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MAXIMUM EIRP AND EMF ESTIMATION BASED ON OVER-THE-AIR MEASUREMENTS OF WCDMA PILOT CHANNEL

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Abstract—This paper presented an estimation method of maximum effective isotropic radiated power (EIRP) and electro-magnetic field (EMF) strength of a wideband code-division multiple-access (WCDMA) base station based on over-the-air measurements of a pilot channel in a code domain. To verify the feasibility of the proposed method, we estimated the maximum EIRP and EMF strengths of the self-designed test base station, and compared them with EIRP and EMF values measured by the traditional test scheme. Then, we applied our estimation scheme to the inspection test for a commercial base station. The maximum difference between the estimated EIRP values from our method and the reported values is 1.3 dB. The estimated EMF results show more than 90% agreement with both the traditional EMF measurement value under a full-traffic load condition and the theoretical value. Therefore, it can be concluded that our proposed estimation method should be an effective inspection test for domestic base stations.

1. INTRODUCTION

In recent years, due to the proliferation of smart phone users and unlimited data fees, the competition has intensified among mobile communication service providers worldwide. This situation is leading to increasing numbers of base stations or repeaters per unit area. Naturally, concern about hazardous exposure to electromagnetic waves

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from base stations is growing, and inspection testing of base stations (BSs) is gradually becoming more important [1–4].

BS inspection testing generally consists of two parts: maximum power measurement and electromagnetic field (EMF) measurement. The former is to check the maximum radiated power of a BS, and the latter is to check the electromagnetic field strength from a BS. For example, Korean radio wave regulations based on the most stringent international standards, the standards of the International Commission on Non-ionizing Radiation Protection (ICNIRP), define that BS inspection testing should be compulsory for any base station whose output is beyond or equal to 30 W. In accordance with the measurement procedure in notice No. 2010-46 of the Radio Research Agency (RRA), the space-averaged EMF strength should be measured for six minutes in all over the operating frequency band [5, 6].

However, even though measurements are performed for a long time, measured values are less than the actual maximal EIRP value [7] because of two problems. First, the maximum power measurement of a BS is carried out at the input port of the BS transmit antenna. But the antenna input power does not mean the power radiated into the air. The actual radiated power from a BS can only be expressed by the effective isotropic radiated power (EIRP) or effective radiated power (ERP). Second, in wideband code-division multiple-access (WCDMA) mobile communication systems, the EIRP and EMF are changed by many factors, such as cable loss, antenna gain, frequency assignments (FA), the varying number of subscribers with time, etc. For the aforementioned reasons, the conventional BS inspection method does not guarantee that the maximum EIRP and EMF values will be effectively obtained.

Fortunately, the maximum EIRP or EMF values of a BS can be estimated using measured values of the EIRP or EMF of a pilot channel in a code domain because the pilot signal is almost constant in time [8, 9]. In this paper, we propose a method to estimate the maximum EIRP and EMF strength of a WCDMA BS based on over-the-air measurements for the pilot signal power in a code domain. To show the feasibility of the proposed method, a test BS was set up and the measured results of the test BS are compared with results obtained using the traditional test scheme. In addition, in the case of EMF, we compared the estimated EMF values with theoretical values. Then, we applied our estimation scheme to commercial BS environments.

2. PROPOSED ESTIMATION METHOD

The WCDMA air interface uses a number of logical channels for data and control information, which are distinguished by spreading codes, scrambling codes, and position within the time slot. Among them, a common pilot channel (CPICH) is not modulated and scrambled with the primary scrambling code of the cell. A mobile station monitors the CPICH's power for cell choice. The CPICH does not contain any information, but it is used as a time-reference for common and dedicated channels. The CPICH carries a pre-defined bit sequence with a fixed bit rate of 30 kbps [10].

The power of CPICH is defined by the factor γ between the power of the CPICH and the maximal power of a cell or sector (%). The possible range of γ is 1% to 30% of the cell power: most probably 10% to 15% for microcells (medium traffic) and 1% to 5% for picocells (high traffic). If a telecom operator will not change the cell coverage, the power deviation of the CPICH becomes less than 0.5 dB. Therefore, if we know the factor γ and measure the received CPICH power, we can estimate the maximum EIRP and EMF values. Figure 1 show the proposed estimation procedure for maximum EIRP and EMF values.

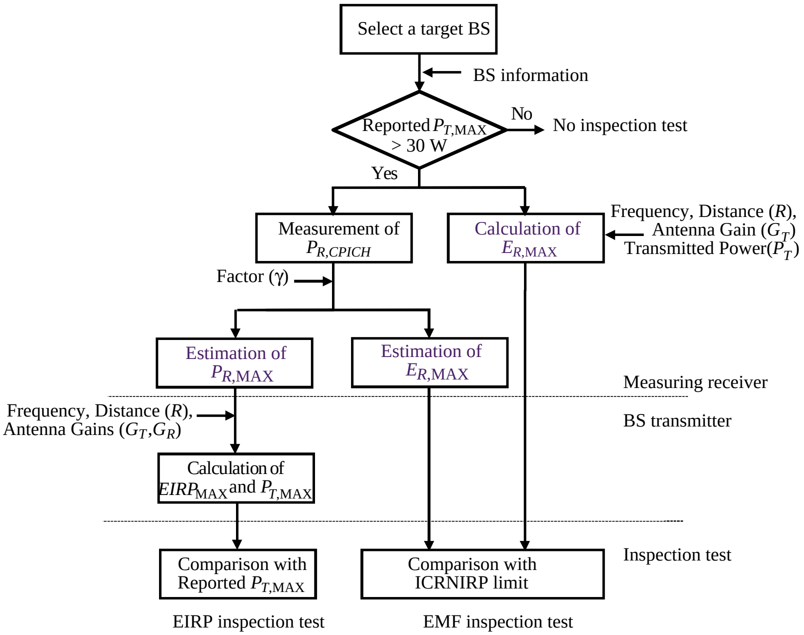

Figure 1. Estimation procedure for maximum EIRP and EMF.

The proposed estimation procedure is divided into three stages:

- Estimation of maximum EIRP or power of transmitter,
- Estimation of maximum EMF at any arbitrary position,
- Calculation of maximum EMF at any arbitrary position.

First, we can estimate the maximum EIRP or transmit power, $EIRP_{\max}$ or $P_{T,\max}$, based on the received CPICH power, $P_{R,CPICH}$, by using additional information, such as the factor γ, frequency, distance, and antenna gains. Second, we can obtain the received maximum EMF, $E_{R,\max}$, by multiplying the received CPICH field strength, $E_{R,CPICH}$, by the factor $\sqrt{1/\gamma}$. Finally, to give a theoretical reference, we calculate $E_{R,\max}$ under the electromagnetic theory. For BS inspection testing, we can decide whether the estimated $P_{T,\max}$ coincides with the previous reported value and the estimated $E_{R,\max}$ is below the ICNIRP limit. Also, the calculation of maximum EMF strength is possible to reduce the measurement cost instead of EMF field tests.

2.1. Maximum EIRP Estimation

The estimation procedure for maximum EIRP value is summarized as follows. Maximum received power can be expressed as

$$P_{R,\max} = (1/\gamma) \cdot P_{R,CPICH}, \tag{1}$$

where $P_{R,\max}$ is the maximum received power at the receiver antenna. To estimate a maximum transmitter's EIRP value from received power exactly, the following line-of-sight (LOS) conditions must be satisfied:

- There is no obstruction around transmit and receive antennas.
- There is only one direct path (no multiple path).

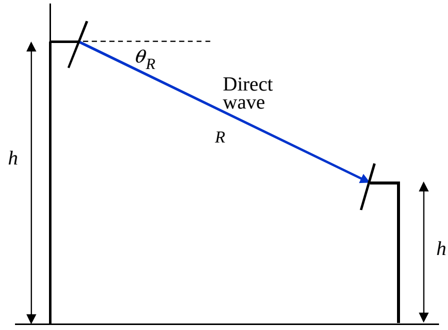

Figure 2. Basic EIRP measurements scenario.

- The main beam direction and polarization of the antennas must match each other.

Figure 2 shows a typical LOS environment. If the height of the receiving antenna, h', is sufficiently high, ground-reflected wave can be ignored. Therefore, the maximum transmitted power, $P_{T,\max}$, can be obtained by the Friis transmission equation and LOS conditions [11, 12]:

$$P_{T,\max} = \left(\frac{1}{G_T \cdot \gamma}\right)\left(\frac{P_{R,CPICH}}{G_R}\right)\left(\frac{4\pi R}{\lambda}\right)^2, \tag{2}$$

where, G_T and G_R are the gains of transmitter and receiver antennas, respectively, λ is the wavelength of the carrier frequency, and R is the separation distance between the transmitter and receiver antennas. Now, the maximum EIRP is defined as

$$EIRP_{\max} = G_T P_{T,\max} \tag{3}$$

In calculating Equation (2), feed losses such as feed lines, cables, and a power divider can be included.

2.2. Maximum EMF Estimation

Contrary to the EIRP measurements, we have to consider several reflected waves as well as direct wave in the maximum EMF estimation procedure. Figure 3 shows a typical scenario to estimate the maximum EMF value of a BS. In Figure 3, there are three waves: direct, ground-reflected, and wall-reflected waves from the back side. Given factor γ it is possible to calculate the maximum EMF value. Obviously, the result will be larger than the EMF value of the summation of all other

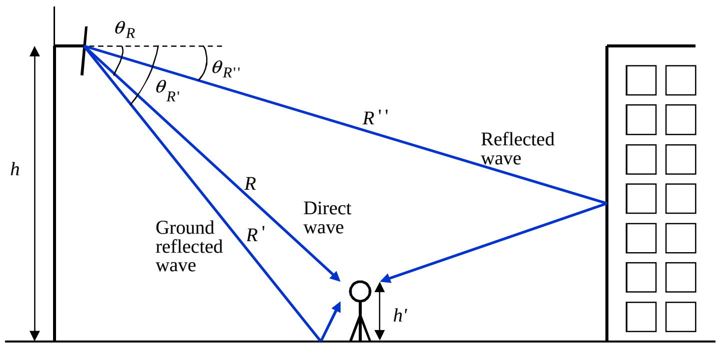

Figure 3. Basic EMF measurements scenario.

channels added to the CPICH. The maximum electric field is estimated as

$$E_{R,\max} = \sqrt{1/\gamma} \cdot E_{R,CPICH} \tag{4}$$

where $E_{R,CPICH}$ is obtained by the conversion of $P_{R,CPICH}$ under the far-field condition.

2.3. Maximum EMF Calculation

As mentioned before, when EMF strength is measured, the ground reflection wave should not be ignored because of the low height ($\sim$ 1.7 m) of the measuring point from the ground as shown in Figure 3. Thus, the electric field at the measuring point is mathematically represented by vector summation of the direct EM wave and reflected EM waves:

$$\vec{E} = \vec{E}_{direct} + \sum \vec{E}_{reflected} \tag{5}$$

where $\vec{E}_{direct}$ is the electric field induced from the direct wave, and $\vec{E}_{reflected}$ is the electric field from reflected waves. As the direct wave and the ground-reflected wave are stronger than multiple reflected waves, we consider three paths, i.e., the direct path (R), the ground-reflected path (R'), and the wall-reflected path (R''), in calculating EMF values. Therefore, (5) can be rewritten as

$$\begin{aligned} \vec{E} \;=\; & \vec{E}_R + \vec{E}_{R'} + \vec{E}_{R''} = \sqrt{60EIRP} \cdot F(\theta_R) \cdot e^{-j\beta R}/R \cdot \vec{\Phi}_T \\ & + \sqrt{60EIRP} \cdot F(\theta'_R) \cdot \Gamma_{R'} \cdot e^{-j\beta R'}/R' \cdot \vec{\Phi}_T \\ & + \sqrt{60EIRP} \cdot F(\theta''_R) \cdot \Gamma_{R''} \cdot e^{-j\beta R''}/R'' \cdot \vec{\Phi}_T \end{aligned} \tag{6}$$

where EIRP denotes the transmitter maximum EIRP, $F(\theta)$ the radiation pattern in the direction θ, β the wave number, and $\vec{\Phi}$ the polarization vector of the transmitter antenna. The reflection coefficients $\Gamma_{R'}$ and $\Gamma_{R''}$ are given as follows:

$$\Gamma_{R'} = \frac{-\varepsilon_r \cos\theta_{R'} + \sqrt{\varepsilon_r - \sin^2\theta_{R'}}}{\varepsilon_r \cos\theta_{R'} + \sqrt{\varepsilon_r - \sin^2\theta_{R'}}}, \tag{7}$$

$$\Gamma_{R''} = \frac{-\varepsilon_r \cos\theta_{R''} + \sqrt{\varepsilon_r - \sin^2\theta_{R''}}}{\varepsilon_r cos\theta_{R''} + \sqrt{\varepsilon_r - \sin^2\theta_{R''}}} \tag{8}$$

where ε_r is the relative permittivity of the propagation medium, and θ_x denotes the angle between the path x and the plane parallel to ground. In general, Equations (7) and (8) should include the complex dielectric constant $\varepsilon = \varepsilon_0\varepsilon_r - j(\frac{\sigma}{2\pi f})$, where σ and f mean a conductivity value of reflection plane and frequency, respectively. However, as imaginary part of a complex dielectric constant can somehow be neglected at WCDMA frequencies, we have just considered the real part of ε in every calculation.

3. MAXIMUM EIRP ESTIMATION BASED ON MEASUREMENT

In this section, we describe maximum EIRP estimation procedure based on the over-the-air measurement value of the CPICH power. First, we discuss results obtained at a test BS to verify the feasibility of the proposed method. Next, we give results obtained at a commercial BS.

3.1. Maximum EIRP Estimation of Test BS

Using (2) and (3), we can estimate the maximum EIRP of a WCDMA BS. To verify the proposed estimation procedure, we fabricated a test BS. Figure 4 depicts the test environment for estimating maximum EIRP. To satisfy LOS conditions, a BS transmit antenna was installed on the roof of a 5-storey building, and a receiver with a spectrum analyzer was installed on the roof of the opposite building. The height of the two buildings was the same. The transmitter antenna was installed on a 2 m height at the outer boundary of building. The antenna was a high-gain antenna of 15.0 dBi gain. The transmit signal was a WCDMA test mode 1 signal made by Agilent's E4437 ESG signal generator at the center frequency of 2122.8 MHz. The test mode 1 signal is a WCDMA signal under full traffic conditions, and the CPICH channel is exactly 10% of the total power. The output of the signal generator was amplified by a self-designed power amplifier (AMP). The transmitted power of the transmit antenna input port was set to 1 W

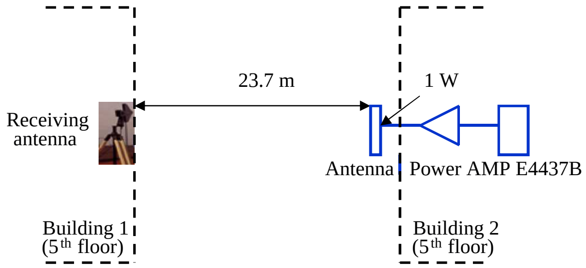

Figure 4. Measurement setup for estimating maximum EIRP at the test base station.

by adjustment of the signal generator output power. The receiving antenna was HE300A from R&S with an antenna gain was 4.14 dBi.

To remove the ground effect, the receive antenna was also installed on a 2 m high tripod at the outer boundary of building. The receiving equipment was an MS2712E spectrum analyzer from Anritsu having a WCDMA measurement option. The spectrum analyzer can measure WCDMA CPICH channel power. It also has an automatic PN code search function and can easily identify a BS. The results are given by Table 1. Because of the LOS environment and stable pilot channel characteristics, the difference between the maximum and minimum values is just 1.3 dB. The reported value of the maximum transmitted power, $P_{T,\max}$, is within these boundaries.

3.2. Maximum EIRP Estimation of Commercial BS

After verifying the proposed EIRP estimation method at the test BS, we applied our method to estimating the EIRP of a commercial WCDMA BS, which is located at Kookmin University, Seoul, Korea.

Table 1. Estimated EIRP values of test base station.

	Minimum	Maximum
Estimated Values	44.9 dBm	46.2 dBm
Real Value	5 dBm (30 dBm + 15 dBi)	

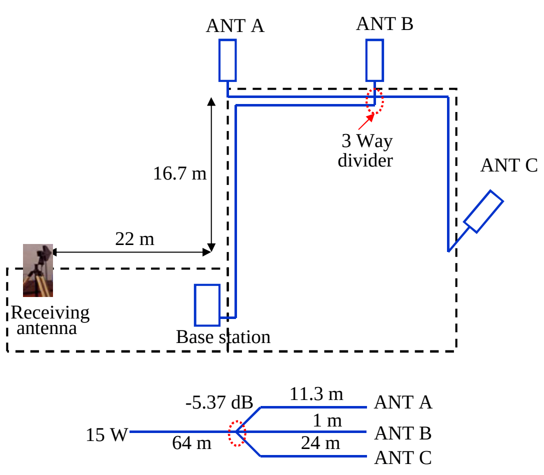

Figure 5. Configuration of commercial base station for estimating maximum EIRP (Kookmin University, Seoul, Korea).

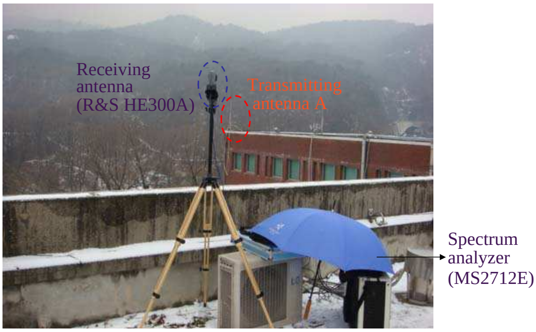

Figure 6. Photograph of received pilot channel power measurement.

The BS site, which meets LOS conditions, is located on the rooftop of the Engineering Building of Kookmin University.

Figure 5 shows a configuration of the commercial BS for estimating maximum BS. The BS has three sectored antennas, A, B, and C. Due to the reverse L-shaped building, the only antenna A satisfies LOS conditions; therefore, we measured the maximum transmitted power of antenna A. The antenna is a high-gain antenna with 14.5 dBi gain, 65° half-power beamwidth in the horizontal direction, 7° half-power beamwidth in the vertical direction, and −2° tilt angle. Polarization of the antenna is +45° linear for the transmitter and −45° linear for the receiver to reduce transmit leakage power to receiver. Six frequency assignment (FA) channels are operated. Each CPICH channel value per FA is 2 W (33 dBm), and the maximum output power is 15 W (41.75 dBm) per FA. Because the total power of the BS is 90 W, the BS inspection test is compulsory. All information about the BS is confirmed by SK telecom, the leading telecom operator in Korea.

As shown in Figure 6 the receive antenna and spectrum analyzer are the same as those in the test BS environment. The height of the receive antenna is a 2 m. But the receive antenna has vertical polarization, whereas the transmit antenna a 45° tilted linear polarization. If there are multiple reflections, the polarization may be changed as a result of reflection. As the height of the receive antenna is large enough to ignore reflected waves and there is only one direct path between the transmit and receive antennas, polarization mismatch loss could be upto 3 dB. The measurement software was programmed to record continuous data for 5 minutes.

Figure 7 shows the CPICH channel variation. Because of the LOS environment and stable pilot channel characteristics, the difference between the maximum and minimum values is just 0.66 dB for 5

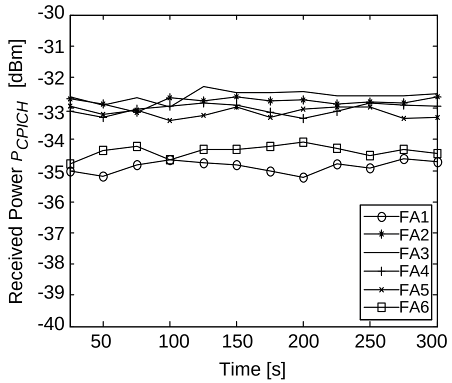

Figure 7. Pilot channel power variations with respect to time.

Table 2. Estimated EIRP values of commercial base station.

		FA2	FA3	FA4	FA5
Estimated	Min (dBm)	46.12	46.34	45.94	45.88
value	Max (dBm)	46.68	46.96	46.44	46.34
Reported Value ($P_{T,\max}-$ cable loss $+G_T$)		$45.39\,\text{dBm} = 41.75\,\text{dBm} - (4.89 + 5.37 + 0.6)\,\text{dB} + 14.5\,\text{dBi}$			

minutes. FA1 and FA6 in Figure 6 were recently added by the telecom operator and are set to 2 dB less than existing FAs. Therefore, 4 FAs (FA2–FA5) were used to calculate the maximum output power of the base station.

As shown in Table 2, using the information from the telecom operator, the EIRP could be calculated to 45.39 dBm per FA. The cable loss of 6.5 dB per 100 m (HFC-FR22D from LS Industrial Systems Co.) was considered. The insertion loss of 0.15 dB was assumed to occur at every cable interconnection. The polarization mismatch loss of 3 dB was assumed. Now, the maximum EIRP value was estimated from the measured CPICH power and the Friis equation. The minimum and maximum power levels were 45.88 dBm and 46.96 dBm, respectively, and the estimated average value of 4 FA was 46.35 dBm. The difference between the reported EIRP value and the estimated average value was just 1 dB.

4. MAXIMUM EMF ESTIMATION AND CALCULATION

In this section, we describe the maximum EMF estimation procedure based on over-the-air measurements of a WCDMA pilot channel. First, we discuss the results from the test BS and then the results of the commercial BS. To verify the proposed method, the estimated maximum EMF values of the test BS are compared with the electromagnetic theoretical results and the traditional EMF measurement values under full-traffic load conditions. In the case of a commercial BS, only calculation results are compared with our estimation results because it is impossible to measure EMF values under a full-traffic load condition.

4.1. Maximum EMF Estimation of the Test BS

Because mobile communication BSs are generally installed on rooftops, we built a test BS at Kookmin University as shown in Figure 8. The WCDMA test mode 1 signal was made by Agilent's E4437 ESG signal

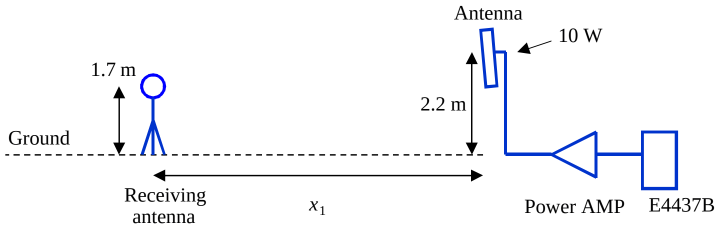

Figure 8. EMF measurement setup at the test base station.

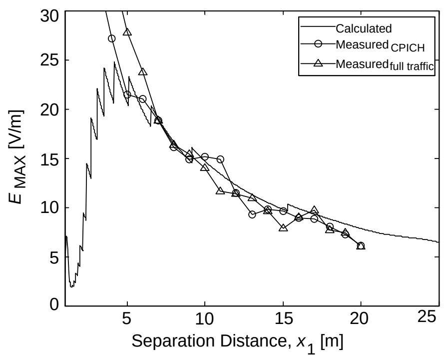

Figure 9. EMF results of test base station.

generator at the center frequency of 2122.8 MHz. Test mode 1 signal is a WCDMA signal under full traffic conditions, and the CPICH channel is exactly 10% of the total power. The signal generator output was amplified by a self-designed 10 W power AMP. Three-axis EMF isotropic probes certified by the Korea Communications Agency (KCA) were installed on a 1.7 m height. The receiving equipment was a MS2712E spectrum analyzer from Anritsu with a WCDMA measurement option.

Figure 9 shows the measured EMF results obtained at the test BS. In the figure, the horizontal axis is the separation distance between the BS antenna and the receiving antenna. The solid line is the theoretical value, the '∘' mark is the estimated EMF from the measured pilot channel power, and the '△' mark is the traditional EMF measurement value under a full-traffic load condition. The measured EMF results using a pilot channel show good agreement with the traditional measurement results and theoretical ones. Therefore, it can be concluded that our maximum EMF estimation methods can be applied to estimate the maximum EMF strength.

4.2. Maximum EMF Estimation of a Commercial BS

After verifying the proposed EMF estimation method, we applied our method to estimating the EMF strength of a commercial WCDMA BS. Unfortunately, because all of the BS antennas in Kookmin University faced towards the outside of the building, we had to select another BS randomly due to KCA. The selected BS is located in Dangsu-dong, Korea, as shown in Figure 10. Because the BS antenna is installed on the narrow rooftop of a building, the EMF measurements have

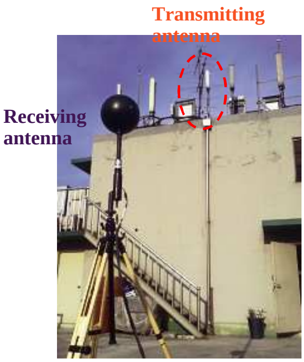

Figure 10. EMF measurement setup at the commercial base station (Dangsu-dong, Korea).

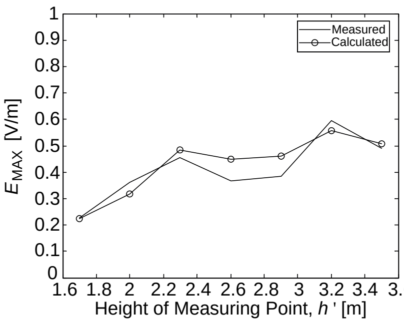

Figure 11. EMF results obtained at a commercial base station (Donsu-dong, Korea).

been done only as a function of the height of the receiving antenna. The measurement results are shown in Figure 11. The x-axis is the probe height. In the case of the commercial BS, only calculation results can be compared with our estimation results because it is impossible to measure EMF values under a full-traffic load condition. In calculating EMF values, we considered only three waves, namely, direct wave, ground-reflected wave, and wall-reflected wave. Therefore, there are some differences between the two sets of data because of various reflected waves around the receiving probes. However, the general tendency of the results is almost consistent. Therefore, we think our estimation method and calculation method are suitable for EMF measurement in commercial BS inspection testing.

5. CONCLUSION

In this paper, we presented a method for estimating the maximum EIRP and EMF strength of a WCDMA BS based on over-the-air measurement values of CPICH power in a code domain. A WCDMA pilot channel always exists in all BSs, and its power is stable. If we can measure the power of the pilot channel, then the maximum EIRP and EMF of the BS can be estimated. Using this principle, we built a test BS for EIRP and EMF in Kookmin University, Seoul, Korea. Also, we measured the maximum EIRP and EMF of a commercial BS. All of the measured EIRP and EMF results show good agreement with the theoretical values. Therefore, it can be concluded that our methods whould be an effective tool for measuring EIRP and EMF in commercial base station inspection testing.

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