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Accurate Method to Estimate EM Radiation from a GSM Base Station

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Abstract—Global System for Mobile Communications (GSM) is currently one of the most widely and most demanding telecommunication applications in the world. Researchers have reported that radiation from base stations may be dangerous to public health and that some human diseases are related to RF field exposure. Considering that in the past almost all the EM radiation assessments were focused on the Maximum transmission power of base station, and no statistical analyses have been performed on transmitted power's variation with the traffic. An accurate method for predicting electromagnetic (EM) radiation from GSM base stations is proposed in this paper. It is based on the Poisson distribution of GSM-transmitted signals to calculate GSM transmitted power at different time periods. The theoretical calculation data fits well with the measurement data. Measurement results confirm that electromagnetic radiation varies with changing traffic and power density at different times with varying traffic strength is more accurate than implementing only maximum power (20 W) calculation. In some occasion, maximal power density is about 6 μW/cm^2 for 15 m in rush hours, but minimum power density is only 0.03 μW/cm^2 for 15 m in idle hours.

1. INTRODUCTION

Global System for Mobile (GSM) is one of the fastest growing and the most demanding telecommunication applications in the world today. Many studies show that the radiation from base stations is dangerous to health [1–4] and in fact it agrees that under some circumstances electromagnetic radiation may have a detrimentally affect on human health. Many researches and studies [5–8] about the Effect of EM radiation towards to the human organism, especially to the brain, indicate the importance of the issue.

The power density depends on three sectors: the transmitted power of base station, the distance of the people between the base station, and the obstacles of the surrounded. Most of EM radiation assessments were based on the Maximum transmission power of base station, the distance to the base station and surround barriers, as shown by Martínez-Búrdalo et al. [9] and Hamid et al. [10]. In [11–13], Mahouz et al., Joseph et al., and Miclaus & Bechetutilized utilized the data of a week's electromagnetic exposure and constructed a three-dimensional Gaussian mixture model to predict base station electromagnetic exposure. Moreover, In [14, 15] the accurate calculation have been developed and analyzed time variability of electric field level in GSM downlink channels.

A GSM base station does not always transmit at maximum power because of the TDMA techniques adopted by the GSM. The power transmitted by a GSM base station is largely variable. Hence, the commonly used worst-case assessment approach overestimates exposure in actual conditions and overlooks the relation between the power transmitted by the base station and the traffic the base station is connected to. However, no statistical analyses have been performed on transmitted power variation so far, and no calculation for base station transmitted power and electromagnetic radiation according to traffic has been implemented.

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The aim of this paper is to analyze the daily variation in radiation from a GSM base station. An approach that regards traffic in the actual environment as having a Poisson distribution is presented. Given that traffic has a positive correlation with the power transmitted by the base station, transmitted power can be calculated through traffic obtained at each hour. The power spectral density of time division multiple access (TDMA) was first calculated. The traffic Poisson parameters at different hours were then determined based on the traffic statistics. These parameters were considered in the power calculation. The formula of Friis transmission was applied to obtain the power density (radiation value) around the base station. Lastly, this power density was compared with the maximum calculated power density and the actual measured power density at different times to demonstrate that the method is feasible and to sum up the daily variation in electromagnetic radiation in the GSM base station.

This paper is organized as follows. The proposed method to calculate the transmitted power spectral density of the GSM base station is presented in Section 2. The parameters of distribution are fitted in Section 3 based on the analysis of actual traffic; these parameters are considered in the power calculation. Section 4 presents the measurement and calculation results. The different calculations and measurements of the power density values are also compared in this section. Section 5 provides the daily variation in electromagnetic radiation in the GSM base station as well as the method and results.

2. CALCULATION OF THE POWER SPECTRAL DENSITY OF THE GSM BASE STATION

As shown in Figure 1, the base station's traffic indicates that the traffic channel resource is occupied by the base station. The relationship between the traffic and the channel resources often use the Erlang B formula when call loss is constant [16]. Therefore, the traffic with the radiation power has a positive correlation from the perspective of average power.

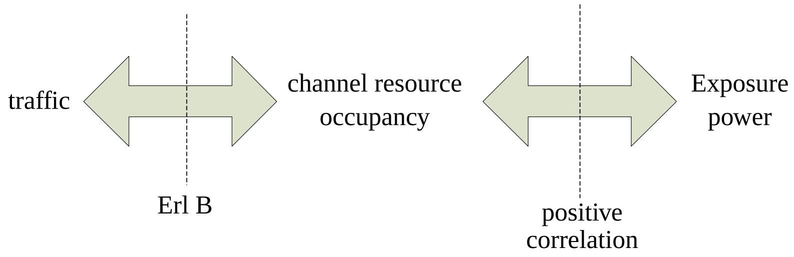

Figure 1. Connection between traffic and exposure power.

The method utilized by the GSM is a combination of time- and frequency-division multiple access (TDMA and FDMA). FDMA involves the division of the (maximum) 25 MHz bandwidth by frequency into 124 carrier frequencies spaced 200 kHz apart [17]. In this study, one or more carrier frequencies were assigned to each base station. Each of these carrier frequencies was then divided in time using a TDMA scheme. The fundamental unit of time in this TDMA scheme is called a burst period, which lasts for 15/26 ms (or approximately 0.577 ms). Eight burst periods were grouped into a TDMA frame (120/26 ms or approximately 4.615 ms), which forms the basic unit of logical channels [18]. One physical channel is one burst period per TDMA frame. The burst in the actual transmission situation has a Poisson distribution [19, 20]. The GSM TDMA frame structure is shown in Figure 2.

The number of cells in a particular GSM base station network as well as the carrier frequency for each cell was determined. In the single-carrier frequency shown in Figure 3, each user call has a probability of P, and no call has a probability of $(1-P)$. The emergence of each pulse is statistically independent.

Most of the digital modulated baseband signals can be written in the form

$$s(t)=\sum_{n} a_n g(t-nT_s). \tag{1}$$

where a_n is the random data bites expressed as Eq. (2), $g(t)$ the pulse shape in [0, T_s], and T_s the bit

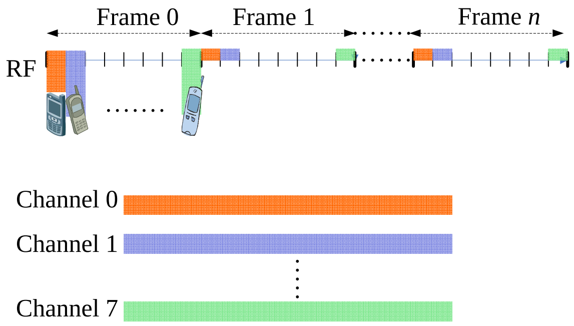

Figure 2. TDMA frame structure.

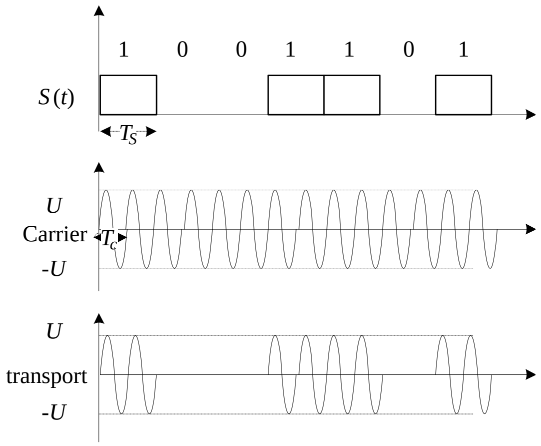

Figure 3. Transmitting signal waveform.

duration. $g(t) = 1$, $0 \le t \le T_s$ and

$$a_n = \begin{cases} 0 & \text{the probability of occurrence is } P, \\ 1 & \text{the probability of occurrence is } 1 - P. \end{cases} \tag{2}$$

TDMA transmitted signal $e(t)$ is the product of binary base band signal $s(t)$ multiplied by modulation $A\cos(\omega_c t)$. ω_c is the angle frequency of the carrier. In China the GSM900 down-link frequency is 935 to 960 MHz. The carrier frequency changes with the frequency point. So the carrier frequency f_c of GSM900 is from 935 to 958.8 MHz and divided into 125 channels of 200 kHz. A is the amplitude of the carrier. In the transmission of communication, value of A is commonly 8.94 V.

$$e(t) = As(t)\cos(\omega_c t). \tag{3}$$

Assuming that s' power spectral density is $P_s(f)$, the following can be obtained by applying Fourier transformation to calculate $e(t)$ power spectral density.

$$P_e(f) = \frac{A^2}{4}[P_s(f + f_c) + P_s(f - f_c)]. \tag{4}$$

Pulse signal flow density Δt is a constant when the pulse obeys a Poisson distribution. According to the characteristics of the Poisson distribution, the probability of n pulses in the Δt time interval is

$$P_n(n, \Delta t) = \frac{(\lambda \Delta t)^n}{n!} e^{(-\lambda \Delta t)}, \quad n = 0, 1, 2, 3 \ldots. \tag{5}$$

When $|\tau < T_s|$, t having pulse s' probability is λT_s; $s(t)$ not having pulse s' probability is $1 - \lambda T_s$; the contribution to the correlation function is 0. When $s(t)$ and $s(t+\tau)$ are not on the same pulse, the contribution to the correlation function is also 0. The probability of $s(t)$ and $s(t+\tau)$ being on the same pulse is $[1 - \frac{|\tau|}{T_s}]$. Therefore, the correlation function is obtained as follows:

$$\begin{aligned} E\{s(t)s(t+\tau)\} &= \sum_{i=1}^{2}\sum_{j=1}^{2} s_i s_j P[s_i, s_j; t_i, t_j] = \sum_{i=1}^{2}\sum_{j=1}^{2} s_i s_j P[s_i, s_j; \tau] \\ &= 1 \times 1 \times P\{s(t) = 1, s(t+\tau) = 1\} \\ &= P\{s(t) = 1\} P\{s(t+\tau) = 1 \mid s(t) = 1\} = \left[1 - \frac{|\tau|}{T_s}\right] \cdot \lambda T_s \end{aligned} \tag{6}$$

When $|\tau| > T_s$, $s(t)$ and $s(t+\tau)$ are not on the same pulse, and the contribution to the correlation function is 0.

Correlation function is then derived.

$$R_s(\tau) = E\{s(t)s(t+\tau)\} = \left[1 - \frac{|\tau|}{T_s}\right] \cdot \lambda T_s = \left[1 - \frac{\tau}{T_s}\right] \cdot \lambda T_s. \tag{7}$$

The Wiener-Khintchine formula [21] was applied to obtain the power spectral density.

$$P_s(f) = \lambda \frac{\sin^2(\pi f T_s)}{(\pi f)^2}. \tag{8}$$

By incorporating the above into Eq. (4), we obtain

$$\begin{aligned} P_p(f) &= \frac{A^2}{4}(P_s(f+f_c) + P_s(f-f_c)) \\ &= \frac{A^2\lambda}{4}\left[\frac{\sin^2(\pi(f+f_c)T_s)}{\pi^2(f+f_c)^2} + \frac{\sin^2(\pi(f-f_c)T_s)}{\pi^2(f-f_c)^2}\right] \end{aligned} \tag{9}$$

3. CALCULATION OF THE TRANSMITTED POWER OF THE GSM900 BASE STATION

In the past decades, the traffic modeling of GSM networks has relied on Erlang B theory called the blocking model, which was originally developed for fixed networks. The application of Erlang B theory assumes that (1) there are many users, (2) the arrival process is a Poisson process with inter-arrival times exponentially distributed, and (3) there is full availability and lost calls are cleared. However, this is not always the case for actual networks where mobiles within the coverage area are only able to seize circuits on the cell site that serve such area, and blocked calls may be reassembled in neighboring cells. Moreover, full availability may not be possible if a priority access scheme is implemented. Traffic in an actual network exhibits a Poisson distribution.

The base station sub-system (BSS) was analyzed, and measurements were collected and recorded in different counters to calculate the transmitted power of the base station. The measurements were performed according to the schedule established by China Unicom's Operations and Maintenance Center over the hours of a day for a period of 16 days. The statistics of the measured data at each time segment were also analyzed. The basic parameters of the Poisson distribution function were fitted with these data. Lastly, the transmitted power of the base station was accurately determined by incorporating these integral parameters into Eq. (8).

The description of the activity area (business center) was highlighted. Figure 4 shows the traffic intensity concluded from performance data provided by BSS counters in the business center. Traffic intensity comprises two cells. The traffic for 24 h on weekdays (Mondays to Fridays) and weekends (Saturdays to Sundays) was exported.

Figure 4 shows that the traffic intensity during weekdays is almost equal to that on the weekend except for the period ten o'clock to seven o'clock. During the given period, the traffic intensity on weekdays exceeds that on the weekend. Two peaks were observed on weekdays; the first busy hour is around eleven o'clock, and the second is around four o'clock afternoon. This finding reflects the "activity

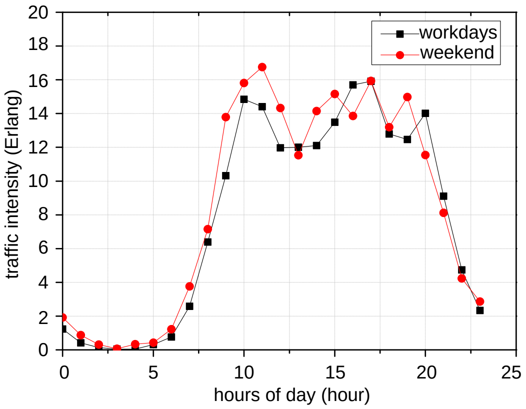

Figure 4. Traffic intensity versus the hours of the day in the business center.

hours” of users when they leave their workplace. For the weekend, the first peak hour is around ten o’clock, and the second is between four and eight o’clock afternoon. Prior to drawing the curves of the business center, the two cells included in this area were checked to verify if they exhibit the same behavior (peak hours, traffic intensity, and variations). Calculating the traffic in one cell is convenient. Analysis of the graph’s peak hours and the law of time evolution of the traffic one day contribute to the improvement of resource use and the proposition of several traffic schemes.

The origin was applied to verify the hypothesis that the base station traffic follows a particular Poisson distribution as well as to characterize the arrival process distributions.

Figure 5 shows the plot of the empirical distribution function with a cumulative Poisson distribution. The observations at 2:00 AM, 6:00 AM, 11:00 AM, and 9:00 PM obey a Poisson distribution with $\lambda = 7.92$, $\lambda = 46.699$, $\lambda = 1123.52$, and $\lambda = 654.48$, respectively.

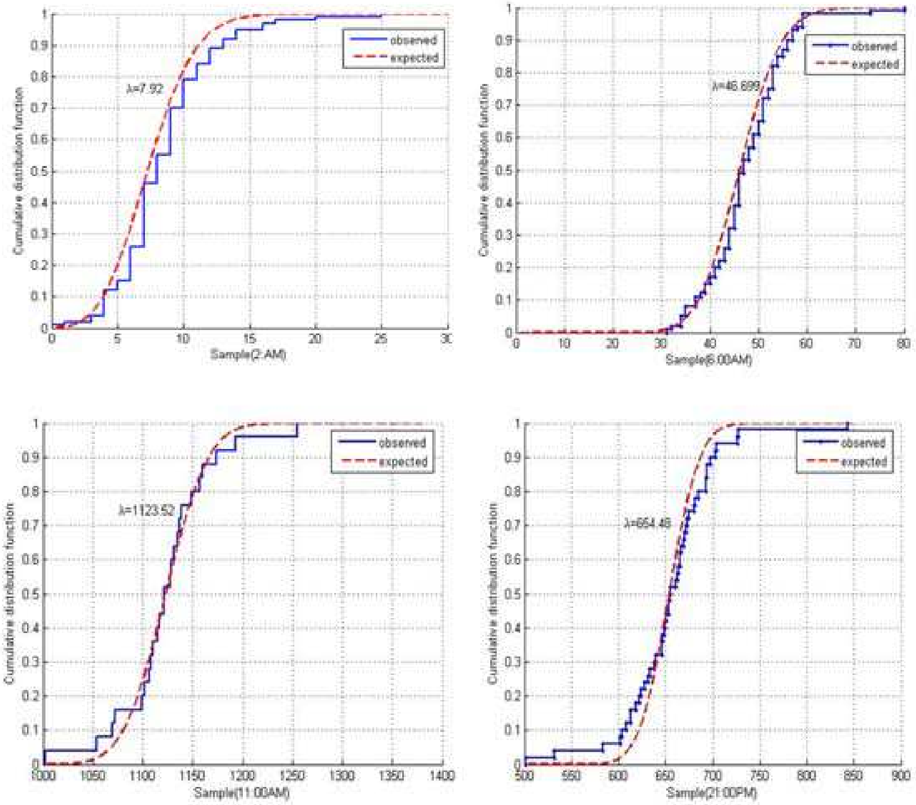

Figure 5. Poisson distribution goodness of fit test at four individual hours.

The same method was utilized to fit the Poisson distribution curve of each hour in a day. All data were a statistical average of the superposition. Figure 5 shows only four representative time segments. The different parameters of each hour’s Poisson distribution were obtained by fitting. These parameters were incorporated into Eq. (9) to obtain power spectral density at different hours in the base station. For example, the fitted values were substituted into Eq. (9) and integrated to calculate the transmitted power in the base station at 2:00 AM. In Eq. (10), we use frequency point 1 to do calculation. Of course, we can also use other frequency point to do calculation. But each frequency point calculated results are the same.

$$\begin{aligned} P_p &= \int_{935100000}^{935300000} P_p(f)df = \int_{935100000}^{935300000} \frac{A^2}{4}\left(P_s(f+f_c)+P_s(f+f_c)\right) \\ &= \int_{935100000}^{935300000} \frac{A^2\lambda}{4}\left[\frac{\sin^2(\pi(f+f_c)T_s)}{\pi^2(f+f_c)^2}+\frac{\sin^2(\pi(f-f_c)T_s)}{\pi^2(f-f_c)^2}\right] = 2.591\,\mathrm{W}. \end{aligned} \tag{10}$$

Table 1. Poisson distribution parameters and transmitted power at different hours in a day.

Mesure. Time (hour)	Parameters (λ)	Power (W)	Mesure. Time (hour)	Parameters (λ)	Power (W)
0	7.93	2.091	12	912.23	12.514
1	6.31	2.073	13	653.19	10.028
2	7.92	2.591	14	881.52	12.161
3	7.12	2.611	15	611.27	9.545
4	38.32	3.172	16	782.93	11.523
5	46.69	3.318	17	714.37	10.833
6	57.31	3.005	18	802.51	11.749
7	162.22	5.347	19	641.73	9.896
8	151.34	5.156	20	691.32	10.468
9	378.28	9.139	21	554.48	8.891
10	713.58	10.221	22	148.10	4.207
11	898.11	12.851	23	76.21	3.378

Following exactly the same method as before, we fitting out the 24 hours Poisson parameters (λ) and calculate the transmitted power different time. Table 1 provides a summary of the base station transmitted power values at different times in a day. The difference between the maximum and minimum transmission power reaches 10 W. Therefore, the transmission power of different time values is very important.

4. MEASUREMENT AND COMPARISON OF THE POWER DENSITY VALUES

The precise measurement of the dynamic variation in power density in a communication base station is difficult. Under normal circumstances, the electromagnetic radiation field is divided into two parts: the far field (radiation) and the near field zone (induction field). This study considers the far field zone.

The Friss' formula of the HJ/T10.2-1996 standard was incorporated in the calculation of power density. The Friis' transmission formula for the radiation system is expressed as

$$S = \frac{PG}{4\pi r^2} \times 100 \tag{11}$$

where S is power density, $\mu\text{W/cm}^2$; r is the distance between the base station and measuring point, m; P is the average transmission power of the base station, W; G is the gain. The typical GSM base station antenna gain is 12 dB.

The power density at 6:00 AM and 11:00 AM was calculated. Figure 6 provides a comparison of the Poisson calculated value with the maximum calculated power density. Different hours have different power densities; a large gap exists among the different power densities. The gap between the maximum power and the 11:00 AM (one day's maximum traffic hour) power density is about 28%. The statistics that represent 6:00 AM show a large gap when compared with the calculated maximum power. Moreover, theoretical predictions show that electromagnetic radiation from the GSM base station generally decreases with distance. That is, the greater the distance from the base station, the lower the radiation.

This measurement should be conducted in an open space and with clear weather to ensure a small measurement error. A PMM8053A and an EP-300 field probe manufactured by an Italian company were utilized for 6 min in each measurement to measure the RMS average; the probes were then used continuously for 24 h testing. Distances of 15 m and 30 m from the base station were measured and calculated. These two distances were selected because they provide a safe distance within the given

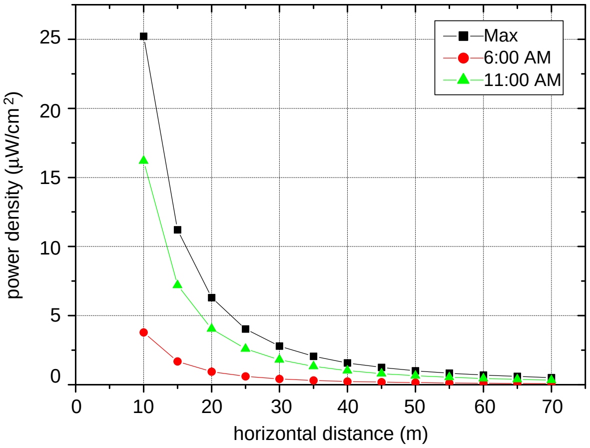

Figure 6. Comparison power density of the base station in the 6:00 AM and 11:30 AM.

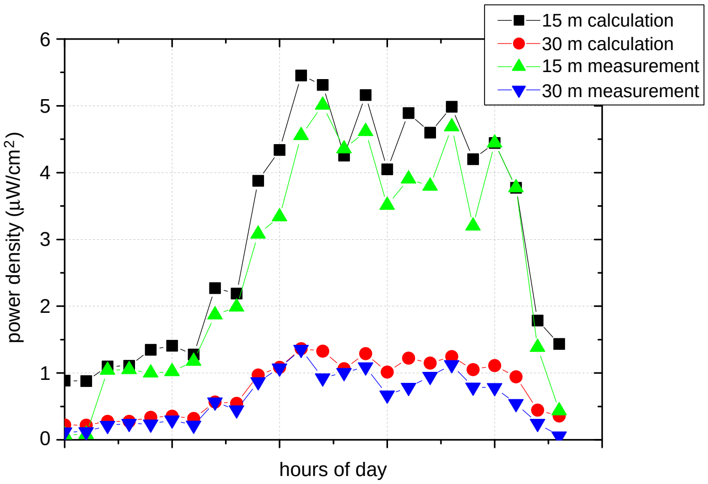

Figure 7. Comparison of the 15 m and 30 m calculation and measurement.

range. The results are shown in Figure 7. The daily power density and measurement curves calculated with the Poisson method are basically consistent in the 15 m and 30 m distance. Those calculated with other distance values are also in good agreement with the measurement.

5. CONCLUSION

An accurate method for predicting electromagnetic radiation is proposed in this study. Given that traffic in GSM base stations exhibits a Poisson distribution, the traced TDMA transmitted signals are sinusoidal pulses. The calculation of electromagnetic radiation in this study considered transmission power at different time periods. Power density at different time periods can be accurately determined by applying the Poisson distribution calculated with different parameters than the calculated maximum power. The difference in maximal transmitted power reaches 10 W at different times in a day.

Maximal values are important for regular people, whereas special work personnel, pregnant women, and adults are more concerned with actual-time exposure values. Therefore, hourly electromagnetic radiation must be examined thoroughly. The use of the proposed method affects the design and engineering of the network, such as tasks involving antenna sectorization, BTS site location, and capacity planning. Thus, base station personnel can select a convenient time to inspect and maintain the base station.

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