Propagation Path Analysis for Planning a Cell in the CDMA Mobile Communication

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Abstract : In microcell or picocell mobile communication using cellular method, we suggested propagation prediction model which can accurately and rapidly interpret mobile communication propagation environment in urban, when subscriber service is done based on the main road in urban. Further, we simulated suggested propagation prediction model under the hypothesis of urban propagation environment of PCS mobile communication, analyzed receiving field strength by area within a cell, and finally suggested the optimal transmitting power and location condition of microcell or picocell mobile communication base station

1. Introduction

The cellular method in an early stage was macrocell method whose service radius was between several kilometers and tens of kilometers. But, because of explosive increase of the number of subscribers a microcell method or a picocell method was introduced. And it could enlarge the call processing capacity and improve the transmission quality.[1][2]

Unlike the macrocell method, the service radius of the microcell method is less than 1 kilometer. Because microcell method is affected by the surface of the earth and buildings in the cell area, the transmitting power of the base station should be minimized and an antenna should be installed at the lower elevation than close buildings to reduce the interference by neighboring cells. Therefore, for predicting the optimal power of the base station according to the feature of the surface of the earth and buildings in the cell area, a propagation prediction model is necessary for low cost and high efficiency of the microcell system design.[3-6] For this case, as the representative propagation prediction models, there are two models using the lay-launching method[7] and the multiple image method. [8] But, these models are not practical because of complex calculation, impossible execution processing, and much time to predict receiving power.

Thus, in this paper developed the triangle analysis algorithm to interpret propagation path, suggested and simulated propagation prediction model which can predict receiving field strength in mobile station, located in a random spot within a service area, and finally presented the optimal power and location condition of microcell base station.

2. Algorithm to interpret a propagation path

Fig. 1 is a virtual propagation path to interpret the number and path of propagation, which vary with the changes in road width and the inclined angle of a straight crossing as well as the incident and reflection angle of propagation coming to base station, using the triangle analysis method and to simulate suggested prediction model, if mobile station is located ①at random propagation shadow area, slightly failed to the straight road of line of sight area ; ②at straight crossing of non-line of sight area which is inclined to certain inclined angle of $\theta_v{}^\circ$ against the straight road; or ③at a random spot, somewhat gone off the straight crossing.

Before the algorithm to interpret the reflection number and path of propagation is suggested until propagation arrives at mobile station located at random spot, the following are hypothesized :

First, the difference in height between base and mobile station is ignored because it is too small compared with propagation path.

Secondly, as propagation path which is travelled by one reflection is short, the road width of that section is considered regular.

Thirdly, available propagation coming at mobile station is only one and it is horizontal travelling wave due to the reflection of wall of building..

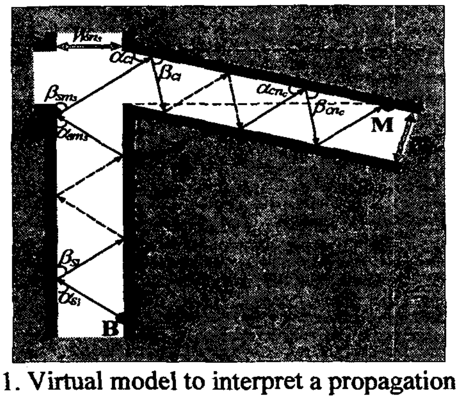

Fig. 1. Virtual model to interpret a propagation path

2.1 Algorithm to interpret the direct path of wave

Transmitting wave from a base station reflects n_s times by random α_{sn_s} (incident angle) and β_{sn_s} (reflection angle) at line of sight area of W_{sn_s} (road width), as shown in Fig. 1, and approaches non-line of sight area again. While it reflects n_c times by α_{cn_c} (incident angle) and β_{cn_c} (reflection angle) again and comes to a mobile station, l_n (the total straight path) is the sum of l_{sn_s} and l_{cn_c}. The algorithm is as follows.

$$l_n = l_{sn_s} + l_{cn_c} = \sum_{n_d}^{m_d} W_{sn_s} \left(\frac{\cos\alpha_{sn_s}}{\sin\alpha_{sn_s}} + \frac{\cos\beta_{sn_s}}{\sin\beta_{sn_s}} \right) + \sum_{n_c=1}^{m_c} W_{cn_s} \left(\frac{\cos\alpha_{cn_c}}{\sin\alpha_{cn_c}} + \frac{\cos\beta_{cn_c}}{\sin\beta_{cn_c}} \right) \quad (1)$$

Where m_s, m_c are the final reflection number of each area.

On the other hand, the algorithm is as follows to find α_{c1}, the first incident angle which approaches non-line of sight area, opposed to β_{sm_s}, the final reflection angle in line of sight area.

$$\alpha_{c1} = 180 - [\beta_{sm_s} + \theta_v] \text{ [degree]} \quad (2)$$

Where θ_v° is considered "+", if rotating counterclockwise, when 6 o'clock is "0".

2.2 Algorithm to interpret propagation path of wave

In the same condition as 1, while wave comes to the mobile station from a base station, the total propagation path, , r_n is the sum of r_{sn_s} (line of sight) and r_{cn_c} (non-line of sight). The algorithm is found as follows.

$$r_n = r_{sn_s} + r_{cn_c} = \sum_{n_s=1}^{m_s} W_{sn_s} \left(\frac{\sin\alpha_{sn_s}}{\sin\alpha_{sn_s}} + \frac{\sin\beta_{sn_s}}{\sin\beta_{sn_s}} \right) + \sum_{n_c=1}^{m_c} W_{cn_c} \left(\frac{\sin\alpha_{cn_c} + \sin\beta_{cn_c}}{\sin\alpha_{cn}\sin\beta_{cn_c}} \right) \quad (3)$$

2.3 Reflection coefficient

To find reflection coefficient before prediction model is suggested, all wave reflection is $\alpha_{n_{sc}}$, if it is direct reflection and vertical polarization, reflection coefficient, $\Gamma(\alpha_{n_{sc}})$, is found as follows.[9]

$$\Gamma(\alpha_{n_{sc}}) = \frac{\sin(\alpha_{n_{sc}}) - \sqrt{\varepsilon_r - \cos^2(\alpha_{n_{sc}})}}{\sin(\alpha_{n_{sc}}) + \sqrt{\varepsilon_r - \cos^2(\alpha_{n_{sc}})}} \quad (4)$$

If $\varepsilon_r = \varepsilon_r' - j60\sigma\lambda$ ($\varepsilon_r' = 15$, $\sigma = 2$), specific inductive capacity of specular surface, is substituted (wavelength=0.167 m[in case of PCS]) for equation(4), reflection coefficient is found as table 1.

Table 1. Reflection coefficient by incident and reflection angle

Incident and reflection angle	Reflection coefficient	Incident and reflection angle	Reflection coefficient
0°	-1	45°	-0.75
5°	-0.965	50°	-0.7324
10°	-0.9316	55°	-0.7169
15°	-0.8998	60°	-0.7035
20°	-0.8698	65°	-0.6922
25°	-0.8417	70°	-0.683
30°	-0.8156	75°	-0.6758
35°	-0.7917	80°	-0.6707
40°	-0.7698	85°	-0.6677

3. Suggestion of propagation prediction model

3.1 Propagation prediction model for line of sight area

L_{SWB} , path loss of broad band to the extent of mobile station, located at propagation shadow area of line of sight, is found from equation(3) applied. The result is as follows.

$$L_{SWB} = 20\log\left\{ \sum_{n_s=1}^{m_s} \frac{\lambda \sin\alpha_{sn_s} \sin\beta_{sn_s}}{4\pi\gamma_{sn_s}} \Gamma_{n_s} \right\} \text{ [dB]} \quad (5)$$

If the effective radiation power of base station is P_t, propagation prediction model to interpret P_{rs} [W, dBm](receiving power of mobile station of line of sight area) is found from equation(5) applied. The result is as follows.

$$P_{rs} = P_t \left\{ \sum_{n_s=1}^{m_s} \frac{\lambda \sin\alpha_{sn_s} \sin\beta_{sn_s}}{4\pi W_{sn_s} (\sin\alpha_{sn_s} + \sin\beta_{sn_s})} \Gamma_{n_s} \right\}^2$$

$$= P_t \left\{ \sum_{n_s=1}^{m_s} \frac{\lambda}{4\pi\gamma_{sn_s}} \Gamma_{n_s} \right\}^2 \text{ [W]}$$

$$= 20\log P_t \times 10^3 \left\{ \sum_{n_s=1}^{m_s} \frac{\lambda}{4\pi\gamma_{sn_s}} \Gamma_{n_s} \right\} \text{ [dBm]} \quad (6)$$

3.2 Propagation prediction model for non-line of sight area

L_{WB} , path loss of broad band to the extent of mobile station, located at propagation shadow area of non-line of sight, is the sum of L_{SWB} and L_{CWB} and found from equation(3) applied. The result is as follows.

$$L_{wB} = L_{SWB} + L_{CWB}$$

$$= 20\log \sum_{n_s=1}^{m_s} \sum_{n_c=1}^{m_c} \frac{\lambda}{4\pi(\gamma_{sn_s} + \gamma_{cn_c})} \Gamma_{n_s} \Gamma_{n_c} \text{ [dB]} \quad (7)$$

If effective radiation power of base station is P_t, propagation model to interpret P_{rc} [W, dBm](receiving power of mobile station of non-line of sight area) is found from equation(7) applied. The result is as follows.

$$P_{rc} = P_t \sum_{n_s=1}^{m_s} \sum_{n_c=1}^{m_c} \left\{ \frac{\lambda}{4\pi(\gamma_{sn_s} + \gamma_{cn_c})} \Gamma_{n_{sr}} \Gamma_{n_c} \right\}^2 \text{ [W]}$$

$$= 20 \log P_t \sum_{n_s=1}^{m_s} \sum_{n_c=1}^{m_c} \frac{10^3 \lambda}{4\pi(\gamma_{sn_s} + \gamma_{cn_c})} \Gamma_{n_c} \Gamma_{n_c} \text{ [dBm]} \quad (8)$$

As a result, if mobile station is located at propagation shadow area of line of sight or non-line of sight area, integration model is found as equation(8) to predict receiving power coming to the mobile station.

4. Simulation

Microcell PCS mobile communication propagation environment with 1.8 GHz of urban living space was selected, as it is relatively similar in using frequency band to IMT-2000 with 2 GHz, which is next generation mobile communication method. Then equation(8) was simulated with specification of table 2 and the result is shown in table 3.

Table 2. Specification of simulation

Virtual propagation path	Fig. 1
Propagation environment	urban microcell PCS mobile communication
Using frequency	1.8GHz, λ : 0.167 m
Effective radiation power	250 mW, (Maximum power per PCS Ch.)
Transmitting Ant. - Receiving Ant.	0[m], ($h_t - h_r$)
Number of effective propagation	1
Service-possible distance based on direct path	0 m ~ 2,000 m
section of direct path	400~2,000 m (step 200m)
Incident and reflection angle in line of sight	25° (regular reflection)
Incident and reflection angle in non-line of sight	Found from equation(2) using variable of θ_p
Sloping of non-line of sight	50° ~ 170°
Road width	10 m, 20 m, 30 m, 40 m
Specific inducture capacity of specular surface	25($\varepsilon_r' = 15, \sigma = 2, \lambda = 0.166$)
Reflection coefficient	table 1

Table 3. Receiving power by direct path of line of sight and non-line of sight area

[dBm]

Total direct path [m]	Prediction distance [m]	Sloping angle / Road width	50	60	70	80	90	100	110	120	130	140	150	160	170
600	line of sight 300	10[m]	50	50	50	50	50	50	50	50	50	50	50	50	50
		20[m]	44	44	44	44	44	44	44	44	44	44	44	44	44
		30[m]	43	43	43	43	43	43	43	43	43	43	43	43	43
		40[m]	42	42	42	42	42	42	42	42	42	42	42	42	42
	non-line of sight 300	10[m]	·	·	[illegible]	[illegible]	93	77	65	59	55	66	59	66	77
		20[m]	·	·	[illegible]	83	69	61	65	52	50	60	52	56	61
		30[m]	·	·	85	71	61	67	63	50	49	49	50	52	57
		40[m]	·	·	78	66	58	54	50	49	48	48	49	50	54
800	line of sight 400	10[m]	56	56	56	56	56	55	55	55	55	56	56	56	56
		20[m]	49	49	49	49	49	49	49	49	49	49	49	49	49
		30[m]	47	47	47	47	47	47	47	47	47	47	47	47	47
		40[m]	45	45	45	45	45	45	45	45	45	45	45	45	45
	non-line of sight 400	10[m]	·	·	[illegible]	[illegible]	[illegible]	91	75	66	62	62	66	75	91
		20[m]	·	·	[illegible]	[illegible]	80	70	62	57	65	65	57	62	70
		30[m]	·	·	[illegible]	83	70	68	57	54	63	63	54	57	63
		40[m]	·	·	89	74	64	59	54	52	51	51	52	54	59
1,000	line of sight 500	10[m]	62	62	62	62	62	62	62	62	62	62	62	62	62
		20[m]	53	53	53	53	53	53	53	53	53	53	53	53	53
		30[m]	50	50	50	50	50	50	50	50	50	50	50	50	50
		40[m]	48	48	48	48	48	48	48	48	48	48	48	48	48
	non-line of sight 500	10[m]	·	·	[illegible]	[illegible]	130	[illegible]	85	73	68	68	73	85	[illegible]
		20[m]	·	·	[illegible]	[illegible]	90	76	67	61	59	69	61	67	76
		30[m]	·	·	[illegible]	91	77	67	61	57	65	65	67	61	67
		40[m]	·	·	[illegible]	81	70	68	58	55	54	54	55	58	63
1,200	line of sight 600	10[m]	66	66	[illegible]	66	66	65	65	65	65	66	66	66	66
		20[m]	56	56	56	56	56	55	55	55	55	56	56	56	56
		30[m]	53	53	53	53	53	53	53	53	53	53	53	53	53
		40[m]	50	50	50	50	50	50	50	50	50	50	50	50	50
	non-line of sight 600	10[m]	·	·	[illegible]	[illegible]	[illegible]	[illegible]	92	79	73	73	79	92	[illegible]
		20[m]	·	·	[illegible]	125	[illegible]	88	71	65	62	62	65	71	83
		30[m]	·	·	[illegible]	101	84	73	65	61	58	58	61	65	73
		40[m]	·	·	112	89	76	67	61	58	56	66	58	61	67
1,400	line of sight 700	10[m]	71	71	[illegible]	71	71	71	71	71	71	71	71	71	71
		20[m]	59	59	59	59	59	59	59	59	59	59	59	59	59
		30[m]	56	56	56	56	56	55	55	55	55	56	56	56	56
		40[m]	53	53	53	53	53	53	53	53	53	53	53	53	53
	non-line of sight 700	10[m]	·	·	[illegible]	[illegible]	166	[illegible]	101	85	78	78	85	101	122
		20[m]	·	·	[illegible]	[illegible]	109	90	77	68	65	65	69	77	90
		30[m]	·	·	[illegible]	111	91	78	68	63	61	61	63	68	78
		40[m]	·	·	122	[illegible]	82	72	65	61	59	59	61	65	72
1,600	line of sight 800	10[m]	76	76	76	76	76	76	76	76	76	76	76	76	76
		20[m]	62	62	62	62	62	62	62	62	62	62	62	62	62
		30[m]	57	57	57	57	57	57	57	57	57	57	57	57	57
		40[m]	55	55	55	56	56	55	55	55	55	55	56	55	56
	non-line of sight 800	10[m]	·	·	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92	83	83	92	[illegible]	[illegible]
		20[m]	·	·	[illegible]	[illegible]	[illegible]	[illegible]	81	72	68	68	72	81	[illegible]
		30[m]	·	·	[illegible]	131	87	82	72	65	63	63	66	72	82
		40[m]	·	·	[illegible]	[illegible]	86	76	68	63	61	61	63	68	76
1,800	line of sight 900	10[m]	80	80	80	80	80	80	80	80	80	80	80	80	80
		20[m]	64	64	64	64	64	64	64	64	64	64	64	64	64
		30[m]	59	59	59	59	59	59	59	59	59	59	59	59	59
		40[m]	57	57	57	57	57	57	57	57	57	57	57	57	57
	non-line of sight 900	10[m]	·	·	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	87	87	[illegible]	[illegible]	[illegible]
		20[m]	·	·	[illegible]	[illegible]	[illegible]	[illegible]	86	76	71	71	76	86	[illegible]
		30[m]	·	·	[illegible]	125	[illegible]	87	75	69	65	65	69	75	87
		40[m]	·	·	[illegible]	[illegible]	92	79	70	65	63	63	53	70	79
2,000	line of sight 1,000	10[m]	86	86	86	86	86	86	86	86	86	86	86	86	86
		20[m]	68	68	68	68	68	68	68	68	68	68	68	68	68
		30[m]	62	62	62	62	62	62	62	62	62	62	62	62	62
		40[m]	59	59	59	59	59	59	59	59	59	59	59	59	59
	non-line of sight 1,000	10[m]	·	·	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92	92	[illegible]	[illegible]	[illegible]
		20[m]	·	·	[illegible]	[illegible]	[illegible]	[illegible]	91	79	74	74	79	91	[illegible]
		30[m]	·	·	[illegible]	[illegible]	118	91	79	71	68	68	71	79	91
		40[m]	·	·	[illegible]	[illegible]	96	82	73	67	65	65	67	73	82

Based on |95dBm|, minimum receiving power of mobile station possible to service, from table 3, subscriber's service-possible distance, which varies with reflection angle and road width, is found in reflection angle of < 70°and the result is shown in table 4.

Table 4. Service-possible direct path by road width and sloping angle

[m]

Road width / Sloping angle	10[m]	20[m]	30[m]	40[m]
70[°]	140	510	710	910
80[°]	400	780	1,080	1,370
90[°]	600	1,140	1,540	1,950
100[°]	850	1,740	2,000	2,000
110[°]	1,250	2,000	2,000	2,000
120[°]	1,750	2,000	2,000	2,000
130[°]	2,000	2,000	2,000	2,000
140[°]	2,000	2,000	2,000	2,000
150[°]	1,720	2,000	2,000	2,000
160[°]	1,270	2,000	2,000	2,000
170[°]	860	1,540	2,000	2,000

5. Conclusion

For microcell mobile communication in urban, suggested prediction model was simulated as shown in table 2. But, the minimum receiving power of mobile station was based on -95 dB m and the wave coming to the mobile station is only one.

When subscriber's service-possible distance, which varies with sloping angle and road width, was simulated in effective wave number of < 100% and sloping angle of < 90°, the results are as follows.

- Although propagation path is irrelative to road width as well as the incident or reflection angle of propagation, because the same incident and reflection angle is inversely proportional to road width, larger road width has less propagation path loss.
- Of wave flowing into non-line of sight area due to the final reflection of line of sight area, effective wave number is > 100% in sloping angle of > 90°, so the location of base station must be sloping angle of < 90°. In sloping angle of 130°~140°, receiving power coming to mobile station becomes maximum. Based on this angle, when sloping angle is increased or decreased, receiving power is decreased.

In reality, when mobile station is located within line of sight area in microcell or picocell mobile communication propagation environment of urban living space, it can be affected by direct, reflection, or diffraction wave simultaneously and it is possible to maintain good call quality. But if it is located within non-line of sight area, at the worst, either of reflection and diffraction wave is only received.

In designing microcell or picocell mobile communication system in urban propagation environment, road situation and road width in urban within cell are important parameters to select optimal power and location of base station. Therefore it is needed to use the results of this study.

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