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REGULAR PAPER

# Evaluation of educational applications in terms of communication delay between tablets with Bluetooth or Wi-Fi Direct

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**Abstract**
This study conducted a survey to implement educational applications that can share information even in environments where access points cannot be used. In particular, we investigated whether Bluetooth (widely used for many years) or Wi-Fi Direct (developed recently) is more suitable when creating educational applications using an ad hoc network. To survey the influence of hand movements on delay time while operating tablets, we created a paint application that shares a drawing screen across two tablets and conducted an experiment. In addition, to survey the influence of human presence on delay time, we conducted an experiment in which we changed the number of students seated between the two tablets in the classroom. From the results of these experiments, we conclude that Bluetooth is less influenced by hand movements and human presence than Wi-Fi Direct. We also verified the practicality of educational applications using Bluetooth communication. We developed an educational application, and students used the application in their actual class. A questionnaire to investigate whether they were conscious of communication delay was administered.

**Keywords** Ad hoc network · Education · Tablet · RTT · Bluetooth · Wi-Fi Direct

## 1 Introduction

Recently, lessons that use tablets have become popular in elementary and middle school education [1–4]. When it is necessary to exchange information among tablets in group learning, Wi-Fi access points are usually used for the communication. However, since access point installation and management entails considerable personnel and monetary costs, it is difficult to establish a wireless communication environment that enables Wi-Fi communication via access points in every classroom of each school.

Therefore, we are considering the use of ad hoc networks. Ad hoc networks are composed of devices with wireless communication capabilities, such as laptops, tablets, and smartphones [5]. Each device communicates directly with other devices. With ad hoc network use, it is possible to share information even when infrastructures such as access points are unavailable; this is why ad hoc networks have been attracting attention in recent years as a means of communication during large-scale disasters [6–9].

To construct an ad hoc network, Bluetooth can be used. Bluetooth is a short-range wireless communication technology that uses IEEE 802.15.1 standard certified by Bluetooth Special Interest Group (Bluetooth SIG) [10]. Bluetooth is the typical communication standard for performing direct wireless communication between devices such as tablets. The 2.4 GHz band is divided into 79 frequency channels, and frequency hopping is performed to change the frequency used randomly. Compared to Wi-Fi, Bluetooth's power consumption is low [11].

Recently, Wi-Fi Direct was developed and the number of devices that support Wi-Fi Direct has been increasing. Wi-Fi Direct is the name of the standard that allows direct wireless connection among Wi-Fi devices [12]. The Wi-Fi Alliance [13] established this standard in 2010, and it performs certification of Wi-Fi Direct-enabled devices. Wi-Fi Direct has the potential to become another communication standard that can be used to construct an ad hoc network.

This paper is an extended version of the paper titled "Comparative Evaluation of Bluetooth and Wi-Fi Direct for Tablet-Oriented Educational Applications" presented at the 9th Asian Conference on Intelligent Information and Database Systems (ACIIDS 2017).

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In this study, we assumed scenarios of education utilizing ad hoc networks in classrooms and performed a comparative evaluation of the two communication standards mentioned above. In particular, we surveyed the influence of hand movements on delay times while using a paint application sharing a drawing screen between two tablets. In this survey, we not only used Bluetooth and Wi-Fi Direct but also communicated via Wi-Fi access points and conducted experiments by sending data to other tablets through a server. Furthermore, we investigated the influence of human presence on delay times by conducting a wireless communication experiment where we changed the number of students seated between two tablets in the classroom.

We also developed an educational application enabling a group of students to organize their opinions using tablets interconnected via Bluetooth. Students used the application in their actual class, and a questionnaire to investigate whether they were conscious of communication delay was administered. Based on the results, we verified the practicality of educational applications using Bluetooth communication.

The rest of this paper is composed of the following sections: In Sect. 2, we introduce some related work. In Sect. 3, we describe the survey on the influence of hand movements on delay times while operating tablets. In Sect. 4, we describe the survey on the influence of human presence on delay times. In Sect. 5, we describe development and evaluation of an educational application using Bluetooth communication. Finally, in Sect. 6, we summarize the study and describe future challenges and implications.

## 2 Related work

Rapiński et al. [14] investigated the influence of the obstruction of line-of-sight between access point and transceiver by a human body in indoor positioning systems. They presented correction formula that allows to minimize the influence of the user on the results obtained during fingerprint creation and positioning. Oliveira et al. [15] characterized user's influence in body area networks, endeavoring to provide useful statistical values for channel models. They statistically analyzed the impact of the body for the source located at different distances. Our study is different from those studies in that we focus on the difference of the influence of hand movements and human presence on delay times between Bluetooth and Wi-Fi Direct.

Several researchers developed prototypes of applications that run on ad hoc networks constructed using Wi-Fi Direct. For example, Shahin et al. [16] presented a framework for supporting formation and management of groups of communicating devices using Wi-Fi Direct. Hoang et al. [17] proposed a platform for building an ad hoc network using Wi-Fi Direct in a delay-tolerant network environment. Wang et al. [18] proposed a Wi-Fi Direct based peer-to-peer social networking framework that enables direct data exchange among users without using infrastructure network when users are located in proximity. Liu et al. [19] introduced a method to achieve multi-hop communication among Android devices using Wi-Fi Direct. They also implemented a proactive routing protocol for a mobile ad hoc network using multiple off-the-shelf smartphones to enable efficient message delivery. In those studies, experiments to evaluate communication delay were not sufficiently conducted. In our study, we conducted some experiments and compared delay characteristics of Wi-Fi Direct and Bluetooth communication.

Pothuganti et al. [20] compared the transmission time, data coding efficiency, protocol complexity, and power consumption of the following four wireless communication standards: Bluetooth, UWB, ZigBee, and Wi-Fi. However, the influence of hand movements or human presence on delay times was not evaluated.

Many researchers study education supported by tablets. Van Deursen et al. [21] conducted a study using a questionnaire for primary school children to provide several recommendations on how tablets can contribute to educational improvements. Uzunboylu et al. [22] developed a scale about the attitudes of students in a private college towards usability of tablet supported education. However, the tablets used in those studies are connected to the Internet with Wi-Fi. In this paper, we developed an educational application using Bluetooth communication.

## 3 Survey on the influence of hand movements

In this section, we describe the survey on the influence of hand movements on delay times while operating tablets. After explaining the metrics used in the survey, survey methods, and survey environment, we describe and discuss the results.

### 3.1 Survey overview

In the survey, we used two Nexus 9, Android-powered tablets. We created an application with a drawing screen shared between two tablets to be used during group work at school. Round Trip Time (RTT) was surveyed based on the return response when one tablet received a packet.

In this section, RTT refers to the time between when a packet (maximum payload of 28 bytes) containing touch coordinate data is sent at a frequency of 60 times per second from one tablet (Tablet A) to another tablet (Tablet B) and when an immediate return response sent from Tablet B is received by Tablet A. The RTT is measured in the Appli-

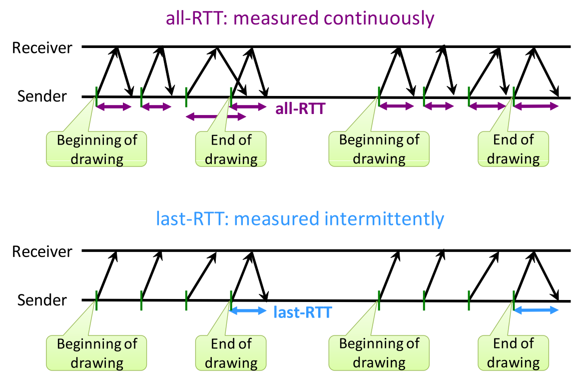


**Fig. 1** How to measure all-RTT and last-RTT


**Fig. 2** Examples of wave and spiral drawings

cation Layer of the Open Systems Interconnection (OSI) model. Therefore, the RTT includes retransmission delay and processing time in the lower layers. We adopted this measurement method because we aim at investigating the delay recognized by the students using the application. The following two types of RTT are surveyed: "all-RTT" is measured when Tablet B returns a response for all packets received, and "last-RTT" is measured when a response is returned only when the touching finger is released (Fig. 1).

Three types of lines are drawn in the all-RTT survey: Hold (the hand does not move), Wave, and Spiral. A screenshot of Wave and Spiral lines are shown in Fig. 2. One line was drawn for 5 s (coordinate data were sent 300 times), and each type of line was drawn five times. In the last-RTT survey, short lines of approximately 3 cm were drawn 100 times.

The survey was conducted in Building 5, Room 9-7 of the Faculty of Engineering of Ehime University, Japan. Two tablets were placed adjacent to each other as shown in Fig. 3.

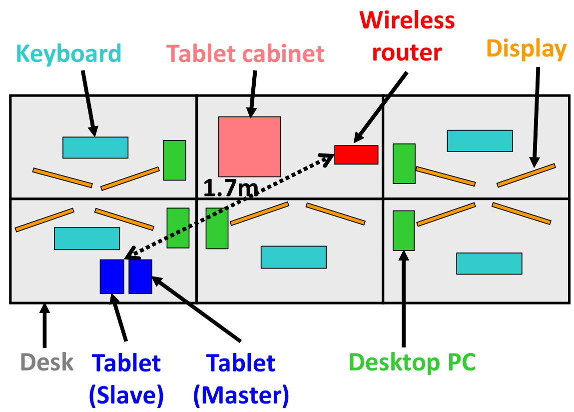


**Fig. 3** Environment for survey on influence of hand movements

When connecting between tablets via Bluetooth or Wi-Fi Direct, the tablet sending the connection request is referred to as Master (M), and the tablet receiving the request is Slave (S). The Master tablet was placed on the right, while the Slave tablet was placed on the left. In the survey using Wi-Fi, the tablets were connected to the wireless router. The positional relationship between the tablets and the wireless router is shown in Fig. 3. The survey using Wi-Fi Direct and Bluetooth was conducted without connection to the wireless router.

In the survey using Wi-Fi, the tablets were connected to the wireless router by 802.11a (5 GHz band). In the survey using Wi-Fi Direct, the tablets were connected via a 2.4 GHz band.

There are some types of Bluetooth, such as High Speed (HS) and Low Energy (LE). In this study, we used Basic Rate (BR), which is the earliest type of Bluetooth. The Nexus 9 tablets used in the survey were Bluetooth Class 1 enabled (output 4.05 mW).

### 3.2 Results and discussion

In this section, we present and discuss the results of the surveys conducted in real environments with the RTT cumulative probability distribution.

The all-RTT cumulative probability distributions for Wi-Fi, Wi-Fi Direct, and Bluetooth are shown in Figs. 4, 5, and 6, respectively.

The difference in RTT among drawing operations is particularly noticeable in Wi-Fi (Fig. 4). When the hand does not move (Hold), there is a 90% probability that the RTT is shorter than 20 ms. However, when the hand moves (Wave and Spiral), the RTT often exceeds 150 ms. Thus, it can be said that with Wi-Fi, hand movements influence communication greatly.

With Wi-Fi Direct (Fig. 5), the difference in RTT among drawing operations is smaller compared with Wi-Fi. One rea-

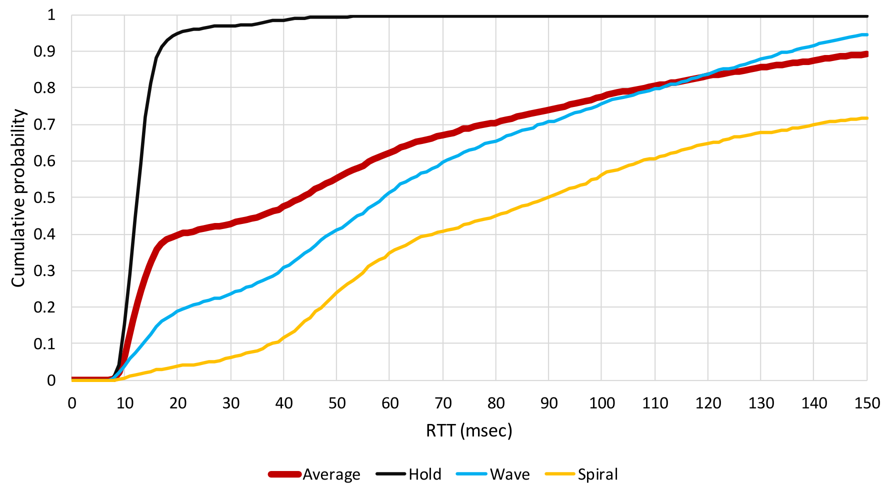


**Fig. 4** All-RTT in Wi-Fi (comparison based on drawing operations)

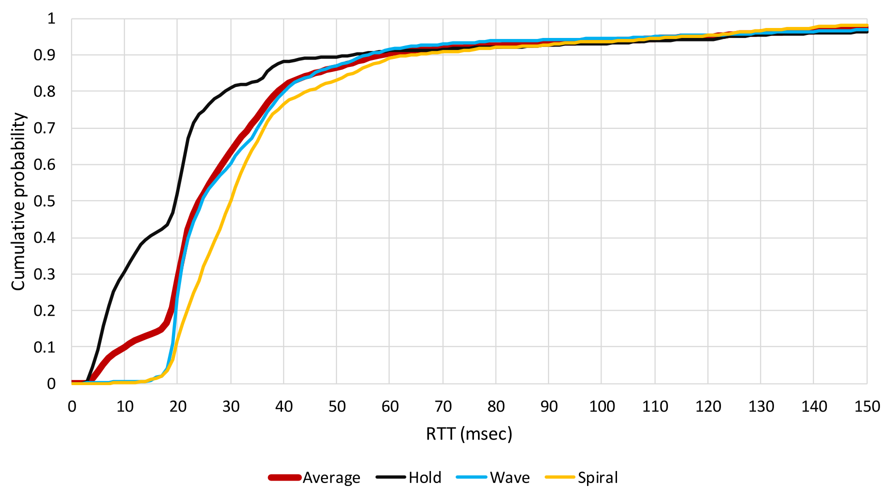


**Fig. 5** All-RTT in Wi-Fi Direct (comparison based on drawing operations)

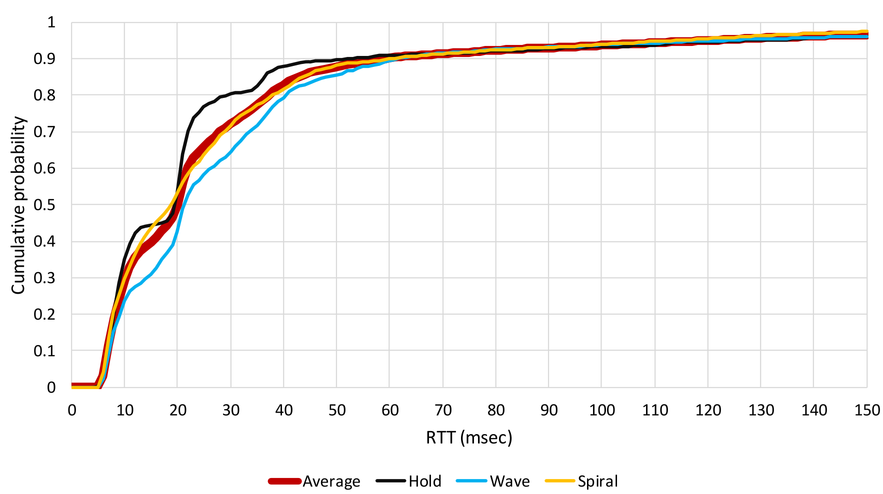


**Fig. 6** All-RTT in Bluetooth (comparison based on drawing operations)

son for the less influence of hand movements in the case of Wi-Fi Direct is thought to be that communication is performed between adjacent tablets unlike in the case of Wi-Fi where the tablets communicate via a wireless router. Another reason could be that, since communication is performed using a 2.4 GHz band in Wi-Fi Direct, it is less susceptible to obstruction influences compared with Wi-Fi communication using a 5 GHz band.

With Bluetooth (Fig. 6), the difference in RTT among drawing operations is even smaller than with Wi-Fi Direct. Bluetooth shows the smallest influence of hand movements among the three standards used in this study's surveys. Blue-

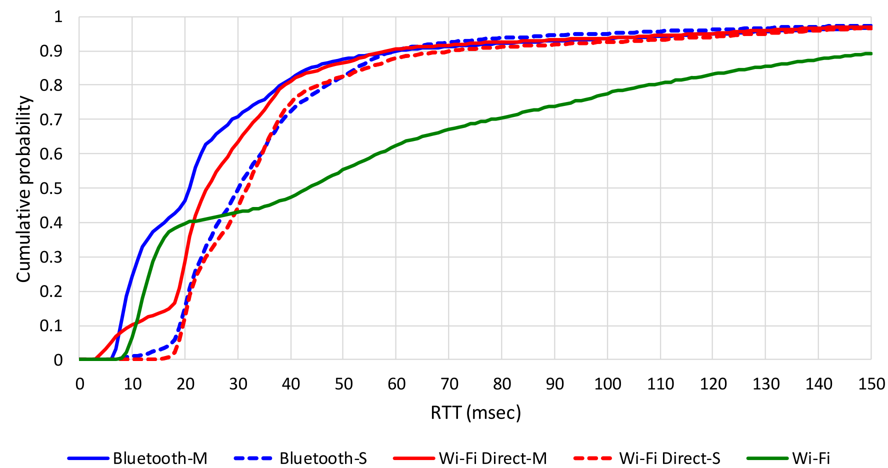


**Fig. 7** All-RTT for all drawing operations (comparison based on communication standards)

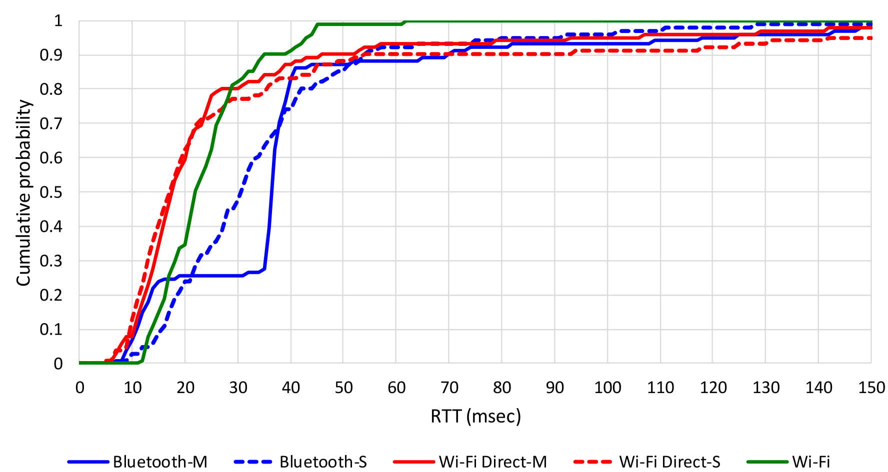


**Fig. 8** Last-RTT for all drawing operations (comparison based on communication standards)

tooth uses Frequency Hopping Spread Spectrum (FHSS), and since communication is performed while switching frequencies between 2402 to 2480 MHz, it is unlikely for multipath fading to occur. Although Orthogonal Frequency-Division Multiplexing (OFDM) used in Wi-Fi and Wi-Fi Direct is also known to be resistant to multipath fading, it is considered to be more susceptible to multipath fading compared to FHSS used in Bluetooth because the channel widths are narrower. In addition, it is possible that the above-described RTT differences occurred due to differences such as header and trailer sizes associated with the data, error correction method, and retransmission protocol in Wi-Fi Direct and Bluetooth.

Figure 7 demonstrates the all-RTT cumulative probability distribution for sending from Master via Bluetooth (Bluetooth-M), sending from Slave via Bluetooth (Bluetooth-S), sending from Master via Wi-Fi Direct (Wi-Fi Direct-M), sending from Slave via Wi-Fi Direct (Wi-Fi Direct-S), and using Wi-Fi (Wi-Fi). With Bluetooth and Wi-Fi Direct, there is an 80% probability that the RTT is shorter than 50 ms. With Wi-Fi, due to the previously described influence of hand movements, the probability that the RTT is shorter than 50 ms is no higher than approximately 55%.

With Bluetooth, RTT when sending from Master (Bluetooth-M) is approximately 10 ms shorter than when sending from Slave (Bluetooth-S). This is considered to be due to the fact that data can be sent at arbitrary timing when sending from Master, while Slave must wait for polling by Master to send data.

There are more instances of smaller RTT with Bluetooth than with Wi-Fi Direct when sending from Master, while the distribution is mostly the same when sending from Slave.

Figure 8 shows the last-RTT cumulative probability distribution. With all the communication standards, there is an over 80% probability that the RTT is shorter than 50 ms.

With Bluetooth, a significant difference between sending from Master (Bluetooth-M) and sending from Slave (Bluetooth-S) is observed in last-RTT cumulative probability distribution. This is believed to be because for Bluetooth, if there is no data to be sent from the Slave, the Slave shifts to a low-power consumption mode called Sniff mode, and it cannot receive data from Master immediately.

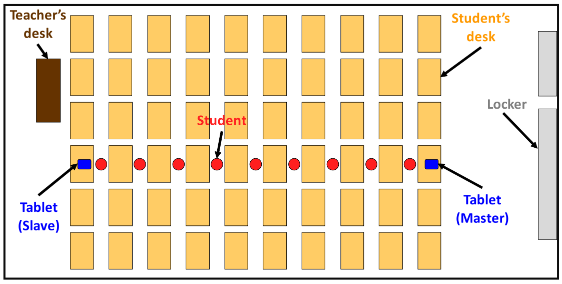


**Fig. 9** Environment for survey on influence of human presence (9 students)

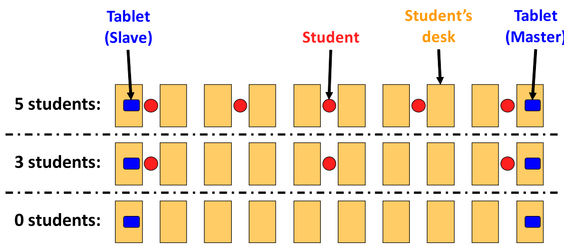


**Fig. 10** Environment for survey on influence of human presence (5, 3, 0 students)

**Fig. 11** Scene of survey on influence of human presence (9 students)

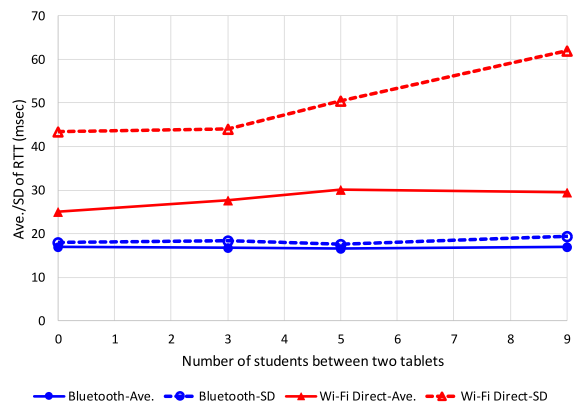


**Fig. 12** Result of survey on influence of human presence

## 4 Survey on the influence of human presence

In this section, we describe the survey on the influence of human presence on delay times.

### 4.1 Survey overview

This survey was conducted in Building 5, Room E591 of the Faculty of Engineering of Ehime University. We conducted an experiment changing the number of students seated between two tablets (Nexus 9) from 9, 5, 3, to 0. When the number of students is 9, students were seated on the chairs by all the desks between the two tablets as shown in Fig. 9. When the number of students is 5, 3, or 0, students were thinned out as shown in Fig. 10. Figure 11 shows the scene of the experiment with 9 students.

In the experiment, the two tablets were wirelessly connected using either Bluetooth or Wi-Fi Direct. Then, packets (with 1 byte payloads) to measure RTT were sent from Slave to Master at 200 ms intervals. The experiment was conducted by sending the packet 300 times for each condition while changing the conditions (communication standard or number of students). RTT was measured in the Application Layer of the OSI model 900 times in total for each condition, and we calculated the averages and standard deviations. Rather than measuring the 900 times at a time, the conditions were changed every 300 times to suppress the influence of interference due to radio waves unrelated to the experiment.

### 4.2 Results and discussion

The result of the experiment is shown in Fig. 12. In this figure, “Bluetooth-Ave.” and “Bluetooth-SD” represent the average and standard deviation of RTT when using Bluetooth, respectively. “Wi-Fi Direct-Ave.” and “Wi-Fi Direct-SD” represent the average and standard deviation of RTT when using Wi-Fi Direct, respectively.

For communication via Wi-Fi Direct, it is observed that the human body as an obstacle influences communication because the RTT average and RTT standard deviation grew bigger by increasing the number of students seated between the two tablets. When the number of students is 9, the average of RTT is 18% longer and standard deviation of RTT is 43% larger than when no students are seated. In contrast, with communication via Bluetooth, we find hardly any influence of the human presence.

Furthermore, regardless of the number of students, when using Bluetooth, RTT average and standard deviation were smaller than when using Wi-Fi Direct. When no students are seated between the two tablets, the average of RTT with Bluetooth is 33% shorter than that with Wi-Fi Direct. The

**Fig. 13** Scene of activities using the educational application

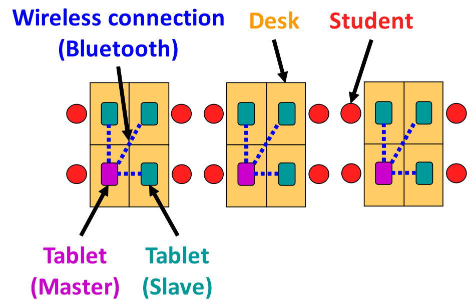


**Fig. 14** Environment for evaluation of the educational application

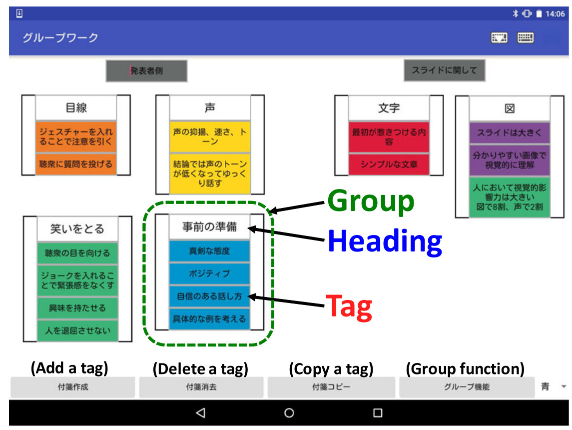


**Fig. 15** Screenshot of the educational application (in Japanese)

difference grows to 43% when 9 students are seated between the two tablets.

Based on the above results, we conclude that Bluetooth has shorter delay times and is less susceptible to influence from human presence when sending small packets. Therefore, when creating educational applications for students in a classroom that can share some data in real time, Bluetooth is more suitable than Wi-Fi Direct.

## 5 Development and evaluation of an educational application using Bluetooth communication

We developed an application for categorizing the opinions of multiple people using tablets interconnected via Bluetooth. With this application, a student can easily create a tag on which an opinion is written. Tags can also be easily moved to another place in the screen. In addition, several similar tags can be collected into groups, and headings can be attached to the respective groups.

With this application, each time an operation is performed on a tablet, a message containing the content of the operation (entered characters, movement coordinates, etc.) is transmitted to other tablets via Bluetooth. This enables real-time synchronization of multiple tablet displays.

In a course named “English Presentation on Engineering Topics” held at Ehime University, students performed activities using this application to organize the points to keep in mind when giving a good presentation. Twelve students attended the course, and the attendants were divided into three teams (each team comprised four students). Figure 13 shows an image of the experimental situation. Each student used one tablet. Of the four tablets in each team, one tablet was designated as the master and the remaining three were connected to the master (Fig. 14).

Figure 15 is a screenshot of the application taken at the end of the activities. After the activities, a questionnaire was administered. The students evaluated various aspects of the application, such as ease of operation. In this paper, we focus on the following question in relation to the operation speed.

Q. Did you experience any delay in the operation of the application?

1. I felt it frequently.
2. I felt it somewhat.
3. I did not really feel it.
4. I did not feel it at all.

The questionnaire was administered to the 12 students, and each responded as follows:

1. 0 students
2. 1 student
3. 9 students
4. 2 students

As 11 out of the 12 students “did not really feel” (3) or “did not feel” (4) a delay, we can say that the operational delay caused by Bluetooth communication and other processes was not a significant obstacle to learning. Therefore, it is possible to develop practical educational applications using Bluetooth communication.

## 6 Conclusion

In this study, we conducted a comparative evaluation of Bluetooth and Wi-Fi Direct, assuming an education in a classroom using ad hoc networks. We conducted surveys on the influence of hand movements while operating the tablets and the influence of human presence on delay times. From the results, we found that Bluetooth is less susceptible to the above-mentioned influences compared to Wi-Fi Direct. Bluetooth can be said to be more suitable for educational applications used on tablets for group work in a classroom where a large number of students are seated.

We also developed a screen-sharing application using Bluetooth to support collaborative learning. We used the application to facilitate collaborative learning in an actual class and administered a questionnaire to evaluate the students' impression of operational delay. The results demonstrate that even 12 students simultaneously used the application communicating via Bluetooth, the delay did not obstruct the learning process.

Future challenges include investigating not only delay characteristics but also throughput characteristics. Additionally, it would be useful to create another educational application that can run on an ad hoc network (Bluetooth scatternet) configured with dozens of tablets and verify its practicality.

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