Characteristics of Non-Line-of-Sight Microwave Propagation in a Suburban Environment

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I. INTRODUCTION

In parallel with the diversification of mobile communications, the need has arisen for frequency bands capable of high-quality and high-speed transmission required by multimedia services. In recent years, the microwave band has come to be seen as the most promising candidate in this regard, and its application to mobile communications is now being studied. To achieve high-speed mobility and high-speed transmission, however, it is indispensable that propagation characteristics be clarified and propagation parameters be empirically understood. To date, there have been many reports on such research in the UHF band [1]-[3]. There have also been various reports on line-of-sight (LOS) measurements in the microwave band within a suburban environment, but few for non-line-of-sight (NLOS); and many areas in NLOS propagation characteristics still remain unclear. With the aim of obtaining an empirical understanding of propagation parameters, we have measured propagation loss, delay spread, and number of arriving radio waves in a suburban environment with an emphasis on NLOS characteristics.

II. EXPERIMENT DESCRIPTION

2.1 Location

The measurements were performed in a low-rise residential area in the suburbs with average house heights of 8 m. A map of the measurement area is shown in Fig. 1. The overall measurement course comprised a LOS course in the east-west direction having a total length of about 480 m and several NLOS courses each of about 200 m in the north-south direction perpendicular to the former. Street width in this area was about 6 m. Each block comprises typically 22 houses in total (i.e. two rows of eleven houses).

2.2 Measurement Setup

For the transmitting base station, we used a 4-m-high antenna and a transmission frequency of 3.35 GHz, and for the receiving mobile station, a measurement vehicle with a 2.7-m-high antenna. Half-wavelength vertical dipole antennas were used for both the transmission and reception.

Continuous wave was used for path loss measurements. A delay profile measurement system[4] was developed utilizing a pseudo noise (PN) code method for high-precision delay measurements in outdoor environments. The transmitter of the system employs PN with a code length of 2047 chips, and the transmission rate was 50 Mchip/s (time resolution = 20 ns) using BPSK modulation. The receiver is configured with a single superheterodyne system. It extracts in-phase and quadrature components from the intermediate frequency signal, performs 2-times over-sampling using a 10-bit analog-to-digital converter, and stores resulting data in receive-waveform memory achieving a sampling speed of 100 Msample/s. Correlation processing is performed off-line and a delay profile is calculated. This delay profile is taken to be an ensemble average with respect to continuous data made up of 32 cycles of the spread code length. Automatic gain control (AGC) of the receive system has a dynamic range of 50 dB in 1dB steps and time constant was 2 μs. The AGC value is constant while the 32 cycles of data is being input, and during this time, the dynamic range of the receive system is nearly 66 dB (= 20 $\log_{10}2047$). Relative amplitude uncertainty is within 3dB.

III. EXPERIMENT RESULTS AND DISCUSSIONS

3.1 Propagation Loss

Figure 2 shows the results of propagation loss measurements. Figure 2(a) shows propagation loss characteristics for both LOS and NLOS streets. As shown, an-attenuation coefficient α of approximately 2.1 (almost equivalent to free space propagation ($\alpha = 2$)) was obtained for the LOS street. Figures 2(b) and 2(c) show propagation-loss characteristics for the two NLOS streets, and they reveal that a corner loss of from 35 to 40 dB occurs on turning into NLOS streets. These corner losses are about 20 dB greater than that measured in an urban environment [5]. According to a waveguide propagation model, this is because the loss is greater in a suburban residential area due to narrower streets. A number of peaks in propagation loss were also observed owing to waves arriving along streets that cross a NLOS street and waves slipping through the gaps between houses. These results demonstrated that propagation loss along NLOS streets is characteristic of a suburban environment, i.e., propagation loss does not necessarily increase monotonically with distance.

3.2 Delay Characteristics

Figures 3(a) and 3(c) show examples of delay profile measurements for LOS and NLOS cases. On the LOS street, almost no delay above 1 μs was observed, while on the NLOS street, delay time increased dramatically at each various points. Figure 4 shows the dependence of delay spread on distance. It can be seen that delay spread on the LOS street is no more than 200 ns, while that on a NLOS street is larger by more than several times this value.

Figure 5 shows the dependence of average delay time on distance on NLOS streets. Comparing the results obtained for course 3 with those of course 4, we see that average delay time is essentially the same near the intersections with the LOS street. As the distance from such an intersection increases, however, the difference between these two values increases. Course 4 is 120 m farther from the transmitter than course 3, and average delay time in the case of the former is about 1.5- to 2.0-times that of the latter. Nevertheless, both courses display a tendency for delay time to increase near intersections and near the gaps between houses. The reason for this increase in delay time is attributed to the multiple reflections that waves undergo in the alleys and off the rows of houses causing the waves to arrive late.

3.3 Number of arriving radio waves

Figure 6(a) shows results of measuring the number of arriving radio waves versus distance for the LOS street, and Figs. 6(b) and 6(c) shows that for NLOS streets. The number of arriving radio waves on the LOS street was obtained by counting the number of waves in delay profiles within 10 dB of the peak power of the dominant wave, and that on the NLOS streets by counting the number of waves within 5 dB of the strongest wave.

The peak value in Fig. 6(a) occurs exactly at intersection B2 (the intersection of the LOS course and NLOS course 2) due, we can think, to waves arriving from many directions at the intersection. This phenomenon, however, cannot be seen at other intersections on the LOS street, and we consider the reason for this to be that those locations have open space like parking lots and fields. In addition, the reason for some locations near the transmitter having an increase in number of arriving waves is attributed to the presence of houses on both sides of the street on some stretches and open space on others in this area. Overall, the number of arriving waves on the LOS street is on the order of several waves, which is smaller than that measured in an urban environment [6]. For NLOS, peak values occurred in a manner similar to the behavior of average delay time, i.e., the number of arriving waves increased near intersections and the gaps between houses.

IV. CONCLUSION

This paper has reported on the measurement of propagation loss, delay characteristics, and number of arriving radio waves with the aim of clarifying the characteristics of NLOS microwave propagation in suburban environments. In these measurements, NLOS propagation loss demonstrated characteristics typical of a suburban environment, that is, attenuation characteristics do not necessarily increase monotonically with distance. Corner loss at 3.35 GHz was found to be about 35 to 40 dB, which is approximately 20 dB greater than that in an urban environment. Excess delay of several μs was observed on NLOS streets. Delay spread was about 200 ns on the LOS street but several times this value on NLOS streets. In addition, the distribution obtained for the number of arriving radio waves showed that only a few waves at the most arrived for LOS, but sometimes over 10 on NLOS streets. It was also found that the number of arriving waves increased near alleys and the gaps between houses. Finally, it was experimentally shown that both LOS and NLOS characteristics have a close relationship with alleys and houses in the immediate area.

References

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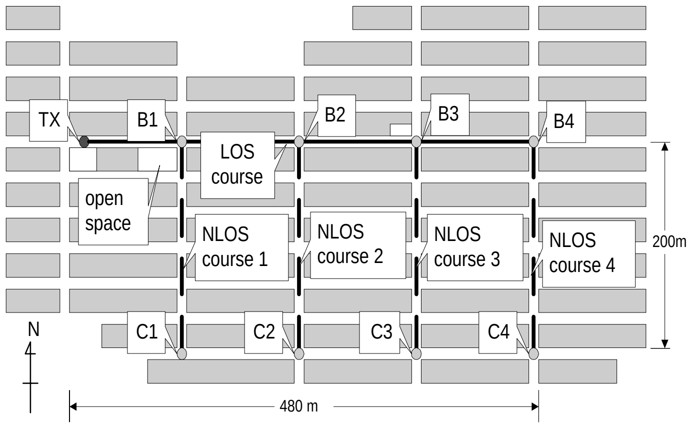
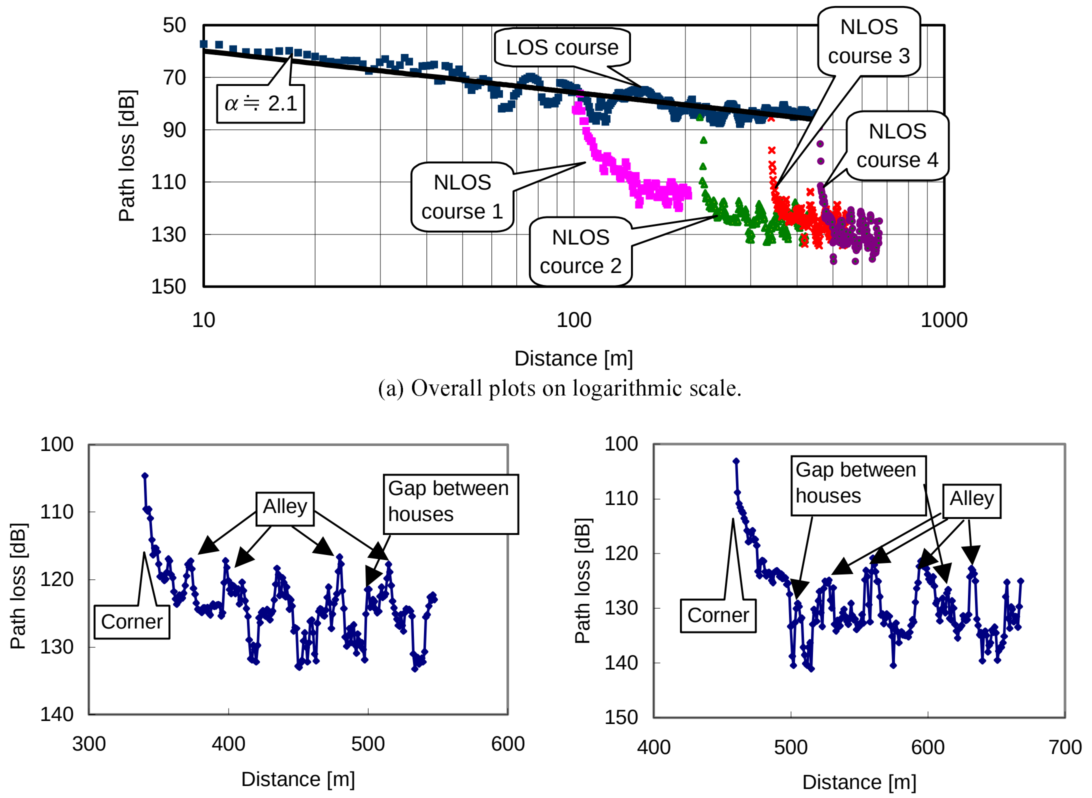


Fig. 1. Measurement environment.

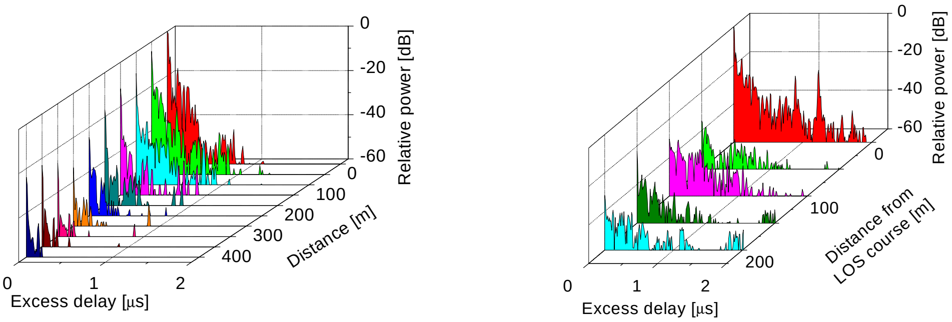


(a) Overall plots on logarithmic scale.

(b) Path loss along NLOS course 3.

(c) Path loss along NLOS course 4.

Fig. 2. Path loss characteristics.



(a) LOS course.

(b) NLOS course 4.

Fig. 3. Examples delay profiles.

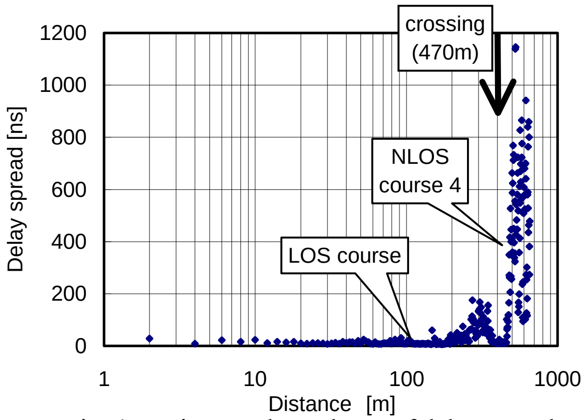


Fig. 4. Distance dependence of delay spread.

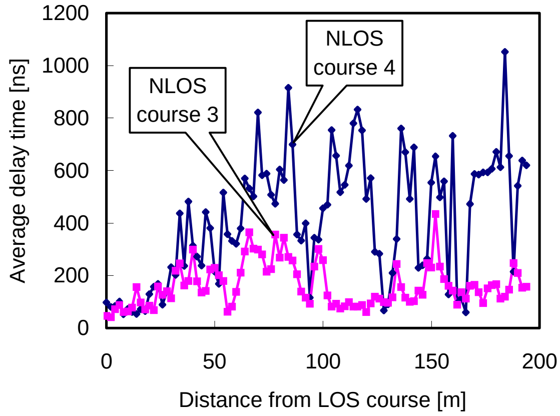
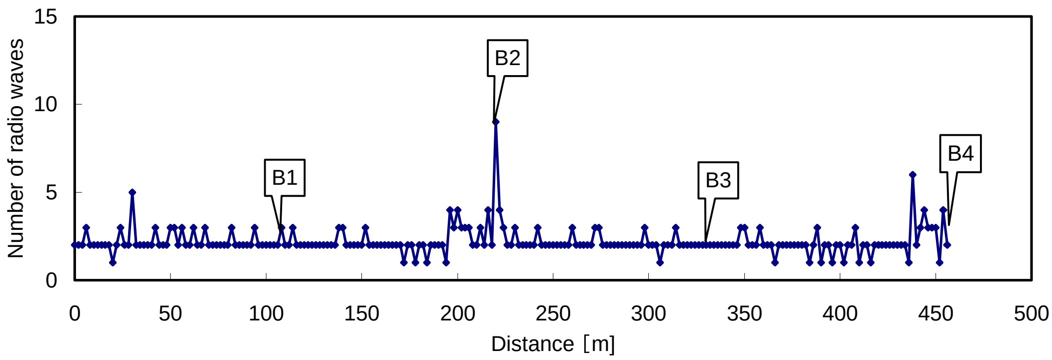
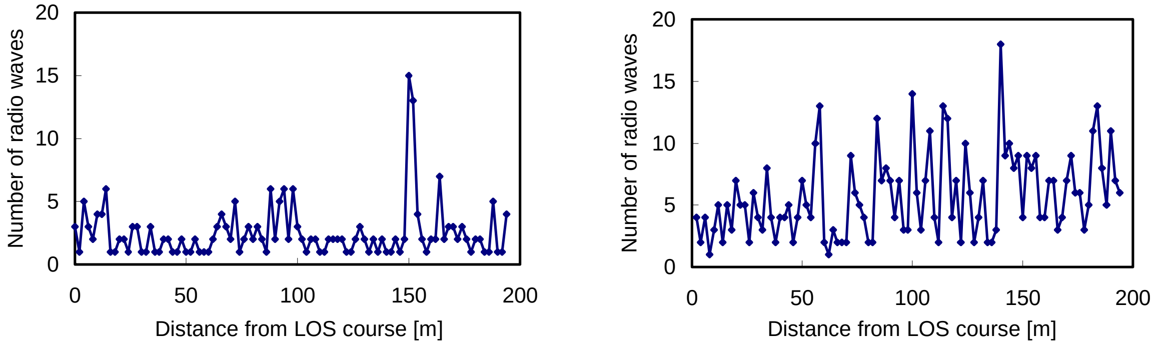


Fig. 5. Distance dependence of average delay time along NLOS course 3 and 4.



(a) LOS course.



(b) NLOS course 3.

(c) NLOS course 4.

Fig. 6. Number of arriving radio waves.