High-Definition Video Monitoring and Light Fidelity (Li-Fi) Services in Hospital on Broadband Passive Optical Network

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Internet access using wireless in medical facilities is limited because the radio waves may cause malfunctions in medical devices. In response to this situation, we proposed a "Hospital Multi-purpose Lighting Communication Network Service" in order to realize the IoT which aims at both sensing and monitoring. This service is carried out on the widely spread FTTH infrastructure. This service enables the Internet access from the hospital and the 4K-video camera to be used for remote surgery to transmit the video. Also, the use of Li-Fi in a hospital room has the advantage of being able to access the Internet regardless of radio wave restriction, as well as being able to use room lighting.

In this study, we investigated the method of bandwidth allocation by simulation and experiment by setting the traffic model, which assumed the actual use condition. Furthermore, due to the co-existence of services of communication, Internet access, and monitoring, we examined priority queue and bandwidth expansion of Li-Fi. From the results, we discuss the prospects for the "Hospital Multi-purpose Lighting Communication Network Service" in the future.

Key words: IoT, Li-Fi, 1G-EPON, Hospital network, Network infrastructure

1. INTRODUCTION

In future IoT era, various sensing and monitoring services using widely deployed access network infrastructure will be expected [1]. In addition to equipment monitoring at plants and power stations, weather observation can cover many points and areas. Sensing and monitoring can also be used for crime prevention monitors in the city and watching over in the home. To utilize the wireless radio access such as 3G and LTE is convenient solution because it can connect the sensing equipment so quickly and easily, and to utilize the existing optical broadband access network connected with in-house wireless network using Wi-Fi routers and compatible equipment is also popular solution. Although the sensing and monitoring service in the hospital is one of the most remarkable markets, the use of radio frequency is restricted because there is a possibility that medical equipment malfunctions. S. Helhel et al. indicated that interference might occur when mobile phones were used around Electroencephalograph (EEG) and Electrocardiograph (ECG) equipment [2]. In addition, the paper describes the existence of an electrocardiograph that receives the influence of 3G at a distance of 1 m. According to the paper published by E. Hans et al. since the talk mode of the mobile phone interferes with the supply amount of the syringe pump used for critical care, as a countermeasure to that, the wireless device should use more than one feet apart [3]. To overcome these interference problems in the hospital, we propose the concept of "Hospital Multi-purpose Lighting Communication Network Service" that can gather all data in the hospital without radio waves. In this paper, we firstly define the model of this network service and propose the network configuration for providing this service in the hospital on the practical FTTH infrastructure. And then we verify the feasibility and scalability of the service on the commercially available FTTH infrastructure. Finally, we discuss the possibility to deploy the Li-Fi communication.

2. Service model and its requirements

First of all, we explain is an outline of the "Hospital Multi-purpose Lighting Communication Network Service" we have proposed.. It consists of three services as follows.

1) High-definition video monitoring and transmission service;

Firstly, the high-definition video monitoring and transmission service at the operating room. From the viewpoint of high-definition monitoring at the operating room. Y. Arakawa [5] reported the trial of the remote guidance in neurosurgical operation using 4 K1 K ultrahigh definition video and 3D HD (3D high definition) video and clarified the feasibility to grasp local surgical conditions and diseased part states even at remote locations. Generally, the 4 K resolution has a horizontal resolution of about 4,000 pixels and a vertical resolution of about 2,000 pixels[6]. By using such ultra high definition images, the data transmission needs to large bandwidth resource of the network and keep connectivity and low delay less than 100 msec during operation. Consequently, we expect that this service can be utilized to send an image of surgery in real time and high definition video, and it is possible to facilitate the judgment of a specialist doctor in the remote place and to obtain appropriate instructions by the local doctor. Moreover, the medical technology data can be obtained from the surgical video.

2) Medical private Cloud service;

Secondly, the medical private Cloud service at the consultation and examination room, handing various medical data for patient’s healthcare based on the commercial broadband access service. The doctors, physicians, and medical personnel can access the medical server located the central office or the data center of a Cloud service provider via Internet.

3) Vital data monitoring and transmission service;

Thirdly, the vital data monitoring and transmission service at the hospital room using Li-Fi transmission technology. From the viewpoint of sensing in hospitals where there are a large number of sensors and monitors, it is an effective way to introduce Li-Fi data collection method in hospital rooms not using radio waves. Li-Fi is a kind of optical space communication. Moreover, secure lighting function and wireless communication function can be provided at the same time. Previously, Y. Perwej reported the application field of Li-Fi, such as smart lighting that can collect data at urban street lights, underwater communications, use in places where it is desired to avoid using radio waves in an aircraft or in a hospital. Assuming Li-Fi communication service is provided widely in the hospital bedroom, over hundred connections is needed. However, Li-Fi data transmission with high bit-rate is difficult because Li-Fi performance strongly depends on the transmission distance and the signal noise ratio of the received signal. Therefore, we decide the requirement of the throughput of Li-Fi connection to several mega-bit per second. To reduce the initial investment of the network infrastructure for these services and the operation cost, we propose these services are provided using the existing broadband optical access network.

Since three services described above must be provided simultaneously, it is necessary to set priorities among theses services. Regarding the importance of each service, we focused on the operation situation of High-definition video camera here. High-definition video monitoring and transmission service is used for cases where advice from a remote doctor is necessary or for recording as a medical technical material. In the case of High-definition video service, surgical images must be reliably delivered. Therefore, the priority of the High-definition video service is set higher than that of the medical private Cloud service and the vital data monitoring and transmission service using Li-Fi transmission. When the high-definition video service is not used, the bandwidth is divided and operated in the maximum by the other two services.

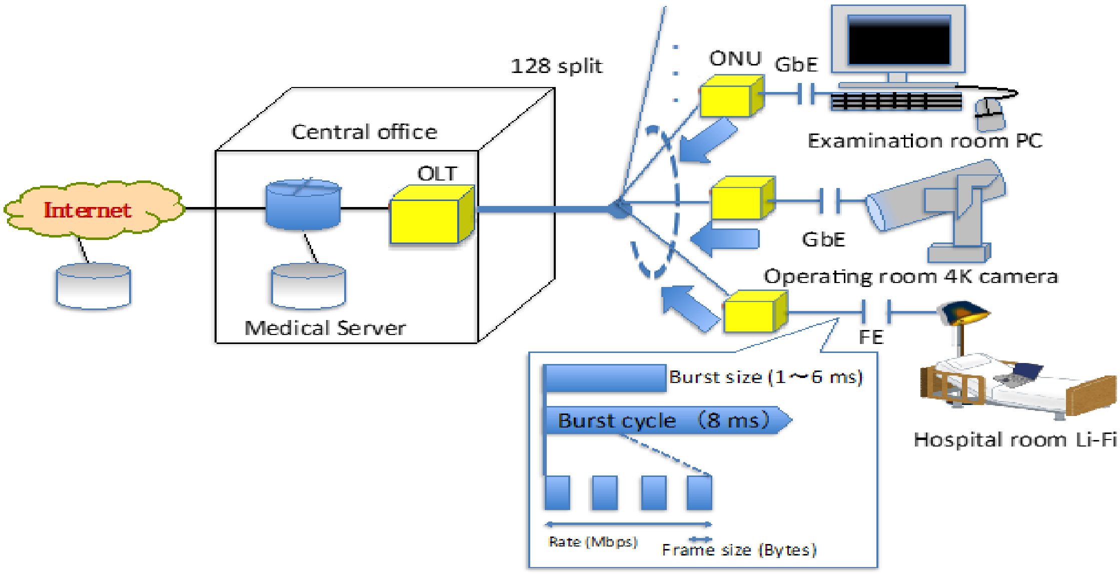

Figure 1. Hospital network configuration based on 1G-EPON connected by video monitoring and Li-Fi

3. Network configuration

Figure 1 shows the network configuration based on the existing broadband network, Giga-bit Ethernet passive optical network (1G-EPON). The ONUs located at the examination rooms, the operating rooms, and the hospital rooms, are connected to the OLT at the central office via the single-mode fiber (SMF) of 10 km long. The personal computer (PC) at the examination room and 4K-camera at the operating room is connected to the ONU via Gigabit Ethernet interface, respectively. The Li-Fi transceiver at the hospital room is connected to the ONU via 100Mbit Ethernet interface. The ONU can be connected to the OLT up to 128. The OLT has two types of bandwidth control function, one is fixed bandwidth allocation (FBA) and the other is dynamic bandwidth allocation (DBA). The ONU has two-level of the priority queue set, one is "priority" and the other is "fair".

4. Simulation results

(1) Traffic model

The traffic direction of the proposed service is mainly upstream. We therefore focus on the upstream traffic. The numerical values set for each service are described below. The burst cycle of the upstream traffic was set to be 8 msec. The data of 4K-camera was assumed to be compressed with H.264/HEVC. The bit rate was set to 1 Gbps, the burst period was set to 1 msec, and the flame size was set to fixed value 1518 byte. The bit rate of the PC was set to 100 Mbps, the burst period was set to 1 msec, and the flame size was set to be randomly variable from 64 to 1518 byte, which is like Internet access. The bit rate of Li-Fi was variable parameter from 1 to 100 Mbps, the burst period was set to 1 msec, and the flame size was set to be randomly variable from 64 to 1518 byte.. Based on the above traffic model, we investigated the feasibility and scalability of the proposed service by using PON traffic simulator "SimOliver"

(2) Dedicated High-definition video monitoring and transmission service

Firstly, we investigated the scalability of the high-definition video monitoring and transmission service on 1G-EPON. It was assumed that this service was dedicated. Here, it is noted that allocated bandwidth of each ONU was guaranteed to 150 Mbps, because, in case of no bandwidth guarantee, the bandwidth allocation is not efficient when a lot of data frames with large size are transmitted. Figure 2 shows the total throughput of the system as a function of the number of connected 4K-video. At this time, we compared the bandwidth allocation method between FBA and DBA to investigate scalability of the number of 4K-video. In case of FBA, the total throughput increases as the number of 4K-video, and reaches to 6. On the other side, in case of DBA, it reaches to 7. However, when eight 4K-videos were connected, it was also found that the throughput became almost zero with either band allocation method. As a result, it was confirmed that the scalability using DBA exceeds that using FBA., because the bandwidth efficiency using DBA is typically better than that using FBA, the total throughput of the

1G-EPON up to 1Gbps can be effectively utilized.

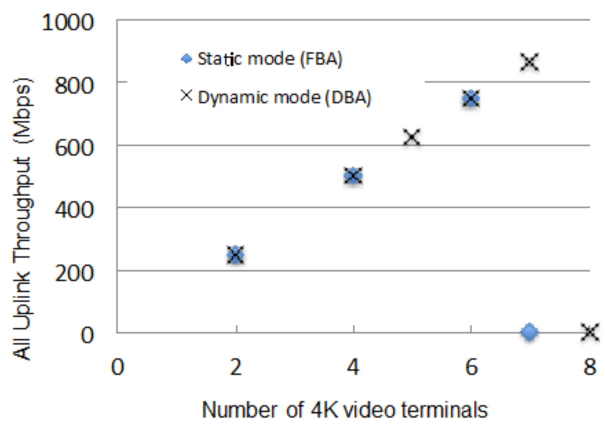

Figure 2. Total uplink throughput as a function of number of 4Kvideo terminals

(3) Co-existence with High-definition video monitoring and transmission service and Medical private Cloud service

Next, we investigated the feasibility of co-existence with high-definition video monitoring and transmission service and medical private Cloud service on 1G-EPON, and also investigated the scalability of the number of connected PCs. From the result above, the bandwidth of each 4K-video is guaranteed, and DBA is used as the bandwidth allocation scheme.

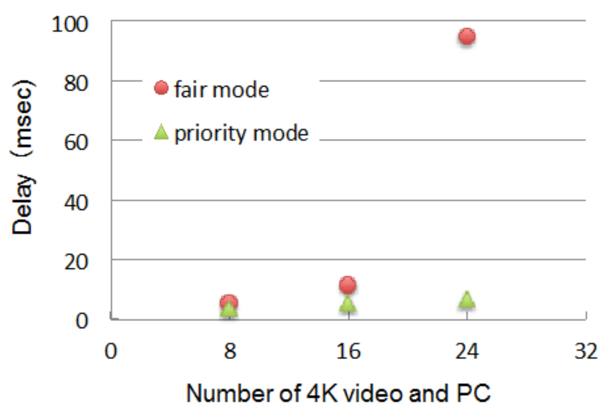

Figure 3. Delay as a function of number of 4K video plus PC

Figure 3 shows that transmission delay as a function of number of 4-K video plus PC. Here, the number of 4-K video was set to 4. As a result, it is confirmed that both data traffic can be transmitted and at least 20 PCs can be connected to the Internet when four 4K-videos are connected. At this time, we also investigated the comparison between the case where the priority queue is set (priority mode) and the case where it is not set (fair mode). The traffic regarding as 4K-video service was set to high priority queue, and the other are set to fair queue. The delay increase can be drastically suppressed by the priority mode. The delay becomes smaller than that in the fair mode in which packets of two services are processed at the same time. This is because the packet processing of 4K-video is preferentially performed using setting the priority queue. Hence, it was confirmed that the priority queue is effective for delay suppression in simultaneous operation of high-definition video monitoring and transmission service and medical private Cloud service.

(4) Triple play service

Finally, we investigated the feasibility of simultaneous provisioning with fully three services including Li-Fi connection on 1G-EPON, and also investigated the bit rate upgradability of Li-Fi terminal and robustness against traffic load. From the result four 4K-videos guaranteed the bandwidth, 20 PC terminals and 104 Li-Fi connections were connected.

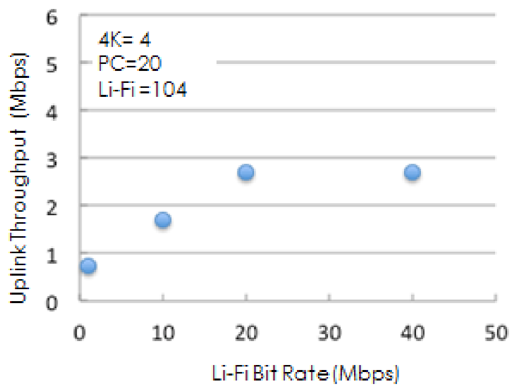

Figure 4. Li-Fi uplink throughput with co-existed 4K video monitoring as a function of bit-rate performance of Li-Fi device

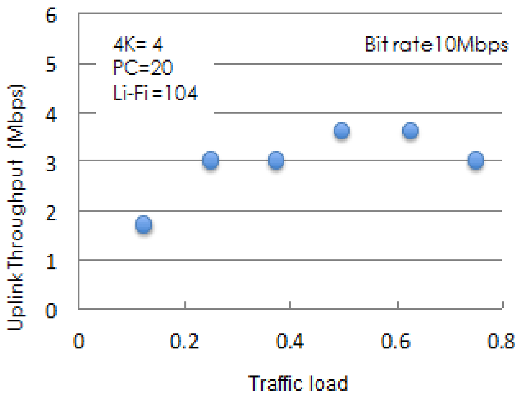

Figure 5. Traffic load dependence of uplink throughput□

Figure 4 shows the simulation result of Li-Fi uplink throughput. The uplink throughput steadily increases as the bit-rate of Li-Fi device increases up to 20 Mbps under the condition of four 4K-video and 20 PC terminals and 104 Li-Fi connections set as above, and the total uplink throughput of Li-Fi can be expected to 3 Mbps. From this result, it was found that Li-Fi upgradability as shown here would be satisfied with typical usage of vital data monitoring in addition to Internet access in the hospital room.

Figure 5 shows the correlation between traffic load and throughput when the Li-Fi bit rate is fixed at 10 Mbps. In this simulation result, it is found that the throughput does not decrease until the load amount of the Li-Fi terminal reaches 60%. The reason why the throughput reduces at the load amount of 20% is because the other two services use the bandwidth. When the Li-Fi load is 30% or less, the traffic throughput of the Li-Fi terminal is proportional, but when the load is 30% or more, it competes with the PC traffic, so the throughput reaches the maximum (about 3 Mbps) even if the Li-Fi traffic load increases.

5. Discussion

In this paper, we could show the feasibility of coexistence of three services consisting of operation of 4K-video camera at the operating room in the hospital, Internet access by PC and wireless network by Li-Fi. We describe the merit of these services from the simulation result. Firstly, Internet access at the hospital is limited to use wired connection from examination room. On the other side, wireless and visible light communication by Li-Fi has an efficient data throughput and its scalability up to 104 terminals and can contribute to useful sensing and patient's Internet access in a hospital room where radio waves cannot be used. Secondly, as a remote medical care, high-definition video service by 4K-video is indispensable. This network service can provide several high-definition video channels with bandwidth guarantee method, so it is possible to communicate for a long time with a high definition video and the influence on the network inside the hospital can be avoided. Thirdly, when these three services are provided at the same time, it is possible to quickly respond by accurately grasping the patient's condition, and it is also possible to provide high-level medical care anywhere.

Next, we briefly discuss a problem of this service. Li-Fi is visible light communication, and communication cannot be performed at turning-off time at night in a hospital. To solve this problem, when using it for sensing of a patient, communication can be performed without interruption by illuminating only the sensing terminal. There is also a way to use infrared rays only at night.

Finally, as a previous work, there is "Distributed 4K-Video Camera Monitoring service on Ethernet PON System using Hybrid Bandwidth Allocation" by A. Shoji et al. [7]. In that research, they proposed 4K-video camera monitoring service on 1G-EPON using DBA mode and queue priority, and showed the feasibility of coexistence with Internet service on the same branch. In this research, we applied another service using Li-Fi on 1G-EPON in the hospital. Consequently, we showed quite different types of service can be provided on the 1G-EPON using adequate bandwidth management. As a future work, sophisticated bandwidth allocation technique would be expected for large scale PON system accommodated with huge amount of various IoT devices.

6. Summary

We proposed "Hospital Multi-purpose Lighting Communication Network Service" on a widely prevalent FTTH infrastructure. This service use 1G-EPON system while dividing it in a large scale, can provide high-definition video surveillance, Li-Fi connection and broadband Internet access.

In consideration of broadband nature and scalability of the number of accommodated users, and economic efficiency, a hospital network was constructed on the premise of a multi-branched Gigabit Ethernet PON system. Moreover, in order to ensure scalability while coexisting multiple types of services, we showed that "bandwidth guarantee", "adoption of priority queue", and "dynamic bandwidth allocation" of 4K video service is effective. As a result, it was shown that it can be extended to four 4 K video, 20 PC terminals and 104 Li-Fi terminals. We showed that the throughput is improved up to about 3 Mbps by improving the bit rate of the Li-Fi terminal in the network where all 128 terminals are accommodated. We also showed that no reduction in throughput is seen even at a load of 60%.

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