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市街地伝搬路における伝搬メカニズムの道路角依存性

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キーワード 市街地伝搬路、伝搬メカニズム、マクロセル、偏波

Analysis of the Propagation Mechanisms in Streets with Different Directions in Urban Mobile Radio Channels

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Abstract In this report the authors presnet the initial investigation of the principal propagation mechanisms in the urban radio channel for co- and cross polar antennas. It is widely believed that dominant propagation mechanisms are identical for all polar combinations even though no firm evidence for this has been delivered. In fact the experimental study of polar urban propagation channel is scarce in the open literature. In the current study we employ the data obtained from a set of measurements at 2.2 GHz in two locations of Tokyo metropolitan areas and one location in Yokohama city for three different base station antenna heights. The received azimuth- and elevation-power-spectra at the mobile terminal (MT) are analyzed with regard to the street direction for all combinations of the transmitter (Tx) and receiver (Rx) antenna polarizations. The directional copolar ratio (CPR) and cross polar ratio (XPR) are also presented.

Key words Urban mobile radio channel, Propagation mechanism, Macrocell, Polarization

1. Introduction

Employing cross-polar systems make it possible to double the antenna numbers for half the necessary spacing compared to copolar antennas. This is a great advantage especially in the mobile-terminal (MT) design, where space is limited. To analyze the performance of such a system an appropriate knowledge of the polar directional channel at the MT is essential whereas relevant reports in the open literature are surprisingly scarce. Hence an extensive analysis of the polar directional channel seems necessary.

It is well known that in the perpendicular streets (to the base-station (BS)-MT direction) vertical-plane propagation (VPP) is dominant, which is well modeled by the Ikegami approach [1]. If the MT however is placed in a parallel street, the waves approaching from the street canyon are dominant. In this technical report we try to analyze how significant any specific propagation mechanism is for each of co- and cross-polar channels in the streets with different orientations relative to the BS-MT direction in urban macrocell environments. The analysis regardless of the street orientation is already reported in [2].

2. Measurement Outline

A set of measurements in two locations of Tokyo metropolitan areas (Aoyama, Yoyogi) and one location in Yokohama city were accomplished. PN-10 sequence with 30 Mcps was transmitted at 2.2 GHz from BS antennas installed over roof-top of tall buildings.

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Table 1 Measurement Specifications

Location	Aoyama	Yoyogi	Yokohama
Tx power	2 W		
Tx signal	PN-10 sequence, 30 Mcps		
Tx antenna	V polarized sleeve dipole (2.2 dBi) H polarized slot antenna (2.2 dBi)		
Tx antenna height	60 m	150 m	40 m
Rx antenna	V/H 8 element vertical linear array 9 dBi, 3 dB V/H beam-width 110°/30°		
Rx antenna height	3.5 m		
Rx points (range)	40 (∼1.5km)	41 (∼1km)	39 (∼0.9km)

Table 2 Number of Measurement Points

Street Oriention	Aoyama	Yoyogi	Yokohama
$[0°, 10°)$	0	1	3
$[10°, 20°)$	0	2	4
$[20°, 30°)$	1	8	3
$[30°, 40°)$	4	3	16
$[40°, 50°)$	7	1	4
$[50°, 60°)$	7	3	2
$[60°, 70°)$	8	2	3
$[70°, 80°)$	8	11	1
$[80°, 90°]$	5	10	3
Total	40	41	39

At the BS (transmitter (Tx)) for each of vertically (V) or horizontally (H) polarized transmission an omnidirective antenna (V: sleeve dipole, H: slot antenna) was employed. At the MT (receiver (Rx)) a linear array of 16 elements –8 channels for each polarization– was mounted over roof-top of the measurement van. The array was vertically installed on a rotatable disk controlled by a precision positioner. At each measurement point, 20 snapshots of the complex channel impulse response received at the array antenna in 24 different azimuth directions, 15° apart each, are stored for off-line data processing. These snapshots are averaged for each azimuth direction in the data processing to improve signal-to-noise ratios. The corresponding number of measurement points, BS antenna height and the maximum range of the measurements in each location as well as other specifications are summarized in Table 1. The measurement points are all in BS non-line-of-sight (nLoS) located randomly in residential or commercial areas. The width of the streets as well as heights of the buildings are inhomogeneous in each location. Moreover measurement streets have mixed directions, from parallel to perpendicular. The street orientation relative to the BS-MT direction in each measurement location are presented in Table 2.

3. Analysis

3.1 Data Processing

The angular-power-spectrum (APS) of the received signal in the azimuth and elevation are derived for all combinations of the Tx-Rx polarizations. The received signal spread in the azimuth is obtained by sampling the azimuth at 15° steps via rotating the vertically deployed array antenna. The 3 dB azimuth beam-width of the antenna elements is 30°. To get the elevation spread of the arriving waves a Chebychev beam-former with 26 dB side-lobe ratio is applied to the vertically deployed 8 element linear array in each polarization. The beam-forming is performed for each delay bin whereas for the discussions in this paper only narrow-band signals have been used. Thus the arrived power at the azimuth ϕ and elevation θ is:

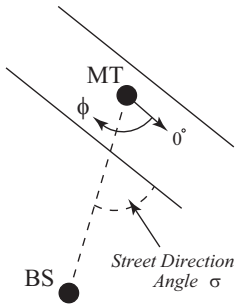


Fig. 1 Street orientation angle and azimuth AoA origin.

$$P(\phi, \theta) = \sum_{\tau} P(\tau, \phi, \theta) \tag{1}$$

where the summation is over delay τ. With the same manner the azimuth APS, $P(\phi)$, or elevation APS, $P(\theta)$, can be obtained by integrating the $P(\phi, \theta)$ values over the elevation or azimuth respectively. Measurement points are categorized based on the orientation of the measurement street, σ, relative to the direction of BS seen from MT as is illustrated in Fig. 1. The figure also shows the origin of the azimuth axis which is always along the street with azimuth calculated clockwise. The total APS at each polarization is normalized to the total received signal at each point:

$$P_{\text{total}} = \frac{1}{2} \sum_{\phi} \sum_{\theta} \left(P^{\text{VV}}(\phi, \theta) + P^{\text{HV}}(\phi, \theta) + P^{\text{VH}}(\phi, \theta) + P^{\text{HH}}(\phi, \theta) \right) \tag{2}$$

where the first and second superscripts indicate the signal polarization at the MT and BS respectively and the first and second summations are taken over elevation and azimuth respectively.

3.2 Propagation Classes

Two principal propagation mechanisms for a nLoS macrocell were introduced in [1]. These are the roof-top diffraction (the roof-top in the BS direction) and the single-reflected (reflected by the building at the opposite to the BS direction) propagation paths. In [3] the BS-direction and the opposite BS-direction propagation classes were introduced to include propagation paths which endeavor more than one diffraction/reflection arriving to the MT from BS-direction or the opposite. Since we do not extract propagation paths in the current analysis, we can not distinguish between single and multiple diffraction/reflections. Hence we generalize the principal propagation classes into the following three classes:

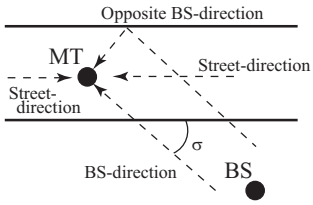
（a） BS-direction: The received signal whose azimuth angle-of-arrival (AoA) is toward BS direction. This class includes single-diffracted path of [1] as well as the BS-direction class of [3]. The azimuth AoA for this class is around σ.

（b） Opposite BS-direction: The signal received from the opposite direction of the BS in the azimuth. This class includes single-reflected path of [1] but is different from the opposite BS-direction class of [3] since its azimuth AoA for this class is around $(360° - \sigma)$ whereas in [3] it is $(180° + \sigma)$. The difference can be related to the different measurement environments.

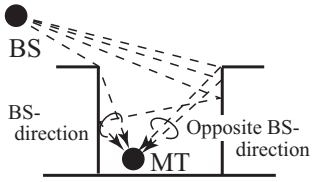
（c） Street-direction: The signal received from the street direction. The azimuth AoA for this class is around 0°, 180° or 360°.

4. Discussion

Since the elevation APS for most cases show a very similar trend we only exhibit the VV polar elevation APS at Yokohama in Fig. 3.



(a) Top View



(b) Side View

Fig. 2 Propagation classes in the urban macrocell.

It is observed that the received signal spread in elevation is mainly between 0° to 30°. Azimuth APS for all polarization combinations in Aoyama, Yoyogi and Yokohama are shown in figures 12-14. A glance at these figures suggests that in most situations the three propagation mechanisms introduced in the previous section are dominant. Obviously the street-direction class is significant not only for the parallel (to the BS-MT direction) streets, but also for the perpendicular roads. In perpendicular streets this class occurs due to far-scattering along the street. To assist the investigation of the propagation mechanisms the delay spread along the azimuth AoA has been exhibited in figures 4 and 5 for a nearly parallel ($\sigma = 14^\circ$) and a perpendicular ($\sigma = 82^\circ$) street respectively. In the parallel street, the excess delay for the street direction class –which is the only significan class in this case– is small as it could be expected. On the other hand, in the perpendicular street it is observed that the street direction class ($\phi \approx 360^\circ$) exhibits longer delays with a spread as is expected again. The interesting point is however that the BS-direction and the opposite BS-direction classes in Fig. 5 also have large delays, which hints on the occurence of multiple scatterings, similar to the observation in [3] but different from the prediction in [1]. More investigation on this regard is being carried out.

The directional copolar ratio (CPR) of the received signals are shown in figures 6-8 for each measurement location which is defined as:

$$\mathrm{CPR}^{\mathrm{V}}(\phi) = \frac{P^{\mathrm{VV}}(\phi)}{P^{\mathrm{HH}}(\phi)} \tag{3}$$

These figure indicate that the vertical copolar transmission mechanism is generally dominant compared to the horizontal copolar transmission. It is also observed that for a taller BS this ratio is generally smaller.

Finally the other observation from figures 12-14 indicates that cross polar signals are generally low, i.e. more than 10 dB weaker than copolar received signals. To investigate the cross polar propagation pattern, the directional cross-polarization ratio (XPR) of the received signals defined as:

$$\mathrm{XPR}^{\mathrm{V}}(\phi) = \frac{P^{\mathrm{VV}}(\phi)}{P^{\mathrm{HV}}(\phi)} \tag{4}$$

$$\mathrm{XPR}^{\mathrm{H}}(\phi) = \frac{P^{\mathrm{HH}}(\phi)}{P^{\mathrm{VH}}(\phi)} \tag{5}$$

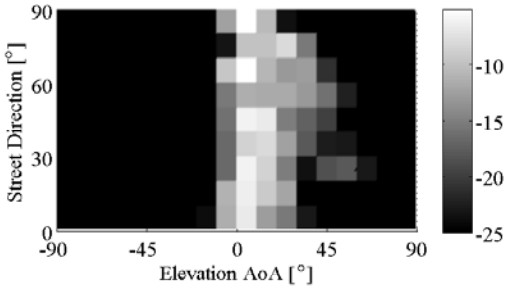


Fig. 3 The polar normalized elevation APS in Yokohama (VV).

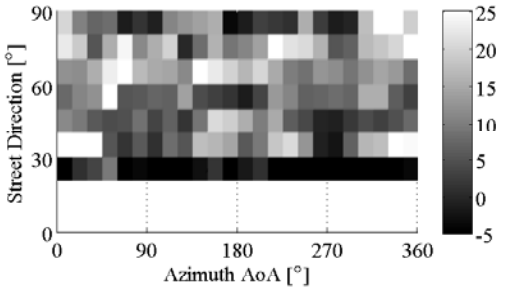


Fig. 6 CPR of the received signals in Aoyama, Tokyo.

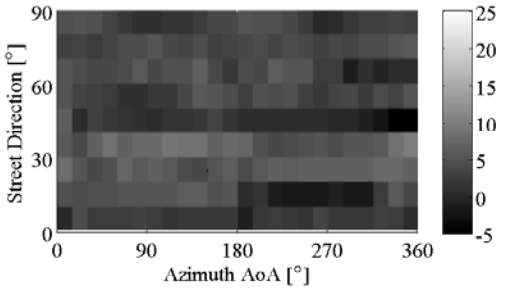


Fig. 7 CPR of the received signals in Yoyogi, Tokyo.

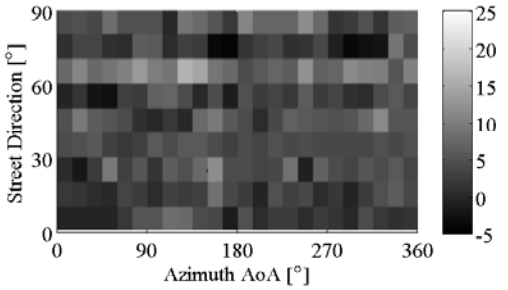
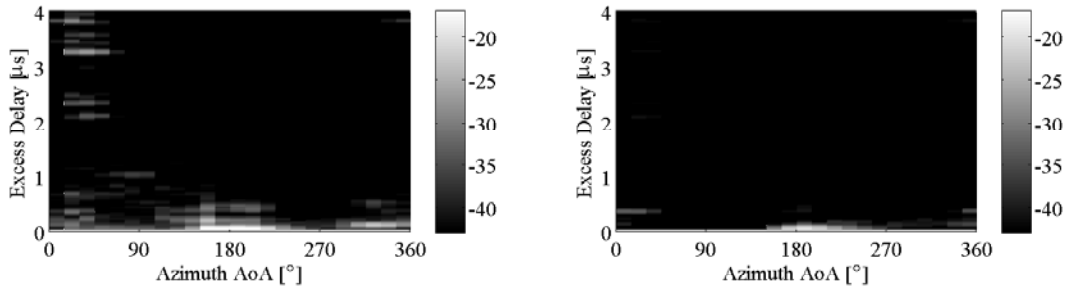


Fig. 8 CPR of the received signals in Yokohama.

are derived. XPR shows how much the polarization of the transmitted signal has changed by receiving at the MT. Figures 9-11 indicate that in the nLoS macrocell scenario the XPR values are generally high which is not a good news for systems which are designed to use cross-polar signals.

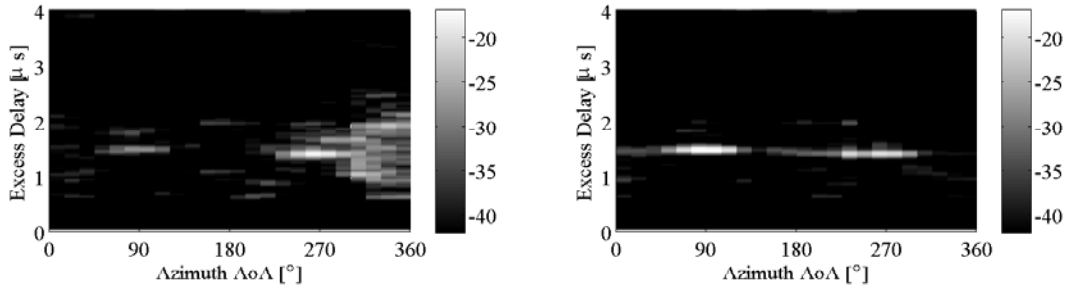
5. Summary

The initial report of the polar directional analysis of the urban nLoS propagation channel at 2.2 GHz was presented in this com-



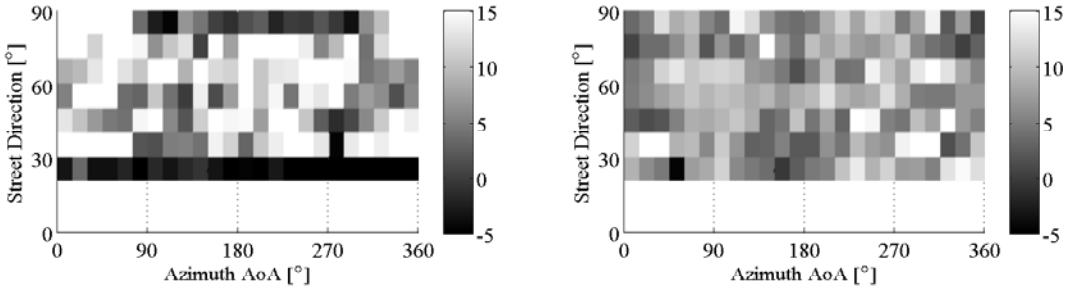
(a) BS:V, MT:V (b) BS:H, MT:H

Fig. 4 The polar delay-azimuth APS in a parallel street of Yoyogi.



(a) BS:V, MT:V (b) BS:H, MT:H

Fig. 5 The polar delay-azimuth APS in a perpendicular street of Yoyogi.



(a) XPR^V (b) XPR^H

Fig. 9 XPR of the received signals in Aoyama, Tokyo.

munication. The investigation of the measured data in Tokyo and Yokohama shows that street-direction propagation class in dominant in all cases which are due to far-clustering. In perpendicular streets the opposite BS-direction and BS-direction are significant according to [1] as well. In general the cross-polarized transmission is insignificant compared to copolar signals, and vertical copolar signals are stronger in any case compared to the horizontal copolar signals.

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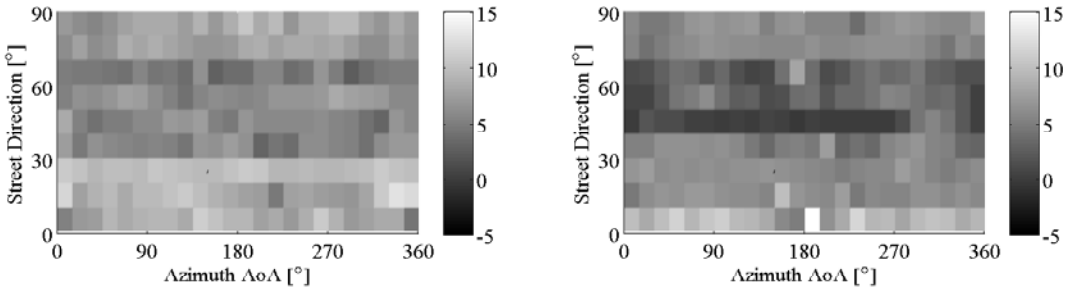
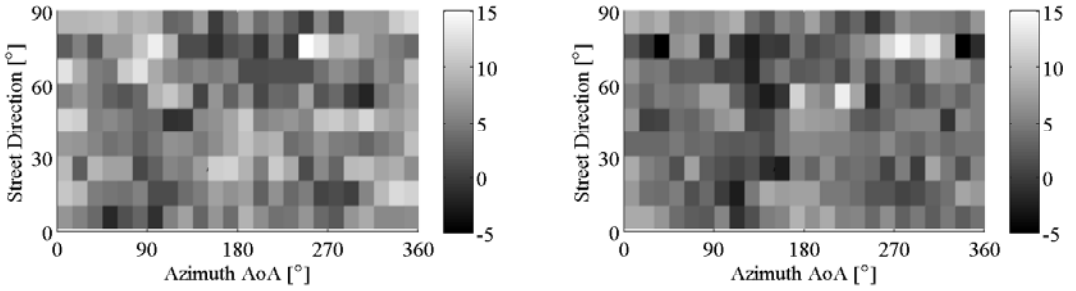


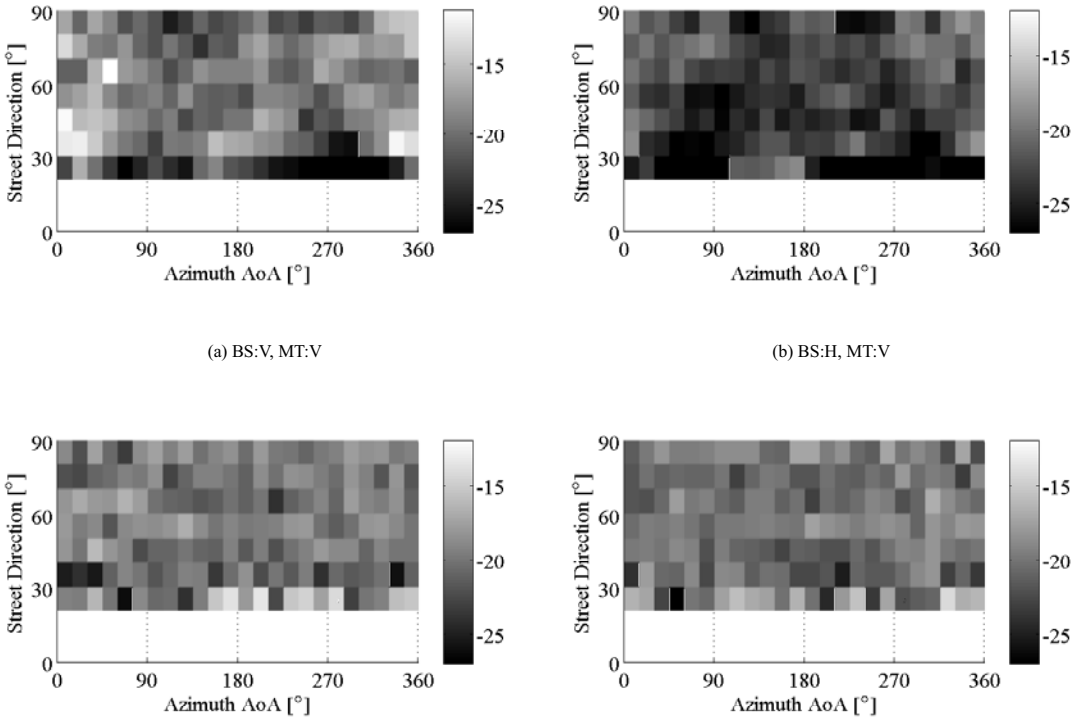
(a) XPR^{V} (b) XPR^{H}

Fig. 10 XPR of the received signals in Yoyogi, Tokyo.



(a) XPR^{V} (b) XPR^{H}

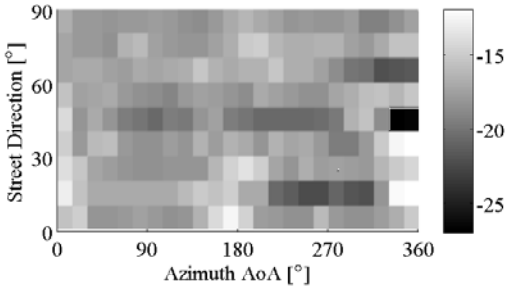
Fig. 11 XPR of the received signals in Yokohama.



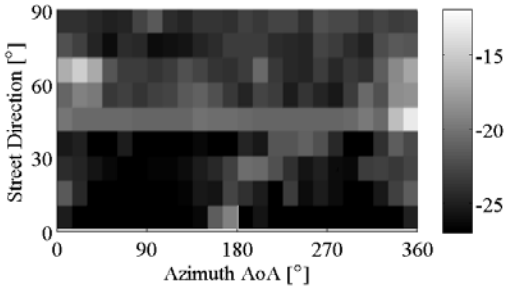
(a) BS:V, MT:V (b) BS:H, MT:V

(c) BS:V, MT:H (d) BS:H, MT:H

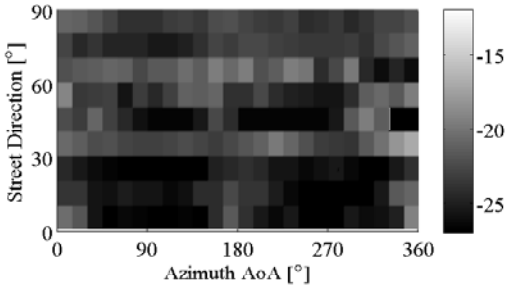
Fig. 12 The polar normalized azimuth APS in Aoyama, Tokyo.



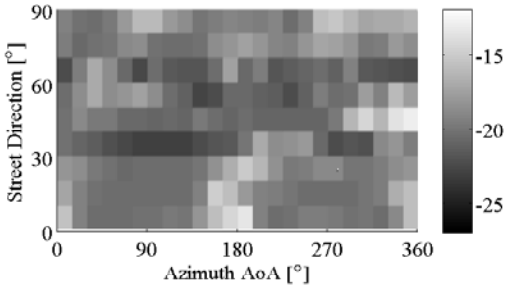
(a) BS:V, MT:V



(b) BS:H, MT:V

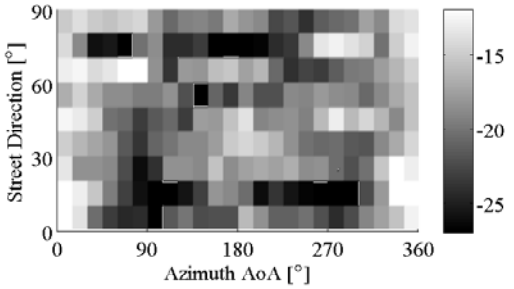


(c) BS:V, MT:H

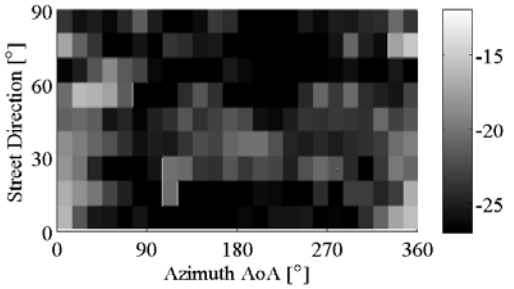


(d) BS:H, MT:H

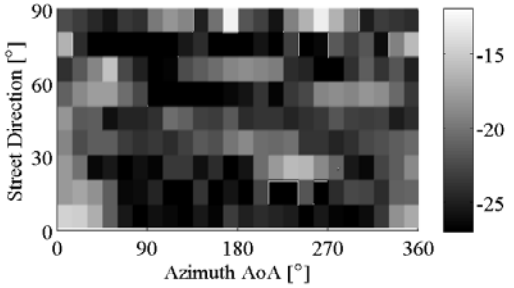
Fig. 13 The polar normalized azimuth APS in Yoyogi, Tokyo.



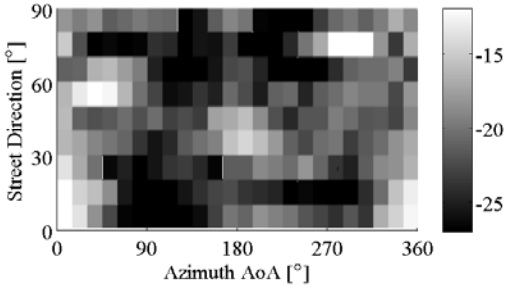
(a) BS:V, MT:V



(b) BS:H, MT:V



(c) BS:V, MT:H



(d) BS:H, MT:H

Fig. 14 The polar normalized azimuth APS in Yokohama.