International Journal of Advanced Research and Development
ISSN: 2455-4030
Impact Factor: RJIF 5.24
www.advancedjournal.com
Volume 3; Issue 2; March 2018; Page No. 1287-1291

A study of development of wireless networking by light control system

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Abstract
The lack of wireless spectrum in the radio frequency bands has led to a rapid growth in research in wireless networking using light, known as Li-Fi (light fidelity). In this paper an overview of the subsystems, challenges and techniques required to achieve this is presented. Overall design framework of the system was introduced and analyzed in detail, which contained realization of hardware design. The wireless light control system was established based on CC2430-chip of Texas Instruments (TI). In this paper, we achieved designing Printed Circuit Board (PCB) for sensor nodes as end device and coordinator and also wrote C codes in IAR embedded workbench development tool to form wireless network. Test results of system show that lights on end device or router in wireless sensor networks (WSN) can be controlled by another switch on coordinator, which achieved remotely wireless intelligence light control.

Keywords: wireless light control, PCB, WSN, development tool, wireless network, wireless intelligence

Introduction

With the emergence of the internet of things, the principles that gave rise to the internet are now leading to a new kind of network of everyday devices, an "Internet-0" [1]. As a new short-range wireless communication technology, aims at solving the function of internet among different hardware devices, which have powerful potential applying in intelligence control [2] such as industry, medical and home. Wireless data communication has become an essential utility in our private and business lives. There are more than 7 billion smartphones primarily used for personal communication. There is a sharp increase in the number of wearables such as smart watches health trackers and digital glasses. The latter will drive new applications around virtual reality (VR), augmented reality (AR), high definition video streaming and Industry 4.0. In the future, there will also be 100 billion internet-of-things (IoT) devices that will underpin our smart homes and smart cities. Currently, all these digital wireless services use radio frequencies which are part of the wider electromagnetic spectrum. However, the lower frequency bands those are easy to use and have desirable propagation properties already have multiple uses. Consequently, there is very little spare resource to support the exponential growth in demand. The wireless community is working on multiple solutions to enhance wireless data transmission capabilities. For example, the new Wi-Gig (wireless gigabit) systems, defined in IEEE 802.11ad and revised in 802.11ay, operate in the 60 GHz region and have access to around 14 GHz of bandwidth in the U.S.A. However, Wi-Gig and other mm-Wave (millimeter-wave) radio frequency (RF) solutions (including the newest version of Wi-Fi (wireless fidelity), 802.11ax) all exhibit similar challenges. For an RF link, the path loss is proportional to the square of the carrier frequency, and propagation becomes line-of-sight (LoS) or almost LoS. This means that moving wireless systems from the now 3 GHz region to the 60 GHz mm Wave region will incur an additional path loss of 400, or 26 dB. Therefore, the high path losses along with the limited signal transmission power constraints require cells to be smaller, and beam steering to dire energy from transmitter to receiver. In addition, the reliable coverage achieved with conventional cellular systems is much more difficult due to the LoS nature of the communications channel. There has been good technical progress to create the systems required to achieve this, with demonstrations at 30 GHz, and 60 GHz [1]. However, it is clear that these systems are complex. Furthermore such high data capacity system does not easily provide the reliable, ubiquitous coverage that third generation (3G) and fourth generation (4G) cellular systems can deliver. The optical spectrum offers a bandwidth which is many orders of magnitude greater than that the RF spectrum can offer. The visible and near infrared (IR) regions together are 2600 times larger than the 0–300 GHz RF spectrum. This spectrum is unlicensed and subject only to eye-safety regulations. Light emitting diode (LED) and laser sources are readily available across much of the spectrum, as are photodiodes to act as receiving elements. This makes optical wireless communication (OWC) systems, which includes the IR region, a potentially attractive medium for wireless communications [2].

Review of literature

In addition to these cm-range links, a number of IR demonstration networks and systems concepts have been reported. Kahn and co-workers demonstrated a limited system operating at 50 Mbit/s [10], as well as introducing angle diversity concepts [11]. Imaging [10] and holographic [12] receiver designs have also been developed. Demonstration networks, operating at rates of up to Gbps have also been reported. Reference provides a recent review of the field. Eye safety regulations have led to a constraint on the amount of maximum emission power of the IR transmitter. Consequently, this has resulted in a limited link budget for IR networks. Therefore, it is not possible to cover typical indoor spaces with a single access point (AP) and achieve high data rates. Such rates, combined with good coverage require multiple transmitters and receivers, which leads to complex systems that do not scale well as data rate increases. Using a limited number of narrow beam optical links within a room, and beam steering to direct these to terminals allows data rates to scale. Furthermore, using light from optical-fibre systems combined with beam steering has led to the highest rate indoor wireless links (RF or optical) demonstrated thus far. With the emergence of energy-efficient white-LEDs, solid state lighting (SSL) is gaining great popularity in the lighting industry. It is expected that LED-based lighting infrastructures will replace all conventional lighting infrastructure in the coming decades. This trend provides a unique opportunity to create novel combined lighting and wireless communication networks. The use of LEDs for wireless data transmission is known as visible light communication (VLC) which was first introduced by Nakagawa. The wireless networking using VLC is referred to as LiFi, first introduced in 2011. During the last 10 years, there have been significant advancements in this field. The link data rates have increased three orders of magnitude from 10 Mbps in 2006 to 10 Gbps in 2016 [22, 23], and in 2011, the Institute of Electrical and Electronics Engineers (IEEE) published the first standard for short-range VLC applications. In the last 5 years, there has been a significant shift from point-to-point, static VLC systems to complete LiFi cellular systems. As a result, now there is a LiFi ‘topic interest group’ in IEEE 802.11, and this has now progressed to an IEEE 802.11 Study Group.

While IR networking requires dedicated infrastructure, VLC requires modification of an existing lighting system, thus offering potential cost-savings. Crucially, as detailed later in the paper, the level of illumination required for human users leads to a link margin many orders of magnitude superior to that in IR systems, enabling high data-rates with good coverage using simple components. These advantages, and others detailed elsewhere in the paper, have led to the rapid growth in this area. This paper introduces the elements required and the challenges faced in creating Li-Fi networks. This paper does not attempt to provide a comprehensive overview of the field of VLC and Li-Fi (for these, the reader is referred to recent review papers and references therein).

System Scheme

The architecture of system including hardware and software were analyzed and discussed as follows. Figure 1 is the system scheme applying in wireless light control network. There are mainly three types of sensor nodes to form a wireless network, which are coordinator, router and end device. Wireless communication was achieved by using CC2430-chip named module [3]. Each coordinator is a control centre, which is responsible to manage the whole network. Light module as end device or router can send signals to coordinator or another router. After achieving lower computer programming, coordinator processed data from routers and end devices. It means that the coordinator is similar to a switch which aims at controlling lights by wireless way in network. Router plays the role of information transmission, which must be a Full Function Device (FFD) with function of sending and receiving data. End device can be a Reduced Function Device (RFD), which is only used for sending or receiving data. To manage the whole network and process complicated data, coordinator usually is connected to computer as control centre via RS232 serial communication port. Through the control centre, we can easily know the condition of network and handle problems happened at any time we need. In this paper, wireless control was mainly carried out in hardware system by lower computer programming with c codes. Management software with tree structure network [4] as control centre with graphic user interface (GUI) will be the next aim we consider.

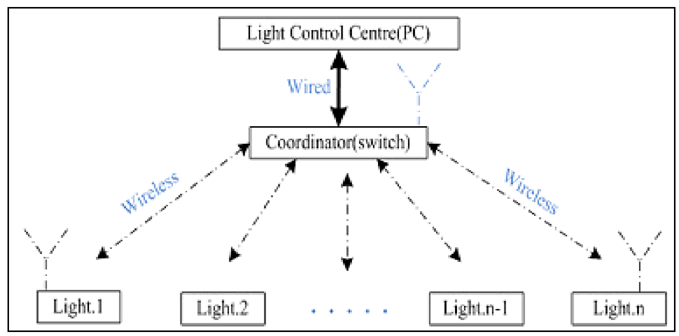

Fig 1: System scheme

Li-Fi attocell networks

Fig. 2 illustrates the concept of a LiFi attocell (LAC) network. The room is lit by a number of light fixtures, which provide illumination and an optical AP to users within the illumination pattern of the light. The illumination can be modulated at high rates, not visible to the occupants of the room, providing an optical downlink. Power and data can be provided to each light fixture using a number of different techniques, including power over Ethernet (PoE) and power line communication (PLC). An optical uplink is implemented by using a transmitter on the user equipment (UE), often using an IR source (so it is invisible to the user), and a receiver close to the light fixture. Each of these light fixtures, which at the same time act as wireless Li-Fi APs, create an extremely small cell (an attocell), which can provide high bandwidth density due to the highly confined illumination from an individual light source. The balance of light fixtures that contain APs and those that provide only illumination is determined by the requirement of the network, but potentially all light fixtures can contain APs. Compared to a single AP wireless hot-spot system, such cellular systems can cover a much larger area and allow multiple UEs to be connected simultaneously. In cellular networks, dense spatial reuse of the wireless transmission resources is used to achieve very high data density - bits per second per square meter (bps/m2). Consequently, the links using the same channel in adjacent cells interfere with each other, which are known as co-channel interference CCI. Fig. 3 illustrates CCI in an optical attocell network. Advanced CCI mitigation techniques often require that these multiple Li-Fi APs are operated by means of a centralized control mechanism such as the ‘hypervisor’ within the server of a software defined network (SDN). The main tasks of the central controller are to adaptively allocate signal power, frequency, time and wavelength resources. Other functions of central controller include achieving multi-user and the handover process from cell to cell when terminals move.

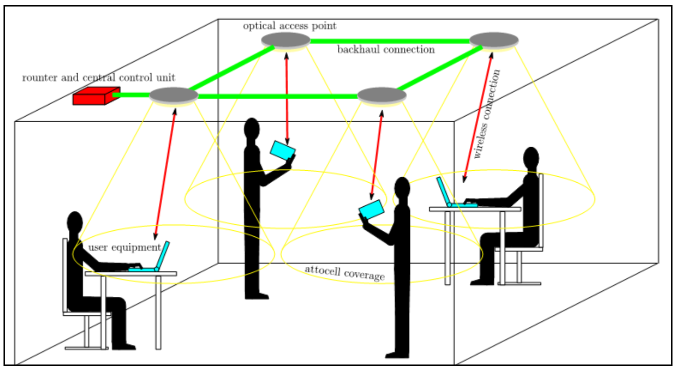

Fig 2: Concept of Li-Fi attocell network

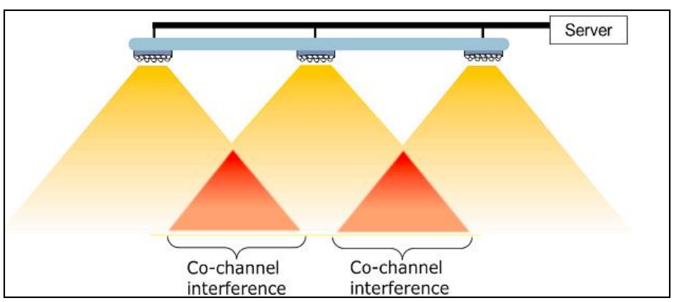

Fig 3: CCI occurs in the region where the same light spectrum of neighboring APs overlaps, and when these APs use the same modulation bandwidth for data encoding.

Key light control circuit

For developing the whole light control system, all circuits related to the network must be designed and tested. To finish this part work, Protel DXP 2004 is a good design tool for us to choose. The next procedure we will demonstrate the global design process of the hardware system. All parameters such resistors and capacitors were set precisely before according to circuit function by us. Figure 4 is the key light control circuit we have designed, which mainly contains JPx (JP1 and JP2) module and JTAG module. JP1 and JP2 are slots of light module with CC2430-chip which has dual lines with entire 40 pins. For making circuit enable to be programmed, JTAG module with 10 pins is used for meeting design requirement. S8 is the reset switch of light module. Remaining pins in circuit are linked to other correlative circuits we used in system. Figure 5 is the switch control circuit, which aims at implementing wireless control. This part circuit includes six switches, one capacitor and some resistors. S1 named UP and S5 named RIGHT are applied in intercommunication among different sensor nodes. According to different voltages on switch node, CC2430- chip as MCU can detect which switch is pressed. When a sensor node joints into wireless network, switch S5 will be used. In contrast, if a sensor node exits from wireless network, S5 will be enable again. S1 is control switch on coordinator, which controls other lights on end device or router. By making use of this approach, lights on different end devices and routers can be controlled by switches on coordinator. Printed Circuit Board (PCB) of the whole circuit will be given in next section and test results will be analyzed as well.

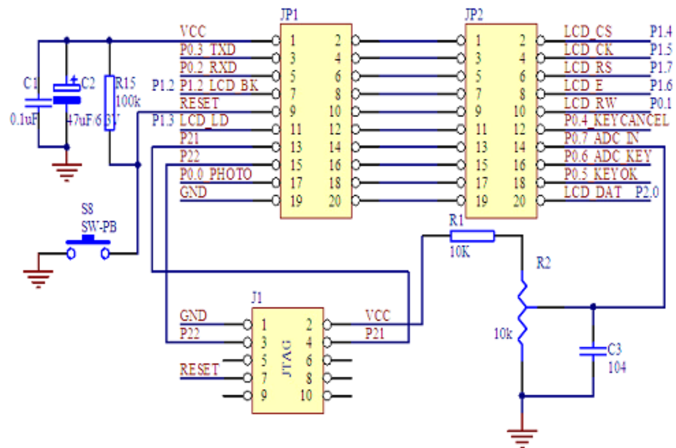

Fig 4: Key hardware circuit of light control

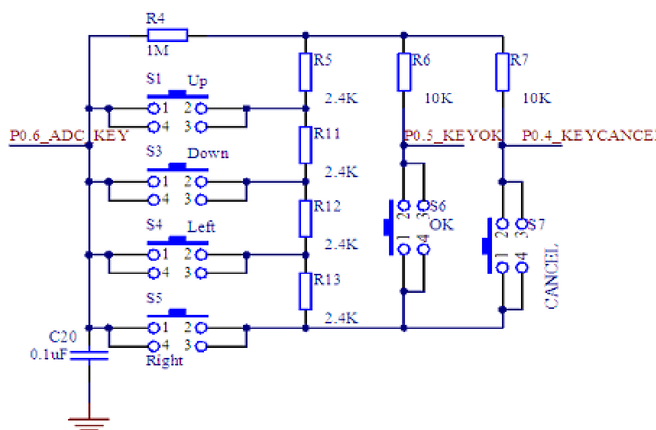

Fig 5: Switch control circuit

Point-to-point link level systems

1. Transmitter

Visible light is typically generated by a white LED, or a combination of red green and blue (RGB) LED emitters. Low cost white LEDs use a blue Gallium Nitride (GaN) emitter that excites a yellow inorganic phosphor. Direct blue emission from the GaN device combines with the broad yellow emission to create white light. Although the modulation bandwidth of white LEDs far exceeds that of traditional lighting sources, the large capacitance of the large area emitters and the slow response of the yellow phosphor limit the 3-dB bandwidth of white LEDs to a few MHz. By removing the signal emitted from this yellow phosphor at the receiver side, the 3-dB modulation bandwidth can be increased to the range of 10–20 MHz.

LEDs designed for lighting are relatively robust and can be driven by a voltage source with the addition of some resistance to limit the driving current. A bias-T is often used to combine the alternating current (AC) data modulation with a direct current (DC) bias that creates the desired illumination level and ensures that the LED is always driven with a net positive signal. There have also been investigations into improving the emitter bandwidth by modification of the driving circuitry. Analogue pre-equalization and fast LED driver circuits as well as resonant equalization have also been investigated. The LED device bandwidth can be altered by the use of different structures, notably by decreasing the size of the LED. Micro-LEDs, with active areas much smaller than those used in LED lamps, can show bandwidths of several hundred MHz, whilst emitting mW of optical power. A series of investigations has been undertaken, with the fastest reported data rates for such single LEDs exceeding 8 Gbps which was only limited by the receiver. If this limitation can be overcome, it was shown in Ref. [60] that a single GaN micro LED is capable of transmitting at speeds of 11 Gbps. The colour conversion phosphors used in commercial devices are not optimized for bandwidth. There has been work on a number of fast colour converting materials, including using organic, semiconductor, and perovskite materials. The tradeoff between efficiency of conversion and speed, and the effect on overall device efficiency has yet to be investigated fully.

2. Receiver

Light is received and concentrated onto a PD using an optical element. The PD then converts this to an electrical signal which is pre-amplified and then fed to data recovery and signal processing. In some cases, an optical filter is used to restrict the spectrum of light that is fed to the receiver. The bandwidth, sensitivity and area of the detector/ preamplifier pair determine the overall performance of the receiver, and ultimately the quality of the communication channel. A small detector is desirable as it can have low capacitance and high bandwidth, but a doubling of the detector area increases the power received by the same factor, and is equivalent to an increase in sensitivity. Therefore, it is not straightforward to determine the optimum receiver design.

3. The optical wireless channel

The communications channel consists of the path taken from the electrical signal that modulates the data onto the transmitter to the electrical signal at the receiver. The quality of the received signal is measured by the signal to noise ratio (SNR) for a single channel. In the case of a network, the signal to interference-plus-noise ratio (SINR) is used to characterize the communication link.

Conclusion

Wireless light control network and also have given the test results of the system. We clearly see the implementation of wireless light control. Based on our development system, it is speculated that the present study is very helpful to design a large wireless network including more end devices and routers applying in real projects. However, there are still some problems not solved in our system such as how to manage the whole network with software when more end devices and routers included. And our future aim is to design a light control system including management software. A crucial aspect of this is the allocation of a new spectrum for additional capacity. Li-Fi networks, using visible light communications, have the potential to provide this with high capacity in the environments with very high user and device density. This paper highlights the challenges of providing wireless communications networks using light, including interference and deployment strategies, and introduces a framework for determining the key parameters in their performance. Specifically, it has shown that an integrated and holistic approach is needed to address these challenges. Optical devices, and their arrangement in an optical transceiver, affect the performance of networking techniques such as interference mitigation algorithms and multiuser access techniques.

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