Receivable Signal Sequence Number Increase by Spatially Parallel Signal Transmission in LED Visible Light Wireless Communications

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SUMMARY This paper evaluates the increase of receivable signal sequence numbers by spatially parallel signal transmission based on reception performance in LED visible light wireless communication. The evaluation results show that spatially parallel signal transmission is feasible at almost all points in the set evaluation area and receivable signal sequence numbers can be increased by appropriately setting the angle between photodetectors on a receiver.
key words: *Visible Light Communication, LED, Spatially Parallel Signal Transmission*

1. Introduction

The traffic of wireless communication systems is rapidly increased by the spread of smartphones and tablets. This traffic increase requires broader frequency bands and new transmission technologies to realize lager capacity wireless communication systems. LED visible light wireless communication is one of effective technologies to expand communication bandwidth [1]-[3].

Spatially parallel signal transmission which uses multiple transmitters with LED lighting and a receiver with plural photodetectors was studied to accelerate the bit rate of visible light communications [4]. The previous study evaluated reception quality according to the arrangement of LED lighting and photodetectors, and revealed the feasibility of spatially parallel signal transmission. However, the evaluation of receivable signal sequence numbers is insufficient based on reception performance by setting a practical evaluation area.

This paper evaluates receivable signal sequence numbers by spatially parallel signal transmission in a set practical evaluation area for LED visible light wireless communications. The increase effect of receivable numbers is evaluated according to the angle between photodetectors on a receiver

2. Spatially parallel signal transmission

Figure 1 shows spatially parallel transmission for LED visible light wireless communications. This method transmits different information signal sequences at the same time and wavelength with a lot of LED lighting and plural photodetectors on a receiver. The light from LED lighting is concentrated by mirrors and lenses in front of a photodetector to increase received light energy. The incident angle limit by this light concentrating can realize one-to-one communication at each photodetector even when different signal sequences are simultaneously transmitted from multiple LED lighting as shown in Fig, 1, and spatially parallel signal transmission is possible without complex signal processing in a receiver.

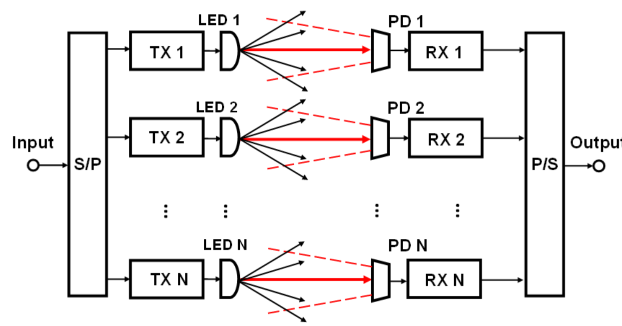

Fig. 1 Spatially parallel transmission in visible light communication

Figure 2 shows the system structure by spatially parallel transmission where 25 LED lighting are arranged in a grid (5 x 5) on a ceiling, and 9 photodetectors are equipped on a receiver with the angle between them of θ.

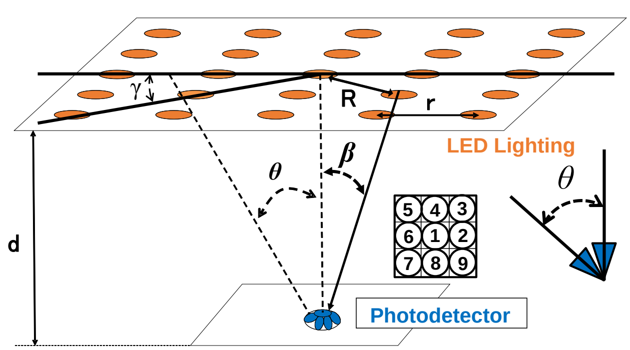

Fig. 2 System structure using spatially parallel transmission

When the normalized reception power of a photodetector is assumed to be P_0 at transmission distance equal to ceiling height of d. The received power P of a photodetector is represented by the following equation

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$$P = GP_0\left\{1+\left(\frac{R}{d}\right)^2\right\}^{-\frac{\alpha}{2}}, \quad (1)$$

where R is the horizontal distance from a photodetector to an LED lighting, α is a distance attenuation factor, and G is power gain of a photodetector at the incident angle of β. G is calculated by the following approximate equation based on measured values in Fig. 3.

$$G = 1 - 0.05|\beta|. \quad (2)$$

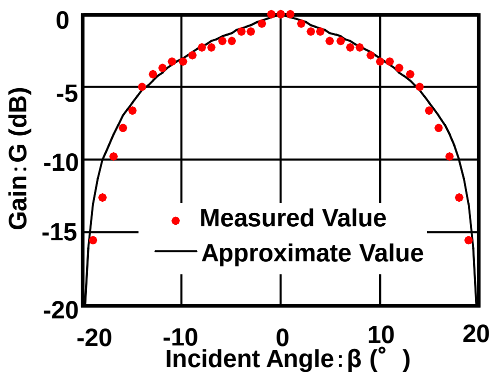

Fig. 3 Photodetector power gain to incident angle

β can be calculated by the following equation with θ.

$$\cos\beta = \frac{\cos\theta + k\sin\theta\cos\gamma}{\sqrt{k^2+1}}, \quad (3)$$

where γ is an LED lighting arrangement angle, and k is the ratio of the lighting distance r to d ($k = r/d$).

3. Evaluation of receivable signal sequences

3.1 Simulation conditions

Computer simulation was performed to evaluate BER performance at photodetectors by spatially parallel transmission. Table 1 shows simulation conditions. QPSK modulation was used. The receivable range of photodetector incident angles was set to be ±20˚ based on measured values. The angles between photodetectors were set to 10˚, 20˚, and 30˚. The distance attenuation factor α in Eq. (1) was set to be 3.0 based on measured values. The carrier-to-noise ratio (CNR) was set to be 20 dB at the received power of P_0. The LED lighting distance r was normalized by the ceiling height d and set to be 0.5d, 0.75d, and 1.0d.

The LED lighting signal with the highest received power was set as the desired signal, and the other LED lighting signals were set as interference signals. When plural photodetectors can receive the light from the same LED lighting, only one photodetectors with the best BER was assumed to be receivable.

Table 1 Simulation conditions.

Modulation scheme	QPSK
Receivable incident angle range	±20˚
Angle between photodetectors: θ	10˚, 20˚, 30˚
Distance attenuation factor: α	3
Distance between LED lighting: r	0.5d, 0.75d, 1.0d
CNR normalized by P_0	20dB

3.2 Evaluation results

In the BER performance evaluation, an evaluation area assumed for actual use was set in which it was divided into 2601 (51 x 51) points. BERs of 9 photodetectors at each point were calculated, and it was determined that the photodetectors with the BER of 1.0×10^{-3} or less were receivable at each point. Receivable bits per symbol time was calculated from the number of the determined photodetectors where QPSK is used, and two bits can be received per photodetector.

Figures 4, 5, and 6 show the number of bits that can be received when the distance between the LED lighting is 0.5d and the angle θ between the photodetectors is set to 10˚, 20˚, and 30˚, respectively. The black dots in the figure indicate LED lighting locations.

Figure 4 shows that the receivable bit number at the evaluation points located between LED lighting is larger than that at the points directly below LED lighting. This is because when θ is small, the desired LED lighting of all photodetectors becomes the same lighting directly above, and it results in only one receivable photodetector. On the other hand, photodetectors at the points between LED lighting can receive the signals from different LED lighting in parallel, and more bits can be received.

Figure 5 shows that signal transmission is possible at all points in the evaluation area, and the transmission with multiple photodetectors can be realized at almost all points. The results show that appropriate angle setting between photodetectors can parallelly transmit multiple signal sequences at the points both directly below and between LED lighting.

Figure 6 shows that there are impossible points for signal transmission between LED lighting where the number of receivable bits is 0. This is because no signal can be received at the center photodetector, and the signals from plural LED lighting are simultaneously received at the other photodetectors in which their signals become interference with each other. On the other hand, the maximum number of receivable bits increases as compared with those of 10˚ and 20˚. This is because no interference is received at several photodetectors of the points directly below LED lighting.

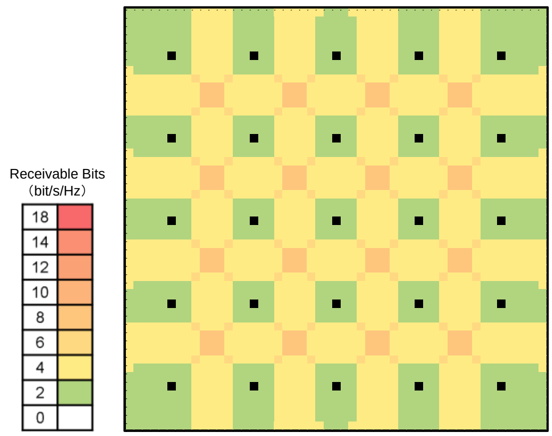

Fig. 4 Receivable bit number in evaluation area ($\theta = 10^\circ$)

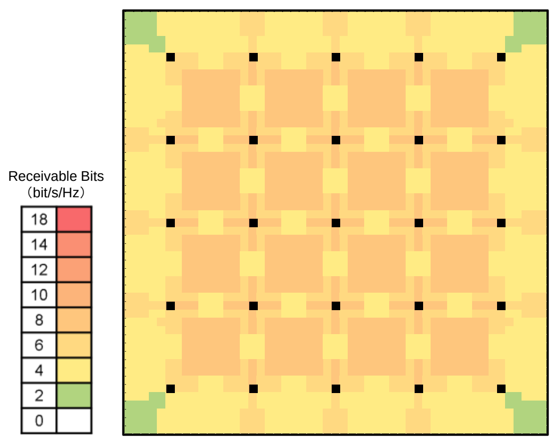

Fig. 5 Receivable bit number in evaluation area ($\theta = 20^\circ$)

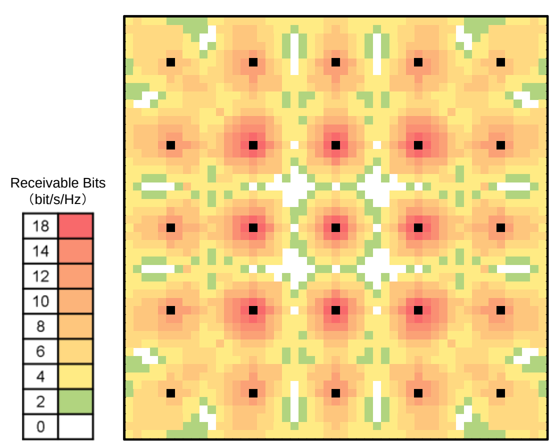

Fig. 6 Receivable bit number in evaluation area ($\theta = 30^\circ$)

Figure 7 shows receivable bit number distribution to θ. The results show that the evaluation points of 97.1% can receive more than 4 bits at the θ of 20˚.

The average receivable bit numbers were calculated based on the results in Fig. 7. The numbers are 3.5 bits, 5.8 bits, and 6.3 bits at the angle θ of 10°, 20°, and 30°, respectively. The results show that spatially parallel signal transmission by the angle θ of 20˚ and 30˚ can receive about 3 signal sequences at the same time, and the angle setting of 20˚ is more practical because there is no point with the receivable bit number of 0.

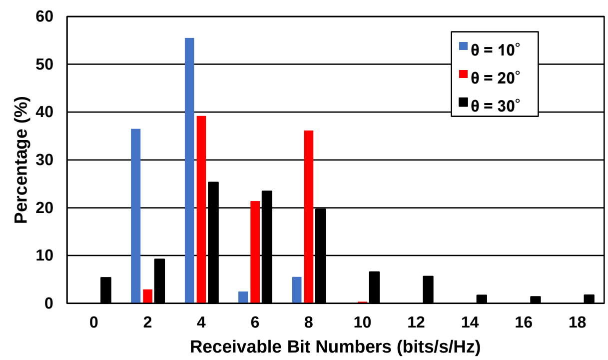

Fig. 7 Distribution of receivable bit number

Figure 8 shows average receivable bit numbers to the angles between photodetectors when the distance between LED lighting r is set to 0.5d, 0.75d, and 1.0d. The results show that there is the angle between photodetectors that maximizes average receivable bit numbers with respect to the LED lighting distance.

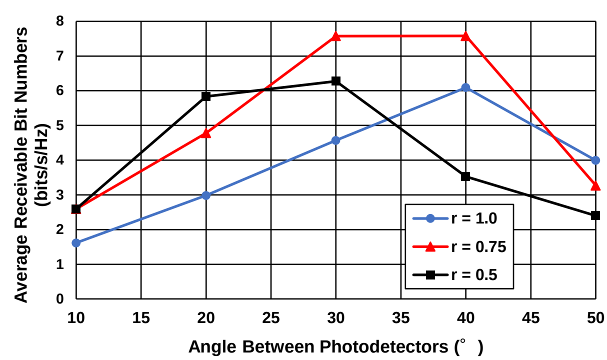

Fig. 8 Average receivable bit number to LED lighting distance

4. Conclusion

This paper has been evaluated the increase of receivable signal sequence numbers by spatially parallel signal transmission based on reception performance in LED visible light wireless communication. The evaluation results show that spatially parallel signal transmission is feasible at almost all evaluation points and receivable signal sequence numbers can be increased by appropriately setting the angle between photodetectors for spatially parallel signal transmission.

Acknowledgments

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