Fiber Optics Communications

Week 14

Selected Topic in Optical Communications: Optical Wireless Communications (Seminar)

Lecturer: ***Zelalem Hailu (Assistant Prof.)***

Addis Ababa Science and Technology University
Addis Ababa, Ethiopia

Topics of Previous Lecture (Week-13)

Fiber Optic Communication Networks

- Optical Network Topologies
- Generation of Optical Networks
- First Generation: SONET/SDH Basics
- Second Generation: Wavelength Routing Networks
- WDM Networks
- Passive Optical Networks (PON)

Week-14: Lecture Learning Outcomes

1. Explain the concept of Optical Wireless Communication (OWC) and how it differs from traditional RF communication systems.
2. Identify Major Application Areas of OWC
3. Differentiate Between Indoor and Outdoor OWC Applications
4. Explain the Unique Advantages of OWC
5. Classify Link Configuration Types in OWC
6. Explain the Concept of Visible Light Communication (VLC) and its potential applications

Week-14: Optical Wireless Communications

Outline

- Introduction: Optical Wireless Communications
- OWC Application Areas
- Indoor and Outdoor OWC applications
- Unique Advantage of OWC
- Link Configuration Types in OWC
- Visible Light Communication (VLC)

Optical Wireless Communications (OWC)

- Optical Wireless Communication (OWC) is a type of optical communication that uses unguided light for transmitting information

Why we need optical wireless communication (OWC)?

- **To solve conventional RF spectrum crunch.**
- **Low cost**
- **Energy efficient**
- **Huge unregulated bandwidth**
- **Secure**
- **No interference on RF signal**

- Wireless traffic in the access network doubles in volume almost every year
- The over utilized RF spectrum can not accommodate this huge traffic alone

Optical Wireless Communications (OWC)

- OWC uses light waves (infrared, visible, or ultraviolet) to transmit data wirelessly through free space.
- It serves as an alternative or complement to radio frequency (RF) communication
- Based on the usage scenario OWC communication can be classified as:
  - In door OWC:
  - Outdoor OWC
- It can also be classified based on transmission distance:
  - Short Reach:
  - Medium Reach
  - Long Reach

Optical Wireless Communications (OWC)

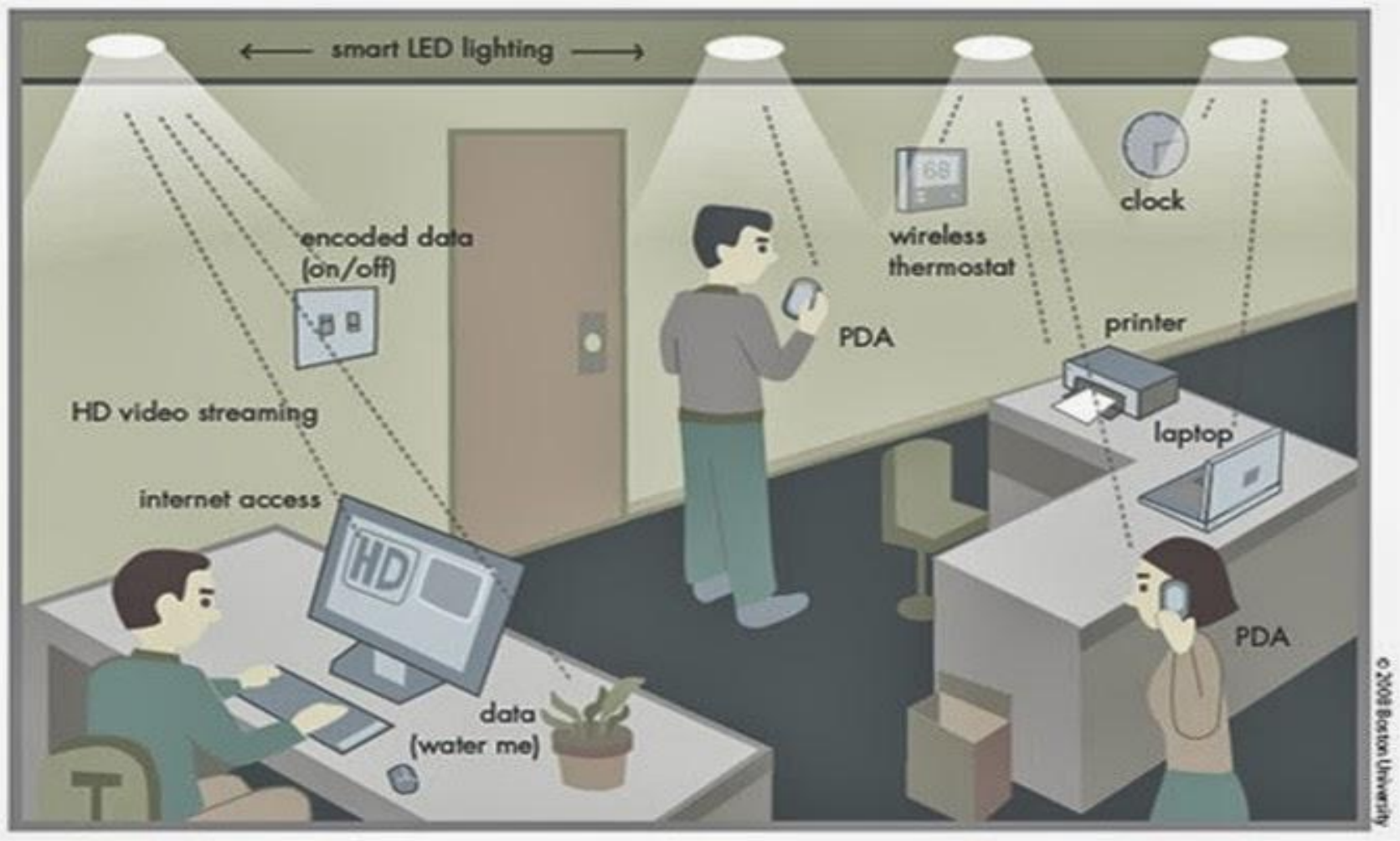

Figure 1: OWC indoor application

Source: "Top 10 Trends In LED Lighting Technology," GBL Infrastructure Solutions Inc., June 29 2017. https://gblsolutionsinc.com/wp-content/uploads/2017/06/future-LED-lighting-trends.jpg

Optical Wireless Communications (OWC)

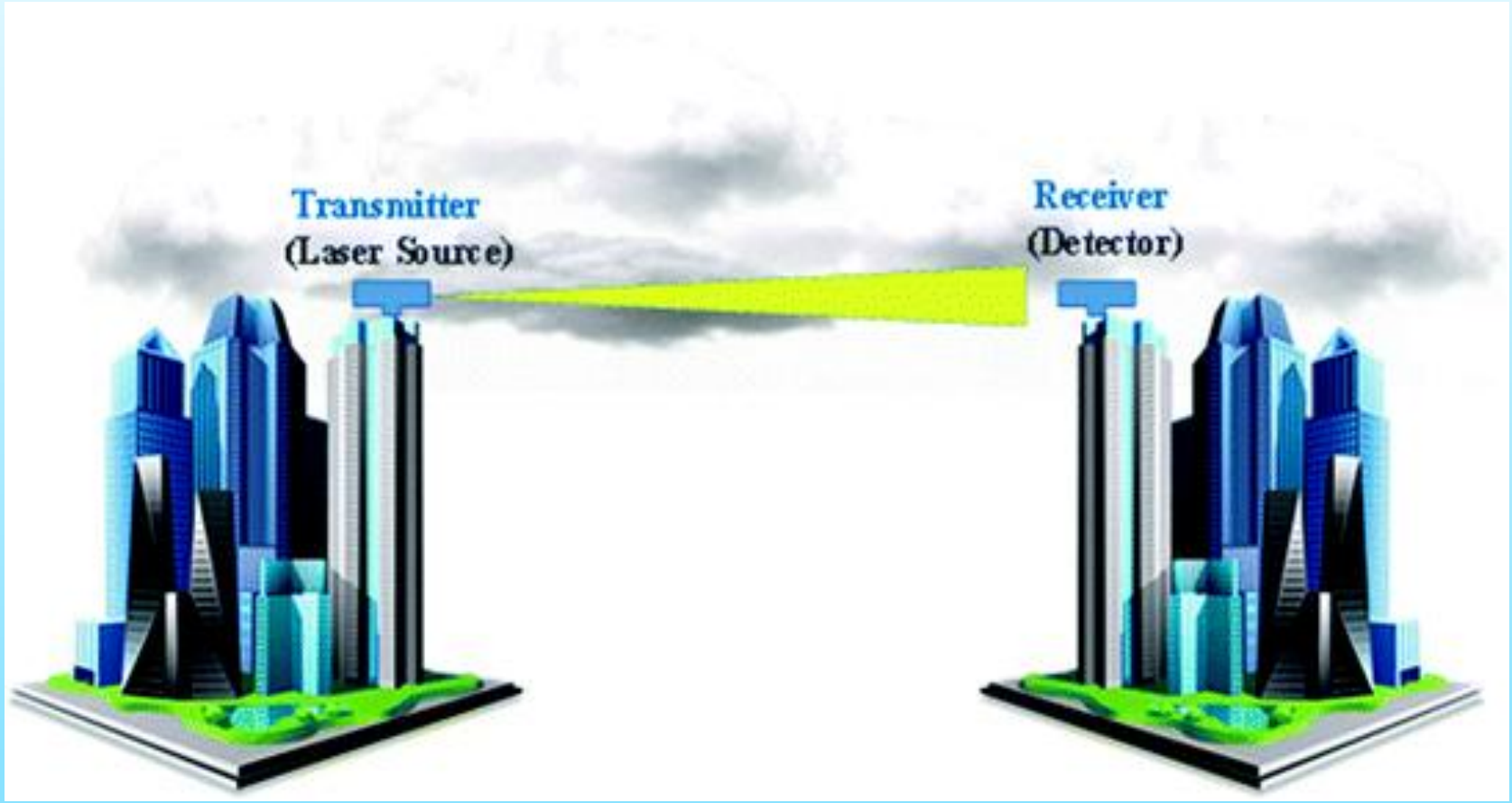

Figure 2: OWC outdoor application

Source: "Optical Wireless Communications : Things You Need To Know," realme Community. https://static.c.realme.com/IN/thread/12540267379189350 40.gif

OWC Application Areas

- OWC applications can be broadly categorized as indoor and outdoor applications

1. Indoor Applications

❖ **High-speed wireless internet (Li-Fi):**

✓ Uses LED lights to transmit data at gigabit speed

✓ Can complement or replace Wi-Fi in areas requiring high security or no RF interference (e.g., hospitals, airplanes)

❖ **Data centers & server rooms:**

✓ short-range optical links can reduce wiring congestion and increase speed between racks

❖ **Industrial Robots Communications:**

✓ VLC or IR links provide low-latency communication for synchronized movements and task sharing of industrial robots

OWC Application Areas

1. Indoor Applications

- **Indoor Localization:**
  - ✓ For high precision indoor localization
  - ✓ **Example:** Optical signals (LED transmitters) help robots locate themselves accurately on the factory floor, supporting navigation without GPS

OWC Application Areas

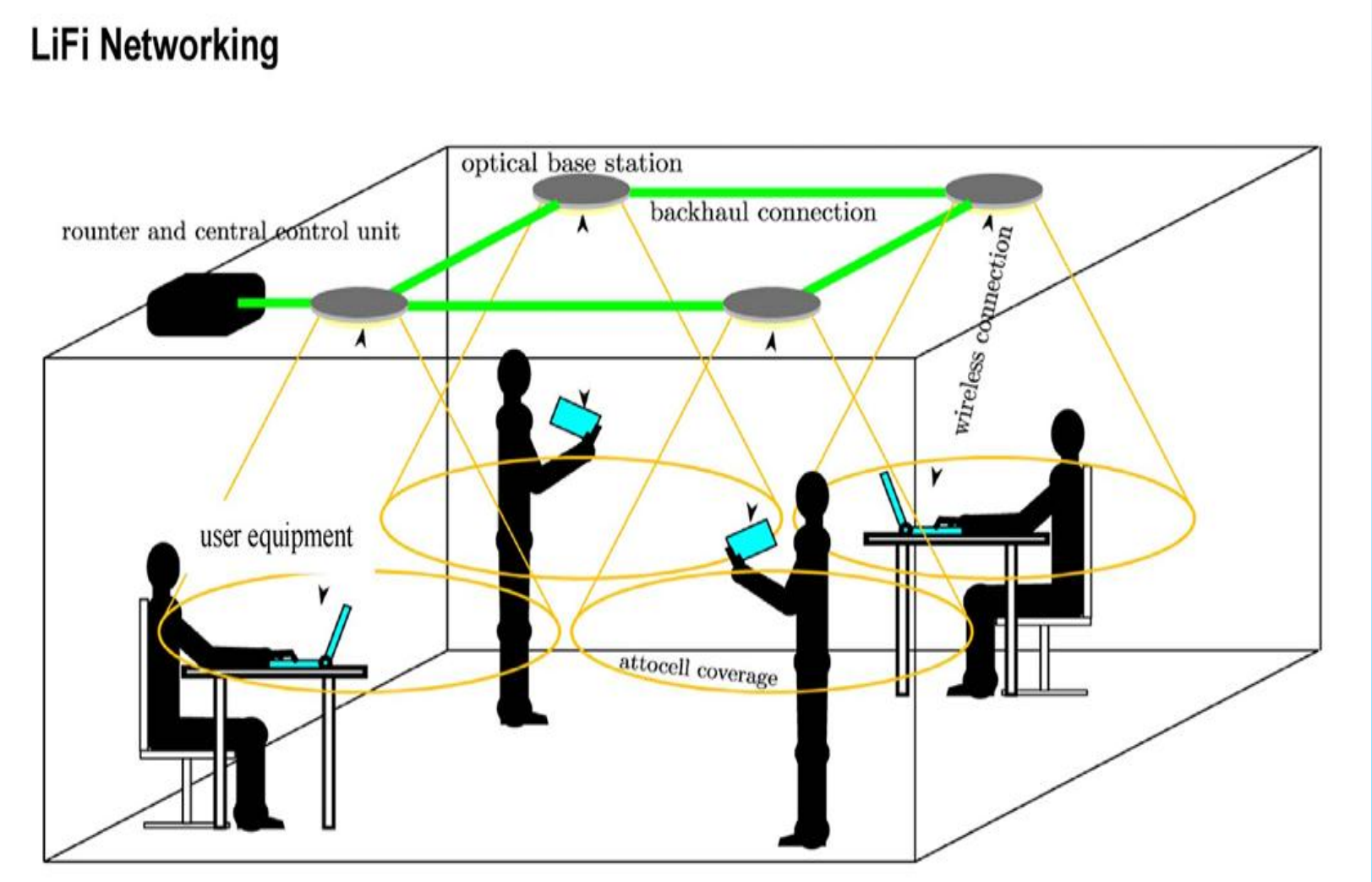

Figure 3: High-speed wireless internet (Li-Fi)

Source: Harald Haas, "LiFi is a paradigm-shifting 5G technology," Reviews in Physics, Volume 3, 2018. https://www.researchgate.net/publication/320680265/figure/fig1/AS:872324056248346@1584989670972/The-concept-of-LiFi-attocell-networks-applied-to-indoor-wireless-networking_W640.jpg

OWC Application Areas

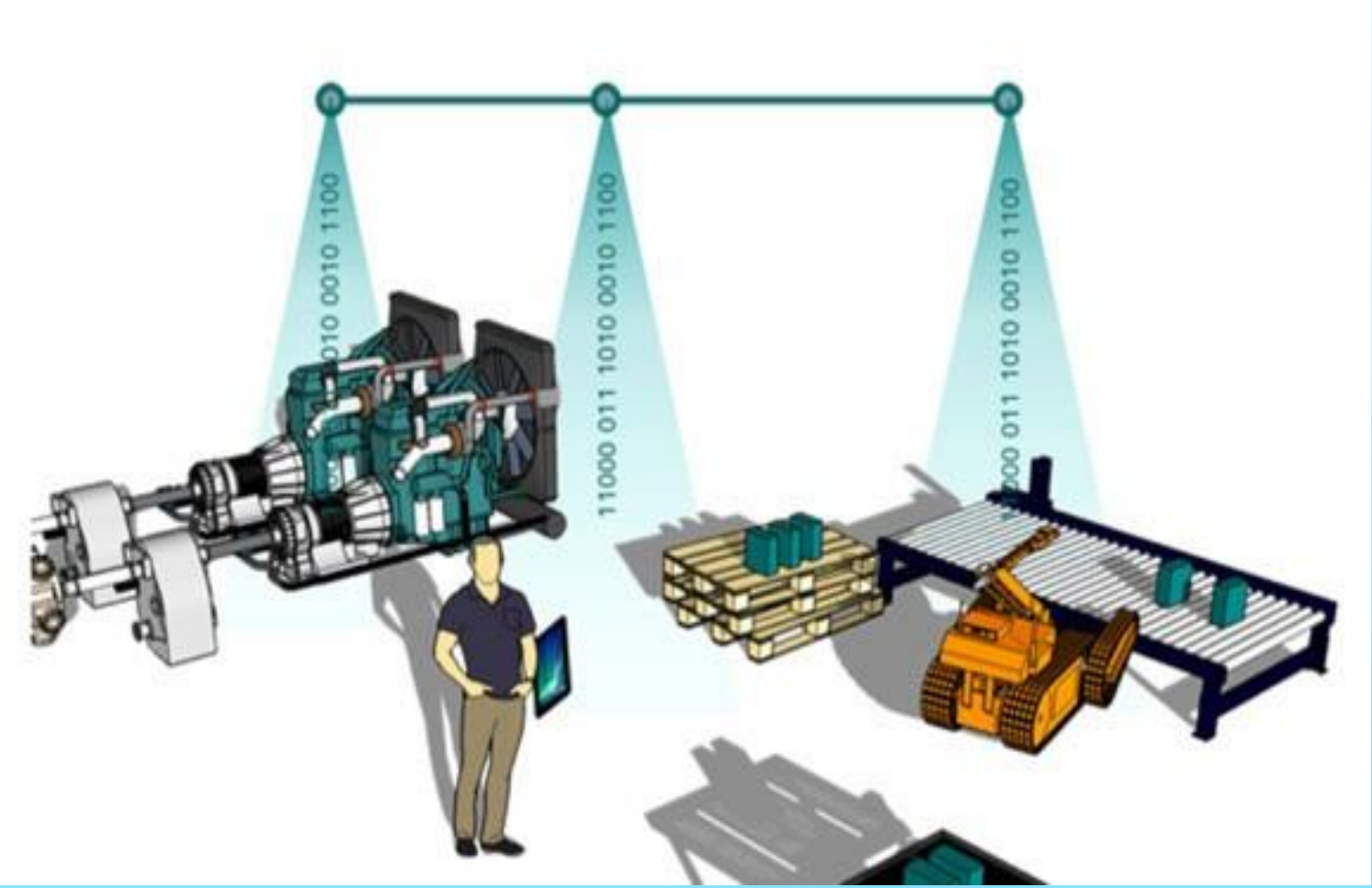

Figure 4: OWC indoor industrial application

Source: Fraunhofer-Gesellschaft, “Wireless signals from ceiling lighting for connected manufacturing,” Research News, Mar. 02, 2020. https://www.fraunhofer.de/en/press/research-news/2020/march/wireless-signals-from-ceiling-lighting-for-connected-manufacturing/jcr:content/contentPar/sectioncomponent/sectionParsys/textwithinlinedimage/imageComponent1/image.img.2col.jpg/1581420066087/iosb-wireless-signals-from-ceiling-lighting-for-connected-manufacturing-pic-i.jpg

OWC Application Areas

2. Outdoor Applications

- **Backhaul for telecom networks:**
  - ✓ FSO links can connect base stations where fiber installation is expensive or impractical
  - ✓ Can be used for 4G/5G mobile backhaul
- **Campus or building-to-building connectivity:**
  - ✓ High-speed data links between two buildings or across a campus
  - ✓ Can reach several kilometers in line-of-sight conditions
- **Disaster recovery & temporary networks:**
  - ✓ Rapid deployment of optical links after natural disasters or during festival and gathering events

OWC Application Areas

2. Outdoor Applications

- **Military and secure communications::**
  - ✓ Difficult to intercept and jam compared to RF signals
  - ✓ Can provide secure battlefield communication links
- **Campus or building-to-building connectivity:**
  - ✓ High-speed data links between two buildings or across a campus
  - ✓ Can reach several kilometers in line-of-sight conditions
- **Smart city & IoT infrastructure:**
  - ✓ Connects streetlights, traffic sensors, or outdoor Wi-Fi hotspots with minimal RF interference
- **Under water Communication:**
  - ✓ is a method of transmitting data through water using light

OWC Application Areas

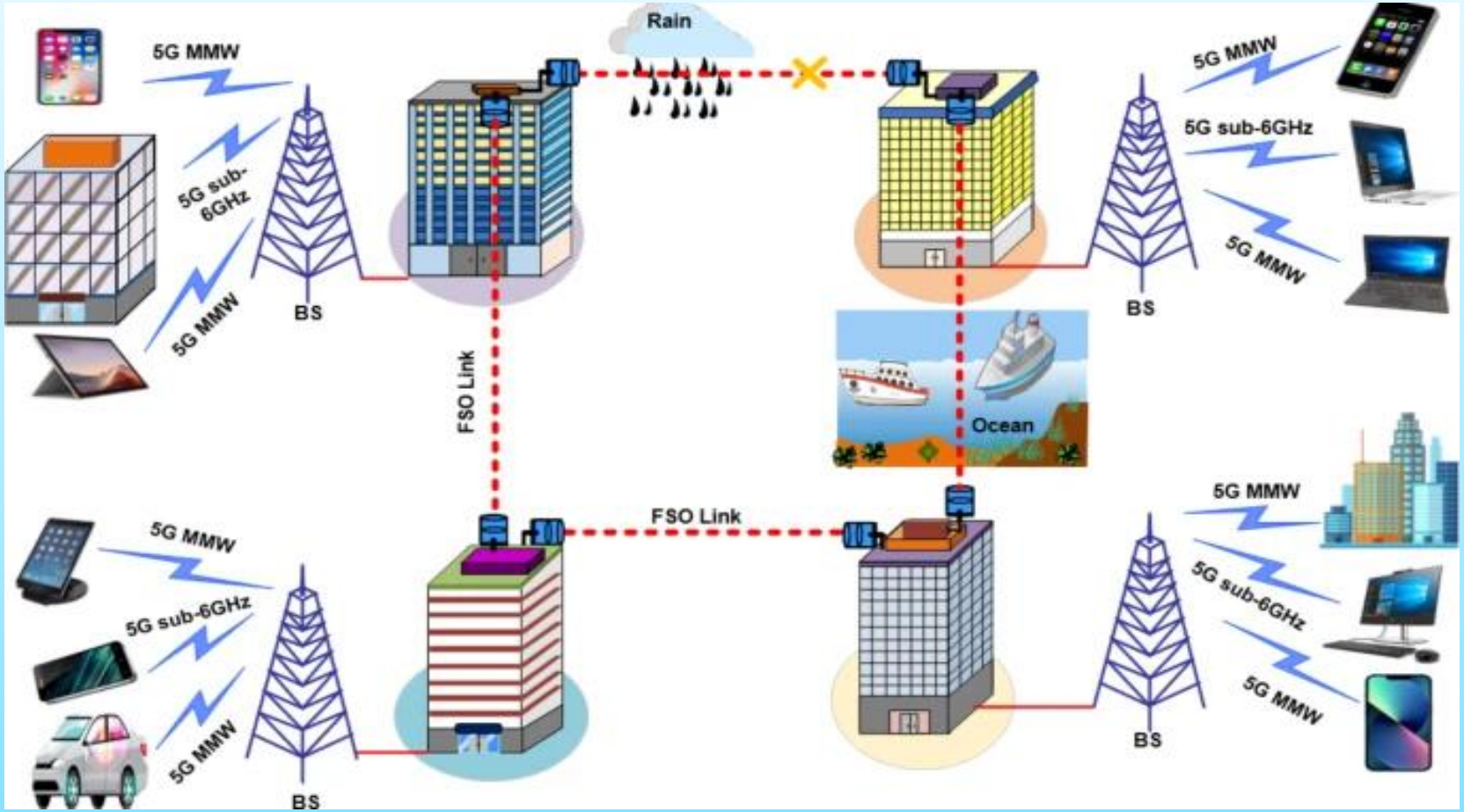

Figure 5: OWC outdoor building to building communication

Source: S. T. Hayle, H.-Y. Hsu, C.-P. Wang, H.-H. Lu, J.-M. Lu, W.-W. Hsu, Y.-C. Chung, Y.-Y. Bai & K. Okram, "High-speed FSO-5G wireless communication system with enhanced loss compensation using high-power EDFA," Scientific Reports, vol. 15, Article No. 379, 2025. https://media.springernature.com/lw685/springer-static/image/art%3A10.1038%2Fs41598-024-84436-7/MediaObjects/41598_2024_84436_Fig1_HTML.png?as=webp

OWC Application Areas

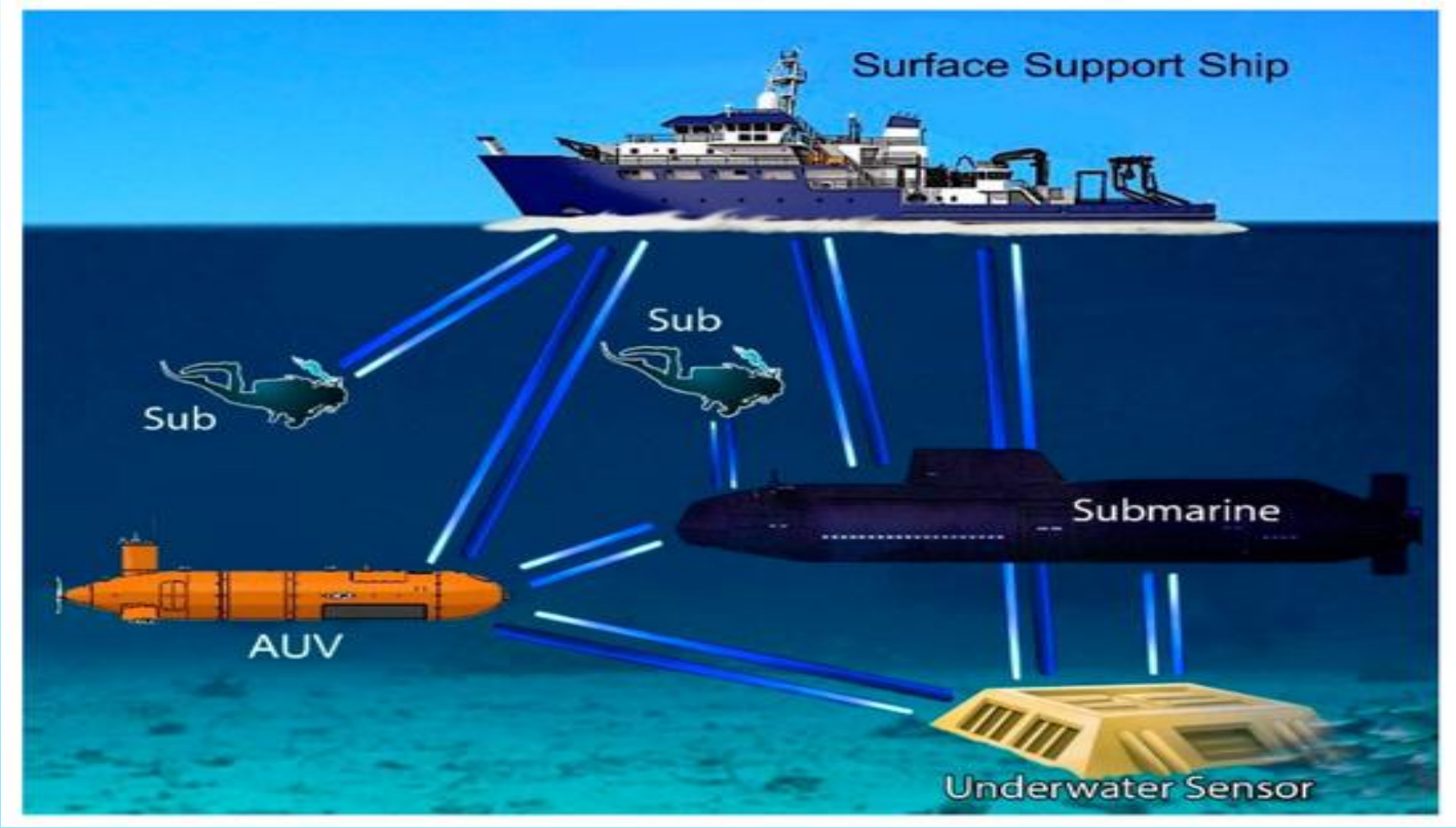

Figure 6: Underwater OWC

Source: G. Schirripa Spagnolo, L. Cozzella and F. Leccese, “Underwater Optical Wireless Communications: Overview,” Sensors, vol. 20, no. 8, article 2261, Apr. 2020. https://www.mdpi.com/sensors/sensors-20-02261/article_deploy/html/images/sensors-20-02261-g001-550.jpg

OWC Application Areas

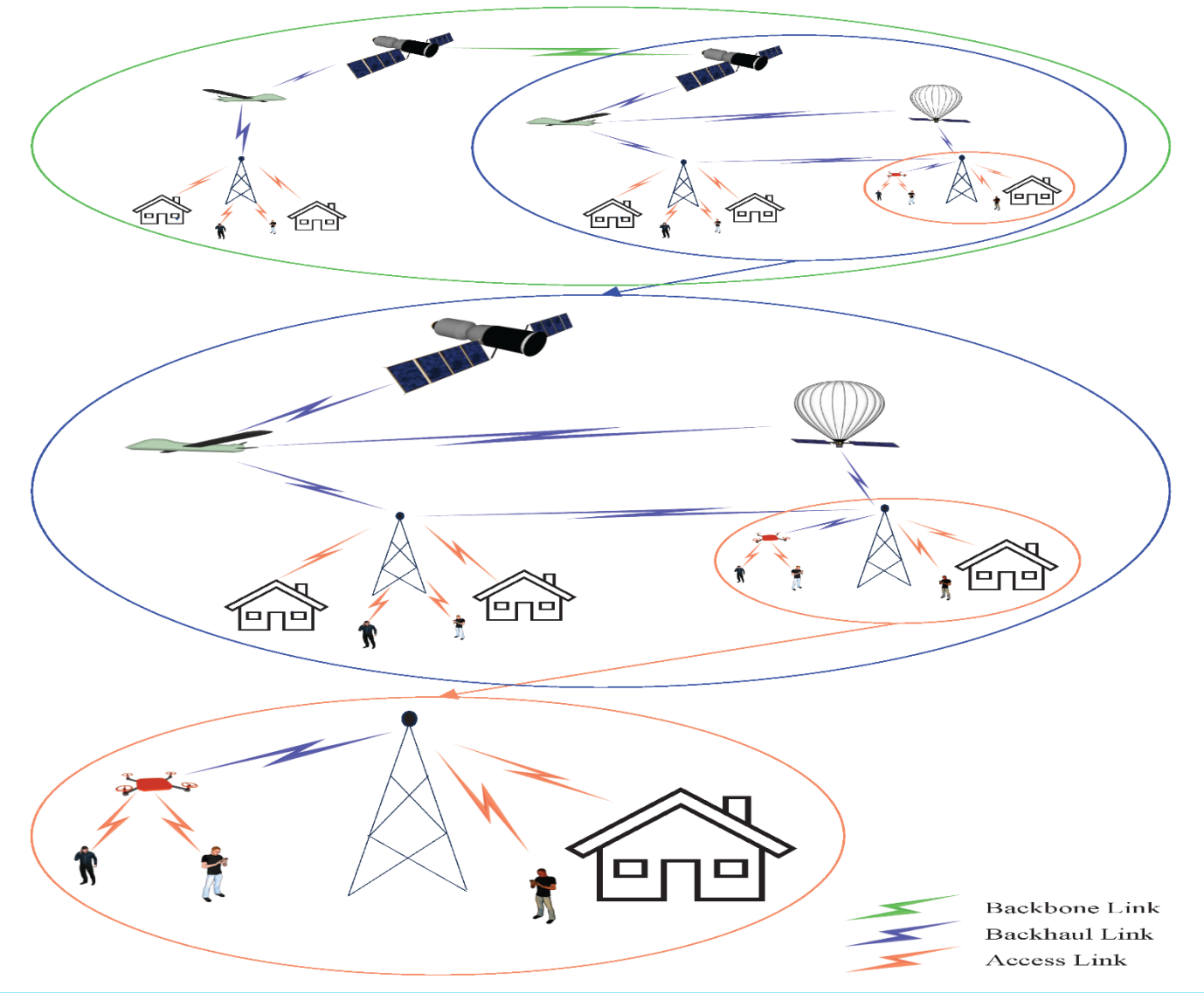

Figure 7: Non-terrestrial OWC Link

Source: Elamassie M, Uysal M., “Free Space Optical Communication: An Enabling Backhaul Technology for 6G Non-Terrestrial Networks,” Photonics. 2023. https://www.mdpi.com/photonics/photonics-10-01210/article_deploy/html/images/photonics-10-01210-g001-550.jpg

Unique Advantage of OWC

- Unique advantage of OWC compared to the RF based communication are as follows [1]:

  - Huge unregulated bandwidth (more than 200 THz in the 400–1500 nm range)
  - Zero utilization tariffs
  - There is no multipath fading effect when Intensity modulation (IM) and direct detection (DD) is used
  - Enhanced network security (The transmitted optical beams are narrow and invisible, making them difficult to detect and even more challenging to intercept)
  - Higher data capacity per unit volume (bps/m^3) is achieved since adjacent cells can reuse the same frequency
  - Small, light, compact smaller size components and relatively low cost
  - Use one wavelength to cover a large number of cell, therefore no frequency reuse problem as in RF

Unique Advantage of OWC

- Well-defined cell boundaries and no inter-channel interference
- Minimal absorption effects at 800–890 nm and 1550 nm
- No need to dig up roads and is easily installed
- Health-friendly (no RF radiation hazards)
- Lower power consumption
- Immunity to the electromagnetic interference

Link Configuration Types in OWC

- There are various ways of configuring the optical wireless links and the can be grouped as follows:

1. Directed Line of Sight (D-LOS) Configuration

- Mainly used for point-to-point communication (outdoor and some indoor applications)
- Uses a narrow optical beam, requiring low transmission power
- Produces high-power flux density at the photodetector
- Highest data rates: hundreds of Mbps and above
- Typical range: a few meters up to 5 km
- **Advantages of D-LOS Link:**
  - ✓ High data rate due to minimal multipath effects
  - ✓ Low ambient light interference when using a narrow Field of View (FOV) receiver

Link Configuration Types in OWC

- There are various ways of configuring the optical wireless links and the can be grouped as Directed line of sight (D-LOS), Non-directed line of sight (ND-LOS), Diffused, and tracked OWC system

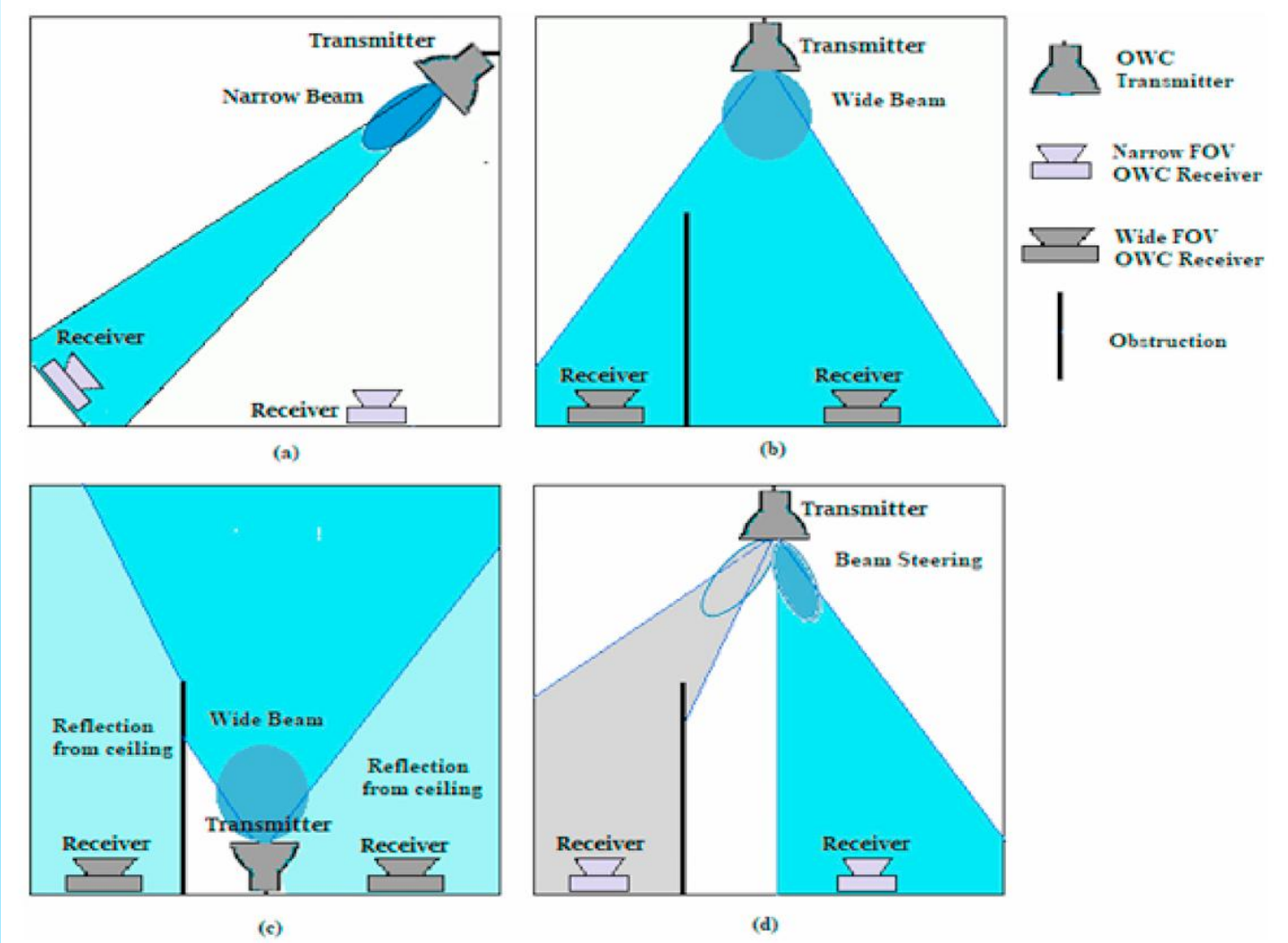

Figure 8: OWC link configurations (a)D-LOS (b) ND-LOS (c) Diffuse (d) Tracked

Source: C. Jenila, R.K. Jeyachitra, "Green indoor optical wireless communication systems: Pathway towards pervasive deployment," Digital Communications and Networks, Volume 7, Issue 3, 2021. https://www.researchgate.net/publication/346809484/figure/fig1/AS:967166622973953@1607601900670/OWC-link-configurations-a-directed-LOS-b-non-directed-LOS-c-diffuse-and-d_W640.jpg

Link Configuration Types in OWC

1. Directed Line of Sight (D-LOS) Configuration

- **Limitations of D-LOS Link:**
  - ✓ Small coverage area for indoor applications
  - ✓ Alignment required between transmitter and receiver that limits mobility
  - ✓ Not suitable for roaming or mobile users

2. Non-Directed Line of Sight (ND-LOS) Configuration

- Commonly used for indoor applications
- Most flexible configuration of OWC
- **Uses:**
  - ✓ Wide-beam transmitters
  - ✓ Wide field-of-view (FOV) receivers
  - ✓ Surface reflections to expand coverage area

Link Configuration Types in OWC

2. Non-Directed Line of Sight (ND-LOS) Configuration

- **Typical data rate:** above 150 Mbps
- **Advantages of ND-LOS Link::**
  - ✓ **Broad coverage:** supports point-to-multipoint communication
  - ✓ No alignment or tracking required between transmitter and receiver
  - ✓ Robust against shadowing and blockage
  - ✓ Reflected light from room surfaces helps maintain connectivity
- **Limitations of ND-LOS Link:**
  - ✓ High optical path loss → requires higher transmit power
  - ✓ Multipath dispersion causes inter-symbol interference (ISI)
  - ✓ Sensitive to ambient light interference, reducing performance

Link Configuration Types in OWC

3. Diffuse Optical Wireless Link Configuration

- Also known as **nondirected non-Line-of-Sight (ND-NLOS)**
- **Transmitter:** points toward the ceiling emitting a wide IR beam
- Operation relies on multiple reflections from ceiling, walls, and objects
- Does not require alignment or a clear LOS path
- **Highly flexible:** suitable for LAN and hoc networks
- **Advantages of Diffuse Link:**
  - ✓ No alignment or tracking required
  - ✓ Immune to blockage (robust under shadowing conditions)
  - ✓ Supports multiple users and dynamic indoor setups
  - ✓ Suitable for mobile environments

Link Configuration Types in OWC

3. Diffuse Optical Wireless Link Configuration

- **Limitations of Diffuse Link:**
  - ✓ **High path loss:** typically 50–70 dB for a 5 m link
  - ✓ Multipath dispersion leads to Inter-Symbol Interference (ISI)
  - ✓ Requires high transmit power due to low reflection coefficients (0.4–0.9)
  - ✓ Power constrained by eye safety

4. Tracked OWC Systems

- **Configuration:** Sources and detectors mounted on the ceiling with a tracking and beam streeting capability
- **Complexity:** Higher than other OWC link configuration types

Link Configuration Types in OWC

4. Tracked OWC Systems

- **Advantages of Tracked OWC system:**
  - ✓ Lower power requirement
  - ✓ Reduced ambient light interference
  - ✓ Minimized multipath-induced ISI
  - ✓ **Narrow-beam transmission and reception:** concentrates most energy in small angles
  - ✓ **High data rates:** similar to directed LOS links
  - ✓ **Large coverage area:** can serve multiple locations without degradation
- **Disadvantages of Tracked OWC system:**
  - ✓ High complexity
  - ✓ High cost

Among major challenges in OWC

- **Low modulation bandwidth of LED: Spectral efficient modulation and multiple access scheme is needed**
  - ✓ **Modulation:** DC biased optical OFDM (DCO-OFDM) [2]
  - ✓ Non-Orthogonal multiple access (NOMA)
- **Limited optical power regulation: Energy efficient modulation scheme is needed**
  - ✓ Asymmetrically clipped optical OFDM (ACO-OFDM) [2]
- **Mobility and handover Issue**
  - ✓ Enhanced mobility by incorporating optical wireless based user localization

Visible Light Communication (VLC)

Visible Light Communication (VLC)

- VLC uses the following key component:
  - **Transmitter:** visible light source
  - **Transmission Media:** air is used as a transmission medium
  - **Receiver:** photodiode as a signal receiving component

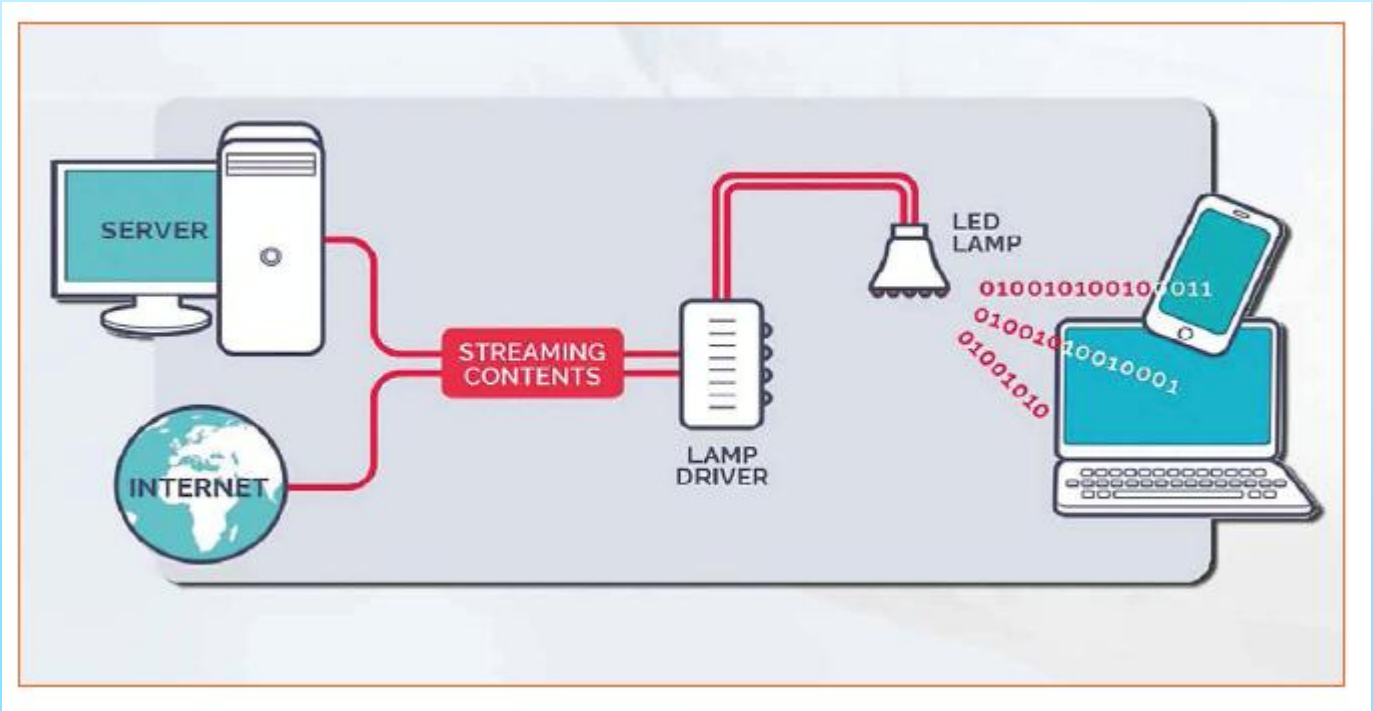

Figure 9: VLC operation

Source: "LiFi – What it is, how it works, what it provides, how to apply and its future prospects," LED Professional, Oct. 2017. https://www.led-professional.com/media/resources-1_articles_lifi-what-it-is-how-it-works-what-it-provides-how-to-apply-and-its-future-prospects_screen-shot-2017-10-31-at-10-44-01.png/@@images/image-1280-353935b3ee22178c7f62e24570c8c407.png

Visible Light Communication (VLC)

- Visible light range of the electromagnetic spectrum is used (400 -700 THz frequency range)

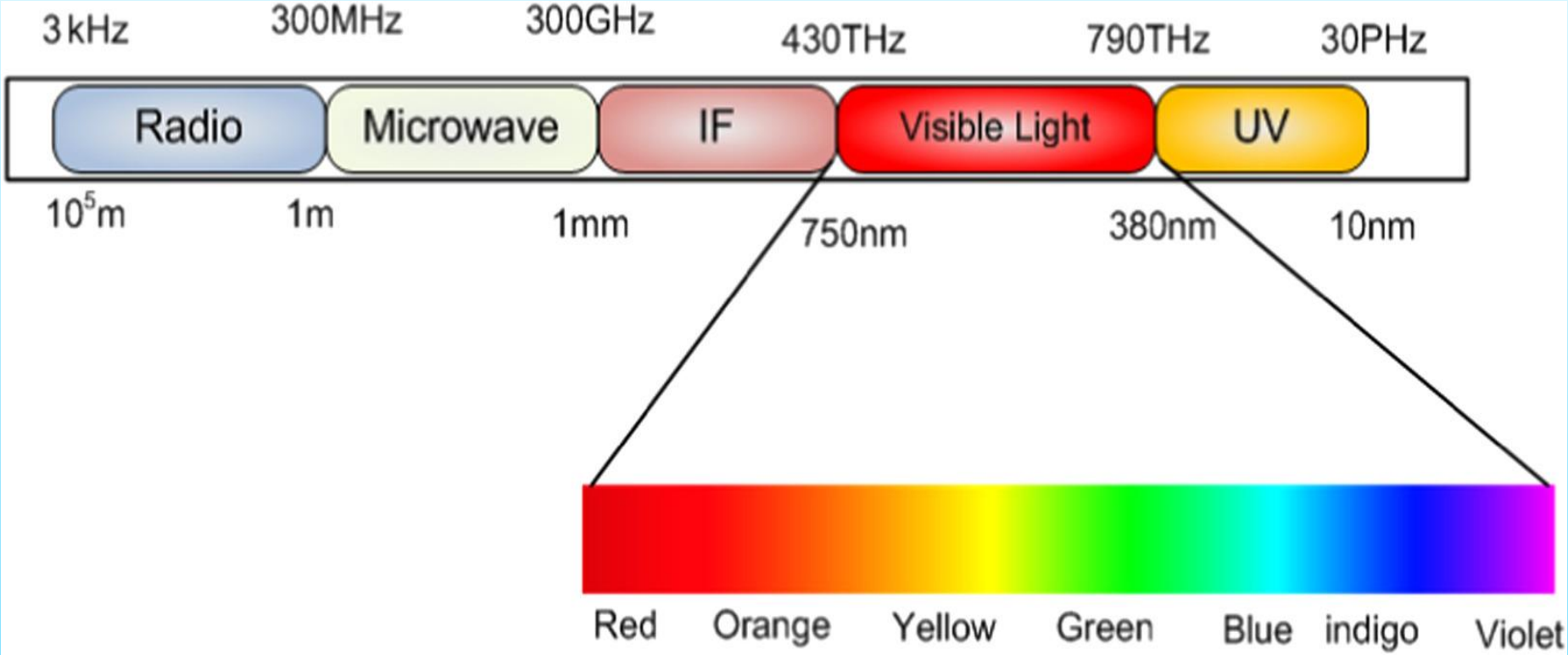

Figure 10: Visible light spectrum

Source: Mohsan, S.A.H., Amjad, H., "A comprehensive survey on hybrid wireless networks: practical considerations, challenges, applications and research directions," Opt. Quant. Electron., 2021. https://www.researchgate.net/publication/353911273/figure/fig4/AS:1143128118062248@1675654244634/Visible-light-spectrum-Rehman-et-al-2019_W640.jpg

Simultaneous Illumination and Communication

Figure 11: Simultaneous illumination and communication application

Source: "LiFi – What it is, how it works, what it provides, how to apply and its future prospects," LED Professional, Oct. 2017. https://www.led-professional.com/media/resources-1_articles_lifi-what-it-is-how-it-works-what-it-provides-how-to-apply-and-its-future-prospects_screen-shot-2017-10-31-at-10-43-15.png/@@images/image-1280-353935b3ee22178c7f62e24570c8c407.png

Multiplexing of RGB Light

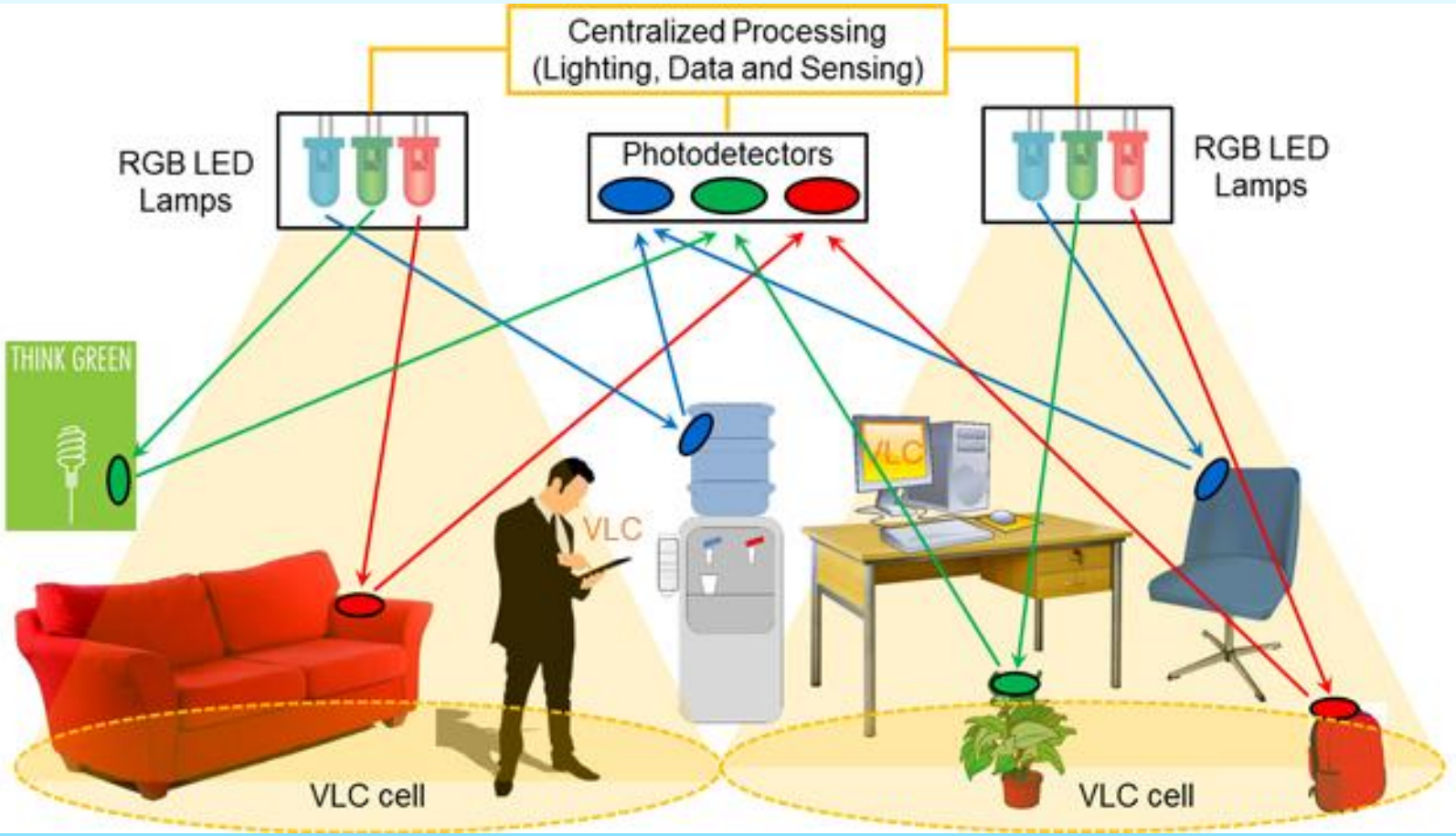

Figure 12: Multiplexing RGB light

Source: "ATTRACT featured stories: Visible light communication for indoor monitoring (VLADIMIR)," ATTRACT – Phase 1, 3 Mar. 2020. https://attract-eu.com/wp-content/uploads/2020/03/ATTRACT_vladimir.jpg

Summary

- **Optical wireless communication (OWC):**
  - ✓ Unguided communication using light
  - ✓ Objective: To complement RF based communication
  - ✓ Low cost and use the unregulated spectrum
- **Application Scenarios:**
  - ✓ Indoor and outdoor applications
  - ✓ Long, medium, and short reach communications
- **Visible light communication (VLC):**
  - ✓ Use the visible light spectrum
  - ✓ **Li-Fi:** fascinating emerging technology for illumination and data connectivity at the same time.

References

[1] Z. Ghassemlooy, W. Popoola, S. Rajbhandari, *“Optical Wireless Communications System and Channel Modelling with MATLAB”,* CRC press, Pp.5, 2013.

[2] R. Alindra, M. O. Fauzan, R. Ramadhan and S. Rahardjo, *"Performance Analysis of DCO-OFDM and ACO-OFDM for Visible Light Communication System,"* 2018 3rd International Seminar on Sensors, Instrumentation, Measurement and Metrology (ISSIMM), Depok, Indonesia, 2018.

Thank You!