# Measurement of Time-Spatial Characteristics Between Indoor Spaces in Different LOS Buildings


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***Abstract*— In order to overcome the increasing traffic problems of mobile terminals used in high-rise offices of buildings, it is necessary to clarify the time-spatial characteristics which are composed of the characteristics of the path loss, the delay profile and the spatial arrival angular profile for travelling waves from one high-rise office to another office in a different building. In this paper, we measure the time-spatial characteristics of radio waves passing from one indoor space to another and identify the key parameters determining the time-spatial characteristics based on measured results.**



***Keywords*— *Mobile communication; Indoor ofiice; 3D cell structure; Time-Spatial profile***


## I. Introduction

Recently, data traffic in cellular mobile communication systems is growing explosively due to the prevalence of smart phones and other mobile terminals. In particular, the traffic in high-rise buildings is rising rapidly and a more efficient method of transmitting data traffic is required. In order to overcome the increasing traffic problems of mobile terminals used in high-rise buildings, the three-dimensional cell configuration which sets small cells on various floors is considered [1]. Fig.1 shows typical three-dimensional cell configurations. In order to evaluate the wireless transmission technology used to implement the three-dimensional cell configurations, it is necessary to clarify the time-spatial characteristics of waves travelling from outdoor macro cells to indoor small cells as shown in (i) and (ii) of Fig.1, from indoor small cells to mobile phones on the road as shown in (iii) and (iv) of Fig.1 and from indoor small cells to other indoor small cells as shown in (v) and (vi) of Fig.1. Here, the time-spatial characteristics are composed of the characteristics of the path loss, the delay profile and the spatial arrival angular profile. In particular, the time-spatial characteristics of (v) and (vi) are strongly required with increasing the high-rise small cells. There are some studies regarding (i) to (iv)[2]-[5]. Also, regarding the path loss characteristics of (v) and (vi), some research has been reported[6]-[9]. However, few studies have considered the delay and the arrival angular characteristics of (v) and (vi).

In this paper, we measure the time-spatial characteristics of radio waves from one indoor space to another indoor space and identify the key parameters for time-spatial characteristics based on measured results.

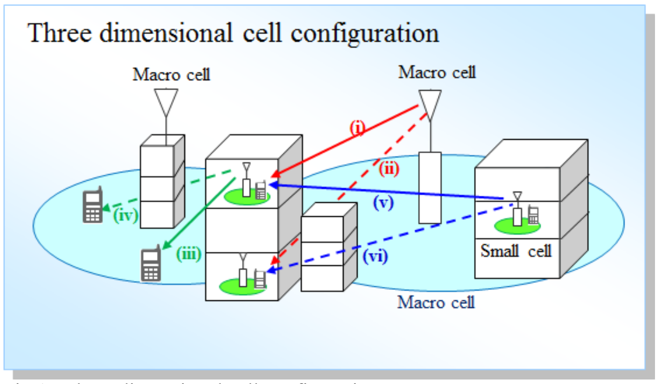



Fig.1. Three dimensional cell configuration

TABLE 1. Measurement Parameters

| Measurement area (environment) | Tokyo (transmitting building:high) (receiving building: high) | Kita-Kyushu (transmitting building:low) (receiving building: high) |
|---|---|---|
| Carrier frequency | 3.35GHz | |
| Chip rate | 50Mcps(resolution: 6m) | |
| Transmitting building height | 100m | 15m |
| Receiving building height | 100m | 32m |
| Distance between buildings | 45m | 58m |
| Transmitting antenna | Sleeve antenna (Omni direction in horizontal plane) | |
| Distance from window to transmitting antenna | 1,4,8m | 1m |
| Transmitting floor | 11F, 13F | 3F |
| Receiving antenna | Sleeve antenna (Delay profile) (Omni direction in horizontal plane) Directional antenna (Arrival angular profile) (3 degrees half-band width in horizontal plane) | |
| Distance from window to Receiving antenna | 1,4,8m | 1m |
| Receiving floor | 13F, 16F | 6F |
| Vertical angle | 0, 18, 29degrees | 11degrees |

## II. Field Measurements

We measured the time-spatial characteristics between indoor spaces in two different buildings in urban areas in Tokyo and in Kita-Kyushu. TABLE I shows the measurement parameters. Fig.2 shows the measurement environment in Tokyo. The buildings face each other, and are both 100m high,

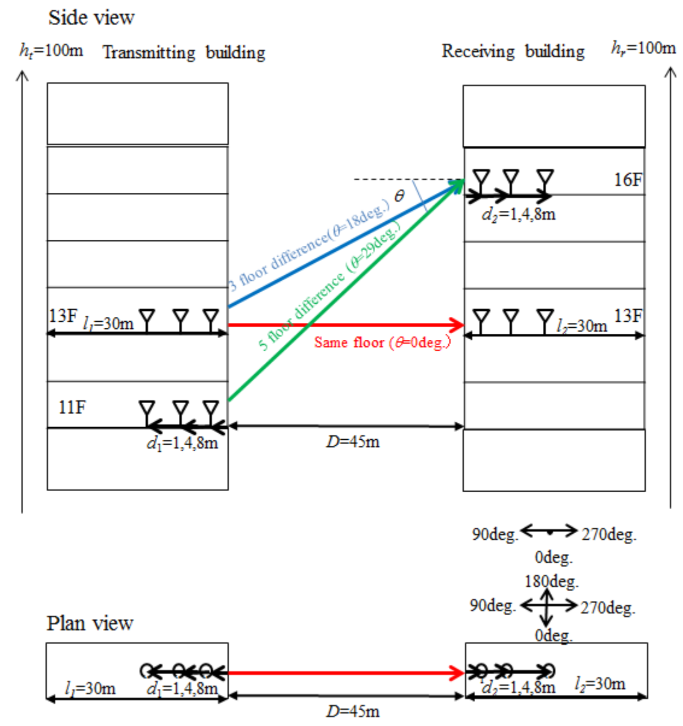


Fig.2. Measurement environment in Tokyo

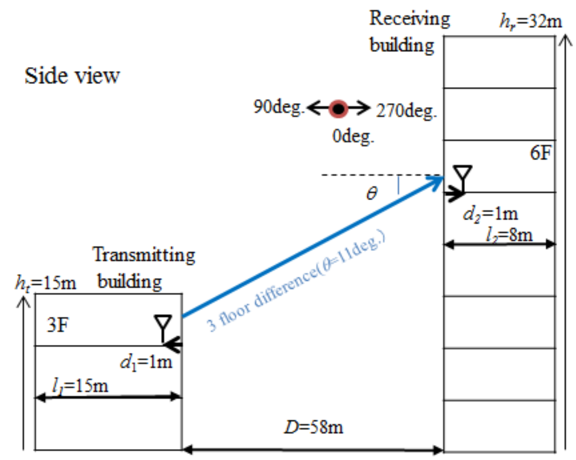
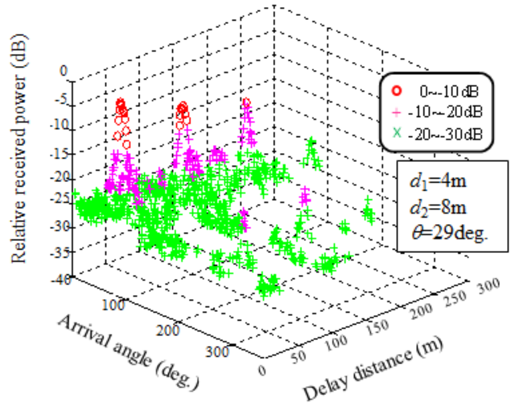
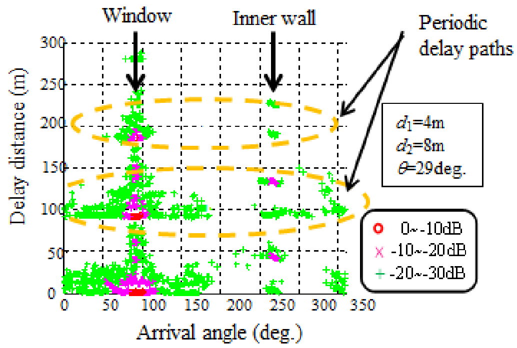


Fig.3. Measurement environment in Kita-Kyushu

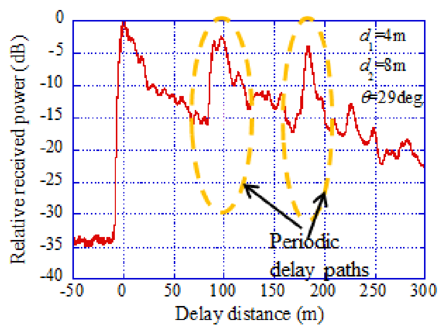
$h_t$, $h_r$. The distance between them, $D$, is 45m. The spaces are located in corridors on the same floors and are line of sight (LOS) to each other. The corridors are 30m long, $l_1$, $l_2$. In order to clarify the vertical angle dependency, we set the transmitting and receiving antennas as follows. (1) The same floors in different buildings (13F-13F), (2) 3 floor difference (13F-16F), and (3) 5 floor difference (11F-18F). The vertical angle, $\theta$, is 0, 18, and 29 degrees, respectively. The distance from window to transmitting antenna or receiving antenna, $d_1$, $d_2$, was set at 1, 4, or 8m. The carrier frequency is 3.35GHz. The chip rate is 50Mcps and the delay resolution is 6m. The transmitting antenna is an omni-directional antenna. We used an omni-directional antenna for measuring delay profile and a



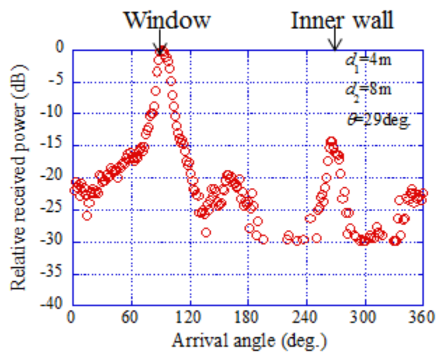
(a) time-spatial profile



(b) Delay vs arrival angle



(c) Delay profile



(d) Arrival angle profile
Fig.4. Results measured in Tokyo

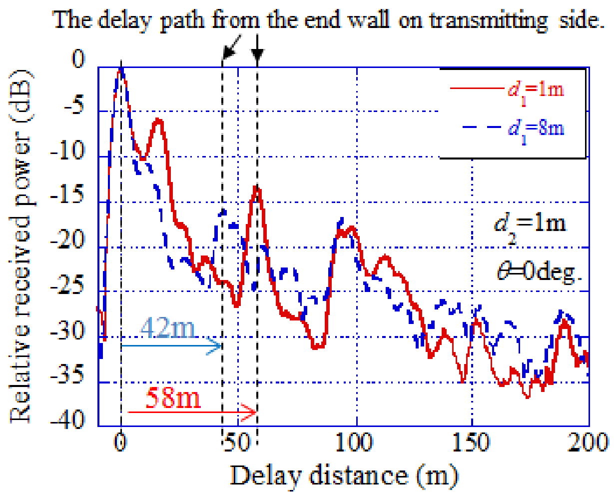



Fig.5. Delay profile ($d_1$ dependency)

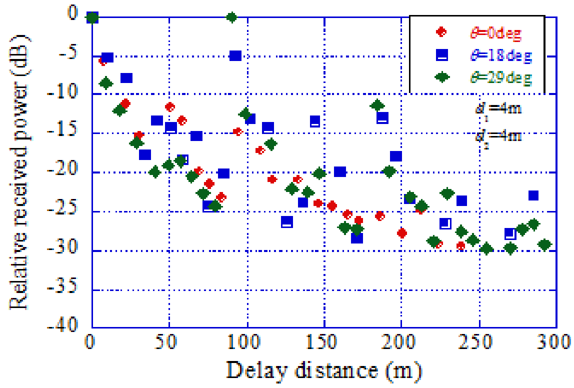



Fig.6. Delay profile (θ dependency)

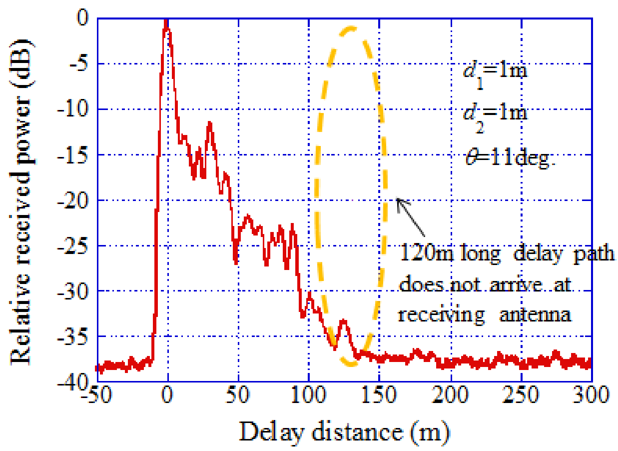



Fig.7. The example of delay profile in Kita-Kyushu

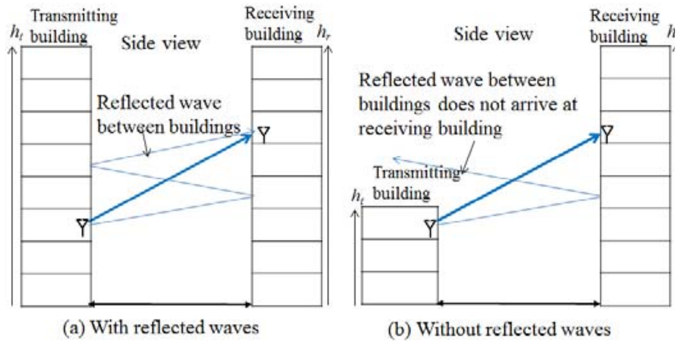



Fig.8. Relation of building height and waves reflected between the buildings

directional antenna with horizontal half angle of 3degrees for measuring the arrival angular profile as the receiving antenna.

Fig.3 shows the measurement environment in Kita-Kyushu. Here, $h_t$=15m, $h_r$=32m, $D$=58m, $l_1$=15m, $l_2$=8m, $d_1$=1m, $d_2$=1m, $\theta$=11 degrees.

## III. Measurement Results

Fig.4 shows an example of the results measured in Tokyo. Here, $\theta$=29 degrees, $d_1$=4m, $d_2$=8m. Fig.4(a) is the time-spatial profile. Fig.4(b), (c) and (d) plot delay vs arrival angle, delay profile and arrival angular profile respectively. It is clear that the electric wave arrives from 90 degrees and 270 degrees. Here, 90 degrees is the direction of the window and 270 degrees is the direction of end wall of the corridor.

### *A. Impact of the distance from the window to antennas or end wall, the distance between buildings*

In Fig.4, $d_2$ is 8m and $l_2$ is 30m. The 45m long delay path arrived from 270 degrees, the distance is twice ($l_2$-$d_2$). Therefore, it is a reflected wave from the inner end wall on receiving side. The time-spatial profile depends on $d_2$ and $l_2$.

Further, the 90m and 180m long delay paths arrive from 90 degrees, the direction of the window. These delay paths include 2 and 4 reflections between the buildings because $D$ is 45m. Therefore, the time-spatial profile depends on $D$.

There is also the almost 50m long delay path from 90 degrees. Fig.5 shows the 90 degrees delay profile in Tokyo; $d_2$=1m, $\theta$=0 degrees, $d_1$=1 and 8m. The length of the delay path marked in Fig.5 is 58m when $d_1$=8m, and 42m when $d_1$=1m. Both these distances are almost the same as twice ($l_1$-$d_1$). It is clear that the delay path is the wave reflected from the end wall on transmitting side. Therefore, the time-spatial profile also depends on $d_1$ and $l_1$.

### *B. The impact of vertical angle*

Fig.6 shows the delay profiles when $d_1$=4m and $d_2$=4m in Tokyo. The relative received power of delay paths increases with vertical angle $\theta$. Since the spaces are non-line of sight (NLOS) when $\theta$ is large, the relative power of the first path decreases. Therefore, the time-spatial profile also depends on $\theta$.

### *C. The impact of building height*

Fig.7 shows the delay profile measured in Kita-Kyushu. Here, $d_1$=1m, $d_2$=1m, $\theta$=11degrees. The two times reflection delay path is 120m long since $D$=60m. However, this reflected wave does not arrive at the receiving antenna. Fig.8 shows the relation of building height and reflected waves between the buildings. In Fig. 8(a), there are reflected waves because the buildings are high. On the other hand, Fig. 8(b) shows that the reflected waves do not arrive at the receiving antenna because the transmitting building is low. In Kita-Kyushu, since the transmitting building is low, $h_t$=15m, the waves reflected between buildings do not arrive at the receiving antenna. The building heights, $h_t$ and $h_r$ are key parameters of the time-spatial characteristic.

## IV. THE ANALYSIS MODEL AND KEY PARAMETER

Fig. 9 shows the analysis model for the time-spatial characteristics of building indoor spaces. For buildings that face each other, the main arrival waves are composed of direct waves including the waves reflected from end wall on transmitting side, the waves reflected between the buildings, and waves reflected from end wall on receiving side. The key parameters we identified from the measured results are as follows.

[Key parameters]

$d_1$: the distance from the window to transmitting antenna
$d_2$: the distance from the window to receiving antenna
$D$: the distance between buildings
$\theta$: the vertical angle
$l_1$: the distance from window to end wall on transmitting side
$l_2$: the distance from window to end wall on receiving side
$h_t$: the transmitting building height
$h_r$: the receiving building height

The reflection coefficient of buildings surfaces, $R$, is also considered as a key parameters.

## V. CONCLUSION

In this paper, we measured the time-spatial characteristics of radio waves transmitted from one indoor space to another indoor space in a different building and from the results identified the key parameters underlying the time-spatial characteristics. The key parameters are the distance from window to antennas, the distance between buildings, the vertical angle and so on.


## ACKNOWLEDGMENT

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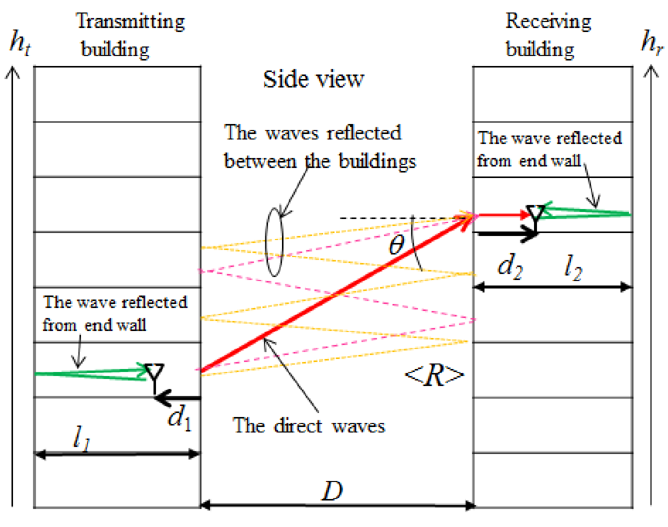


Fig.9. The analysis model

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