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10km を越える 5GHz 帯移動伝搬特性の検討
Frequency Scaling for Path Loss Estimation of 5-GHz Band Around 10-km Distance

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1. INTRODUCTION

Active studies on mobile propagation characteristics in the 5-GHz band are continuing in Japan. This band is designated for use by broadband mobile systems such as high-speed wireless access and next generation mobile systems. For the use of high-speed wireless access systems, measurements up to several kilometers were carried out in urban and suburban areas around Tokyo [1]. Results of these measurements have contributed to the development of recommendation ITU-R P.1411 titled “Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks”[2]. On the other hand, in recommendation P.1546, a method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 GHz, is expected to extend the frequency band above 3 GHz [3]. Five-GHz band propagation data measured at a distance of greater than 10 km will be useful to develop this recommendation.

This paper presents results of measurements carried out at distances ranging from approximately 5 to 30 km. In these measurements, frequencies in the 2 GHz and 5 GHz bands are used simultaneously. The results enable us to estimate the path loss for the 5-GHz band from that of the 2-GHz band.

2. MEASUREMENT OF PATH LOSS CHARACTERISTICS FOR DISTANT AREA

In order to measure the path loss in an area distant from the transmission point, three sets of measurements were carried out around Tokyo. The paths are indicated in Fig. 1 by arrows. The starting point of the arrow indicates the transmission point and the direction of the arrow represents the direction of the antenna at this point. Table I gives details regarding the transmission stations. The Shinjuku-Kawagoe measurement area is an urban area that changes to a suburban area. The distance range for the measurement is from 4 km to approximately 30 km. In this case, the transmission antennas were placed on the rooftop of the Mitsui building, which is one of the 200-m skyscrapers in the west Shinjuku area. The propagation environment is considered to be urban to suburban in the northwest part of the central Tokyo. Hilly terrain with a height variation of 20 m to 50 m persists into the Kawagoe area. The Shiroyama-Jujo measurement area is a suburban area that changes into an urban area. The measurement range is from 20 km to approximately 50 km and the transmission antenna was placed on top of an approximately 600-m high mountain. There is a microwave relay station at the top of the mountain and we used this antenna platform to establish both the transmission equipment and antennas for 2.2 GHz and 5.2 GHz. The average ground level at the measurement point gradually drops from approximately 70 m to 20 m in the 20 km to 50 km range. Most of the area in the Karagasaki-Chofu measurement is considered to be urban. The distance range of measurement is 1 to 10 km and the transmission antenna height is 30 m from the ground. The transmission antenna was placed on the rooftop of the Karagasaki building, which is used for a microwave relay station. The 2.2-GHz transmission antenna is a six-element Yagi antenna with the gain of 12 dBi, and a pyramidal horn antenna was used for the 5.2-GHz transmission antenna with the gain of 20 dBi. When transmitting from Shiroyama, a 32-dBi gain parabola antenna was used for the 5-GHz band. The transmitter power for the 2.2 GHz and 5.2 GHz antennas was 30 dBm in the three cases.

The mobile terminal received a carrier wave (CW) at the frequency of 5.2 GHz and 2.2 GHz. The antenna is a vertical polarized dual band antenna with the gain of 2 dBi [1]. The antenna height of the mobile terminal was set to 2.2 m or 3.8 m above ground.

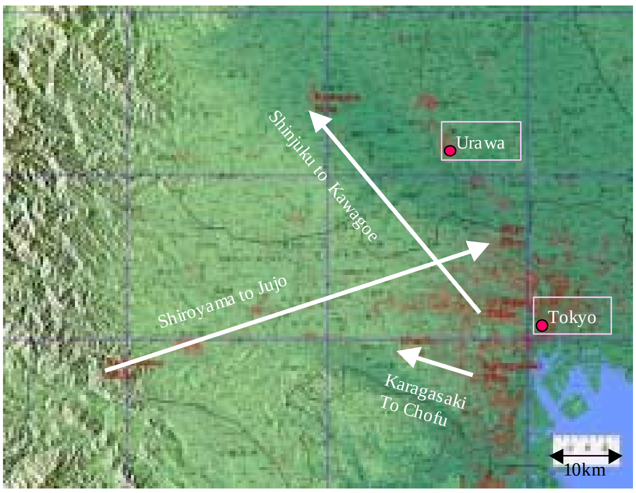
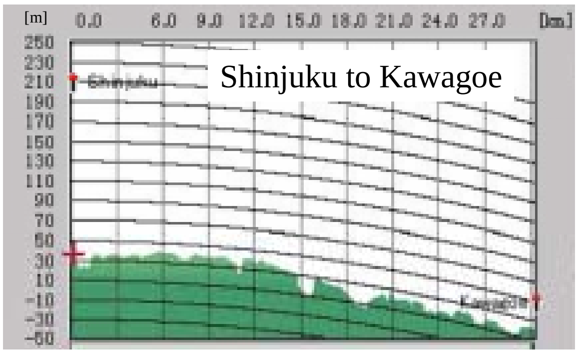
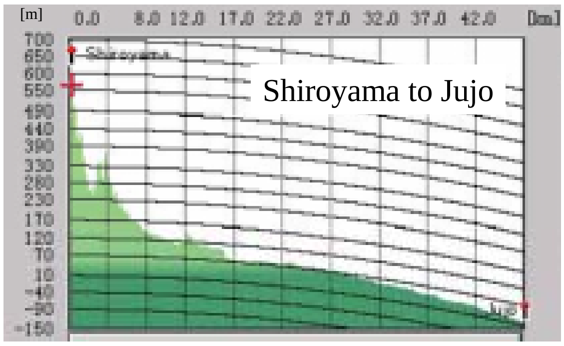


Fig. 1 (a) Three paths for path-loss

Because it is practically impossible to measure all locations in the transmission antenna coverage area, we selected several areas or courses according to the distance from the transmission point. In the Shinjuku-Kawagoe measurement, each measurement area is relatively large. The length of the measurement course is several hundred meters to approximately one kilometer. The measurement vehicle moves along a selected course or in an area to obtain a set of data. In both the Shiroyama-Jujo and Karagasaki-Chofu measurements, the measurement area was about 100 m ×100 m-square to 200 m×200 m-square for each distance.





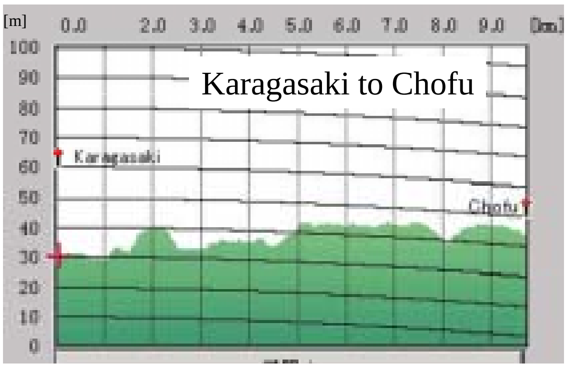


Fig.1(b) Path profiles for the three measurements

Table I. Transmission Stations

Transmission station	Shinjuku	Shiroyama	Karagasaki
Height above sea level [m]	232	683	62
Range of measurement area [km]	4 to 30	20 to 45	1 to 10
Average ground level of measurement area [m above sea level]	15 to 45	20 to 70	30 to 45

3. MEASUREMENT RESULTS

(a) Shinjuku-Kawagoe Measurement

Figure 2 shows the distance dependency of the path loss in the 2-GHz and 5-GHz bands obtained in the Shinjuku-Kawagoe case. The measured data are median values of the path loss at 100-m intervals. Approximately 2×10^4 data points were obtained in a 100-m interval when the vehicle speed was assumed to be 18 km/hr because the sampling speed of data recorder was 1 kHz. Red circles and blue triangles correspond to 2.2 GHz and 5.2 GHz, respectively. The free space path loss (FSL) and calculated values by using the Okumura-Hata equation are plotted as references. Around the 10 km and 20 km points, the path loss decreases locally. These decreases may be caused by a line-of-sight (LOS) condition that occurred at a high elevation point such as when crossing a bridge over a road or railway. Except for these low loss locations, most of the path loss values along the measurement course exhibited an approximate 30 dB decrease compared to the free space path loss values in both the 2.2-GHz and 5.2-GHz cases. The measured results indicate that the path losses of these frequencies decrease similarly with distance and a greater than 30-dB path loss (difference between the free space path loss and measured path loss) is observed. However, occasionally a sudden path loss decrease occurs depending on the occurrence of the LOS condition.

Figure 3 shows an example of the distance dependency in a short period of 500 m. The figure shows a comparison of the variation between 100-m median values and 10-m median values. It is obvious that the 10-m median values fluctuate significantly, which causes a large standard deviation in the path loss values.

In order to study the statistical relationship between the two values, a correlation characteristic, sometimes expressed by a scatter gram, is useful. Figure 4 is a correlation between the median values of the path loss at 2.2 GHz and 5.2 GHz derived from 100-m median values. In a low path loss region such as below 150 dB, the difference in path loss is approximately 7 dB. In a higher path loss region such as over 150 dB, the difference in path loss increases gradually up to approximately 8.5 dB. Figure 5 is also shows the correlation derived from 10-m median values. Since the scattering pattern has a large width compared to that in Fig. 4 because of the larger standard deviation in the variation of the loss, the path loss dependency of the difference in the two losses of the two frequencies is not very clear.

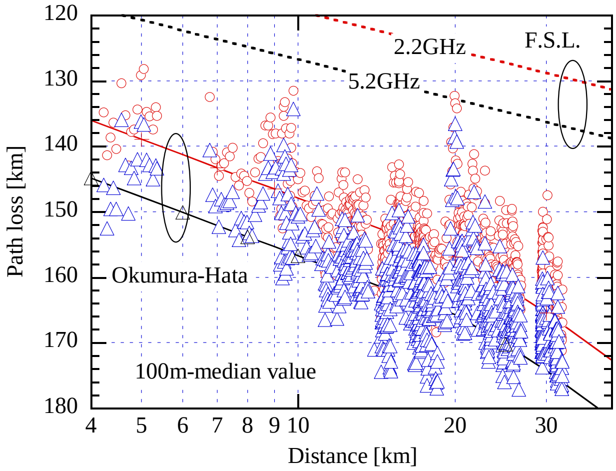


Fig. 2 Path loss vs. distance in Shinjuku-Kawagoe measurement

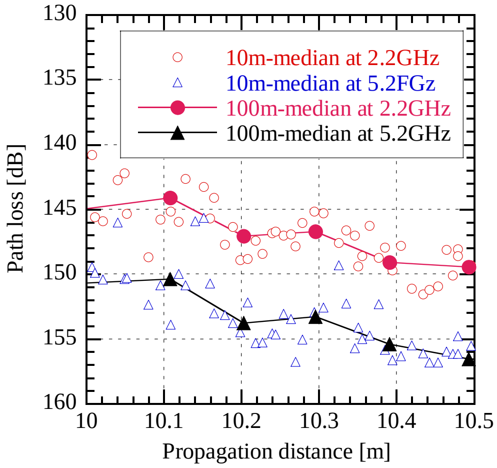


Fig. 3 Example of path loss variations in a short period

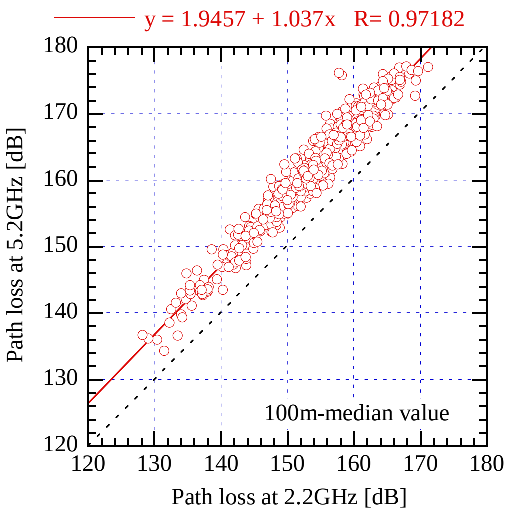


Fig. 4 Path loss correlation between 2.2 GHz and 5.2 GHz in Shinjuku-Kawagoe measurement obtained from 100-m median value

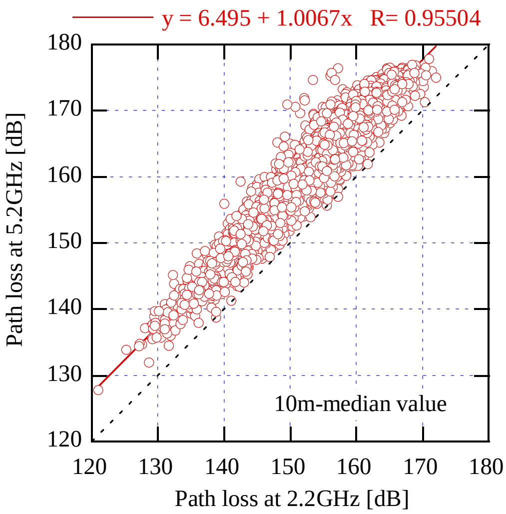


Fig. 5 Path loss correlation between 2.2 GHz and 5.2 GHz in Shinjuku-Kawagoe measurement obtained from 10-m median value

For further analysis of the statistical characteristics of the difference in path loss between the two frequencies, the cumulative probability of the difference in the path loss is investigated. Figure 6 shows two cumulative probabilities of the difference in path loss covering the whole distance range. The median value of the 100-m interval path loss median values is 7.57 dB and the standard deviation is 1.8 dB. In Fig. 7, the median value of the 10-m period path loss median values is 7.51 dB and the standard deviation is 2.15 dB.

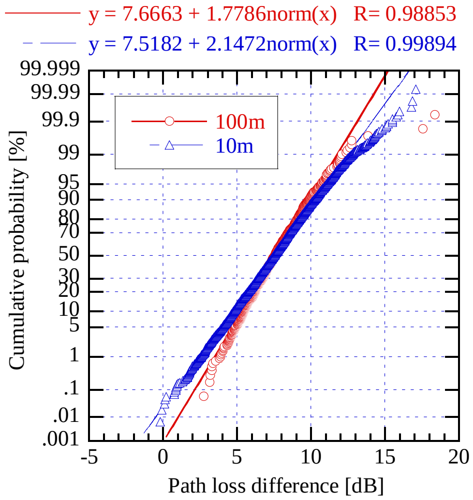


Fig.6 Cumulative probabilities of the difference in path loss between 2.2 GHz and 5.2 GHz

Figure 8 shows the cumulative probabilities for different measurement ranges such as 10 km < d < 20 km and 20 km < d. The median in the measurement region is slightly larger than that within 20 km. Figure 8 shows the same tendency, but for 100-m median values. The results of the median values and standard deviations are summarized in Table II in addition to the results obtained in the other two measurement cases.

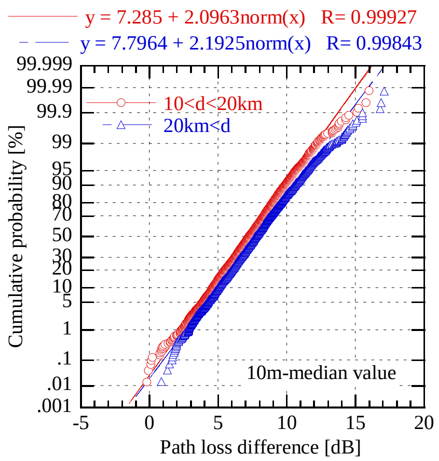


Fig. 7 Cumulative probabilities of the difference in path loss between 2.2 GHz and 5.2 GHz in case of 10-m median value

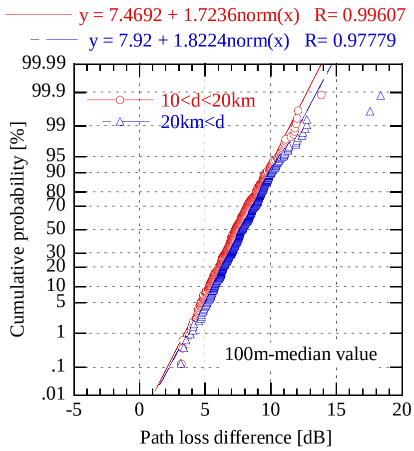


Fig. 8 Cumulative probabilities of the difference in path loss between 2.2 GHz and 5.2 GHz in case of 100-m median value

(b) Shiroyama-Jujo Measurement

In the Shiroyama-Jujo measurement, a distance of nearly 50 km was achieved by transmitting from the mountaintop. We established measurement areas in 5 km intervals from 20 km to 45 km distance from the transmission point. Figure 9 shows the distance dependency of the path loss for 2.2 GHz and 5.2 GHz. Free space path loss and calculated results of the Okumura-Hata equation are also plotted. At this distance range, the calculated loss of the Okumura-Hata equation increases in curvature and is not straight in a log scale with respect to the distance. This is because of the correction for the curvature of the earth's surface.

However, this curvature tendency is not pronounced in the measured results for the 2.2-GHz and 5.2-GHz bands. Excess loss from the free space path loss is kept to approximately 25 dB even at a distance from the transmission point.

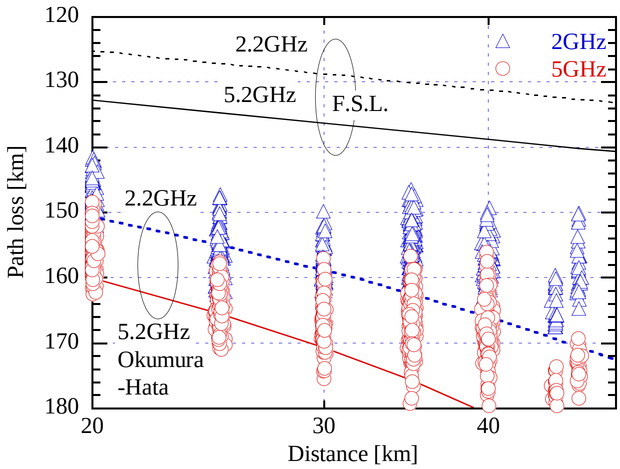


Fig. 9 Path loss vs. distance in Shiroyama-Jujo measurement

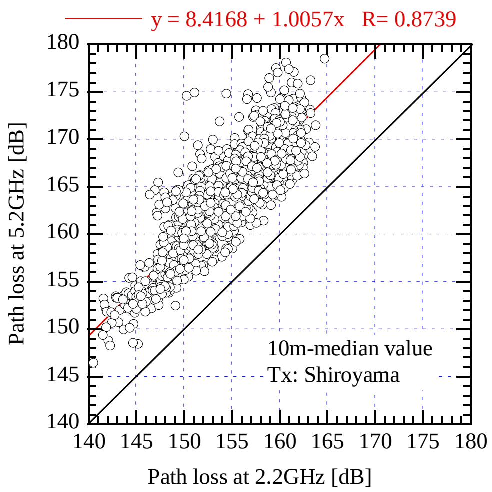


Fig.10 Path loss correlation between 2.2 GHz and 5.2 GHz in Shiroyama-Jujo measurement obtained from 10-m median value

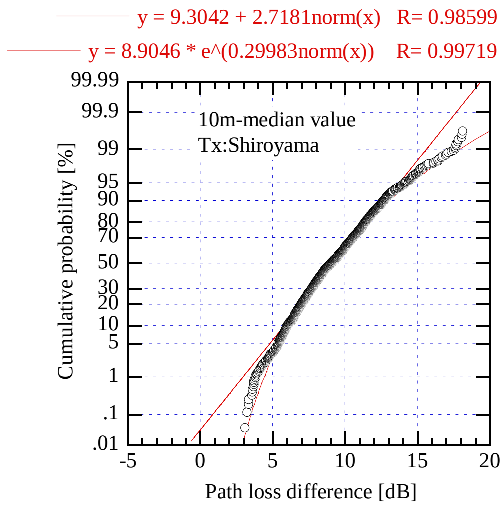


Fig. 11 Cumulative probabilities of the difference in path loss between 2.2 GHz and 5.2 GHz in case of 10-m median value

Figure 10 is a scatter gram of the path losses at 2.2 GHz and 5.2 GHz. The width of scatter area of the measured data is larger than that for the Shinjuku-Kawagoe measurement shown in Fig. 6. There is a tendency to shift to a larger loss in the 5.2-GHz band. Figure 11 shows the cumulative probability of the difference in path loss. The median and standard deviation are 9.05 dB and 2.75 dB, respectively. The median value of the difference in path loss is larger than that for the Shinjuku-Kawagoe measurement. The distribution shape is not straight in this normal distribution graph. It can be said that a lognormal type approximation is suitable when we formulate this measured distribution.

(c) Karagasaki-Chofu Measurement

In this measurement, the measurement range is up to 10 km. Since the height of the transmission antenna was lower in comparison to those of other two measurements, the applicable dynamic range was not enough to measure the measurement area. However, it is useful to study the frequency scaling in the path loss estimation in an urban area. Figure 12 shows the distance dependency of the path loss for 10-m median values. The free space path loss and calculated results by using the Okumura-Hata equation are plotted. The distance between 1 to 2 km is covered continuously. Other areas at 1 km intervals seems to be separated because the measurement vehicle moved around selected area of approximately 200m ×200m. Since this area is an urban area, an excess of 25 dB loss is observed over the measurement range. In the following study of the difference in path loss, the measured data within 7 km are used because of the lack of the dynamic range in measurement area.

Figure 13 shows the path loss correlation between the 2.2 GHz and 5.2 GHz measured data. A linear shift of the 5.2-GHz path loss values from the 2.2-GHz path loss values is observed in the 130 to 160 dB range. Figure 14 shows the cumulative probability of the difference in path loss. A probability distribution of the measured difference in path loss can be assumed to be a normal distribution because a straight line in a normal distribution probability graph can approximate the data. The median and standard deviation are 8.57 dB and 32.38 dB, respectively.

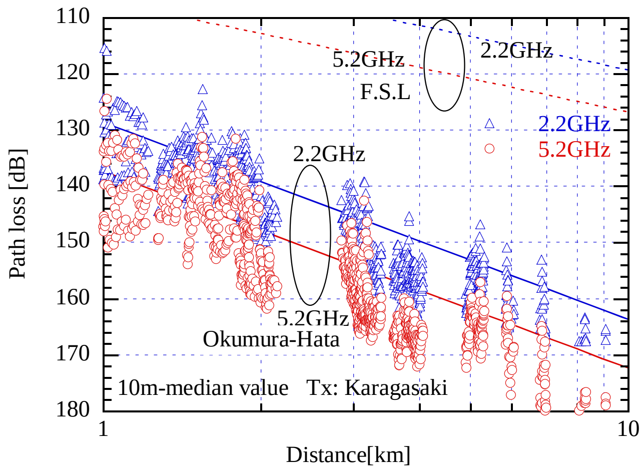


Fig. 12 Path loss vs. distance in Karagasaki-Chofu measurement

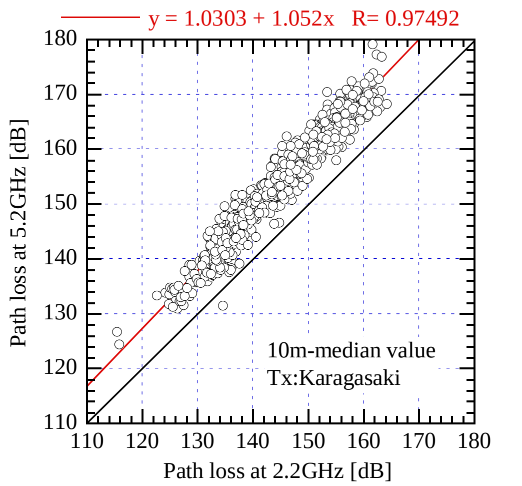


Fig.13 Path loss correlation between 2.2 GHz and 5.2 GHz in Karagasaki-Chofu measurement obtained from 10-m median value

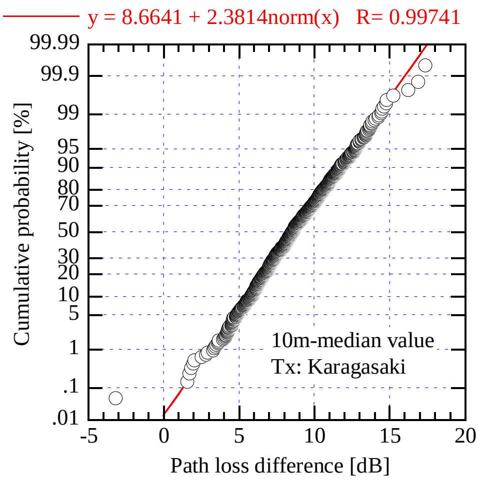


Fig. 14 Path loss correlation between 2.2 GHz and 5.2 GHz in Karagasaki-Chofu measurement obtained from 10-m median value

Table II summarizes the statistical parameters related to the difference in path loss obtained in the three measurements. In the free space path loss model, the path loss depends on the frequency and is expressed as 20*log(f). The difference in path loss between 2.2 GHz and 5.2 GHz is 7.47 dB according to the free space path loss model. In the Shinjuku-Kawagoe measurement, median values of the path loss are distributed from 7.29 to 7.79 dB. It can be said that the difference in path loss in this measurement is similar to that of the free space path loss. At a distance beyond 20 km, the difference in path loss increases slightly. The Shiroyama-Jujo measurement was carried out at 20 to 50 km. The largest difference in path loss of 9 dB (median) and 2.75 dB (standard deviation) were obtained in these three measurements. Otherwise, we had a large median and standard deviation, 8.57 dB and 2.38 dB, within 10 km range for the Karagasaki-Chofu measurement.

Table II. Statistical Parameters Obtained in Three Measurements

	Median [dB]	Standard deviation [dB]
Shinjuku-Kawagoe 100-m period measurement	7.57	1.80
10 km < d < 20 km	7.34	1.73
20 km < d	7.79	1.86
Shinjuku-Kawagoe 10-m period measurement	7.51	2.15
10 km < d < 20 km	7.29	2.01
20 km < d	7.76	2.19
Shiroyama-Jujo 10-m period measurement	9.05	2.75
Karagasaki-Chofu 10-m period measurement	8.57	2.38

We can say that the difference in path loss between the 2-GHz band and the 5-GHz band in a mobile propagation environment is almost the same as that of the free space path loss model if we had only the Shinjuku-Kawagoe measurement data. However, the other two measurements indicate that there is some complexity to the direct conversion of the path loss in the 2-GHz band to the 5-GHz band. This may indicate that the path category such as urban, suburban, and rural should be considered more precisely to derive a conversion method.

4. CONCLUSION

We carried out three sets of propagation measurements to investigate the difference in path loss between the 2-GHz band and 5-GHz band in order to develop a frequency scaling method to estimate the path loss in the SHF band. The difference in path loss is approximately 7 to 9 dB based on the analysis of measured data for median values in 10-m intervals. Further data will be necessary to clarify the measurement area especially beyond 20 km from the transmission point.

REFERENCES

[1] N. Kita, S. Uwano, A. Sato and M.Umehira, “A Path Loss Model in Residential Areas Based on Measurement Studies Using a 5.2-GHz/2.2-GHz Dual Band Antenna”, IEICE Trans. Vol. E84-B, No.3, pp. 368-376 (2001).
[2] Recommendation P.1411, “Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks”, ITU-R Recommendations P-series 2003.
[3] Recommendation P.1546, “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz”, ITU-R Recommendations P-series 2003.