Carrier Frequency Characteristic of Time-Spatial Profile in Outdoor LOS Environments

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***Abstract*— In order to evaluate spatial processing techniques such as MIMO for wideband mobile communications, a Time-Spatial Propagation (TSP) model is required. The Time-Spatial profile consists of the delay profile, the spatial arrival angular profiles at the base station (BS) and the mobile station (MS) for traveling waves. One key parameter of the TSP model is carrier frequency. We have proposed a Time-Spatial profile prediction formula for wideband mobile communication systems in Non-line of sight (NLOS) environments and clarified that the Time-Spatial profile does not depend on the carrier frequency. We have also carried out measurements to develop the Time-Spatial profile prediction formula for Line of sight (LOS) environments. In this paper, we evaluate the carrier frequency characteristics of the Time-Spatial profile in Line of sight (LOS) environments based on the measurement data, and show that our proposed Time-Spatial profile prediction formula in LOS environments is valid for various carrier frequencies.**

Mobile communication, Propagation model , Line of Sight (LOS), Time-Spatial profile

I. Introduction

In order to assess the performance of spatial processing techniques such as Multi-Input-Multi-Output (MIMO) for wideband mobile communication systems, a Time-Spatial Propagation (TSP) model that can simulate the characteristics of actual Time-Spatial profiles is required. The Time-Spatial profile consists of the delay profile, the arrival angular profiles at the base station (BS) and the mobile station (MS) for traveling waves.

One of key parameters of the TSP model is carrier frequency. We have proposed a Time-Spatial profile prediction formula for wideband mobile communication systems in Non-line of sight (NLOS) environments and clarified that the Time-Spatial profile does not depend on the carrier frequency [1]-[5].

We have also proposed a Time-Spatial profile prediction formula in Line of sight (LOS) environments based on measurement made in various areas and with various carrier frequencies (SHF band) [6]-[9]. This formula also does not contain the carrier frequency as a parameter because each profile depends on the carrier frequency only to an insignificant degree.

We have explained the carrier frequency characteristics of each profile in LOS environments [10]. Unfortunately, BS positioning was somewhat restricted. In this paper, we detail the carrier frequency characteristics of each profile in additional LOS environments based on the measurement data.

II. LOS Environment Considered

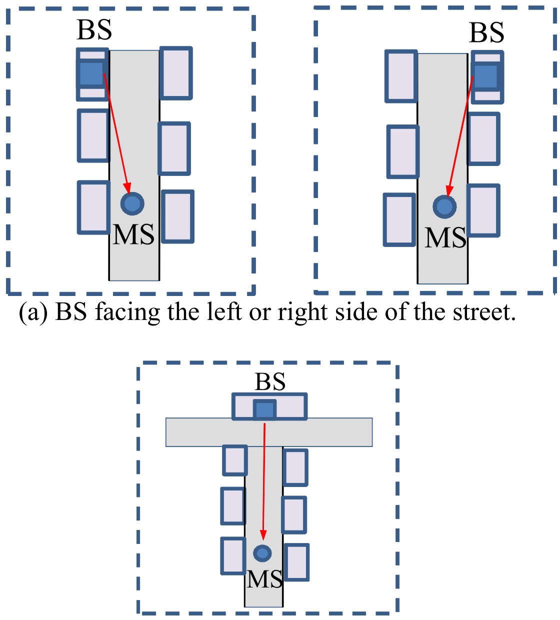
Fig.1 shows the LOS environments considered. Fig. 1(a) shows that the BS is located on the top of a building facing the left or right side of the street and the MS is in the middle of the street; the BS has a direct line of sight to the MS. Fig. 1(b) shows that the BS is located roughly at the center of the rooftop of a building facing at the end of the street and the MS is in the middle of the street.

III. Measurements

We carried out field measurements in both LOS environments shown in Fig.1 on urban streets in Tokyo, Japan.

Table.1 shows the measurement parameters. The BS antenna height, h_b, average building height $<H>$ and average street width W were about 40m, 40m and 25m, respectively. The carrier frequency, f, is 3.3GHz and 5.2GHz and each frequency bandwidth was 100MHz. We measured the delay profile, the arrival angular profiles at the BS and the MS.

To measure the delay profile, we used a sliding correlator as a receiver in order to divide the delay paths. The chip rate was 50Mchips per second. We used omni directional antennas as the transmitting and receiving antennas. The transmitting



(a) BS facing the left or right side of the street.

(b) BS facing the end of the street
Fig.1 LOS environments considered.

TABLE.1 MEASUREMENT PARAMETERS

Measurement Area		Tamachi (Urban)	
BS location		BS facing the left or right side of the street	BS facing the end of the street
Career frequency		3.3GHz, 5.2GHz	
Chip rate		50Mcps	
Transmitter power		10W	
MS	Antenna	The directional antenna (half-band width 3degree) for arrival angular profile at MS Sleeve antenna (Omni-directional) for delay profile and arrival angular profile at BS	
	Antenna height	3m	
BS	Antenna	The directional antenna (half-band width 3degree) for arrival angular profile at BS Sleeve antenna (Omni-directional) for delay profile and arrival angular profile at MS	
	Antenna height	40m	

antenna was placed on the tops of buildings and the receiving antenna was mounted on the rooftop of a van. We measured the instantaneous delay profiles at various points on the street. Next, the short term delay profiles were obtained by averaging 200 instantaneous delay profiles. The long-term delay profile was obtained by averaging the short-term delay profiles at the same BS-MS distance.

For measuring the arrival angular profiles at the BS, we used a directional antenna with horizontal half angle of 3 degrees as the transmitting antenna. An omni directional antenna was used as the receiving antenna. The transmitting antenna was placed on the tops of buildings and the receiving antenna was mounted on the rooftop of a van. We then measured the delay profiles at 3 degree intervals by rotating the directional antenna at various points on the street. The short-term arrival angular profile at the BS was obtained by summing the delay path's power at each arrival angle. Long-term arrival angular profile at the BS was obtained by averaging the short-term arrival angular profiles at the same BS-MS distance.

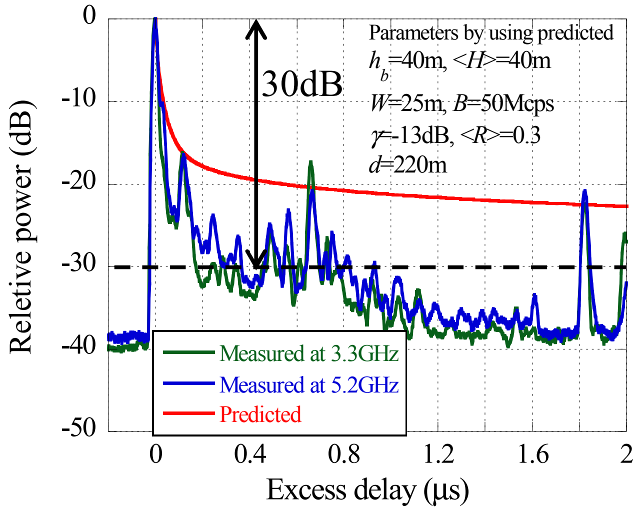
For measuring the arrival angular profiles at the MS, we reversed the position of the omni directional antenna and the directional antenna. We then measured the long-term arrival angular profile at the MS using the same process as was used for the long-term arrival angular profile at the BS.

IV. MEASURED RESULTS

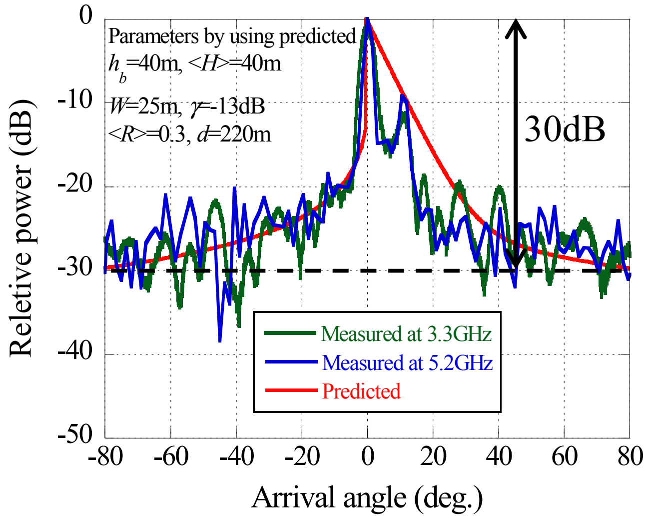
Fig. 2 shows examples of the delay profiles, the arrival angular profiles at the BS and the MS, measured at the carrier frequencies of 3.3GHz and 5.2GHz when the BS faces the left or right side of the street. The distance between the BS and the MS is 220m.

Fig.3 shows examples of the delay profiles, the arrival angular profiles at the BS and the MS, measured at the carrier frequencies of 3.3GHz and 5.2GHz when the BS faces the end of the street. The distance between the BS and the MS is 220m, which is the same as the case of Fig.2.

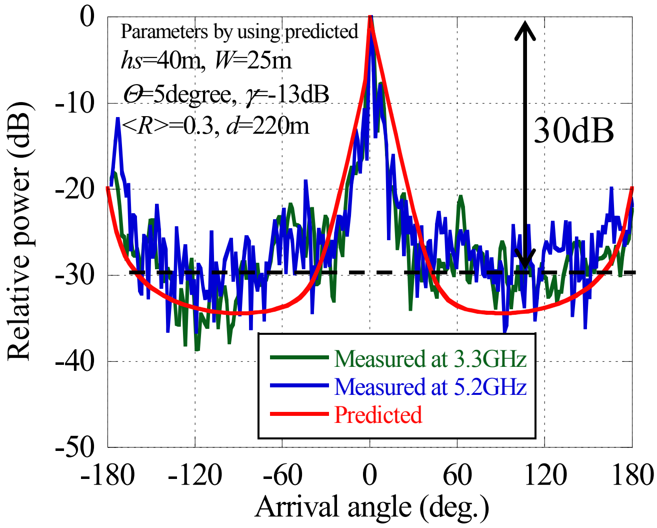
These figures show that the delay profiles and arrival angular profiles at carrier frequencies of 3.3GHz and 5.2GHz are very close, and the impact of frequency on the profile is very slight.



(a) Delay profiles



(b) Arrival angular profiles at the BS



(c) Arrival angular profiles at the MS

Fig.2 Measured Time-Spatial profiles when the BS faces the left or right side of the street

By the way, in the environment when the BS faces the left or right side of the street, the arrival angular profiles at the BS and the MS are asymmetric. On the other hand, in the environment when the BS faces the end of the street, the arrival angular profiles at the BS and the MS are symmetric.

To assess the frequency-originated profile difference in quantitative terms, we calculated the correlation coefficient of profiles at the frequencies of 3.3GHz and 5.2GHz.

Furthermore, we calculated the delay spread and the arrival angular spreads at the BS and the MS at frequencies of 3.3GHz and 5.2GHz, and compared the spreads.

A. Correlation coefficient of profiles at the frequencies of 3.3GHz and 5.2GHz

The correlation coefficient (or covariance coefficient) of profiles at the frequencies of f_1 and f_2, $C(f_1, f_2)$ is given as follow.

$$C(f_1,f_2)=\frac{\sum_x (P(f_1,x)-m_1)(P(f_2,x)-m_2)}{\sqrt{\sum_x (P(f_1,x)-m_1)^2}\sqrt{\sum_x (P(f_2,x)-m_1)^2}} \quad (1)$$

Here, $P(f,x)$ denotes the shape of each profile at each frequency. x is the excess delay time, τ and is the arrival angle, $\Delta\theta$ when $P(f,x)$ is the delay profile or the arrival angular profile. m_1 and m_2 are the average values of each profile.

We apply eq.(1) to each profile for the range of -30dB down from the maximum path.

Fig.4 plots the measured cumulative probability of the correlation coefficient of delay profiles in both LOS environments. From this figure, we find that the correlation coefficient of the delay profile is 0.9 or more. Therefore, the delay profile depends only slightly on the carrier frequency.

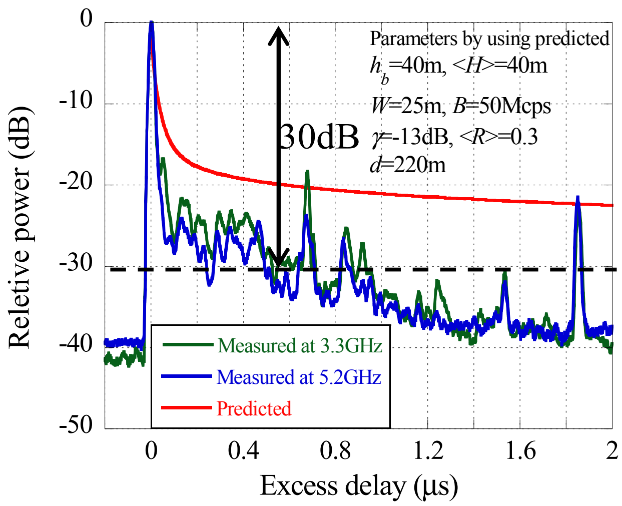
Fig.5 plots the measured cumulative probability of the correlation coefficient of arrival angular profiles at the BS and the MS in both LOS environments. From this figure, we find that the 50% value of correlation coefficient of each profile is 0.9 or more. Therefore, the arrival angular profiles at the BS and the MS depend only slightly on the carrier frequency.

B. Spread

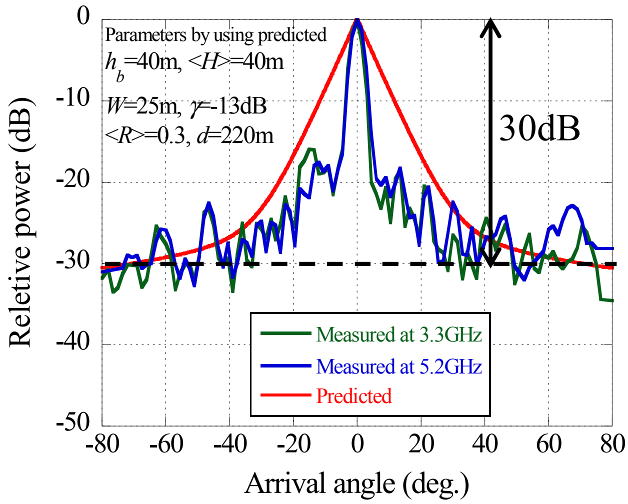
We compare the spreads of each profile at the frequencies of 3.3GHz and 5.2GHz.

Fig.6 shows a comparison of measured delay spreads in both LOS environments. The x axis shows the measured delay spread at 3.3GHz. The y axis shows the measured delay spread at 5.2GHz. The delay spreads at 3.3GHz and 5.2GHz are very similar.

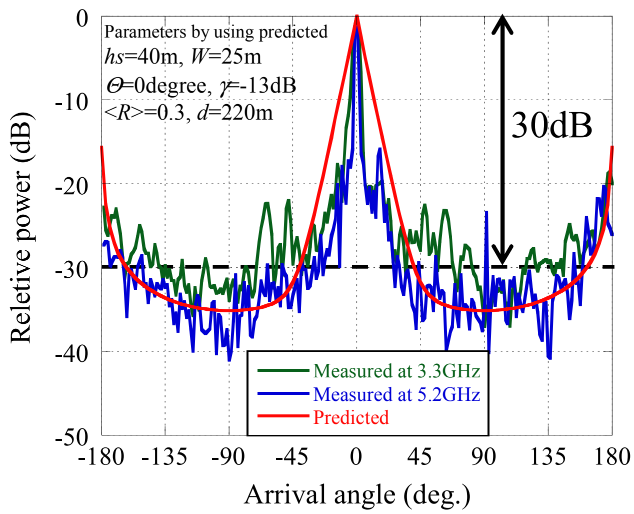
Fig.7 shows a comparison of measured arrival angular spreads at the BS and MS in both LOS environments. The x axis shows the measured angular spread at 3.3GHz. The y axis shows the measured angular spread at 5.2GHz. The angular spreads at 3.3GHz and 5.2GHz are very similar.



(a) Delay profiles



(b) Arrival angular profiles at the BS



(c) Arrival angular profiles at the MS

Fig.3 Measured Time-Spatial profiles when the BS faces the end of the street

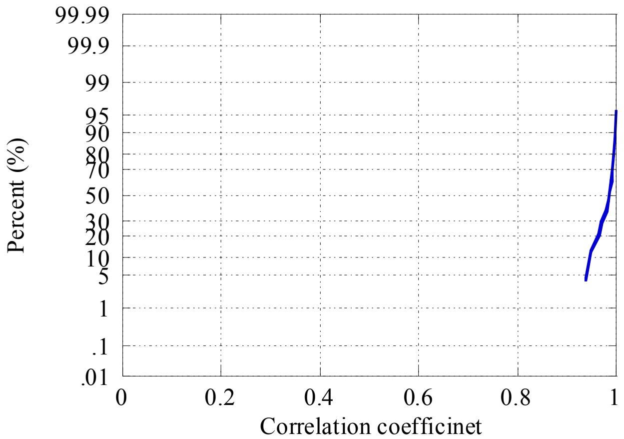


Fig.4 Correlation coefficient of delay profiles at the frequencies of 3.3GHz and 5.2GHz

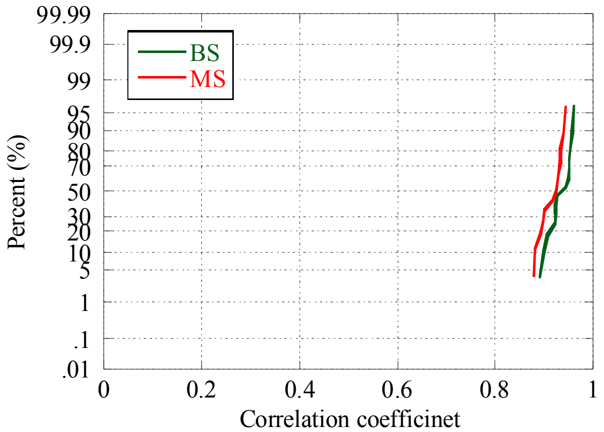


Fig.5 Correlation coefficient of arrival angular profiles at the frequencies of 3.3GHz and 5.2GHz

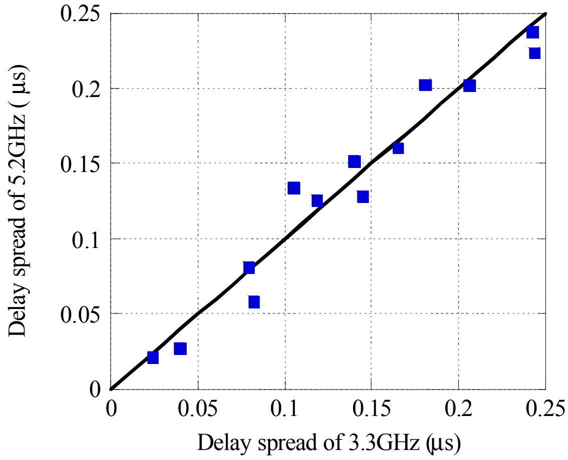


Fig.6 Delay spreads of 3.3GHz and 5.2GHz

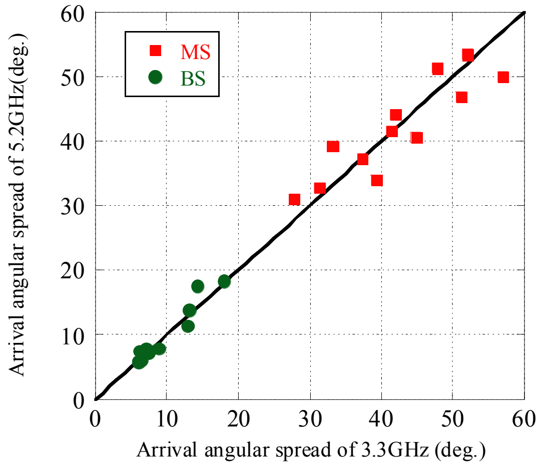


Fig.7 Arrival angular spreads of 3.3GHz and 5.2GHz

V. EVALUATIONS

From the measured correlation coefficient of the delay profiles and the delay spreads, it is clear that the delay profile does not depend on the carrier frequency if the carrier frequency is under 6GHz.

From the measured correlation coefficient of arrival angular profiles and the arrival angular spreads, it is clear that the arrival angular profiles at the BS and at the MS don't depend on the carrier frequency if the carrier frequency is under 6GHz.

Therefore our proposed Time-Spatial profile prediction formula in LOS environments described in Appendix does not contain the carrier frequency as a parameter. Fig.2 and Fig.3 also show the predicted results. The parameters by using predictions are as follows; the BS antenna height h_b=40m, the average building height $<H>$=40m, the average street width W=25m, the chip rate B=50Mcps, the distance between the BS and the MS d=220m, the average height of the buildings along the road h_s=40m, constant value γ=-13dB and the average power reflection coefficient at wall $<R>$=0.3. The road angle Θ were set at 5 degrees for Fig.2 and 0 degrees for Fig.3, respectively. The predicted and measured results agree so the proposed prediction formula is valid.

VI. CONCLUSIONS

In this paper, we detail the carrier frequency characteristics of delay profile, the arrival angular profiles at the BS and MS in LOS environments based on measured data.

The results confirm that the time-spatial profile does not depend on the carrier frequency if the carrier frequency is under 6GHz.

Our proposed Time-Spatial profile prediction formula for LOS environments, which does not contain the carrier frequency as a parameter, can be applied for various carrier frequency under 6GHz.

ACKNOWLEDGMENT

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APPENDIX PROPOSED TIME-SPATIAL PROFILE PREDICTION FORMULA FOR LOS ENVIRONMENTS

(i) *Key parameters and their applicable ranges*

τ: excess delay time (μs)
<*H*>: average building height (5-50 m: height above the mobile station ground level), (m)
h_b: base station antenna height (20-150 m: height above the mobile station ground level), (m)
d: distance from the base station (0.05-3 km), (km)
W: street width (5-50 m), (m)
B: bandwidth or chip rate (0.5-50 MHz), (MHz)
f: carrier frequency (0.7-6 GHz), (GHz)
Θ: the road angle (0-90degree), (degree)
h_s: the average height of the buildings along the road (5-30m), (m)
<*R*> : average power reflection coefficient at wall on the street, (<-1)
$\Delta\theta$: arrival angle (-180, 180), (degree)
γ : constant value (dB), (-16dB- -12dB)

(ii) *Time-Spatial profile prediction formula for LOS environments*

a) Delay profile

[BS facing the left or right side of the street]

$$PDP_{LOS}(\tau,d) = \langle R\rangle^{\left(\frac{\sqrt{1+8\cdot(1000d)\cdot(300\tau)/W^2}-1}{2}\right)} + \gamma\cdot 10^{PDP_{NLOS}(\tau,d)/10} \quad \text{(A-1)}$$

[BS facing the end of the street]

$$\begin{aligned} PDP_{LOS}(\tau,d) &= \langle R\rangle^{\sqrt{2(1000d)\cdot(300\tau)/W^2}}\cdot\left(2-e^{-5\cdot 2(1000d)\cdot(300\tau)/W^2}\right)+\gamma\cdot 10^{PDP_{NLOS}(\tau,d)/10} \\ &\approx \langle R\rangle^{\left(\frac{\sqrt{1+8(1000d)\cdot(300\tau)/W^2}-1}{2}\right)}+\gamma\cdot 10^{PDP_{NLOS}(\tau,d)/10} \end{aligned} \quad \text{(A-2)}$$

Here, $PDP_{NLOS}(\tau,d)$ represents the following delay profile prediction formula for NLOS environments normalized by the first arriving path’s power at distance d [1],[2],[4].

$$\begin{aligned} PDP_{NLOS}(\tau,d) &= -\{19.1+9.68\log(h_b/<H>)\}B^{\{-0.36+0.12\log(h_b/<H>)\}} \\ &\times d^{\{-0.38+0.21\log(B)\}}\log(1+B\tau) \end{aligned} \quad \text{(A-3)}$$

b) Arrival angular profile at BS

[BS facing the left or right side of the street]

$$AOD_{LOS}(\Delta\theta,d)=\begin{cases}\langle R\rangle^{1000d|\Delta\theta|\pi/(180W)}+\gamma\cdot 10^{(AOD_{NLOS}(\Delta\theta,d))/10} & (\Delta\theta\geq 0)\\ \gamma\cdot 10^{(AOD_{NLOS}(\Delta\theta,d))/10} & (\Delta\theta<0)\end{cases} \quad \text{(A-4)}$$

[BS facing the end of the street]

$$AOD_{LOS}(\Delta\theta,d)=\langle R\rangle^{1000d|\Delta\theta|\pi/(180W)}+\gamma\cdot 10^{(AOD_{NLOS}(\Delta\theta,d))/10} \quad \text{(A-5)}$$

Here, $AOD_{NLOS}(\Delta\theta,d)$ represents the following arrival angular profile prediction formula at the BS for NLOS environments [3],[4].

$$AOD_{NLOS}(\Delta\theta,d)=10\log\left(1+|\Delta\theta|/a\right)^{-\beta} \quad \text{(A-6)}$$

$$\begin{aligned} a &= -\frac{0.2d}{1000}+2.1\left\{\left(\frac{<H>}{h_b}\right)^{0.23}\right\} \\ \beta &= (-0.015<H>+0.63)\frac{d}{1000}-0.16+0.76\log(h_b) \end{aligned} \quad \text{(A-7)}$$

c) Arrival angular profile at MS

[BS facing the left or right side of the street]

$$AOA_{LOS}(\Delta\theta,d)=\begin{cases}\langle R\rangle^{|1000d\Delta\theta\pi/(180W)|}+\gamma\cdot 10^{(AOA_{NLOS}(\Delta\theta,d))/10} & (\Delta\theta\geq 0)\\ \langle R\rangle^{|1000d\Delta\theta\pi/(180W)|-1}+\gamma\cdot 10^{(AOA_{NLOS}(\Delta\theta,d))/10} & (\Delta\theta<0)\end{cases} \quad \text{(A-8)}$$

[BS facing the end of the street]

$$AOA_{Los}(\Delta\theta,d)=\langle R\rangle^{|1000d\Delta\theta\pi/(180W)|}+\gamma\cdot 10^{(AOA_{NLOS}(\Delta\theta,d))/10} \quad \text{(A-9)}$$

Here, $AOA_{NLOS}(\Delta\theta,d)$ represents the following arrival angular profile prediction formula at the MS for NLOS environments [5].

$$AOA_{NLOS}(\Delta\theta,d)=10\log\left(\frac{1}{\sqrt{\cos\Delta\theta^2+\sin\Delta\theta^2/\eta^2}}\right) \quad \text{(A-10)}$$

$$\eta=\mathrm{Min}\left(1,\left[2.6/h_s^{0.5}\cdot\{1-\exp(-0.03\cdot\Theta)\}+0.05\right]^{1.5}\right) \quad \text{(A-11)}$$