Heterogeneous Network for Indoor Communication

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ABSTRACT
This paper proposes an idea of a wireless Heterogeneous Network (HetNet) in an indoor environment for increasing the spectrum efficiency due to the ever-increasing demand of bandwidth. Most of the data is consumed indoors and wireless HetNets in an indoor environment will provide high quality of service thus satisfying the spectrum needs. The use of light as a new access medium is p roposed in addition with general characteristics of WiFi & VLC.

Keywords
Heterogeneous Network (HetNet), Wireless Fidelity (WiFi), Visible Light Communication (VLC), Light Fidelity (LiFi).

1. INTRODUCTION
Recently, there has been a rapid increase in the number of internet connected devices. The main user activities consuming data are watching HD videos and accessing cloud services. This type of data consumption mostly takes place in an indoor environment. This type of high demand for data is expected to grow exponentially & it motivates the adoption of a new spectrum. This increased demand has given rise to a new technology named Heterogeneous Network (HetNet). Heterogeneous Network integrates a diverse spectrum to provide a high quality of service (QoS) especially in an indoor environment. The combination of macrocells providing lower rate services, RF small cells (RF-SCs) & localised small LiFi cells providing additional capacity has been proposed in this paper. According to Cisco Visual Networking Index (Global Mobile Data Traffic Forecast Update (2014-2019)), approximately 50 percent of this traffic is expected to be offloaded to WiFi in 2016.

2. LITERATURE REVIEW
Fast and reliable WiFi connection is a result of high signal strength of WiFi in an indoor environment. In an enclosed area with different types of obstructions such as walls, and as distance increases the quality of WiFi signal strength degrades i.e. it gets attenuated. Due to such degradation in signal strength, users experience slow speed and poor connectivity. Interference from neighbouring Access Points (APs) and multiple active users sharing limited bandwidth also causes slow connectivity [1].

WiFi evolution considers higher frequencies in the mm-wave spectrum to reach higher data rates and achieve greater bandwidth. This higher bandwidth will accompany more number of parallel users. Light Fidelity (LiFi) also known as Visible Light Communication (VLC) offer dual functionality to transmit data on varying light intensity [2]. Integrated architecture for 5G mobile networks that includes SCs and enhanced WiFi as the scaling factor for wireless capacity can be deployed. In dense environment, the performance of WiFi can be reduced due to carrier sense multiple access with collision avoidance (CSMA/CA). CSMA/CA allows only one link to be active at a time and is random & demand-driven. This can be problematic with the adoption of IP video streaming, which increases both data consumption and the need for continuous data delivery [3].

Concurrent multiuser transmission can be the next step in WiFi evolution same as the multiuser multiple input and multiple output (MU-MIMO) in Long Term Evolution (LTE). In dense deployments, cooperative beamforming between adjacent APs is also considered in [4].

A big standardization is required to define such a new mode of simultaneous transmissions to multiple users that should also be backward compatible. There are also complexity limits with the increase in the number of antennas. The complexity of linear MIMO equalizers scales with N^3, where N is the number of antennas. Recently, a practical solution has been developed. Due to these standardization, scalability, and complexity issues, and due to the increasing demand for WiFi, scalability is limited and it is obvious to consider another wireless media [5].

The Visible Light Communication (VLC) is a new technology, which provides fast data transmission, secure data transmission, high data rate wireless transmission, etc. Instead of radio frequency, VLC uses light, to transfer data. The visible light spectrum is unlicensed and 10,000 times larger than the range of radio frequencies. It can be used as an alternate to the existing radio based wireless communication technologies or in hybrid. Light Fidelity (LiFi) is a recent technology under VLC, which can be used for wireless communication as it has many advantages [6].

Light Fidelity (LiFi) is a continuation of the trend to move to higher frequencies in the electromagnetic spectrum. LiFi can be classified as a mm-wave communication technology [7]. The frequency of light signals in electromagnetic spectrum lies in the THz range. LiFi uses light emitting diodes (LEDs) for high speed wireless communication, and can reach to speeds over 3 Gb/s from a single micro-LED [8]. Given that there is a widespread deployment of LED lighting in homes, offices and streetlights because of their energy efficiency, there is an added benefit for LiFi cellular deployment in that it can be built on existing lighting infrastructure [9]. Moreover, the cell sizes can be reduced further compared with mm-wave communication leading to the concept of LiFi attocells [10]. LiFi attocells are an additional network layer within the existing heterogeneous wireless networks, and they have zero interference from, and add zero interference to, the radio frequency (RF) counterparts such as femtocell networks. A LiFi attocell network uses the lighting system to provide fully networked (multiuser access and handover) wireless access [11].

3. PROBLEM DEFINITION
The ever-increasing demand for spectrum is the main reason for the requirement of Heterogeneous Networks (HetNets). The main challenge of HetNets in an indoor environment lies in intelligently converging WiFi & LiFi networks to provide a

high quality of service (QoS). The network should be able to identify the users' requirements and offloading the data to the best suited network. A proper networking framework also needs to be designed to form the converged network of WiFi & LiFi following the basic protocol infrastructures. User mobility is also an important consideration for the provision of seamless connectivity and is required in order to properly evaluate the performance of the proposed Li+WiFi network.

4. BASIC CONCEPTS

A. Heterogeneous Network (HetNet)

Heterogeneous Networks form a very compelling approach for cellular networks to provide the coverage & capacity needed to move forwards. These heterogeneous networks, often labelled as HetNets are typically composed of variety of formats of base station, radio access technologies, transmission solutions & power levels. Combining such variety of technologies together enables the best option to be chosen for a given area, but it also presents problems in terms of ubiquity & operation with such variation of technologies & approaches.

B. Visible Light Communication (VLC) & Light Fidelity (LiFi)

The radio spectrum available below 10GHz has become insufficient due to increase in demand for wireless communication. Visible Light Communication (VLC) is a short range optical wireless communication technology that uses light to transmit data. VLC increases the data rates in wireless communication & has better performance of networks especially in an indoor environment using LED lamps. LED based LiFi can be used as a wireless communication technology instead of conventional radio waves since it has many advantages such as high data rate, low cost, no interference, secure, etc. IEEE standard for VLC is 802.15.7, which refers to free space optical communication standard.

As all wireless communication technologies, VLC has two main components i.e. a transmitter & a receiver. Transmitter consists of an LED lamp with signal processing unit. Receiver consists of a photodetector. Figure 1 shows the basic VLC communication scenario.

The ceiling LED lamp consists of a signal processing unit that encodes and modulates the data in its light intensity to achieve high speed data transfer. The photodetector detects the varying light intensity and converts it into an equivalent electrical form.

1) LiFi versus VLC: Intensity Modulation (IM) technique is used in VLC for data transmission. The receiver detects the signal by using the principle of direct detection. VLC is essentially a point to point communication technology. The standard for VLC is IEEE 802.15.7. This standard is being revised to include LiFi. LiFi describes a complete wireless networking system i.e. bidirectional, multiuser, point to multipoint and multipoint to point communication. LiFi also has multiple access points to support user mobility with seamless handover technique. Figure 2 shows the various layers of LiFi in comparison to VLC. LEDs are natural beamformers which has an added advantage to security.

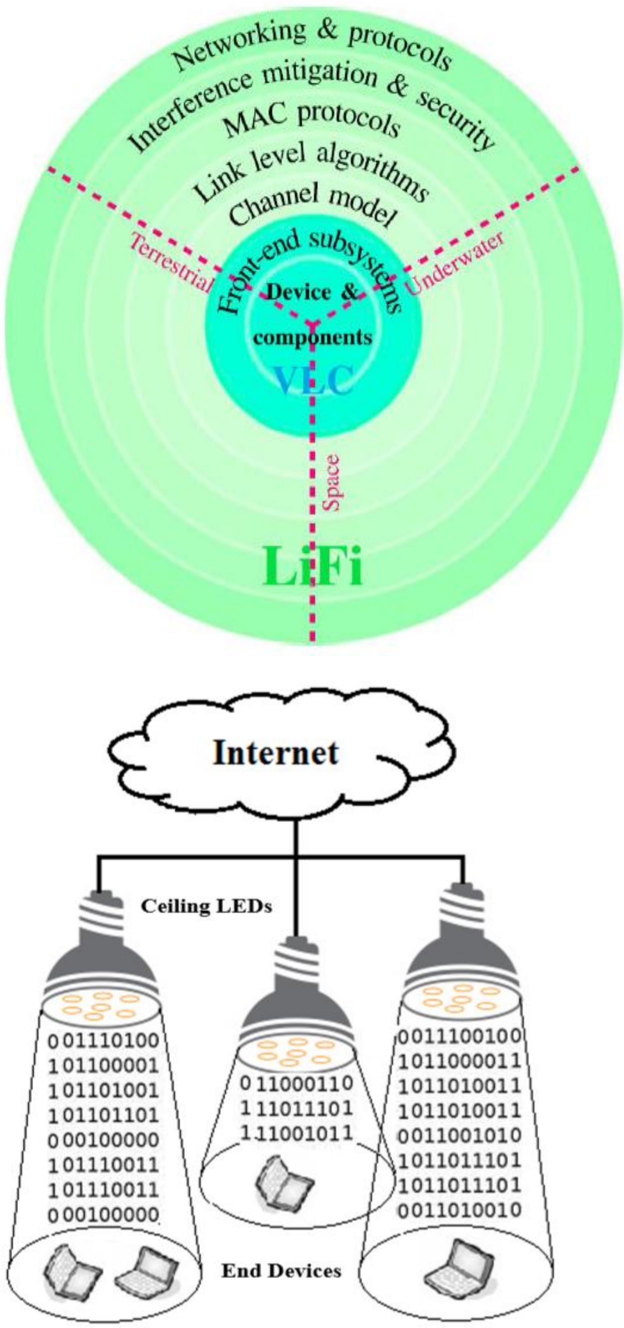

Fig. 1 Indoor VLC System

5. COMPARISON OF LIFI, WIFI & WIMAX

Currently there are multiple wireless communication technologies in use. These technologies have significant impact on humans. WiFi technology is a wireless local area network (WLAN) while WiMAX is wireless metropolitan area network (WMAN). LiFi can be used to replace these technologies with added advantages as shown in table below.

Table 1 Comparison of Wireless Communication Technologies

Specification	Wireless Data Communication Technologies		
	LiFi	WiFi	WiMAX
IEEE Standard	802.15.7	802.11a/b/g/n/ac/ad	802.16a/c/d/e/…/m
Medium	Light	Radio	Microwave
Speed	1-10 Gb/s	11 Mb/s – 6.75 Gb/s	4 Mb/s – 1 Gb/s
Communication Range	10 meters	20-250 meters	50 kilometres
Network Topology	Point to Multipoint	Point to Multipoint	Point to Multipoint
Frequency	400-800 THz	2.4/3/5/60 GHz	2.3/2.5/2.5 GHz
Cost	Cheaper than WiFi & WiMAX	Cheaper than WiMAX	Costly
Data Density	High	Low	Low
Security	High	Medium	Medium

6. PROPOSED METHODOLOGY

Considering the above-mentioned challenges, an additional tier in wireless Heterogeneous Networks comprising of indoor gigabit SCs is required to offer additional wireless capacity. LiFi-enabled indoor luminaires i.e. LED lights can be designed as optical Small Cells (O-SCs) in a Heterogeneous Network, where a three-layer network formed using RF macrocells, RF-SCs, and O-SCs. The performance of a single WiFi access point or multiple WiFi access points is expected to be enhanced by offloading network traffic to the most localized and directional LiFi luminaire. Along with high-speed traffic offloading with fast & seamless connectivity, the proposed Li+WiFi system also offers interesting features, such as enhanced security and improved indoor positioning. Visible light does not penetrate through walls, hence the enhanced security and improved indoor positioning is a result of a better resolution in a compared to other RF based technologies.

According to the recent study, 80 percent of mobile traffic occurs indoors; therefore, the combination of LiFi and WiFi has great potential in future HetNets, also including the next generation (5G) mobile systems. Current research is focused on enhancing the performance of each technology individually, although there is an immense need for reliable WiFi and LiFi coexistence.

As shown in Figure 3, stationary and quasi-stationary mobile users are accessing data via LiFi-enabled luminaires. This approach can overcome the congestion issues and free RF resources to serve more mobile users or the users those are outside the LiFi coverage area. In the Li+WiFi network, user devices (UDs) must support LiFi technology. To evaluate the development of LiFi supporting devices, the evolution of other cellular networks can be used as a reference for comparison. By delivering higher mobile broadband experiences, LiFi-enabled smartphones can offer a considerable amount of profit to the manufacturers. Most of the smartphones currently in use already support multiple radios and protocols. Even though the Li+WiFi network is asymmetric with LiFi as the downlink, and WiFi as uplink, this will free up the WiFi system capacity to accommodate any future growth in network traffic. Despite the asymmetry, tVhe advantages of the added LiFi channels are significant.

1. Current Research Activities

The major issues in designing and implementing a Li+WiFi network includes dealing with how a User Device (UD) connects to the network, how mobility is supported as the UD moves from one cell to another cell and between networks, and how multiple users are accommodated on the network. The combined performance of the LiFi and WiFi networks aggregate to match available the capacity. The proposed Li+WiFi network is described with a vision to provide seamless connectivity and to evenly distribute network resources among multiple users.

2. Multiple Links & Aggregation

Since the luminaires are placed throughout the living spaces, it is often possible to be within the range of more than one luminaire at a time. This can be exploited by using a multichannel receiver like a RAKE receiver. Consider that the lighting infrastructure is enabling Multiple-Input-Multiple-Output (MIMO) transmission using a multi-detector UD. However, the forming link or links involving one or more luminaires in the presence of multiple user devices is difficult. This will be more challenging with mobility and the UD orientation. Therefore, it is very critical to design reliable sensing of the optical link quality among multiple luminaires within the UD receiver's beam width and it requires careful investigation. In previous work in this field, it is assumed that the transmitting device knows exactly the channel state information (CSI) of each UD in the room. CSI may be easier to be calculated in a static condition, however from a practical point of view in the case of user mobility, calculating the CSI is an estimation problem and it cannot be error free. Therefore, understanding the effect of the channel estimation error on the system throughput in a multiuser (MU) environment is important.

Whenever the application needs a higher throughput, connecting a user on multiple optical channels can be an advantage. Since multiple LiFi-enabled luminaires are in each room, frequency reuse technique can be implemented to some extent at some to achieve a higher throughput. Carrier and channel aggregation is one key approach to increase the transmission bandwidth. The network traffic between RF and optical links must be efficiently split to handle packet drops and to reorder packets. These issues can affect higher layer protocols such as the Transmission Control Protocol (TCP). Three possible access scenarios can be considered in scenarios in which a user is attached to a single luminaire (SISO configuration) or simultaneously connected to multiple luminaires (MIMO configuration). Initially, the UD is connected to a single luminaire which provides the highest link quality. Multiple luminaires which serve a single user can be allowed to satisfy the user's requirements. To ensure fairness and minimum QoS among multiple users, the number of luminaires serving a single user can be intelligently managed depending on availability of the resources.

Typically, a single-user MIMO (SU-MIMO) scenario is considered in MIMO research on LiFi, where a single multi-detector user device communicates with a single multi-chip LED based luminaire or distributed luminaires.

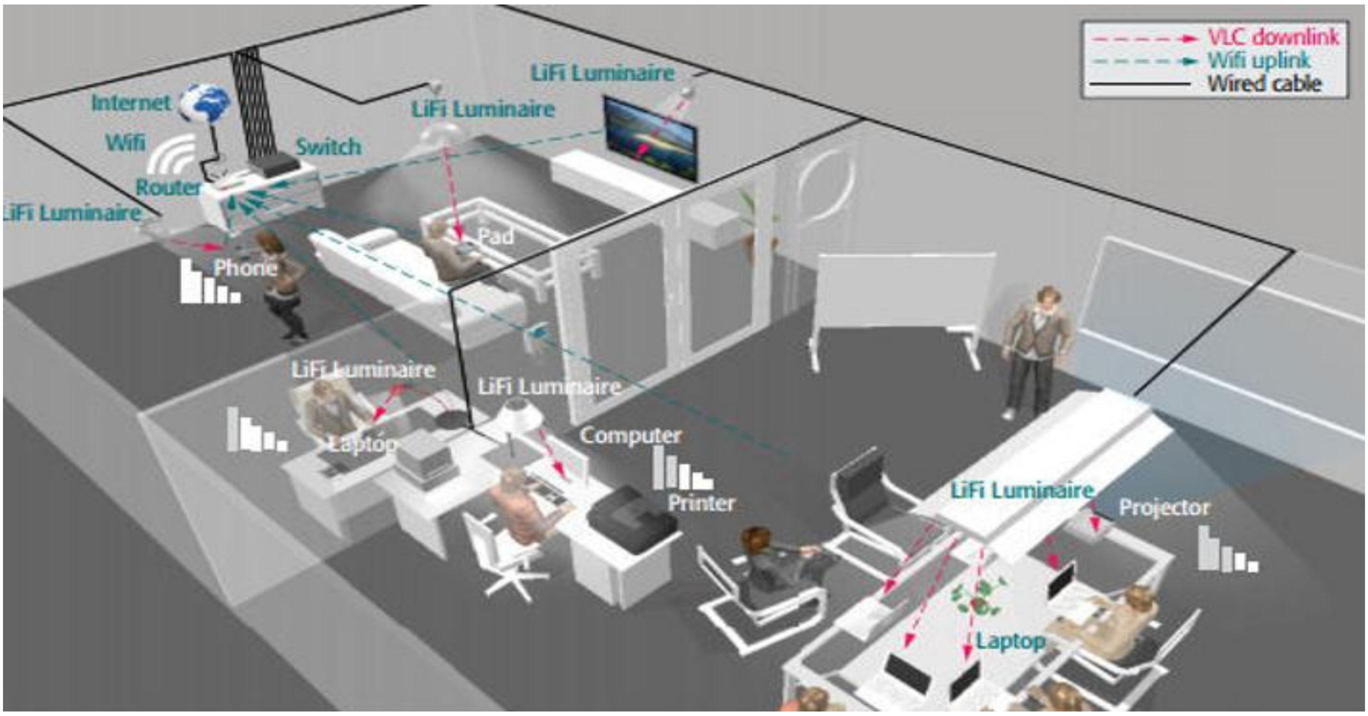

Fig 3. Li+WiFi Heterogeneous Network

Aforementioned, optical beamforming, e.g. through a spatial light modulator (SLM), provides spatial separation and higher channel quality. In a multiuser-MIMO scenario, the rank of the MIMO channel can be improved depending on the location of the selected user. Multiple luminaires can send signals to multi-detector UDs to serve these multiple users in parallel. Parallel transmissions are common in RF communications, while multi-source, multiple-access technologies, also including luminaires of various colours and wavelengths, are only just emerging.

3. Mobility & Medium Access

Careful examination of the issue of overlapping and non-overlapping coverage of the distributed luminaires is required. It has a great impact on the handover between the distributed luminaires & also between LiFi & WiFi. The information about UD location maybe involved in the handover mechanism. The handover mechanism can be employed using both the technologies, but LiFi is more efficient.

To support mobility, the user devices must adapt to the changing channels on both slow and fast time scales. The LiFi link changes more slowly, as the instantaneous power of the signal is proportional to the integral of the optical power over the detector surface. The WiFi link is subject to fast fading in which the radio channel can fade randomly.

The main challenge is to maintain continuous connectivity. As the coverage area of each luminaire is small, handover on the same wireless access technology is required. Hence, user mobility triggers frequent switching among the O-SCs, resulting in connectivity losses and/or undesired latency. This handover may thus be complemented by a second handover mechanism, where the traffic from a UD is rerouted from O-SCs to RF-SCs and vice versa. Handover in RF cellular networks is an important research area, where the signal-to-interference and noise ratio (SINR) is commonly the optimal metric for decisions regarding channel selection between cells within a tier. In multi-tier and/or HetNets, a preference to connect is often given to SCs. This is due to the aggregate performance improvement that dense networks provide. The sensitivity of LiFi to occlusions and vulnerability due to sudden losses in the LOS path also requires additional metrics. Specifically, a history of previous losses should be considered in the decision process because large overhead due to frequent handover may make the LiFi connection less desirable than the RF macrocell or SC.

The handover between the SCs of the same technology and between SCs of a different technology (O-SCs to RF-SCs and vice versa) are combined using orthogonal frequency-division multiple access (OFDMA). In OFDMA, data is transmitted on orthogonal narrow-band subcarriers, where users are allocated subcarrier-groups to enable concurrent transmissions. In this OFDMA scheme, system complexity is relatively increased compared to CSMA/CA, because transmission needs a tight coordination of resource assignment in the entire network. Alternatively, and while targeting fairness among users, a parallel transmission MAC (PT-MAC) protocol containing both the CSMA/CA algorithm and parallel transmission is proposed. This PT-MAC protocol improves the throughput and efficiency of the hybrid (IEEE 802.11n and VLC) network.

Motion information can also be considered as an important and distinctive metric in the utility function for traffic routing and handover in Li+WiFi systems. For example, a predictive handoff scheme is proposed using real-time user tracking information (e.g. user location, moving direction, and velocity). This approach minimizes the number of luminaires involved in the handoff mechanism while maintaining a seamless transition. The mobility models of users and several performance metrics, such as file size, average connectivity, and system throughput, are considered in.

4. Configuration of HetNets

Figure 4 shows two different configurations of Li+WiFi HetNet. In the (a) hybrid system, the unidirectional LiFi is exploited while in the (b) aggregated system both bidirectional WiFi and LiFi links are utilized to improve the throughput and provide seamless network connectivity.

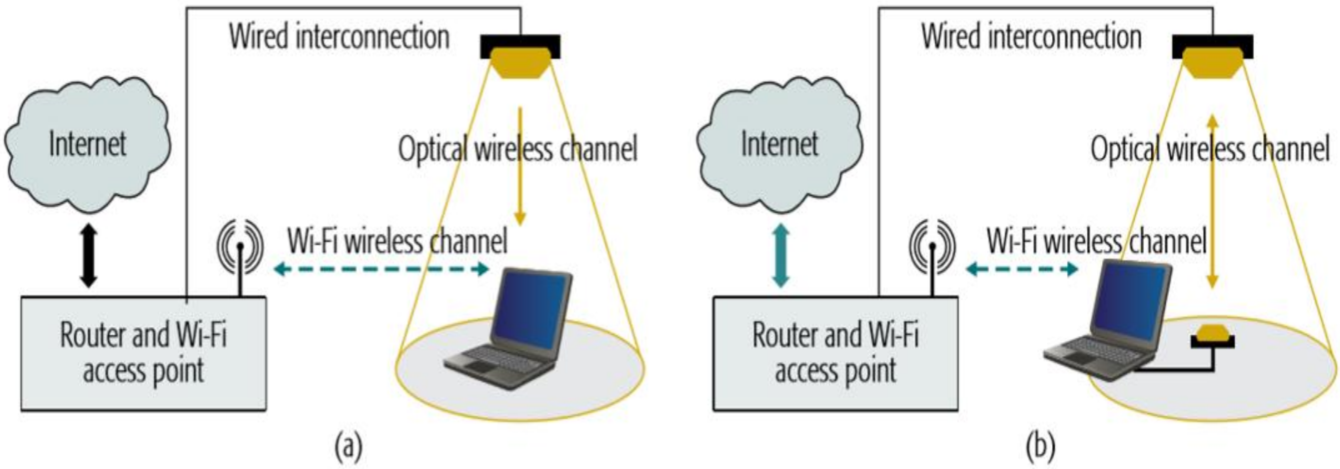

Fig 4. Configurations of the a) Hybrid System, and b) Aggregated System

The hybrid system more than doubles the throughput near the LiFi AP, while degrading quickly as the distance increases. The throughput of WiFi surpasses that of the hybrid system when the distance is increased, because as the distance increases, the downlink capacity of LiFi decreases with distance, eventually becoming insignificant. The throughput of the hybrid system depends only on the capacity of the LiFi downlink.

The aggregated system triples the achievable average throughput. Therefore, the aggregation technique not only enhances the available integrated bandwidth, but also provides reliable network communication.

7. APPLICATIONS

1. Application in Smart Home:

With providing data services, Heterogeneous Networks can also be used in Smart Homes for seamless performance and ease of access. This technology can be incorporated in all the home appliances such as air conditioners, television, refrigerators, lights, fans, etc. The transmitter used for sending control signals will be household ceiling lights which use LEDs. LED lights are the best for data transmission as their ON/OFF time is much faster than conventional lights, consume less power, and are more durable. The change in the light intensity will be so fast that it will be unrecognizable and hence won't disrupt basic functioning.

Considering a particular device such as an air conditioner whose basic control options are on, off, increase and decrease temp. A light sensor will be used in the device to receive the control signal (downlink), and WiFi or Bluetooth can be used to send information about the device (uplink). A common device such as a mobile phone, tablet PC, etc. can be used to send the necessary control signals.

If the LED light used to send control signal to a particular device is off, then the signal can still be sent by automatically turning on the light for a few moments and then turning it off after the signals have been sent thus to save power.

Another approach for application of this technology in smart homes is completely offloading the data services over the LiFi network. This is because sending control signals to home appliances require very less data, so these signals can be transmitted over the WiFi network while users can experience high quality uninterrupted data over the LiFi network. Of course, the uplink data transfer will be done over the WiFi due to power considerations of the user device. Also, clients require more downloading speeds than uploading speeds. Sensors can be used to detect the position of the users inside the house and turning on the lights only in the vicinity of the user. Handoff techniques will also be required to stay connected while moving from one access point to another.

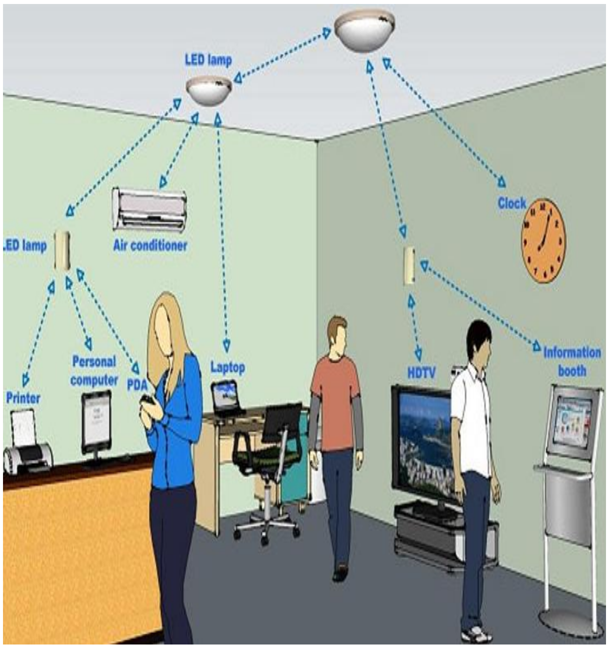

Fig 5. HetNet in a Smart Home

2. Application in Smart City

As mentioned earlier due to the increasing demand of the spectrum & to satisfy current needs, network offloading is required. The concept of smart cities is currently a hot topic in which the public, devices, vehicles, etc. will be connected to a common network. Hence, there will be a huge demand for bandwidth and spectrum efficiency.

The HetNet technology can be used for such huge spectrum requirements, in which streetlights will keep the users connected to the network, find them parking spaces, nearest hospitals, petrol pumps, etc. These services can also be provided at bus stops, railway stations, etc. to notify the user about expected arrival time, traffic, time of travel, routes to reach destination, etc.

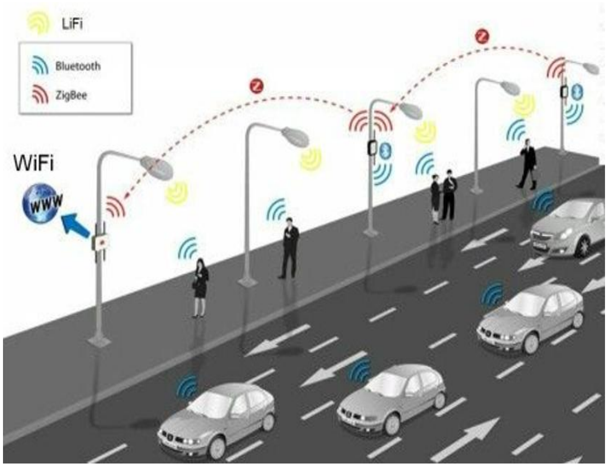

Fig 6. Smart Urban Communication Network

8. FUTURE SCOPE

Firstly, both technologies (i.e. LiFi & WiFi) will experience further evolution to higher data rates. LiFi allows Gb/s throughput using higher bandwidth, monochromatic LEDs or lasers together with wavelength division multiplexing as well as MIMO. WiFi is currently also upgraded by using more antennas and more bandwidth.

Research is needed to explore potential effects of LiFi data offloading when licensed indoor femtocells and outdoor macrocells are included in the system. The obtained results will yield a complete picture and offer first insights into a practical multi-tiered HetNet under practical illumination constraints. A proper system design must carefully consider the unique illumination qualities and services of individual spaces and applications to achieve the best compromise between VLC performance and illumination needs.

Channel aggregation of Li+WiFi is another interesting challenge. Two models are of interest:

- Aggregating channels from one access technology.
- Aggregating channels from different access technologies.

These can include multiple channels within either RF or optical spectrum. Both approaches can be implemented on different layers of the OSI reference model ranging from the data link to the application layer. Relying on higher layers requires modifying both the client and server sides. Aggregation at lower layers must remain compatible with higher-layer protocols such as TCP, otherwise cross-layer aggregation must be achieved.

User mobility is also an important consideration for the provision of seamless connectivity and is required in order to properly evaluate the performance of the proposed Li+WiFi network.

9. CONCLUSION

The WiFi and LiFi HetNet is a new promising research area. The primary characteristics of both technologies and the possibility for them to coexist has been discussed. A close integration of both technologies enables off-loading opportunities for the WiFi network to free resources for more mobile users because stationary users will preferably be served by LiFi. In this way, LiFi and WiFi can efficiently collaborate. Both technologies together can more than triple the throughput for individual users and offer significant synergies, yielding a combined solution that can adequately address the need for enhanced indoor coverage with the highest data rates needed in the 5th generation of mobile networks (5G). Finally, a roadmap for future research opportunities towards the integration of both technologies has been outlined.

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