An Architecture Design of Auto Channel Switching Unit for Hybrid Visible Light Communication System

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Abstract —The revolution in multimedia devices has promoted indoor wireless communication in the last decades. Wireless fidelity (Wi-Fi) connections have expanded rapidly, and more than 5 billion devices have been connected to Wi-Fi each day since 2013, which causes system overloading. This bountiful usage of wireless devices has consumed an excessive amount of the radio spectrum, and the current standard for wireless communication is not able to provide enough capacity for indoor wireless traffic in the next decade. Wi-Fi currently holds 60% of the global traffic; however, secure communication for the internet of things (IoT) and spectrum congestion are two significant challenges for future communication development. Therefore, an affordable, secure, and fast medium for wireless communication is in urgent demand. It should be noted that the spectrum provided by visible light communication (VLC) can be thousands of times wider than the radio frequency (RF) spectrum. The challenge of spectrum congestion and the urgent demand for a high-speed medium can be solved through the application of visible light for indoor communication. It has been proved that each user can achieve a data rate of hundreds of Mbps in the congestion scenario through the application of VLC. But beside these advantages Li-Fi also have some limitations like unavailability in excess and in low light and also limited coverage due to walls and etc. To overcome these limitations the Wi-Fi and VLC hybrid network can be a good solution to continue using privileges of both technologies. A lot of research has been done to introduce a numerous techniques for such hybrid network but we are proposing Auto channel switching unit in this system which will be responsible for shifting and sharing data traffic on both Li-Fi and Wi-Fi channel.

Index Terms—Visible light; Wi-Fi; Auto channel; Indoor; RoF

I. Introduction

A. Overview

First transmission of sound on a beam of light was demonstrated by Dr. Alexander Graham Bell and his assistant Charles Summer Tainter by developing photo-phone around 1880's. [1]. Infrared Association (IrDA) was formed in 1993. In 2001 Free space optics device RONJA (Reasonable Optical Near Joint Access) was developed by Czech Republic. In 2007 NEC developed VLC and was showcased by Fuji television and same year Mostafa Afghani research assistant of Prof. Hraald Haas send data using light signal. Integration of visible light communication with indoor GPS was successfully demonstrated in Japan in 2010. In 2011 Dr. Harald HAAS presented his invention "Li-Fi" in his TED global talk [2]. In order to get high data rates and make electromagnetic free environment universities and industry is supporting researcher to work on Visible light communication [3], [4]. In Li-Fi system on transmitter side LED (light emitting diode) is used as Access Point (AP) and PD (photo diode) at receiver converts received light to electrical signal. Li-Fi can be used on RF prohibited places like in industries and also in medical applications without any health concerns. Li-Fi spectrum is 10,000 times more than RF and also can transfer data in gigabits. But beside these advantages there are few drawbacks of Li-Fi. For example presence of sun light, less coverage area as compared to Wi-Fi and uploading issues. Currently infrared is being used for uploading but it need line of sight with user so it's not convenient in many cases. A lot of research has being going to integrate both technologies LiFi and Wi-Fi to get privileges of both of them. LiFi can provide huge spectrum and high speed while Wi-Fi can provide large coverage area [5]. Ref [6]-[9] shows that the hybrid network can provide greater throughput as compared to alone Wi-Fi or Li-Fi network and researchers introduced many load sharing techniques in hybrid network, mostly work was done on simulation level. As load balancing in hybrid network is a challenge so some work in [10] & [11] has been done to highlight this issue and introduce few schemes. Mostly research in this area is done on load sharing to improve performance of data rate in hybrid network [11]-[13].

B. Visible Light Communication (VLC)

Visible light communication can be integrated with other wireless technologies like radio frequency, Infrared, Bluetooth, and WiMax. As in the previous section, we mentioned that visible light communication has some limitations in different situations, so to overcome these limitations we can make use of few currently existing technologies and make a hybrid system. We can have the privileges of existing technologies along with visible light communication. Our goal is to propose a connectivity solution for hybridized wireless system.

C. High Speed Hybrid System Concept

Two or more standards and systems are integrated into a hybrid system. Hybrid technology adds flexibility by

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using a combination of the most efficient technologies to meet the requirements of the modern world. Each technology has advantages and disadvantages, and a hybrid system helps to overcome the cons of one technology with the pros of another technology. A prime example is combining wired and wireless technologies. A typical hybrid device provides network connectivity to both wireless and wired devices. Our wireless router is the most common example of a hybrid device that provides optical, Ethernet, and RF connectivity. Hybrid connectivity enables one to enjoy the privileges of all the systems that are integrated. For example, if someone requires fast file sharing, he can use an Ethernet connection with a router, and in the case of video streaming, he can switch to a wireless connection.

Recently almost every industry is introducing hybrid technology due to the number of benefits those can be achieved by utilizing currently existing technologies. The proposed hybridized system also solve backhaul and uplink issue of visible light communication with the integration of RF technology.

The integration of radio signals into optical technology offers numerous benefits and has been the focus of industry and researchers for three decades. Applications such as mobile network backhaul, indoor communication systems, and ultra-broadband wireless networks use microwave photonics hybrid technology. Low loss and broad bandwidth make the optical medium ideal for high traffic systems. Hybrid fiber radio (HFR) is an essential technology for wireless broadband and optical network integration, and it offers a wide range of services and applications.

D. Cost Benefit Analysis

Cost benefit is one of the advantages we get from hybrid systems. As hybrid systems are the combination of currently existing technologies, so the cost of hybrid systems are always low as compared to manufacture or introduce some totally new standalone technology. Indoor optical cables reduce the cost of whole indoor network by eliminating router and repeaters from network which are used in the deployment of Ethernet. Secondly for uplink hybrid system will use Wi-Fi technology and currently every communication device have ability to access Wi-Fi through built-in Wi-Fi module. Using Wi-Fi for uplink can reduce the cost because users are not going to buy extra infrared plugin devices for uplink through their devices.

E. Main Contributions

- Propose Auto channel switching unit architecture for hybrid visible light communication.
- FPGA based behavioral simulation.

In section 2 Auto channel switching unit is proposed and architecture design is presented. Simulation results are presented in section 3. Conclusion of research is in section 4.

F. Problems Undertaken

A wireless communication network is incomplete without the facility of uplink communication. In light fidelity (LiFi), uplink requires that the transmitter and receiver maintain a directional link during transmission. It can significantly reduce the overall throughput of the network if both devices are constantly moving. So, in Li-Fi, the way in which the uplink traffic in a network will be operating is also a challenge. The RF and infrared (IR) can be considered for transmitting uplink data in Li-Fi networks; nevertheless, more innovative ideas are required to solve the uplink issues in Li-Fi networks. The three main hindrances to visible light uplinks are (a) the possibility of interference with the downlink signal; (b) line of sight issues between TX and RX; and (c) power consumption in both scenarios if uplink is through a device or a plugin device for uplink communication, as not all the devices currently support an IR module, which is the current solution in the market. A feasible solution is the hybridisation of the visible light network with RF.

I. Proposed Solution

The proposed hybrid system in this dissertation provides uplink connectivity through Wi-Fi. Also, the auto channel switching unit (ACSU) shifts the downloading traffic to Wi-Fi in the absence of a visible light channel. As Wi-Fi is easily accessible via all devices and there is also no issue with LoS in Wi-Fi, it will be a better solution than IR.

II. Proposed Auto Channel Switching Unit (ACSU)

Auto Channel switching unit is the main block in this hybrid system. It is responsible for routing traffic on desired channel. The block diagram of Hybrid system with ACSU is shown in Fig. 1. The common function of this unit is to handle Li-Fi downloading traffic and Wi-Fi uploading traffic. Moreover providing full duplex Wi-Fi communication in case when Li-Fi is not available is also handled by ACSU unit. Access point selection in heterogeneous network is more complicated as compared to homogeneous [14].

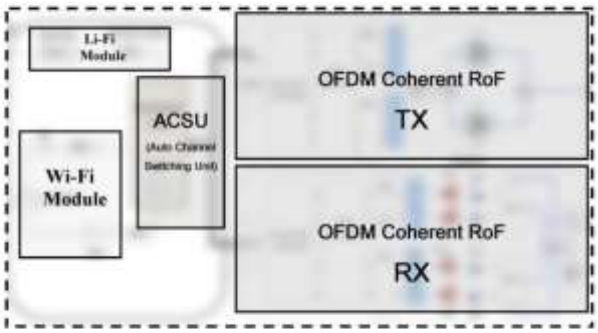

Fig. 1. Hybrid system with auto channel switching unit

A lot of research is going on for load sharing in heterogeneous network and few are using same methods of homogeneous network [5] & [10]. Ref [9] proposed a novel APS method for hybrid Li-Fi and Wi-Fi network by using fuzzy logic. ACSU is good platform for practical use of such techniques. As in load balancing field of area is still need time for getting mature, so we started ACSU unit with simple rules of sharing and switching of traffic. Fig. 2 shows and overview of ACSU. In proposed ACSU the traffic will be routed based on Algorithm 1 Algorithm 2 and Algorithm 3.

Algorithm 1 WiFi/ Light Signal Routing

1: **function** ESTABLISH CONNECTION (A, p, q, r)
2: Search Device
3: **if** Device Free **then**
4: **if** If WiFi Device Free **then**
5: Connect WiFi
6: **else if** LiFi device free **then**
7: Connect LiFi
8: **end if**
9: Send Conformation
10: **else**
11: Check Again Go to Step 3
12: **end if**
13: **end function**

A. Scenario 1

One of the biggest Visible Light Communication bottle neck is the working of VLC in the presence of sunlight or very low light. As sunlight is big issue for Visible light communication and in dark areas where there is no or very low light is available also need some alternate so external light sensor data can be used for switching downloading traffic to Wi-Fi channel as shown in Algorithm 2.

Algorithm 2 LiFi Routing

1: **function** CHECK LIGHT SENSOR (Light Indoor lx)
2: **if** Sensor Available **then**
3: **if** Light Indoor lx < 10 lx or > 77000 lx **then**
4: Shift Download Wifi
5: **else if**
6: **then** stay LiFi
7: **end if**
8: Send Conformation
9: **end if**

B. Scenario 2

Second common scenario of Wi-Fi failure or conjunction is lack of bandwidth when number of user increases. ACSU can differentiate users according to their bandwidth need. Table I shows some bandwidth needs in different scenarios. Channel traffic can be balanced according to the user's bandwidth as in Algorithm 3.

Algorithm 3 User Switching

1: **function** CHECK LIGHT Application Bandwidth (Light Indoor lx)
2: **if** User Available **then**
3: **if** download bandwidth required >2Mbps **then**
4: Shift Download LiFi
5: **else if**
6: **then** stay WiFi
7: **end if**
8: Send Conformation
9: **end if**

A. System Setup

Fig. 1 shows an over view of ACSU based indoor hybrid system. The Li-Fi and Wi-Fi AP's are connected with optical back-haul network FTTH. Li-Fi AP is a large lamp with LEDS in it for transmitting data and user's devices are having Photo Diode. Each Li-Fi area of coverage is limited to a certain distance depending on the power of LED and AP's near windows will also get some issues in coverage due to outside light and due to shadows optical signals can be blocked. So the Li-Fi channel impulse response can be modulated as equation from Ref. [17].

$$H_{\mu a}(f) = \begin{cases} \big(H_L + H_D(f)\big)H_F(f), & LoS\ not\ blocked \\ H_D(f)H_F(f), & LoS\ blocked, \end{cases} \tag{1}$$

H_L = path loss of a LoS channel, $H_D(f)$ = channel gain by multipath propagation, $H_F(f)$ = Front end device frequency response. Equation 5 from Ref. [19]

$$H_L = \begin{cases} \dfrac{(m+1)A_p x^2}{2\pi(z^2 + h_w^2)sin^2\Theta_F} T_s(\theta)\cos^m(\Phi)\cos(\theta), & \theta \le \Theta_F \\ 0, & \theta > \Theta_F \end{cases} \tag{2}$$

m = Lambertian index, Ap = Photo diode Physical area, z = Horizontal distance from Li-Fi AP, h_w = Room height, Φ = angle of irradiation, θ = angle of incidence to Photo Diode, Θ_F = receiver half angle, $T_s(\theta)$ = Optical fiber gain, x = refractive index

ACSU will first check the availability of channels as shown in Algorithm 1. An external sensor data can be used for this process. For simple scenario we can assume the MAX 77000 LUX (Max light for reading) and min 10 LUX (parking area or bedroom low light scenario).

TABLE I: BANDWIDTH FOR DIFFERENT APPLICATIONS

No#	Application	Mbps
1	E-mail	0.4
2	Web Browsing	0.4
3	HD Video Streaming	4
4	Audio Streaming	2
5	Online gaming	4
6	Video call	0.3
7	Audio call	0.03

After passing this stage then ACSU will make use of Algorithm 2 the check the bandwidth of channel. As in case of max users in both Li-Fi and Wi-Fi AP's then the ACSU will distribute users according to channel data rate. Users can be shifted to another channel according to the data rate requirements.

The data rate between transmitter and user can be expressed by equation as in [17]

$$R_{\mu,a}^{(n)} = B\log_2\left(1 + SINR_{\mu,a}^{(n)}\right) \tag{3}$$

Handover time in an indoor scenario is in milliseconds (ms) [17] and modeled in Poisson random process [18]. According to [17] & [19] the PMF probability mass function of hand over time is expressed by following Equation from Ref. [17].

$$P_r(t_{ij} = x) = \frac{\zeta_{ij}^{x} e^{-\zeta ij}}{x!}, x = 0,1,2\ldots \quad (4)$$

t_{ij}= overhead switch from AP (i) to AP (j), ζ_{ij}= expectation of overhead

Handover issue is out of the scope of this work but Reference [19] proposed some handover techniques which can be used in future in hybrid systems. Algorithms are implemented in 4th step of table. Further the data traffic will be routed accordingly. Fig. 4 shows the front end of integrated Wi-Fi and Li-Fi system.

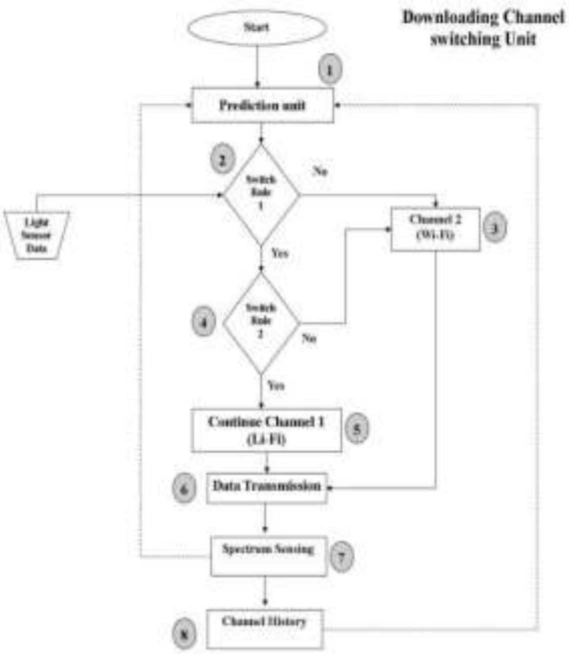

Fig. 2. Auto channel switching unit flow table

III. Simulation

The main work of Auto channel switching unit is to switch the data traffic on either of two channels, Wi-Fi or LiFi. In order to demonstrate this we can use FPGA as it's easily programmable for such purpose. As uploading channel is totally rely on Wi-Fi but downloading channel is controlled by auto channel switching unit. The downloading traffic can be switched by using different algorithms and discussed in previous session and in Table I.

We used FPGA Virtex-7 VC707 Evaluation kit for Auto channel switching unit simulation Fig. 3. A 32-bit signal (sw_in_1) is feed in the demux as shown in Fig. 4. The Signal was switched to one of the channels, sw_out_1, and sw_out_2 which can be assumed as Wi-Fi and Li-Fi channel. The signal was switched to one of the two outputs sw_out_1 or sw_out_2 via algorithms, and in this simulation, we assume the simple scenario that if the Li-Fi channel is Off, then the signal will be switched to Wi-Fi channel. Fig. 5 shows behavioral signal simulation result. We can see when the ctrl signal is zero the data traffic flows through channel sw_out_1 and the data traffic is switched to sw_out_2 when ctrl signal 1.

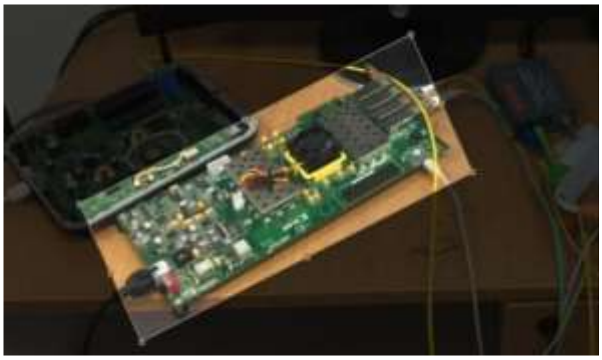

Fig. 3. Virtex-7 Evaluation Kit

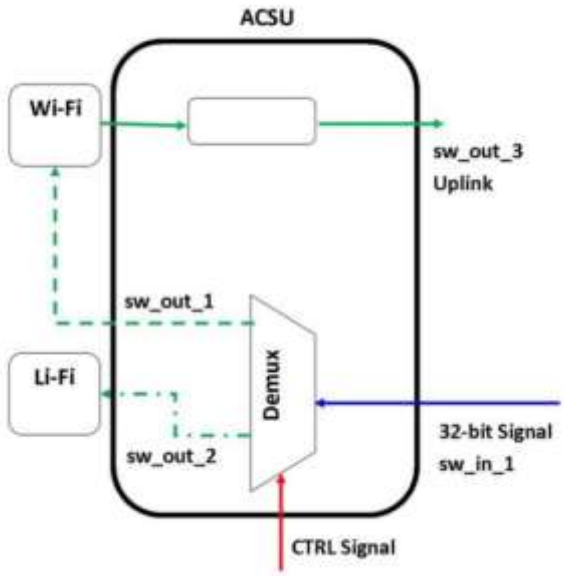

Fig. 4. Auto channel switching unit Architecture

Fig. 5. Behavioral Simulation

IV. Conclusion & Future Work

There are some of the factors we need to consider for analysis. (a) Is the solution practical? (b) Do we have the technology now? So the answers can be YES. The solution provided for backhaul connectivity is by using OFDM coherent radio over fiber technology and all these three technologies are currently available and also implemented in different areas. Secondly the technology proposed for ACSU (auto channel switching unit) is also available even though there is a need of integration of some technologies but due to the advancement in FPGA and other ASIC devices it's possible to bring the concept of ACSU (auto channel switching unit) for practical use in future.

Auto channel switching unit architecture was presented and FPGA was used to demonstrate a simulation for clarify the concept of Auto channel switching unit. ACSU plays vital role for future hybrid network as by using this unit we can take privileges of RF and visible light communication systems. In future FPGA can be used as ACSU and by connecting with visible light and Wi-Fi system a complete demonstration of hybrid network can be done.

Researchers are already conducting future sixth generation (6G) and seventh generation (7G) research work, and according to some predictions, 6G will be an integration of satellite and optical networks, which will provide ultra-high speeds and a large flow of data communication. The proposed system can also handle the traffic for future hybrid networks, and with some system-level modification, this system can provide direct home broadband connectivity to broadband satellite networks. With regard to the ACSU, there should be a move from a system level towards a circuit level, and circuits and devices should be designed and made applicable in real indoor scenarios

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Author R. Kashif conducted the research and design Autochannel switching unit. O. John analyzed the overall data. S. Haider performs the FPGA work. F. Lin supervised the work as a supervisor.

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