Emerging Trends in Mobile Communications

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1 Acoustic data transmission

> I tried to discover, in the rumor of forests and waves, words that other men could not hear, and I pricked up my ears to listen to the revelation of their harmony.
>
> Flaubert, (*November*)

1.1 Introduction

The rise of IoT devices in the home and workplace has created a world where data and connectivity are becoming increasingly complex. Lucero, (*IoT platforms: enabling the Internet of Things*) predicts a staggering 75 billion connected devices by 2025, up from 26 billion in 2019, as shown in Figure 1. As IoT technology advances and the demand for efficient ways of communicating data between these devices grows, the world has witnessed a rise in emerging new data transmission technologies which are looking to provide secure and effective solutions for sharing information. One solution to meet these rising new demands is data-over-sound.

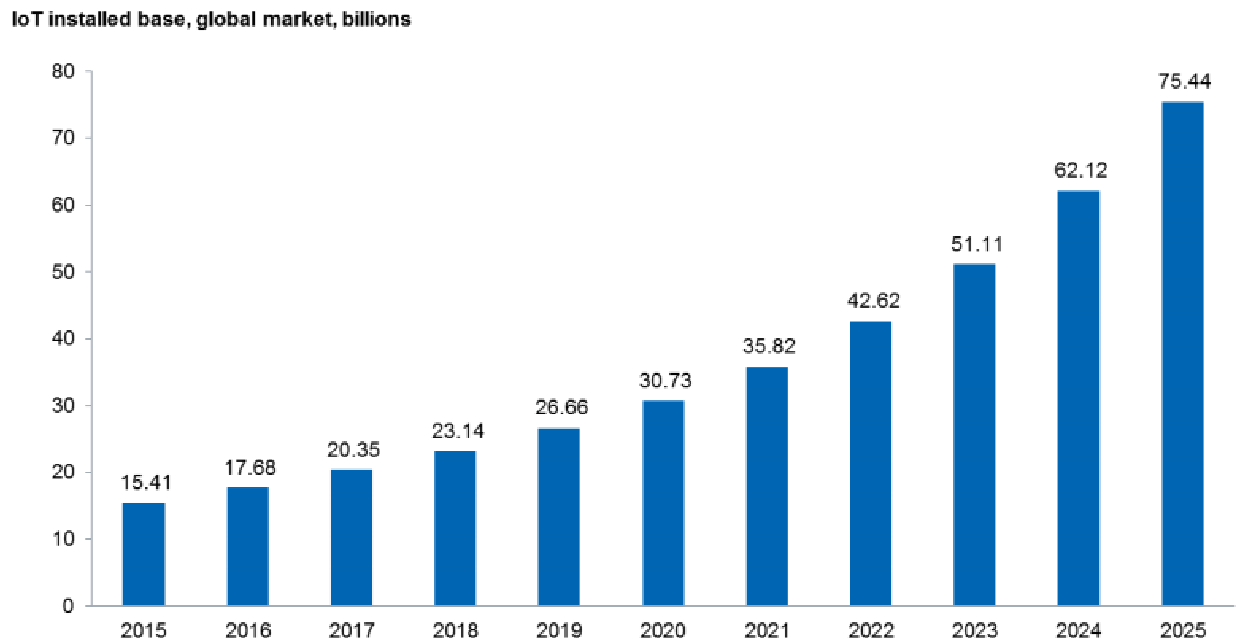

Figure 1: Number of IOT devices that will be installed worldwide from 2019 to 2025 (in billions).

Data-over-sound (DoS) presents a compelling solution for many device-to-device connectivity applications, particularly for use cases that require frictionless, low cost connectivity with nearby devices. DoS harnesses devices existing speakers and microphones to send and receive data over an acoustic channel. Because it doesnt require any additional networking hardware, DoS has captured the interest of companies interested in adding wireless connectivity functionality to existing devices. Some big names such as Google and Cisco already have point-product DoS integrations

There are a number of connectivity technologies available in the market today, including extremely short range (NFC and QR); short range, high bandwidth (Bluetooth and Wi-Fi). Each technology has its advantages which makes it more or less suitable for certain applications. An overview of these considerations are given in Table 1.

1.2 Advantages of Data-over-Sound

According to Table 1 following advantages can be listed.

	DoS	QR	NFC	Bluetooth	Wi-Fi	Li-Fi
Two-way communication	1	0	0	1	1	1
One-to-many broadcast	1	0	0	0	0	1
Non line-of-sight communication	1	0	0	1	1	0
Zero pairing/set-up procedure	1	1	1	0	0	0
Low power operation	1	1	1	1	0	0
max data rate	1 kb/s	3 kb	424 kb/s	25 mb/s	70 mb/s	1 gb/s
max range	100m	10:1	20/cm	100/cm	50m	10m

Table 1: Feature comparison for DoS vs alternative technologies

Device interoperability The simple hardware requirement of a speaker and/ or microphone make data-over-sound arguably the most wide-reaching wireless communication technology in terms of device compatibility. Mobile phones, voice controlled devices, and any device with an alarm speaker are able to communicate using data-over-sound. This includes many legacy devices. Data can also be transmitted over media channels such as radio and TV, and over existing telephone lines.

Frictionless UX Data-over-sound requires no pairing or configuration, making data transfer as simple as pressing a button.

Physically Bounded Because sound waves respect room boundaries, particularly in the near-ultrasonic range commonly used in data-over-sound, transmissions do not pass between neighbouring rooms. This means that it can be used for detecting the presence of a device with room-level granularity.

Zero power The advent of wake-on-sound MEMs microphones such as the Vesper VM1010 enables devices to communicate using data-over-sound, whilst draining virtually no battery power in between communications (< 10 A).

1.3 Applications of DoS

Based on these advantages, four key use cases for Chirp (a DoS implementation) are emerging, which are identified here.

IoT device provisioning Configuring a new smart device with network credentials and functional configuration remains a disproportionately complex task, particularly for headless devices. Chirp offers an approach to provisioning which is offline, locally-bounded, and does not require any infrastructure modifications. Credentials are encoded as audio, optionally layered with cryptography for secure scenarios, and broadcast over-the-air to nearby smart devices.

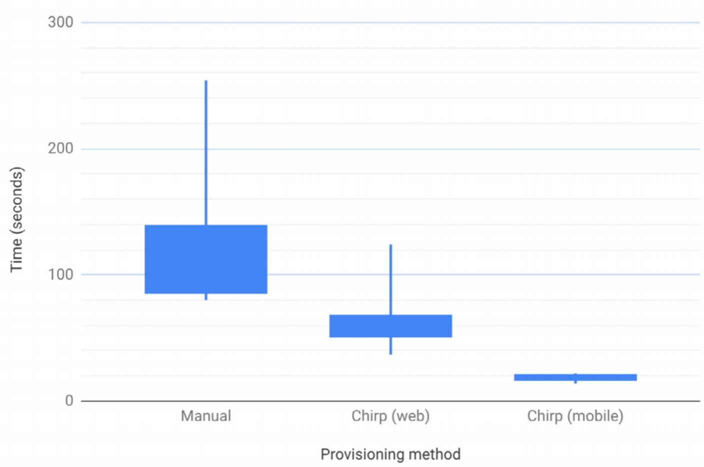

Figure 2: Time taken to provision a smart device.

Figure 2 shows the result of a study in which some experience of IoT were asked to provision a headless smart device using three methods:

1. Manually, by creating a temporary Wi-Fi hotspot on the device, connecting to the hotspot with a web browser, and entering credentials;
2. Using a Chirp-enabled web interface which asks the user to enter credentials and transmits them to the device via data-over-sound;
3. Using a Chirp-enabled mobile app which was able to use the devices existing knowledge of the credentials

The Chirp-enabled solutions reduced the provisioning time by 48% with the web-based scenario, and 86% with the mobile scenario.

Proximity Detection A key property of acoustic signals is that their propagation respects room boundaries, particularly in the near-ultrasonic range. As a consequence, there is a growing uptake for near-ultrasonic acoustic beacons for presence sensing at room-level granularity

Two way acoustic NFC Data-over-sound also supports near-field communication scenarios whilst offering a two-way full-duplex mode of communication, thus addressing a critical limitation of NFC. Enabling two-way data exchange means that devices can perform challenge-and-response dialogues - for example, Diffie-Hellman key exchange for secure financial transactions, or securely sending un-spoofable receipts to a merchant or buyer.

Telemetry in RF-restricted environments In many sensitive environments, RF-based communications are prohibited due to the risk of sparks or interference with equipment that pre-dates RF regulation. Chirp overcomes these limitations, allowing the industrial IoT to harness the benefits of wireless communication without limitation.

1.4 How it all works?

The basic idea of data-over-sound is no more complex than a traditional telephone modem. Data is encoded into an acoustic signal - either audibly as bleeps and tones inaudibly above human hearing range or hidden as imperceptible modifications of existing speech or music - which is then played through a medium (typically the air, although it could equally be a wired telephone line or VoIP stream), and received and demodulated by a listening device. The listening device then decodes the acoustic signal and returns the original data. This process is described in Figure 3.

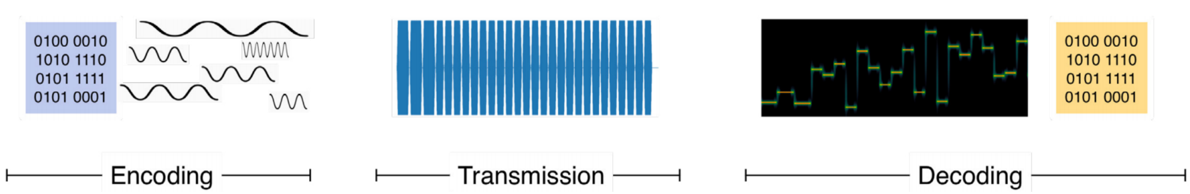

Figure 3: life-cycle of data-over-sound

As with other data transmission protocols, the entire message can include specific sequences to indicate the start and expected length of a message, as well as additional bytes for error detection and correction, as shown in Figure 4. Messages are typically encoded using frequency-shift keying (FSK) modulation, which is robust to background noise and distortion from acoustic effects such as reverberation. Following extensive testing of a large range of consumer devices, Chirp considers the safe range to be between 1kHz-20kHz. This enables the production of audible messages, or near ultrasonic when limited to 17kHz-20kHz, which is imperceptible to most adult humans.

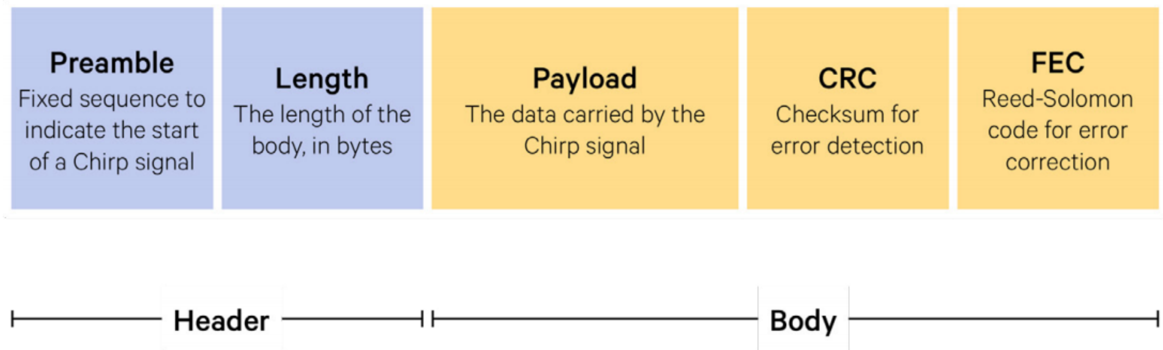

Figure 4: Makeup of the message

All of Chirps standard profiles are tested to perform at $> 99\%$ reliability under normal operating conditions. Of the existing data-over-sound solutions on the market, the main differentiator for Chirp is this reliability and robustness of the internal decoding technology. This has been demonstrated and stress-tested in acoustically extreme environments, including nuclear power stations with upwards of 100dB(A) of background noise, across ranges exceeding 100m.

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2 Centralized-RAN

Technology offers us a unique opportunity, though rarely welcome, to practice patience.

(Lokos, *Patience: The Art of Peaceful Living*)

2.1 Introduction

Global mobile data traffic is increasing at a substantial rate. It is estimated by cisco, (*Global Mobile Data Traffic Forecast Update, 2017-2022*) that it will grow seven fold from 2017 to 2022, with cell network advances and cut off in data price. To satisfy the consumer demands the network capacity is to be increased. It can be done by adding cell sites or by implementing the techniques like Multiple Input Multiple Output(MIMO). But increasing cell sites requires high capital investment and also results in increase in interference.

2.2 Architecture

2.2.1 Traditional Macro Base

In the traditional architecture(Figure 6a), radio and baseband processing is done inside a base station. The antenna module is generally located near the radio module, coaxial cables are used to connect them, signal loss associated with them is high. This architecture was popular during 1G and 2G mobile networks.

2.2.2 Base station with RRH

In the Remote Radio Head (RRH) architecture(Figure 6b), the base station has two components namely, a radio unit and a signal processing unit. The radio unit is called a RRH or Remote Radio Unit (RRU). The signal processing part is called a BBU or Data Unit (DU). This architecture was introduced during 3G networks and right now the majority of base stations use it.

The distance between a RRH and a BBU can be extended up to 40 km, where the limitation is coming from processing and propagation delay. In this architecture, the BBU equipment can be placed in a more convenient place, enabling cost savings on site rental and maintenance compared to the traditional RAN architecture. RRHs can be placed up on poles, leveraging efficient cooling and saving on airconditioning in BBU housing. One BBU can serve many RRHs. RRHs can be connected to each other in a daisy chained architecture. Common Public Radio Interface (CPRI) is the radio interface protocol widely used for IQ data transmission between RRHs and BBUs.(Figure 5)

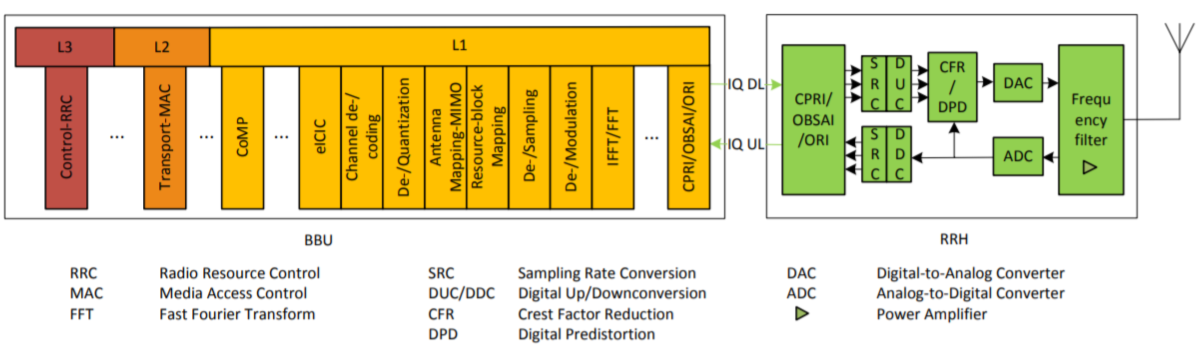

Figure 5: Sub modules of BBU and RRH. Source: (Checko et al., *Cloud RAN for Mobile Networks - a Technology Overview*)

2.2.3 Centralized base station architecture, C-RAN

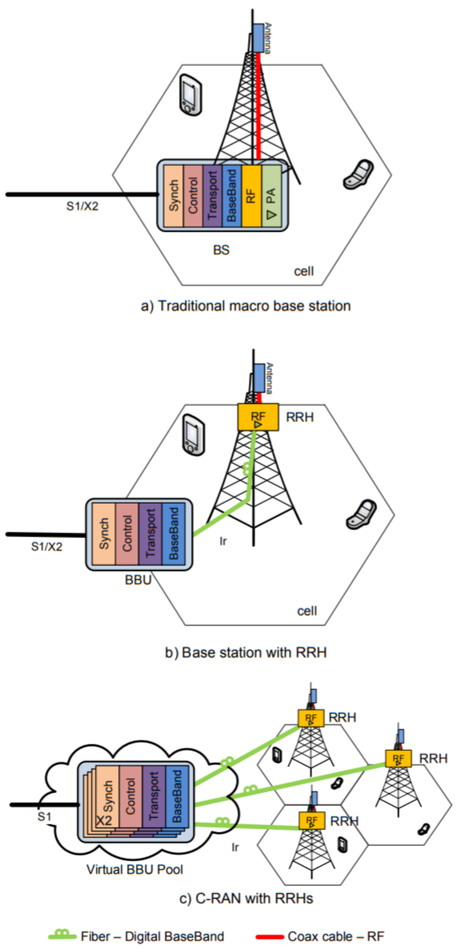

Figure 6: Base station architecture evolution. Source: (Checko et al., *Cloud RAN for Mobile Networks - a Technology Overview*)

In C-RAN(Figure 6c), in order to optimize BBU utilization between heavily and lightly loaded base stations, the BBUs are centralized into one entity that is called a BBU Pool. A BBU Pool acts as a virtualized cluster to perform baseband processing. The concept of C-RAN was first introduced by IBM under the name Wireless Network Cloud (WNC) and builds on the concept of Distributed Wireless Communication System. Since then various companies exploited the architecture and proposed improvements.

Figure 7 shows an example of a C-RAN mobile LTE network. The fronthaul part of the network spans from the RRHs sites to the BBU Pool. The backhaul connects the BBU Pool with the mobile core network. At a remote site, RRHs are co-located with the antennas. RRHs are connected to the high performance processors in the BBU Pool through low latency, high bandwidth optical transport links. Digital baseband, i.e., IQ samples, are sent between a RRH and a BBU.

2.3 Advantages

Energy Efficient and Cost-saving With centralized processing, the number of BS sites can be reduced. Thus the air conditioning and other site support equipment's power consumption can be largely reduced.
As the BBU pool is a shared resource among a large number of virtual BS, it means a much higher utilization rate of processing resources and lower power consumption can be achieved.

Capacity Improvement In C-RAN, virtual BS's can work together in a large physical BBU pool and they can easily share the signaling, traffic data and channel state information.

Adaptability to Non-uniform Traffic C-RAN is also suitable for non-uniformly distributed traffic due to the load-balancing capability in the distributed BBU pool.

2.4 Challenges

Bandwidth, Latency and Jitter C-RAN brings a huge overhead on optical links between RRH and BBU pool as shown in figure 5. The transport network not only needs to support high bandwidth and be cost efficient, but also needs to support strict latency and jitter requirements.

BBU cooperation, interconnection and clustering There is a need to improve the performance between BBUs. Cells should be optimally clustered to be assigned to one BBU Pool, in order to achieve statistical multiplexing gain, facilitate CoMP, but also to prevent the BBU Pool and the transport network from overloading.

Virtualization technique A virtualization technique needs to be proposed to distribute or group processing between virtual base station entities and sharing of resources among multiple operators. Any processing algorithm should be expected to work real time - dynamic processing capacity allocation is necessary to deal with a dynamically changing cell load.

2.5 C-RANs towards 5G

It is envisioned that 5G will bring a 1000x increase in terms of area capacity compared with 4G, achieve a peak rate in the range of tens of Gbps, support a roundtrip latency of about 1 ms as well as connections for a trillion of devices, and guarantee ultra reliability.

The field trials conducted by China Mobile have verified the throughput gain brought by C-RANs based on an uplink LTE model, reaching up to near 300%. Through dense RRHs in C-RANs, massive connections are efficiently supported, and it is not hard to provide good service for trillion of devices if the density of RRHs is sufficiently high. Although a big gap is still observed compared to 5G requirements, the result has shown the potential advantages of C-RANs. Meanwhile, different advanced techniques can be involved in C-RANs to further improve the spectrum efficiency.

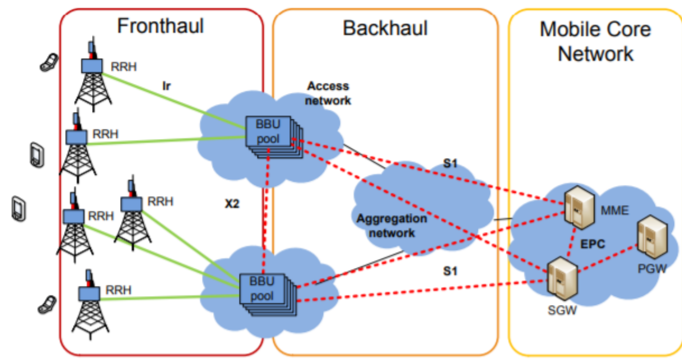

Figure 7: C-RAN LTE mobile network. Source: (Checko et al., *Cloud RAN for Mobile Networks - a Technology Overview*)

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3 Li-Fi

There is a crack in everything. That's how the light gets in.

(Cohen, *Anthem*)

3.1 Introduction

Today, when the world is exploring 5G technology, and smart devices are connecting to the cloud for fluid communication and IOT. Daily data traffic is increasing at the steepest rate. According to cisco, (*Global Mobile Data Traffic Forecast Update, 2017-2022*) it has been estimated that, mobile data traffic will reach to 77 exabytes per month by 2022. It is not hidden from the industry that current transmission system is under pressure.

Figure 8: Mobile data traffic. Source: (cisco, *Global Mobile Data Traffic Forecast Update, 2017-2022*)

To revive the radio-wave spectrum from high traffic concentration, a new technology is attracting scientists, it's Visible light communication using the concept of Orthogonal Frequency Division Multiplexing(OFDM) or simply termed as Li-Fi(Light Fidelity).
Li-Fi was first introduced to the world by Prof. Herald Haas during a TEDGLobal Talk in July 2011. In that talk, Harald Haas, (*Wireless data from every light buld*), showcased the potential of the technology to be integrated in the future communication system. From then, scientists from various parts of world started studying for various ways to improve the transmission method.

The technology uses visible-light spectrum as a medium for data transmission. It comprises of a huge bandwidth of 400THz as compared to radio-waves in GHz. Moreover, visible light does not have any adverse effect on our body as that of radio-waves. LEDs are perfect candidates for light transmission as they have the property that their intensity can be changed at a very high speed.

3.2 Working of Li-Fi

3.2.1 Modulation-Demodulation

According to Dimitrov et al., (*Clipping Noise in OFDM-Based Optical Wireless Communication Systems*), the system uses Orthogonal Frequency Division Multiplexing(OFDM) for modulating the signals. As shown in the figure 11, first the transmitting data is mapped to complex symbols X(l) by some modulation scheme

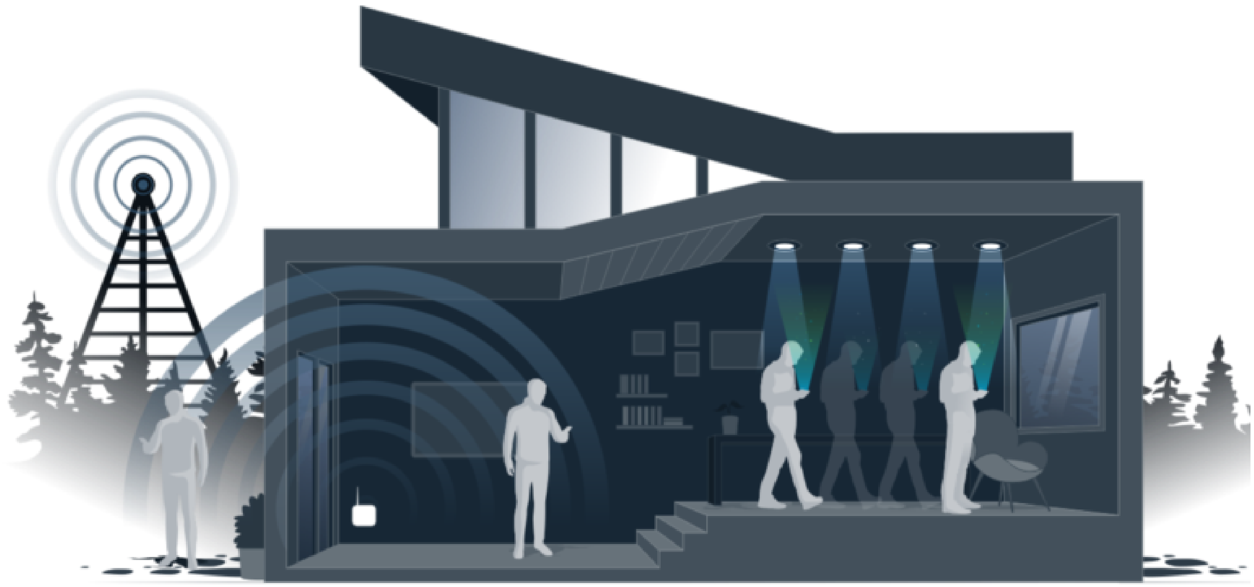

Figure 9: Li-Fi. Source: (pureLiFi, *Light becomes data*)

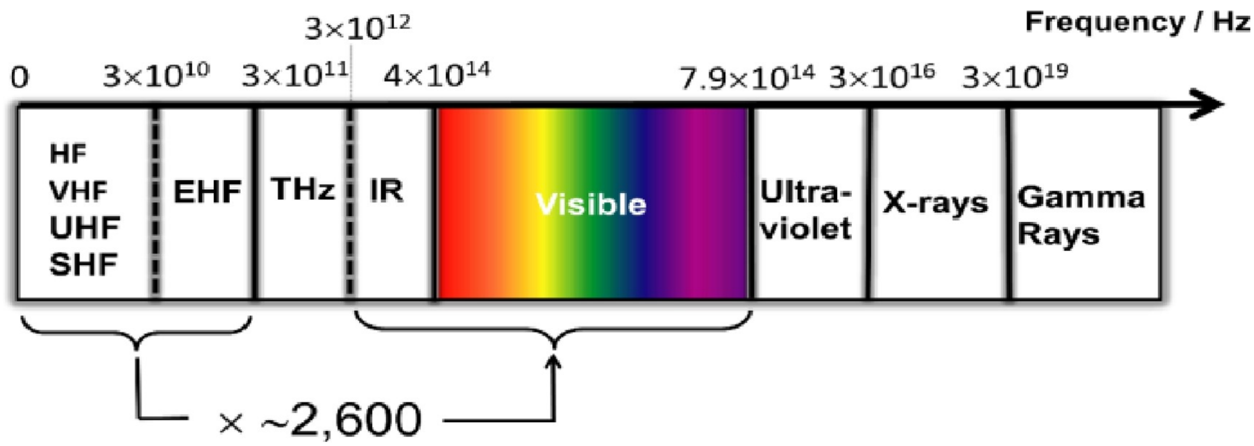

Figure 10: spectrum comparison. Source: (Herald Haas, *LiFi is a paradigm-shifting 5G technology*)

like M-QAM. Then signals are summed using IFFT(Inverse Fast Fourier Transformation). Then signal is guarded after P/S conversion and transmitted through light source.

At the receiver's end, the signals are converted from serial to parallel and individual signals are extracted using FFT(Fast Fourier Transformation). Signals are then demodulated and send to the receiver.

3.2.2 Hardware Requirements

Elgala et al., (*Indoor Broadcasting via White LEDs and OFDM*) states that LiFi requires two DSP(Digital Signal Processor) boards, at transmitter and receiver ends respectively, one LED bulb and a Photo-Diode reciever.
The Electric Signal from the transmitter are first modulated using OFDM by the DSP board, installed between transmitter and the LED. The intensity of the LED to generate the signal is controlled by this DSP.

At the other end, Photo-Diode receiver detects the high speed fluctuations of the intensity of LED. DSP connected to Photo-Diode receiver decodes the OFDM signals and transmits it to the receiver. The fluctuations caused in LED are so fast that it's impossible to detect them by naked eye, and hence serves

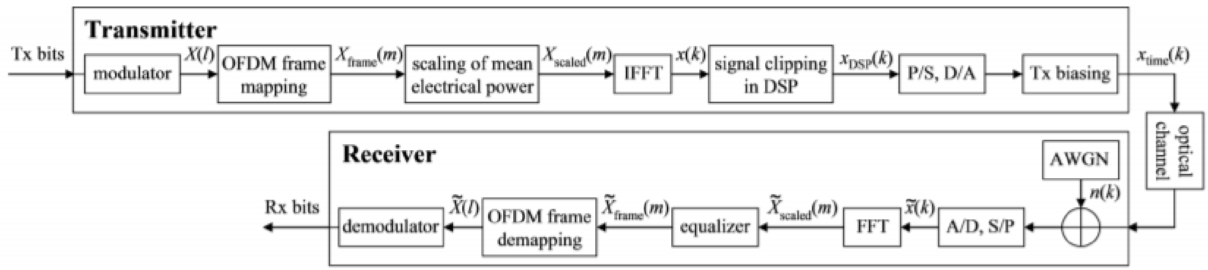

Figure 11: General OFDM. Source: (Dimitrov et al., *Clipping Noise in OFDM-Based Optical Wireless Communication Systems*)

the purpose of normal LED.

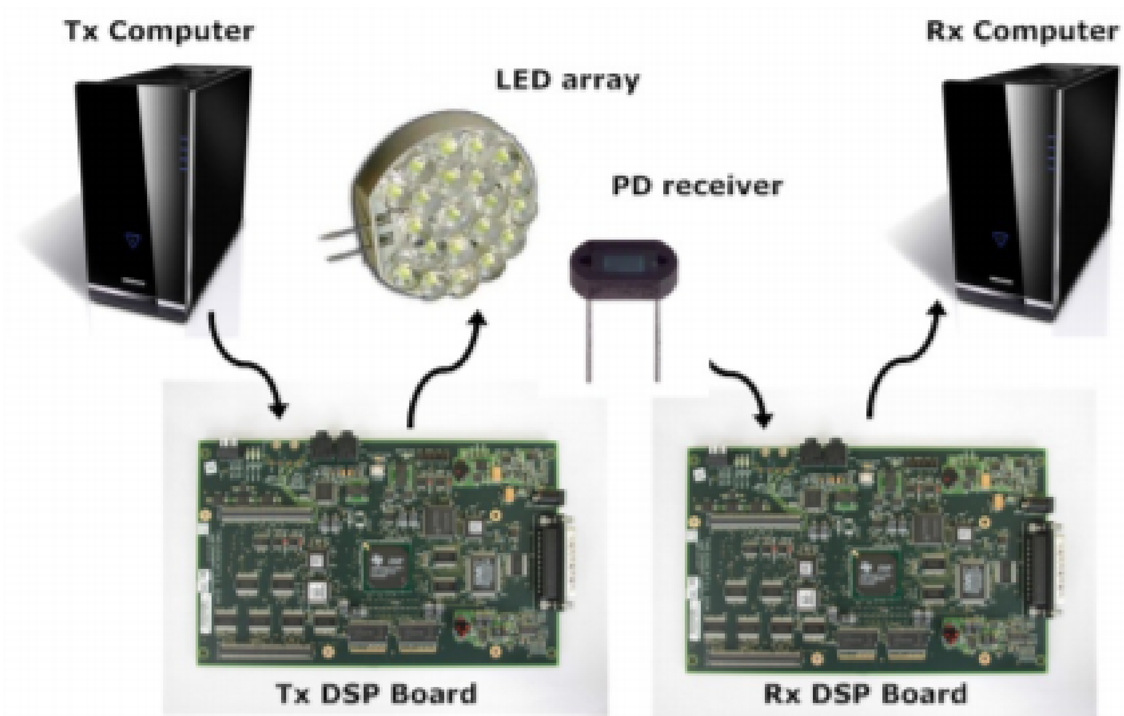

Figure 12: simple OW system. Source: (Elgala et al., *Indoor Broadcasting via White LEDs and OFDM*)

3.3 Advantages

Speed Data transmission speed can reach as high as 224 gigabits per second under light transmission.

Bandwidth The unused bandwidth of 400THz in Visible Light Spectrum can be exploit for transmission.

Cost and Availability There is no issue of initial setup and availability, the LEDs are much cheaper and can be used in place of fluorescent bulbs easily.

Security Light cannot penetrate through walls, and can be localized to the area of operation. Hence, provide secure environment for data transmission.

Efficiency Energy consumption of LED is much less than other artificial light source and there is not much addition energy required for data transmission making it much efficient.

3.4 Misconceptions

It won't work in dark As data is transmitted through light, one can think that we have to switch on the LED always, and we cannot keep the room dark. But these LEDs can be dimmed low enough that it will not be visible to human eye and still can be used for transmission.

It won't work in fog The PD receiver can detect the mere fluctuations from the light source even if there is fog in-between.

It's not bidirectional Li-Fi is a Fully duplex system and networked, hence handover as you move around in space.

Li-Fi doesn't work in sunlight Li-Fi relies on fast change in light intensity, and not on slowly changing natural sources. Various filters can be used to decrease the interference from other sources.

3.5 Global light communication standards

In 2019, IEEE announced formation of 802.11 bb task group which will develop and ratify the Global standard for Li-Fi, opening the doors for the use of technology at global level. The team aims to deliver the standards by mid 2021.

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