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Examination of Optical Wireless LAN on Distance Learning System

Kayo Shimizu[1], Chiemi Fujikawa[1], Makoto Akiba[2], Kazuhiko Wakamori[3] and Kashiko Kodate[1]
[1]Department of Mathematical and Physical Sciences, Japan Women's University
[2]National Institute of Information and Communications Technology
[3]Hamamatsu Photonics K.K.

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Abstract: We studied the weather dependability of an optical wireless system which was set up in Japan Women's University-Waseda University (a distance of 800m). By field experiments, we obtained the availability of 99.9%. We also investigated the relation between real-time distribution image and bit error rate, and questionnaires on the distribution image were given to students. As a result, the normal image for use in lectures is obtained when bit error rate in this optical wireless LAN was 7.0×10^{-7} or less. Therefore we confirmed that this system could utilize as an e-learning system and the distance learning. Since, we carried out twice actual classes using the optical wireless LAN with Waseda University. Furthermore, we have observed about sudden drops (dips) in the received optical power, which continues approximately 1ms at the time of the rain in this optical wireless system. We confirmed that the bit error rate of this LAN falls when the dip occur.

Key words: optical wireless LAN, distance learning, real-time interactive distribution, atmospheric propagation

1. Introduction

The educational system has gradually shifted from a face-to-face to an e-learning system, which has become prevalent in advanced countries with the advance of information technology, and connection of global networks. In North America and Europe, 80% of the educational institutions have introduced some form of e-learning. For example, since April 2001 the Massachusetts Institute of Technology has provided its syllabi, lecture notebooks, question sections, examinations, and lecture references through the Internet. Video files of lectures are also available[1)]. At Stanford University, about 250 courses for engineers have been established through the Stanford Center for Professional Development (SCPD) and lectures have been distributed through the Internet since 1995[2)].

In Japan, university establishment standards were revised in March, 2001, and course credits can now be earned through not only "the remote class of the video-conferencing type" but also "the Internet utilization class". This change was made to support the development of e-learning systems. Many studies have been done on the systems needed to support e-learning and on the development of suitable content. Furthermore, an educational style that will strengthen interaction and cooperative learning abilities, considered an improvement over conventional class behavior, has been implemented. For example, the "iii online" Internet site provides lectures through joint cooperation between the University of Tokyo's Graduate School of Interdisciplinary Information Studies and the National Institute of Multimedia Education (NIME)[3)]. In addition, the "on-demand classes circulation forum" of Waseda and Keio Universities which mainly manages, will start at 2005[4)], and e-learning has been introduced in many other organizations offering higher education.

At Japan Women's University, the "Research and development of an education content and delivery system among more than two universities for the next-generation Internet environment" project (September, 2001 - March, 2004) was completed by the Telecommunications Advancement Organization of Japan (TAO). This project had three main themes: (1)

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content creation: teaching materials and lecture notes that can be recycled through a common platform, (2) a next-generation multimedia content delivery system based on an optical wireless LAN, and (3) data acquisition for an education/research system and a corresponding control system[5]. So far, we have been examining the following about the theme of (3), we have studied the effectiveness of an optical wireless LAN as a next-generation multimedia distribution system for e-learning[6], and the application of an optical wireless LAN to a next-generation education system[7].

To realize an e-learning system that provides an acceptable download time and image quality, sufficient line capacity is needed. A broadband line enables (1) short download times, (2) high-quality images, (3) no delay in the streaming of large images. If high-quality images can be delivered, such a system can approach the reality of a face-to-face lecture environment.

In the current e-learning market, most systems are based on a video-on-demand (VOD) approach. However, if stable real-time interactive distribution is enabled, students will be able to watch and listen to a lecture as it is given, and participate in a subsequent Q&A session and discuss the topic with other students in real-time. This should support the development of a more effective educational style.

Optical fiber cables are typically used as broadband transmission lines. However, an optical wireless system is sometimes used instead in areas where local conditions make infrastructure maintenance difficult. An optical wireless LAN combines the high-volume distribution of optical fibers with the flexibility of a wireless connection. The advantages of optical wireless LAN compared with wireless LAN using the 2.4 GHz band provides high throughput (the maximum commercial transmission speed is 2.5 Gbps) that is secure and has no effect on the human body or other electronic devices. An optical wireless LAN offers the advantages, compared to optical fiber, of a favorable cost/performance ratio, the rapidity, and excellent flexibility. An exclusive-use LAN connecting distant points can be quickly and easily installed, so connection fees after construction are unnecessary. In Wakkanai City, a network that combines 2.4GHz wireless (IEEE802.11b, 11 Mbps) and optical wireless (100 Mbps) connection links junior high schools, high schools, universities, civic centers, and a library in the city[8]. In "the school Internet project", optical wireless LAN is used in a lot of area as one of the FWA lines[9]. In addition, as was demonstrated immediately following the September 11, 2001 attack on the World Trade Center, an optical wireless system can be used to help restore a communications network that is almost completely destroyed and provides a valuable backup line to optical fiber or wireless communication networks.

Optical wireless can be used to interconnect the LANs of schools and regional intranets, but not much technical data has been collected on how atmospheric propagation characteristics affect the system availability of optical wireless compared with electric-wave wireless. To apply optical wireless connection to e-learning, which needs large-volume, real-time, interactive communication, several technical issues must be resolved: (1) light wave propagation characteristics must be analyzed to enable highly reliable connection, (2) an outdoor point-to-multi-point (P-MP) connection system is needed that is inexpensive and easy to use, (3) a wavelength should be used that will not damage the eye.

In this paper, we focus on the light wave propagation characteristics and verifying the usefulness of optical wireless LANs as a distribution system for distance learning. In Section 2, we discuss our results regarding the effect of weather conditions on transmission and the degradation of transmitted images and sounds. Section 3 describes our evaluation of distributed images based on a student questionnaire regarding the real-time distance learning distribution of images in both directions between Japan Women's University and Waseda University. We discuss the light wave propagation and how we can realize a more stable distance learning distribution in Section 4 and conclude in Section 5.

2. Influence of atmospheric propagation in real-time image distribution

2.1 Reduction of received optical power in atmospheric propagation

To establish an e-learning environment, stable long-distance distribution and real-time image distribution are required. Because an optical wireless LAN relies on free-space transmission, the transmission property is likely to be affected by the absorption and dispersion of gas molecules and aerosols in the atmosphere, and by precipitation such as rain or snow. Although degradation of the line quality due to weather phenomena is expected, there is no general basis for evaluating the influence of such phenomena. The Infrared Communication

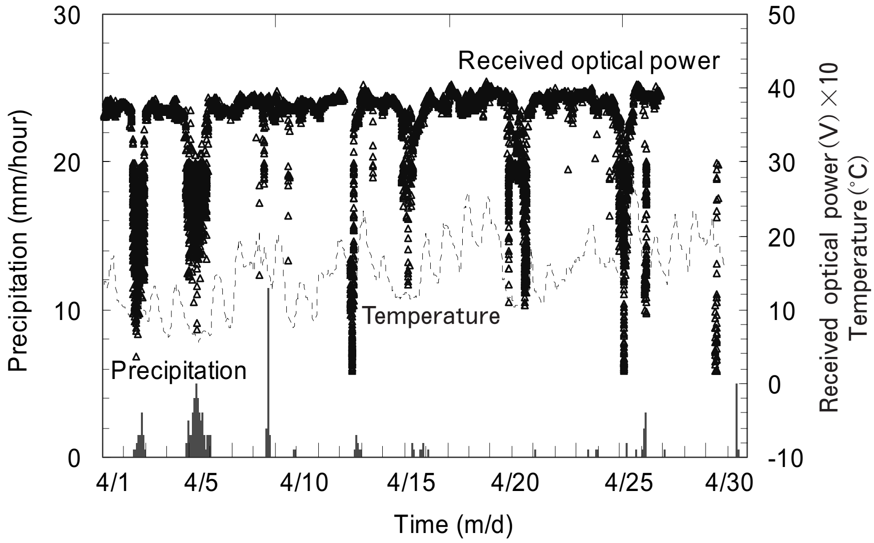


Fig. 1 Example of weather dependence of received power.

Table 1 Charcteristics of the optical wireless communications system.

Company	Hamamatsu Photonics K.K.
Product	PHOTOLINER DO-L1000
Wavelength	780, 830 nm
Average Power	10 mW
Bandwidth	10 Mbps－300 Mbps
Detector	Si-APD
Range (Max)	2 km
Size	160 (W) ×200 (H) ×464 (D) mm

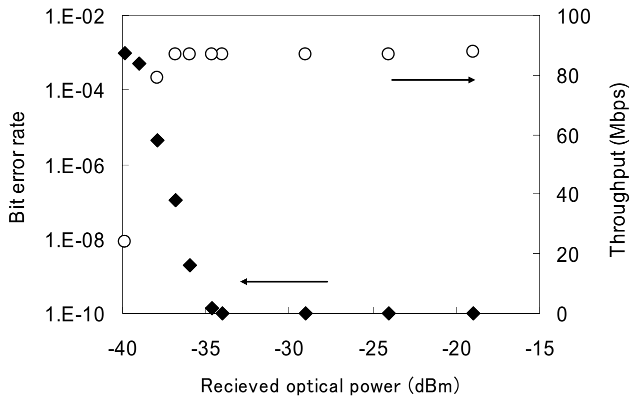


Fig. 2 BER and throughput as functions of incident power.

Systems Association (ICSA) has studied the dependence of light wave propagation on weather with the goal of establishing a line design index that would be useful for maintaining line quality[10]. Transmission properties were measured for one year (October, 2001 - October, 2002) in Tokyo, and visibility was shown to be an effective index for the amount of light wave attenuation[10]. However, more data is needed. A method needs to be established for evaluating line quality based on precipitation, and this would lead to more data of higher accuracy.

In December 2002, a high-speed optical wireless system (PHOTOLINER DO-L1000: Hamamatsu Photonics K.K.) was set up to distribute mass content between Japan Women's University and Waseda University (a distance of 800 m). The specifications of this system are shown in Table 1. We have continuously measured the received optical power, precipitation, and temperature for one year to determine the weather dependence of this system's transmission. These results are shown in Fig. 1. In this system, if the received power decreases, the bit error rate (BER) will rise and throughput is likely to fall. The BER of a signal (125 MHz) and throughput as functions of the received optical power are shown in Fig. 2. When the received optical power was greater than -37 dBm, the transmission was error free and the throughput was 80 Mbps. During this measurement, the received optical power was less than -37 dBm 0.1% of the time. That is, the estimated availability in this optical wireless LAN was 99.9%.

2.2 Image quality degradation when received optical power is attenuated

We next carried out a real-time image distribution experiment. We used a DV server (C9290: Hamamatsu Photonics K.K.) as the streaming server, and an IEC61834 (picture size: 720×480, frame rate: 30 fps) digital video signal. Weather conditions often reduced the received optical power, which we expected to lower throughput. For images to be useful as teaching materials for distance learning, the degradation of distributed images due to light wave attenuation must be within a certain limit. In an optical wireless system, the amount of light wave attenuation during propagation in the atmosphere depends on atmospheric conditions, and it is difficult to quantitatively reproduce the amount of light wave attenuation by artificial means such as by using a filter. In this experiment, we set up an optical wireless system where the sender and receiver were within 3 m of each other inside a room. Since the effect of transmission through the atmosphere would be negligible, we artificially created light wave attenuation using an ND filter. We then distributed an image, recorded the distributed image on videotape, and measured the BER under the same conditions. We examined the relation between the amount of light wave attenuation and the BER, and found that it was possible to quantitatively evaluate the degradation of an image using this BER.

As shown in Table 2, the image was distributed with a random error condition ranging from a BER of 1.0×10^{-4} to an error-free state. The quality of each image was evaluated through a questionnaire survey of 12 students. We showed the students the distributed image when the received optical power was artificially decreased by the ND filter, and had the students rate the image quality, sound quality, and applicability to an e-learning lecture. More than 50% of the students reported that a BER of 5.0×10^{-5} produced the best results. In reference to the image quality, the students

Table 2 Relation between BER and image degradation.

BER	Image degradation
1.0×10^{-11}	Without ND filter
2.0×10^{-9}	Sometimes, a sound with slight noise
7.0×10^{-7}	At all times, a sound with slight noise
3.0×10^{-7}	At all times, a sound with noise
2.0×10^{-6}	At all times, a sound with a large amount of noise
5.0×10^{-5}	In addition to a sound, block-noise was sometimes generated on an image.
1.0×10^{-4}	At all times, a sound is submerged within noise and cannot be heard, and block-noise is generated on an image at the intense scene of a motion.

reported that a BER of 7.0×10^{-7} was the limit value that is possible for students to understand the contents of lecture. More than 50% of the students reported that the image corresponding to a BER of 5×10^{-5} was equivalent to the image without error. From these results, we estimated that the probability of a BER of 10×10^{-7} or less was 99.9%. We concluded that this optical wireless LAN was adequate for use as an e-learning system.

Consequently, when the received optical power was -37 dBm or higher, it was possible to receive a normal image without degradation. These results indicate that the optical wireless LAN is a stable system regardless of weather. Moreover, good results were also obtained regarding the real-time distribution of mass content and animation, indicating that the LAN is an effective means of distributing multimedia teaching-materials.

3. Distance learning field trials

Having confirmed that an optical wireless system is an effective distribution system for e-learning, we next tested an optical wireless LAN in two distance learning trials. The system was used for “the foundation of multimedia” course taught to third-year students in the faculty of science (number of participants: 48). Real-time images were distributed from Waseda University to Japan Women’s University. The distributed image was compared with DV stream and MPEG2 stream by the DV and MPEG compression methods, and a question-and-answer session was held by connecting participants in both locations. During the class, the distributed images were received on laptop computers and also projected onto an 80-inch screen. The distribution system is shown in Fig. 3. The streaming image received from Waseda University was distributed through an intramural optical wireless LAN between buildings, and then distributed through an indoor optical wireless LAN. After the class, the questionnaire responses given by the students showed that each would like to experience a lecture delivered through a laptop computer. Therefore, the students were given laptop computers during the next class so that they could access the system (each computer was shared by two students). This example of distance learning is shown in Fig. 4. The streaming images were distributed from Waseda University by optical wireless LAN as before, and transmitted via the intramural cable network (100 Mbps) after that.

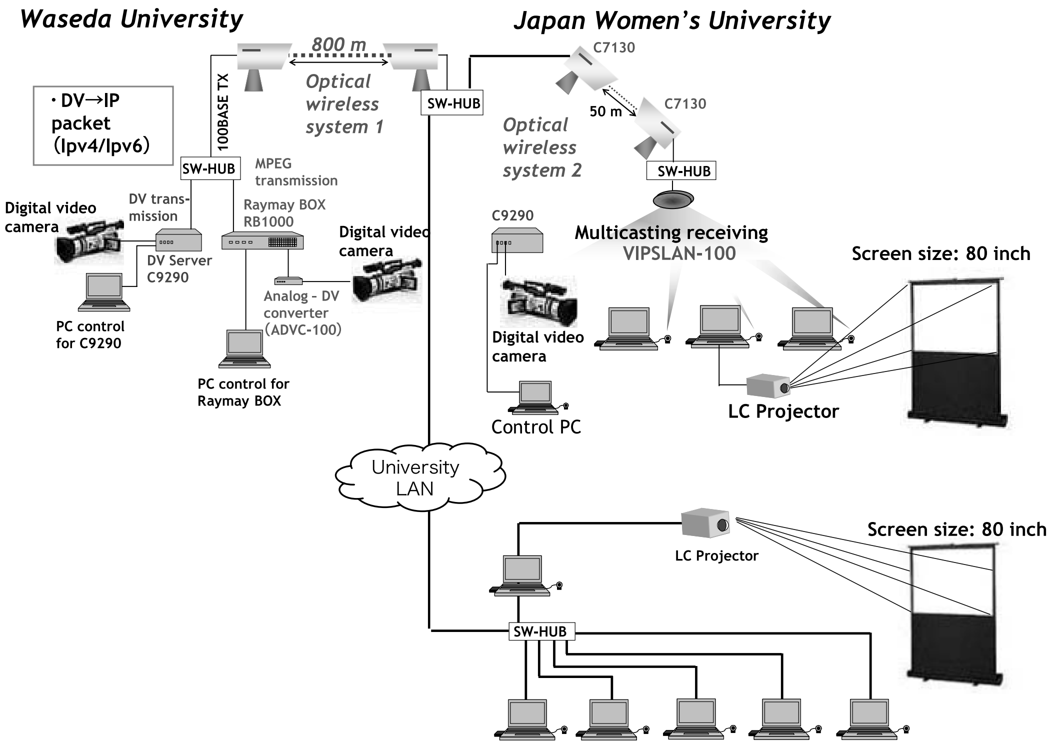
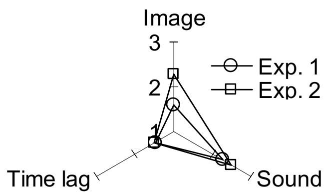


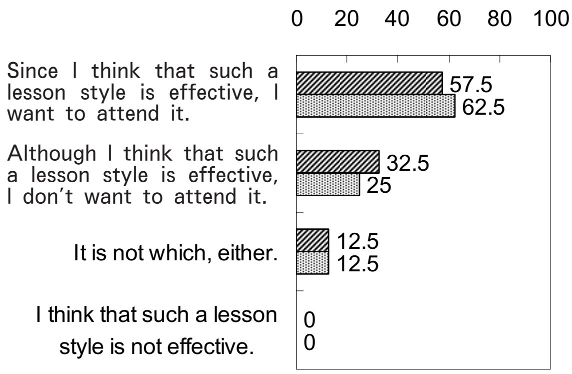
Fig. 3 Interactive distance learning with optical wireless LAN.

Fig. 4 The second distance lecture at Japan Women's University.

After each class, the degree-of-comprehension was examined using WebCT (Web Course Tool). Questionnaire results are shown in Fig. 5. Five responses were available for each question. The averaged responses for the first and second lectures are shown in Fig. 5(a). For the distributed image and the time lag of the question-and-answer session, the average response was 1.6 or less for the first lecture where the optical wireless system was used. The average questionnaire response scores for the second lecture, where the



(b)



(a)

Fig. 5 (a) Evaluation of distribution images by student attendees. (b) Evaluation of distance learning through real-time animation distribution.

intramural fiber cable LAN was used, were higher, indicating less satisfaction on the part of the students. For both lectures, the average questionnaire response regarding sound quality was 2.2 or higher. A throughput of 60 Mbps is needed for the bidirectional distribution of DV files. Since the second lecture used the university LAN, the throughput fell because other users were using the LAN. Therefore, block noise occurred, and the quality of the distribution image and sound was lower. As shown in Fig. 5(b), the students evaluated the second lecture more highly than the first, and 62.5% of the student answered that the style of the second lecture was effective for distance learning. The following results were obtained from the comments section of the questionnaire: "I have experienced "ubiquitous computing" and "e-learning", which we have often heard about recently, and it was very good.", "I took an interest in the structure of the distance lecture.", and so on. These results show that the students were attentive to the distance learning lecture style and participated in the lecture positively.

4. Discussion

There is a significant and growing interest in student e-learning, and educational organizations would like to increase the number of lectures accessible through distance learning. There is necessity which can be used through one year. For application to real-time image distribution, the availability and stability of an optical wireless LAN becomes important.

Wireless and optical wireless systems are now used extensively. One reason for this is that communication systems such as the Internet provide best-effort performance using the TCP protocol. The streaming distribution needed for distance learning and similar applications is a non-TCP protocol. To ensure stable distribution, we need to take into consideration burst errors which interfere with network operations.

With the optical wireless system described in Section 2, the distribution of real-time images with accompanying content to aid student comprehension is possible. However, in previous distribution experiments, although the average received optical power was sufficient noise still affected the distributed sound and images[11, 12]. The relation between average received optical power and the BER after a burst error occurred is shown in Fig. 6. As the solid line in Fig. 6 shows, the back-to-back characteristic of the receiver, the BER fell as the received optical power rose. In a conventional line design, a transmission margin can be calculated according to Eq. (1) of the correlation of visibility and light wave attenuation[10].

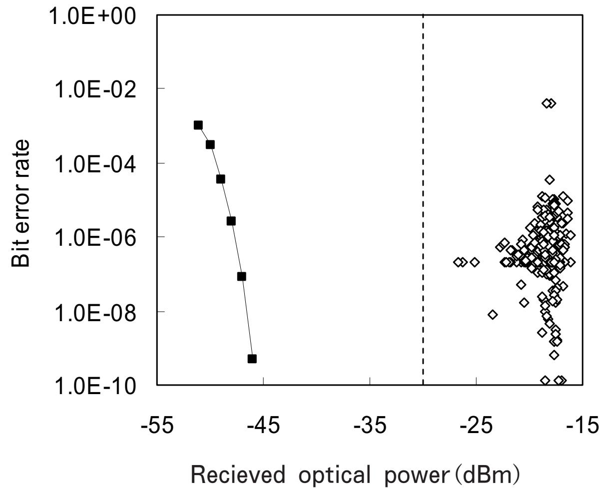


Fig. 6 BER characteristic when dips occur at an atmospheric propagation distance of 800 m.

$$La=13/Va \quad (1)$$

Here, Va[km] is visibility which can secure desired line operating ratio. This is obtained from the data of the accumulation probability of visibility, which was acquired in the past. and La[dB/km] is the loss of light. A transmission margin required since the rate of operation is expected to be securable 99.9% or more from the probability of the distribution of the range of visibility in the past in Tokyo is about 17dB (dashed line position in a Fig. 6). Therefore, the transmission error should not be produced when received optical power is in this transmission margin. However, even if received optical power was enough, the remarkable fall of BER was observed. Although temporary cover by the scintillation or by the bird could be considered as a generating factor of this burst error, in our latest observation, it was found out that attenuation (dip) of rapid received optical power to which 1msec continues at the time of rain has arisen[13]. An example of the dip phenomenon observed is shown in Fig. 7. Conventionally, the scintillation appeared strongly, when daytime especially temperature change was sharp, and it has been considered that there is little influence at the time of rain. During our experiments based on the e-learning lectures, the weather was fine so our results were not affected by such dips. During a distribution experiment

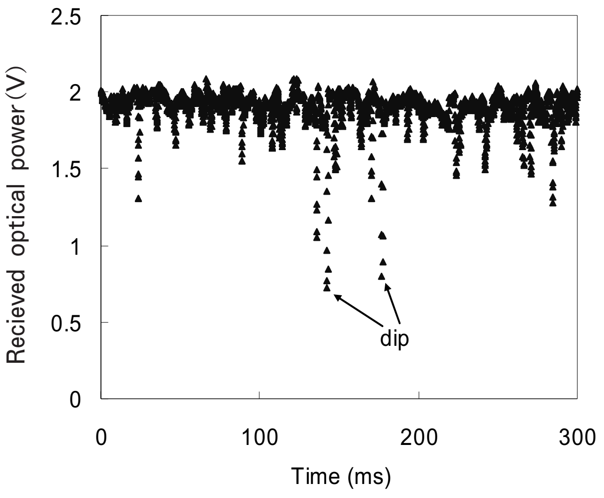


Fig. 7 A dip is a sudden drop in the received optical power during rainfall, which continues for about 1 ms.

on a rainy day, we found that there was either noise generated within the transmitted sound or instantaneous breaking. Therefore, improvements are needed to ensure a consistently high level of sound quality in distribution. To achieve more stable communication quality through line design, it is important to take the dip phenomenon into consideration during equipment design.

Moreover, while the line for the first lecture enjoyed exclusive use of the optical wireless system, the distribution for the second lecture was done through the intramural cable LAN. Consequently, there was more noise affecting the distributed images due to the higher volume of traffic on the university LAN. Thus, we will need to stabilize the line not only with regard to the optical wireless LAN, but also with regard to other networks which are not exclusive.

5. Conclusion

We measured the atmospheric propagation characteristic of an optical wireless system over a one-year period and obtained availability of 99.9%. In addition, we investigated the relation between the real-time distribution of animated images and the BER, and had students complete questionnaires with respect to the distributed images. We found that normal images suitable for use in lectures were obtained when the BER was 7.0×10^{-7} or less. Therefore, the image distribution operating ratio of a distance lecture with this system was 99.9% or more, which we feel is adequate for a distance learning distribution system. To confirm this, we conducted an experiment where two remote lectures were delivered using our optical wireless LAN system for real-time interactive animation distribution. This system functioned adequately and was highly evaluated by the students.

Since the BER can be treated as an absolute evaluation measure independent of distance or the installation environment, the distribution threshold value used in this paper represents a distribution standard value for a distribution system used for distance lectures. Furthermore, to enable uninterrupted distance learning using an optical wireless LAN system, line stability is needed with improved availability. However, the BER sometimes declines when the average received power level is high enough. Despite obtaining sufficient received optical power, as measured by the atmospheric propagation characteristic, we confirmed that the BER falls when burst errors occur. In the future, to enable stable system configuration, we will analyze the burst error phenomenon and then focus on line design and equipment design to prevent such errors.

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Examination of optical wireless LAN on distance learning system

遠隔講義システムにおける光無線LANの検討

清水　賀代[1]，藤川知栄美[1]，秋葉　　誠[2]，若森　和彦[3]，小舘香椎子[1]
[1]日本女子大学理学部数物科学科，[2]情報通信研究機構，[3]浜松ホトニクス株式会社

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要　旨　近年のIT技術の進展により，多くの教育機関が遠隔講義システムとしてe-ラーニングを導入している。そのコンテンツはマルチメディア化が進んでおり，受講生にダウンロード時間および映像品質におけるストレスを生じさせることのないe-ラーニングシステムを実現するためには，十分な回線容量が必要となる。光無線LANは，光ファイバの大容量性と無線の簡便性を兼ね備えたシステムであるが，大気を伝送路とするため，大気中の気体分子，エアロゾル，雨や雪などに含まれる水滴による吸収・散乱の影響を受けやすいと予想され，気象現象による回線品質の劣化が指摘されている。そこで，日本女子大学－早稲田大学間（距離800 m）に光無線LANを設置し，1年以上にわたり伝送路上の気象条件による伝送特性への影響を計測し，99.9％以上の回線稼働率が得られることを確認した。また，擬似的に光波減衰状況を作り出し，遠隔講義用としての適用可能な映像・音声の評価をアンケート調査により行い，リアルタイム双方向遠隔講義用配信システムとして必要な回線品質を求めた。その結果，回線のビット誤り率（BER）が7.0×10^{-7}以下の場合，講義用として問題のない映像品質が得られ，十分遠隔講義配信に用いることができることを確認した。すなわち，距離や設置環境に依存しないBERを用いて，遠隔講義用配信システムにおける配信基準を示すことができた。これらの結果をうけ，実証実験として，現状の光無線システムを実時間双方向動画配信として用いた遠隔講義を2回実施し，本システムは十分機能することを確認し，受講した学生からも高い評価を得た。さらに，恒常的に遠隔講義を行うためには，回線稼働率とともに回線の安定性が必要となることから，大気伝搬特性の計測を行った。その結果，1 msと非常に短い時間での受信光量の低下（dip）が生じることがあり，十分な受信光量を得ている場合でもバーストエラーの発生により，BERが低下することを確認した。

キーワード：光無線LAN，遠隔講義，リアルタイム双方向動画配信，大気伝搬