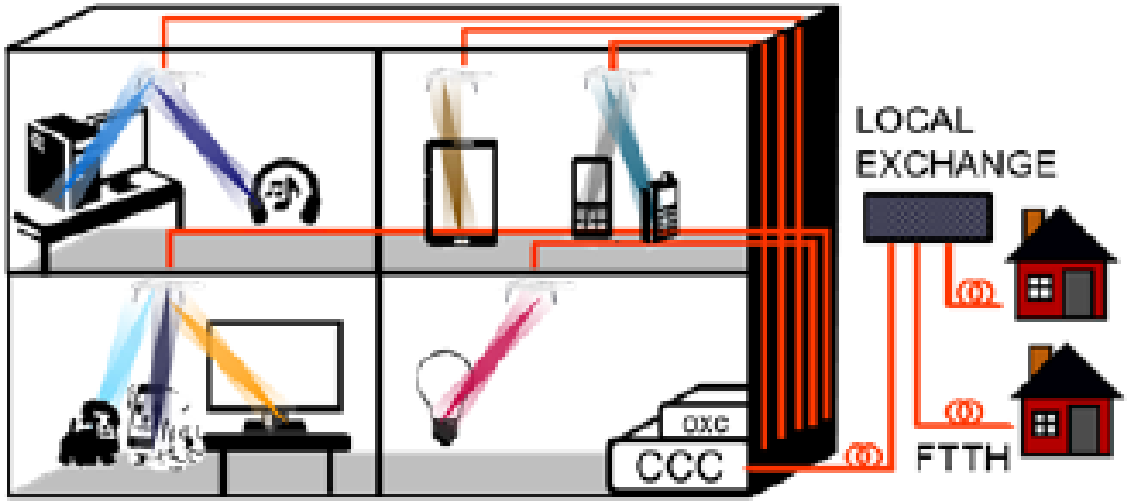
VLC – OCC - Projects

1. **Last meter access network**
2. Medical
3. IoT
4. Smart environments
5. GPS
6. Internet of Vehicles (IoV)
7. Others

VLC – OCC – Access Network

Oh Chin Wan, et al, Low-crosstalk Full-duplex All-optical Indoor Wireless Transmission with Carrier Recovery, IEEE PTL, 2016, Eindhoven University of Technology

- **Connected to indoor network via central communication controller (CCC)**
- **Data routed to different rooms via optical cross-connect and a fiber-backbone network.**



- Still no decision been made
- **WiFi** - typically offers a lower channel capacity, but highly mobile
- **IR – Mature technology**
- **VLC** – LED and Laser
  - Broad beam profile of LEDs - a trade-off between the link budget and bandwidth
  - Laser source - The need for beam steering, which leads to latency and complex receiver hardware.
- **Hybrid**

K. Wang et al., "Experimental Demonstration of Full-Duplex Optical Wireless Personal Area Communication System with 16-CAP Modulation," in *Proc. OFC*, Los Angeles, 2015, paper M2F.7

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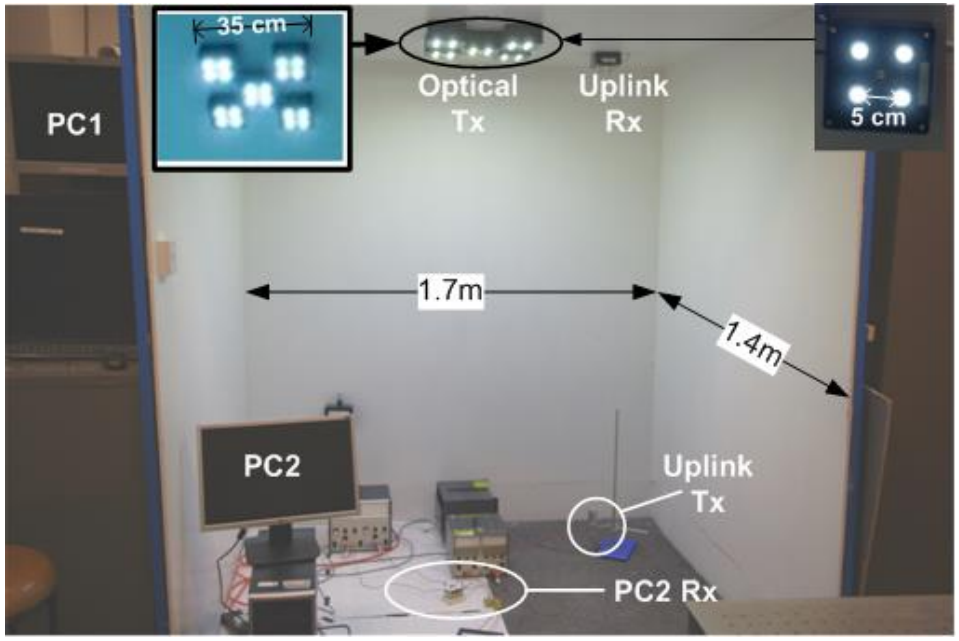
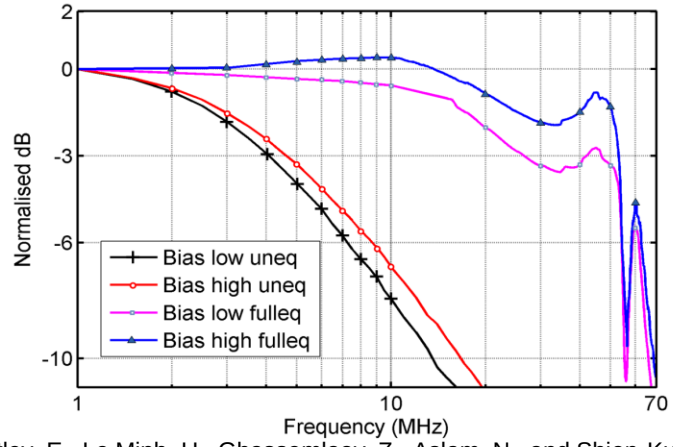
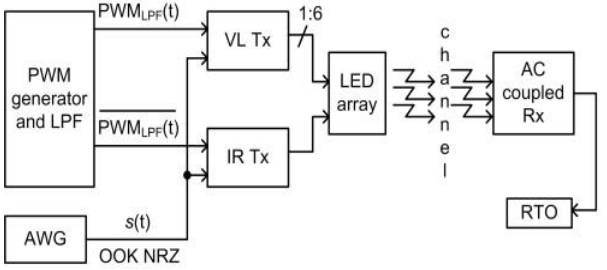
VLC – OCC – Access Network

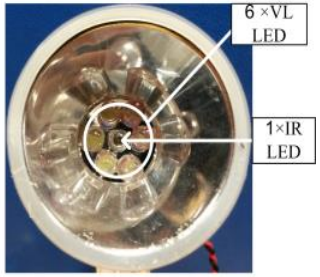
Hybrid VLC – IR (down link)

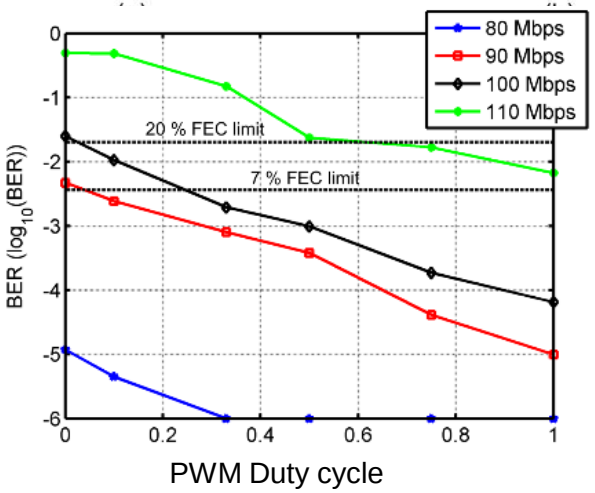


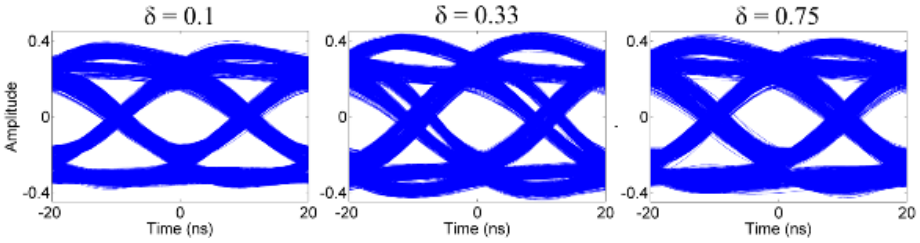


Hybrid Dimmable VLC - IR







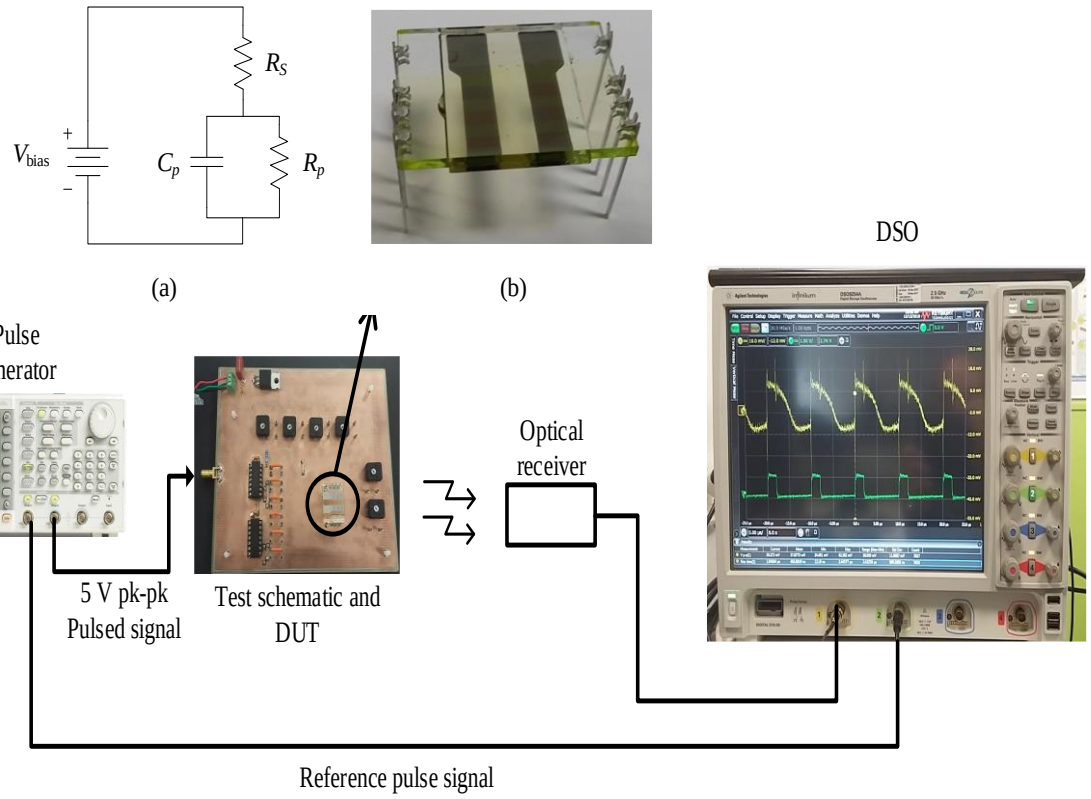


Burton, A., Bentley, E., Le Minh, H., Ghassemlooy, Z., Aslam, N., and Shien-Kuei L.: "Experimental demonstration of a 10BASE-T Ethernet visible light communications system using white phosphor light-emitting diodes," IET Circuit, Devices and Systems, 8 (4), pp. 322-330, 2014

VLC – OCC – Access Network

OLEDs

- Highly flexible
- As bright as standard LEDs
- Wide applications
- Lower modulation bandwidth – a few hundred KHz.

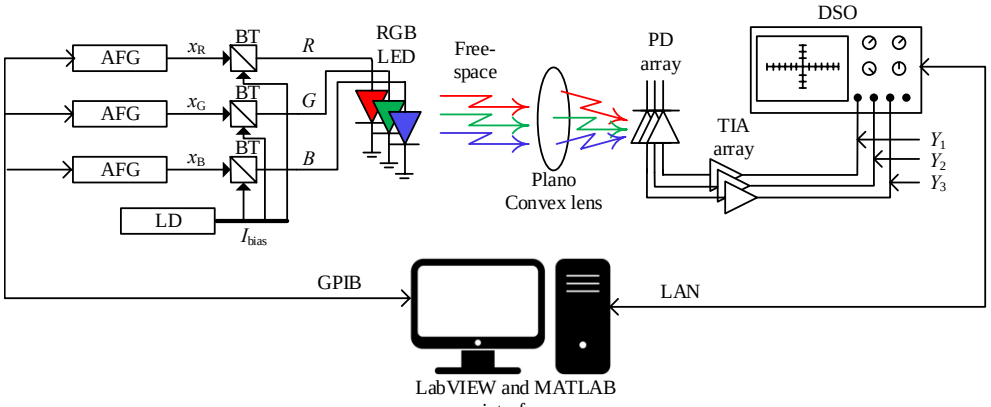


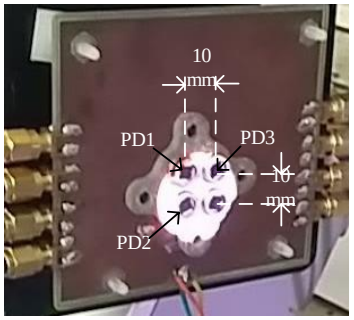
Signal	Q-factor		Statistical BER	
	1 Mbps	2 Mbps	1 Mbps	2 Mbps
Non equalised	3.14	1.72	8.38e-04	4.24e-2
Equalised	3.40	2.00	3.35e-4	2.26e-2

A Burton, A Minotto, P A Haigh, Z Ghassemlooy, et al, Optoelectronic Modelling, Circuit Design and Modulation for Polymer-Light Emitting Diodes for Visible Light Communication Systems, ICT Conf. 2019

VLC - Defocused RGB MIMO

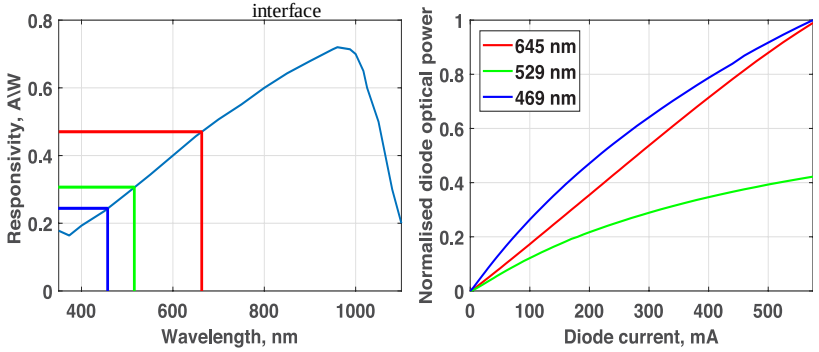
De-multiplexing R, G and B streams out of the cumulative white beam to recover the data on each colour without using tunned optical filters.



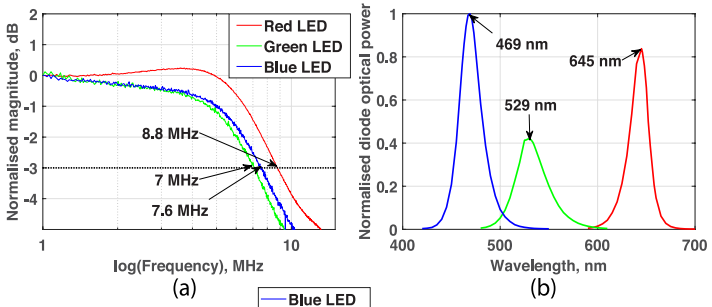


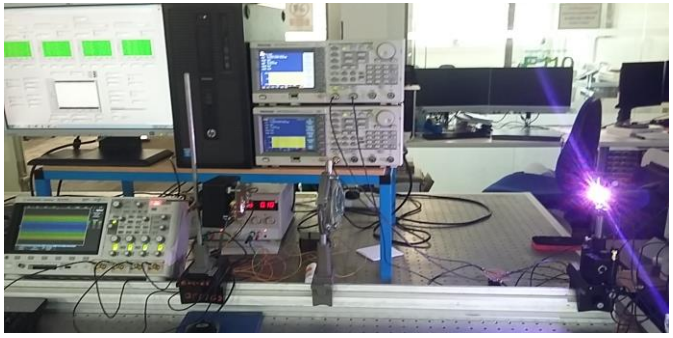
Demultiplexing via ZF algorithm on **H** matrix channel state information.

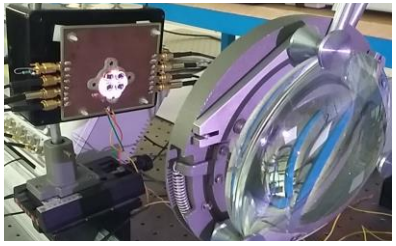
Diversity required by **H** is achieved via electro-optical conversion of LEDs, PD array wavelength-dependent responsivity and the defocused beam spot on PD array.

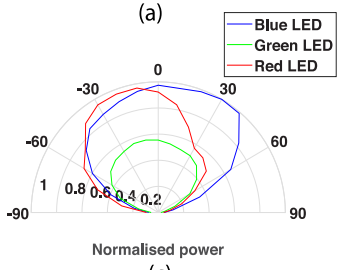


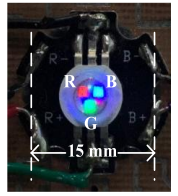
(b)











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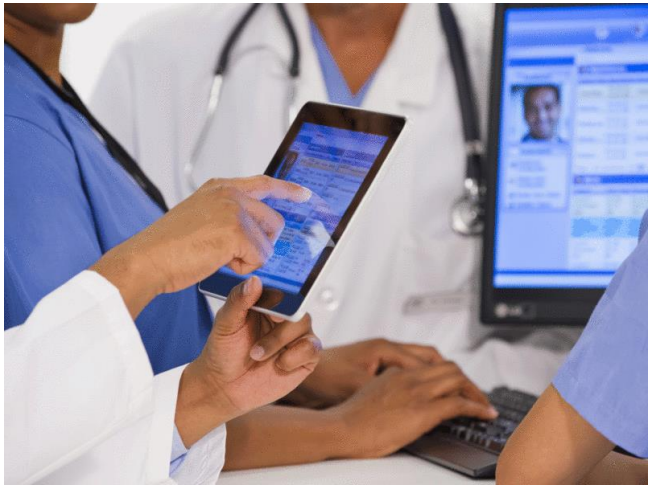
VLC – OCC - Projects

1. Last meter access network
2. **Medical**
3. IoT
4. Smart environments
5. GPS
6. Internet of Vehicles (IoV)
7. Others

HoF - Digital Technology

- With the world going mobile and more connected, **the use of IoT and AI (Machin Learning)** are making the big leap in healthcare sector.
- **Telemedicine -** promotes continuity of care, decreases the cost of care, and improves patient self-management and overall clinical outcomes
  - In the past, telemedicine was strictly limited to doctor and nurse consultation.
- However, proliferation of **smart mobile devices** capable of transmitting high-quality videos has opened up avenues for virtual healthcare services from specialists to patients straight in their homes.



HoF - Requirements

	Data rate	Reliability	Mobility	Security	Latency	Sensitivity (interference)	Sensitivity (exposure to RF)	Capacity (supported devices)
Inpatient care	2–5	4–5	1–2	4–5	1–3	3–4	2–4	3–5
Ambulatory care	2–5	4–5	1–2	4–5	1–3	3–4	2–4	2–4
Diagnostic/ treatment	4–5	4–5	1–2	4–5	1–3	3–5	2–4	2–4
Support services	4–5	4-5	1–3	4–5	1–3	3–5	2–4	3–5
Public spaces	3–4	3–4	1–3	4–5	2–4	1–2	2–4	3–5
Outpatient care (at home)	1–3	4–5	1–2	4–5	2-4	1–2	2–4	3–5
Outpatient care (on the move)	1–3	4–5	2–5	4–5	2–4	1–2	2–4	3–5

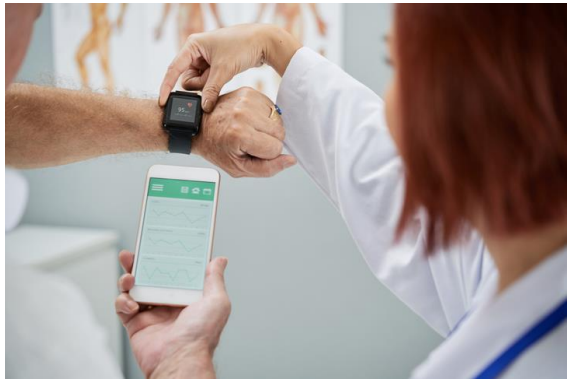
5: very-high; 4: high; 3: moderate, 2: low; 1: very-low

HoF - Requirements

- Enhanced performance
- Security
- Interference generation and tolerance
- Safety and privacy
- Spectrum usage
- Energy efficiency

So, which technologies?

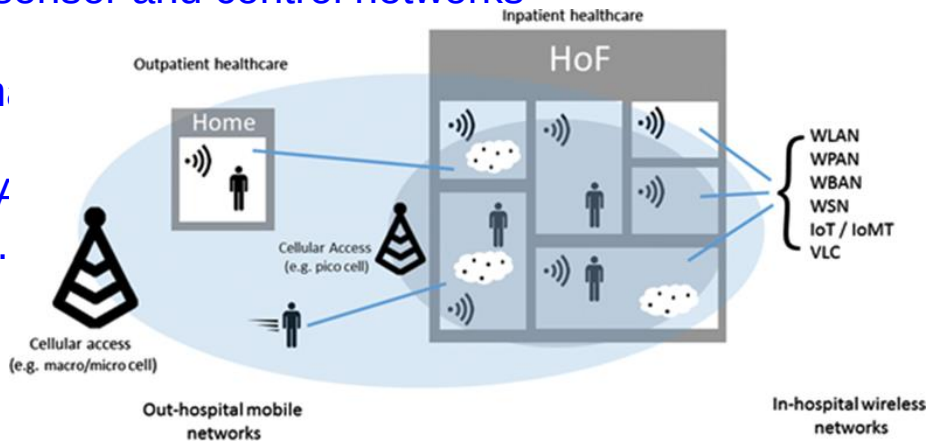
- RF
- VLC
- Hybrid optical-RF:
  - efficient
  - high-performance
  - dynamically reconfigured to transmit and receive optical, RF or both signals, depending on the requirements of the application.



C. X. Wang, F. Haider, X. Gao, X. H. You, Y. Yang, D. Yuan and E. Hepsaydir, Cellular architecture and key technologies for 5G wireless communication networks, *IEEE Communications Magazine*, Vol. 52, No. 2, pp. 122–130, 2014.
H. Thimbleby, Technology and the future of healthcare. Journal of Public Health Research, Vol. 2, No. 3, 2013.
Ahmed, I., Karvonen, H., Kumpuniemi, T. et al. Int J Wireless Inf Networks (2019).

HoF – RF Technologies

- Well-developed, flexible, inexpensive and widely standardized.
- Two major approaches:
  - **Centralized cellular networks:** wide area coverage – 5G Pico-cell
  - **Short-range:** shorter than few hundred meters
    - Wireless local area networks (e.g., Wi-Fi)
    - WiGig: High-speed wireless 802.11ac, 1Gbps using the 40 GHz increasing to 10 Gbps at 60 GHz
    - Bluetooth smart
    - ZigBee: low-power, low-cost wireless sensor and control networks
    - Apple iBeacon: Retail-oriented
    - Cisco Intelligent Proximity: Content Sh
    - Wireless sensor networks (WSN)
    - Wireless personal area networks (WP/
    - Wireless body area networks (WBAN).



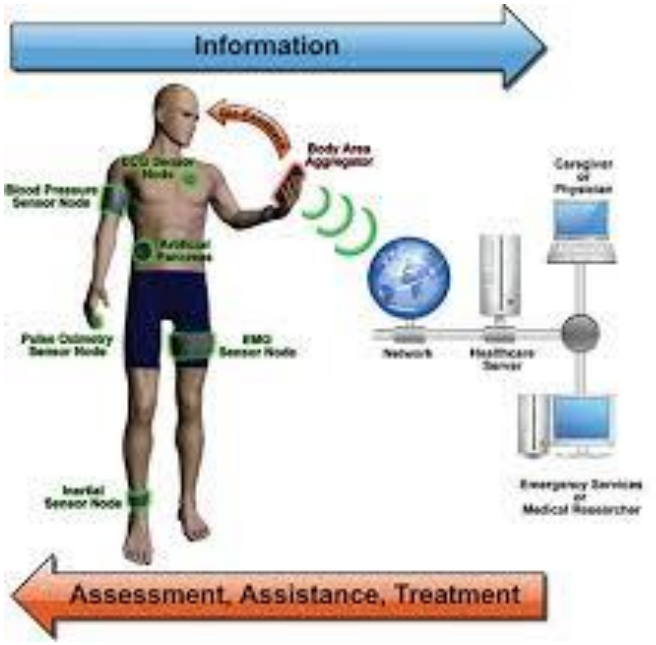
But

- **Interference** with medical equipment
- **Security**
- **Range** - May need repeaters or additional access points
- **Speed** - Slower than the slowest common wired networks.

Alemdar and C. Ersoy, Wireless sensor networks for healthcare: a survey, *Computer Networks*, Vol. 54, No. 15, pp. 2688–2710, 2010. 22.
A. Mainwaring, et al, Wireless sensor networks for habitat monitoring. *Proce. of the 1st ACM Intern. Workshop on Wireless Sensor Networks and Applications*, ACM, pp. 88–97, 2002. 23.
V. Jones, R. Bults, D. Konstantas, and P. Vierhout, Healthcare PANs: Personal Area Networks for trauma care and home care, 2001. 24.
S. Ullah, et al, A comprehensive survey of wireless body area networks, *Journal of medical Systems*, Vol. 36, No. 3, pp. 1065–1094, 2012. 25.
H. Zhang, et al, Connecting intelligent things in smart hospitals using NB-IoT, *IEEE Internet of Things Journal*, Vol. 5, No. 3, pp. 1550–1560, 2018.

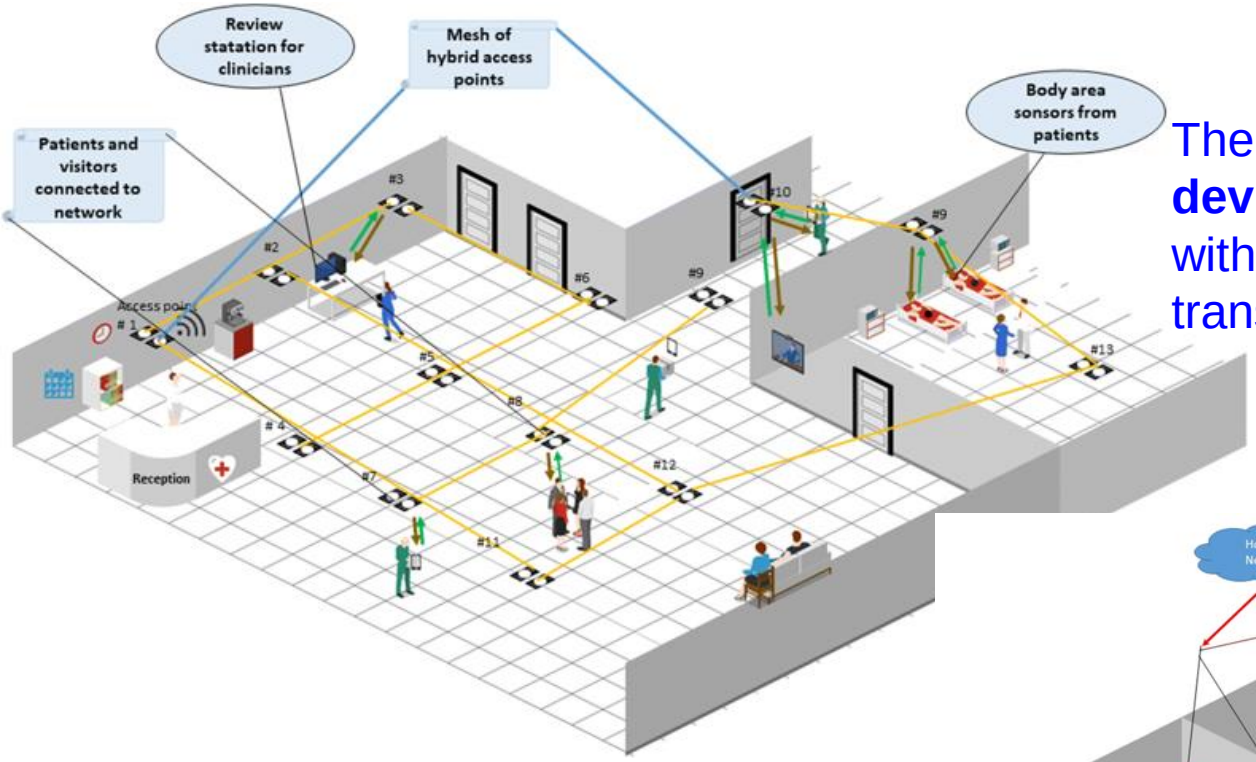
HoF - 5G with VLC – OCC

- Cover small areas
- For expansion of both **preventative** and **monitoring practices** via wearable devices. *For track everything from sleep to blood glucose levels to physical activity, .*
- Remote diagnoses – *Using microscopic cameras to provide real-time video in and out of patients' bodies.*
- Wearables devices - *Tracking patients for more personalized monitoring and care without visiting a hospital.*
- Robotic surgery - *To expand the ability of doctors to bring critical and specialized care services to patients worldwide.*
- No eavesdropping
- Reduced RF radiation exposure to patients
- Localization and positioning – *Staff, patient, equipment*

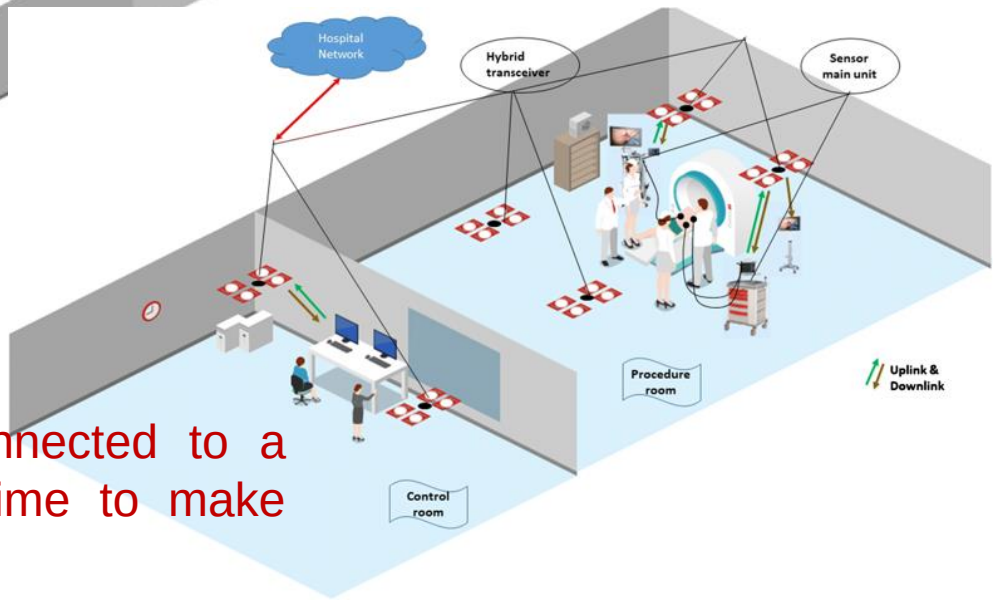


W. Noonpakdee, Adaptive wireless optical transmission scheme for health monitoring system, in 2013 IEEE ICCE-Berlin, pp. 161–64, 2013.
R. Murai, et al, A novel visible light communication system for enhanced control of autonomous delivery robots in a hospital, in 2012 IEEE/SICE SII, pp. 510–6, 2012.15.
C. Huang and X. Zhang, Impact and Feasibility of Darklight LED on Indoor visible light positioning system, in *2017 IEEE 17th International Conf. on Ubiquitous Wireless Broadband (ICUWB)*, IEEE, pp. 1–5, 2017.

HoF - Hybrid Optical-RF Access Points



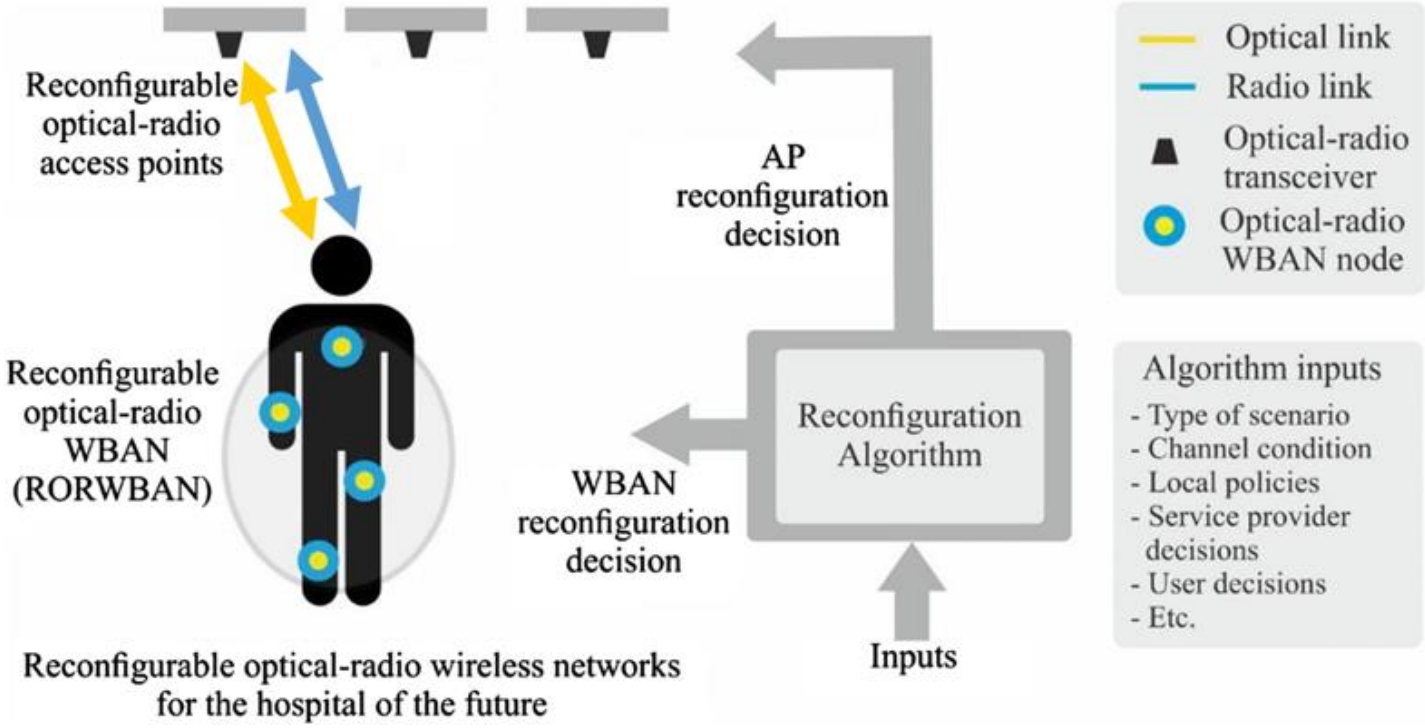
The data from **lifesaving devices** transmitted via **VLC** with **high throughput** and for transmitting bulk data.



VLC in RF sensitive area.

A number of sensing devices are connected to a patient and data is observed in real-time to make decisions.

HoF - Hybrid Optical-RF Access Points



Reconfigurable optical-radio wireless networks for the hospital of the future

	Inpatient care	Ambulatory care	Diagnostic/ treatment	Support services	Public spaces	Outpatient care (home)	Outpatient care (on the move)
RF	3–4	3–4	2–3	4–5	4–5	3–4	4–5
VLC	3–5	3–5	4–5	4–5	2–3	3–5	1–2
VLC + RF	4–5	4–5	4–5	4–5	3	4–5	

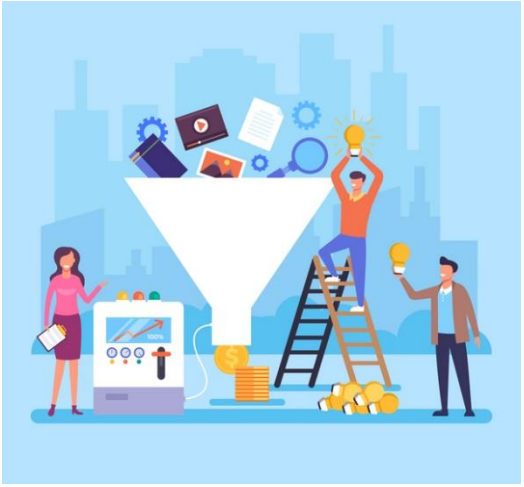
5: very-high; 4: high; 3: moderate, 2: low; 1: very-low

Ahmed, I., Karvonen, H., Kumpuniemi, T. et al. Int J Wireless Inf Networks (2019)

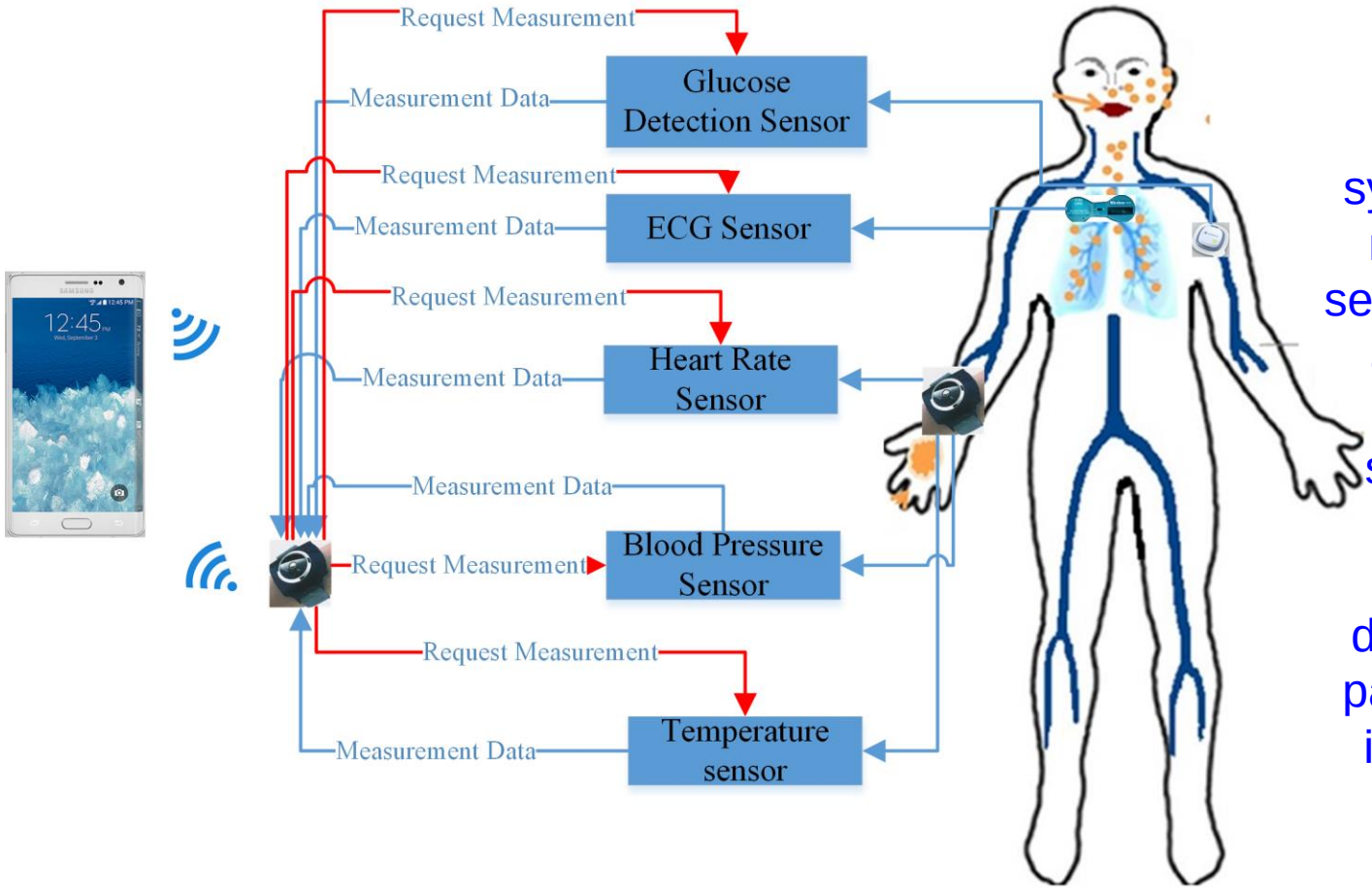
HoF - Hybrid Optical-RF Access Points

Challenges:

- **VLC with no LOS path** – Use hybrid systems in a seamless way in real-time to ensure communications without sacrificing security and reliability.
- **A smooth handover mechanism** - To ensure seamless communications
- **Latency**
- **Robust decision making algorithm** - Users moving around.
- **Load balancing** - To maximize the throughput in crowded hybrid network.
- **Eavesdropping** - Parallel **optical-RF** transmission
- **Optimize the hybrid system performance** - Collecting information on network nodes behaviour and communication related parameters and using **machine learning** and **AI**.



HoF - Optical IoT



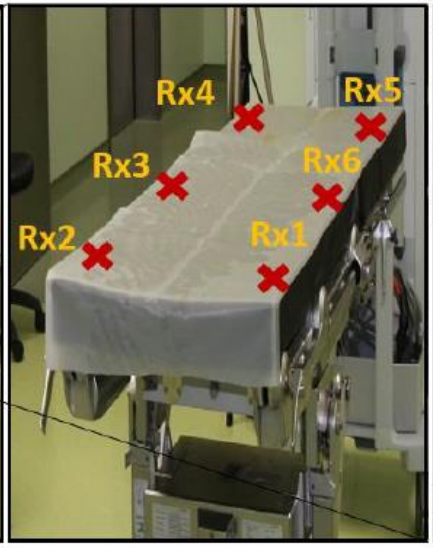
Sensors are periodically synchronized with the mobile node, which sends data sequentially and securely to the femtocell and subsequently to the cloud.

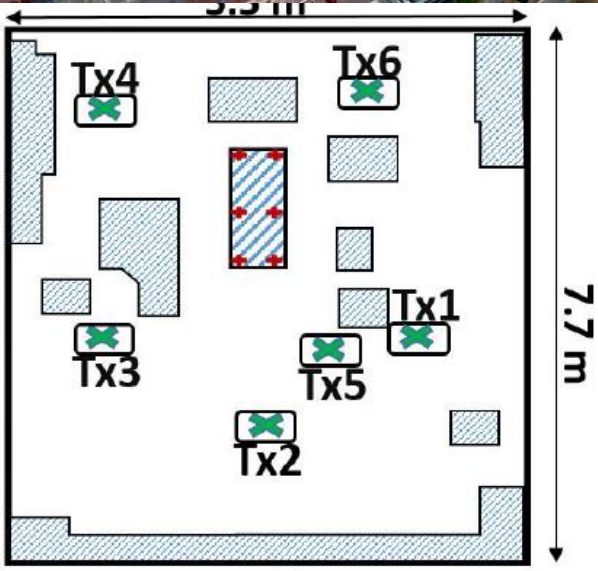
This sequence is directly related to the patient's situation and is predefined by the medical consultant section.

Hindia MN, Rahman TA, Ojukwu H, Hanafi EB, Fattouh A (2016) Enabling Remote Health-Caring Utilizing IoT Concept over LTE-Femtocell Networks. PLoS ONE 11(5): e0155077. https://doi.org/10.1371/journal.pone.0155077

HoF - MIMO VLC

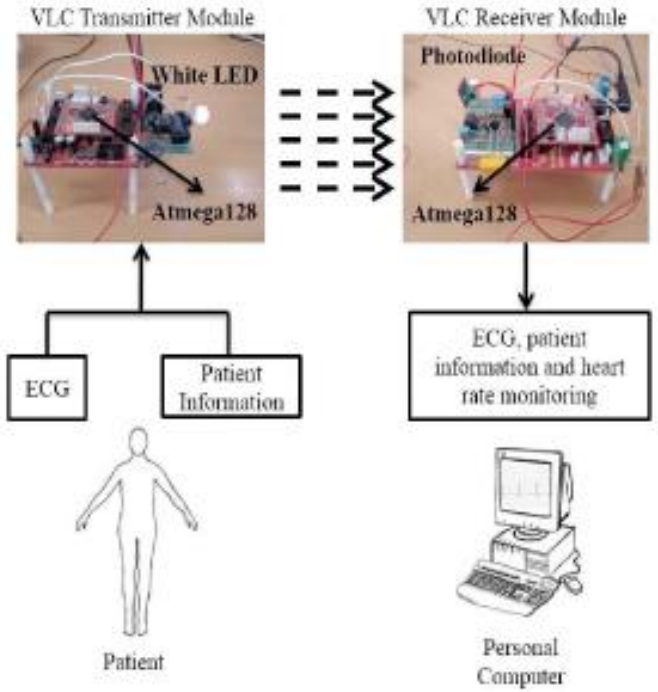
MOTOL hospital (Prague, Czech Rep.) – **children neurosurgery operational room**

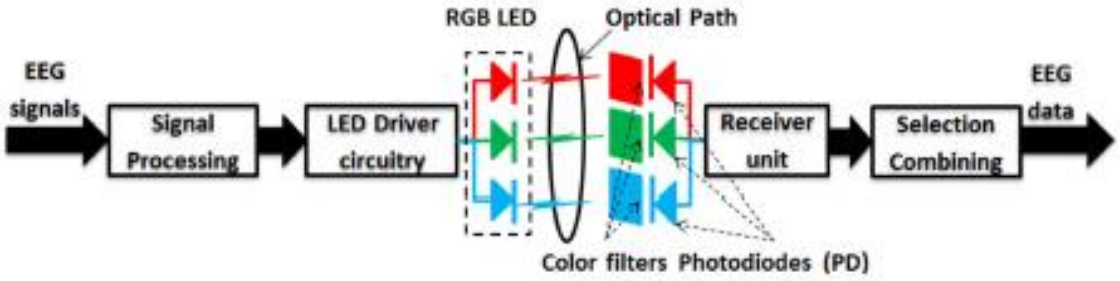




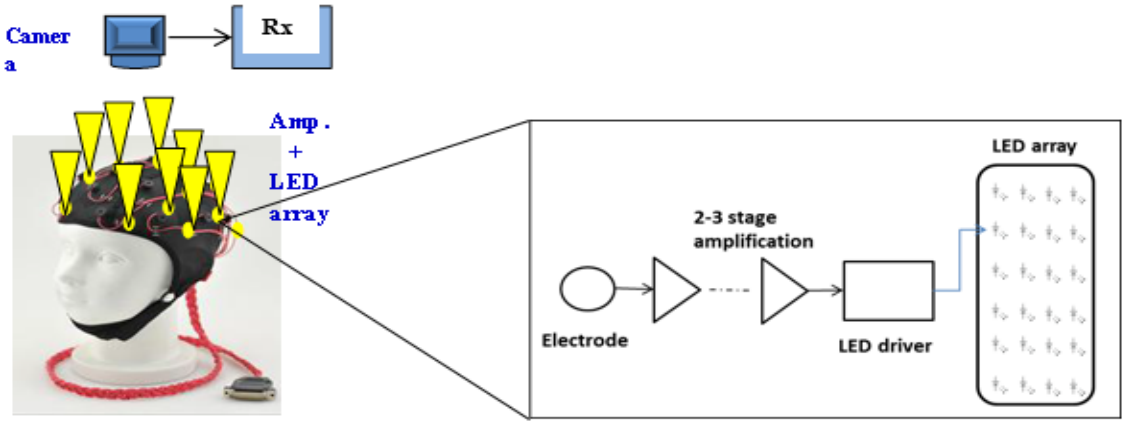
S. Maravanchery Mana, P. Hellwig, J. Hilt, K. Lennert Bober, V. Jungnickel, K. Hirmanova, P. Chvojka, R. Janca, S. Zvánovec, LiFi Experiments in a Hospital, The Optical Networking and Communication Conference, OFC 2020, submitted…

HoF – VCL-OCC for Electroencephalography (EEG)





VLC + OCC



Li-Fi transmission of electrocardiogram readings[1]

[1] Yee Yong Tan; et al, "Real time biomedical signal transmission of mixed ECG Signal and patient information using visible light communication," *Engineering in Medicine and Biology Society, 2013 35th Annual International Conference of the IEEE* , vol., no., pp.4791-4794, 3-7 July 2013

HoF – VLC-OCC for Medical Robots

MEDi robot to comfort patients

Mobile laboratory robot

- To see
- To communicate
- To do
- Etc.

Robotic nurses in Bangkok hospital

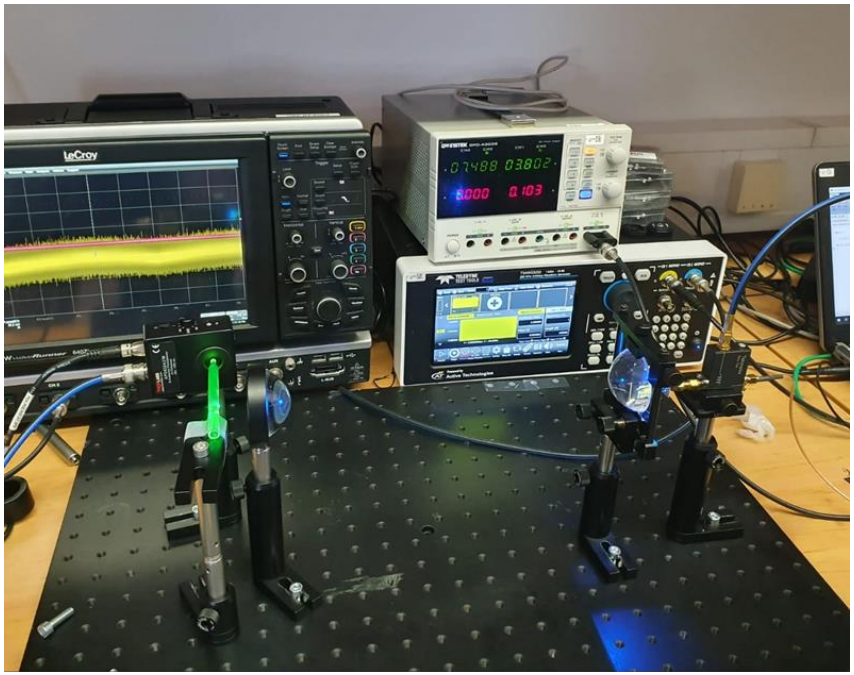
Robots for surgery

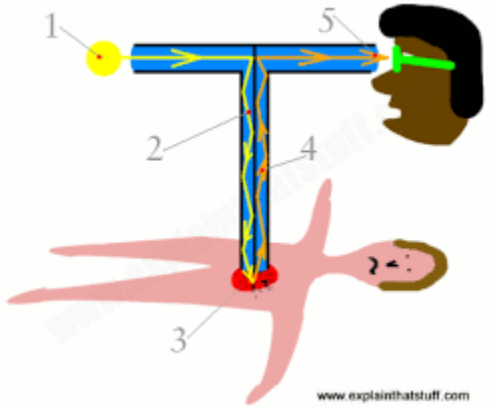
Northumbria University NEWCASTLE

Imperial College London

OCRG

VLC with Fluorescent Concentrator - Endoscopy



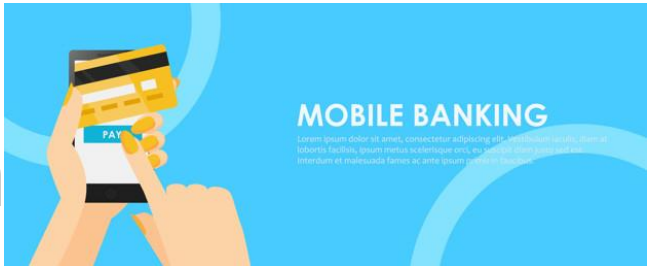


Developing LED sources for a range of application including Medical

Using blue LEDs

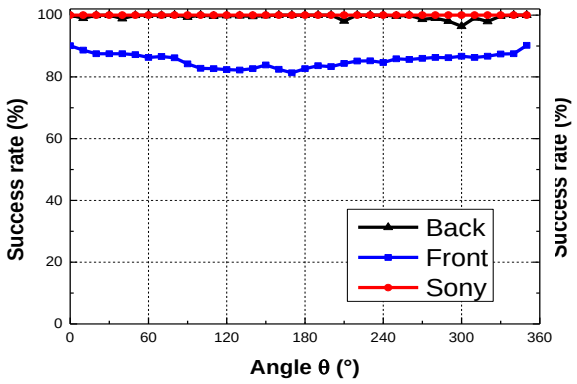
VLC – OCC - Projects

1. Last meter access network
2. Medical
3. **IoT**
4. Smart environments
5. GPS
6. Internet of Veh
7. Others

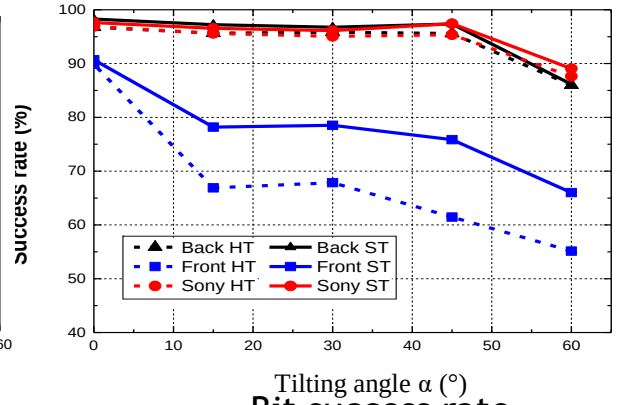


VLC-OCC – D2DC for IoT

- **Alternative** to NFC for short range communications
- **Software based**
  - Android-based object recognition requires fast learning from a pre-trained model, classification, and detection from a real-time video.
  - Deep neural network-based detection for real-time video processing - Faster region-convolutional neural network (R-CNN) and mask R-CNN
- **Rolling shutter - in CMOS cameras for image capturi**
  - CMOS cameras capture rate: 20 - 30 frame
- **Mobility** - LED detection and tracking is needed and thus extra processing time.
  - For a 20 fps each frame requires additional 20 ms

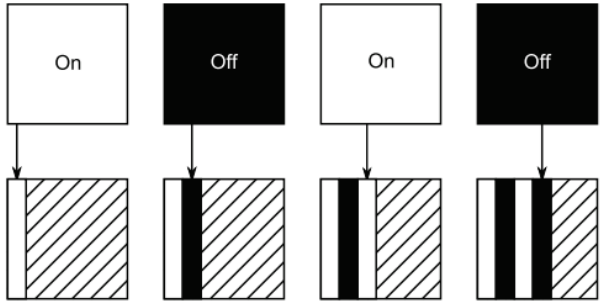


Bit success rate against rotation angle



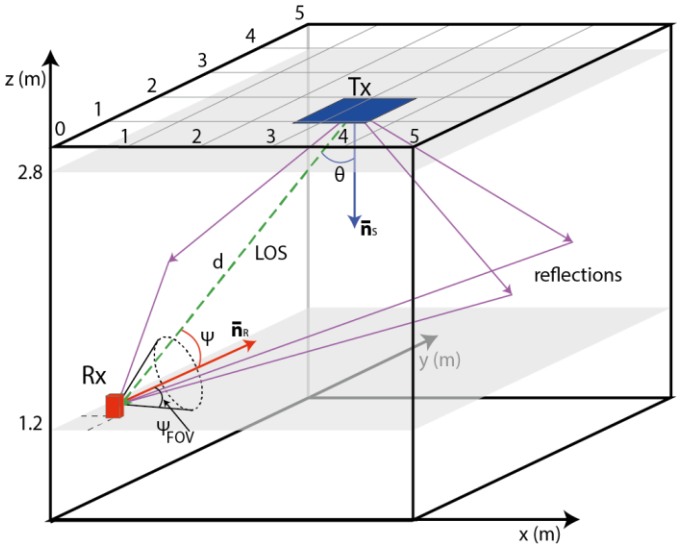
Tilting angle α (°)

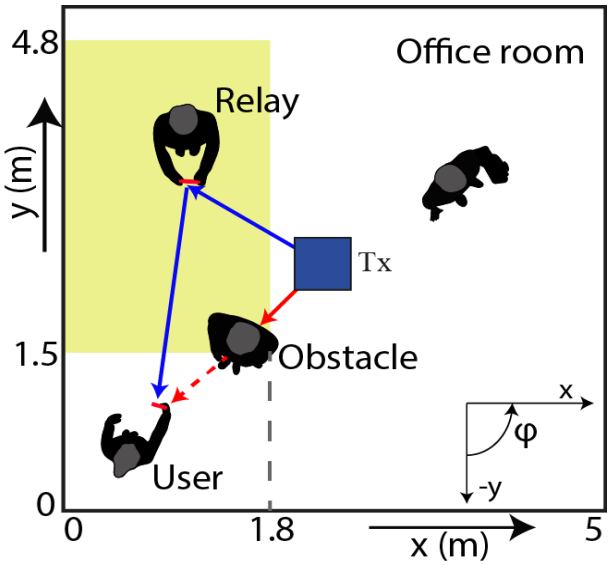
Bit success rate against tilting angle

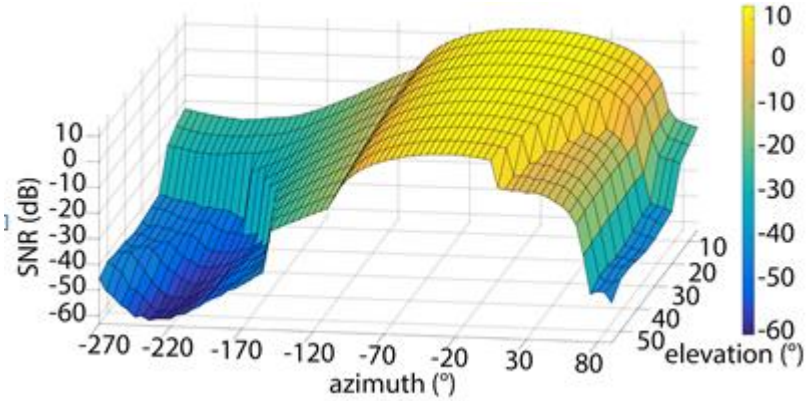


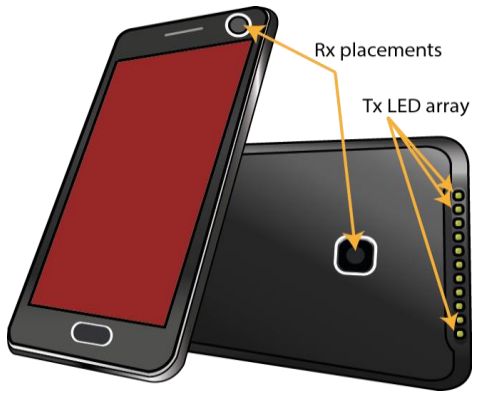
Boubezari, R., Le Minh, H., **Ghassemlooy, Z.**, and Bouridane, A.: "Smartphone camera based visible light communication," J. of Lightwave Technology, 34 (17), pp. 4121-4127, Sept.1, 1 2016.

VLC – OCC – Relay Assisted









Based on observations of 1300 people using their MPs on the street, airports, on trains and buses:

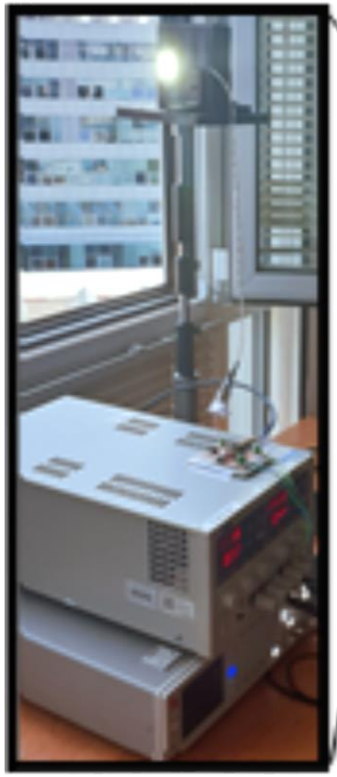
- **49 % used MPs with only one hand**
- **90 % held it vertically facing upwards [1].**

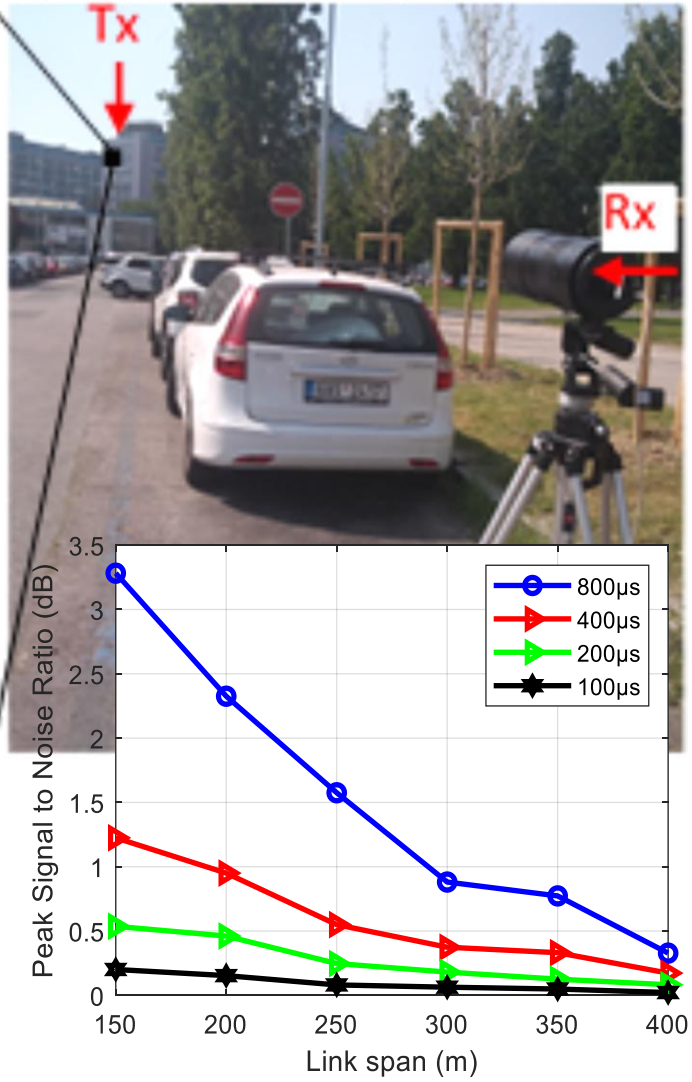
Based on our own tests, people were reading messages and surfing the internet by holding MP typically with the elevation angle within the range of 5° - 65°.

[1] "How Do Users Really Hold Mobile Devices? :: UXmatters." [Online]. Available: http://www.uxmatters.com/mt/archives/2013/02/how-do-users-really-hold-mobile-devices.php. [Accessed: 02-Feb-2017].

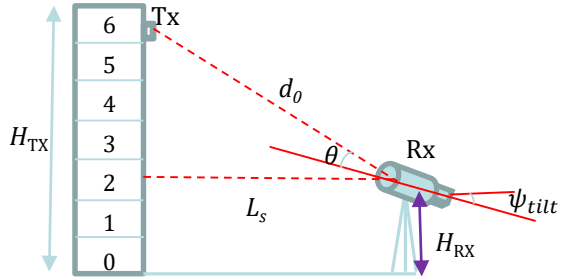
Mobile User Connectivity in Relay-Assisted Visible Light CommunicationsP Pešek, S Zvanovec, P Chvojka, MR Bhatnagar, Z Ghassemlooy, ... Sensors 18 (4), 1125

VLC-OCC – Long Range (400 m)





- **Transmitter** - A bright 40 COB-LED
- **Receiver** - A telescope camera composed of 2 concave mirrors with a narrow the field of view (FoV) of ~0.5º.
- **Frame rate**: 25 fps and the number of received data bits per frame is 18.
- **Range**: 150 to 400 m.



VLC-OCC – Long Range (400 m)

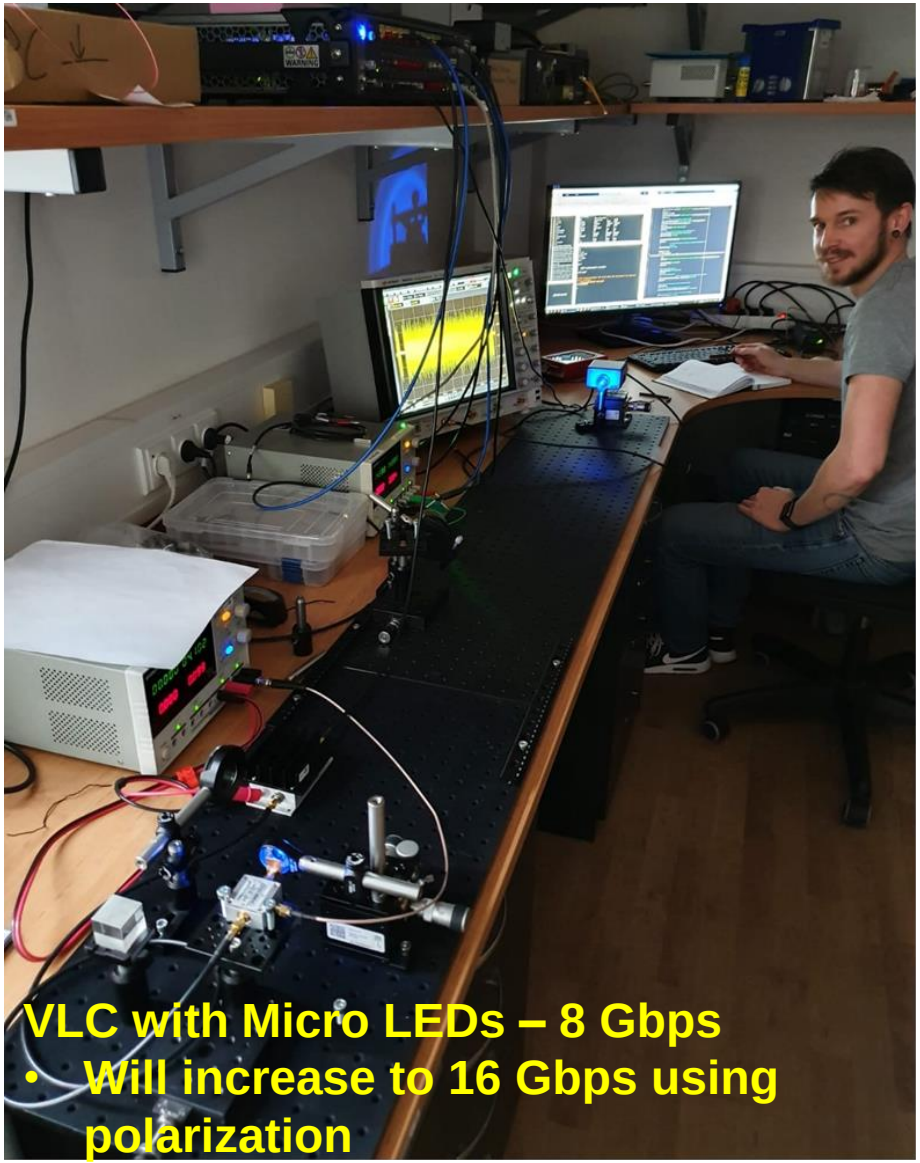
Refs.	Tx (size)	Link span	Bit rate	BER	Shutter type
[6]	-	2 m	68 bit/frame	Error free	RS
[7]	18.7×3.8 cm^2	120 m	< 200 bps 200 bps @4 m	$>10^{-2}$	RS
[8]	48 × 48cm^2	328 m	15bps	~0.04	Global shutter
Our work	**2.5 × 2.5cm^2**	**400 m**	**450 bps**	**Error free**	**RS**

[6] W.C. Wang, et al, "Long distance non-line-of-sight (NLOS) visible light signal detection based on rolling shutter patterning of mobile-phone camera," Opt. Express 25, 2017

[7] P. Chavez-Burbano et al., "Optical camera communication system for Internet of Things based on organic light emitting diodes,"Electron. Lett. 55, 334–336, 2019.

[8] P. Chavez-Burbano, et al., IEEE/CIC , (ICCC Workshops) pp. 22-2,. 2017.

VLC – High Speed Data Transmission (8 Gbps)



Micro LED

- Composed of RGB LED chips
  - But red LEDs are made from AlIGaP which is more challenging and perform lower efficiency compared to blue and green LEDs made by InGaN.
- Outpaces OLED in terms of
  - brightness,
  - contrast,
  - durability and more
- But, higher production cost.
  - To reduce cost, the miniaturize process of LED might lead to efficiency degrease.
  - 10 μm Micro LEDs chip is able to achieve 42% EOE.

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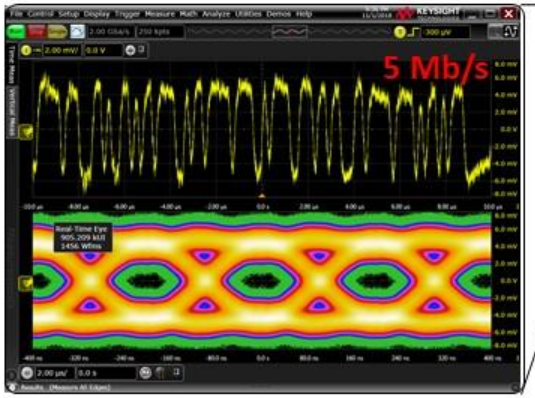
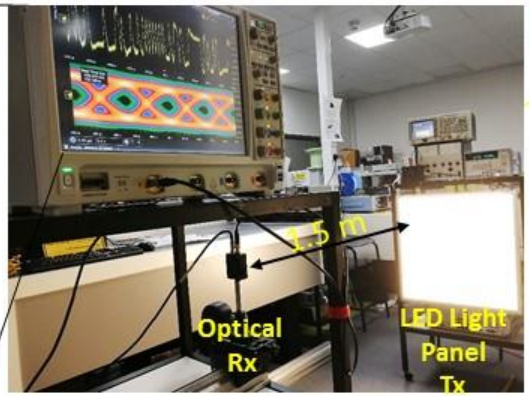
VLC – OCC - Projects

1. Last meter access network
2. Medical
3. IoT
4. **Smart environments**
5. GPS
6. Internet of Vehicles (IoV)
7. Others

VLC for Smart Environments – A Collaborative EU H2020 Project





Data Rate	**> 5 Mb/s** OOK NRZ
Diffuse LED Panel	3900014-WW-EU, 1200 lm, 3000K, 0.6 x 0.6 m 192 LEDs, Beam angle 120° Bandwidth 400 kHz Illumination level 300 lux@1.5 m
Receiver	PIN Photodetector Tans-impedance amplifier
Distance	1.5 meter
Post-equalization	LMS adaptive equalizer

Research

- Use standard **light emitting diodes** (LEDs) lights – with over 40% energy efficiency compared to the traditional bulbs
- To design efficient time-domain or frequency-domain based equalizers of reasonable complexity to increase the data rate of Visible Light Communications, which is limited by the LED bandwidth
- To mitigate multipath induced inter-symbol interference considering features and characteristics of indoor/outdoor channel and bandwidth limiting components

Team

- **Prof Zabih Ghassemlooy** (*NU–Newcastle*)
- **Prof Stanislav Zvanovec** (*CTU–Prague*)
- **Xicong Li** (*NU–Newcastle*) **– ESR1**

VISION is a European project funded by the European Union' s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement n° 76446

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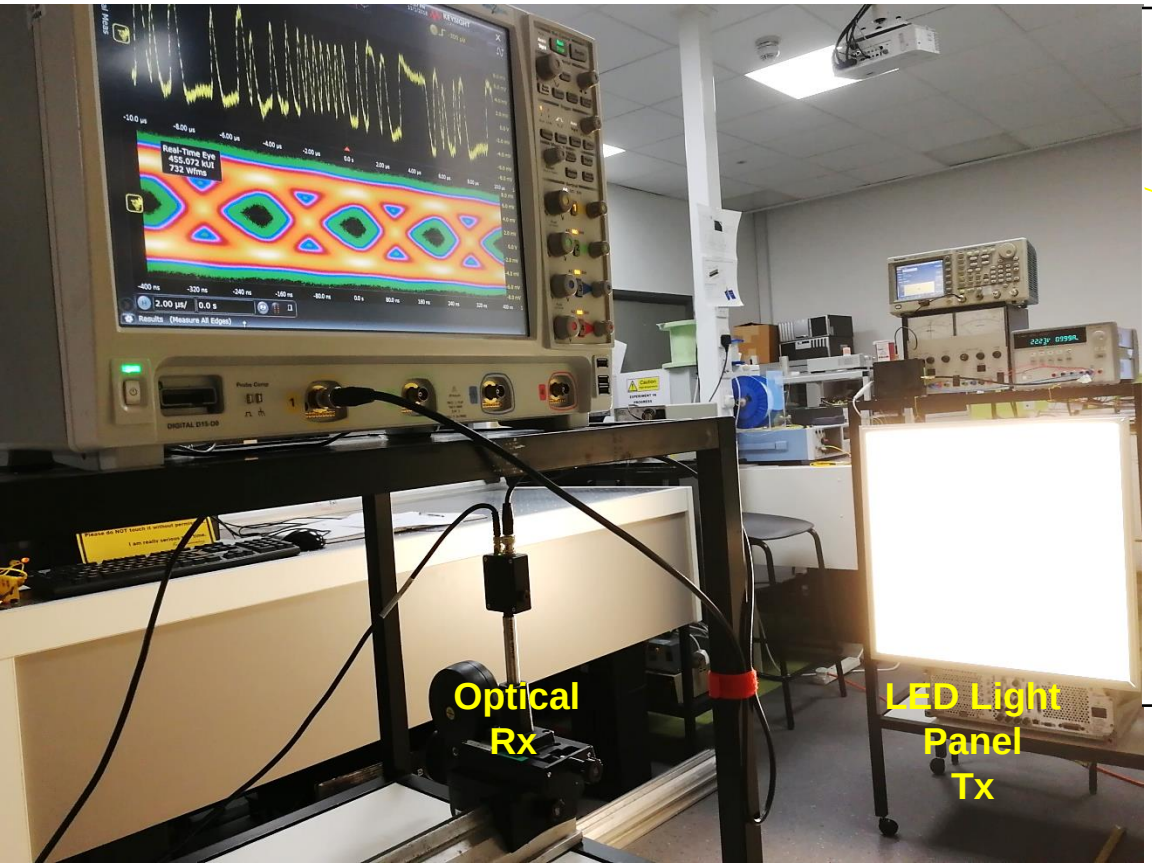
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

VLC – Diffuse LED Panel lighting

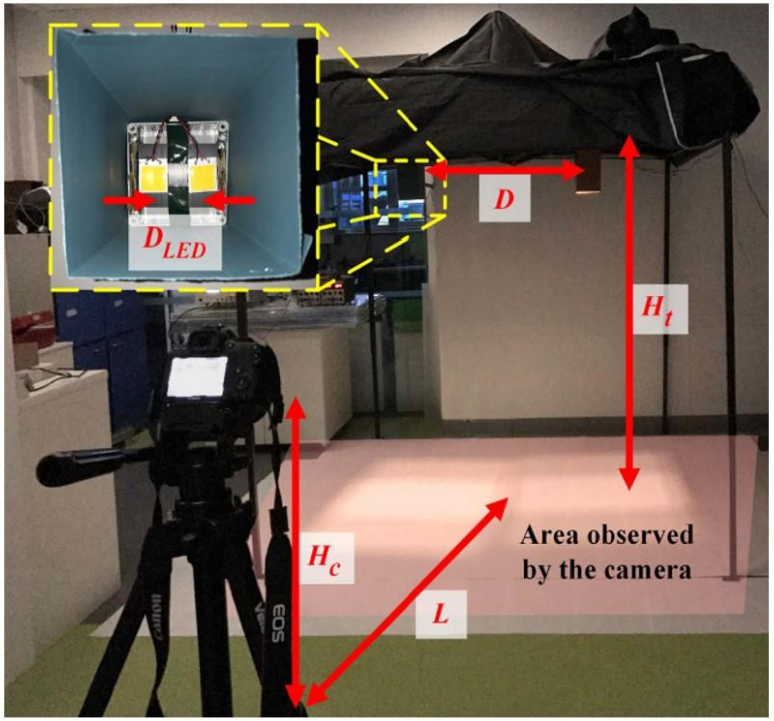


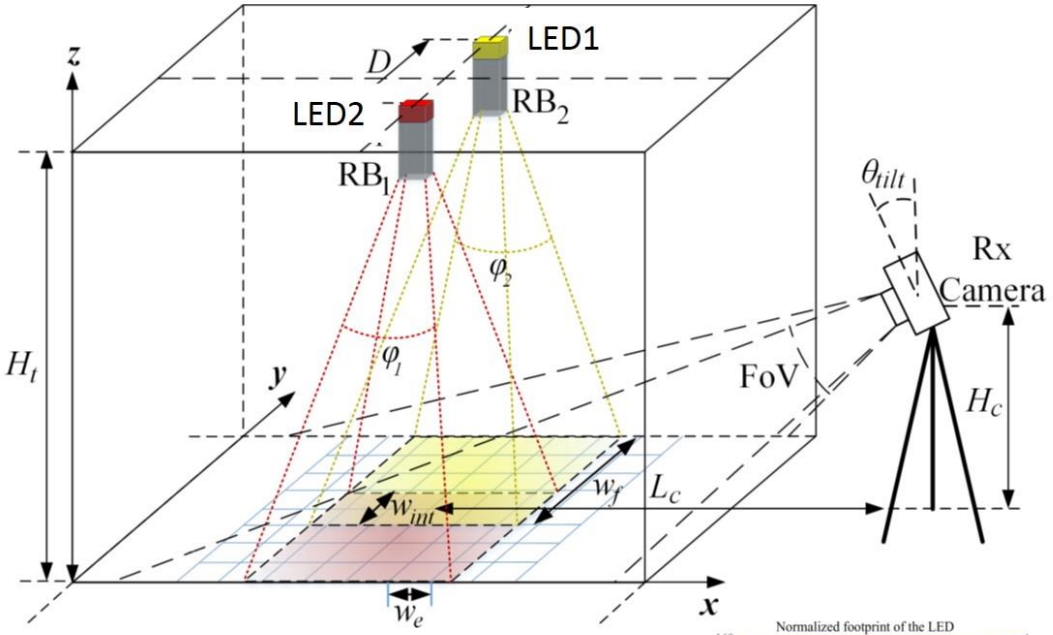
Data Rate	**> 5 Mb/s** OOK NRZ
Diffuse LED Panel	3900014-WW-EU, 1200 lm, 3000K, 0.6 x 0.6 m 192 LEDs, Beam angle 120^{o} Bandwidth 400 kHz Illumination level 300 lux@1.5 m
Receiver	PIN Photodetector Tans-impedance amplifier
Distance	1.5 meter
Post-equalization	LMS adaptive equalizer

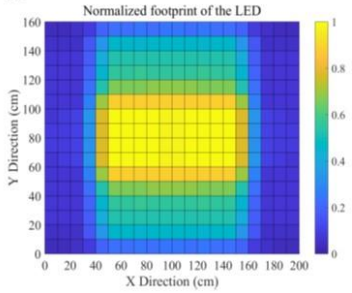
For smart environments:

- Home
- Office
- Hospital
- Public places, etc.

Non-line-of-sight 2 × *N* Indoor VLC-based Optical Camera Communications







A normalized footprint of the LED on the floor plane

A collaborative work between:

- Optical Communications Research Group, *Northumbria University, Newcastle-upon-Tyne, UK*
- Department of Electromagnetic Field, *Czech Technical University in Prague, Czech Republic*
- Research Department of HiSilicon, *Huawei Technologies Co., Ltd, Beijing , P. R. China*
- Dep. of DIET engineering, *Sapienza University of Rome*, and *Department of Engineering, Roma Tre University, Italy*
- State Key Laboratory of Information Photonics & Optical Communications, *Beijing Univ. of Posts & Telecom, Beijing, China*

N. Bani Hassan, Z. Ghassemlooy, S. Zvanovec, M. Biagi, A. M. Vegni, M. Zhang, and P. Luo, "Non-Line-of-Sight MIMO Space-Time Division Multiplexing Visible Light Optical Camera Communications," IEEE/OSA J. Lightwave Technol. 37, 2409-2417, 2019.

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VCL-OCC - Smart Agriculture

Optical beam

Optical Rx

To server/ Back-bone NW

Optical Tx

Low data rate data transmission

VLC-OCC – Motion Detections

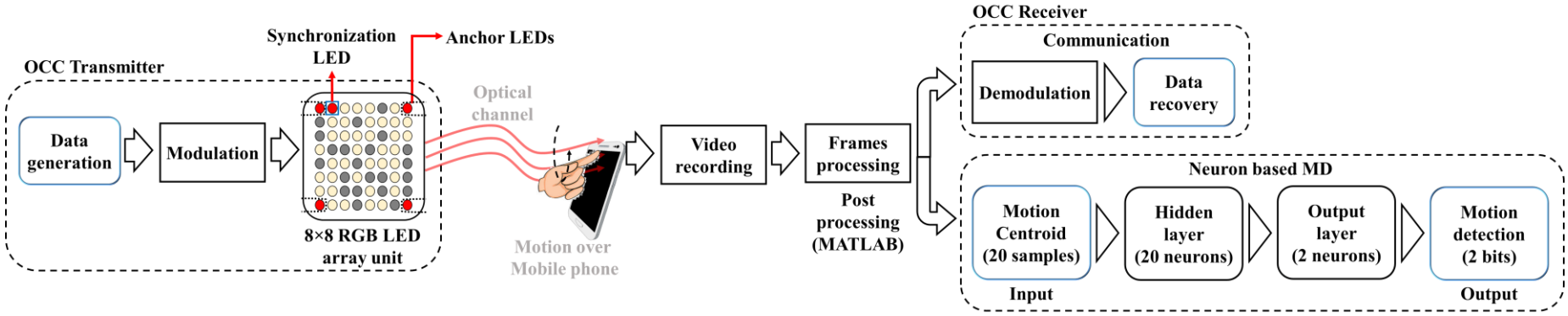
- Conventional **motion detection** (MD) schemes - C**omplex detection** algorithm
  - Complexity increases with complex motions (shapes).
- **Neural network (NN) based MD** at the receiver side.

➢ **Why NN?**
  - Motion includes some **pattern**
  - NN is ideal in **pattern recognition.**

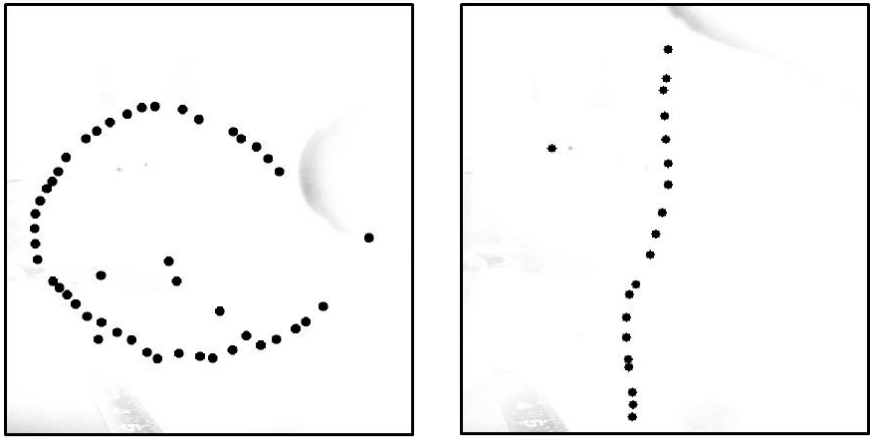
➢ **Principle of NN:** Artificial neurons in the hidden layers of the network receive multiple input samples to train the network.

➢ **Conventional NN**: Based on images that represent the patterns.
  - **NN based MD in OCC:** based on the motion represented by data samples in the form of the centroids.

VLC-OCC – Motion Detections



- The user's finger movement is captured using the front camera of a mobile phone.
- Communication is performed simultaneously along with motion detection.
- Data is obstructed due to motion.



(a) (b)

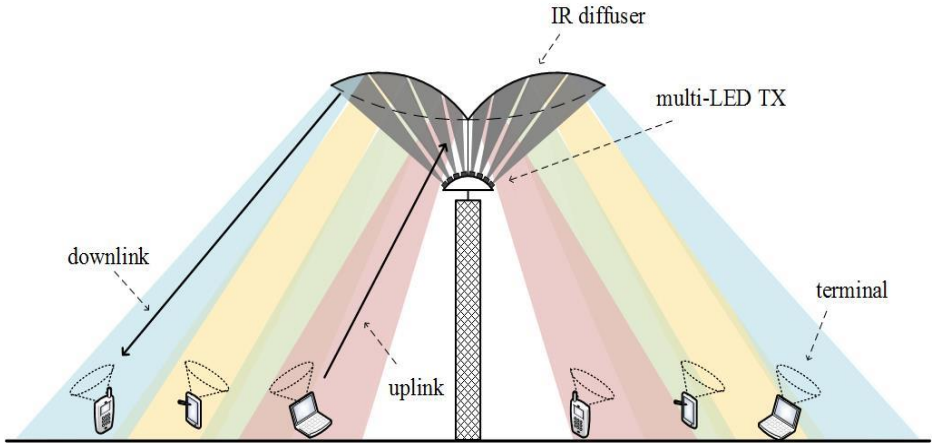
Circular and linear motion centroids.

VCL – IOT - Manufacturing

The manufacturing is becoming smarter and reaching a new level of flexibility, allowing fabrication of personalized products in a software-defined manufacturing process.

- **Replaced cables/wires with wireless links**
- **Optical waves**
  - Confined
  - Security (no wiretapping or jamming)
  - Safety
- **For short range**
  - Distributed MIMO to ensure link at all times
- **For long range**
  - Optimization of PHY and upper-layer under low SNR
  - Closed-loop adaptation of data-rate and the power

VCL – IR - Outdoor Wireless Access



Diffuse Infrared as the key technology of future (5G and beyond-5G) high-speed wireless access to the end-user in certain application areas (plazas, café, restaurants, sport venues, concert halls, train/bus station, airports, etc.).

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ARISTOTLE UNIVERSITY OF THESSALONIKI
infoscope hellas
ÖZYEĞİN ÜNİVERSİTESİ
Northumbria University NEWCASTLE
Fraunhofer Heinrich Hertz Institute
e-trikala

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VLC – OCC - Projects

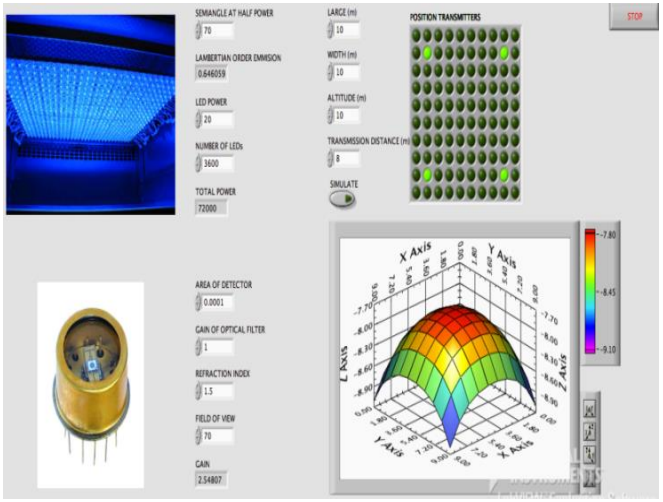
1. Last meter access network
2. Medical
3. IoT
4. Smart environments
5. **GPS**
6. Internet of Vehicles (IoV)
7. Others

VLC – Indoor GPS

University of Santiago, Chile, Northumbria Univ. UK

LEDs broadcast their location ID (LID) based on multi-access techniques: WDM; FDMA; CDMA (is more robust to noise)

- There are many techniques to locate a mobile node inside a room based on GPS assisted Techniques that could be use in VLC
  - Time of Arrival (TOA),
  - Angle of Arrival
  - Received Signal Strength (RSS)



[1] J. Kahn; J. Barry, Wireless infrared communications, Proceedings of the IEEE , vol.85, no.2, pp.265,298, Feb 1997.
[2] S. De Lausnay; et al, Design of a visible light communication transmitter for the evaluation of a wide range of modulation techniques, Optical Wireless Communications (IWOW), 2013 2nd International Workshop on , vol., no., pp.30,34, 21-21 Oct. 2013.
[3] H. Ghafouri-Shiraz and M.Karbassian, Optical CDMA Networks: Principles, Analysis and Applications, ISBN: 978-0-470-66517-6, 432 pages, Wiley-IEEE Press, March 2012.
[4] T. Do, J. Hwang and M. Yoo, TDoA Based Indoor Visible Light Positioning System, Ubiquitous and Future Networks (ICUFN), 2013 Fifth International Conference on, 2013
[5] Lin, Bangjiang, Z Ghassemlooy, et al. "An Indoor Visible Light Positioning System Based on Optical Camera Communications." *IEEE Photonics Technology Letters* 29.7(2017):579-582.

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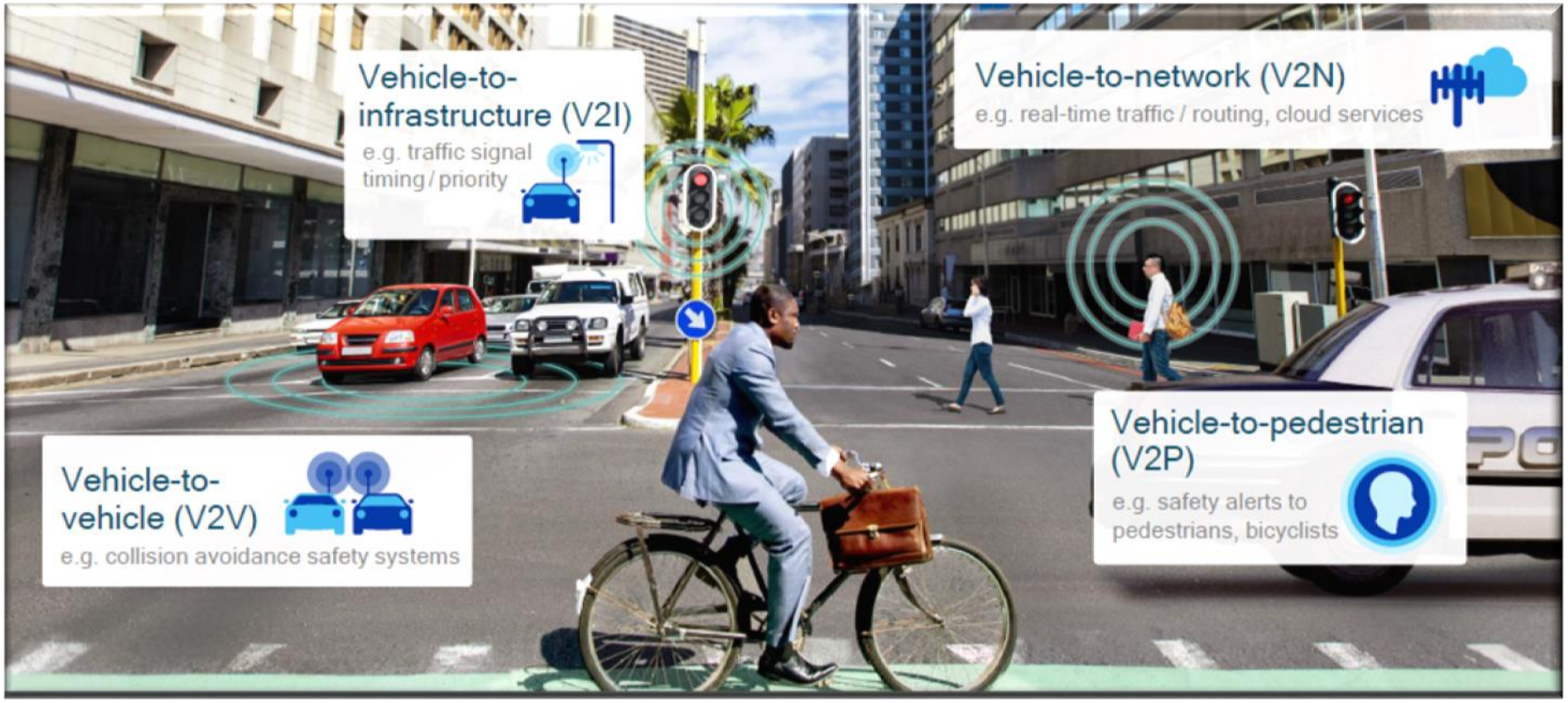
VLC – OCC - Projects

1. Last meter access network
2. Medical
3. IoT
4. Smart environments
5. GPS
6. **Internet of Vehicles (IoV)**
7. Others

VisIon Project - VLC for Intelligent Transportation

NU, UK, Tech. Univ. of Prague, Czech Rep., and Beijing Post and Telecommunications Univ, China



Gartner Research - forecast that new vehicles equipped with data connectivity will increase from 6.9 m/year in 2015 to 61 m/year in 2020.

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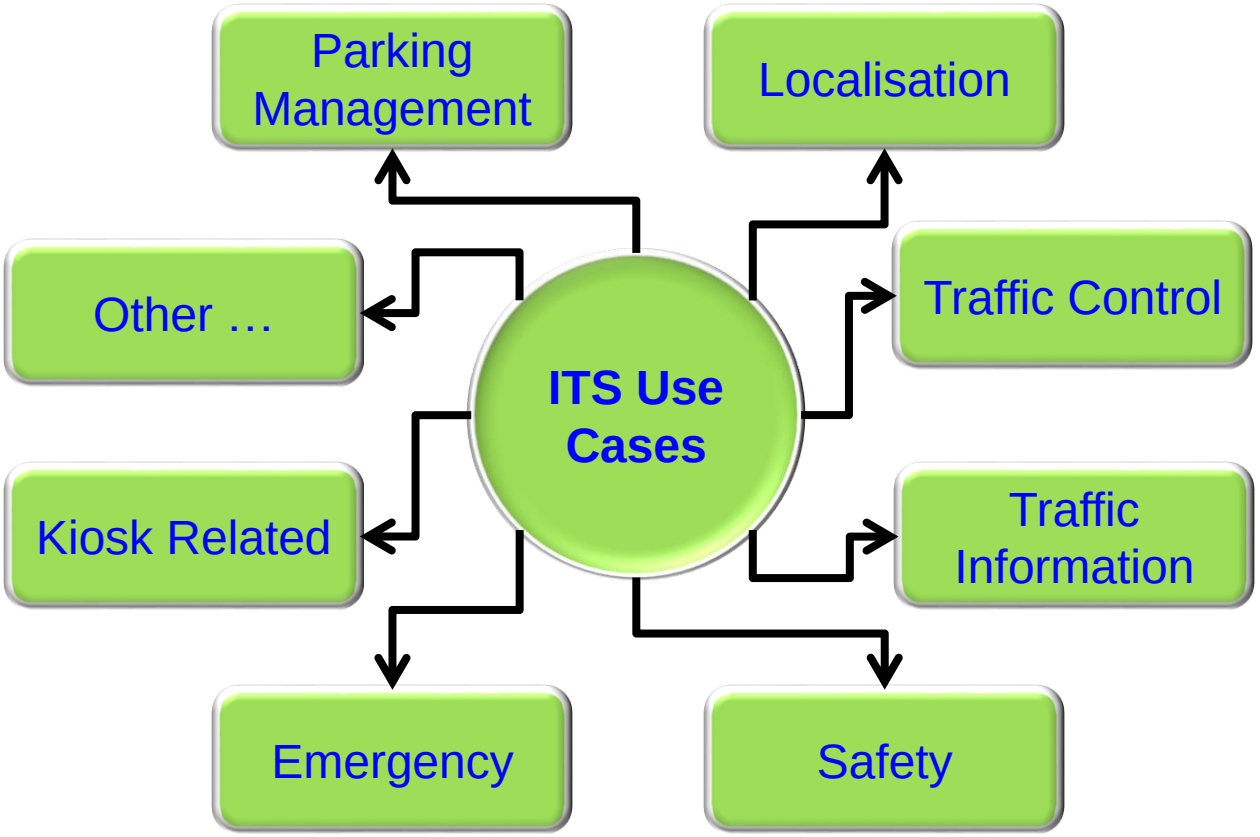
ITS - Applications



Wireless Technology:

- **Radio Frequency**
- **Visible Light**

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ITS - How to Separate the Information?

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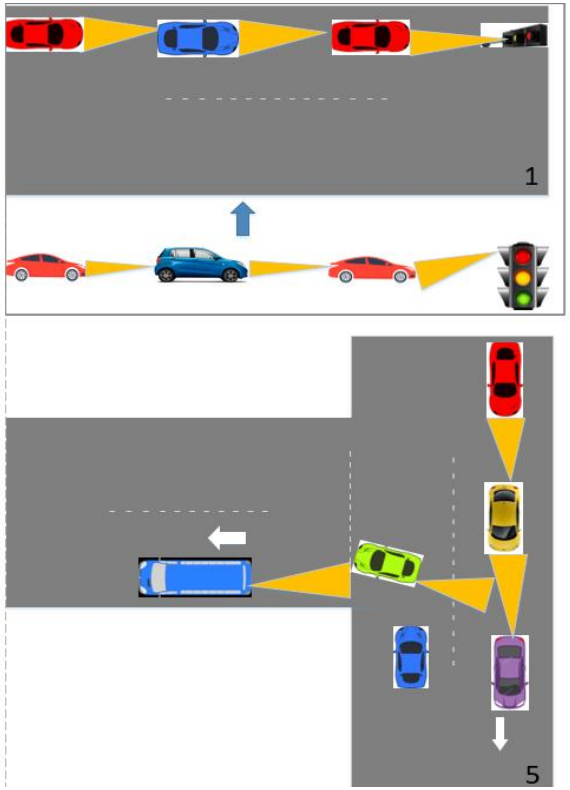
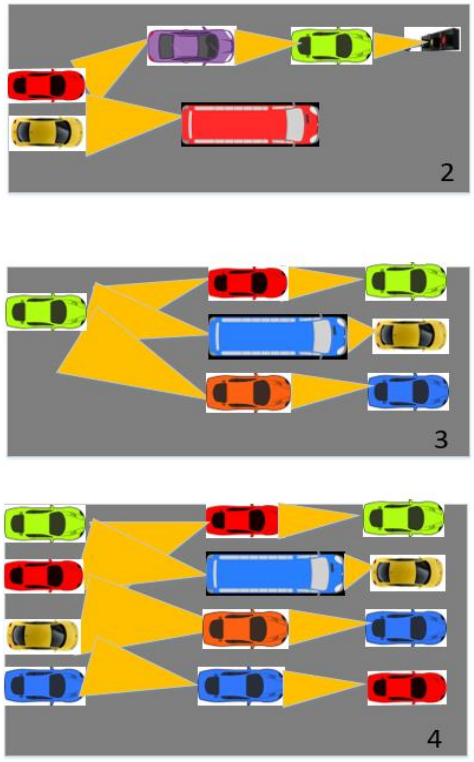
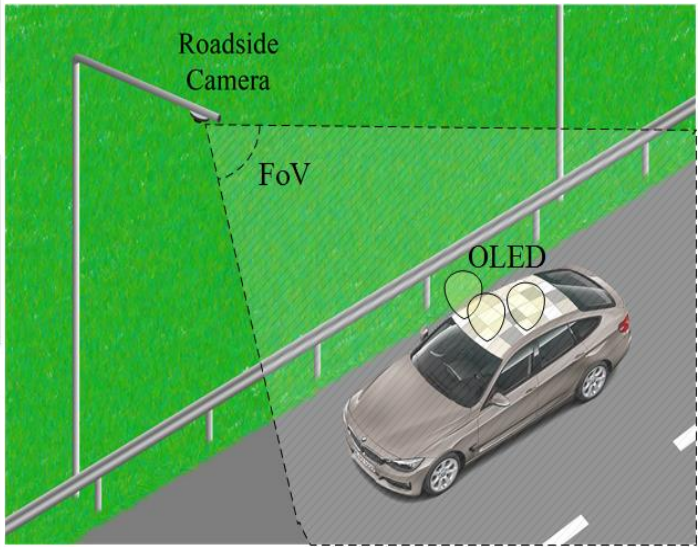
- Spatial Division
- Time Division
- Frequency Division
- Wavelength Division
- Code Division
- Orthogonal Frequency Division

VLC – OCC - Multi-hop Vehicular Communications

Modes: SISO; SIMO; MISO and MIMO





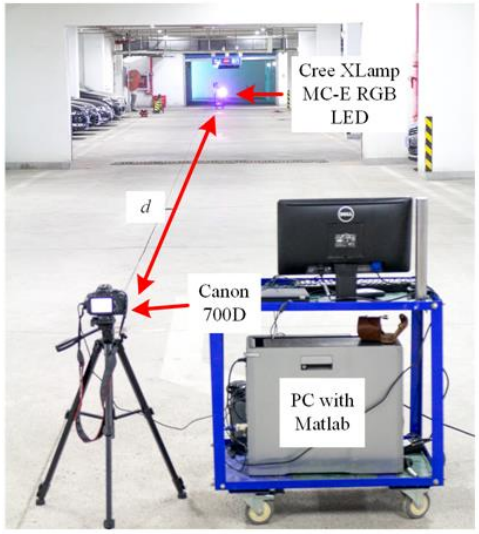


P. Luo, T. Jiang, P. A. Haigh, Z. Ghassemlooy and S. Zvanovec, "Undersampled Pulse Width Modulation for Optical Camera Communications," 2018 IEEE International Conference on Communications Workshops (ICC Workshops), Kansas City, MO, USA, 2018, pp. 1-6.

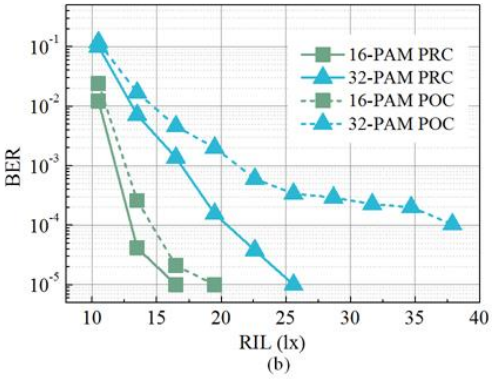
VLC-OCC – Vehicular Communications

NU, UK, Tech. Univ. of Prague, Czech Rep., and Beijing Post and Telecommun. Univ, China

(a)



(c)



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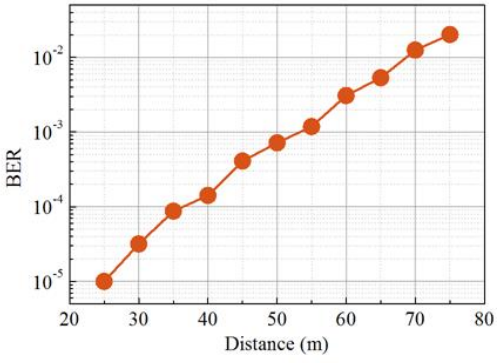

(d)

Luo, P., Zhang, M., **Ghassemlooy, Z**., Zvanovec, S., Feng, S., and Zhang, P.: "Undersampled-based modulation schemes for optical camera communications," in *IEEE Communications Magazine*, vol. 56, no. 2, pp. 204-212, Feb. 2018.

P. Luo, Z. Ghassemlooy, H. L. Minh, H. M. Tsai, and X. Tang, "Undersampled-PAM with subcarrier modulation for camera communications," in *Opto-Electronics and Communications Conference (OECC)*, 2015, pp. 1-3.

LUO, P., Ghassemloot, .Z, et al. Performance analysis of a car-to-car visible light communication system. *Applied Optics*. 2015, 54.7: 169-1706.

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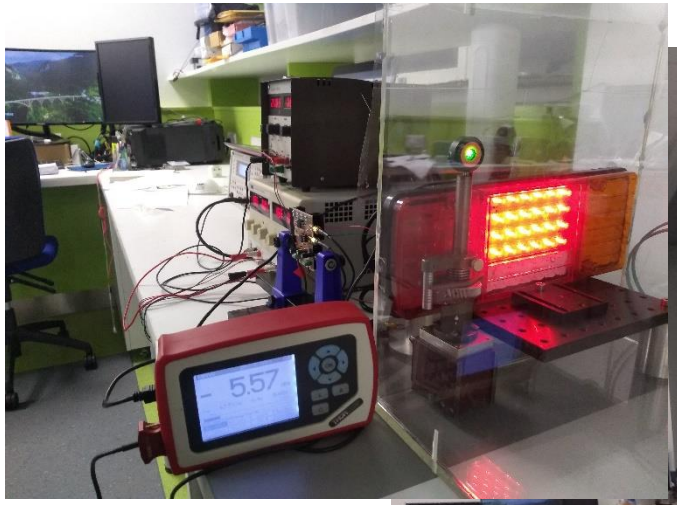
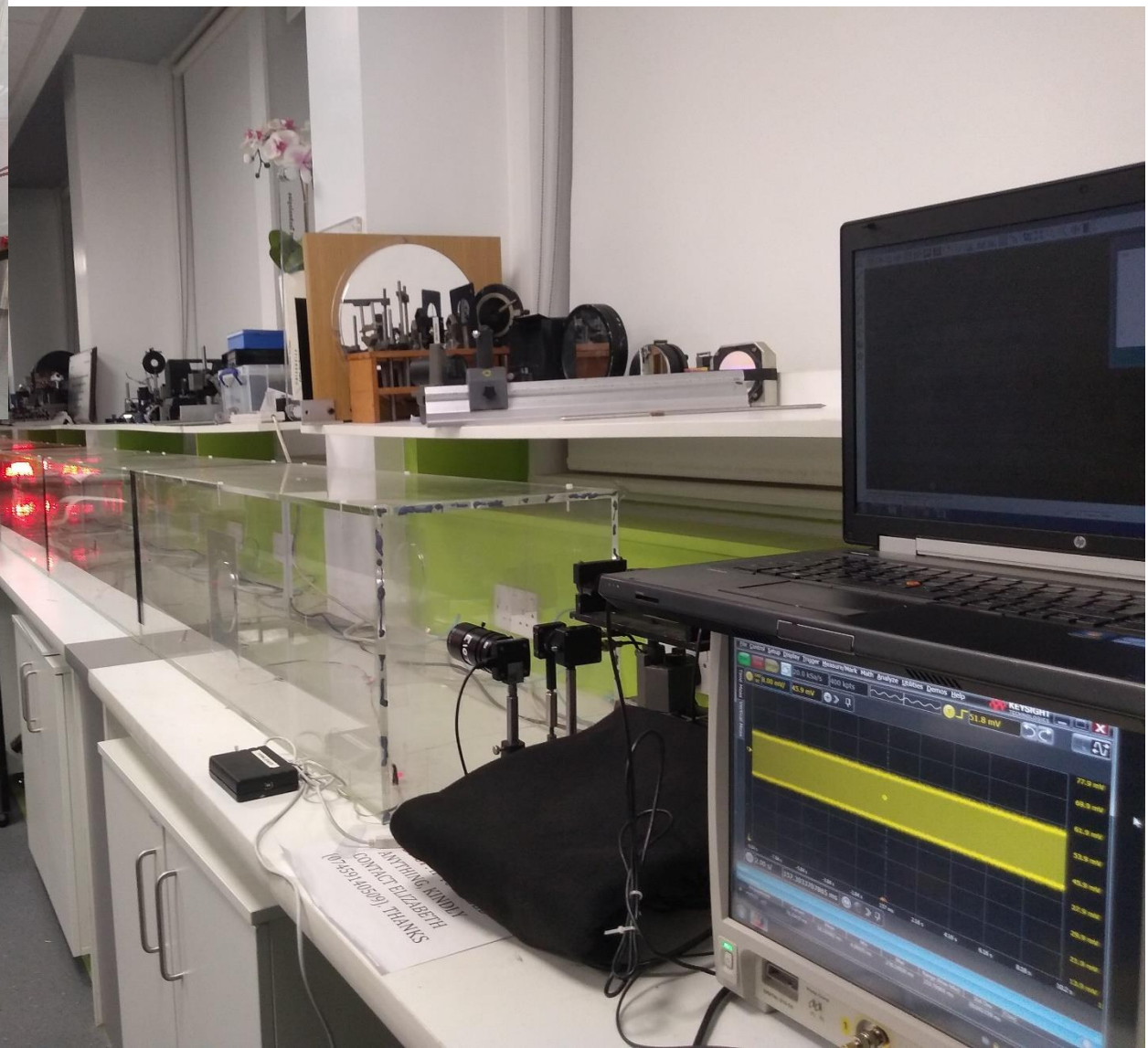
VLC-OCC – Vehicular Communications

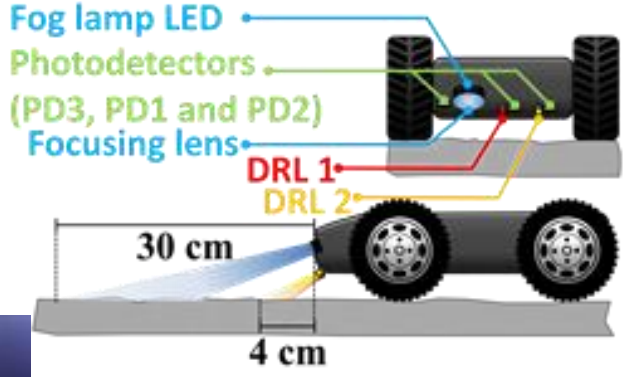


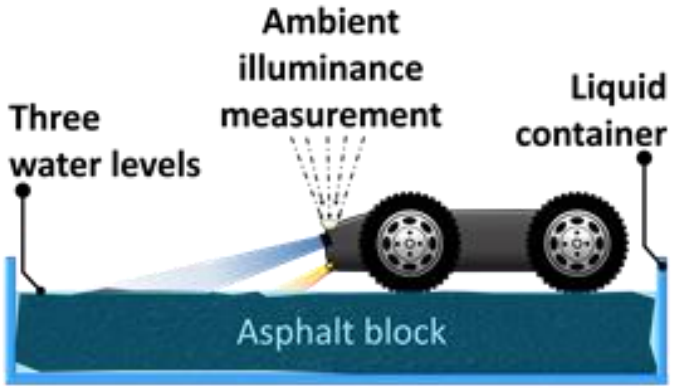


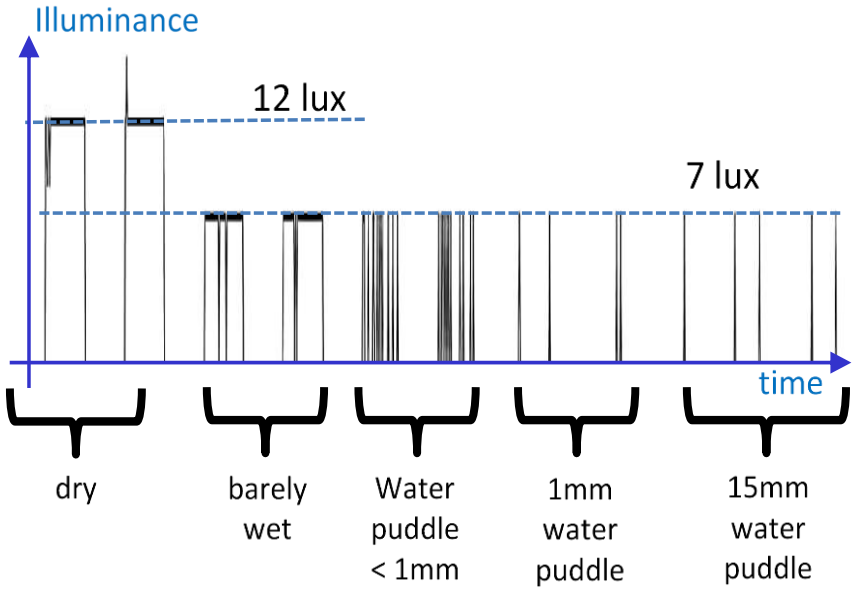
VLC-OCC – Sensing

For

- **Road surface**
- **Air pollution**
- **Water quality**
- **Etc.**







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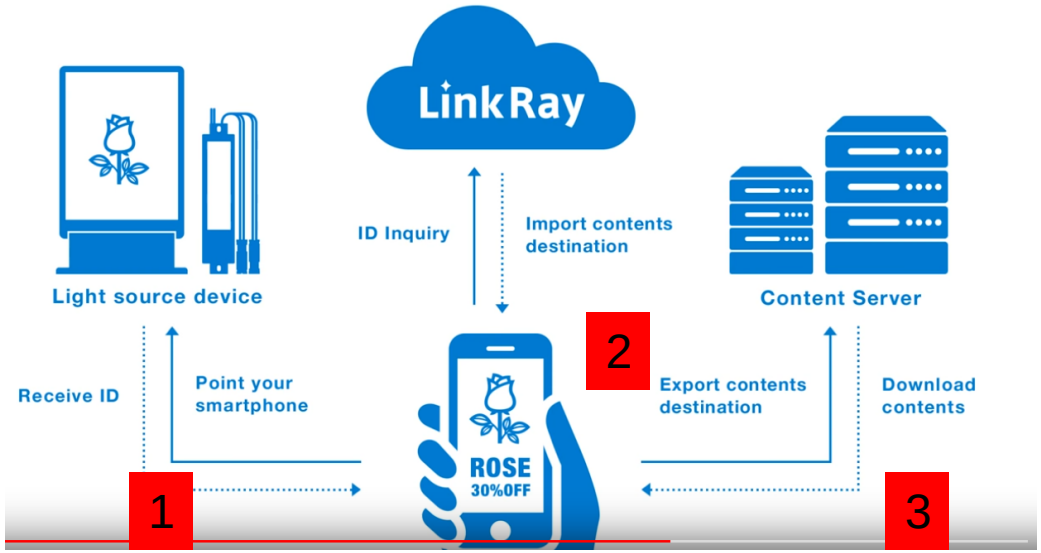
VLC – OCC - Projects

1. Last meter access network
2. Medical
3. IoT
4. Smart environments
5. GPS
6. Internet of Vehicles (IoV)
7. **Others**

VCL – Link Ray

Delivers mobile content using smartphones to read IDs sent from LEDs



Fast and Intuitive

Effective even in crowds

Effective in the distance if light reaches smartphone

https://www.youtube.com/watch?v=7IvuGXr3DPE Video

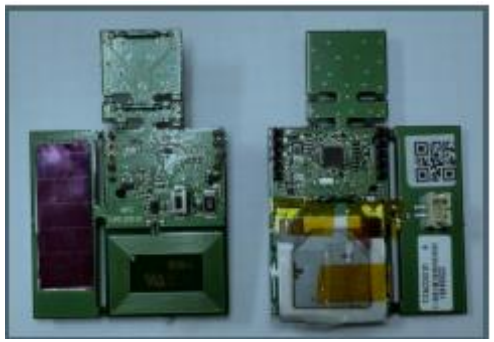
Internet of Things – Hybrid Cloud

Public cloud - Traditional cloud computing

Local cloud - A private cloud deployed at the edge of the network

Infrastructure layer

- The physical layer consists of data producers and end users
- Use Li-Fi between IoT devices and local cloud nodes.



LiFI (VLC) Node

- Uses LED as the Tx and the Rx

Pradip Kumar Sharma, et al, Li-Fi based on security cloud framework for future IT environment, Hum. Cent. Comput. Inf. Sci. (2018) 8:23
Vercellone et al. Demo Abstract: Using LEDs for Visible Light Communication and as aWake-up Mechanism in the IoT, SenSys'17, Nov.6–8, 2017

Internet of Things – Smart Cities

The importance of social support for individuals with visual impairment.

- According to the World Health Organization, globally we have ~ **1.3 billion** people with some form of vision impairment.
- Old people not going out due to vsision problems, etc.

Pedestrian support systems:

- Localization infrastructures (radio marker, infrared markers, IC tag, QR code tag, and positioning techniques) and GPS:
  - GPS walking assistance accuracy is deteriorated in the shadow of a building or indoors [1].
- VLC-OCC:
  - Provides user safety information in the neighborhood or the route information,
  - Receives a request from the user and traffic information.
  - Data rate: 125 kbps
  - Range: A few meters

S. Oshiba *et al*., "Visibility evaluation experiments of optical wireless pedestrian-support system using self-illuminating bollard," *2016 IEEE/ACIS 15th International Conference on Computer and Information Science (ICIS)*, Okayama, 2016, pp. 1-6.

http://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

VLC – OCC – An Overview

Wireless – Technology and Standards (short range)

Technology	Speed	Data Density
Wireless – Current		
WiFi (IEEE 802.11N)	150 Mbps	*
Bluetooth	3 Mbps	*
IrDa	4 Mbps	***
Wireless – Future		
Wi-Gig (IEEE 802.11ad)	2 Gbps @ 60 GHz; 10 m within a room	**
White WiFi (IEEE 802.11af & IEEE 802.11ah,	24 Mbps @54 and 790, 900 MHz	* (across huge areas a few km)
Giga-IR	1 Gbps	***
VLC	> 10 Gbps; a few meters within a room	****

Wireless Technologies

Wi Fi		Li Fi
Wireless fidelity	FULL FORM	Light fidelity
RF antenna & router	OPERATION	Uses LEDs and photodetectors
Yes	INTERFERENCE	None
WLAN 802.11a/b/g/n/ac/ad	TECHNOLOGY	IEEE Standard 802.15
Interference is high; High power use High mobility	MERITS (ADVANTAGES)	Interference is low; Low power use Low mobility
Low	PRIVACY	High
150 Mbps (WALN-11n) 1-2 Gbps (WiGig/Giga-IR)	DATA TRANSFER SPEED	> 1 Gbps
2.4 GHz, 4.9 GHz, GHz	FREQUENCY OF OPERATION	375 THz
Less dense areas (interference)	DATA DENSITY	High dense areas
~30-40 m (depends on power & antenna)	COVERAGE DISTANCE	Up to 20 m (No. of LEDs)

VLC – Commercial World

LIGHTPOINTE

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

pureVLC™

PHILIPS

GE Lighting

intel

Supreme Architecture

CASIO

VLCC Visible Light Communications Consortium

infsoft smart connected locations

SIEMENS

VLC Ltd

Disney

RENESAS

COLOR KINETICS

LiFi Consortium

IEEE 802.15.7

Panasonic

eldoLED your product | our drive

SAMSUNG

Nakagawa Laboratories, Inc.

IBSENtelecom optical telecom designed with people in mind

LVX System

ByteLight

FIREFLY WIRELESS NETWORKS

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

Outstanding Technology Co., Ltd.

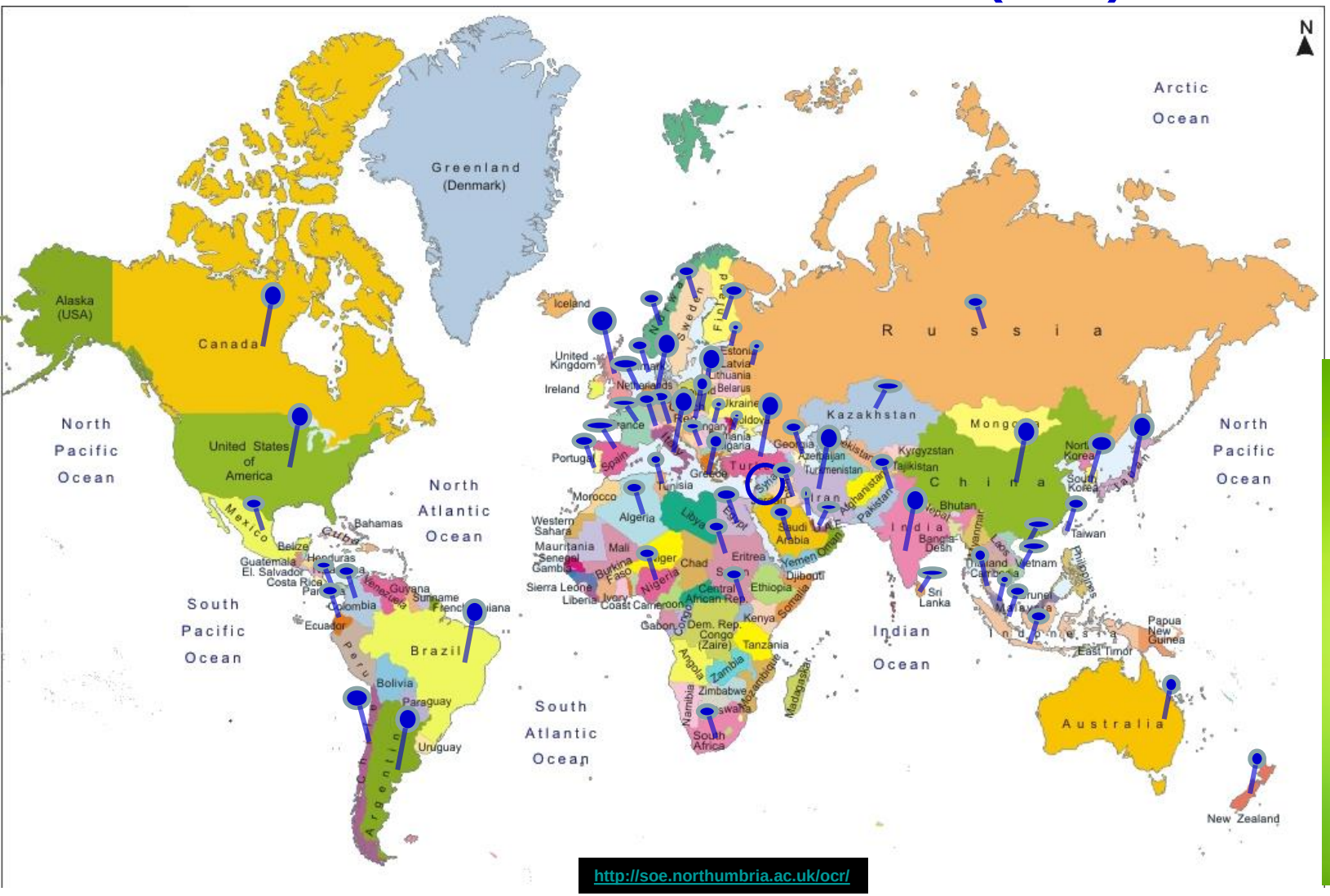
NEC Corporation

Thomas Little, Boston University

Northumbria University NEWCASTLE

OCRG

Global Research On Visible Light Communications (VLC)



http://soe.northumbria.ac.uk/ocr/

The VLC (or LiFi) journey started in late 1970 in Japan and it has now become global.

VLC-OCC – Final Comments

- A new revolution in wireless communications
- A complementary technology to RF
- Ideal for Smart Environments (Medical, business, others)

Future Challenges

VLC

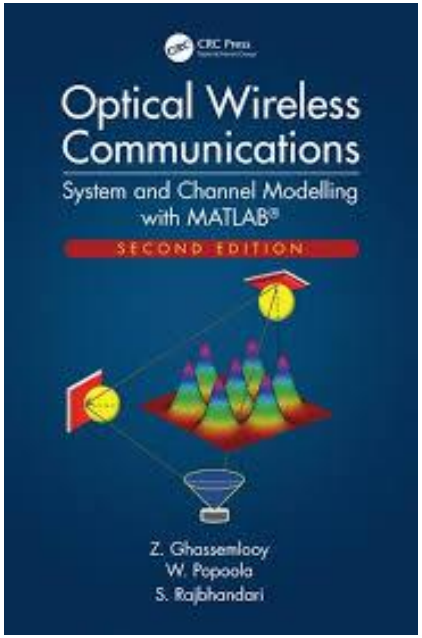
- **L**ED bandwidth and nonlinearity
- **C**overage and distance
- **D**imming and no light
- **B**locking
- **M**obility
- **U**plink

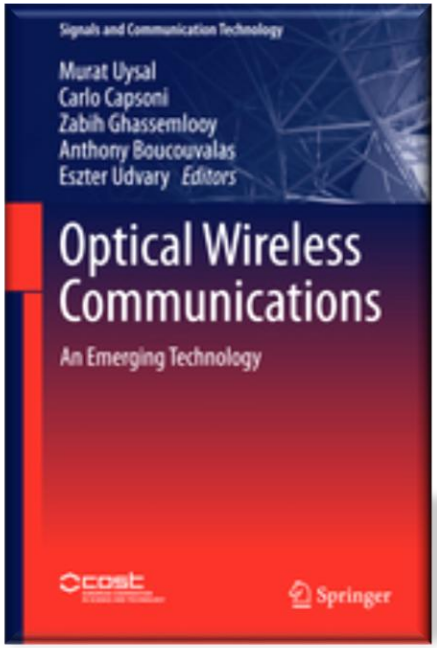
OCC

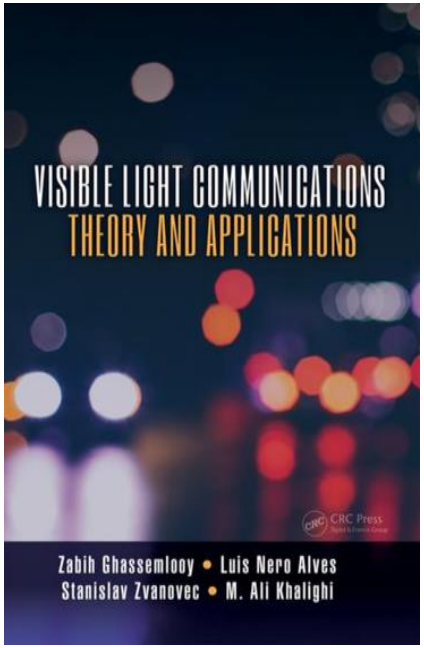
- **T**he same application - cannot be used in all smart devices, since smartphones come with various operating systems (Android, Windows, or iOS)
- **L**ow data rates

Further Reading

Our Contributions:





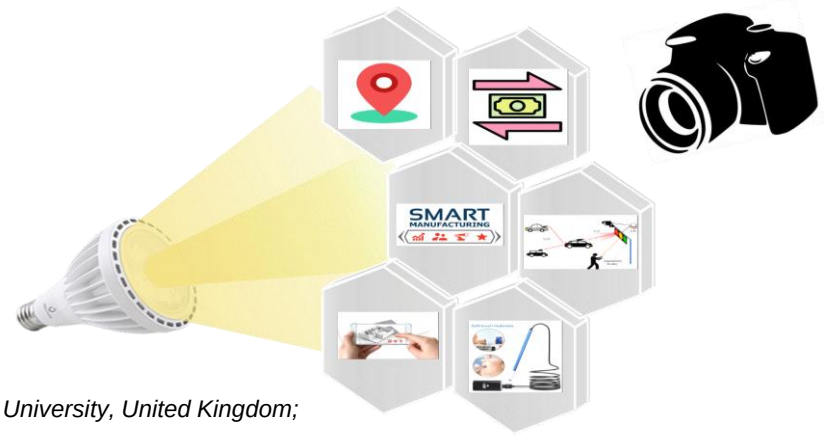


+

A few hundred papers

VLC - OCC – International Forum

Visible light communications (VLC) is seen as a potential wireless technology for the 5th Generation and beyond wireless networks. VLC systems using an image sensor-based detectors (i.e., cameras) are best known as Optical Camera Communications (OCC). In OCC systems, the communication function of cameras is supplementary to their primary function of capturing images. OCC aims to expand the potential of VLC by using the cameras in smart-devices in smart environments for data transmission, localization and sensing. The existing and future infrastructure will be an advantage of OCC for the market acceptance, and there are growing research interests and activities in this area. The aim of OCC Forum is to bring together researchers from academia and industry working in this field to further enhance understanding, knowledge and skills in the emerging field of OCC by coordinating research activities, exchanging information, sharing knowledge and experties and promoting it at the global level. Research groups are encouraged to join, and there are no official formalities. If working in this field and interested to join please let us know.



Founding Members

- Prof Zabih Ghassemlooy, *Northumbria University, United Kingdom;* z.ghassemlooy@northumbria.ac.uk
- Prof Rafael Perez Jimenez, *Universidad de Las Palmas de Gran Canaria, Spain*; rafael.perez@ulpgc.es
- Prof Stanislav Zvanovec, *Czech Technical University in Prague, Czech Republic;* xzvanove@fel.cvut.cz
- Dr Luis Nero Alves, *University of Aveiro/Instituto de Telecomunicações, Portugal;* nero@ua.pt
- Prof Yeon Ho Chung, *Pukyong National University, Busan, Korea*; ychung@pknu.ac.kr
- Prof Zhengyuan Xu, *University of Science and Technology of China, P R China;* xuzy@tsinghua.edu.cn
- Dr Trang Nguyen, *the University of Edinburgh, UK;* Trang.Nguyen@ed.ac.uk

IEEE 802.15.7m std., 2018, **includes OCC modes**

Who can join: Anyone working in VLC and OCC

Events

Topics

Call for Papers

- All organic visible light communications (VLCs);
- Channel modelling and characterisation, channel capacity analysis;
- Diversity techniques, dimming, data communications and localisation in VLCs;
- Free space optics (FSO), outdoor and under water - Last meter to last mile;
- Hybrid millimetre-wave (MMW)- optical wireless communications (OWC) links;
- Hybrid IR/VLC technology;
- Modelling of various noises in MMW/OWC systems;
- Modulation, coding and detection schemes;
- Mobile-to-infrastructure and mobile-to-mobile communications;
- OWC, MMW, and THz novel devices and components ;
- OWC and MMW networks: architecture, PHY/MAC design, cross-layer design;
- Applications of OWC (VLC, FSO) and MMW for: Device-to-device communications, e-Health,e-Commerce, Intelligent transportation systems (e.g. vehicle-to-vehicle and vehicle-to-infrastructure communications, trains, aircrafts, etc.), Underwater, Indoor positioning, Inter and intra chip communications, Internet-of-Things (IoT), Medical, Space, Manufacturing, Wireless sensor networks;
- Next generation OWC and MMW networks;
- OWC and MMW transceiver design and optimization;
- Ultraviolet communications;
- Massive MIMO for optical and MMW links;
- Others

http://wasowc2020.modares.ac.ir/

The 3rd West Asian Symposium on *Optical and Millimeter-wave Wireless Communications* (WASOWC2020) is hosted at the Tarbiat Modares University (TMU), Tehran, Iran. It follows the successful previous events held in Isfahan University of Technology (2018) and Shahid Beheshti University (2019). WASOWC2020 aims to bring together researchers from academia and industry to share their latest findings in the field of optical & millimetre-wave wireless communications as part of the 5th Generation and beyond wireless networks. The 3rd Symposium will also include workshops, invited and keynote speakers. High quality and original technical papers are welcome to be presented at WASOWC2020.

+ Workshop on Matlab Simulation for OWC

Sponsors

CSNDSP, ISC, ELSEVIER, MTN

Keynote Speakers

Prof Beatriz Ortega Tamarit – *Universidad Politécnica de V Alência, Spain*

Prof Min Zhang – *Beijing University of Posts & Telecommunications, China*

Invited Speakers

Prof Murat Uysal - *Özyeğin Univ., Turkey*
Prof Abdolali Abdipour - *Amirkabir Univ. of Technology, Iran*
Prof Ismael Soto Gómez – *Univ. of Santiago, Chile*
Dr Wasiu O Popoola - *Edinburgh Univ., UK*
Dr Hamdi Torun - *Northumbria Univ., UK*
Dr Hamzeh Beyranvand - *Amirkabir Univ. of Technology, Iran*

Important Dates:
Paper submission deadline: 15 Dec. 2019
Notification of acceptance: 25 Feb. 2020
Submission of final papers deadline: 10 March 2020

Steering Committee - Prof Z. Ghassemlooy, *Northumbria Univ., UK, **General Chair;*** Prof V. Ahmadi, Tarbiat Modares Univ., Iran, ***Local Chair;*** Dr M-A. Khalighi, *Ecole Centrale Marseille-Institut Fresnel, France;* Prof S. Zvanovec, *Czech Technical Univ. in Prague, Czech Republic;* Dr A. Gholami, *Isfahan Univ. of Technology, Iran;* Dr M. S. Sadough, *S B Univ., Iran;* Dr L. N. Alves, *Univ. of Aveiro, Portugal*

CSNDSP 2020 – Biennial since 1998

The 7th Biennial Colloquium on Optical Wireless Communications

12th IEEE/IET International Symposium on Communication Systems, Networks, and Digital Signal Processing

20-22 July 2020, Porto, PORTUGAL - *https://csndsp2020.av.it.pt/*

Venue: Fundação Dr. António Cupertino de Miranda

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Voted the ***European Best Destination*** in 2017, **Porto**, is the 2nd largest city in Portugal. Located in the north of the country by the outlet of the Douro River, it has a unique atmosphere of elegant neighbourhoods and large villas sitting on narrow cobbled streets. One of the older cities in Europe (dating back to 300 BCE), this soulful city was classified as a World Heritage Site by UNESCO in 1996.

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Prof Zhengyuan Xu – *University of Science and Technology of China, China*
Dr Wasiu O. Popoola – *The Univ. of Edinburgh, UK*
Prof Rafael Perez Jimenez – *Universidad de Las Palmas de Gran Canaria, Spain*

Full Paper by *16 Feb. 2020*

Thank You!

Would be happy to take a few questions!