Characterization of Spatial Channel Model Based on Ray Path Analysis in High-rise Urban Environment

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Abstract—**The strongest ray analysis based on the computer simulation of wave propagation between a base station(BS) and mobile stations(MSs) is carried out to obtain the spatial-time wideband channel characteristics. The strongest rays are responsible for about 70% of the total received power for BS-MS pairs on the average and their arrival angles rarely deviate from the shortest path lines between a BS and MSs. However, this does not mean that the strongest ray is necessarily the first arrived ray for each BS-MS pair. The AOA statistics reveal that AOAs of the strongest and the second strongest rays are very close each other for uplink channel, while those are quite apart for downlink channel.**

Keywords-spatial channel model; ray-tracing; ray analysis

I. INTRODUCTION

The spatial properties of wireless channel can be characterized with the angle of arrival(AOA) statistics of the received signals at each receiver locations. Hence the information of AOA is crucial to develop a next generation wireless communication systems with adaptive array antennas. In order to achieve the AOA statistics, experiments were usually carried out[1]-[5], meanwhile theoretical approach based on ray-tracing technique is to be another useful method despite of its heavy computational loads[6], [7]. Accuracy of wave propagation prediction tools based on ray tracing technique such as Vertical-Plane-Launch(VPL) or Wireless System Engineering (WiSE) is known to be good enough for practical use[8], [9]. In this study, fast ray search algorithm was developed to resolve heavy computational loads problem.

In typical high-rise urban environment, the street shapes and the building heights have strong influence on wave propagation due to diffraction/scattering and wave guiding effects. Therefore computer simulation was carried out for environment which is assumed to include the effects of streets and relative heights of base station(BS) with respect to the surrounding buildings.

The analysis of individual ray paths, especially of the strongest ray path between BS and mobile stations(MSs), based on the computer simulation of wave propagation at 2 GHz for the area with 259 buildings, is described, which will be very useful to understand the time delay properties of wireless channel as well as the spatial properties of channel.

II. COMPUTER SIMULATION

Prediction accuracy and computation time are the most important factors to measure the performance of computer simulation tool for the prediction of wave propagation using ray-tracing technique. In order to ensure the prediction accuracy of the simulation tool developed for this study, computed results of wave propagation at 908 MHz was compared with the measured results reported in [9]. The same simulation environments as for [9] are used in the test simulation. Figure 1 compares the measured results and the predictions using the developed simulation tool.

The comparison shows a fairly good agreement with mean error of 3.78 dB and standard deviation of 9.53 dB. The predicted results for some receivers numbered by 1357-1400 show poor prediction accuracy, which is guessed to be caused by inaccurate building database near by these receivers. The error statistics excluding these receivers give mean error of 2.21 dB and standard deviation of 8.37 dB. In [9], the measurement results only at 908 MHz are given, while tables claim the similar accuracy both at 908 and 1900 MHz. Therefore the prediction accuracy of the developed simulation tool at 2 GHz also can be assured even though prediction at 2 GHz are not compared with measured results. For the test simulation, 6 reflections on building walls, a single diffraction at vertical edge and 4 rooftop diffractions are considered along a propagation path.

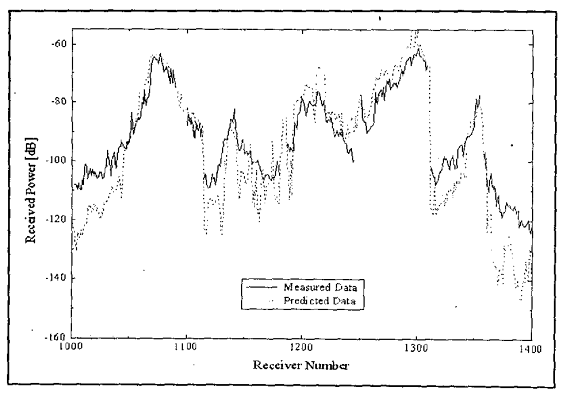

Figure 1. Comparison of the measurements and predictions for Rosslyn area

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The computer simulation of wave propagation using the developed ray-tracing tool was carried out at 2 GHz for about 1500 m × 1200 m area in Yeoui-do, Seoul, Korea, which looks like a typical high-rise urban environment. Building footprints as well as the BS locations are shown in Figure 2.

The locations of BS1, BS2, and BS3 are corresponding to the existing BS locations of currently operating IS-95 based Personal Communication Service(PCS) and BS4, BS5 are locations of virtual BSs. The average height of buildings in this area is about 34 m, which is equivalent to the height of a 10 stories building, and the standard deviation is 19.5 m. The histogram of building heights is shown in Figure 3. In addition, the area in interest has almost flat terrain and its street shapes are close to rectangular grids.

With new ray search algorithm developed in this study, it took about 2 hours to complete the prediction of wave propagation between one BS and about 3000 receivers scattered over the target environment by Pentium III 800MHz PC system. The same condition for reflections and diffractions as in the test simulation are assumed in the simulation. Rays carrying power of -20 dB or less relative to the strongest ray at each receiver are neglected in simulation in order to avoid excessive computations.

Although the computer simulation was carried out only for downlink(BS-to-MS) direction, channel characteristics for uplink(MS-to-BS) can be obtained assuming the reciprocity of electromagnetic wave propagation.

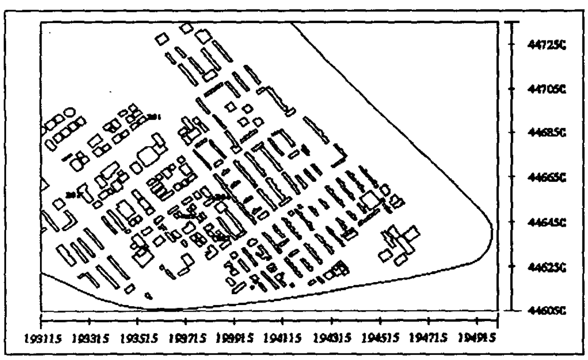


Figure 2. Building footprint of Yeoui-do

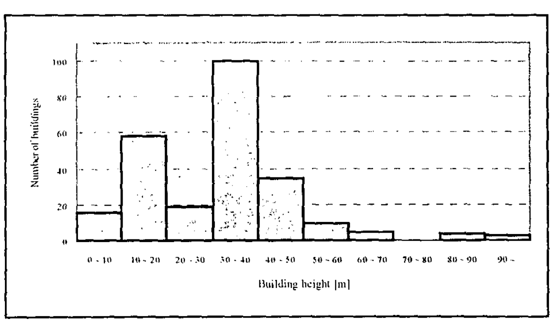


Figure 3. The histogram of building heights

For the computer simulation, both BS and MS are assumed to have omni-directional patterns in horizontal plane, which lead to ignore the effects of antenna gain in horizontal plane during the ray analysis. However, antenna patterns of BSs in vertical plane are shown in Figure 4 and those are down tilted by 2° when their heights are near or higher than the average height of surrounding buildings.

The MSs are located along the concentric circles, on whose center BS is located. The radii of concentric circles are increased by 40 m from 40 m to 520 m considering that typical microcell radius in urban environment is about 500 m[10]. The distance between adjacent MSs located along each concentric circle is set to be 5 m. The antenna height of entire MSs is assumed to be 1.7 m from the ground.

III. NORMALIZATION OF RECEIVED POWER AND ANGLE OF ARRIVAL

Due to the randomness of propagation environment between BS and MSs, the total received power of each BS-MS pair is different from each other. Considering the perfect power control for both uplink and downlink, the power carried by each ray path is to be normalized by the total received power at each BS-MS pair.

If N ray paths exist for i-th BS-MS pair, the power carried by the j-th ray path is denoted as $\alpha_{i,j}^2$ and the total received power P_i can be calculated by the following equation[11].

$$P_i = \sum_{j=1}^{N} \alpha_{i,j}^{2}$$

The normalized power carried by the j-th ray path $\beta_{i,j}^2$ is as follows.

$$\beta_{i,j}^{2} = \alpha_{i,j}^{2} / P_i$$

In the analysis of power proportion of the strongest ray path to the total received power, the normalized power $\beta_{i,j}^2$ of the strongest ray path is used.

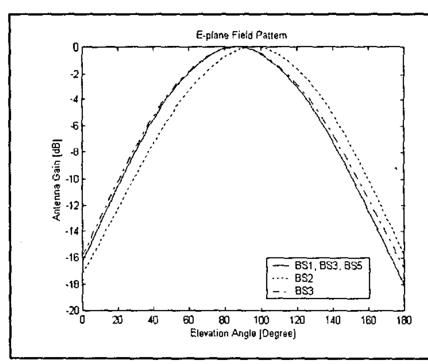


Figure 4. E-plane antenna pattern

We also normalize the AOA of each ray path by the angle of the shortest path line between BS and MS. Specifically angle information of each ray path is the relative angle with respect to the shortest path line. Moreover in order to obtain the AOA statistics, relative frequency in every 1° interval of AOA is calculated.

IV. RESULTS AND DISCUSSION

The statistics of the power proportion of the strongest ray to the total received power are given in Table I. The power proportion of the strongest ray varies from 13.4% to 100% depending on propagation environment between a BS and MSs. For any given BS, the power proportion of the strongest rays averaged over BS-MS pairs is about 70% and their standard deviation is about 20%. The complementary cumulative distribution functions (ccdf) of the power proportions of the strongest ray for different BSs are described in Figure 5 and 6. Ccdf types are classified into two groups such as group I(BS1, BS2) and group II(BS3, BS4, BS5). As figures shows, the key factor to determine ccdf type is not BS antenna height but BS location. BS antennas in group I locate at the top of building on the corner of the crossboulevards while BS antennas in group II locate off from the crossboulevards. The strongest ray of group I usually carries more power than that of group II.

TABLE I. STATISTICS OF THE POWER PROPORTION OF THE STRONGEST RAY TO THE TOTAL RECEIVED POWER

	BS 1 h_b=42.9m	BS 2 h_b=17.5m	BS 2 h_b=34m	BS 2 h_b=50.5m	BS 4 h_b=24m
Avg.(%)	78.13	74.22	75.92	75.46	65.73
Stdev.(%)	20.60	21.80	21.22	20.52	23.27
	BS 4 h_b=34m	**BS 4 h_b=44m**	**BS 5 h_b=24m**	**BS 5 h_b=34m**	**BS 5 h_b=44m**
Avg.(%)	68.37	67.83	64.99	68.76	70.03
Stdev.(%)	21.68	21.93	22.20	21.86	22.01

* h_b: Height of BS antenna

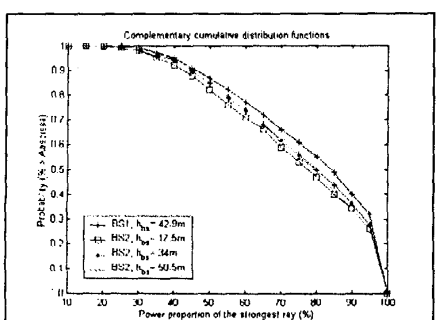


Figure 5. CCDF of the power proportion for group I

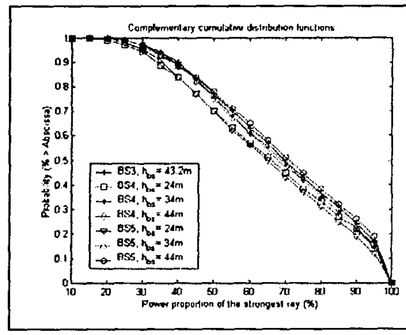


Figure 6. CCDF of the power proportion for group II

The statistics of the arrival time orders of the strongest rays in multipaths and their excess delay <τ> relative to the first arrived ray averaged over BS-MS pairs are given in Table II. When BS antenna is higher than the average height of surrounding buildings, the BS antenna location(group I or group II) is to be very important parameters in the statistics of the arrival time orders of the strongest rays as shown in Figure 7. But when BS antenna height is lower or near to the average height of surrounding buildings, the influence of the BS antenna location on the arrival time order of the strongest ray is not so much distinct as high BS antenna.

TABLE II. STATISTICS OF THE ARRIVAL TIME ORDERS OF THE STRONGEST RAY

		BS 2 h_b=17.5m	BS 2 h_b=34m	BS 2 h_b=50.5m	BS 3 h_b=43.2m	BS 4 h_b=24m
1st	Percent	49.0	54.1	52.6	48.8	41.3
2nd	Percent	21.5	20.6	23.0	17.3	20.5
	<τ> (μsec)	0.474	0.545	0.451	0.337	0.214
3rd	Percent	10.3	12.1	12.7	11.5	13.2
	<τ> (μsec)	0.842	0.837	0.862	0.685	0.393
4th	Percent	7.2	5.9	5.2	6.4	7.5
	<τ> (μsec)	1.304	1.154	1.181	1.253	0.533
Over 5th	Percent	12.1	7.4	6.6	16.1	17.6
	<τ> (μsec)	1.561	1.475	1.826	2.388	1.016
		BS 4 h_b=34m	**BS 4 h_b=44m**	**BS 5 h_b=24m**	**BS 5 h_b=34m**	**BS 5 h_b=44m**
1st	Percent	48.1	45.8	36.4	44.2	49.5
2nd	Percent	21.3	21.6	20.1	20.6	19.6
	<τ> (μsec)	0.248	0.301	0.221	0.276	0.341
3rd	Percent	11.8	11.4	13.5	11.9	10.5
	<τ> (μsec)	0.447	0.627	0.494	0.527	0.594
4th	Percent	6.1	6.4	8.7	8.3	6.9
	<τ> (μsec)	0.776	1.081	0.657	0.792	1.006
Over 5th	Percent	12.7	14.8	21.4	15.1	13.6
	<τ> (μsec)	1.596	2.116	1.224	1.364	2.032

* <τ>: Average of Excess Delay of the strongest ray

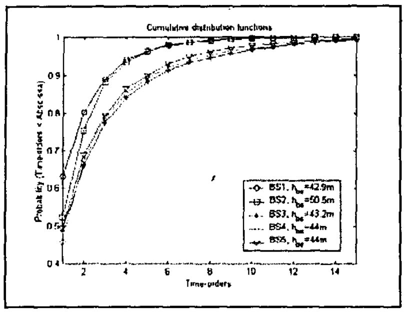
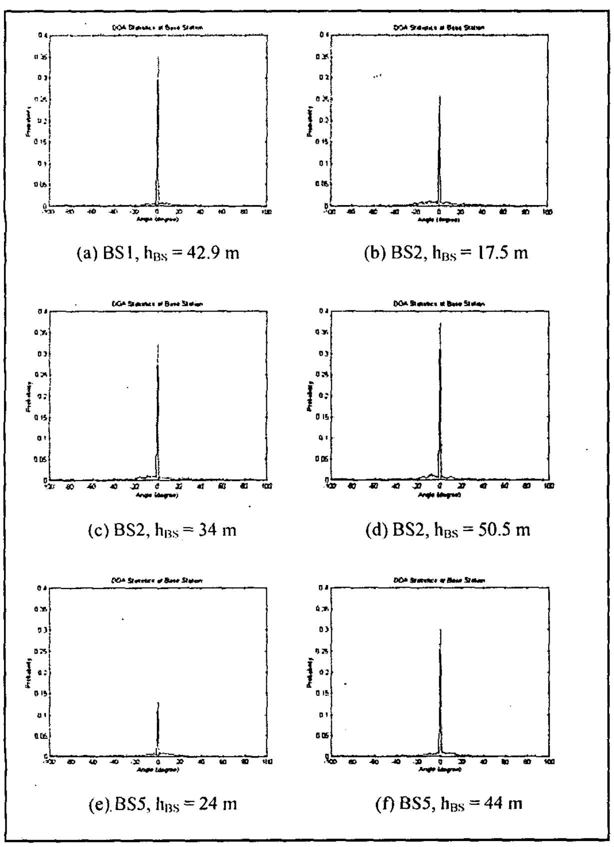


Figure 7. CDF of the time-orders for high BS antennas

Since the strongest ray is usually responsible for the very large proportion of the total received power, it is very important to identify the AOA of the strongest ray in SDMA(Space Division Multiple Access) system. In order to develop the time-spatial channel models for SDMA system, it is necessary to characterize the statistical properties of AOA of the strongest rays in diverse BS-MS pairs. Figure 8 shows the normalized AOA distribution of the strongest rays in uplink channel for various BS antenna heights and locations while Figure 9 showing those for downlink channel.

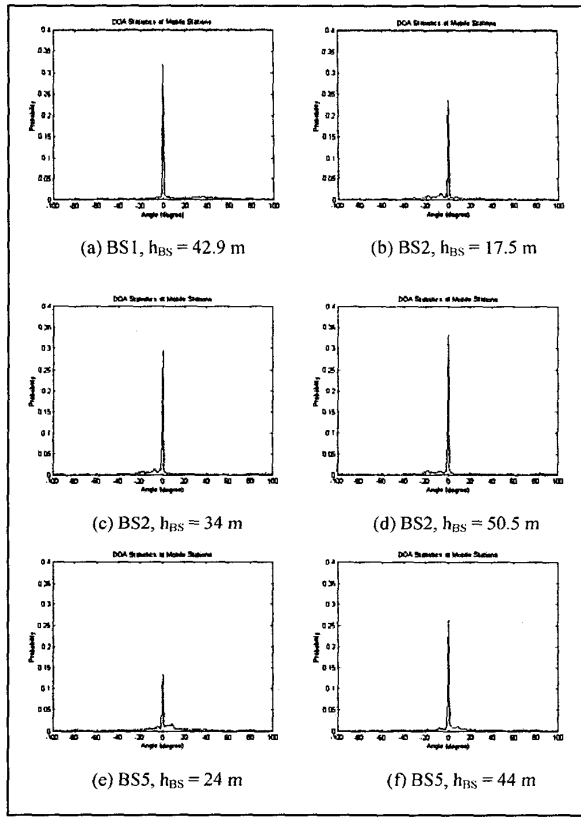


(a) BS1, h_{BS} = 42.9 m (b) BS2, h_{BS} = 17.5 m

(c) BS2, h_{BS} = 34 m (d) BS2, h_{BS} = 50.5 m

(e) BS5, h_{BS} = 24 m (f) BS5, h_{BS} = 44 m

Figure 8. AOA distribution of the strongest ray for uplink



(a) BS1, h_{BS} = 42.9 m (b) BS2, h_{BS} = 17.5 m

(c) BS2, h_{BS} = 34 m (d) BS2, h_{BS} = 50.5 m

(e) BS5, h_{BS} = 24 m (f) BS5, h_{BS} = 44 m

Figure 9. AOA distribution of the strongest ray for uplink

The AOAs of the strongest rays both for uplink and downlink highly concentrate on the shortest path line between BS and MS. The probability that the AOAs of the strongest rays fall into the angle interval between -5° and 5° is more than 30% with a couple of exceptions. Characterizing the effect of BS antenna locations on the AOA statistics, the probabilities for BS antennas located at the corner of the crossboulevards are about 10% higher than those for other BS locations with the same antenna height. On the other hand, the change of BS antenna heights from higher than to lower than the average height of surrounding buildings at the same BS locations bring in 10% of decrease in probabilities. Therefore both the BS location and antenna height are very important parameters for the AOA statistics of the strongest ray.

Analyzing the statistical properties of the power differences between the strongest ray and the second strongest ray, their average is about 7.5 dB and 6.5 dB and standard deviation is 5.4 dB and 4.9 dB for group I and group II, respectively. In order to understand the correlations of AOAs between the strongest and the second strongest ray, the angle deviation of them is obtained as shown in Figure 10 and 11.

Characteristics of angle deviation for uplink are distinctly different from those for downlink. The probabilities that the angle deviation between them fall into the angle interval between -5° and 5° are from 28% to 42% for uplink direction.

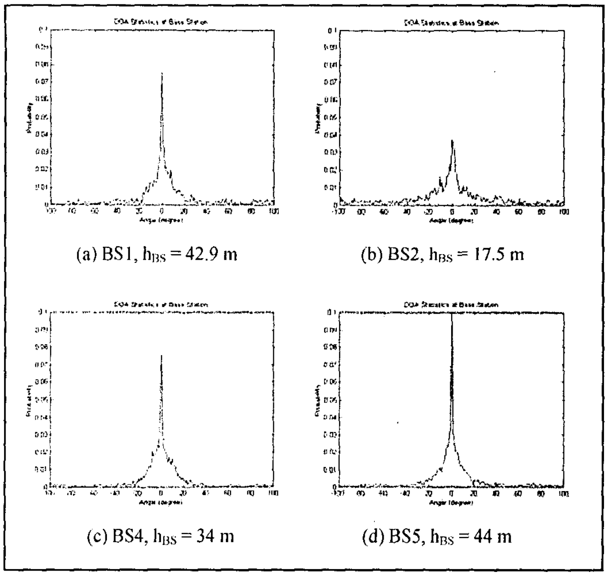


Figure 10. Angle deviation between the strongest and the second strongest rays for uplink

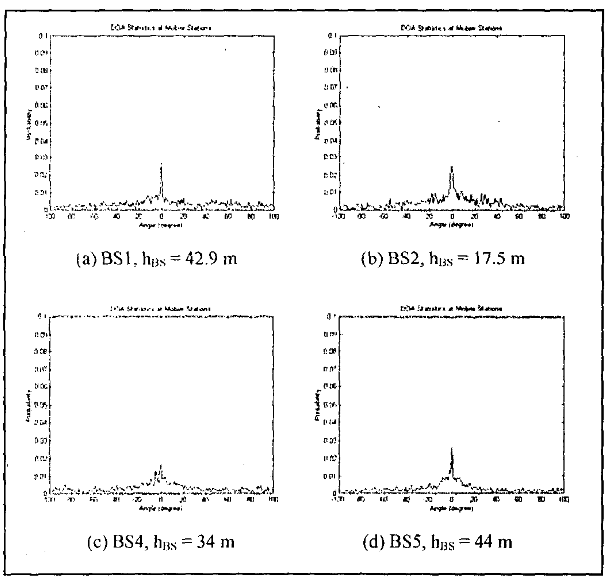


Figure 11. Angle deviation between the strongest and the second strongest rays for uplink

Meanwhile for downlink the probabilities are from 10% to 19%. Analyzing angle deviation between the strongest and the second strongest rays, the key factor to determine them is not BS antenna height but BS location similar to power proportion of the strongest ray.

In addition, about 1.2 ray paths exist within the angle interval between -5° and 5° around the strongest ray for downlink, while about 0.5 ray paths exist within that interval for uplink on the average.

V. CONCLUSION

In this study the characterization of time-spatial channel model is carried out based on computer simulation using ray-tracing technique by analyzing the strongest ray properties. The strongest ray is usually responsible for the very large proportion of the total received power and the power proportion is dependent not on the BS antenna heights but the BS antenna locations. However, it does not mean that the strongest ray is necessarily the first arrived ray and when BS antenna is higher than the average height of surrounding buildings, the BS antenna location is to be very important parameters in the statistics of the arrival time orders. The AOAs of the strongest rays both for uplink and downlink highly concentrate on the shortest path line between BS and MS and also both the BS location and antenna height are very important parameters for the AOA statistics of the strongest ray. The second strongest ray rarely deviates from the strongest ray for uplink while the secondary strongest ray much deviates from the strongest ray for downlink. Also the BS location is key parameter for the statistics of the angle deviation between them.

In this analysis the target environment is high-rise urban environment with flat terrain. But in order to generalize the results of this study, more simulation and analysis for various high-rise urban environments, i.e. irregular terrain, with vegetation, or with river, are necessary for future study.

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