Light Communications for 802.11

Date: 2017-07-09

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Light Communications for 802.11

Date: 2017-05-11

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Abstract

- **Light Communications (LC) is applicable to a wide range of different use-cases.**
- **LC is shown to be technically feasible from both a theoretical and practical perspective, with a number of demonstration systems identified in the market.**
- **The light spectrum can be used to provide data off-loading and link aggregation capabilities in conjunction with other 802.11 technologies in an globally harmonized and license exempt spectrum.**
- **The use of light as a communication medium can be developed through a marginal cost impact for the infrastructure, by using the lighting infrastructure in the building, along with the well understood costs for introducing new communications modules in handheld devices, which could open multiple adjacent markets.**
- **The market size for LC is expected to be over $75.5 billion by 2023 when across the value chain with over 550 million light bulbs installed annually.**
- **Standardizing LC as part of the 802.11 will help accelerate the introduction of products to the market, leveraging established product introduction and certification processes (e.g. Wi-Fi Alliance).**
- **The LC TIG strongly recommends that the 802.11 WG establish a Study Group to draft the scope and project authorization request for a LC standard.**

It is proposed that an SG be formed to consider the standardization of LC within 802.11

- LC is high speed, bidirectional and networked wireless communications using light, providing a similar user experience as traditional 802.11 technologies, such as mobility including handover and multiple access, except using the light spectrum.
- Application areas include:
  - Enterprise and home wireless deployments, retail, industrial environments, and more
- Market research indicates that LC will become a $75.5 billion industry by 2023, according to Global Market Insight. Limited changes to the existing 802.11 protocols will increase its reach into this new market.
- Over 550 million LED lights sold annually with 13% CAGR – every light can be LC enabled.
- LC has comparable computational energy consumption to existing 802.11. The energy already required for illumination is also used for LC communications.
- The light spectrum is considered license exempt by several spectrum regulators and outside of the regulation remit for many others. Light provides a globally harmonized spectrum that can be used for wireless data off-loading or increased throughput with link aggregation.

LC has unique features that are beneficial in some environments

Spectrum

LC spectrum is globally harmonised & unlicensed

Spectrum is complementary and non-interfering to all existing and emerging 802.11 technologies

Energy

LC operates with potentially minimal extra energy requirements

Energy used for illumination is reused for communications

Global lighting standards provide **guaranteed signal strength**, e.g., mandatory office lighting levels

Infrastructure

LC provides new connectivity at low marginal cost

New wave in Power over Ethernet provides connectivity to the LEDs

The "transmit antenna" (LEDs) and access to power already available at installation site

Volumes

LC piggybacks on the lighting market

Over 550 million lights sold annually with 13% CAGR

Drive to provide energy efficiency and wireless communications can be combined

LC complements Wi-Fi and WiGig in a similar manner to how WiGig complements Wi-Fi

	Problem Source	Alternative solutions	
	Wi-Fi	WiGig	LC
Confinement	✗	✓	✓
RF interference	✗	Mostly ok	✓
Spectrum	Increasingly Crowded	Additional in 60GHz	Additional in light/IR

The demand for mobile wireless communications is increasing at over 50% per year creating a need for more spectrum

- Wi-Fi is ubiquitous, affordable, and offers performance that is well suited for current and emerging applications, untethered internet access via Wi-Fi is essential for consumers worldwide.
- User demand for data continues to grow at an exponential rate. IP traffic is projected to increase nearly threefold in the next five years with a majority of that traffic delivered over Wi-Fi.
  - http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html
- The availability of corresponding unlicensed spectrum access has not kept pace with the extraordinary growth and adoption of Wi-Fi, and Wi-Fi functionality is dependent on adequate unlicensed spectrum access.
  - http://www.wi-fi.org/beacon/alex-roytblat/wi-fi-study-reveals-need-for-additional-unlicensed-spectrum
- Spectrum is scarce and there is increasing commercial pressure from competing technologies operating in the licensed band to access and influence access on currently license exempt spectrum.
  - https://mentor.ieee.org/802.18/dcn/17/18-17-0073-00-0000-ieee-802-positions-on-wrc19-agenda-items.pptx

Multiple solutions can offer additional spectrum for wireless communications such as WiGig and LC

- The licensed exempt spectrum available at 60 GHz for WiGig offers complementary spectrum for data off-loading
  - However, there is still a lack of global harmonization for accessing the 60 GHz spectrum
  - https://mentor.ieee.org/802.18/dcn/17/18-17-0073-00-0000-ieee-802-positions-on-wrc19-agenda-items.pptx

- **The continued deployment and growth of 802.11 technology relies on accessing further unlicensed spectrum satisfying complementary use-cases and cost effective deployment.**

The light spectrum has already been classified as license exempt from regulators

- "The Info-Communications Media Development Authority (IMDA) took steps to facilitate trials of the emerging technology, which uses light to transmit data wirelessly, by removing some regulatory barriers, including waiving spectrum fees in the 400-800THz band." – IMDA, Singapore
  - https://www.imda.gov.sg/regulations-licensing-and-consultations/frameworks-and-policies/spectrum-management-and-coordination/spectrum-planning/li-fi-technology

- The Federal Communications Commission in the USA does not regulate frequencies above 3,000 GHz
  - https://www.ecfr.gov/cgi-bin/text-idx?SID=4bbc9fe06f4f8a5d00aada54fe757d3d&mc=true&node=se47.1.2_1106&rgn=div8

- "The LiFi technology uses unregulated spectrum of visible light that does not need licensing. On the other hand, it has to be ensured that the LiFi systems do not pose any health hazards and that they are correctly installed so that they do not create any EMI." – OFCOM Switzerland
  - https://www.bakom.admin.ch/bakom/de/home/das-bakom/medieninformationen/bakom-infomailing/bakom-infomailing-44.html

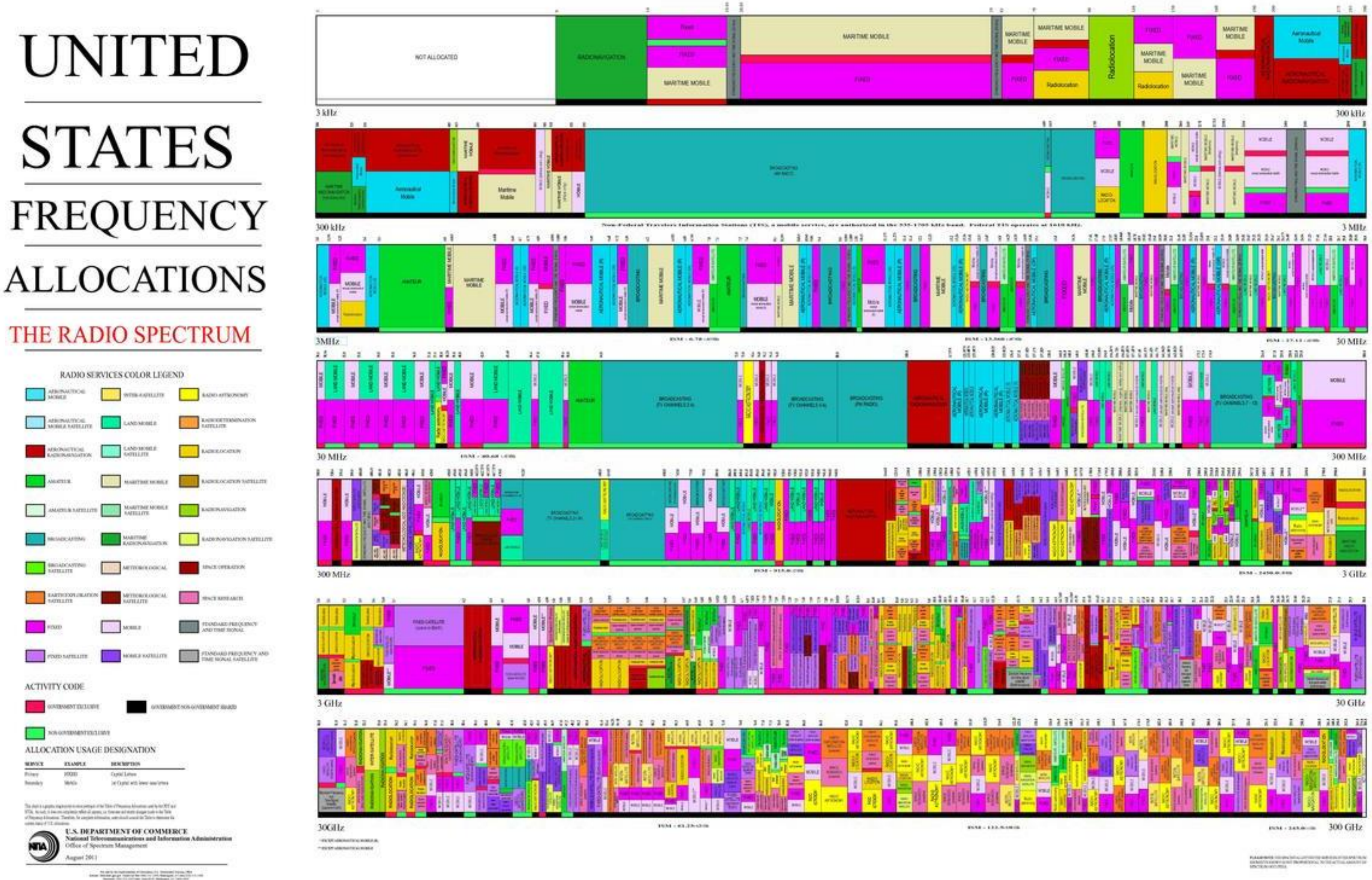
- **International radio frequency spectrum regulation usually stops at 3 THz**.
  - http://www.desktopsdr.com/more/worldwide-frequency-allocation-tables

International radio frequency spectrum regulation usually stops at 3 THz.

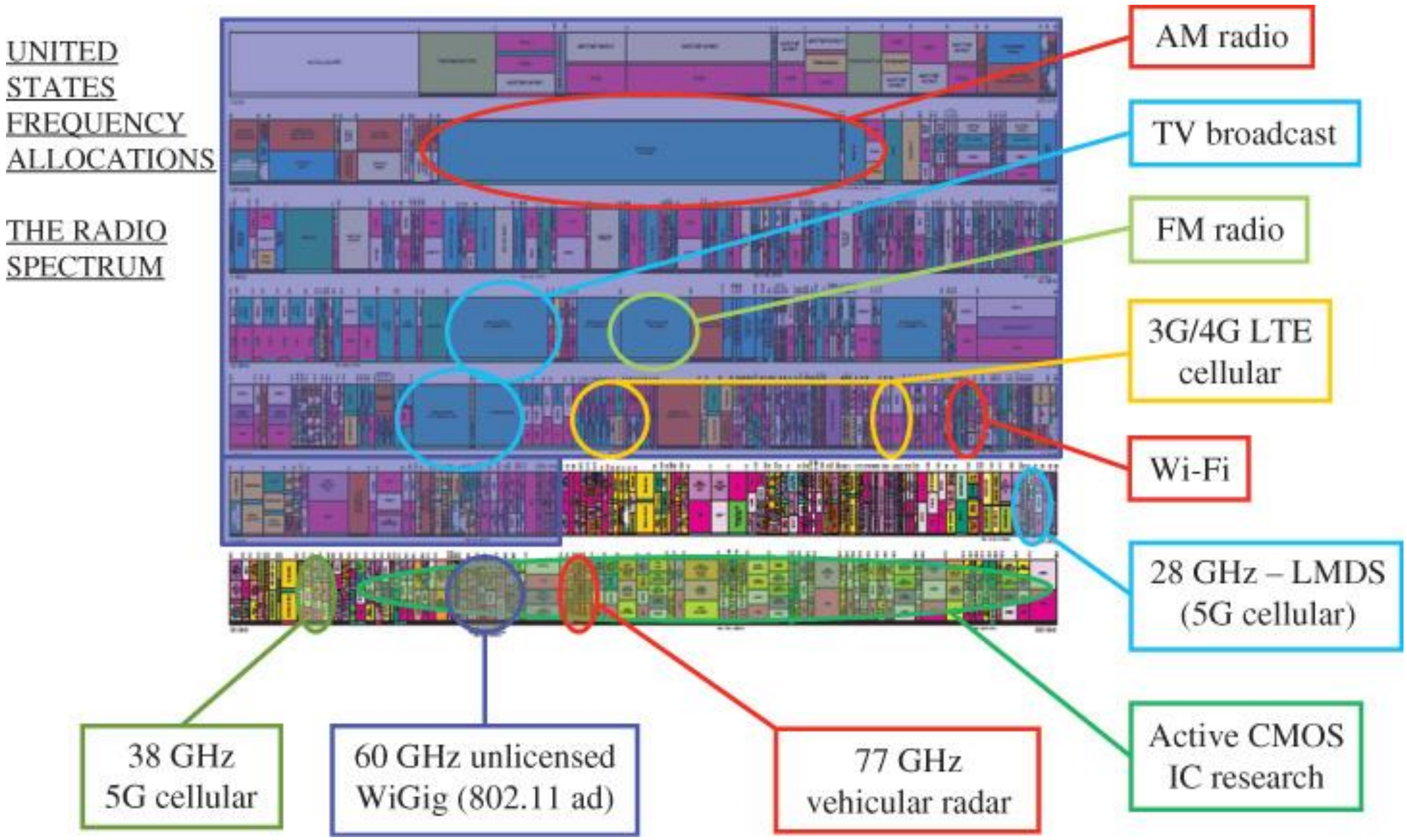
- Australia – up to 3 THz.
- Bangladesh – up to 1 THz
- Brazil – up to 1 THz
- Canada – up to 3 THz
- China – up to 3 THz
- Europe – up to 3 THz
- India – up to 1 THz
- Japan – up to 3 THz
- Pakistan – up to 1 THz
- Thailand – up to 1 THz
- UK – up to 3 THz
- USA – up to 3 THz
  - http://www.desktopsdr.com/more/worldwide-frequency-allocation-tables
  - http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057735/n3057748/n3057751/c4713815/part/4713817.doc
  - http://www.erodocdb.dk/docs/doc98/official/pdf/ERCRep025.pdf
  - http://pta.gov.pk/media/Pakistan_Table_of_Frequency_Allocations.pdf

The People's Republic of China Frequency Allocations – all below 3 THz

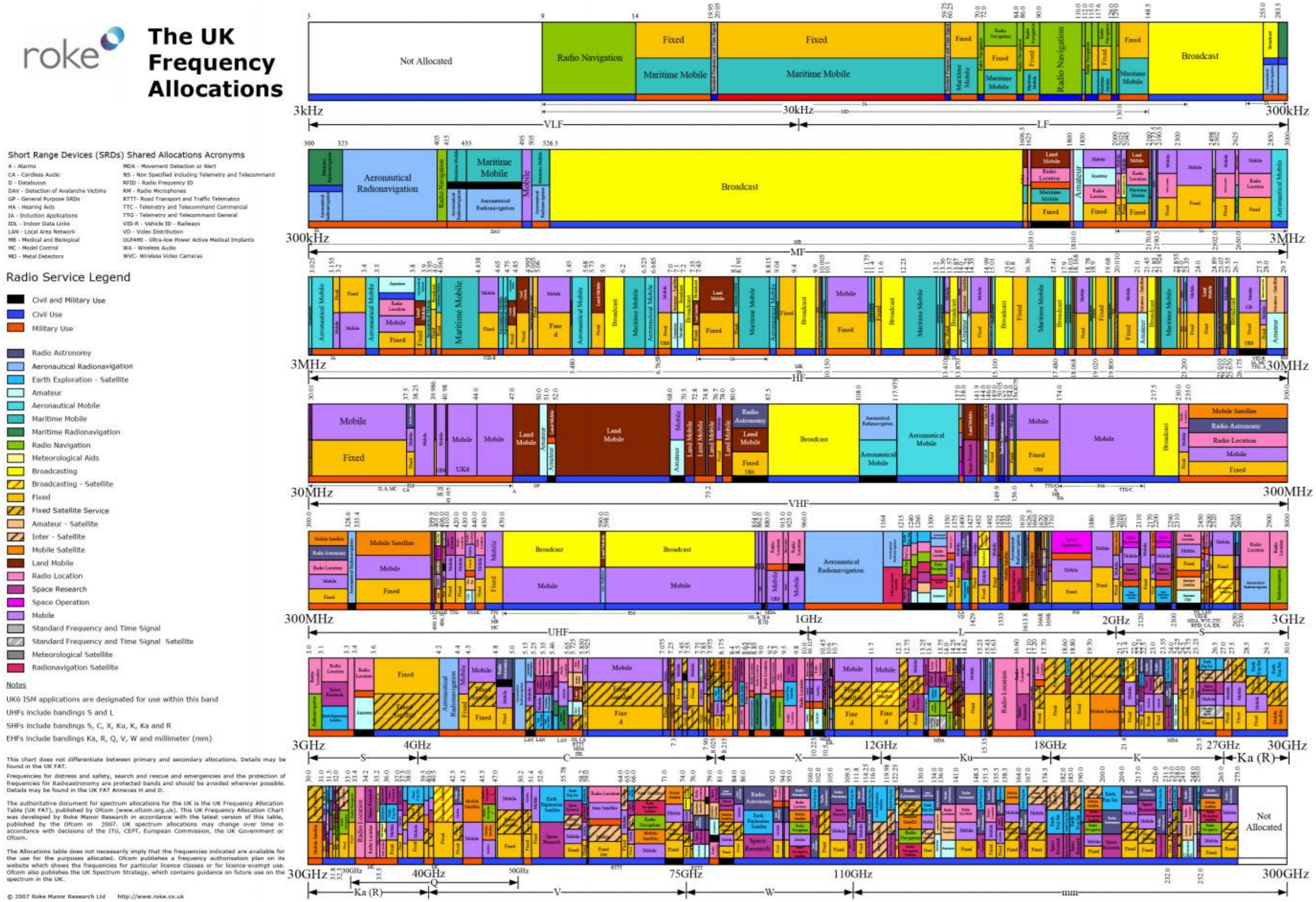
USA Frequency Allocations – all below 3 THz



USA Frequency Allocations – all below 3 THz

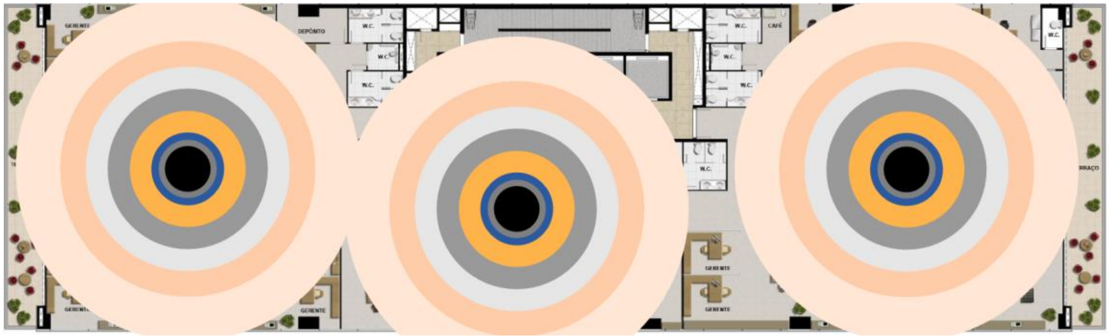


United Kingdom Frequency Allocations – all below 3 THz

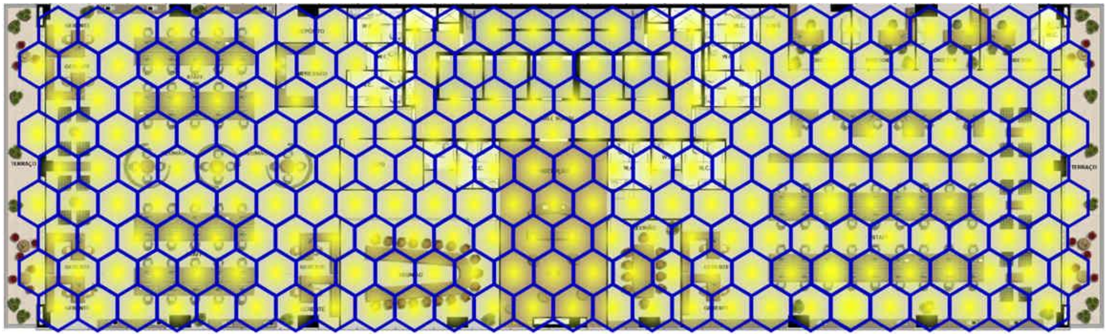


Increasing the operating frequency for wireless communications requires denser cell deployment

– Accessing the licensed exempt spectrum at higher frequencies requires denser cell deployments, which means increased costs for deploying a wireless solutions

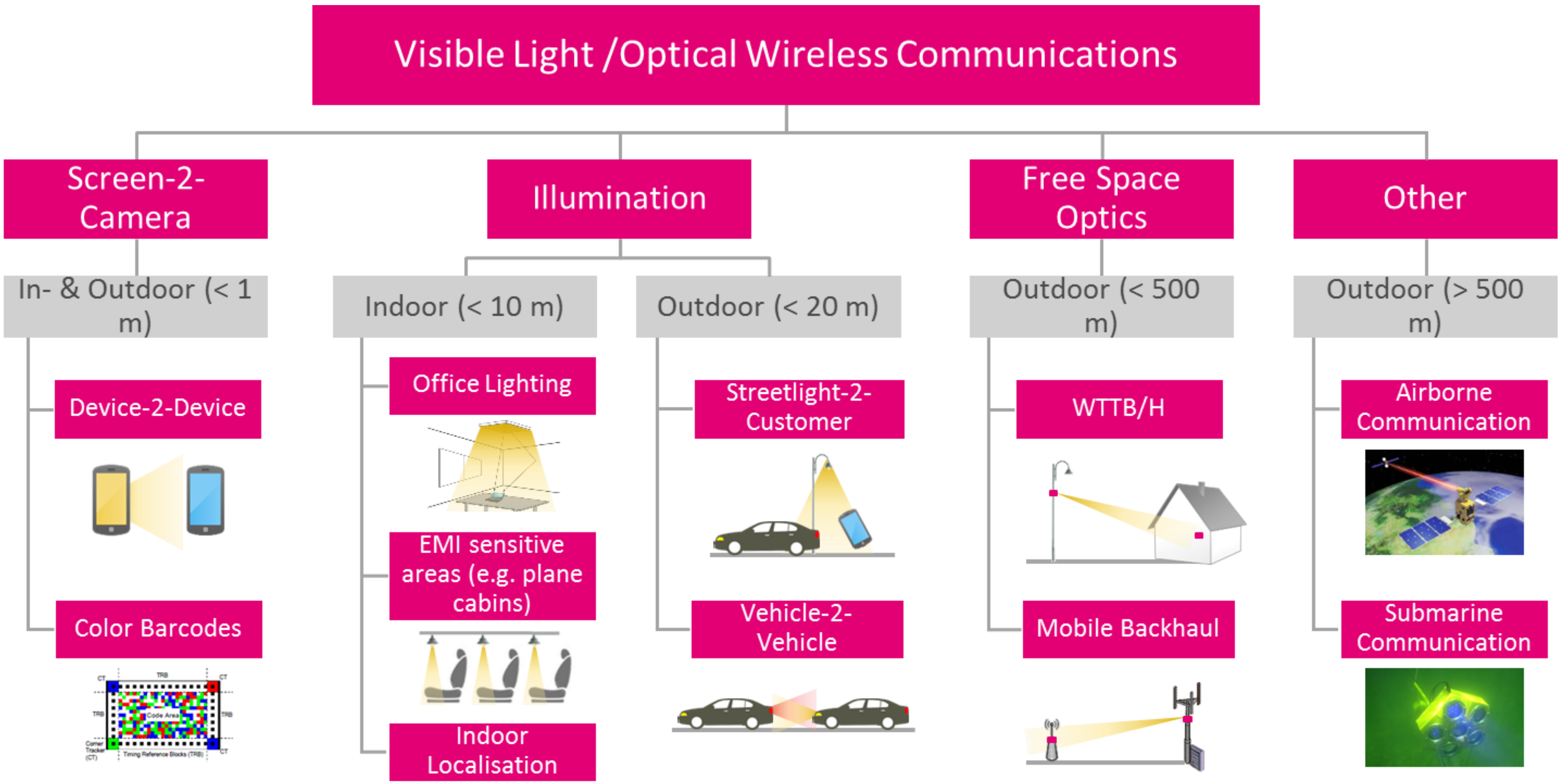


Wi-Fi Coverage



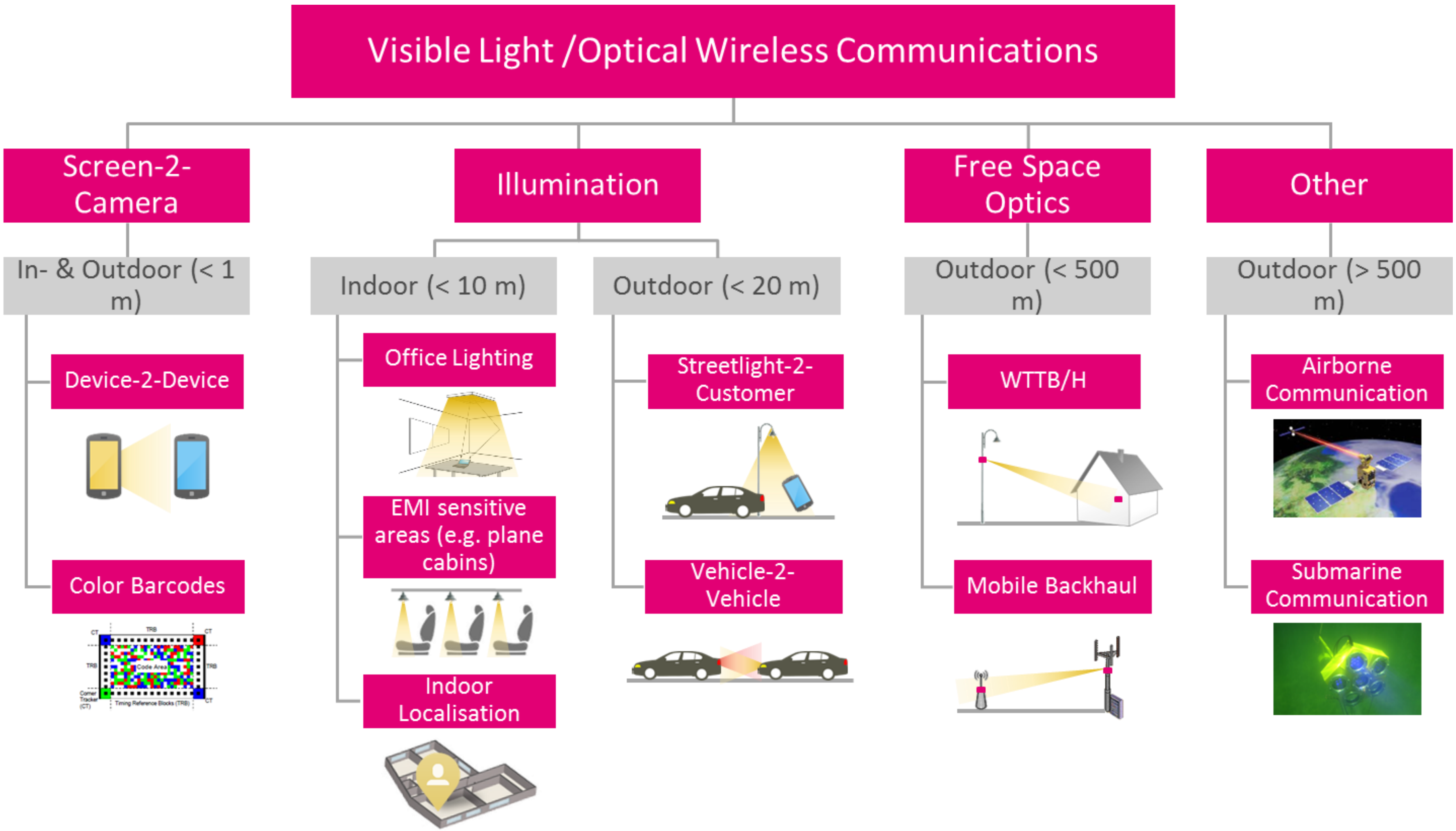
LC Coverage

LC can address a number of different use-cases



This is just an illustration of the possible use-cases.
Additional use-cases such as in-home, virtual reality and more can also be considered.

A future SG would determine the scope of a LC standard, potentially focusing on mass market solutions



Use-Case: Enterprise – LC can enable link aggregation alongside other 802.11 technologies, improve security and expand access in EMI-sensitive markets

- LC does not cause any interference with other RF technologies and the licence exempt spectrum along with the dense cell deployment, means that LC can be used to deliver link aggregation, releasing precious spectrum at the lower bands for other applications.

- Radio Frequency (RF) communications in the lower spectrum cannot be deployed in areas that are particular sensitive to electromagnetic interference (EMI).

- LC can enable 802.11 technology to expand in adjacent markets such as hospitals, mining, nuclear power plants and more.

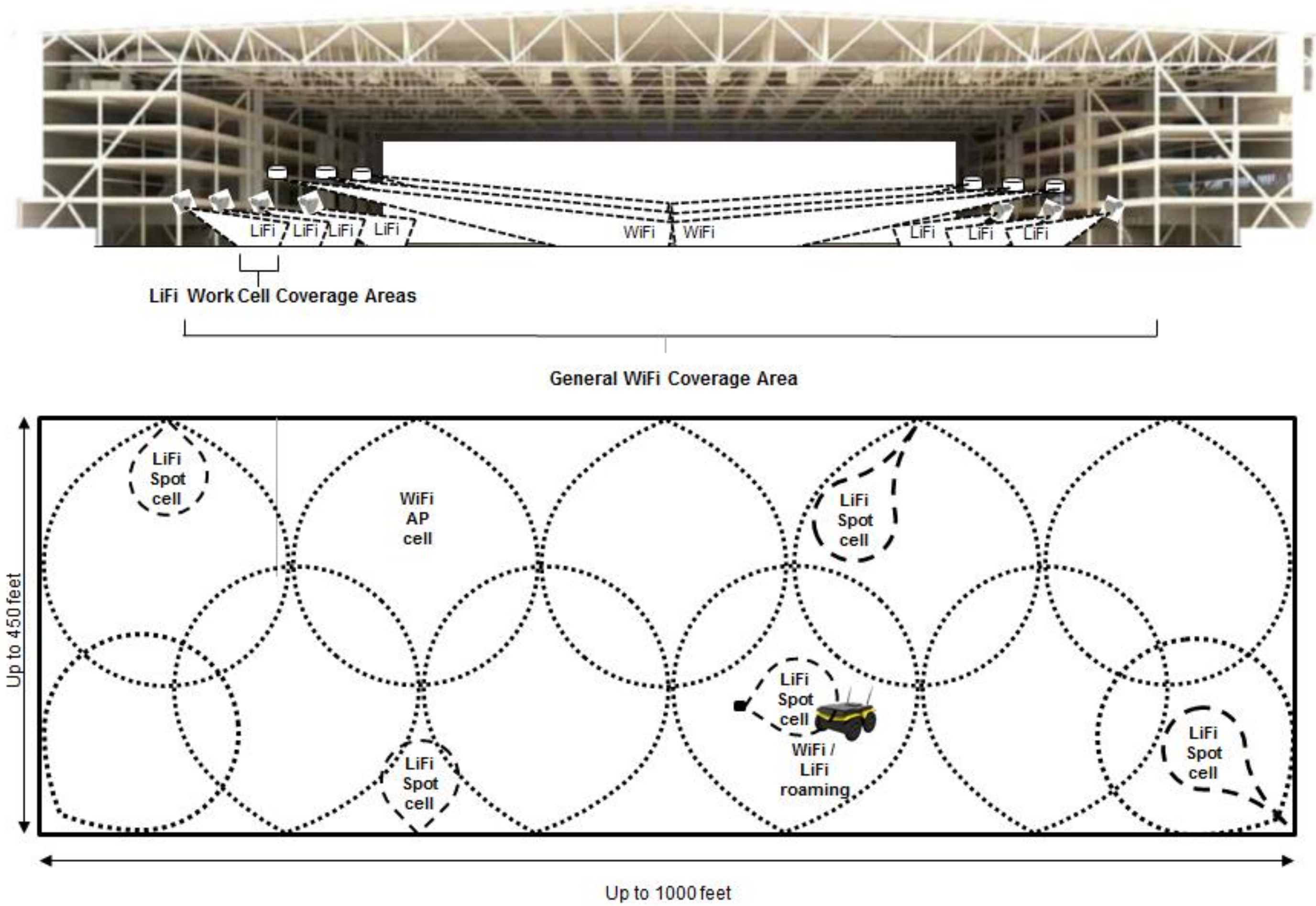
Use-case: Home – LC can provide link aggregation and increased security

- **Users can intuitively understand the best coverage locations, by seeing the light.**
- Similar to the Enterprise environment, LC can offer link aggregation and wireless data off loading
- Various stationary devices, such as TV or speakers, can be connected wirelessly and securely through LC without occupying the lower RF spectrum
- Virtual reality goggles can be connected to provide a highly localized and high capacity channel

Use-case: Retail – LC enables rapid alteration of retail space to create new customer experiences as a key part of retailer strategy

- Density of light fixtures and LC APs allows highly precise localisation of users and paths. This enables the provision of navigational directions for users within a store or mall.
- Data density of LC enables very-high bandwidth content without fear of interference with other wireless resources.
- The fact that light is non-penetrative and highly containable enables the establishment of very secure wireless signals.
- Highly reliable, secure and flexible retail space connected through LC enables cost reductions for retailers when modifying or refitting the space.

Use-case: Industrial – provide RF interference free, deterministic, communications within industrial and automated work cell areas



Use-case: Internet of Things – homes, cities, factories, healthcare and more

- Home
  - Connecting devices that convey sensitive information like CCTV cameras, baby monitors, etc. via a more private and secure LC network.
- Cities
  - LC AP can be installed on street furniture and ease congestion on spectrum resources by off-loading and releasing RF spectrum
- Factories
  - High requirements with respect to robustness (availability), low latency and security.
  - Very high cell density deployments as a complement to RF
  - LC is inert against RF jamming and EMI, the propagation is confined, and it does not create EMI.
- Healthcare
  - Providing the same reliability and security as a wired connection with the flexibility of a wireless solution for indoor communications,
  - Reliable and precise indoor positioning for patient/doctor/asset tracking
  - Wireless connectivity in EMI sensitive environments like operating theaters or MRI rooms.

LC does not have the same constraints as the original 802.11 IR PHY in the operating environment

Time has changed key factors relative to 802.11 IR PHY

Components

- Improved Components have created a global drive to use LEDs offering better energy efficiency, range and data rates.

Energy

- LEDs are being used for illumination and communications, removing constraints on the transmit power for the downlink.

Use-Cases

- Complementary deployments to Wi-Fi with:
  - Data off-loading
  - IoT
  - Localization
  - Etc.

Technical Considerations

LC can achieve a link budget of over 30 dB in example deployments in an indoor environment

- **The detailed link budget calculation can be seen in doc. 11-17/0262r1**

- The link budget for a specific example deployment with specific components has been calculated to be between 30 – 40 dB when deployments at ranges of 2m – 4m

- The strict definition of the remaining LC metrics is left to the Study Group such as:
  - Data rate
  - Latency – average range
  - Channel access fairness
  - Area capacity (area spectral density (bit/s/sqm))
  - Considerations for the MAC efficiency on the capacity – measured at the MAC SAP

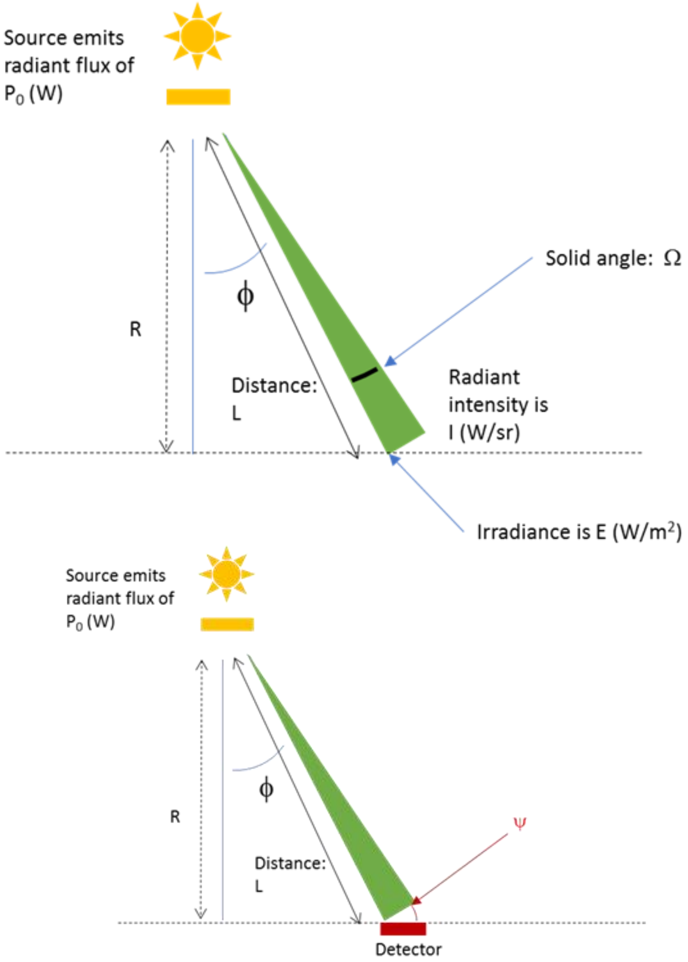


Figure 2: Receiver geometry

How does LC work?

- Any baseband electrical signal that is supplied to a light-emitting or laser diode (LED/LD) generates a light output with power proportional to the amplitude of the electrical signal.
- The LED/LD effectively serves the purpose of an upconverter in RF that generates light-frequency waves with intensity proportional to the electrical current that flows through the device.
- Any light that is incident on a photodetector such as a photodiode leads to current flowing through the device, which is proportional to the light intensity.
- A photodiode converts light variations into current variations or a light information signal into a current information signal.

How does LC work in a bright room with sunlight?

- Typical light communication system can function even at high indirect sunlight illumination levels. The boundaries of transmission are easily seen by the average person.
- The information signal is encoded in fast changes of the light intensity. For high speed communication, these intensity variations are very fast as the bandwidth of the information signal is in the order of tens to hundreds of MHz. Variations in sunlight and ambient light from light sources are quite constant relative to the light used for communication. As a result, they lead to zero or low-frequency signal interference that is easily avoided/filtered out.
- First possible distortion effect due to ambient light can occur when the ambient light is strong enough to saturate the receiver.
- Background light can cause additional shot noise (modelled as Gaussian noise) in the photodiode.
- In typical short-distance scenarios, the shot noise is not strong enough to compromise the system performance.

How does LC work when you turn off the lights?

- Visible light communication would typically no longer work, when you turn off the lights, i.e., there is no power transmitted in the visible light spectrum.

- For typical visible light communication systems that are currently being envisioned, communication would not be possible when the lights are off. However, if communication capabilities are required in such a scenario, one would resort to infrared light for communication and/or radio frequency communication.

Can we see LC lights flicker?

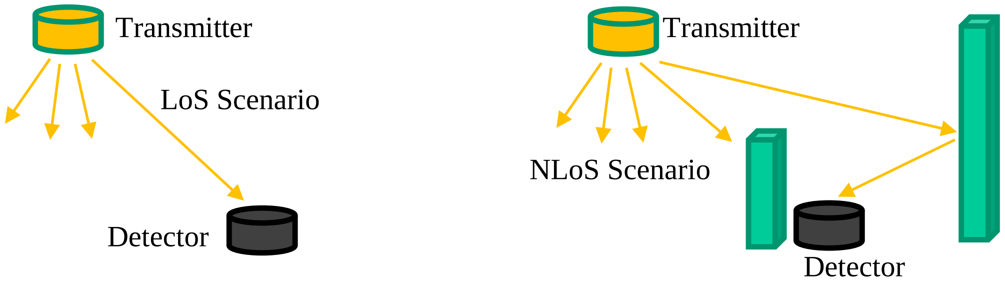
- No, the human eye cannot really discern light changes above 10 kHz. Because communication lights change intensity (flicker) at rates in the order of 10s or 100s of MHz, no visible flickering effects should occur in a VLC system.

Is the flicker created by modulation safe?

– No extensive studies have been done on this effect. However, one would assume that it is no more harmful than is the flickering of a TV screen, computer screen or a mobile phone screen.

Is LC a line of sight (LoS) technology?

- By design, light communication can be made line-of-sight or non-line-of-sight technology. It all depends on the communication scenario (received power, light propagation) and the technology that is employed.
- LC robustness can be increased in NLOS scenarios by using digital signal processing techniques similar to those in RF.



An example of LoS and non-LoS scnearios for LC operation

If LC is a non-line-of-sight technology then how is it more secure than other wireless technologies?

- Light radiation (especially visible light radiation) is significantly easier to constrain and police compared to RF radiation.
- The extremely short light wavelengths lead to significant attenuation effects even over moderate distances. This leads to more confined operating environments where secrecy rates become relevant.
- Jamming light communication signals is harder to achieve than with RF solutions.

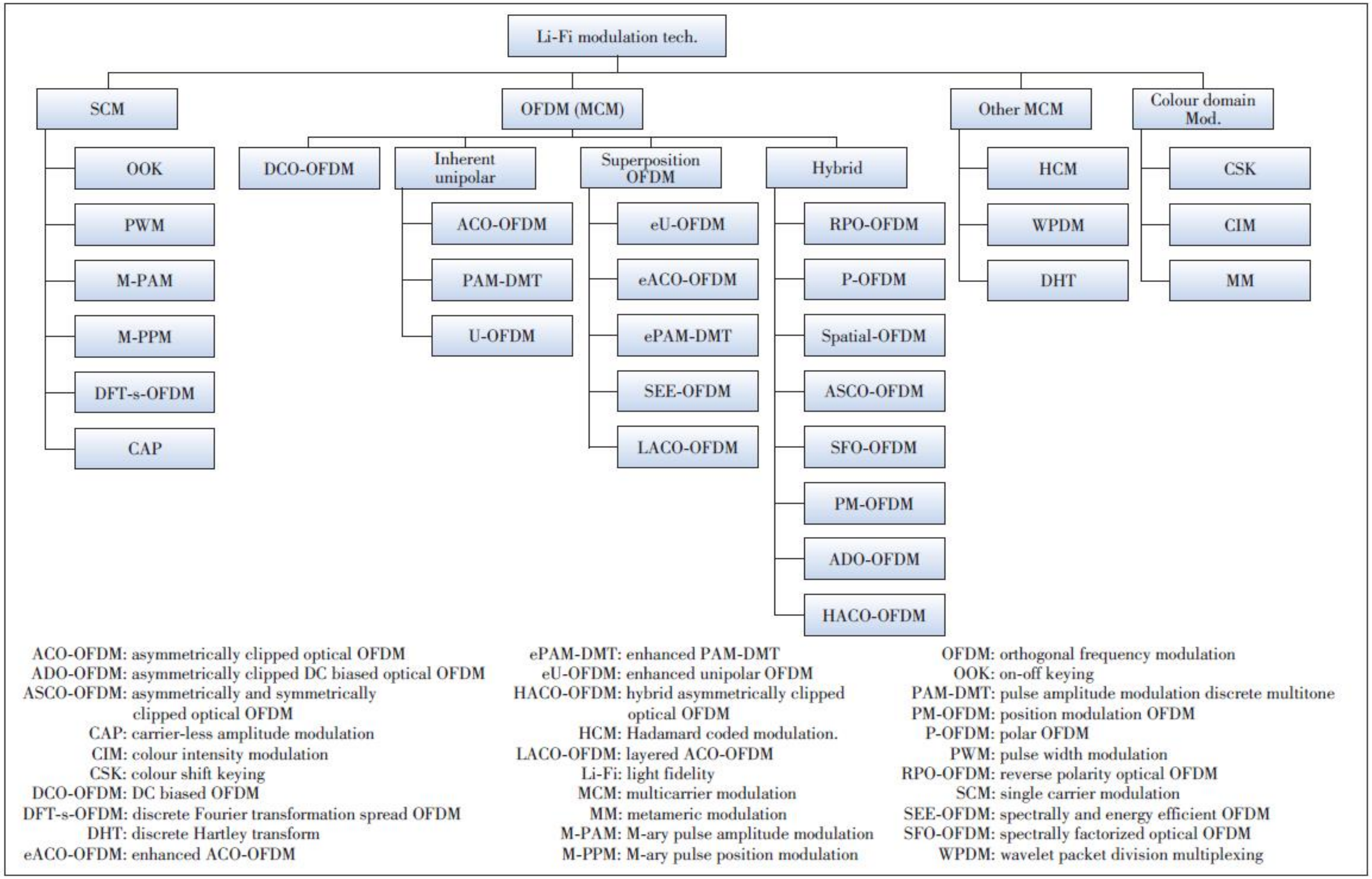
Can we enable LC to be Full-Duplex in 802.11?

- Yes, it could theoretically be achieved. Full-duplexing in light communication can be achieved using the same or different wavelengths (colors) for the uplink and downlink.
- The uplink could use infrared radiation at a certain wavelength, whereas the downlink could use visible light or infrared radiation depending on the illumination scenario.
- As in RF, full duplex is a matter of cost, in particular in small user devices. Excellent EMI isolation is obviously needed between transmitter and receiver in the same device.

Are LC systems subject to multipath fading?

- No. Light communication systems typically employ incoherent modulation and demodulation.
- The light photons themselves interact constructively and destructively between each other. As there is no correlation between the individual light modes, the light that reaches a given surface on average is the same.
- A typical photodiode detector has an area (in the order of mm) that is much larger than the size of an individual photon (in the order of hundreds of nm to a few um). Hence, receiver diversity over thousands of transmission wave modes is achieved in a photodetector, which mitigate some fading effects.
- Using coherent, narrowband laser sources, there is a similar effect like fading called the Speckle pattern. This is well known from diffusely reflected laser pointers. However, the photodiode is much larger than the wavelength and averages over any signal variation. In addition, the spectrum of LEDs is 10s of nanometers wide, and incoherent in its nature, i.e. there is no Speckle pattern.
- This should not be confused with multipath interference and inter-symbol interference, which still exist.

What modulation techniques are available for LC?

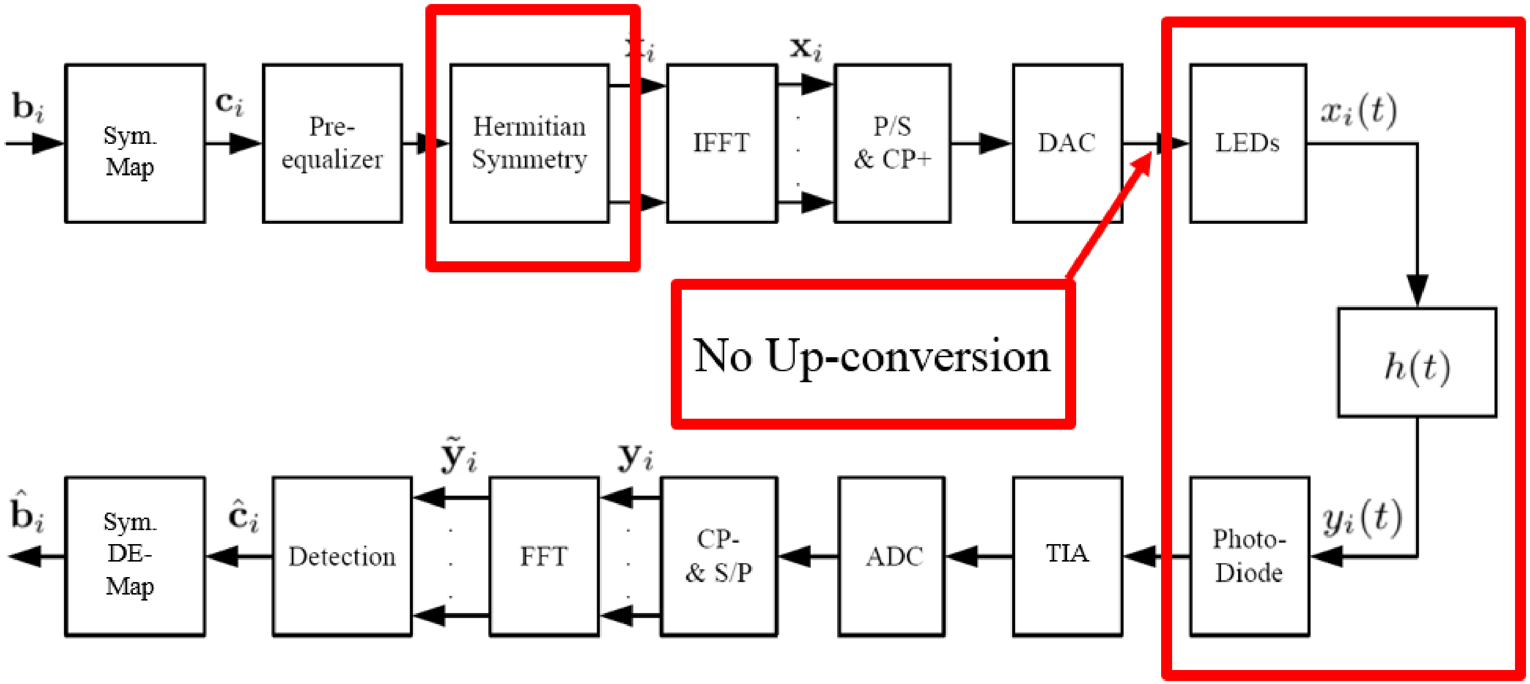


A selection of different LC modulation techniques

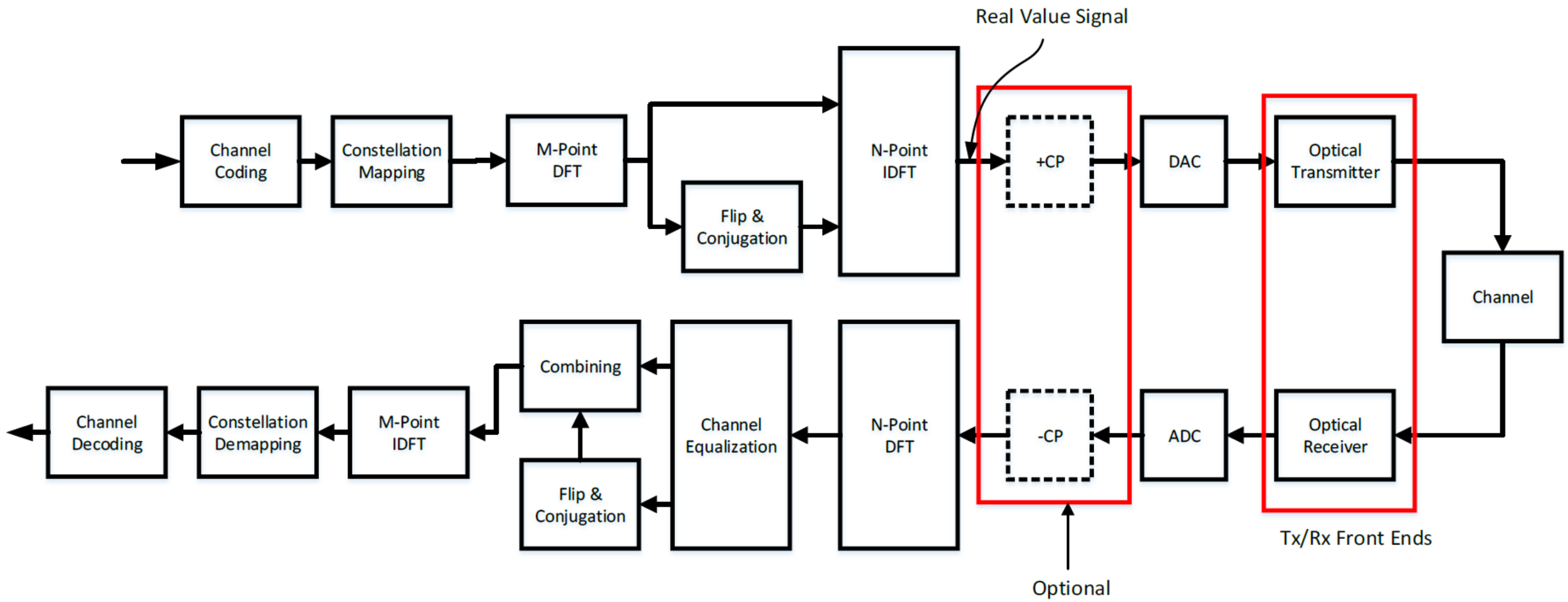
M. Sufyian and H. Haas, "Modulation Techniques for Li-Fi", ZTE Communications, April 2016, vol. 14 No. 2. Available at:

http://wwwen.zte.com.cn/endata/magazine/ztecommunications/2016/2/articles/201605/t20160512_458048.html

Example of an OFDM modulation and demodulation chain for LC



Example of DFT-s-OFDM modulation and demodulation chain for LC



How does uplink of LC-systems work?

- LC can also be used for uplink.
- For devices that have RF capabilities, it is envisioned that RF communication may be used for uplink (hybrid LC/RF), as well as in parallel to light communication for “link aggregation” for both up- and downlink (aggregated LC/RF).

Can network connectivity be maintained under mobility scenarios?

- Yes.
- In the coverage area of a single LC light, rate adaptation can be used to maintain a stable link.
- When a user moves among neighbouring LC-lights, fast handoff may be beneficial to reduce interruption time.
- For devices with RF capabilities, RF may be used as a fall-back solution to maintain the connection during mobility.

Does LC interfere with existing products that use the light medium, e.g., remote controls for TV sets?

- No, because the lower part of the base-band bandwidth, e.g., less than 100 kHz, can be easily removed from LC communication systems such that it is not subject to any interference from slowly varying signals and does not cause interference to other slowly varying light signals.

Does LC impact the colour quality of lighting?

- No, for a DC-balanced modulating signal, with a non-varying average value, any fluctuations in the instantaneous driving current due to data modulation do not have any significant impact on the measured light quality metrics.

- **“Provided adequate thermal management is used, the average drive current dictates the emitted light quality (CRI, CCT and chromaticity) but not the instantaneous drive current. Hence to preserve the expected light quality of LEDs used for LiFi, the modulating signal must be balanced.”**
  - W. O. Popoola, “Impact of VLC on Light Emission Quality of White LEDs,” Journal of Lightwave Technology, Vol. 34, No. 10, May15, 2016.

How does the backhaul work?

- The backhaul in light communication systems is expected to work as the backhaul for any wireless access network.
- Power over Ethernet (PoE) could be used to provide both data and power to the LED lighting.
- Power line communication (PLC) could also be used for retrofitting of LC into building environments where modern communication infrastructure does not exist.

A general system level architecture for a LC deployment

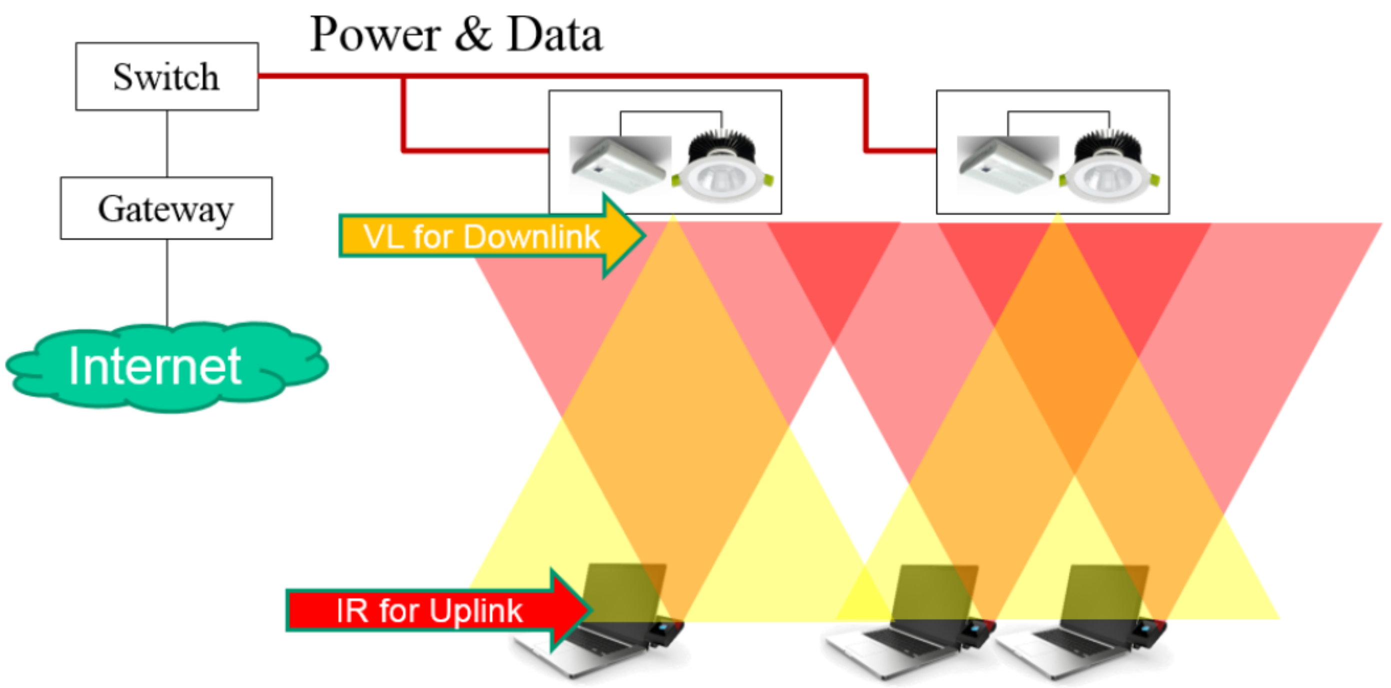


Figure 6: Example of the overall architecture for LC.

– The visible light spectrum can be used to provide both illumination and communications, while the infrared spectrum can be used from mobile devices to provide the uplink.

Minor changes in the PHY and lower MAC are required with most aspects unaffected

	802.11	LC
Medium	RF	Visible Light and IR
Signal Modulation	Coherent	Intensity Modulation & Direct Detection
Duplex	Half	Half or Full
Hidden Node	Can Occur and be managed	Can Occur and be managed
PHY/MAC interface	802.11 PPDU	Identical
MAC/Network Layer interface	MLME	Identical
Security	802.1X	802.1X

LC has a natural place in 802.11 using the same/similar PHY/MAC/Network Layer Interfaces

- **Common**
  - Authentication, security protocols, addressing and MAC frame structure are preserved from the 802.11 protocol.
  - The PPDU and PHY layer processing algorithms are preserved.
  - The hybrid contention-based and scheduling-based network access concepts from 802.11ax could be re-used
- **Different**
  - No frequency up-conversion is required as electrical baseband modulation of the light source translates into intensity modulation of the optical wave carrier
  - Hermitian symmetry is imposed on the modulated subcarriers in order to generate a real time-domain signal. Hence, the sampling rate and the baseband are doubled to preserve the data rate.
  - A positive waveform is needed, clipping of negative waveform samples creates interference that needs to be taken into account in the PHY design. Same holds for bandwidth limitations of LED and PD, and in non-line-of-sight channels.
  - Need to suitably address the hidden node problem in the uplink.

The System Architecture for LC is substantially the same as existing 802.11

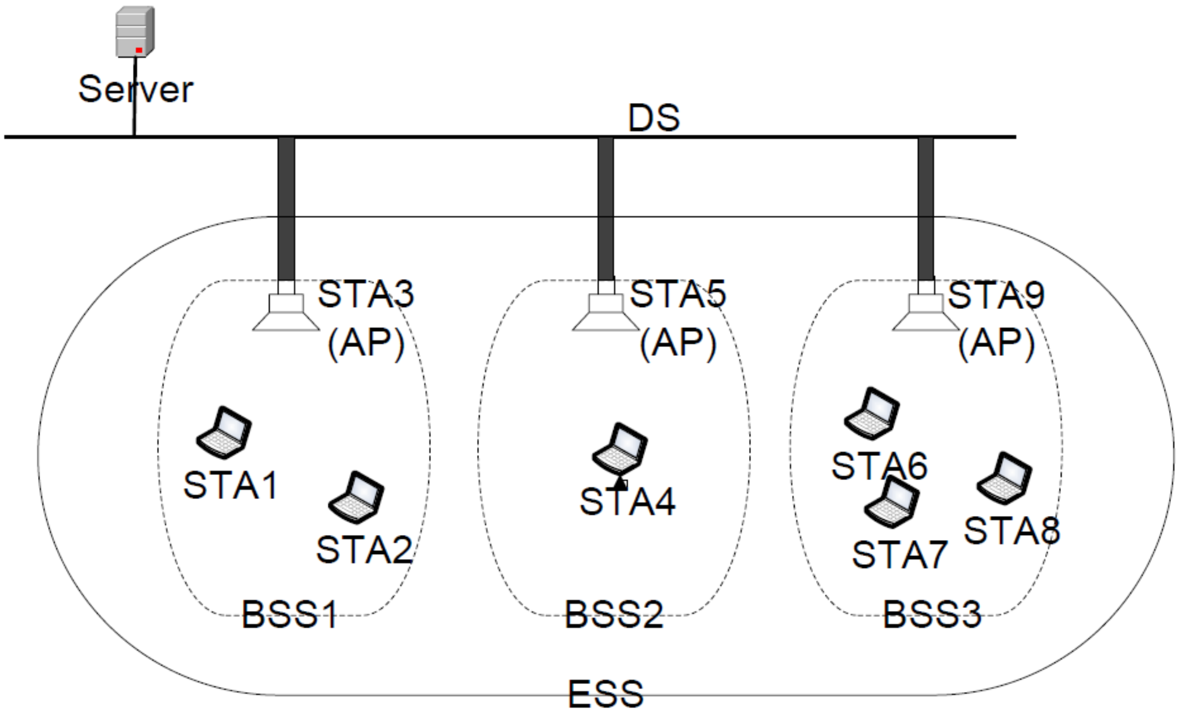


Figure 5: Example of the overall architecture for LC.

- LC may be able to use the basic service set (BSS), extended service set (ESS) and independent basic service set (IBSS).
- Neighbouring BSSs may be interconnected by a distribution system (DS) to form an ESS in order to cover a large area.
- IBSS, where stations communicate with one another directly in an ad-hoc manner, may also be useful.

LC should be considered to become an 802.11 amendment rather than a standalone standard

- The decision of whether LC should be a standalone standard (i.e., 802.11.3) or an amendment (802.11xx), should be left to the Study Group.
- The benefits of inheriting the upper portion of the 802.11 MAC and services it provides are seen as key enablers for the commercial success of the technology.
- LC would be able to provide seamless channel aggregation, hand-over and coexistence with other 802.11 technologies in this way.

IEEE 802.11 can make LC more successful than other SDOs

- **802.11 has the opportunity to exploit the light spectrum**

Existing Standardization Efforts

ITU-T Study Group G.vlc	802.15.7r1	802.15.13
•Based on G.hn – **Home Networking standard** •**Customer Premises Equipment may use G.hn**	•Originally based on 802.15.4 - Not designed for networking, e.g., **NO 48 bit MAC address, different security,…**	•Based on 802.15.7r1 with focus on Muli-Gigabit/s Optical Wireless Communications **suitable for speciality wireless networks**

Problem

Neither effort has the comprehensive **ecosystem of partners** required for mass market adoption of LC.

Proposed – 802.11 has unique ecosystem

Chipset vendors	Network Infrastructure	Device Integrators	End Customer and Operators

The 802.11 offers a unique collection of the relevant ecosystem partners and technological capabilities relevant for LC standardization

- The difference between LC and the existing 802 light communications standards is the use of the 802.11 MAC and associated services that are already optimized for low-cost wireless local area networks relative to the other efforts (802.15.7r1 and 802.15.13) efforts that are focusing on deploying the technology for wireless specialty networks.
- The existing standardization efforts aim at short-term market opportunities while taking higher energy consumption and higher costs into account
- The coexistence and hand-over with other 802.11 PHY types creates a unique market capability for LC as part of 802.11.
- The well established commercialization steps from technology standardization in 802.11 through to product certification, offer a unique capability to drive rapid product introduction in the market.
- LC in 802.11 is seen as way forward to introducing the technology the mass market

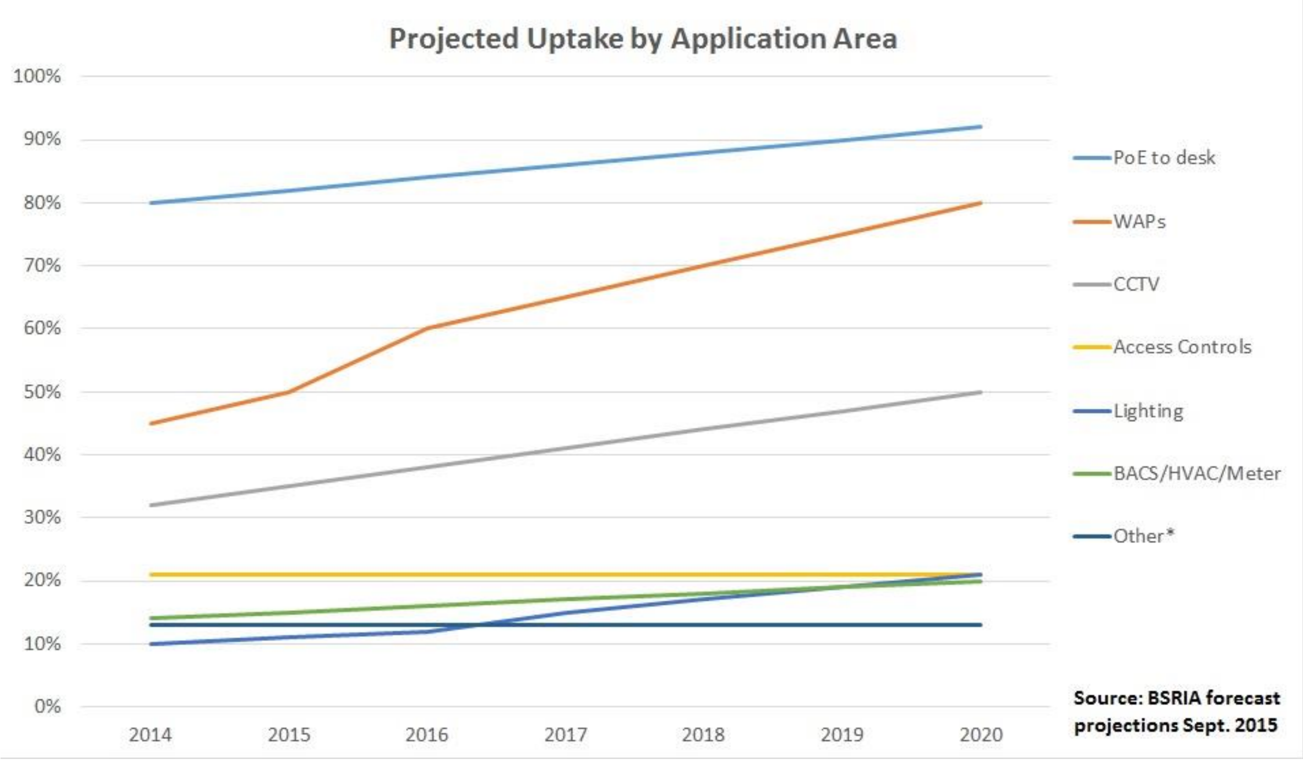
A number of LC demonstrator systems exist with no interoperability and a need for standardization

- There are numerous wireless LC systems demonstrated delivering data rates from 1 Mbps through to multiple Gbps from entities such as Fraunhofer HHI, FireFly, VLNcomm, Oledcomm, pureLiFi, etc.
- However, these systems are generally based on proprietary technologies and there is a growing need to standardize the technology.

Economic Considerations for LC

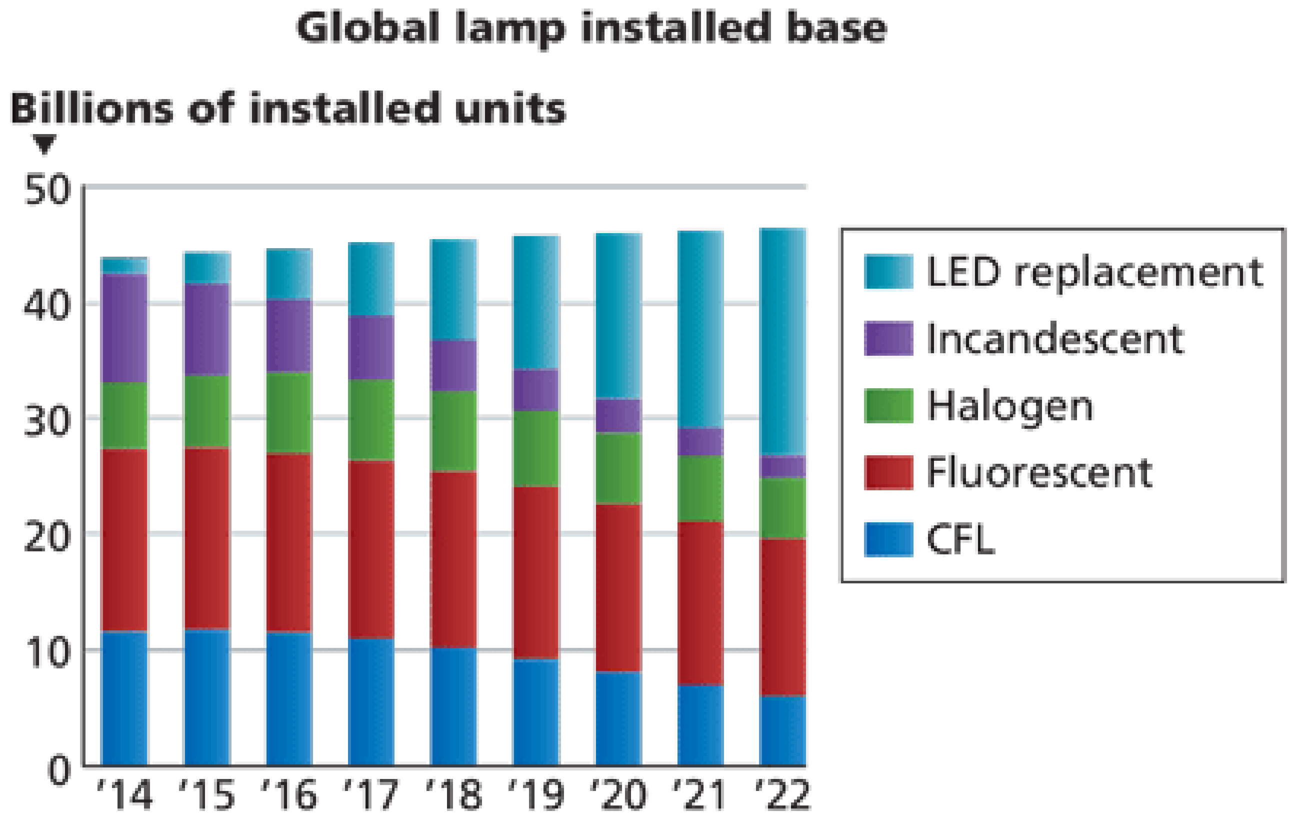
The infrastructure necessary for LC is already being installed and PoE adoption for lighting is accelerating

- Lighting infrastructure is one of the first elements added when constructing a building
- Power over Ethernet (PoE) is increasingly used to provide a backbone for lighting in new office buildings as it offers reduced deployment cost and time.



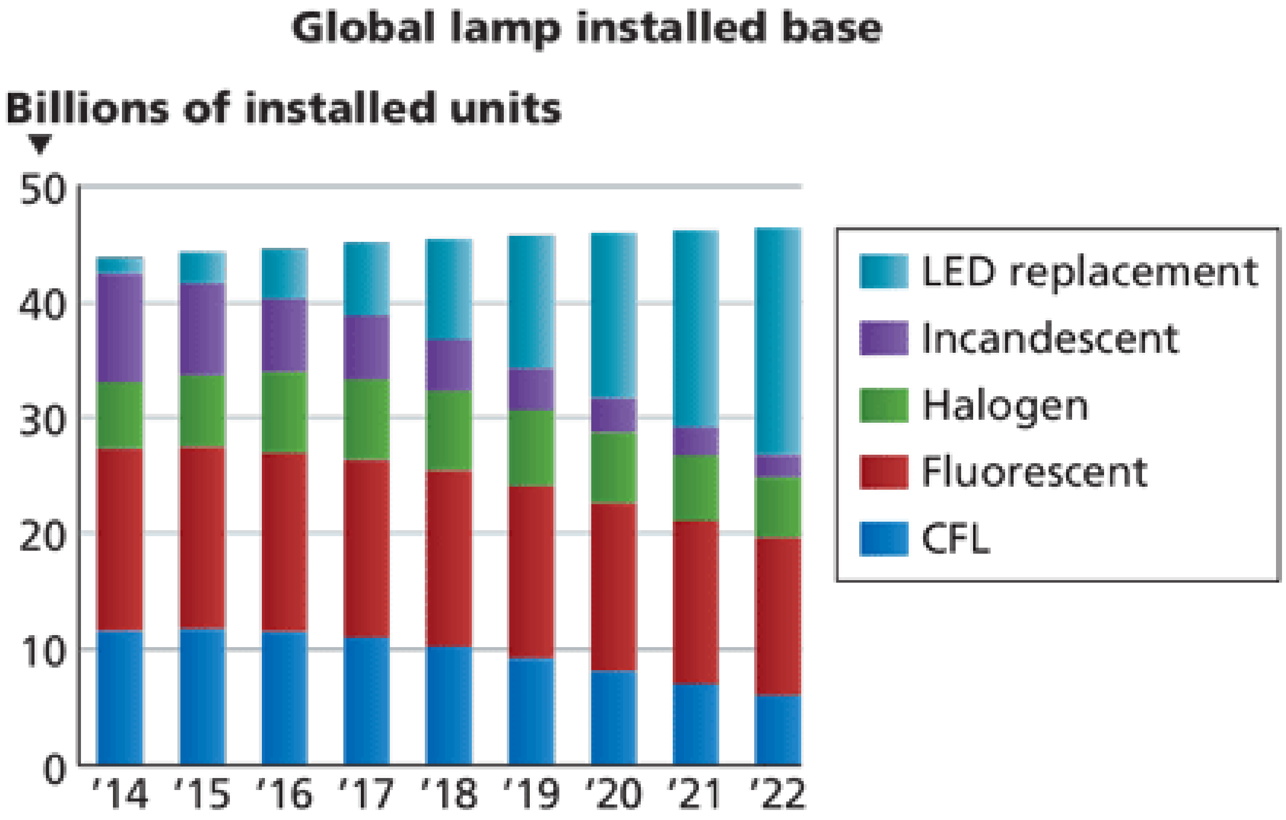
The Edge Building in Amsterdam has over 6500 PoE powered LED lights connected to a Building Management System and offered a 25% reduction in installation costs with over 50% reduction in installation time

LED lighting in 2017 still accounts for <10% of the over 45 billion lighting sockets available



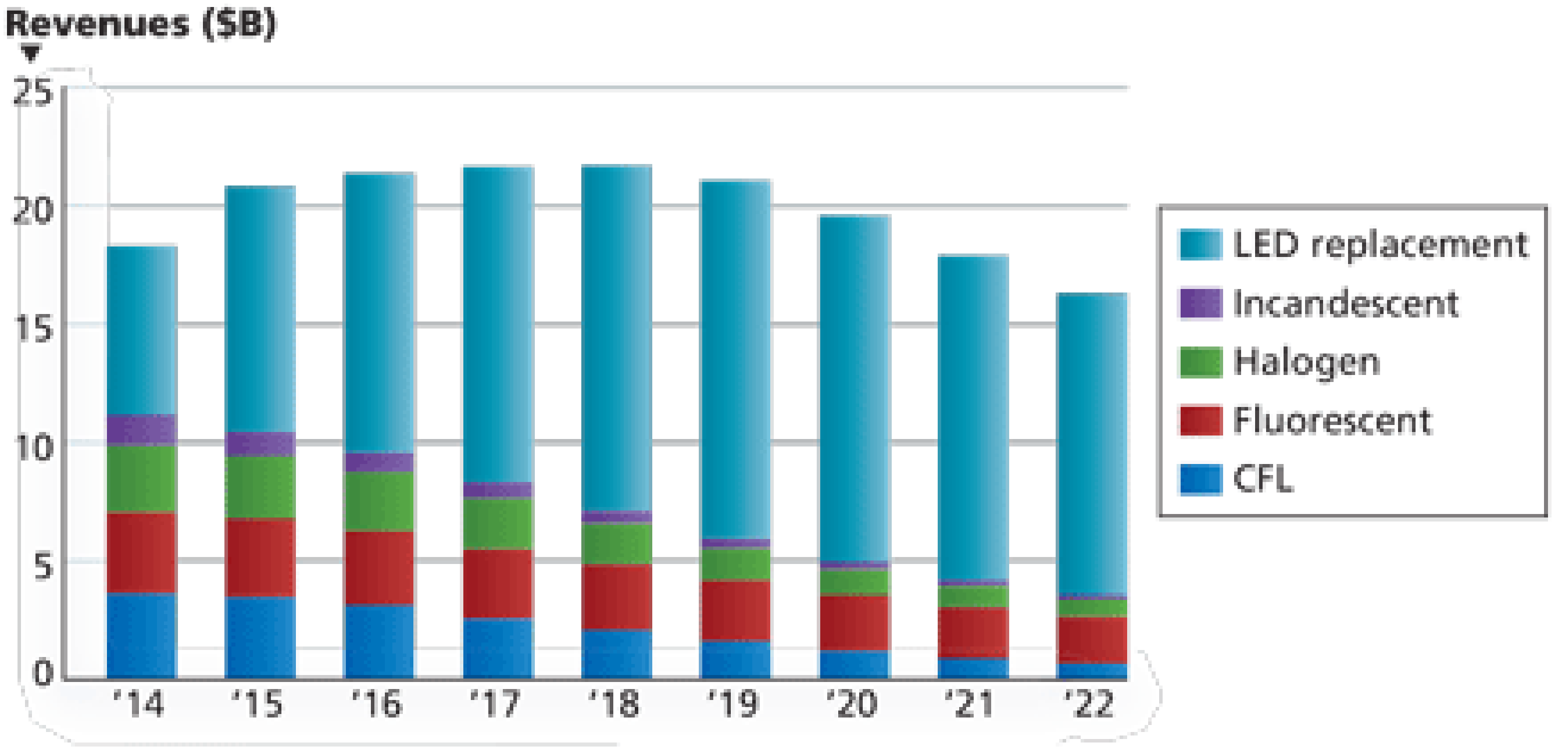
Source: Philip Smallwood, co-chair of Strategies in Light and director of research at Strategies Unlimited presenting at the The LED Show conference, March 1 – 3, 2016

LED lighting will replace over 50% of the current compact fluorescent lighting by 2020



Source: Philip Smallwood, co-chair of Strategies in Light and director of research at Strategies Unlimited presenting at the The LED Show conference, March 1 – 3, 2016

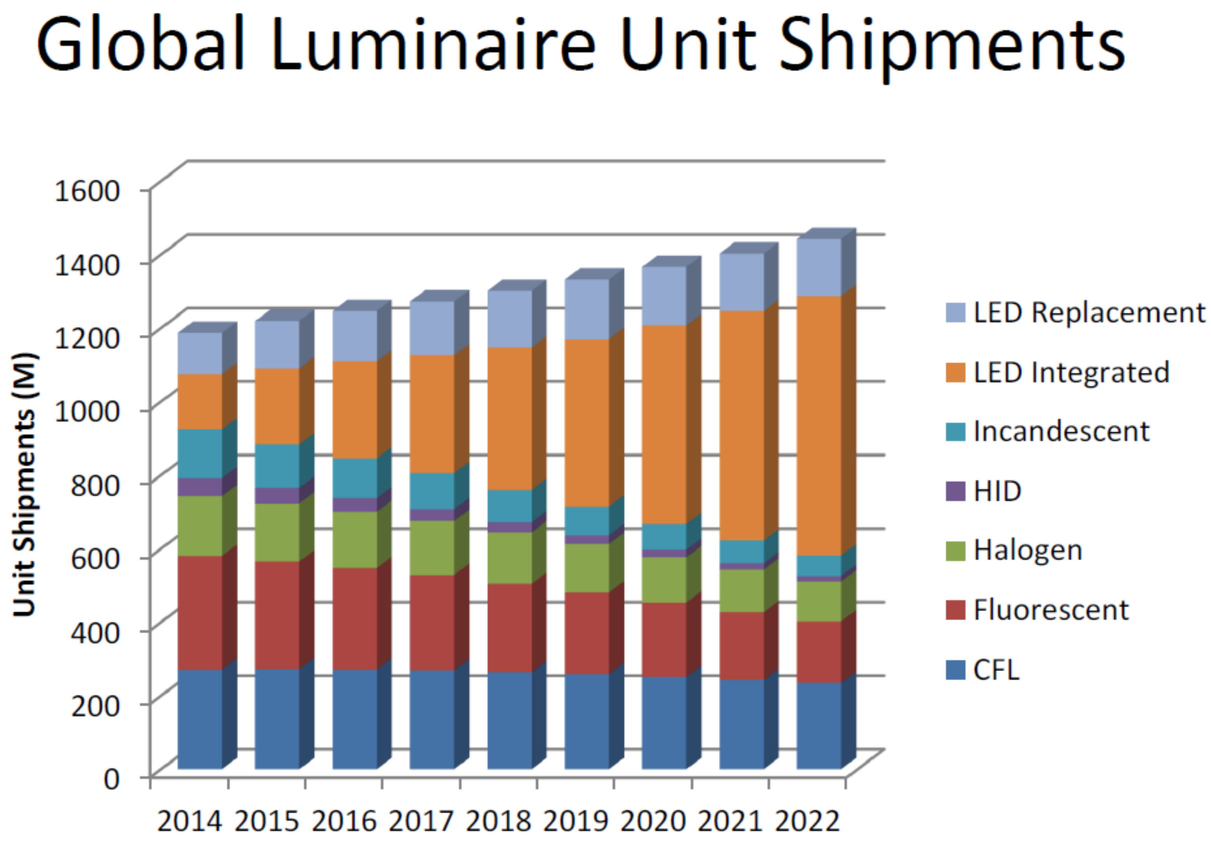
LED lighting accounts for over 50% of the revenue for the lighting industry in 2017 and are fast replacing traditional light sources



Source: Philip Smallwood, co-chair of Strategies in Light and director of research at Strategies Unlimited presenting at the The LED Show conference, March 1 – 3, 2016

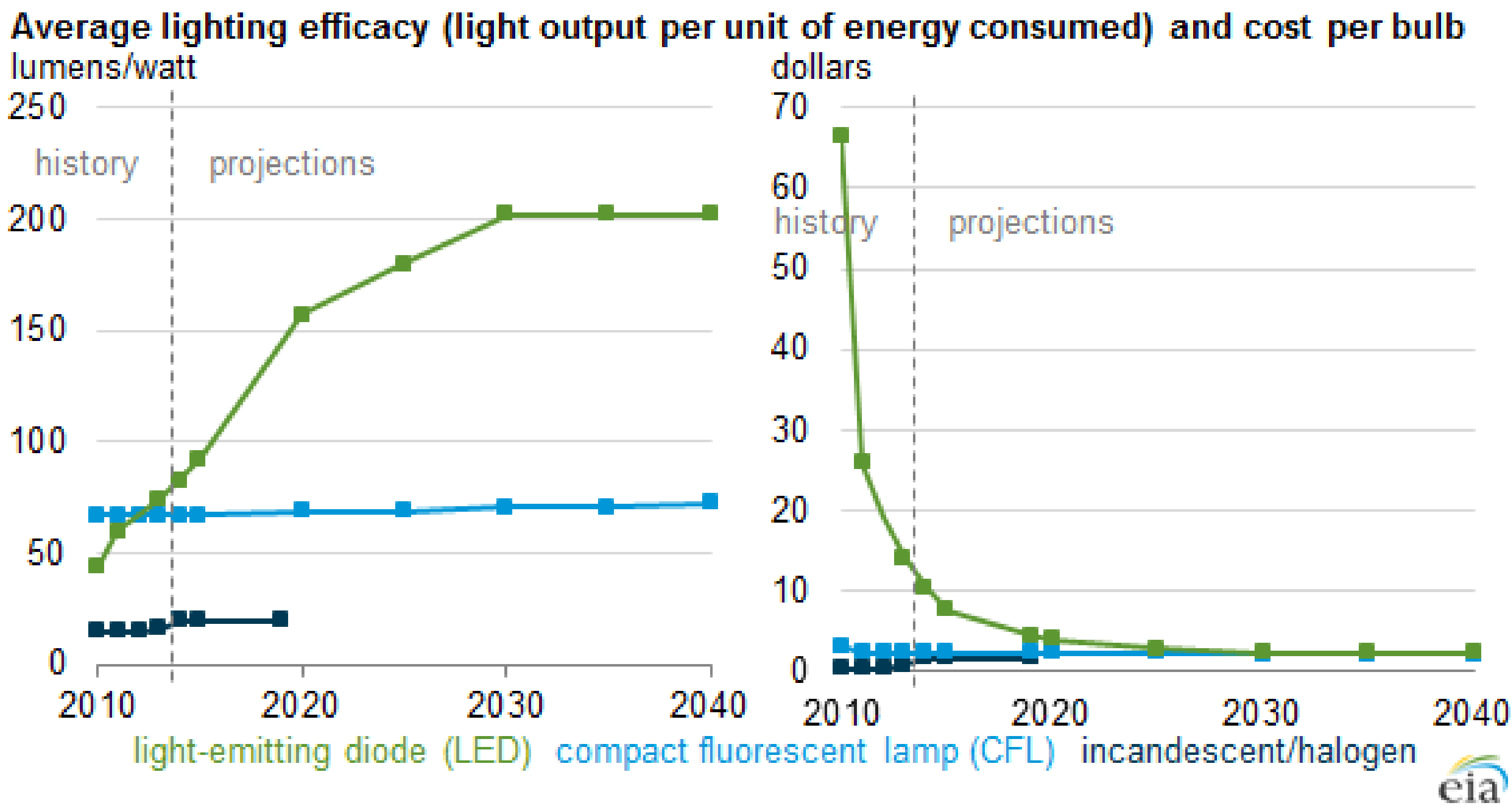
Sustained supply growth in LEDs has resulted in cost erosion and lower regular retail price (RRP) creating an opportunity for value add solutions in the cost structure

Over 550 million LED luminaires (lights) are projected to be sold in 2017 – each could be LC-enabled



Source: Philip Smallwood, co-chair of Strategies in Light and director of research at Strategies Unlimited presenting at the The LED Show conference, March 1 – 3, 2016

Lighting emission efficacy for LEDs is projected to saturate by 2030. The corresponding plateau of the cost creates an opportunity to add additional services.



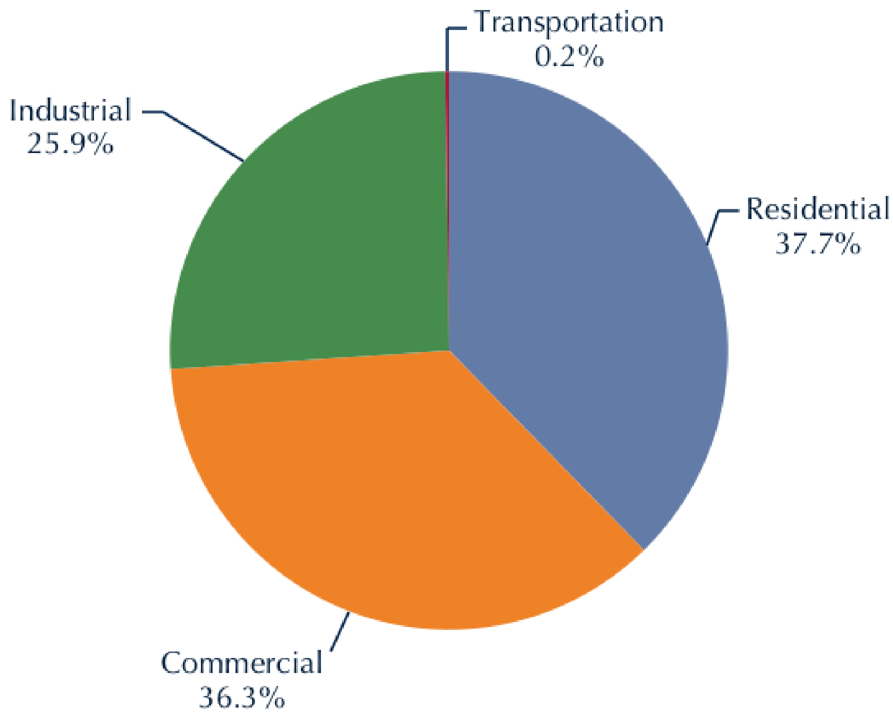
Light communications capabilities could be added to LED lights at a limited cost considering the increasing proliferation of multiple wireless comms. modules in lights

- The cost for simple LED drivers is between $10 - $50 for commercial (enterprise and industrial industries) LED drivers and lower for the general consumer market.
- The growing trend and competition in LED lighting is creating cost erosion in the market and there is an opportunity within the lighting industry to create added value.
- The addition of various communication chips in LED lighting drivers is already underway with various Wi-Fi, Bluetooth, ZigBee, LoRa and other wireless communication modules already introduced in lighting drivers, such as:
  - LIGHTIFY by OSRAM (https://www.osram.com/corporate/lightify/lightify-pro/lightify_pro_products.jsp)
  - Philips Hue (http://www2.meethue.com/en-us/products/)
  - C-life by GE (https://www.cbyge.com/products/c-life)
  - Cree connected light (http://creebulb.com/connected-60-watt-replacement-soft-white)
- The addition of LC as part of a comprehensive 802.11 communications module can create new market opportunities for both, the lighting industry and the wireless communications industry.

The price-point for commercial and industrial LED lighting are higher than for the general consumer market with an expected product replacement cycle of 5 – 10 years.

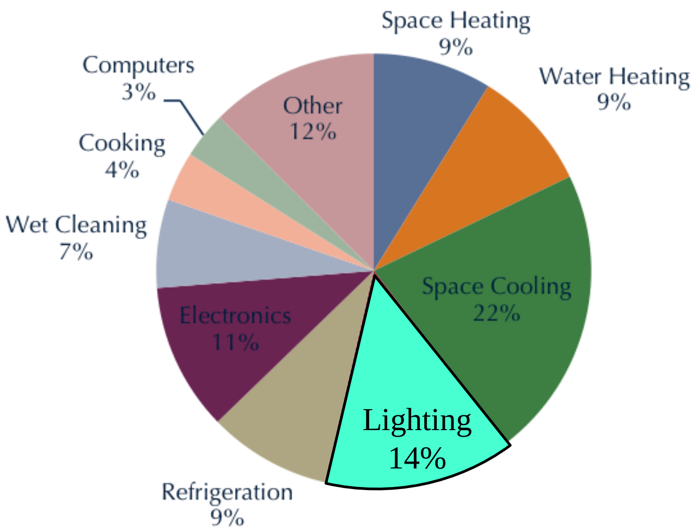
- The emergence of Light as a Service business model is the next step in the evolution of the lighting industry.
- With the introduction of smart lighting control and increasingly the Internet of Things (IoT) connectivity modules, the lighting industry is relying more on creating value for the end customer based on the available data about the building and behaviour or the users.
  - Examples of location-based services with Philips Lighting in Carrefour in France
  - The Edge Building in Amsterdam
- This shifting business model in lighting can leverage light communications and other wireless communications to improve the utility of lights.
- **The 5 – 10 year product replacement cycle is similar to the evolution of various 802.11 standards, ensuring that the future lighting sockets can all have 802.11 technologies embedded in the next generation of devices.**

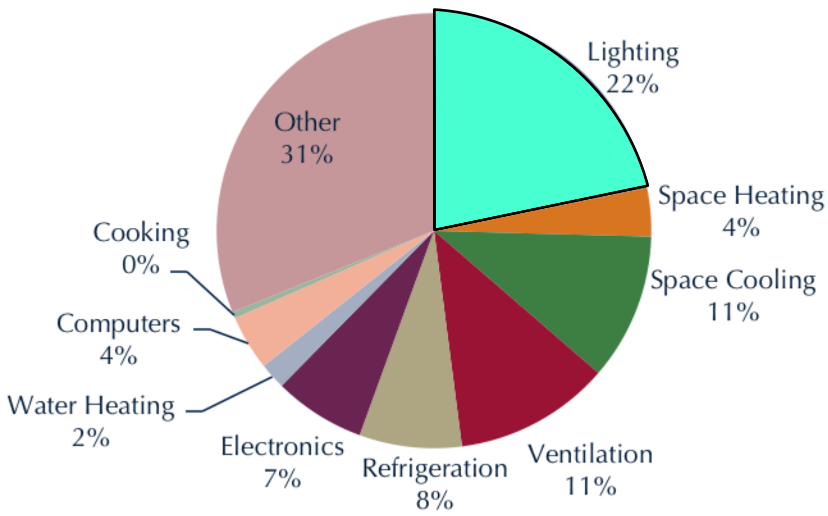
Over 72% of the global use of electricity is in Commercial and Residential premises



- Retail Sales of Electricity to Ultimate Customers, Total by End Use Sector (2013)
  - Source: EIA, *Electric Power Monthly*, Table 5.1, May 29, 2014. http://www.eia.doe.gov/cneaf/electricity/epm/table5_1.html.

Lighting will always consume energy - over 13% of global electricity use.





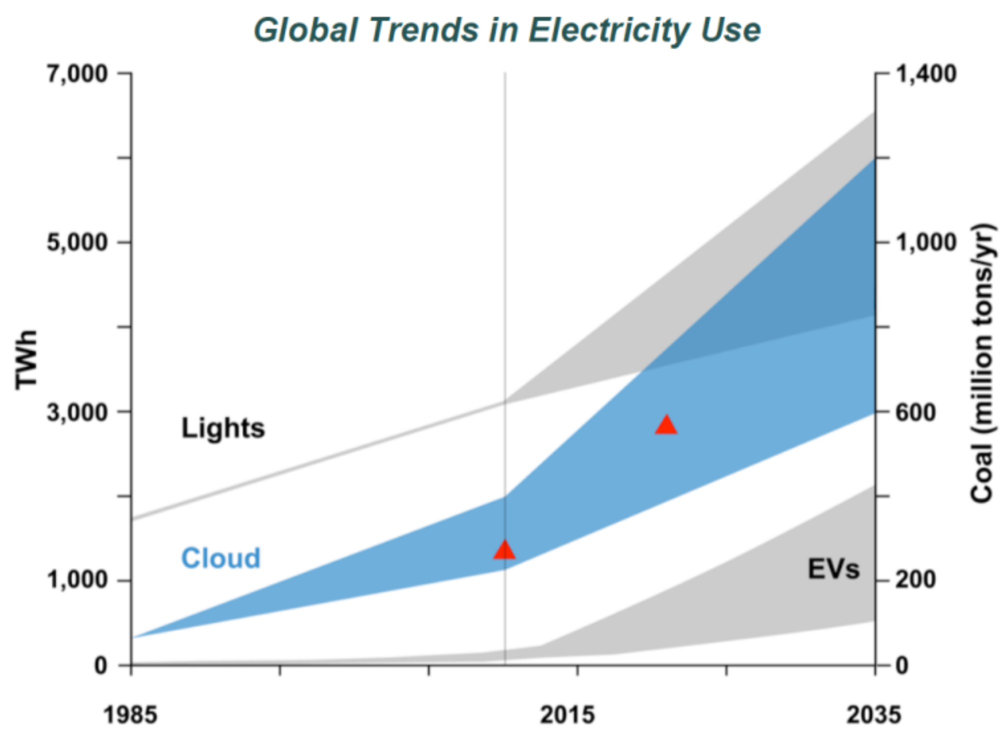
- **Residential** Electricity Consumption by End Use (2010)
  - Source: DOE, *Buildings Energy Data Book*, Table 2.1.5, March 2012. http://buildingsdatabook.eren.doe.gov/ChapterIntro2.aspx.
- **14% of residential electricity use is consumed by Lighting**

- **Commercial** Electricity Consumption by End Use (2010)
  - Source: DOE, *Buildings Energy Data Book*, Table 3.1.5, March 2012. http://buildingsdatabook.eren.doe.gov/ChapterIntro3.aspx.
- **22% of commercial electricity use is consumed by Lighting**

LC can use the energy already consumed for illumination to provide wireless communications

- Lighting consumes over 13% of global electric energy
- Aside from illumination, the energy used for lighting can also be used to provide some heating (98% of the energy used by incandescent lights is generated as heat)
- LC can use the energy consumed by lighting to provide wireless communication and therefore avoid the waste of energy

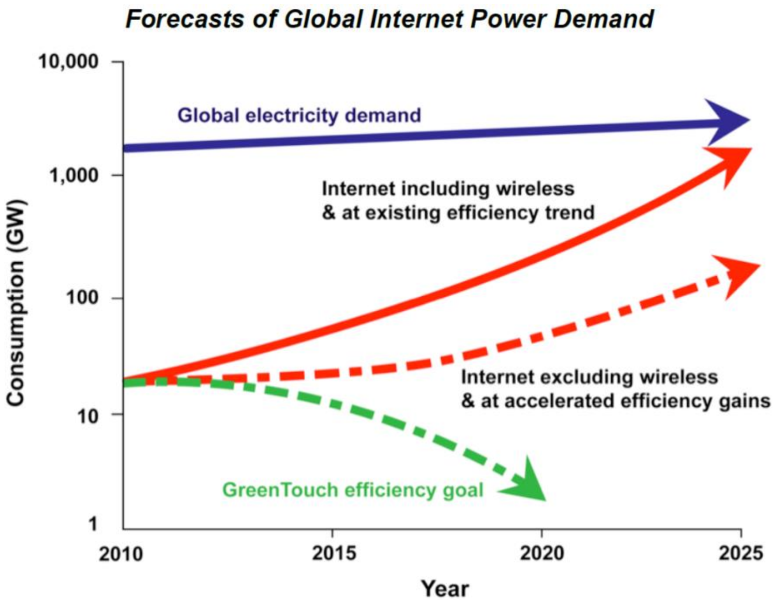
Lighting consumes more electrical energy than the entire "cloud" and this can be used to offset the energy required for wireless transmission



Data Source: For EVs, Polk & calculation; lights from IEA; Cloud from this report.
One industry analysis forecasts 2020 ICT energy use at 140% of today's level.[94] Greenpeace estimates it will triple in a decade.

– Source: Boston Consulting Group SMARTER

LC can increase the sustainability of wireless communications and maintain the industry growth rates



Source: GreenTouch, CEET

– Source: Centre for Energy Efficient Telecommunications (CEET)

– GreenTouch is an industry initiative to reduce the energy consumption of wireless communications, *e.g.*, by reducing the wireless cell sizes.

– The current energy demands for Internet access are due to hit the limit of the global electricity demand by 2025 if current efficiency trends are maintained and a large part of the energy consumption can be attributed to wireless communications.

– LC can reuse the energy consumed for illumination to offset the energy required for wireless transmission by offering wireless communication capabilities to lighting devices for a marginal increase in the energy consumption of the devices.

– Therefore, LC can increase the sustainability of wireless communications and maintain the industry growth rates.

LC has comparable energy efficiency to 802.11 and more available energy for the downlink

Energy Requirements

Available

- Lighting is already present and consuming power
- Regulation requires minimum indoor illumination levels

Computational

- Similar complexity as existing 802.11 PHY and MAC protocols

Radiated

- More energy is required to achieve the same distance as RF due to smaller wavelengths and intensity modulation / direct detection

The costs for integrating LC in mobile devices are well understood in the industry

- LC requires optical elements for the transmission and detection of modulated light signals as well as digital signal processing elements.
- An increasing number of industries have and are introducing optical detection modules (eg., digital cameras) in mobile devices, cars, industrial devices and more with known cost factors.
- The mobile devices industry has a clear understanding of the associated costs and integration effort for multiple communication modules.
- LC modules that can be integrated in mobile devices could easily scale to be deployed in multiple other verticals.

LC devices are expected to have substantially similar complexity and therefore cost as existing Wi-Fi chipsets

- The creation of a LC standard within 802.11 would ensure that aside from the physical modulation (transmitter and receiver) devices, the remaining elements would have substantially similar capabilities and therefore similar device costs as existing Wi-Fi products.

- On the access point side:
  - There are over 550 million LED lights sold annually with a 13% CAGR.
  - Each light already has the transmitting element (LEDs)
  - Each light already has the required connection to the backbone (assuming power line communications or PoE connectivity)
  - Each light already has the AC/DC conversion circuitry
  - Each light would need only a LC chipset along with the relevant receiver (LED driver and photodiode)

- On the device side, each mobile phone has:
  - Multiple connectivity chipsets are available on mobile devices, which could include a LC core
  - Multiple optical elements that are indicative of the devices that may be used for LC

LC offers significant market growth potential with over 550 million lights sold annually and 13% CAGR

- "The LiFi market is expected to grow to $75.5 Billion by 2023 with CAGR of 80%." – Global Market Insights, Inc.
- "The visible light communication market is expected to grow at a CAGR of 62.9% between 2017 and 2022, to reach USD 14.91 Billion by 2022 from USD 1.30 Billion in 2017." – MarketsAndMarkets
- A possible 802.11 LC standard could be ready for 2021 with a likely market of over USD 10 Billion.
- Providing wired connectivity to lights is key for smart buildings with RF sensitive environments.
  - Machine condition monitoring market size was valued over USD 1.5 billion in 2014. It is likely to grow at over 7.5% and exceed USD 3 billion from 2016 to 2023. – Global Market Insight
  - Similarly restricted areas such as mining and Oil & Gas would increase the potential market value several times over.

Straw Polls and Counts

- **Room count:**
- **Would you support the formation of a Study Group for LC to evaluate and to develop a PAR proposal?**
- **Yes:**
- **No:**
- **Abstain:**