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LiFi : The Next Generation WPAN Technology

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ABSTRACT

Recent years, the idea of ubiquitous computing or networking is attracting much attention. The wireless communication technology has demonstrated tremendous growth, and the numbers of mobile users also have increased rapidly over the past decade. The exhaustion of frequency resources has been a problem and utilized frequency bands are becoming highly allocated. As a method of realizing high speed wireless networks, the optical wireless communication systems are capturing the spotlight, on the other hand. Meanwhile, LiFi(Light Fidelity) based on white LEDs has emerged as an eco-friendly IT green technology using unregulated THz visible light spectrum in provision of both lighting and wireless access. In this paper, the key ideas on visible light communication (VLC) have been reviewed in relationship with optical wireless communication. The standardization activities and the applications are summarized. It also deals with the technical specifications including channel model for constructing a VLC PHY layer prototype.

Keywords: LiFi, Visible light communication, Intensity modulation with direct detection (IM/DD), Discrete multi-tone modulation

I. INTRODUCTION

Lighting is the ubiquitous infrastructure, which can be multi-functional whose second function is visible light communication (VLC) [1]. LiFi (Light Fidelity) is an IEEE international standard of visible light communication (VLC) system [2], [3], [4]. The light beam is used as the physical layer of this wireless communication link in Wireless personal area network (WPAN) [5], [6], [7]. The compound annual growth rate (CAGR) of mobile data usage per month is hovering high enough nowadays. It can be apprehended that mobile data demand will exceed available capacity by 2013 and will reach a deficit by 2014. At the same time the network spectrum efficiency of state-of-the-art cellular systems exhibits a saturating trend because the available radio frequency spectrum is limited. In addition, it is unlikely that significant new spectrum is made available for mobile communications. As the spectrum crisis gets more serious, the shouts for more spectrum are getting louder, and the next option is to either increase the spectrum efficiency of wireless systems, or to utilise the free, vast and unlicensed infrared and visible light spectrum. Meanwhile, VLC is drawing much attention as a potential solution to short range wireless access using OFDM technique [8], [9]. Through its Light Fidelity technology, the VLC is envisaged to answer to the higher demand of mobile internet connectivity, to the congestion in radio networks and to issues raised by the electromagnetic pollution. LEDs, which are the predominant choice for VLC-transmitters, send data by flashing light at speeds undetectable to the human eyes [10], [11]. A flickering light can be incredibly annoying, but has turned out to have its upside, being precisely what makes it possible to modulate light intensity for wireless data transmission. The intensity-modulated data can be detected via photodiode, CCD or CMOS sensors etc.

The rest of the paper is organized as follows. In Section II, a comparison between light wave and radio wave are studied. Section III discusses LED as a choice for LiFi technology. Section IV and V provides the standardization and applications of LiFi respectively. Methodology and simulation results are discussed in Section VI .and VII. Section VIII concludes the paper.

II. COMPARISON BETWEEN LIGHT-WAVE AND RADIO MEDIA

As a medium for wireless communication, light-wave radiation offers several significant advantages over radio. Light-wave emitters and detectors capable of high speed operation are available at low cost. The light-wave spectral region offers a virtually unlimited bandwidth that is unregulated worldwide. Infrared and visible light are close together in wavelength, and the exhibit qualitatively similar behaviour [12], [13], [14]. Both are absorbed by dark objects, diffusely reflected by light-colored objects, and directionally reflected from shiny surfaces. Both types of light penetrate through glass, but not through walls or other opaque barriers, so that optical wireless transmissions are confined to the room in which they originate. This signal confinement makes it easy to secure transmissions against casual eavesdropping, and it prevents interference between links operating in different rooms. Thus, optical wireless networks can potentially achieve a very high aggregate capacity, and their design may be simplified, since transmissions in different rooms need not be coordinated. When an optical wireless link employs intensity modulation with direct detection (IM/DD), the short carrier wavelength and large-area, square-law detector lead to efficient spatial diversity that prevents multipath fading. By contrast, radio links are typically subject to large fluctuations in received signal magnitude and phase. Freedom from multipath fading greatly simplifies the design of optical wireless links.

The light-wave is not without drawbacks, however. Because light-wave cannot penetrate walls, communication from one room to another requires the installation of optical wireless access points that are interconnected via a wired backbone. In many applications, there exists intense ambient light noise, arising from sunlight, incandescent lighting and fluorescent lighting, which induce noise in an optical wireless receiver. In virtually all short-range, indoor applications, IM/DD is the only practical transmission technique. The signal-to-noise ratio (SNR) of a direct-detection receiver is proportional to the square of the received optical power, implying that IM/DD links can tolerate only a comparatively limited path loss. Often, optical wireless links must employ relatively high transmit power levels and operate over a relatively limited range. While the transmitter power level can usually be increased without fear of interfering with other users, transmitter power may be limited by concerns of power consumption and eye safety, particularly in portable transmitters. The characteristics of radio and indoor optical wireless links are compared in Table I.

TABLE I. VLC vs. RF Communication

Characteristics	**RF communication**	**Visible Light Communication (VLC)**
Spectral availability	Limited, especially in low frequency bands	Unlimited
Spectral Regulation	Highly regulated	No regulation (other than eye safety)
Security of data	Requires encryption	Signal confined by room, better security
Path losses	High	High
Multipath fading	needs spreading or OFDM-like techniques	None (large collector area)
Multipath distortion	High	Only in diffuse indoor systems
Inter-Symbol Interference	Weak	Potentially important to high bit-rate
Electromagnetic Interference	Possible	None
LOS link (Line of Sight)	Possible without LOS	Extremely required due to IM/DD channel
Dominant noise source	Other users	Natural and artificial light, amplifier noise at very high data rates
SNR	Depends on RF signal power	Depends on optical signal power
Detection type	Coherent/Incoherent	Incoherent
Inter-connectivity	Electrical (Cable, PLC) or radio or optical (FTTx)	Electrical (Cable, PLC) or radio or optical (FTTx)
Effect of humans	No evidence, but probably harmful	No evidence
Quality of	Best effort QoS	Best effort

service	in evolution	
Coverage, Distance	Wide, Medium	Narrow, Short
Mobility	Mobile communication typically based on RF	Limited
Power consumption	Medium	Relatively low

To better understand the place of optical wireless (OW) systems in the wireless world, Figure 1 summarizes state-of-the art commercial RF and OW technologies, as well as technologies under standardization by major bodies including IEEE, 3GPP, Bluetooth and IrDA.

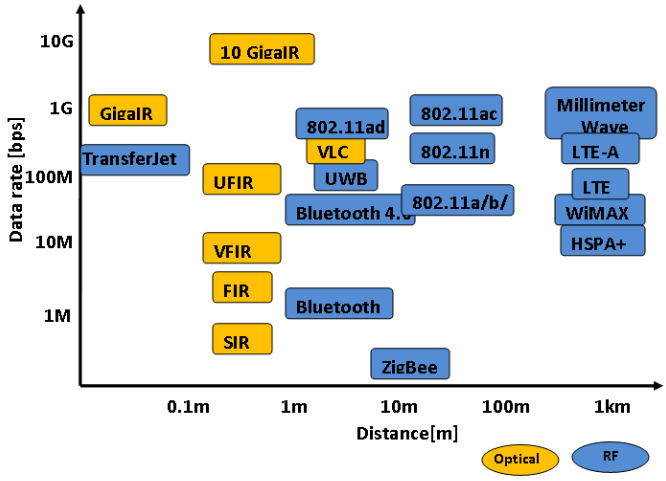

Figure 1. .RF and OW technologies as defined in standards and deployed in commercial products. [10]

Technologies are presented with respect to their area of coverage, ranging from a few centimetres in personal communications to over 1 km in outdoor communications, and the data rates they attain, including low rate legacy links under 1 Mb/s (Bluetooth and older IrDA systems). Interference cancellation schemes between UWB System and LiFi technology are discussed in WPAN [15], [16], [17]. Clearly, contemporary OW links provide channel rates up to 10 Gb/s, which directly compare to the ones of optical fibers. At the same time, commercial OW links operate at link distances that are challenging to attain in RF (3G/4G) and millimeter-wave (60 GHz) broadband communications.

III. LEDS–THE PREDOMINANT CHOICE FOR LiFi

Today's lighting systems operate on three primary technologies: incandescent, florescent, or solid-state components. It is widely believed that solid-state illumination (lighting that utilizes LED technology) will dominate the next lighting generation. LEDs offer incredible advantages compared to their predecessors - incandescent and florescent tubes in terms of long life expectancy, high tolerance to humidity, low power consumption, and minimal heat generation lighting.

LED is a very green technology. Since very little heat is produced, it can reduce interior temperatures by 1 to 2 degrees, thus lowering air-conditioning costs and carbon dioxide emissions. LED lighting is also much safer for the living and working environment because it is mercury free and does not produce IR or UV rays which can be harmful to human eyes and skin [10].

LED's are extremely cheap and because most LED's emit light from a sufficiently large surface area that they are generally considered eye-safe. Typical packaged LED's emit light into semi angle (at half power) ranging from approximately 10-30 degrees, making them suitable for directed transmitters. Non-directed transmitters frequency employ multiple LED's oriented in different directions. Potential drawbacks of present LED's include: 1) typically poor electro-optic power conversion efficiencies of 10-20 % (though new devices have efficiencies as high as 40 %), 2) modulation band widths that are limited to tens of MHz in typical low-cost devices2, 3) broad spectral widths (typically 25-100 nm), which require the use of a wide receiver optical passband, leading to poor rejection of ambient light, and 4) the fact that wide modulation bandwidth is usually obtained at the expense of reduced electro-optic conversion efficiency.

Laser diodes (LD's) are much more expensive than LED's, but offer many nearly ideal characteristics: 1) electro-optic conversion efficiencies of 30-70 %, 2) wide modulation bandwidths, which range from hundreds of MHz to more than 10 GHz, and 3) very narrow spectral widths (spectral widths ranging from several nm to well below 1nm are available). On the other hand it is a great concerned issue with LD's to accomplish eye-safety as per the allowable exposure limit set by the International Electro technical Commission (IEC) standards.

IV. STANDARDIZATION ACTIVITIES

The incorporation of VLC components into everyday technology is being investigated by a number of universities, corporations and organisations worldwide, and has already resulted in the creation of the Japan Electronics and Information Technology Industries Association's JEITA standards (2007) for a "visible light ID system", and a Specification Standard in 2008 by the Visible Light Communications Consortium (VLCC) - as a result of its joint cooperative agreement with the Infrared Data Association (IrDA). The VLCC member includes NEC corporation, Panasonic Electric Works, Nippon Signal, Toshiba corporation, Samsung Electronics, NTT DoCoMo, Casio Computer, Nakagawa Laboratories, Sumitomo Mitsui Construction, Sharp corporation, etc. In Europe, the working group 5 of the wireless world research forum (WWRF) deals with VLC technology as one of next-generation wireless access technology (WWRF website). The WWRF has published a white paper on killer application of VLC, market forecast, and technology roadmap.

In IEEE, Wireless Personal Area Networks working group 802.15 in IEEE 802 LMSC (LAN/MAN Standards Committee) has organized the study group on VLC and the group is now the task group 7 (TG7) (TGVLC website) [1]. In South Korea, the telecommunications technology association (TTA) (TTA website) supports standardization of VLC for Korean standard and international standard.

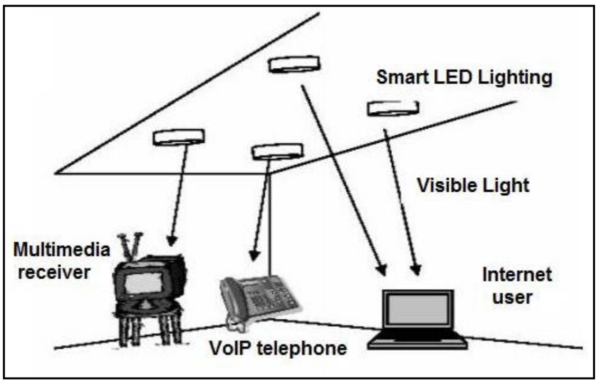

Figure 2. .LiFi using LEDs as access points [11]

V. APPLICATION INSTANCES

Radio and light-wave are complementary transmission media, and different applications favor the use of either one medium or the other. Radio is favoured in applications where user mobility must be maximized or transmission through walls or over long ranges is required and may be favored when transmitter power consumption must be minimized. Light-wave is favored for short-range applications in which per-link bit rate and aggregate system capacity must be maximized, cost must be minimized, international compatibility is required, or receiver signal-processing complexity must be minimized.

VLC is a unique technology that provides an attractive alternative in niche application areas, complementing fiber-optic and RF wireless solutions when they are either too costly to deploy, create undesirable interference, or are not feasible at all. Two mainstream application areas of VLC are last-mile broadband access and office interconnection; both are the business objectives of a number of component and system manufacturers. The plural white LEDs can be employed as internet access points or hot spots, indoor navigation and positioning in homes, labs, offices. Besides these can be spotted as local information points in shops, airports, railway stations, museum etc.. The Figure 2 illustrates such applications. LiFi is typically targeted at being the "last-leg" of the network (Figure 3).Each LED becomes a router of telecommunication, without a saturation of bandwidth so that the Internet-LiFi can be achieved. In such applications, state-of-the-art VLC systems support 10 Gb/s Ethernet, which equals the bandwidth provided by metro fiber optic systems and is significantly higher than the 1.25 Gb/s Ethernet provided by competing RF wireless systems that operate in the 60 GHz frequency range. At the same time the deployment cost of VLC systems is significantly lower than that of fiber optics, which can easily reach $1M/mile in urban areas. VLC installation only requires the alignment of two free-space optical transceivers rather than digging trenches and repairing roads.

More to the point, Li-Fi could be used in almost every location where regulations forbid the use of Wi-Fi: aircraft cabins and hospitals, petrol pump, coalmines. Current positioning services like car navigators utilise GPS, but GPS cannot be used indoors where reception is poor. So the idea is to use indoor lighting for navigation indoors. More recently this system has found some applications like Intelligent Transport System (ITS)in particular military aircraft power-line network and onboard aircraft networking. LiFi is the future communication technology that may be used in underwater communication [18], [19], [20], [21], [22], [23]. LiFi may replace acoustic sensors that requires more power and complexity [24].

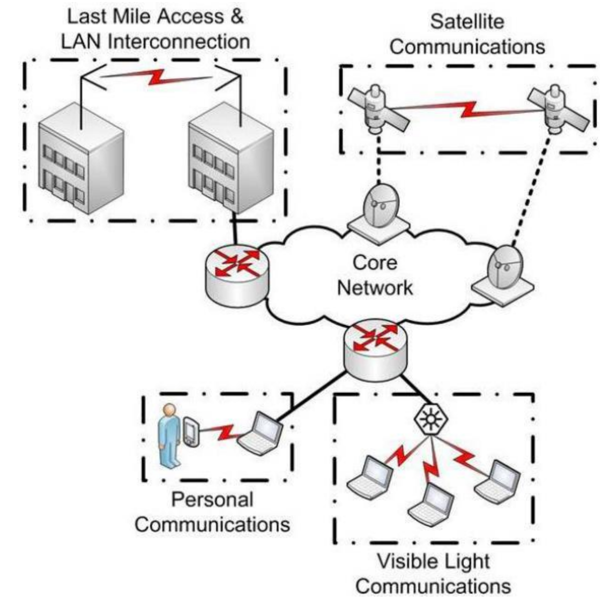

Figure 3. Application areas of VLC. [10]

LiFi technology is still in the introductory phase. Indoor networking and location based services are the only applications that are quite penetrated in the market. Products for other applications (intelligent traffic management system, in-flight entertainment, and underwater communication) are expected to hit the market by the end of 2013. LiFi may be implemented as a complementary technology to the existing WiFi. LiFi is expected to penetrate M2M communication, smart cities, power over Ethernet (PoE), wireless sensor networks, ubiquitous networks, augmented reality etc. in coming days.

VI. METHODOLOGY USING DMT-QAM

A. Optical Wireless Channel Model:

The VLC channel is modelled as a linear AWGN channel and is given as: The VLC channel is modelled as a linear AWGN channel and is given as [18]

$$I_P(t) = RP_t(t) \otimes h(t) + n(t) \quad (1)$$

where $P_t(t)$ is instantaneous transmitted optical power, h(t) is the channel impulse response, n(t) is the signal independent additive noise. This AWGN noise is independent of the optical power. When little or no ambient light is present, the dominant noise source is receiver preamplifier noise, which is also signal-independent and Gaussian (though often non-white). Thus we usually model the noise as Gaussian and signal-independent. Multipath fading in VLC can be ignored because an information carrier is in the order of 1014 Hz. Detector dimensions are in the order of hundreds of wavelengths, which leads to efficient spectral diversity that minimizes the effects of multipath fading [10].

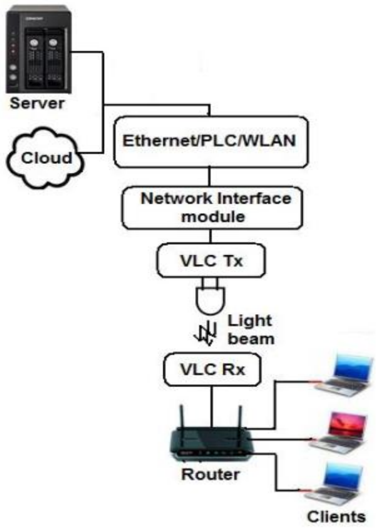

Figure 4.VLC prototype abstraction [4]

B. Analogue Front End:

The figure 5 depicts a VLC PHY layer that consists of DMT modulator and demodulator. The analogue front end includes a LED driving circuit (trans-conductance amplifier, TCA [14]) and visible-light source, viz. the LED. The receiver includes imaging optics, a photo diode, a trans-impedance amplifier (TIA), and a band-pass filter. The DMT PHY delivers an AC baseband signal to a driving circuit that linearly amplifies the AC signal and transforms it into a current. This current is then then added onto the DC bias current by aid of, e.g., a bias tee. Since LEDs works in a linear region with unipolar driving currents, the absolute driving current (DC+AC) has to be larger than zero. The total current is fed to the LED, which, in turn, emits a modulated optical power. The received power impinges onto an optical concentrator (lens), is directed through an optical filter, and converted into a current in a photo diode. The AC component of the current is then trans-impedance amplified and band-pass filtered. The output from the band-pass filter is demodulated.

C. DMT Transmission

In a fading channel, subcarrier modulation enhances system robustness. In an optical wireless system on the other hand, moving the signal spectrum away from dc offers better robustness against ambient-light noise and interference from fluorescent lighting, which is particularly strong around dc. In particular, DMT is a special type of modulation technique that offers high bandwidth efficiency, inherently deals with ISI, allows for simple equalization at the receiver, and can be entirely realised with digital signal processing. As shown in Fig. 5, at the Tx the input data are divided into several parallel streams, which will be encoded and imprinted onto different subcarriers. These are then mapped to 16–QAM symbols by aid of Gray coding.

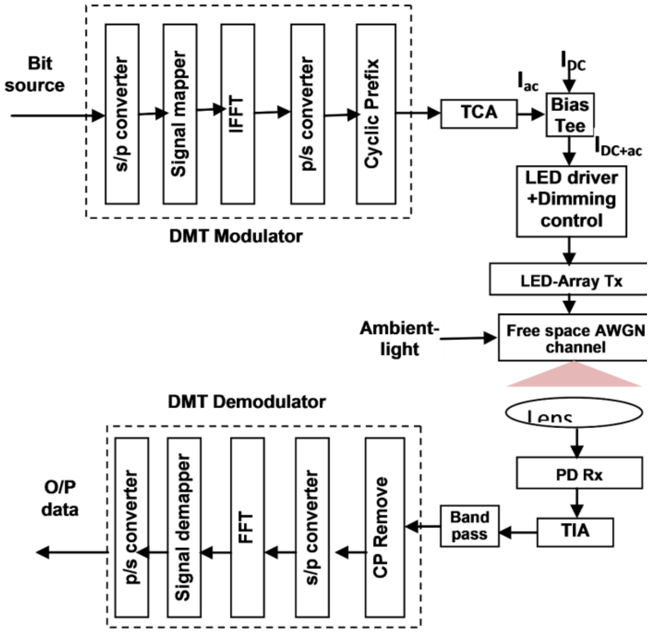

Figure 5.VLC PHY complete prototype using DMT modulation scheme [8]

A DMT symbol is formed via digital signal processing, and used to directly modulate the optical source. At the input of the inverse fast Fourier transformation (IFFT) block, conjugate symmetry is enforced on the vector of QAM symbols, to ensure a real-valued modulation signal. This means that for independent subcarriers (first input of the IFFT block corresponds to dc, which does not carry any data), a - IFFT block is necessary. After detection and DMT demodulation, subcarriers are separately processed.

VII. SYSTEM PERFORMANCE EVALUATION

Probably the most useful system performance figure-of-merit is the bit error probability at the receiver, also referred to as the Bit Error Rate (BER).

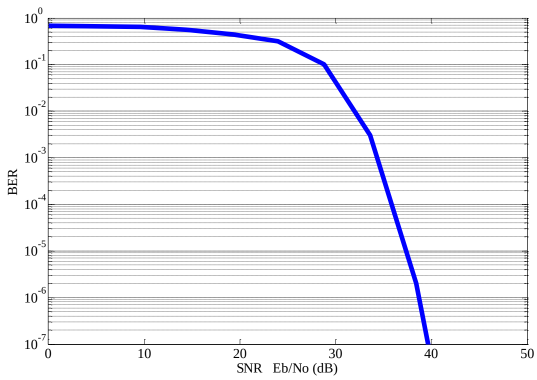

Figure 6.BER vs. SNR (Eb/N0) for VLC channel

Using the bertool in MATLAB-Simulink , the BER vs SNR (Eb/No in dB) has been plotted and shown in figure 6. The waterfall like structure conveys that very high SNR is available upto around 40 dB and for lower SNR the penalty is increase in BER.

VIII. CONCLUSION

This article has presented an understanding of LiFi using LEDs. The key requirements for a VLC PHY layer were identified and major applications areas have been discussed. Reliability and network coverage are the major issues to be considered by the companies while providing VLC services. Interferences from external light sources like sun light, normal bulbs; and opaque materials in the path of transmission will cause interruption in the communication. High installation cost of the VLC systems can be complemented by large-scale implementation of VLC. Adopting VLC technology will reduce further operating costs like electricity charges, maintenance charges etc.LiFi appears to be an important potential component in expanding useable bandwidth, protecting sensitive electrical equipment and data, creating more biologically friendly communications technology, and helping develop seamless computing applications. Properly developed LiFi could also be used, in conjunction with other existing communication system like WiFi, PL Cetc., to help create more equipment-friendly and biologically friendly electromagnetic environments helping to create truly sustainable communications technology.

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