논문 2009-4-14

가시광통신을 위한 색채공간매핑과 MAC 기법 연구

Color Space Mapping and Medium Access Control Techniques in Visible Light Communication

모하마드 사이퍼 라만*, 김병연*, 방민석*, 박영일*, 김기두*

Mohammad Shaifur Rahman, Byung-Yeon Kim, Min-Suk Bang, Youngil Park, and Ki-Doo Kim

요 약 가시광통신(VLC)은 가까운 장래에 각광받을 무선 통신 기술로서 전자파 간섭 없이 무료로 넓은 대역폭을 사용할 수 있기 때문에 RF에 민감한 운용 환경에 유용성이 매우 기대된다. 무선통신에 제약을 받는 병원 등에서 의료장비들 운용에 유용하게 쓰일 수 있는 음성인식 시스템을 포함한 LED 기반의 VLC 시스템을 제안한다. 특히 주변빛에 의한 잡음 영향을 극복하기위해 색채공간을 기반으로 한 새로운 변조기법을 제안하고, 또한 BER을 줄이기 위해 심벌 수에 따른 다양한 색채공간 성좌도의 가능성을 제시한다. 끝으로 VLC에서의 다중 사용자 접속을 위해 Slotted ALOHA 및 TDMA MAC 프로토콜의 정당성을 기술하였다.

Abstract Visible Light Communication (VLC) is a promising wireless communication technology. It offers huge, worldwide available and free bandwidth without electro-magnetic interference, which makes it very attractive for RF-sensitive operating environments. We propose colored LED-based VLC system for hospital use which includes voice recognition system for operating the medical equipments. New Mr hlation Scheme based on the Light Color Space is suggested to overcome the effect of noise generated by background light. Different color space constellations for different symbol sizes are also suggested which would give better bit error rate performance. Finally, Slotted ALOHA or TDMA medium access control protocols are suggested for multi-user operations.

Key Words : VLC, Voice Recognition, Color Space, Slotted ALOHA, TDMA, u-Health.

Ⅰ. Introduction

Visible Light Communication is the promising optical wireless communication technology in free space using white or colored LEDs for the transmission of information using light that is visible to the human eye. The use of visible light as a communication medium is still at a very early stage, compared to what has been achieved in areas like infrared and laser (free space optics). The VLC system using LEDs has many distinctive features and high potential to be a ubiquitous communication system. This system is expected to undergo rapid progress, inspiring numerous indoor and outdoor applications. With recent advancement in high power colored and white LEDs, the advantages of Infrared (IR) technology can be explored by VLC systems. In this system white and colored LEDs can be used for data transmission and at the same time provide lighting and signaling functionalities. LED has a special characteristic to light on and off very fast. The data can be transmitted by lighting LED on and off at ultra high speed. By using

*정회원, Dept. of Electronics Engineering, Kookmin University, Seoul, Korea
접수일자 2009.7.14, 수정완료 2009.8.7

the visible light for the data transmission, many problems related to radio

그림 1. VLC가 적용 가능한 병원 환경 예
Fig. 1. VLC can be a safe communication technology for hospitals.

and infrared communications can be solved. The visible light communication has characteristics to be ubiquitous, transmitted at ultra high speed and harmless for human body and electronic devices, compared to those by radio and infrared communications.

There are various advantages to use the visible light communication. Visible light is very safe for human. On the other hand, the radio wireless communications have several problems although they are widely in use of cell phones and wireless LAN. The wireless transmission power cannot be increased because of the bad effect to human body. The radio wave cannot be used in hospitals due to the bad effect to the precision instruments/devices. These radio wave problems can be easily solved by using visible light communications.

VLC can be a promising communication technology in the hospital environment. Different types of life supporting and monitoring equipments are used in the hospitals. The equipments use wired or radio frequency (RF) transmission for the communication among them. However, both these two media has some basic limitations which can be overcome by using VLC. VLC avails all the facilities of RF wireless communication without the health hazards that is occurred by RF communication. It offers huge, worldwide available and free bandwidth without electro-magnetic interference, which makes it very attractive for RF-sensitive operating environments.

Objective of our research is to develop a VLC system for hospital use which incorporates voice recognition system to operate the medical equipments. The system will contain a voice recognition module which will detect the voice command and convert it to data which will be transmitted to the control server using VLC. All the equipments will be connected to the control server using VLC module. In this way, all the equipments can be operated using voice command. In addition, this system will provide an RF hazard-free wireless environment. One major problem of VLC that has to be overcome is noise generated by background lights, such as fluorescent lamps, incandescent lamps and other sources of lights. The modulation method used must offer high robustness to background light. We study different modulation schemes for VLC which are suggested so far by other research groups and propose new efficient modulation method for colored LED-based VLC using color space modulation. The present study covers different types of light color space that can be used for modulation in VLC and constellation diagram for the light color space. We also study Medium Access Control (MAC) protocols suitable for VLC.

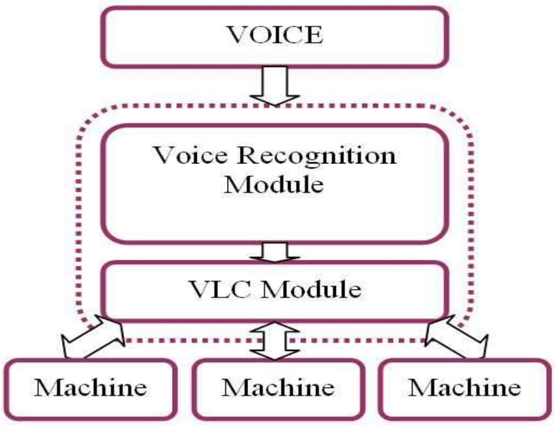


그림 2. VLC와 음성인식 시스템의 블록도
Fig. 2. Block diagram for VLC and voice recognition system.

Ⅱ. Various Light Color Spaces

So far various light spaces (or light color spaces or color spaces) have been suggested for representation of light colors. Colors of light signals can be represented by points in a light color space. This light color space can be defined in various ways. Typical examples of these light color spaces are CIE 1931, CIE 1967, and CIE 1976 spaces[1, 2] approved by International Commission on Illumination (Commission Internationale d'Eclairage, CIE). Any light source such as an LED can be represented with a point in a light color space for its color. Any photo detector such as a photo diode output can be represented with a point in a light color space. In the following sections, these spaces are briefly described.

1. CIE 1931 Color Space

The tristimulus values of a color are the amounts of three primary colors in a three-component additive color model needed to match that target color which are denoted X, Y, and Z.

To calculate these values, three color matching functions are used for this space. A set of these three color-matching functions are called $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$. For spectral power distribution, $S(\lambda)$, of a light source, these three tristimulus values can be calculated using the following equations:

$$X = \int S(\lambda)\bar{x}(\lambda)d\lambda$$
$$Y = \int S(\lambda)\bar{y}(\lambda)d\lambda$$
$$Z = \int S(\lambda)\bar{z}(\lambda)d\lambda \qquad (1)$$

where λ is the wavelength of the equivalent monochromatic light (measured in nanometers). For this space, three color-matching functions have spectral distributions shown in Fig. 3. These three tristimulus values can be normalized by (2). Using these three normalized values, a chromaticity diagram can be drawn as shown in Fig. 4. In this diagram, the concept of color can be divided into two parts: brightness and chromaticity. The Y parameter is a measure of the brightness or luminance of a color. The outer curved boundary is the spectral (or monochromatic) locus, with wavelengths shown in nanometers.

$$x = \frac{X}{X+Y+Z},\ y = \frac{Y}{X+Y+Z},$$
$$z = \frac{Z}{X+Y+Z} \qquad (2)$$
$$x + y + z = 1 \qquad (3)$$

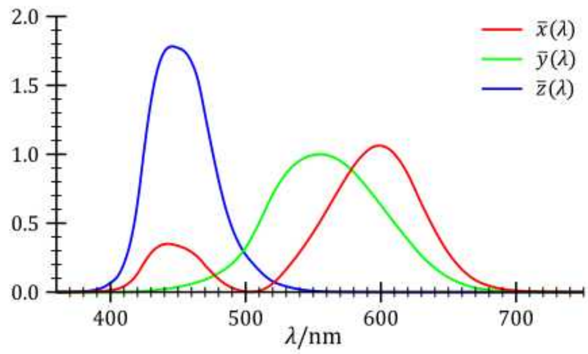


그림 3. CIE1931 색공간에서의 color matching function 스펙트럼 분포

Fig. 3. Spectral distributions of three color matching functions in CIE1931 color space.

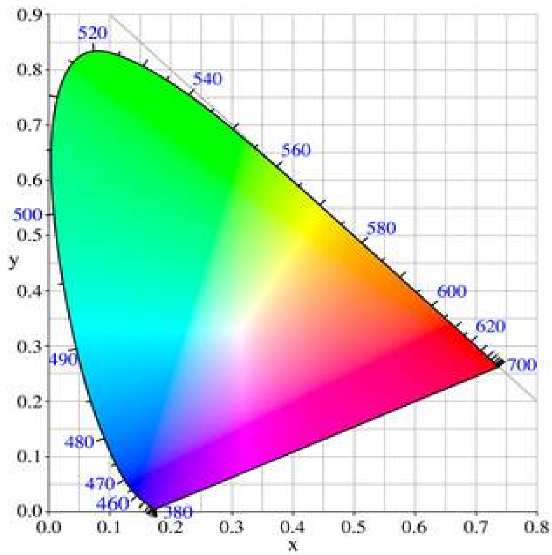


그림 4. CIE 9131 색공간 색좌표

Fig. 4. CIE 1931 color space chromaticity diagram.

2. 1976 CIE u'v' (or CIE LUV) Chromaticity Diagram

The advantage of the 1976 diagram is that the distance between any two points is now approximately proportional to the perceived color difference, something definitely not true in the 1931 diagram because it attempted perceptual uniformity. Additive mixtures of different colored lights will fall on a line in CIE LUV's uniform chromaticity diagram with a condition that the mixtures are constant in lightness. The CIE 1976 chromaticity diagram is shown in Fig. 5. Historical inertia has won out over technical superiority: the 1976 diagram is not used as much as the original 1931 diagram.

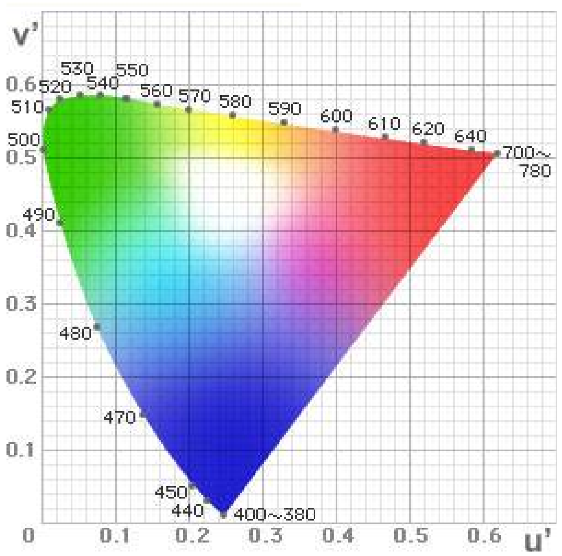


그림 5. 1976 CIE LUV 색좌표
Fig. 5. 1976 CIE LUV chromaticity diagram.

3. 1976 CIELAB

CIE L*a*b* (CIELAB) is a complete color space specified by CIE. It describes all the colors visible to the human eye and was created to serve as a device independent model to be used as a reference. The three coordinates of CIELAB represent the lightness of the color (L* = 0 yields black and L* = 100 indicates diffuse white; specular white may be higher), its position between red/magenta and green (a*, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (b*, negative values indicate blue and positive values indicate yellow). Since the L*a*b* model is a three-dimensional model, it can only be represented properly in a three-dimensional space. Two-dimensional depictions are chromaticity diagrams: sections of the color solid with a fixed lightness as shown in Fig. 6. The L* coordinate ranges from 0 to 100. The possible range of a* and b* coordinates depends on the color space that one is converting from. For example, when converting from RGB, a* coordinate range is [-0.86, 0.98], and b* coordinate range is [-1.07, 0.94].

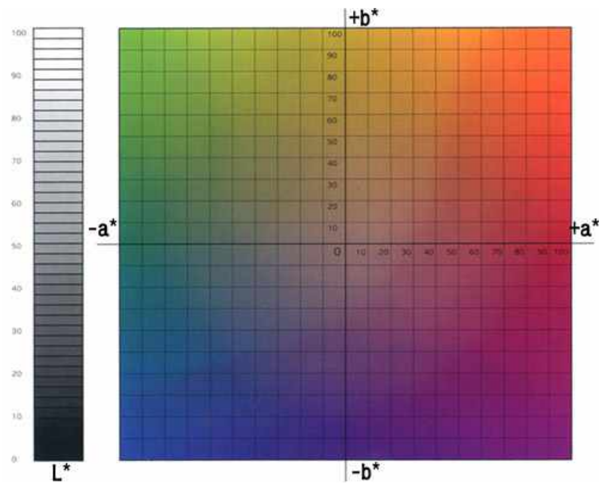


그림 6. 1976 CIE LAB 색좌표
Fig. 6. 1976 CIE LAB chromaticity diagram.

Ⅲ. New Modulation Scheme based on the Light Color Space

Visible light communication has its own signal source and channel. These signal and channel have unique characteristics which are different from those of radio signals. Therefore, new and more efficient signal manipulation methods and modulation schemes are needed to be devised for more efficient VLC communication. In this study, some manipulation methods are discussed which can be uniquely applied to manipulate light signals to deliver data information and eventually a new modulation method is introduced.

VLC Transmitter and receiver have a block structure as shown in Fig. 7[3]. In this study, data-to-modulation mapping at transmitter and modulation-to-data demapping at receiver are introduced for visible light signal modulation and demodulation. Hence, various concepts on these blocks are dealt in the present study.

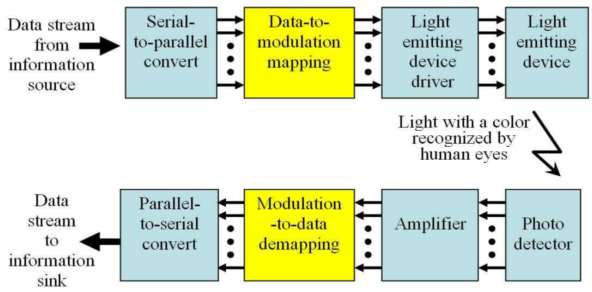


그림 7. VLC를 위한 송수신 블록도
Fig. 7. Transmitter and receiver block diagram for VLC.

After converting the serial bit-streams into parallel bits, an m bit input is represented by a predefined point in a light color space, which is one of constellation points. This constellation is formed by considering all parameters including color information of light sources. An m bit input which is represented by one of 2^m points in a light color space (or one of 2^m symbol elements) is mapped into intensities of n light emitting devices (or n color components). Thus the output ng dn device intensities or color components: each of 2^m points is represented by a mponents: set of n (color) intensity componentsrepre parameters used to determine mapping outputs include the target color generated by combining 2^m light signals each of which is generated by mixing n color components with a set of intensities applied to these components. The target color is a color perceivable to human eyes after modulation and determined by color information input (or given) from outside.

In the modulation scheme, suggested in this paper, two chromaticity coordinates for a two dimensional light color space are considered. Any point in a space can be represented by a unique pair of these values and a color is represented by a unique point in a space, not by multiple points, although any multi-dimensional spaces with unique color representation (that is, with a color to a point matching) can be considered for this modulation. It is similar to Quadrature Amplitude Modulation (QAM) for conventional communications[4]. In a constellation, there are points which maximize the minimum distance among distances between any two points to minimize interference effect. Equidistance strategy is one possible way to assign points in the constellation.

The CIE 1960, CIE 1964, and CIE 1976 color spaces were developed, with the goal of achieving perceptual uniformity (to have an equal distance in the color space correspond to equal differences in color). Although they were a distinct improvement over the CIE 1931 system, they were not completely free of distortion. To utilize better perceptual uniformity, the CIE 1976 is more appropriate for a color space for modulation schemes using the constellation planes in a light color space. It has less area that can not be covered by an area made with any light sources (or point colors).

Other more perceptually uniform spaces are more desirable for the modulation, studied in the present work, for its better performance. CIE1976 is a strong candidate for the modulation of VLC. It should be considered which uniformity is more important, perceptual uniformity for human eyes or detection uniformity for photptuetectors. If perceptual uniformity is more emphasized, more natural colors may be more easily realized. On the contrary, if detection uniformity is emphasized, lower BER may be achieved dvedto equal distances between two adjacent points if the modulation invented here is applied. For both light emitting devices at transmitters and photo detectors at receivers, the same light color space can be applied. Therefore the same uniformity is applied without any distortion due to different light color spaces.

1. Coordinate Transformations between Color Spaces

The coordinate systems XYZ and RGB are related to each other by linear equations. (R: 700nm, G: 546.1nm, B: 435.8nm)

$$X = 0.49R + 0.31G + 0.2B \quad (4)$$

$$Y = 0.17697R + 0.8124G + 0.01063B \quad (5)$$

$$Z = 0.01G + 0.99B \quad (6)$$

The vertical projection onto the xy-plane is the CIE1931 chromaticity diagram xyY (view direction) as shown in Fig. 4. All visible colors differ only by luminance map to the same point in the chromaticity diagram. To reconstruct a color triple XYZ from the chromaticity values xy we need additional information, the luminance Y. Using (2) and (3)

$$z = 1 - x - y,\ X = \frac{x}{y}Y,\ Z = \frac{z}{y}Y \quad (7)$$

The CIE 1976 chromaticity coordinates u', v' are given by[1]

$$u' = \frac{4X}{X + 15Y + 3Z} = \frac{4X}{-2 + 12y + 3}$$
$$v' = \frac{9Y}{X + 15Y + 3Z} = \frac{9y}{-2x + 12y + 3} \quad (8)$$

The reverse transformation is

$$x = \frac{27u'}{18u' - 48v' + 36}, y = \frac{12v'}{18u' - 48v' + 36} \quad (9)$$

The equations for CIE1976L*a*b*(CIELAB) color space are [1]

$$L^* = 116(Y/Y_n)^{1/3} - 16,$$
$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}], \quad (10)$$
$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}},\ h_{ab} = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (11)$$

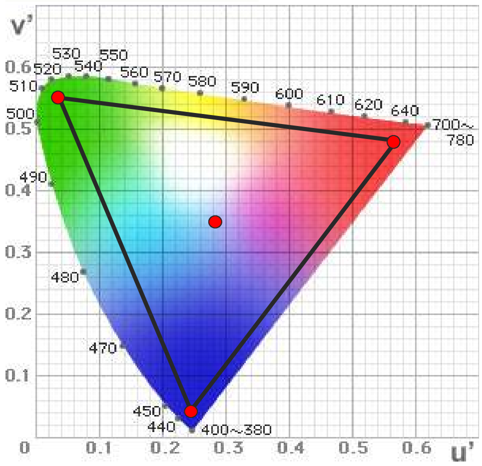
In (10) X_n, Y_n, and Z_n are the tristimulus values of the reference white.

2. Color Space Constellation

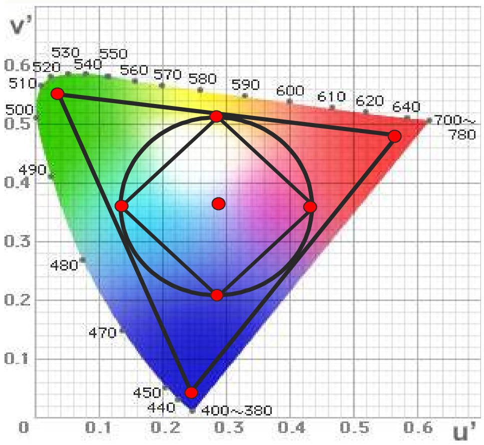
There are several light color spaces introduced to represent light colors. In a constellation plane of a modulation scheme, to determine a possible area of the symbol points of a constellation where most efficient modulation can be realized, one of light color spaces can be used as a constellation plane. To mix multiple colors to generate a target color, a set of color coordination coefficients can be considered to define intensities of available color components. Minimum distance between any two points in this constellation is needed to be maximized. Equidistance between any two adjacent points is one of the best when points are detected by photo detectors at the receiver to lower data error rates (or BER) by minimizing influence from interference. To make the minimum distance between any two points in a constellation be maximized, the constellation area should be maximized. We propose the 4, 8, and 16 point constellations, as shown in Fig. 8, as an introductory understanding point of view, however, this concept may be generalized in a various way under any color space. We focus on maximizing the minimum Euclidean of the constellation points to lower the BER probability.

3. Medium Access Control

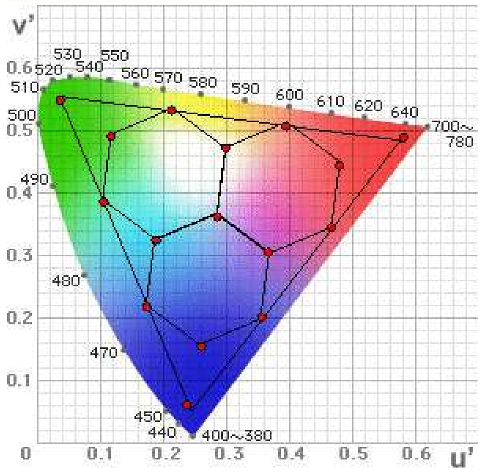
Multiple access method is required for sharing the visible light communication channel. In the case of VLC, carrier sensing and collision detection is not possible, and the collision area may be limited to the receiving part of AP due to the simultaneous access of several terminals. Since contention-based protocol like CSMA used for LAN cannot be used for VLC MAC protocol, we suggest simple multiple access methods such as ALOHA and slotted ALOHA. However, to minimize the collision probability and to improve the throughput, we may take the MAC protocol of TDMA method.



(a) 4 point 성좌도
(a) 4 point constellation



(b) 8 point 성좌도
(b) 8 point constellation



(c) 16 point 성좌도
(c) 16 point constellation

그림 8. 1976 LUV에서의 색 공간 성좌도
Fig. 8. Color space constellation in 1976 LUV.

ALOHA is the first contention-based MAC protocol developed by Abramson in the early 1970s [5]. In this protocol, nodes can transmit whenever a packet is ready for transmission. An acknowledgement is sent from the receiver after the successful reception of the data packet. If the packet is corrupted due to collision, the sender does not receive the acknowledgement. Then, the sender waits for a random amount of time and retransmits the packet. ALOHA is easy to implement but suffers low throughput problem. The maximum achievable throughput is only 18.4% of the total available bandwidth.

Slotted ALOHA improves the performance of the simple ALOHA by synchronizing the transmission time slots of all nodes. In this protocol, time is divided into slots and the nodes can only transmit at the beginning of a time slot. By restricting the starting time of frame transmissions, collisions can occur only when two frames are transmitted in the same time slot. Therefore, the vulnerable period for slotted ALOHA is only one time slot vs. two time slots as in ALOHA. The introduction of time slots doubles the throughput by reducing the probability of collisions by one-half compared to ALOHA. Slotted ALOHA is described in Fig. 9.

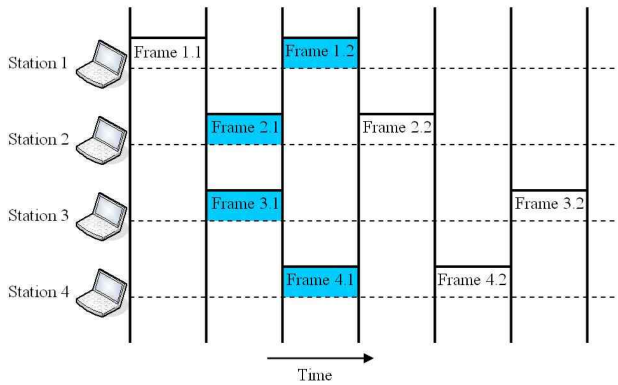


그림 9. Slotted ALOHA MAC 프로토콜
Fig. 9. Slotted ALOHA MAC protocol.

The Time Division Multiple Access (TDMA) scheme[6] subdivides the time axis into fixed-length superframes and each superframe is again subdivided into a fixed number of time slots (Fig. 10). These time slots are assigned to nodes exclusively and hence the node can transmit in this time slot periodically in every super frame. TDMA requires tight time synchronization between nodes to avoid overlapping of signals in adjacent time slots. Since in TDMA, each user is assigned a specific time slot, collision probability is reduced. Hence, TDMA can be adopted for VLC system to reduce the collision[7].

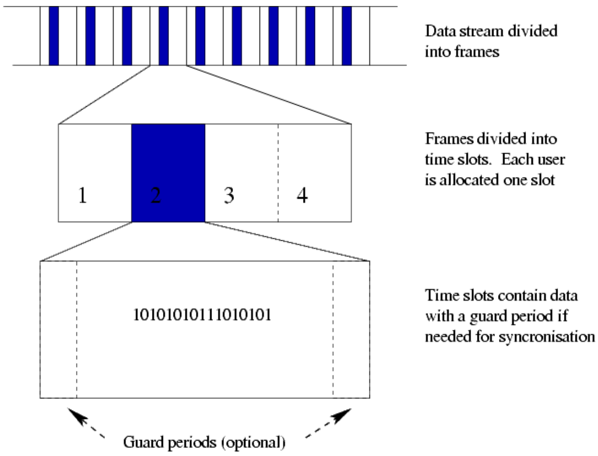


그림 10. TDMA frame 구조
Fig. 10. TDMA frame structure.

Ⅳ. Conclusions

We have suggested a colored LED-based VLC system for hospitals that includes voice recognition system which is able to operate the medical equipments by voice command. The VLC technique provides a safe communication in RF-sensitive hospital environments. Color space modulation and medium access control techniques are studied for the proposed VLC system. After detailed study of different types of available color spaces, we recommend CIE1976 since it is more appropriate for color space for modulation schemes using the constellation planes in a light color space. It has less area that cannot be covered by an area made with any light sources. Hence, it has the ability to suppress background light noise. As contention-based protocol like CSMA used for LAN cannot be used for VLC MAC protocol, we suggest simple multiple access methods such as ALOHA and slotted ALOHA. To minimize the collision probability and improve the throughput, we can also use TDMA for multiple access.

References

[1] Roy S. Berns, "Principles of Color Technology," 3rd Edition, John Wiley & Sons, Inc., 2000.

[2] Gernot Hoffmann, CIE Color Space, http://www.emdem.de/~hoffmann/cielab

[3] 장수영, “가시광 무선통신의 기술 특징 분석,” 한국통신학회지, 26권, 5호, pp. 15-22, 2009년 5월.

[4] Andy Bateman, Digital Communications - Design for the Real World, Addison-Wesley, 1998.

[5] N. Abramson, “The ALOHA system-another alternative for computer communications.” In Proc. AFIPS Fal Joint Computer Conf., Montvale, NJ, pp. 281-285, 1970.

[6] I. Rubin,“Access-control disciplines for multi-access communication channels: Reservation and TDMA schemes,” IEEE Transactions on Information Theory, vol. 25, no. 5, pp. 516-536, 1979.

[7] 신홍석 외, “무선 가시광 통신을 위한 MAC Protocol에 대한 연구,” 한국통신학회지, 26권, 5호, pp. 30-35, 2009년 5월.

※ 본 연구는 중소기업청 산학협력실지원사업과 한국과학재단 특정기초연구(R01-2008-20570-0) 지원으로 수행되었음.

저자 소개

모하마드 사이퍼 라만(정회원)

- 2001년 BSC Engineering from Khulna University of Engineering and Technology, Bangladesh
- 2005년 MSC Engineering from Khulna University of Engineering and Technology, Bangladesh
- 2007년~ 현재 국민대학교 Ph.D. 과정 재학중

<주관심분야 : 디지털 통신, 디지털신호처리>

김 병 연(정회원)

- 2003년~현재 국민대학교 전자공학부 학사 과정 재학중

<주관심분야 : 디지털통신, 디지털 신호처리>

방 민 석(정회원)

- 2006년~현재 국민대학교 전자공학부 학사 과정 재학중

<주관심분야 : 디지털통신, 디지털 신호처리>

박 영 일(정회원)

- 1987년 서울대학교 전기공학과 졸업
- 1995년 Texas A&M Univ. 공학박사
- 1995년~1999년 KT 연구개발본부 선임연구원
- 1999년~현재 국민대학교 전자공학부 부교수

<관심분야> 광가입자망, 광대역 통합망, 가시광통신

김 기 두(정회원)

- 1980년 서강대학교 전자공학과 졸업
- 1980년~1985년 국방과학연구소 연구소
- 1988년 7월 미국 펜실베니아주립 대학교 전자공학(MS)
- 1990년 12월 미국 펜실베니아주립대학교 전자공학 (Ph.D.)
- 1997년~1998년 미국 UCSD, Visiting Scholar
- 1991년~현재 국민대학교 전자공학부 교수

<주관심분야 : 디지털통신, 디지털신호처리>