IMPROVEMENTS FOR STABILIZING THE COLLABORATIVE E-LEARNING SYSTEM ON UNSTABLE ENVIRONMENTS

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Abstract

The target of our collaborative e-learning system consists of schools in the rural villages of developing countries. We have continued study the Kaski district of Nepal as our research field since 2012. In this area, there are not only problems such as a lack of learning resources and instructors, but also issues related to power failure and network outages due to the high altitude and the irregular weather. For such an unstable environment, we have developed a cluster-based e-learning system that can be used independently for each school, despite network disconnections. Since 2016, we have used this system; however, following COVID-19, it became difficult to maintain the system due to lockdown restrictions. Consequently, many devices in our system broke due to aging; therefore, we must improve the system. We changed our mind and found that this as an opportunity, re-construct our system for better stability. In this paper, we propose our new system to achieve stability by providing redundancy on the cloud, and by implementing a new function that enables a new node to join the system automatically.

Keywords: *Collaborative e-Learning, Unstable Environment, Database Sharing, Developing Countries*

1. INTRODUCTION

Recently, e-learning has increased in popularity globally as an excellent educational engineering technique [1]. Excellent educational materials are published in the world, and learners can utilize them by paying a fee or can use them free of charge. The e-learning technology has reduced the geographic educational inequality, and it has provided an equality in learning opportunities [2]. Teaching materials for e-learning are provided through various media such as web documents, audio files, and movie files. Many learners globally can utilize them with high-speed communication networks and large-scale information systems. With the development of ICT, the further development of e-learning technology is expected to evolve in the future.

E-learning is a comprehensive technique that assumes a stable high-speed network environment for effective operation. The quality of contents has been improving, and its capacity has also increased. Learners who live in developed countries or in metropolitan areas have a stable and high-speed communication environment. Therefore, they can obtain benefits with no limit. However, the school environment of developing countries is still under poverty. In addition, these countries are underdeveloped regarding ICT and their availability. Their basic infrastructure, such as communication networks and power transmission lines remains insufficiently established. Therefore, for learners who live in these countries, it is difficult to obtain excellent e-learning contents that have been published globally. Within these unstable environments, other problems are often noticed: a lack of computers, narrow network bandwidth, and frequent power failure due to poor power supply. Therefore, learners of developing countries cannot stably obtain the learning opportunities from e-learning. However, these problems can be easily solved by the improvement and stabilization of the infrastructure, although its cost is enormous.

In our previous research [3]-[8], we designed and implemented a collaborative e-learning system that has redundant robustness. This system can operate stably in an unstable environment. This facilitates and supports collaborative learning among several schools in rural areas within a developing country. Generally, to use the e-learning system in a classrooms, a power system for running the e-learning system is essential. If there is a power control mechanism, the system can be operated stably in an environment where a power failure occurs frequently. The network can be operated stably by the usage of the redundancy of load balancing and other needful nodes. Alternatively, our system has teaching material contents replicated on the school server, and it is possible to switch between the usage form by connecting schools and the stand-alone use. The independence of each school can be realized by the redundancy of the database of e-learning system. If any of these redundancies is available, the system becomes more stable. The system will be robust by each redundancy.

However, the previous system had various problems. In addition, the COVID-19 pandemic imposed a prolonged lockdown on Nepal and created new issues. In particular, the previous systems were not perfect at maintaining data sharing in the event of a partial system failure. Therefore, further stabilization is required to ensure the core system can continue to operate even when many schools are cut off. In this paper, we improve the stabilization of the previous system by reconstructing the cloud-side system. Moreover, we implement a new mechanism to add a new node to our sharing cluster group semi-automatically only by connecting the internet.

2. UNSTABLE ENVIRONMENT

2.1. Overview

In this section, we discuss the unstable network environment and the rapidly changing behavior of the system that are the causes of instability of those networks. Various definitions are given to an unstable network environment. A system is considered unstable if any factors related to that system cease functioning properly (software, hardware, physical environment, etc.). The majority of network infrastructure of developing countries are unstable. However, we can define an unstable network under the basis of its surrounding environment such as connection media, geographical situations, and hardware stability. The network with very low availability due to frequent network outage can be defined as an unstable network.

The overall objectives of this research are to develop collaborative e-learning tools and their learning materials for improving the education of rural schools. To conduct experiments, we have chosen the Community Wireless Networks (CWN), located in the Kaski district of Nepal. This CWN test-bed has a multi-dimensional research area where varieties of investigations have been undertaken since 2011 [3][4]. The motivation of network implementation in this region is to provide internet access to remote schools in developing countries such as Nepal. However, because the network has been affected by various serious problems, its performance is unstable.

According to the network quality and performance of CWN in Nepal, we have found major reasons behind the instability of these networks. In this study, we define an unstable environment as one in which there exists any of the problems listed below:

- Lack of supporting infrastructure (teachers, local network administrators, etc.)
- Lack of redundant network hardware (servers and communications nodes, etc.)
- Slow internet speed
- Single point of failure on a network
- Proper safety measures against the natural disasters (such as thunder, lightning)
- Frequent power failure problems

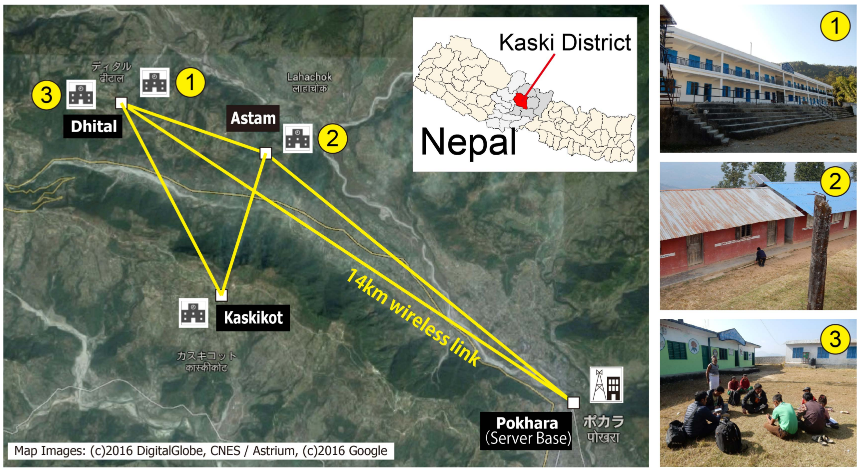

Fig. 1. Geographical Location of Targeted Schools [7]

2.2. Current Situation of Schools in Nepal

Figure 1 shows a map of the Kaski district of Nepal, where is a target area of our research. This area includes three primary schools. Geographically, these schools are located at a certain distance far from each connecting two remote villages: Dhital and Astam. The distance from those schools to Pokhara, the primary city in this area, is approximately 14 km in a straight line. However, these schools are situated at high altitudes, and it is very difficult for village people to move from village to town areas.

In village schools, the lack of educational equipment and the lack of teachers who have enthusiasm and capabilities pose serious problems. In the homes of rural areas, children do not have enough time to study, as they must help with the daily work. In addition, there is no lighting at night.

These schools are equipped with up to 10 computers by international support. Due to the lack of useful content and applications, students must depend only on an analog (particularly textbooks) based education system for learning. These computers are used by certain authorized persons for official use only. For example, sending and receiving emails. However, they must wait for network connectivity the majority of the time.

2.3. Current Situation of Network in Nepal

The network situation in Nepal has regional disparities. Urban areas have relatively extensive equipment. Generally, users can use internet service via an optical line for home use. Many places such as stores and restaurants provide free Wi-Fi service, and many people have access to mobile phones or smart phones. These communication networks are also available during power failure.

However, the current situation in rural areas is more serious. Villages in rural areas are located on the hillside of a steep gradient. From the beginning of our research, there was a communication network of the mobile phone in those villages. However, there was no communication network for connecting the internet. It is difficult to connect the wired network from the town at the foot of the hill to the village. The wireless network also suffers from the limitation of the communication strength by the terrain.

Since 2011, we have continued to implement the communication wireless networks (CWN). During the 5-year period (2011–2015), our CWN has been evolving every year since its establishment. Figure 2 represents the latest network topology of CWN, which was last upgraded in 2014. There are five active nodes. The server base in Pokhara is connected to local ISP, and it further distributes internet services to the remaining nodes via a wireless medium.

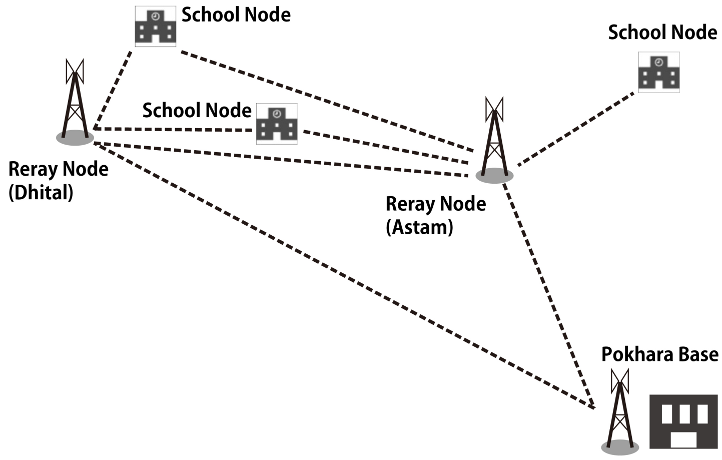

Fig. 2. Network Topology of Dhital-Kaski CWN in 2016 [7]

2.4. Physical Limitations and Our Preferences

Beyond the adverse effects of geographical localities, providing highly available and sustainable communication platforms poses a serious challenge. The majority of communication networks in developing countries suffer from severe instability. It is still a challenging task to reach and solve the problems in the rural areas instantly during network disasters due to the lack of proper roadways and transportation.

The connection between nodes is established using either wired or wireless technology. The rate of packet loss in wired media is less than that experienced in the wireless media; however, due to the geographical constraints, we preferred wireless media for this research.

3. PREVIOUS SYSTEMS AND ITS PROBLEMS

Here, we detail an overview of our previous system [7][8], developed in 2019. Subsequently, unsolved problems of the system are shown. In addition, the damage that the system suffered during the three years of the COVID-19 disaster is explained.

3.1. Overview

We have developed a cooperative e-learning system to eliminate the academic achievement gap between urban and rural areas. The system connects several distant schools, such as schools in urban areas and schools in rural areas, through a cloud network. Each school has an individual e-learning sub-system called UNIT. UNIT can share e-learning contents, and the UNIT of each school can keep its operation individually when the network was down. Nepali school students can use high-quality teaching materials created by teachers who work in urban schools. Teaching materials created in urban areas are shared with schools in other locations via the cloud. Students at each school can access the e-learning system on UNIT at the school using tablets, etc., and can learn using the e-learning system.

3.2. Functional Requirements

3.2.1. Mechanism for sharing teaching materials

This function is realized by adopting the database replication function of the Galera Cluster [9][10], included in MariaDB. MariaDB is a major open-source RDBMS. The Galera Cluster guarantees high usability, high performance, high availability, high reliability, and robustness, and it is suitable for operation in an environment where the network is unstable, such as in Nepal. In addition, the Galera Cluster can be configured with multiple masters and can perform fully synchronous replication. It can synchronize databases even between remote locations without having to stop the database server during replication. In this study, we installed a cluster node called "Galera Node", equipped with the Galera Cluster in the UNIT of each school, and it is possible to use the same database in the e-learning system of the urban school and the e-learning system of the mountain village school. The Galera Cluster automatically reconnects to the cluster after power is restored, even if the school node is disconnected during a power outage and updates the latest information. Data integrity is ensured even if a connection is disconnected during an update.

3.2.2. Mechanism for stable e-learning even on an unstable network environment

This system duplicates the database so that it can be used in each school individually, even when the network is cut off. One is a database for teaching material sharing, stores the connection status with other schools. This is the Galera Node described in the previous section. The other is the database for the e-learning system, stores teaching materials and user data for students to use e-learning. This database installs in another node: the school node. The Galera Node communicates with the other Galera Nodes of other schools when the network is connected and duplicates the shared data to the school node internally. Hence, the school node is unaffected by the network. Consequently, e-learning materials are saved in the local environment of the school, so the e-learning system can be used even when the network is disconnected. If the teaching materials are updated while the network is disconnected, by sharing the teaching materials after the network is restored, learning using e-learning can be stabilized even when the network environment is unstable.

3.2.3. Mechanism that enables the e-learning system to operate even during power outages

By separating the equipment for sharing teaching materials and the equipment for the e-learning system, the system can operate independently despite network disconnections. In addition, equipment with low power consumption is adopted to maintain operation for as long as possible even in the event of a power outage. The equipment for the e-learning system should have a backup power source such as a mobile battery, so that the power supply will not be interrupted and to ensure that e-learning can be used even in the event of a power outage. In addition, since it is assumed that students will use e-learning using tablets, if the power supply for the equipment for the e-learning system can be secured, it will be possible to use it in the school even during power outages.

3.3. System Configuration

Figure 3 and 4 show the system constructed in previous studies. The system consisted of one cloud unit and multiple school units. The cloud unit is a database system for teaching material sharing implemented on the cloud, and it is used to stock teaching material data. The cloud unit is built on the cloud service, Google Cloud Platform, provided by Google, and it is called "master node". However, the school unit is a set of a devices equipped with a database for e-learning and a device equipped with a database for sharing teaching materials. The former is called an "e-learning node" and the latter is called a "Galera Node". One school unit was installed in each school.

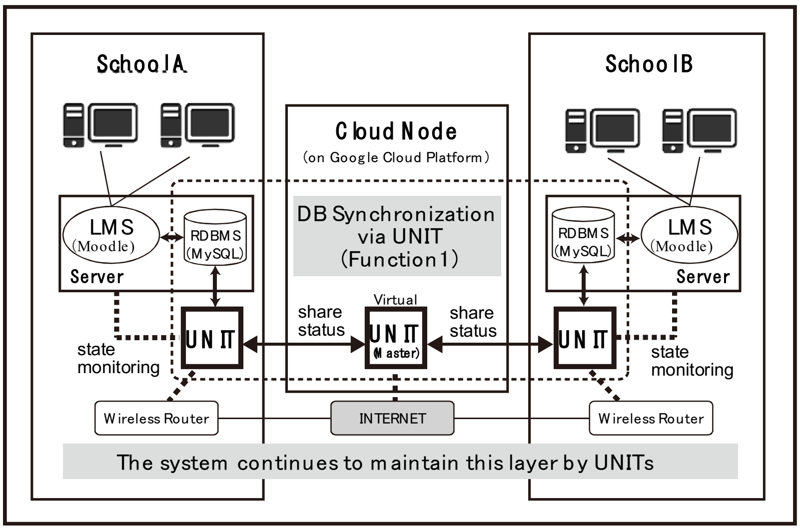

Fig. 3. Overall of the Previous System

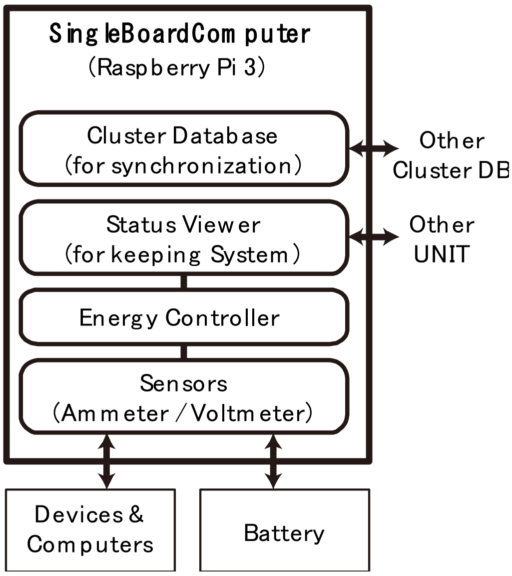

Fig. 4. Structure of UNIT

We adopted Raspberry Pi with low power consumption for each device. The e-learning node uses "Moodle" as the LMS and "MariaDB" as the database management system for managing the LMS. Each Galera Node communicates with other Galera Nodes installed at other locations via the master node to share teaching materials. Sharing is realized using the Galera Cluster, which is a function of MariaDB. Since sharing using the Galera Cluster requires all sharing nodes to be on the same network. VPN software "Softether" is used for this purpose. At that time, the master node and the galera node communicate using the VPN. Teaching materials on a Galera Node are shared with a paired e-learning node via LAN communication. The e-learning node is applied to Moodle so that students can use the shared teaching materials. Students use tablets to connect to the e-learning node via Wi-Fi and use e-learning materials.

3.4. Unsolved Problems

The previous system realized the sharing of teaching materials between schools using the Galera Cluster. The system implemented succeeded to against network disconnection by dividing the school unit into two: the Galera Node and the e-learning node. Through the experiment, teaching materials can be shared without problems on our system, as was confirmed. However, several unresolved issues remained:

Issue 1: A mechanism for supplying power from an outlet when the power supply is stable and supplying power from a mobile battery during a power outage is not suitable for the local environment and has not been completed.

Issue 2: The previous systems were not perfect at maintaining data sharing in the event of a partial system failure. Therefore, further stabilization is required to ensure the core system can continue to operate even when many schools are cut off.

Issue 3: Our system is a prototype, and the user interface has not been fully considered. Assuming the actual operation, it is necessary to design an easy-to-understand UI because the computer literacy skills of teachers at schools in mountain villages are low. In addition, COVID-19 imposed a prolonged lockdown on Nepal. This also created new issues.

Issue 4: Our system was also unable to be maintained for a long period of time, and equipment broke down or deteriorated.

Issue 5: During the lockdown period, our local collaborators left, and stable management became impossible.

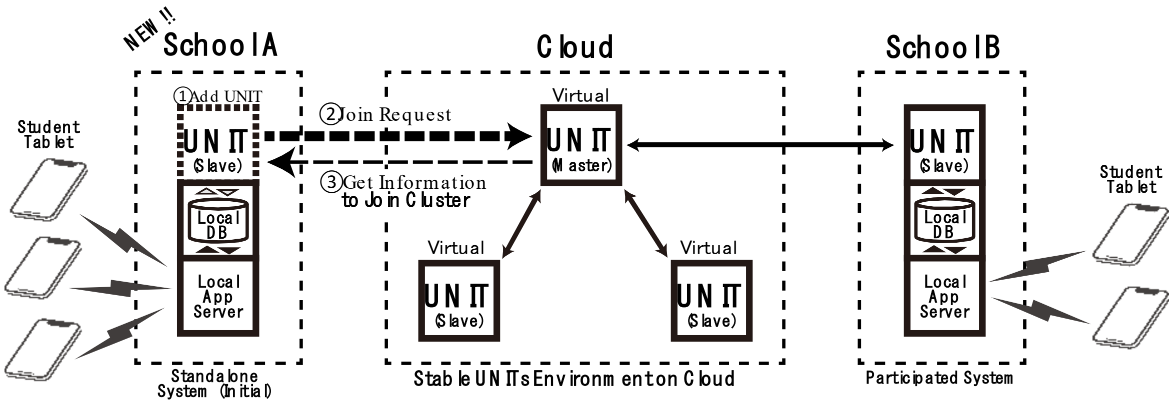

Fig. 5. Configuration Image of an Improved System

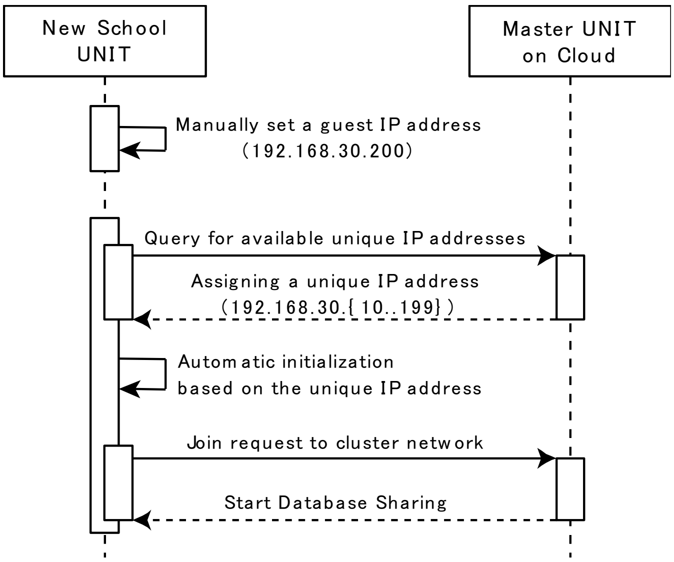

Fig. 6. Sequence Diagram for Installation of new UNIT

Therefore, in this paper, we focus on issues 2 and 3, the most critical problems, and improve the system to solve it.

4. IMPROVEMENT THE SYSTEM FOR STABILIZING

4.1. Stabilizing on Cloud -side Environment

To ensure that the core system can continue to operate even when the power supply of many school UNITs is cut off, we improved data sharing between surviving nodes by making the database redundant. As a concrete countermeasure, as shown in Figure 5, multiple virtual UNITs will be constructed on the cloud, and the system itself will always operate permanently even when there is no connection to the school UNIT. The Galera Cluster requires a total of three or more nodes as an operational requirement; therefore, we implemented three virtual UNITs on the cloud. Since the minimum-required number of nodes is secured on the cloud, there is no problem in maintaining the cluster even if the UNIT of each school is disconnected. In addition, each school's UNIT can also maintain its e-learning environment independently even if it cannot participate in the cluster. The latest content is always managed on the cloud, and each UNIT will share that information as appropriate when the network is established.

4.2. Semi-automatic Connection of New Nodes

In a collaborative e-learning system, each school UNIT communicates with the master UNIT on the cloud via a VPN. Nepali schools do not have teachers with the ability to manage this system. Therefore, we implemented a semi-automatic connection mechanism in the UNIT, assuming that the support of engineers cannot be expected when installing a new UNIT. Figure 6 shows the new UNIT introduction sequence diagram. To connect the new UNIT to our cluster network, try to connect the master Node using a guest IP address via the VPN, then the initializing process will start after installed VPN software. Since UNIT adopts Raspberry Pi, the initial setting for booting is completed by simply copying the master image to the media, such as an SD card. Only the initializing of the VPN requires manual work. This issue requires resolution in the future.

4.3. UNIT Upgrade

As UNIT of the previous system, Raspberry Pi3 was adopted. During COVID-19, the UNITs at each school were left in a state of neglect with almost no maintenance. Consequently, many devices have broken down. In addition, aging deterioration of hardware was also been found. Therefore, this time, we updated the hardware and newly adopted the Raspberry Pi4 model B. The previous system was a 32-bit-based environment; however, this update requires all software to be 64-bit. Therefore, I decided to check the operation of the new UNIT.

5. EXPERIMENTS AND RESULT

5.1. Overall of Experiments

In this experiment, we verified that the two functions of the UNIT, “automatic enrollment” and “learning material sharing” work on the new UNIT. After verifying the operation on the experimental network built in the lab, we visited Nepal and conducted field experiments. Experiments were undertaken by establishing UNITs in three remote locations: (1) our university in Japan, (2) Nepal’s urban area (Simpani Chork, Pokhara), and (3) Nepal’s mountain village (Dithar village, Kaski district).

5.2. Experiment1: Semi-automatic Connection of New Nodes

We measured the time required for an automatic setting when a new UNIT was made to participate as a new node of the collaborative e-learning system at each point. We tested 10 times for each point and an average score. On the first day of the experiment in a mountainous village, the internet network went down in the entire village, and we changed the test using mobile terminal tethering. The experiment was conducted again in the Wi-Fi environment that was restored the following day. The results are shown in Table 1. Consequently, we were able to confirm that they joined the cluster as a new UNIT within a minute, regardless of the location or communication method.

Table 1. A Result of Auto-enrollment Test

Location	AVG time (sec)
Laboratory in Japan	35
Urban Area (Simpani Chork, Pokhara)	42
Mountain Village (Dithar village, Kaski district) by tethering	51
Mountain Village (Dithar village, Kaski district) by Wi-Fi	48

5.3. Experiment 2: e-Learning Contents Sharing

An experiment was conducted in which 10 sets of content, such as slides and exercise programs for an object-oriented language (which the author is in charge of) were taken as one set for a total of 15 weeks. We measured the time from registration on UNIT in the target area to completion of sharing on the cloud. In addition, we measured the time it took for content added on a UNIT installed in another area to be shared with the UNIT in the target area. This was repeated 10 times to obtain an average required time. The results of experiments conducted with UNITs installed in each region are shown in Figure 7. Content sharing completed successfully in all target areas. It took more time in UNIT in urban areas than in mountain villages because the wired network at the test point in the urban area was very slow.

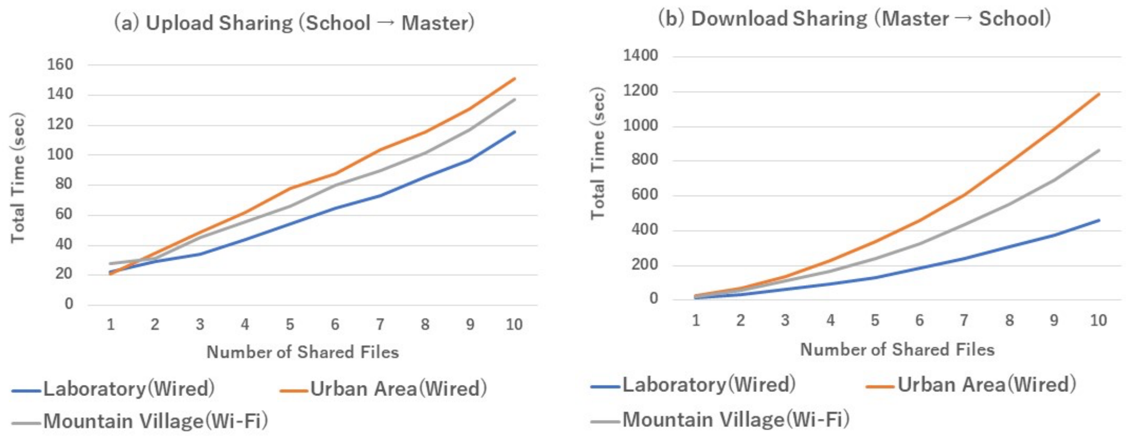

Fig. 7. Results of Experiments2, (a) Uploading and (b) Downloading

6. CONCLUSION

In this paper, we improved the system and updated the equipment and confirmed whether the new system works normally. Consequently, we confirmed that the automatic enrollment function and teaching material sharing function work correctly in Nepal's urban and mountainous areas. In addition, it was found that the network in the mountain village area is faster than the network in the urban area of Nepal. Unlike before, this is believed to be because a sufficient internet environment has been developed in the mountain village area since the COVID-19 pandemic.

However, it is clear that the local network remains unstable, because we experienced the trouble of being disconnected networks in many times while staying in a mountain village in Nepal. Therefore, in the future, it is necessary to have a new function to switch the connection method to school units and work depending on the situation automatically. Moreover, it is necessary to solve the unsolved issues highlighted in section 3.4.

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