

Miyair, Kantaro; Matsuda, Shunsuke

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Multi-use of urban infrastructure: Wireless light carried digital communication based on LED street lighting

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**Multi-use of urban infrastructure;
Wireless light carried digital communication based on LED street lighting**

Kantaro Miyairi

Address: Keio University Shonan Fujisawa- campus Kokuryo laboratory
Kanagawa- ken Fujisawa-shi Endo 2322

Affiliation: Graduate school of media and governance Ph.D. course

Email address: miyairi@sfc.keio.ac.jp

Phone number: 046-649-3557

Dr. Shunsuke Matsuda

Address: Yokohama-shi Kohoku-ku Ookurayama 1-10-6

Affiliation: Director of experience laboratory

Email address: shunsuke.matsuda@gmail.com

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Abstract

The rate of diffusion of mobile phones among consumers is increasing rapidly. Therefore connect ability of mobile phone is very important issues in Japan. In some scenes such as in the elevator, car, and after big earthquakes, the connection is unstable. Man cannot see the radio waves therefore it is very inconvenient when he or she wants to find the connection. This study will propose an easy to find and stable connection spot using Visible Light Communication (VLC) which is immature and minor technology. Easy to find is the most important, therefore existing facility is chosen as a base of VLC. In this point, this paper will examine the concept of multi-use of urban infrastructure using Light emitted diode (LED) street light for both function of lighting and wireless digital communication. There are some examples of multi-use: ADSL service using the pre-existing copper cable that is mainly used for telecommunication (voice). And glass fiber that is railed inside of sewerage system. From these cases, there is prerequisite for using pre existing building for another function as follows: 1) the additional purpose does not ruin the basic purpose. 2) Foresee ability there is technological and economic benefits between basic purpose and additional purpose. 3) Multi-use will add new business potential to the basic purpose. The multi-use of infrastructure is generally regarded as a part of Private Finance Initiative (PFI) and main purpose of it is public utilities with market power. This paper defines multi-use of infrastructure as "Using one physical building that is constructed basic purpose for additional purposes" and focuses on affinity of both basic function and additional function. The appearance of new technology may enable the multi-use of infrastructure and it is important to examine its potential usage. From this view point, the research groups plan to examine how this concept can be applied with LED street lighting which is added VLC (Research Question). From the point of policy, due to low CO₂ consumption of LED lighting, it is dipped that street light of High Intensity Discharged lamp (HID) will be replaced by LED street light in near future. Therefore, it is meaningful to design to propose good combination of multi-use of LED street light. VLC is a data communications medium using visible light from LED. And it is selected because of several technological reasons, VLC have a good affinity with LED lighting and potentially seems to provide good business services. The main advantage of VLC is as follows. 1) Currying the data as an advertisement to the area where the light reaches. 2) Harmless to human and other animals. 3) Do not ruin the design and landscape of the small shopping area. The characteristic of it is safety, simple installation procedures and band-licensing free. First of all, the study groups focus on VLC to adopt LED street lighting in outside environments. An experiment was made in La La garden: small business shopping street located in Kita-ward Tokyo from 26th February to 5th March 2010. The research groups developed LED street lighting modulated by text and movie data and mobile Augmented Reality (AR) terminal test set. The transmission of both text data and movie data is one way from the LED street lighting to AR terminal device. It is first trial in the world to examine it in outside environment where the sunshine disturbs the communication. Finally, the maximum transmission speed marks 4Mbps and transmission amount marks 5kbt. It enables to send information related to shop that is located next to street light. Due to this characteristic, the people who test this service can choose information which they need and they are not annoyed by too much information. This function which radio wave cannot achieve is brought by visible light. From the interview of the participants of this service, there are further potential business needs existing in VLC based on lightings. As a conclusion, there are technological achievements and business suggestion as follows: 1) the outside environment the VLC one way communication device is fit for use. 2) There is tangible and potential business usage in the multi-use of LED street light from the point of area controlled communication.

In addition, it is estimated that if the all of street light in Japan have replaced to LED from HID, the saving of CO₂

emission will meet about 70% (2,550,000t) of recommended CO₂ emission in the light sector by the Kyoto protocol (1997). Multi-use of LED street light may accelerate implementation of LED and may contribute the environments.

1. Introduction

1.1 Visible light communication (VLC)

The rate of diffusion of mobile phones among consumers is increasing rapidly. Therefore the connect ability of mobile phone is very important issues in Japan. In some scenes such as in the elevator, car, and after big earthquakes, the connection is unstable. Man cannot see the radio waves therefore it is very inconvenient when he or she want to find the connection. This study will propose an easy to find and stable connection spot using Visible Light Communication (VLC) which is immature and minor technology.

VLC is developed in Japan. Haruyama(2006) defined this as follows, "Data communications medium using visible light". It is one of the most advanced wireless technologies and from the following table its wave length is on lighting layer. In 2010, this layer does not required to take band-license for usage. From some other experiments, it has high reputation from people who used it such as "It is easy to understand where he or she can communicate.", "It is very stable to transmit data." and "He or she has futuristic feeling when he or she uses it."

Table 1 wave and frequency

Frequency	Wave length	name	application
3kHz-	100km	Very Low Frequency	
30kHz-	10km	Low Frequency	
300kHz-	1km	Medium Frequency	AM radio,
3MHz-	100m	High Frequency	International radio
30MHz-	10m	Very High Frequency	FM broadcasting, TV
300MHz-	1m	Ultra High Frequency	TV, mobile phone, wireless LAN
3GHz-	10cm	Super High Frequency	Wireless LAN, Radar, satellite broadcasting
30GHz	1cm	Extremely High Frequency	Radar
300GHz	1mm	Sub millimeter wave	
3THz-	0.1mm	Infrared	(fiber communication)
-	<u>0.7μm</u>	<u>Visible</u>	<u>“visible light communication”</u>
-	0.4μm	Ultra Visible	

1.2 Affinity to Light Emitted Diode (LED)

To use the LED street light as a base of VLC, it is important to check the affinity between VLC to several lamps. The following table is about the affinity between VLC and lightings. It shows that LED has very good affinity to VLC.

Table 2 The affinity between VLC and several lamps

	LED	Fluorescent lamp	HID
Modulation rate	○	△	×
Cost for lighting	△	◎	○
Safety for human body	○	○	△
Freeform	○	△	×

Then further characteristics of VLC for usage are as follows;

- 1) Carrying the data within the light reaches. In other words, it can control the communication area.
- 2) Harmless to human and other animal. In other words, it does not use radio wave.
- 3) The LED lighting has both function of communication and lighting.

VLC has these merits. At the same time VLC has demerits 1) It is difficult to use it outside environment where the sunshine disturb the communication. 2) It is difficult to make 2 way communications at the same time. From these characteristics the study groups focus on “Area controlled communication” in outside environment because it seems to contribute to create the “easy to find connection spot”. To create mobile phone connection, these characteristics of VLC are big advantage. As a base of mobile phone connection, the existing building is chosen. Therefore it is important to examine the usage of multi-use theoretically. Next section is about review of “multi-use” and significance of replacement from HID to LED street light.

2. Existing evidence

2.1 Concept of “Multi-use”

The multi-use of infrastructure is generally regarded as a part of Private Finance Initiative (PFI) and main purpose of it is public utilities with market power. Another point of view, there is a possibility to see the multi-use as platform business. Imai and Kokuryo [1994] proposed the concept of “platform businesses”, which are defined as follows, “Business that provide, as a private entity and in an open manner, such products or services that stimulate trade among third parties and / or the creation of new businesses”. While the Platform business concept is developed to explain marketing strategy of personal computer and subsidized goods, this paper puts this concept into the multi-use of infrastructure. There are some examples of “multi-use” in the field of digital communication. This paper defines multi-use of infrastructure especially in the field of digital communication as “Using one physical building that is constructed basic purpose for additional purposes”. From the literature review, some categories are found as follows. The horizontal bar is about physical layer (divided /same) and vertical bar is about purpose layer (same / different). Purpose layer is very important because Japanese infrastructure is strictly bound by specific law. In other words usually it is not allowed to use it for multi-purpose. Therefore, following examples especially cell C and cell D are special in this point. Cell A is about rental room type × same purpose; example is “Dark fiber”. Dark fiber is an optical fiber infrastructure (cabling and repeaters) that is currently in place but is not being used. And it is available for use in fiber-optic communications. In this cell, the optical fibers are physically divided and purpose is same. Cell B is derivation type × versatility; example is ADSL.

ADSL (Asymmetric Digital Subscriber Line) is a high-speed Internet access service that utilizes existing copper telephones lines to send and receive data at speeds that far exceed conventional dial-up modems. It shares same physical lines and the purpose is about communication. The cell C is rental room type × same purpose; example is Wi-Fi on street light. In this case, Wi-Fi device is settled on the street lights. The purpose of Wi-Fi differs from the purpose of street light and this case physical layer is divided. The cell D is derivation type × versatility ; example is PLC(Power line communication). PLC is a system for carrying data on a conductor also used for electric power transmission. This service shares same line for both electric power transmission and carrying data. And the purpose is different. It is clear multi-use contributes to cost efficiency to additional service, but not all of multi-use is able to success. In the Japanese case of ADSL, service was strongly objected from NTT because it was against NTT's practice. From the interview, it was founded that the fiber cable that is constructed in sewage system that is categorized on cell B is not meet cost benefit. In the Japanese case of PLC does not technologically meet the practical use. And wireless Lan is now commodity in the market. Therefore it may not win the competition. Furthermore, distant transfer does not legally be allowed in Japan.

Table 3 several types of “Multi-use”

	Rental room type	Derivation type
Same purpose	<u>A</u> <u>Dark fiber</u> Basic: Information transfer Additional: Information transfer	<u>B</u> <u>ADSL</u> Basic: Voice communication Additional: Internet
Versatility	<u>C</u> <u>Wi-Fi on street light</u> Basic: Street light Additional: Wi-Fi	<u>D</u> <u>PLC</u> Basic: Energy supply Additional: Information transfer

From these reviews, the study groups find the essential prerequisite for using pre existing building for another function as follows:

- 1) The additional-purpose does not ruin the basic purpose.
- 2) Foresee ability there is technological and economic benefits between basic purpose and additional purpose.
- 3) Multi-use will add new business potential to the basic purpose.

The study groups plan to make an experiment that can meet these essential prerequisite, using Visible light communication (VLC) on LED street light. VLC meets the needs of people from small shopping area. From the interview there are clear needs for wireless communication outside as follows.

- 1) Some people are very negative to radio wave; they need wireless communication without using radio wave.
- 2) People from small shopping street do not want to take band-license for wireless communication; they need wireless communication without band-license.
- 3) There are some devices on small shopping street such as speaker, camera and lighting which are controlled individually with lan cable. In the future, people from small shopping street want to control all these devices using wireless communication.

Without 3), VLC seems to meet these requirements.

2.2 The significance of LED street light in La La garden and whole Japan

In section 1.2 it is clear that VLC has a good affinity to LED. There is a movement to replacing current HID street light to LED in the policy section. LED is smaller than HID therefore after replacement there is a vacant room. And this vacant room can be used for other additional devices as “multi-use”. Therefore, it is important to calculate the significance of LED street light.

First of all, to clear the efficiency of LED for both purpose of economic merit and CO₂ emission, the study groups calculate the efficiency of the site (La La garden). Then, the study groups spread the calculation into the whole Japan. The following table shows the comparison between HID and LED. The result shows that economically 50% of the fee is cut off, electronic consumption: 76% cut off, the CO₂ emission is defrayed to 80%. From this calculation, the replacement from HID to LED is significant.

Table 4 The impact of LED street light on La La garden.

	Feather type street light			
	HID	LED	Reduction	Ratio of reduction
Product age (hour)	12,000	40,000		
Electricity consumption / one product	200VA	40VA		
Electricity consumption / Month(yen/USD)*1\$=¥82	¥752 (\$9.17)	¥376 (\$4.58)		-50%
Numbers in La La garden	44	44		
Electricity consumption / year	¥397,426 (\$4,846.65)	¥92,564 (\$1,128.82)	¥-304,862 (\$-3,717.8)	-76%
CO ₂ emission /year	13066.8kg	2613.6kg	-10453kg	-80%

Then the study groups calculate the impact of LED to all over Japan. There are approximately 11, 000,000 street lights all over Japan. Currently it is estimated that CO₂ emissions from them is approximately 340,000 t . If the HID street light replaced by LED street light, the CO₂ emission will drop by approximately 1/3. This will meet about 70% reduction of emission in the light sector recommended by the Kyoto protocols (1996). From this result, the social impact of LED is significant in Japan. Then it is very important to replace speedy. From the policy point of view HID street light will be replaced by LED. If the “multi use” produces the useful business and it accelerate the replacement, “multi-use can contribute to social norm.

3. Experiment

3.1 Technological prerequisite

In the section 2.2 it is clear the significance of LED street light and from the review several prerequisites are important for “multi-use”. In this point, “multi-use” for VLC on LED street light fits for use. As to create narrow area communication with VLC, followings are required;

- 1) It can transmit text data and movie data
- 2) It is easy to handle.
- 3) It can be used outside environment where sunshine disturbs communication.
- 4) The distance between street light to AR-mobile phone is about 6m. Therefore it is required to guarantee at least 6m distant communication.

The study groups which are entrusted by Ministry of Internal Affairs and Communication developed the 2 kinds of prototype communication test set which meets these 4 requirements;

- 1) A LED street light which is modulated by VLC.
- 2) An Android mobile phone which can receive VLC.

VLC is a special communication method, therefore commercial mobile phones are not able to receive VLC. This test set is designed to receive one way communication from LED lighting modulated by VLC to mobile phone.

3.2 Site

The site is “La La garden”, small business shopping street located in Kita-ward Tokyo. There are approximately 72 small shops in the main street and there are 42 street lights. The length of street is about 330m and it has highest arcade in Tokyo. This site is selected because of several reasons; 1) it is typical Tokyo metropolitan landscape. 2) People in this site are interested in new technology. 3) There was a plant to replacing current HID street light to LED before the experiment was made. Therefore it is good proposal to experiment VLC.



Fig1 the picture of LaLa garden Kita-ward Tokyo

3.3 Method

The following figure2 is the advanced image of experiment. As to use LED street light multi-use, the image is drawn. From the interview of small shopping area, people have clear needs to control individual devices such as camera or speaker with one wireless network. Therefore, the study groups made a futuristic image that every device is converged inside of LED street light. However the experiment was made only with VLC based on LED lighting (Fig3).

3.3.1 VLC on LED street light

The study groups invested to install the VLC devices to 42 street lights in the site. The Ethernet is railed to each

LED street so that VLC can transmit data from LED street light to AR-mobile phones.

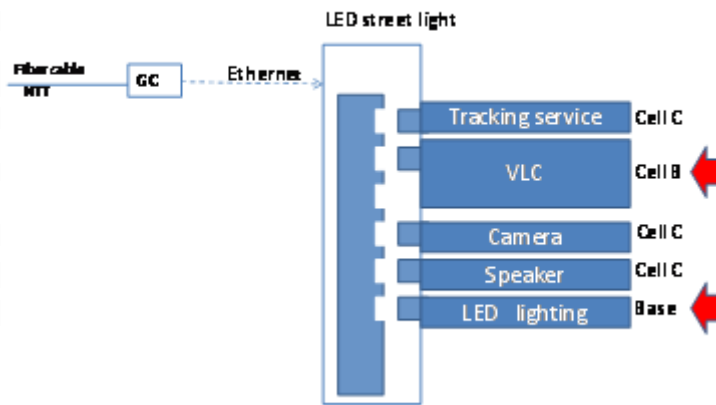


Fig.2 an image of multi use of LED street light



Fig.3 VLC on LED street light

3.3.2 Augmented Reality (AR)-mobile phone

The study groups investigated AR-mobile phone which can capture the image of small shopping street with photo-sensor. Then it shows the data which is transmitted by VLC from LED street light. Fig4 shows that AR-mobile phone captures both the landscape of La La garden and the text data which is transmitted by VLC.



Fig .4 AR-mobile phone

3.4 Experiment

The experiment was made from 14th January to 20th February 2010. The communication was one way from LED street light to AR-mobile phone. Some patterns of contents were made and they were selected to deliver most suitable street light. Due to the peoples' activity delivering time was also selected. When the street lights were transmitted contents through Ethernet, the lightings were blinked. Therefore, people who passed by the streets can get to know visually when the new contents were delivered. The contents were advertisement of small shopping street using both text data and movie data. People who had AR-mobile phone can capture the landscape of La La garden and it shows the data from LED street light. Then he or she could choose the specific street light and got the information.

4 Results

4.1 Technology part

The AR-mobile which was developed by study groups could capture the information where the sunshine disturbed transmission. Communication was one way transmission from VLC on LED street light to AR-mobile

phone. The maximum transmission speed marked 4Mbps and transmission amount marked 500kbits. This could transmit both movie data and text data.

4.2 From the interview

Not only business sector like employee of Panasonic or Google but also people who came to La La garden for shopping tried this service. Then there was more than 60 participants tried this service. Most of them said that "It is very easy to handle and very clear where he or she can get the specific information." And participants of Old people and children were also easily to use it, because 1) Operation of AR-mobile phone was mostly same with usual mobile phone. 2) Easy to find the specific street light which delivered specific information. Therefore, this test set was very familiar to even those who do not use computer or other digital communication devices. Some of the small shop owners attracted the function of area and time control service. The bakery shop owner wanted to deliver the information when the bread was baked. And people who walked near by the shop could get the information. This test set could provide such kind of services. And it did not ruin the landscape. From the employee of Google said that "The data of GPS is still inaccurate, therefore it is very useful to use ID of street light." And "There will be a business chance to propose area based searching service." A person who came from local government said that "It is useful to use it in historical landscape where advertisements are not allowed."

5 Conclusion

There were achievements of both technological and business potentials from this experiment. In 2010, it was first trial in the world to examine the usage of VLC in the outside environment. One way transmission and the maximum transmission speed marked 4Mbps and transmission amount marked 500kbits. This could transmit both movie data and text data. And transmission was very stable. Therefore, it was proved one way transmission of VLC in outside environment was practical. However, point of view of business usage it is important to design to use VLC two ways; 1) Street light to AR-mobile phone and AR-mobile phone to street light. 2) Communication between street light to street light as to reduce Ethernet terminals.

On the business potential, the best advantage of VLC is easy to understand to those who do not use digital devices. This characteristic brings the shop owners, telecommunications carriers and IT companies some potential business needs and merits. Especially, the test set which is developed by the research groups is band-license free, easy to install and do not ruin the landscape of small shopping area. The biggest contribution of this experiment is that, VLC can materialize the concept of "Area controlled communication".

On the discussion of "multi-use", there are several business advantages using street light as the base of digital communication as follows. 1) It is easy to get energy. 2) Street lights are placed in same distance. 3) The density of street light is directly proportional to population density. 4) Due to the function of lighting, street light is constructed the place without any interruption. Therefore "multi-use" for VLC on LED street light is useful in this point. On the further discussion, there is a possibility that the function of "multi-use" may be reversible. In other words, the basic function of street light is lighting, and additional function is VLC. And It may be possible to image that the basic function is VLC and additional function is lighting. This may contribute to accelerate the replacing HID street light to LED.

The big earthquakes 11th march 2011 in Japan, there was many troubles for connection of mobile phone, on the other hand, Twitter and other social media contributed the people's communication. It is true, VLC is still very minor and immature technology, but in the future VLC on LED street light will be able to contribute the mobile phone connect ability as a third way.

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