Overview of LED Communication Networks

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Abstract

Visible light communication(VLC) is one type of short-range, optical, and wireless communication system utilizing light emitting diode(LED) and laser diode(LD) as optical source. In a VLC system, visible light is used as a transmission medium and used to illuminate. Using VLC has a lot of advantages: it is harmless to human body; it transmits with high power, and it has excellent security, a high data rate, and a license free frequency band. With such a unique blend of communication and illumination in one system, the most common application would be an indoor environment. We aim at reviewing key issues in VLC network such as : FOV(field of view), priority MAC, cooperative MAC, link switching, LED-ID technique, cell site diversity, and link recovery.

I. Introduction

Visible light communication(VLC) is interesting and timely research topic. VLC was created to utilize the advantage of visible light and the existed lighting systems from anywhere in the world. By using visible light, we can know when we are sending and receiving data, with whom we are communicating, and we also can see the data stream when devices communicate with each other. Light emitting diode(LED) and laser diode(LD) are used as optical sources for the VLC system [1]. The typical LED has special characteristics to light up and off at an ultra-high speed. By using visible light for the data transmission, most of the problems related to radio communications are resolved or relieved. It also has the advantage of large potential bandwidth(THz) with no regulation or license. The human eye would not be able to follow these variations, and, hence, the lighting will not be affected. The incorporation of VLC components into everyday technology is being investigated by a number of universities, corporations and organizations worldwide. The IEEE Wireless Personal Area Networks working group 802.15.7 Task Group 7 also developed a standard for VLC [1].

In this paper, we will explain VLC network architecture, two service scenarios and will discuss on some key technologies and issues for VLC. There are some disadvantages for VLC. Field of view is one of the problems in visible light communication. Visible light cannot pass through the wall or any other obstacle as well; therefore, FOV is the critical issue in VLC network [5]. Data packets with various levels of importance are considered in the VLC system. The distinction between important and less-important messages depends on their applications. A fire, typhoon, earthquake, enemy attack, location-based service, and medical crisis are some examples of emergency data packets. Therefore, supporting priority in VLC system is necessary for different types of data packets [8]. To improve the system performance, traditional techniques use extra nodes(other than the source and the destination) to actively help deliver the data frame correctly to the destination. This practice is referred to as cooperative communications. Cooperation communication comes as a new form of spatial diversity designed to overcome the limitation of wireless communication. When device moves within the whole VLC network area, the link switching time is increased very quickly. Therefore, the system needs a fast link switching scheme to maintain the seamless communication between device and coordinator [9]. LED-ID technology is the new paradigm in the identification technology. LED-ID technology based on the LED communication is ubiquitous information communication service that is used to supply variable information at museums, super markets, restaurants, and many other places. LEDs can be used as tags in LED-ID systems without losing their main functionality as illumination sources [10]. In a VLC network environment, multiple propagation paths often exist from a coordinator to a device due to scattering by different objects. So, this is necessary to reduce the problem of fading, but not at the cost of extra power or additional bandwidth. An indoor case link may become blocked due to people or other obstacles. Site diversity is one of the solutions to handle this kind of shadowing [11]. The temporal blocking, like walking people, can cause burst frame errors, or even the link failure, and can occur frequently. Since VLC can be highly directional, it is difficult to reestablish a link that has been lost due to movement or rotation of one of the devices in the link. Considering such issues, it is necessary and important to have a fast link recovery scheme for VLC systems, for both point-to-point and point-to-multipoint connections.

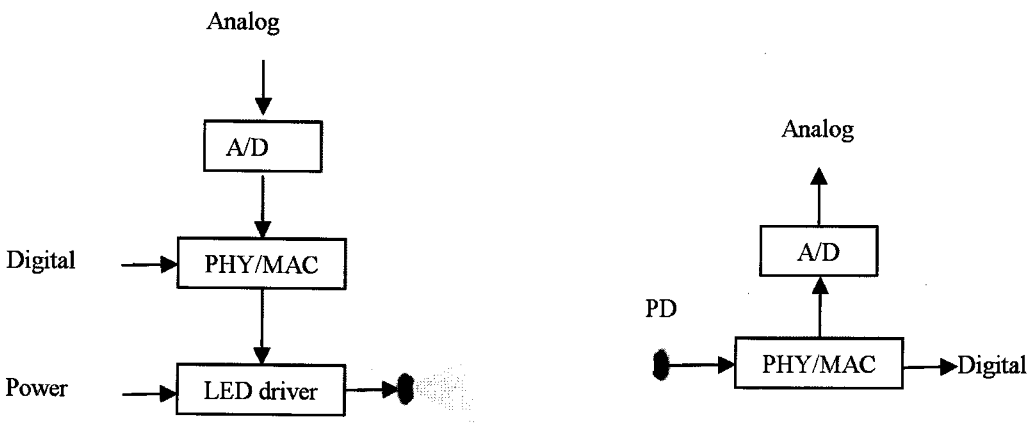
The rest of the paper is organized as follows : Section II describes VLC network architecture and service scenario. Some key technologies and issues for VLC protocols will be presented in Section III. Section IV concludes this paper.

II. VLC Network Architecture and Service Scenarios

1. VLC Architecture

A VLC device is comprised of a PHY layer, which contains the light transceiver along with its low-level control mechanism, and a MAC sublayer that provides access to the physical channel for all types of transfers. The upper layers consist of a network layer, which provides network configuration, manipulation, and message routing; and an application layer, which provides the intended function of the device. A logical link control layer(LLC) can access the MAC sublayer through the service-specific convergence sublayer(SSCS). A device management entity(DME) is also supported in the architecture. The DME can talk to the PLME(physical-layer management entity) and MLME for the purposes of interfacing the MAC and the PHY with a dimmer. The DME can access certain dimmer related attributes from the MLME and PLME in order to provide dimming information to the MAC and the PHY. The DME can also control the PHY switch using the PLME for selection of the optical sources and photo detectors. The PHY switch interfaces to the optical SAP and connects to the optical media, which may consist of a single or multiple optical sources and photo detectors. Multiple optical sources and photo detectors are supported in the standard for PHY layer as well for VLC cell mobility. The PLME controls the PHY switch in order to select a cell. The PLME controls the PHY switch in order to select a cell.

A block diagram of a typical VLC system is illustrated in Figure1. A basic VLC system consists of a light source(LED), free space as the propagation medium, and a photo detector(PD). Information, in the form of digital or analog signals, is applied to electronic circuitry that modulates the



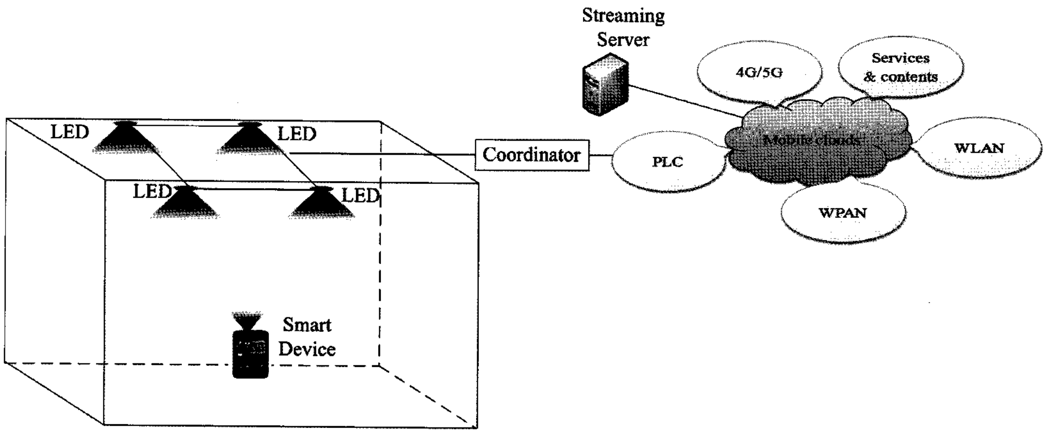
(Figure 1) VLC device architecture

light source. The source output passes through an LED into the free space. The received signal comes through a PD, passes along the detector, and the resulting photocurrent is amplified before the signal processing electronics.

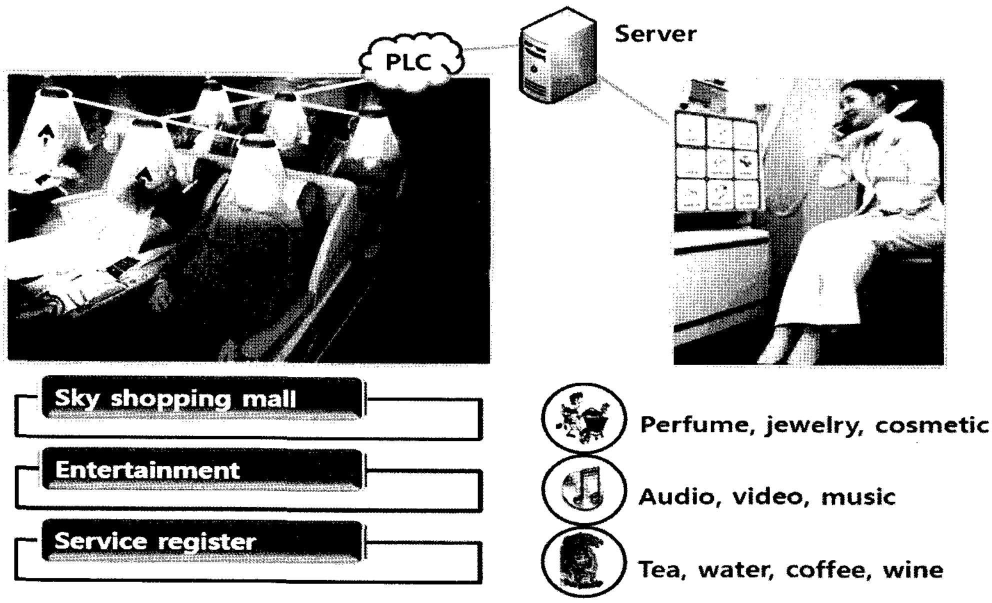
(Figure 2) presents the VLC network architecture in office or home environment. In VLC network, device or user connect with network through LEDs system and every LED is connected with coordinators which control the communication between LEDs and device. The office or home network can connect with other network such as IP network, cellular network or PLC network.

2. Service Scenarios

VLC network has many advantages, so it can be used in many applications such as: medical instrument, museum, restaurant, supermarket, airplane and indoor localization. They are applications in the indoor environment, and they can utilize existed light system would have already been installed. The existing system simply needs to integrate



(Figure 2) Office and home network architecture using VLC



(Figure 3) Air plane scenarios

existing system with communication component to use as VLC system. In here, this paper describes two service scenarios which are air plane scenario and museum scenario:

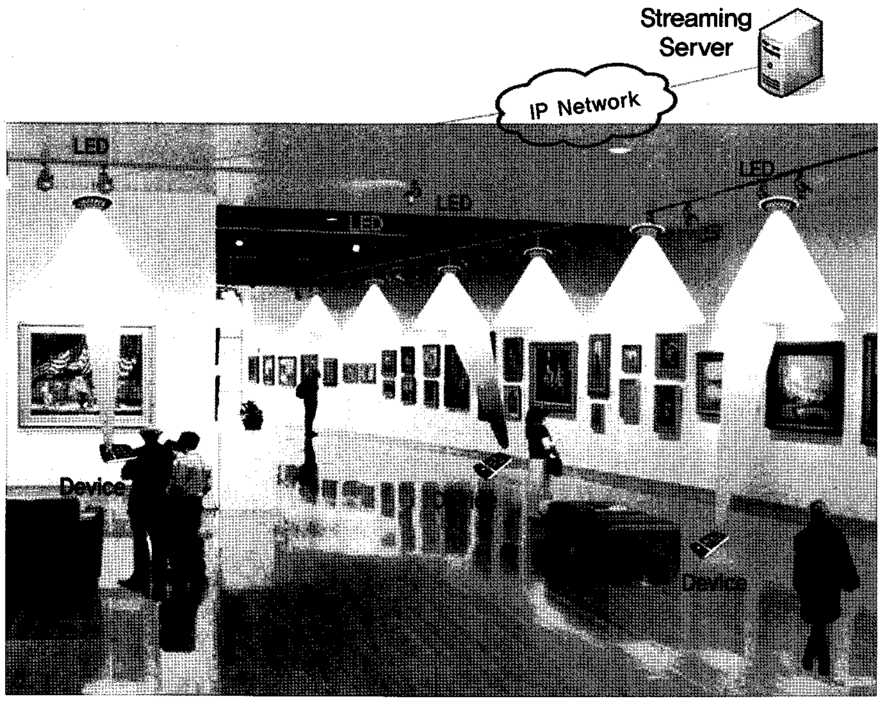
(Figure 3) shows the example of air plane scenario. In the air plane application, when passengers have a request, they can use the VLC network in the plane to make their request to the flight attendant. Thus, the flight attendants will not need to approach each passenger. This application will simply the flight attendant' s job as well as benefit the passenger. By using VLC network in the plane, the interference between VLC network and radio frequency system in the plane will not occur. Many kinds of service can be served by using VLC technique such as sky shopping mall, entertainment, and service register.

(Figure 4) describes the museum scenario applying VLC network. In the museum application, customers can get exhibition information by using the VLC device to communicate with the LED system. By using VLC technique, customers can easily download information from streaming server about the artists and their style, the works of art, and even historic or culture facts. They also can recognize the visible data streaming when they transmit and receive data.

III. Key Technologies and Issues for VLC Protocols

1. FOV(field of view) and LOS Problem

For any optical-transmitter angle and for any optical receiver, FOV is defined. FOV is the highest angle within which the receiver can receive signal rays [5]. FOV are limited around 60 degree ; the description can be shown in (Figure 5) Visible light communication is a new and strong candidate for next generation wireless communication compared with radio wave wireless communication. But FOV is one the problems in visible light communication.



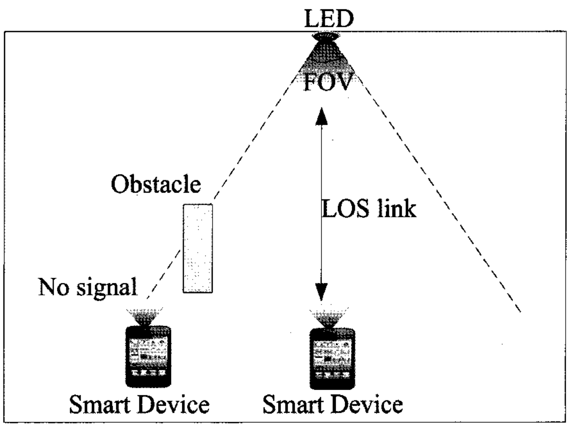
(Figure 4) Museum scenario

Visible light cannot pass through the wall or other solid obstacles. Due to this limitation, we use line of sight(LOS) communication in visible light WPANs system. Even though line of sight communication offers a high data rate, LOS must rely upon direct link between transmitter and receiver. Therefore, the LOS link is less robust and less convenient to use specially in the case of mobility [1], [5]. (Figure 5) shows in the home environment how one VLC receiver receive signal when it was in LOS, but when one obstacle or short wall comes between transmitter and receiver then VLC receiver will not receive signal.

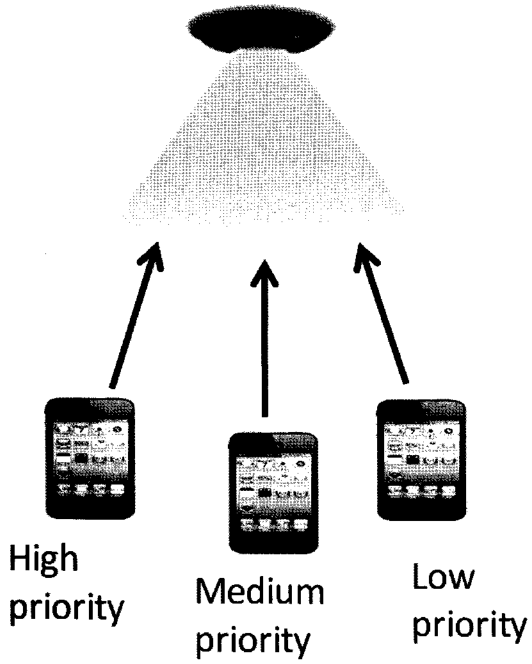
2. Priority MAC

Priority MAC is a mechanism to access the channel following the differentiated priority level of packet. By using multi-parameters in VLC network, it is possible to support priority for the device in the system to utilize the advantages of VLC system. The beacon-enable VLC network mode with slotted version for random access algorithm is considered in this paper. (Figure 6) shows the priority MAC scenario in VLC networks.

We define multilevel priority for diffirentiated service as L



(Figure 5) Indoor VLC systems with the limitation of LOS and narrow FOV



(Figure 6) Priority MAC in VLC network

levels. We have the set of levels priority {*level0*, *level1*, ... , *levelL*}

$$LevelL < level(L-1) < \ldots < level0 \quad (1)$$

Equation (1) shows the order of multilevel priority in VLC system. In this equation, level0 and levelL indicate the highest and lowest priority levels, respectively.

We proposed a multi-parameter with three variables: NB, BE and CW to support multilevel priority. Multi-parameter is a mechanism assigning various values of NB, BE and CW according to the priority levels. We differentiate the corresponding multi-parameter of priority level l $(0 \leq l \leq L)$ as follows :

$$NB[0] \geq NB[1] \geq \ldots \geq NB[L] \quad (2)$$
$$BE[0] \leq BE[1] \leq \ldots \leq BE[L] \quad (3)$$
$$CW[0] \leq CW[1] \leq \ldots \leq CW[L] \quad (4)$$

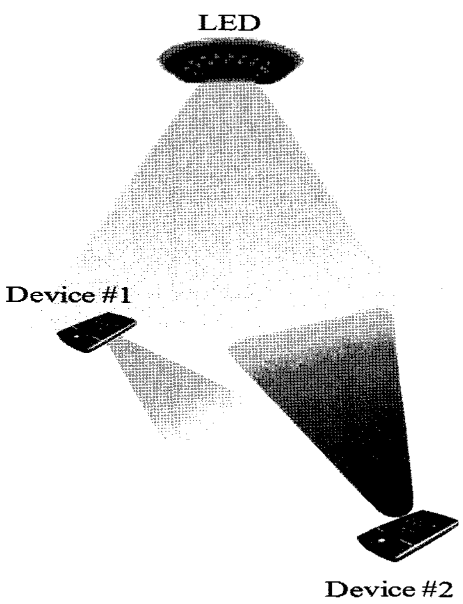
By using multi-parameter mechanism, VLC system can guarantees a better rate of successful transmission for a device with high priority when we compare with the IEEE 802.15.7 MAC protocol.

3. Cooperative MAC

In wireless communication, cooperative communication is the clear winner as the most promising technique to enhance system reliability and performance. In the VLC system, with the limitation of transmission range and FOV, cooperative communication shows more reliability and coverage. The proposed cooperative MAC protocol is based on the IEEE 802.15.7 MAC standard for short-range wireless optical communication using visible light. It exploits cooperative communication via multipoint relay to improve the reliable, throughput from source to destination. More specifically, the sender and the receiver will choose some relay nodes for their cooperative communication. Multi-node cooperation enhances the throughput compared to single relay cooperation. If the primary link imposed by direct communication can offer enough bandwidth and QoS requirement, the conventional MAC is operated and no cooperative transmission is applied. Otherwise, the sender and destination receiver will initiate cooperative mechanism to find relay nodes for cooperative communication. The approach scheme proposes new protocols for the control process and data transmission of the IEEE 802.15.7 MAC layer, while maintaining backward compatibility to the current MAC. A main function of control plane design is the mechanism for the sender and receiver to make decision about direction communication or cooperative communication. The process can be shown in (Figure 7) The cooperation network will be established when the direct communication cannot be guaranteed and reliable.

4. Link Switching

In IEEE P802.15.7 standard [1], the link switching process

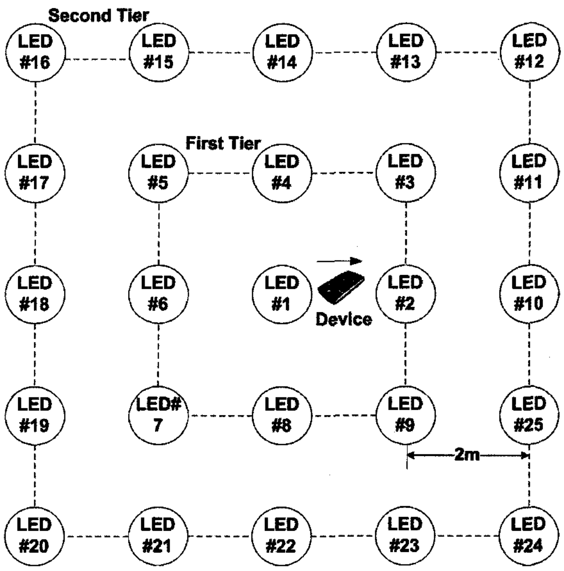


(Figure 7) Cooperative scenario of VLC network

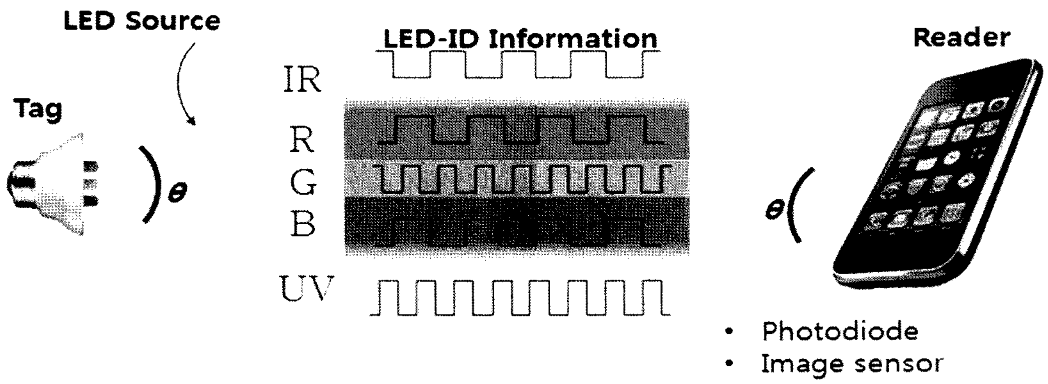
can be divided into some steps : device detection in boundary area, assign and return time slot, and link setup, and resource assignment. When a device comes to the boundary area of some other cells, a coordinator detects the device by using personal-area-network identifier(PID) received the signal. In the second step, the coordinator sends the boundary information through cells in that area. When a device receives the boundary information message, it requests and is assigned another time slot by the coordinator to transmit data parallel with current time slot. After completing the move from boundary area to distinguished cell area, the device returns the old time slot and continues using the new assigned time slot. The last step will complete the switching process and begin data transition. A link switching procedure is necessary and appropriate to maintain or improve communications. Link switching is needed due to interference or mobility of the device. Mobility can be one of two types : physical and logical. Physical mobility occurs when the device changes its position due to the movement within the coverage area of a coordinator. Logical mobility occurs when the device changes its communication link from a link with one coordinator to another coordinator due to interference or deliberate link switching. (Figure 8) shows the link switching scenario of VLC system. In this scenario, we assume that device is covered by first tier LEDs when performing the link switching process. The second tier LEDs has little effect because its position is far from device. Otherwise, first tier tags are enough to cover the reader movement area.

5. LED-ID Technique

LED-ID is a technology that uses communication via light waves(especially visible light) to contactless exchange voice/video/data among one tag or reader to one or more identified readers or tags. LED-ID includes at least one LED and one photo-detector(PD) to transmit and receive the signal. LED-ID is a novel ID technique, and it may coexist with current ID technique such as RFID, hologram-ID, and barcode instead of replacement. LED-ID tags are classified into active tags and semi-active tags. Both active tags and semi-active tags use internal batteries to power their circuits. The power which is used for communication in active tags

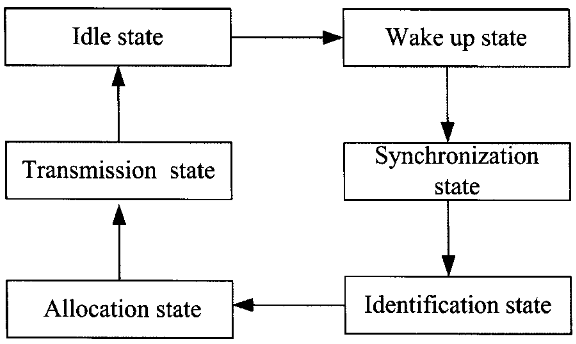


(Figure 8) Link switching scenario of VLC system



(Figure 9) Tag and Reader of the LED-ID system

comes from internal battery, but the semi-active tags uses energy which it receives from the reader to communicate. With the advantage of visible light, LED-ID will become a main trend in the future of ID techniques using visible light as transmit medium. LED-ID can be applied in many service scenarios such as: museums, product expositions, intelligent menu systems, advertisement, sign board, and indoor localization(LBS applications). (Figure 9) and (Figure 10) show the fundamental component of tags, readers and the processing state in LED-ID system.



(Figure 10) Processing state in LED-ID system

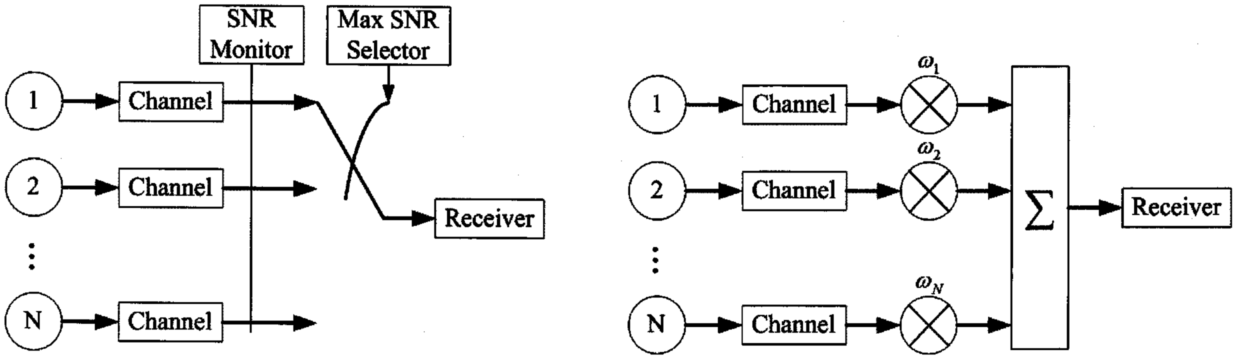
6. Site Diversity Technique

In a VLC system, coordinators are provided with multiple copies of the same information signal which are transmitted over two or more real or virtual communication channels. Diversity techniques are effective when the branches considered are assumed to be independently faded or the envelopes are uncorrelated. There are some techniques of diversity are as frequency diversity, time diversity, polarization diversity, spatial diversity. The idea of diversity is to combine several copies of the transmitted signal, which undergo independent fading, to increase the overall received power. In this case received signal should be uncorrelated to minimize the variance of error. The most common diversity combining methods are selection combining, maximal ratio combining, and equal gain combining.

In VLC system some part of the room is covered by one tag, some part by two tags, three tags and four tags. Based on the position of the device, the receiver can activate the receiver branch to achieve the SNR greater than threshold value.

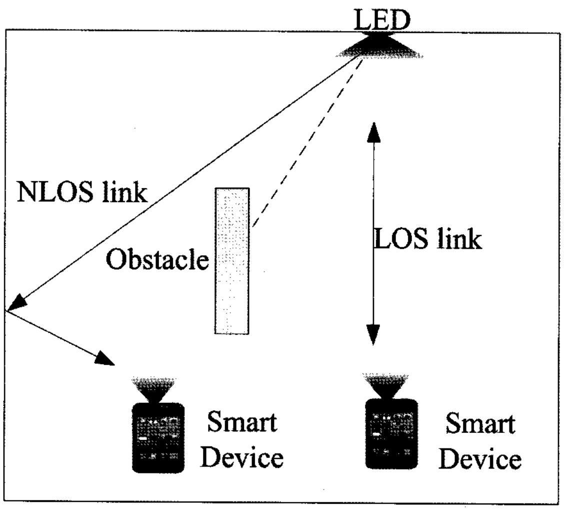
7. Link Recovery Technique

Link recovery scheme enables a user to recognize the disconnection of a link as soon as possible, so that the communication link may be reestablished by using this technique. In the link recovery process, the device may decide on its own to stop sending data. The device may also



(Figure 11) Selection and Maximum ratio combining

send the fast link recovery(FLR) signal repeatedly(within the allocated resource) to the coordinator if the device is connected to the coordinator. Upon receiving the FLR signal, the coordinator will send a FLR response to the device. The communication resumes after the device receives the response. If there is bi-directional data transfer during communication, the device may wait after it stops sending data. If the device does not receive any FLR response signal within a set time given by the MAC PIB attribute macLinkTimeOut, the device may assume the link is broken and may disassociate.



(Figure 12) Link recovery using NLOS link

The line of sight links employ narrow FOV transceivers that must be aimed in order to establish a communication link, while non-line of sight(NLOS) links employ wide FOV transceivers that alleviate the need for such positioning. LOS links rely upon a direct path between the transmitter and receiver for communication; whereas NLOS links usually rely upon reflection of the light from the ceiling or some other diffusely reflecting surface. LOS link between two transceivers is important for maintaining a high data rate. However, link failure when temporary blocking or poor orientation of a transmitter frequently causes burst frame errors and sometimes the link is broken as well. In general, LOS links minimize path loss and maximize the power efficiency, and they can achieve higher transmission rates. However, they are less robust and less convenient to use. While suffering from lower transmission rates, NLOS links increase robustness and ease of use, allowing high user mobility and the links to operate even when there are barriers between the transmitter and the receiver. The Figure 12 shows the LOS and NLOS links in order to achieve the advantages of both. A transmitter is mounted on the ceiling and the mobile node (MN) is located throughout the workplace at table top height. In this configuration, the direct path is clear for the majority of mobile node locations; thus, a tracked LOS link can be used for communication. When it has been temporary for a long time, the direct path is blocked; a secondary NLOS link can be used to hold the connection at a reduced rate. The wide FOV transceivers is used to detect signals in the case of NLOS, and the higher order reflections can be used for communication when the direct path is blocked [5].

IV. Conclusion

This paper reviews VLC and illumination network, some key techniques and issues which are currently challenging research activities. Some approach also presented in this paper to overcome the problems in VLC system. These issues will become very critical issues in the future VLC network because they include some problems and disadvantages of VLC system. After resolving these challenges, VLC networks and LED-ID networks will be very useful and easy to apply in every environment.

감사의 글

This work has been supported partially by 'Broadcasting-Communications R&D Program' of Korea Communications Commission/Korea Communications Agency (No. 11911-01111).

참 고 문 헌

[1] IEEE P802.15.7 Part 15.7 : and MAC standard for short-range wireless optical communication using visible light, 2011.

[2] Dominic C. O' Brien, LubinZengl, Hoa Le-Minh, Grahame Faulkner, Joachim W. Walewski, Sebastian Randel, "Visible light communications : challenges and possibilities," Personal, Indoor and Mobile Radio Communications, 2008.

[3] P. Amirshahi, M. Kaverrad, "Broadband access over medium and low voltage power-lines and use of white light emitting diodes for indoor communications," Consumer Communications and Networking Conference, 2006.

[4] T. Komine, M. Nakagawa, "Fundamental analysis for visible light communication system using LED lights," IEEE Transactions on Consumer Electronics, Vol.50, 2004.

[5] T. Komine, Masao Nakagawa, "Fundamental analysis for visible light communication system using LED lights," IEEE Transactions on Consumer Electronics, 2004.

[6] Yeong Min Jang and et al, "Network composition for interconnecting cellular networks and visible light communication(VLC)," IEEE 802 Contributions, 2009.

[7] Yeong Min Jang and et al, "Some considerations for draft visible light communication(VLC) specification," IEEE 802 Contributions, July 2010.

[8] Mario E. Rivero-Ángeles, Domingo Lara-Rodríguez, and Felipe A. Cruz-Pérez, "Differentiated backoff strategies for prioritized random access delay in multiservice cellular networks," IEEE Transactions on Vehicular Technology, vol. 58, pp. 381-397, Jan. 2009.

[9] V. Pandey, D. Ghosal, B. Mukherjee, and X. Wu, "Call admission and handoff control in multi-tier cellular networks : algorithms and analysis," Wireless Personal Communications, 2007.

[10] Hwan Park, Yoon Hyun Kim, Jaesang Cha, Kyesan Lee, Yeong Min Jang, and Jin Young Kim, "Scalable optical relay for LED-ID systems," IEEE International Conference on Information and Communications Technology Convergence(ICTC), pp. 415-420, 2010.

[11] M. Shukla, P.S. Sharma, A Singh et al, "Performance analysis of iterative IDMA systems with MRC diversity in multipath fading environment using optimum tree based interweaver," IEEE Conference on Computational Intelligence and Computing Research, 2010.

[12] Ying Li,S. Rajagopal, "Fast and energy-efficient link

recovery in visible light," IEEE Consumer Communications and Networking Conference(CCNC), 2010.

[13] Elgala, Mesleh, Haas, "Indoor optical wireless communication : potential and state-of-the-art," IEEE Communications Magazine, September 2011.

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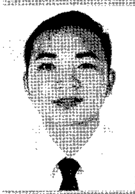

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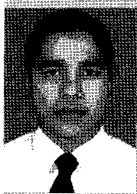

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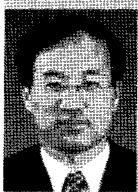

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