EFFECT OF NARROW-BEAM BASE STATION ANTENNA FOR LINE-OF-SIGHT PROPAGATION IN MICROWAVE FREQUENCY BAND

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I. Introduction

This article evaluates base station (BS) antenna technologies for the 4th generation (4G) mobile communication systems. The target of the 4G is to establish high-speed broadband signal transmissions in the microwave frequency band, which is higher than that of the 3rd generation known as the IMT-2000 [1]. Of the recent investigations on BS antennas for the IMT-2000, one deals with sector antennas for multi-frequency operations from 800 MHz to 2000 MHz even to cover PDC frequency bands (current cellular system in Japan) [2]. A characteristic common to conventional BS antennas is a vertically-aligned linear array used to maximize the radio zone on the ground plane. Furthermore, to enhance BS antenna systems, a horizontally-aligned array is considered to be essential because the main beam must be narrowed in the horizontal (*H*)-plane not only to increase the antenna gain but also to improve the delay characteristics for high-speed signal transmission. The effectiveness of the latter is recognized as the potential of the adaptive antenna system to achieve better compactness of signal spatial isolation than can the conventional schemes such as sectorization and/or antenna tilting. Nevertheless, little has been presented thus far regarding array antenna construction and its radiation patterns from the elements arranged in both *H* and vertical (*V*) directions in mobile BS antenna systems.

Based on this background, we focus on examining the optimum radiation pattern for line-of-sight (LOS) street microcells of 4G systems based on computer simulations. First, this paper introduces a propagation model of an LOS street environment to grasp the characteristics of incident waves in the microwave frequency band. The effect of a narrow-beam BS antenna is then evaluated. Furthermore, the dependency of the relative level and delay spread on distance is analyzed.

II. Effect of narrow-beam base station antenna

In a street microcell environment where a BS antenna is installed at a position lower than the surrounding buildings, rays launched from the transmitter (BS) propagate along the street on the way to the receiver (MS), with geometrical reflection and diffraction occurring at various building components. A propagation path such as this can be modeled by three-sided reflection areas that are formed by the ground plane and either wall of the street.

Figure 1 shows the propagation model (wall discontinuity model [3]). Also, the simulation parameters and the antenna configurations are shown in Table 1. These numerical values are set to simulate an ordinary LOS street environment. The ray-tracing method is introduced for this model to predict characteristics of incident waves reaching the MS. It must be noted here that based on the assumptions of this simulation we analyze ideal conditions in which the main beam radiated from the BS antenna is always directed towards the MS. Altering the phase applied to the individual elements controls the direction of the main beam.

Figure 2 shows the dependence of relative level and delay spread on distance when BS antenna gain *G* is 0 dBi (omni-directional), 20 dBi, and 30 dBi, respectively. When *G* = 0 dBi corresponds to propagation loss. The beamwidths (BWs) in both the *H*-plane and *V*-plane are the same, that is, a square aperture array. The dependency of the delay spread and relative level on distance are shown in this figure, and the delay spread at any distance is decreased when *G* is increased.

To aid in the explanation of these results, we present Fig. 3, which is the angular profile of an incident wave at *D* = 60 m in comparison with the radiation patterns mentioned above. The range of the received level is plotted with the limit of –30 dB from the maximum level. Figure 3(a) shows that the spread of the direction of arrival (DOA) is approximately 120 degrees in the *H*-plane. Here, using a narrow-beam antenna, which is equal to a high-gain antenna, results in the same effect as using a narrow DOA distribution. This influence suppresses the delay. On the other hand, in Fig. 3(b), the spread of the DOA is only 8 degrees showing that the narrow beam in the *V*-plane is not a valid procedure to improve the delay characteristics.

III. Relationship between angular distribution of incident wave and beamwidth

Figure 4 shows the dependency of the relative level and delay spread on distance when the BW in the *H*-plane or *V*-plane is changed. The BS antenna gain is maintained at *G* = 28 dBi on the presumption of our radio link design, and the BW variation is controlled by the antenna aperture ratio. The simulation results show that the relative level had no relevance to the aperture ratio; however, an array antenna with aperture ratio *H*:*V* = 2:1 (BW: *H* = 3.2 degrees, *V* = 6.4 degrees) more strongly suppressed the delay than the aperture ratio *H*:*V* = 1:2 (BW: *H* = 6.4 degrees, *V* = 3.2 degrees) or *H*:*V* = 1:1 (BW: *H* = *V* = 4.8 degrees) when *D* was greater than approximately 150 m.

The reason for this is that the angular distribution of the incident wave depends on distance. When *D* < 150 m, since the DOA distribution is far wider than the BW in the *H*-plane, and since either *H* = 3.2 or 6.4 degrees is sufficiently narrow, the BW difference of the delay spread does not radically change. However, when *D* is greater than or equal to 150 m, as the DOA distribution becomes sufficiently narrow for the BW in the *H*-plane, the BW difference between the three aperture ratios increases dramatically as a result. In contrast, the BW is a constant value, i.e., there is no relation to distance. This fact indicates that the area limit to achieve high-speed signal transmission is different regarding the BW although the antenna gain is the same. Consequently, an array antenna with a narrower beam in the *H*-plane causes an immediate result in keeping the delay level low for a long distance.

In this paper, we assumed a rectangular array antenna arranged in the x-z plane to form desired radiation patterns. The element spacing along the x-axis is a half wavelength to avoid radiating grating lobes in the *H*-plane. The excitation of the array elements is uniformly distributed to obtain the maximum directive gain. Therefore, a beam shaping such as cosecant beam in the *V*-plane is not considered. The antenna gain is defined by the number of elements arranged uniformly for each axis to ensure the aperture area when the aperture efficiency is estimated at 50%.

IV. Conclusions

We outlined the effectiveness of narrow-beam radiation patterns for both *H*- and *V*-aligned elements as a case study to construct a BS antenna for 4G systems. The results of our experiments clearly show that the narrow beam has a significant effect on the reduction of the delay spread; however we found a difference between the *H*-plane and the *V*-plane due to the influence of the angular distribution of the incident wave. In addition, we analyzed the dependency of the relative level and delay spread on distance when the antenna aperture ratio was changed. It was evident that the effect of a low delay level would last for a long distance owing to the use of an array antenna with a narrow beam in the *H*-plane. Finally, we emphasize the importance of developing an antenna design policy with careful consideration and harmonization of propagation and radiation patterns.

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References

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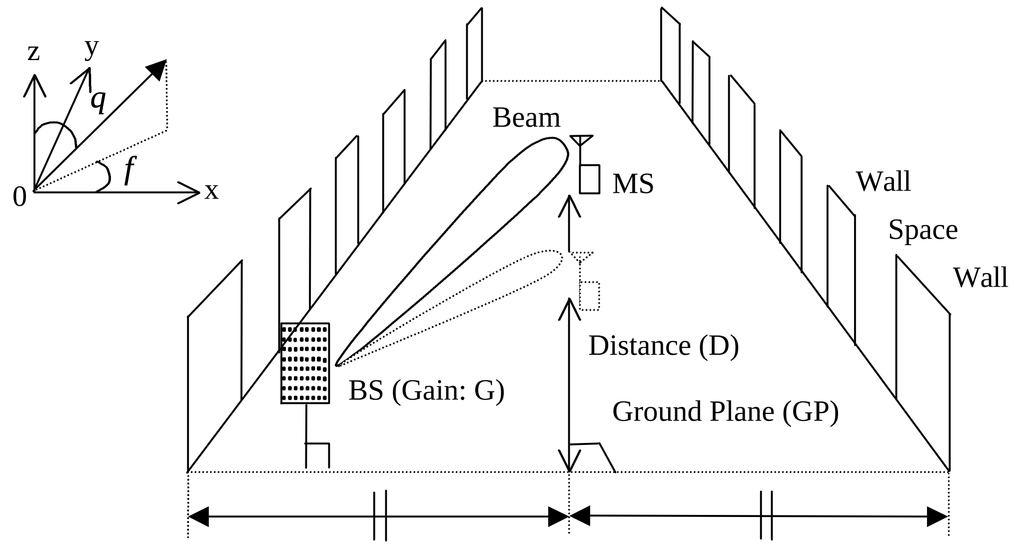


Figure 1. Propagation Model for LOS Street Microcells

Table 1. Simulation Parameters

Frequency	8.45 GHz $(l = 35.5mm)$	Base station (BS) antenna	Array
Road width	30 m	Horizontal element spacing	$0.5l$
Wall width	20 m	Vertical element spacing	l
Wall interval	20 m	Distance from wall	4 m
Ray-tracing	: Direct wave	Height	8 m
	: Reflection by wall	Mobile station (MS) antenna	Omni
	: Reflection by GP	Distance from wall	15 m
	: Diffraction by edge	Height	1.5 m

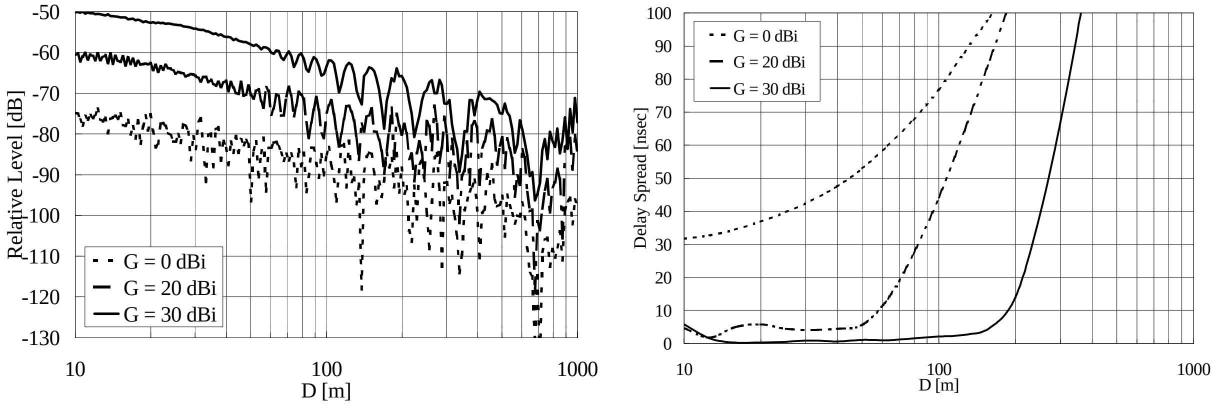
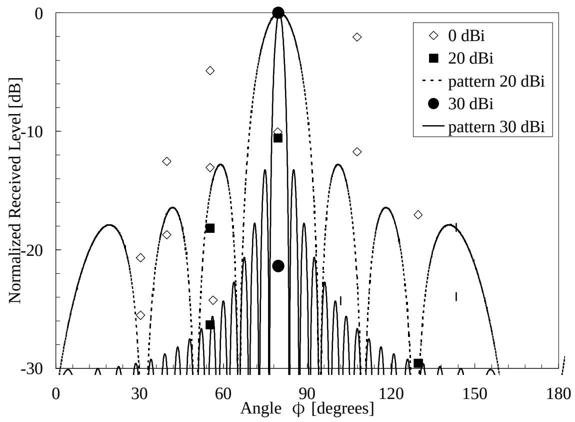
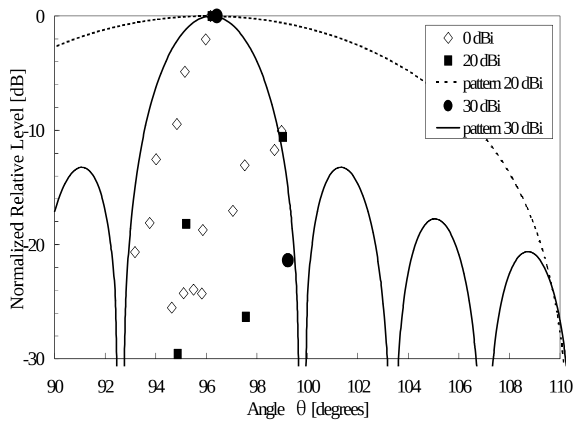


Figure 2. Relative Level and Delay Spread versus Distance (Parameter : Gain)



(a) *H*-Plane



(b) *V*-Plane

Figure 3. Angular Profile (D = 60 m)

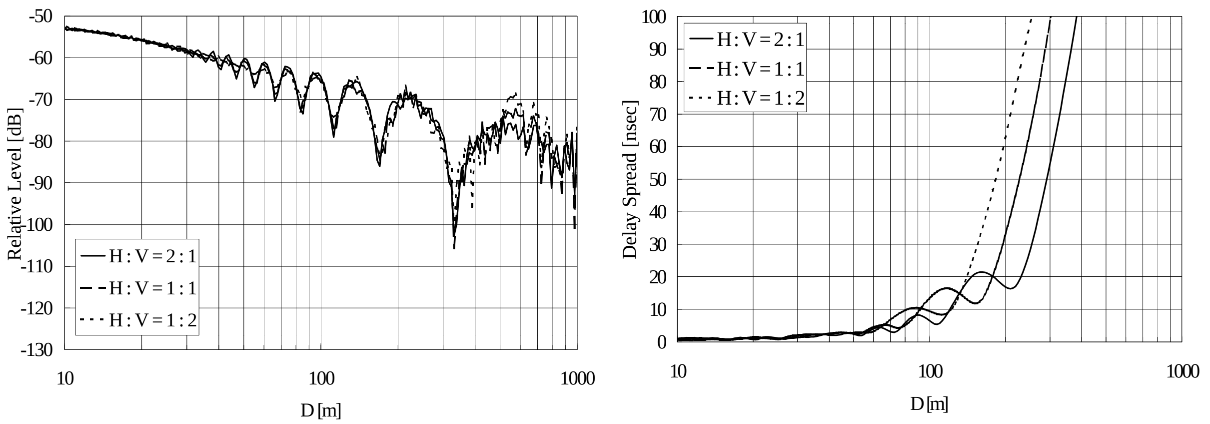


Figure 4. Relative Level and Delay Spread versus Distance (Parameter : Aperture Ratio)