An Empirical Modeling of Electromagnetic Pollution on a University Campus

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Abstract **─** In this study, electric field strength (E) levels were measured on Ondokuz Mayıs University's Kurupelit Campus and Faculty of Medicine Hospital in Samsun, Turkey between years 2013-2015. 840 short term and two long term measurements were performed using PMM–8053 and SRM–3006 at 60 different locations of which 30 were on both the campus and hospital. The results show that the measured E levels are far below the limits that are determined by ICNIRP. Based on the measurement analysis, a novel empirical model that allows characterizing the total E of medium using three main electromagnetic (EM) sources with 99.7% accuracy was proposed. Then other new models to estimate main distribution of total E were suggested. With the use of these models, E values of main pollution sources can be estimated with 95.2% accuracy and easily lead to prediction of future EM pollution levels.

Index Terms **─** Electric field strength, electromagnetic (EM) measurement, EM pollution, statistical analysis.

I. INTRODUCTION

Electromagnetic waves are radiated from many sources, both natural and man-made, that produce electromagnetic pollution. Since the increase in the use of electromagnetic radiation (EMR) for communication such as radio, TV, wireless internet and cellular communication, the exposure levels of EMR have also increased. Growing demand for mobile communication and multimedia services pushes operators to expand the wireless network capabilities with additional base station installations. Because each base station is an EMR source, one cannot eliminate the exposure of EMR, whether one is a user of the system or not. Therefore, measuring and evaluating the environmental level of EMR, while also determining the detrimental effects of EMR on human health, become more crucial. Therefore, this topic is subject to ongoing research [1-6].

Although the wireless systems and base stations operate at frequencies below 300 GHz, which is within the non-ionizing spectrum, there has been much debate about their potential health effects. There are international standards and limits on the effects of EMR on human health. Each country has determined its own limits. The limits are recommended, with the assumption of 24 hour exposure, by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which is recognized by the World Health Organization (WHO) [7]. According to guidelines [7] by the ICINRP, the limit value of E at 900 MHz, 1800 MHz and 2100 MHz are 41(V/m), 57(V/m) and 61(V/m) respectively.

Although many factors can cause change in EMR, the number of users, line of sight (LOS), distance from a base station, and geographical structure of coverage area mainly affect EMR levels. Thus, measuring and evaluating the levels of EMR that cause pollution in crowded places where cellular systems are densely used has become of utmost importance. Therefore, in this study, EMR measurements were conducted at 60 different locations in Samsun Ondokuz Mayıs University's Kurupelit Campus and Faculty of Medicine Hospital over a two year period during various times of day. Statistical analysis of the measurement results were performed, then the distribution of each pollution source into the total E was determined.

II. MEASUREMENT OF EM POLLUTION

This study aims to observe the short and long term radiation levels in 100 kHz - 3 GHz frequency band EM sources on OMU's Kurupelit Campus and Faculty of Medicine Hospital, which is one of Turkey's largest university hospitals. The Kurupelit campus, which mainly consists of academic and administrative units, is established on an 8,800 acre field (Fig. 1 (a)). There are approximately 25,000 people on this campus per day, including students, academic and administrative personnel. The Faculty of Medicine Hospital consists of two main buildings, one for adult care and one for pediatric care, and have 11 and 4 floors respectively (Fig. 1 (b)). The hospital is visited by over 700,000 patients each year, equating to approximately 5,000 people (including patients and staff) per day.

Figure 1 (a) shows an aerial photo of the Kurupelit Campus. In the figure, the dashed line indicates Campus boundaries and each measurement location (L) is marked with a circle, while base stations (BS) are marked with

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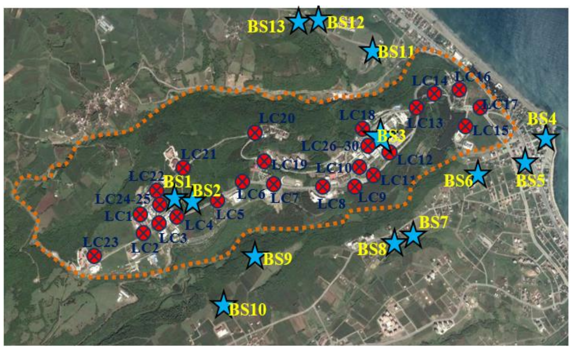
star. There are 13 base stations, of which three rest inside and ten rest outside of campus. The output power of the base stations vary from 10W to 40W. There are also over 200 indoor base stations whose powers vary between 0.13W and 1.34W in the hospital. Currently, there are three mobile communication operators in Turkey and all base stations on and/or outside of campus belong to the operators. Two of them use 900 MHz, and the other one uses 1800 MHz for 2G (GSM). Each operator uses 2100 MHz frequency band for 3G (UMTS).

In this study, EMR measurements were conducted between the years 2013-2015 at 60 different locations, of which 30 were on both the campus and hospital. These locations were chosen based on their distance to base stations on campus while different two locations on each floor of the Hospital. Total EMR in the band between 100 kHz – 3 GHz is measured with PMM–8053 with EP-330 isotropic electric field probe [8] while band selective are done with Narda SRM–3006 with 3501/03 isotropic electric field probe [9]. The duration of each measurement was six minutes. For each measurement, the maximum electric field strength (E_{max}) and average electric field strength (E_{avg}) were recorded.



(a)

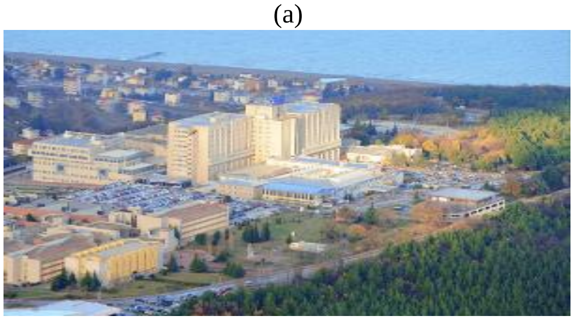


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Fig. 1. (a) Kurupelit Campus, measurement locations and base stations, and (b) Faculty of Medicine Hospital.

III. MEASUREMENT RESULTS

The recorded E values through 840 short term measurements that were performed eight different times (on different days and hours) between the years 2013-2015 are shown in Fig. 2. In the figure, the measurement time represents the specific measurements dates (16.12.2013, 19.02.2014, 17.04.2014, 17.06.2014, 19.09.2014, 19.11.2014, 17.02.2015, 15.04.2015 for Campus respectively, while 25.12.2013, 21.04.2014, 26.08.2014, 24.12.2014 and 22.04.2015 for Hospital) mentioned. As seen in Fig. 2, E values may vary depending on measurement location and time. The following can be seen from the campus measurements: in the case of LOS, being close to the base station, e.g., location 24 (LC24, refers to 24th location on campus), gives rise to higher E levels of 3.60 V/m in the year 2015; the highest E_{avg} of 2.56 V/m was recorded at LC24 as expected; additionally, E_{max} and E_{avg} values were measured at 2.68 V/m and 1.95 V/m respectively in the hospital measurements at location 9 (LH9, refers to 9th location in the hospital).

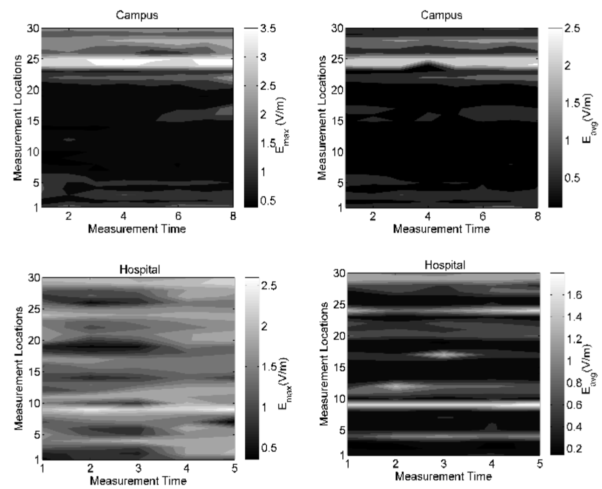

Fig. 2. E_{max}, E_{avg} values versus location for campus and hospital.

Statistical analysis of all the recorded Es were performed, and the maximum, mean values and standard deviations are given in Table 1.

Table 1: Statistical results of campus and hospital measurements

Location	Max.	Mean	Std.
Campus, E_{max}	3.60	1.284	0.828
Campus, E_{avg}	2.56	0.633	0.554
Hospital, E_{max}	2.68	1.509	0.447
Hospital, E_{avg}	1.95	0.574	0.417

Band selective measurements were done using SRM–3006 at all locations on campus and in the hospital. The maximum E strength was also obtained at LC24 on campus, while at LH9 in the hospital. The details of SRM–3006 measurements, which contain the E sources (service name, frequency ranges etc.) caused pollution at LC24 and LH9 as illustrated in Table 2. In the Table, each E source has a specific index number and the 18th index represents E levels within undefined frequency bands. Total E (E_T) strength of medium is calculated as follows:

$$E_T = \sqrt{\sum_{i=1}^{18} (E_i)^2}\ , \quad (1)$$

where E_i is the electric field strength for ith band.

Table 2: Frequency selective E values for LC24 and LH9

Index	Service Name	Lower Frequency	Upper Frequency	Average E (mV/m)	
				LC24	LH9
1	Low Band	30 MHz	87.4 MHz	61.63	56.24
2	FM Band	87.5 MHz	108 MHz	40.34	80.99
3	Air Band	108.1 MHz	136 MHz	18.66	17.29
4	Land Band-I	136.1 MHz	173 MHz	18.61	17.35
5	TV VHF Band	173.1 MHz	230 MHz	20.01	17.94
6	Land Band-II	230.1 MHz	400 MHz	24.22	22.60
7	Land Band-III	400.1 MHz	470 MHz	13.40	12.64
8	TV UHF Band	470.1 MHz	861 MHz	54.46	37.01
9	ETC1	861.1 MHz	889.9 MHz	6.298	6.228
10	GSM 900	890 MHz	960 MHz	984.2	850.40
11	ETC2	960.1 MHz	1.7 GHz	30.9	30.15
12	GSM 1800	1.701 GHz	1.88 GHz	682.1	1007
13	DECT	1.881 GHz	1.899 GHz	5.746	5.345
14	UMTS 2100	1.9 GHz	2.17 GHz	1926	1259
15	ETC4	2.171 GHz	2.399 GHz	31.27	30.53
16	WLAN	2.400 GHz	2.483 GHz	21.83	36.83
17	ETC5	2.484 GHz	3.000 GHz	57.24	55.58
18	Others			4.882	4.706
19	Total			2.272 V/m	1.823 V/m

All band selective measurements on campus and in the hospital are shown in Fig. 3. In the figure, the 19th index presents E_T values of the medium. As seen in the figure, the sources that have the most contribution to E_T are GSM900, GSM1800 and UMTS2100. For simplicity, all service names' E value will be referred to with an index number (e.g., E_{10} for GSM900) throughout the rest of the paper. The maximum E value was recorded at LC24 as 2.272V/m. Distance from the base station (BS1 in Fig. 1 (a)) to LC24 approximately 100m and there is LOS between the units. In addition, the max E value of 1.823V/m was obtained at LH9 in the hospital, where most of the contributions were given by E_{10}, E_{12} and E_{14}.

All SRM–3006 measurements were analyzed and the max, mean and standard deviations were calculated as 2.27, 0.678 and 0.565 on campus, and 1.83, 0.602 and 0.501 for the hospital. In order to evaluate the change in E for a long-term time period, measurements were carried out at the locations (LC24, LH9) where the maximum Es were obtained. Two long term measurements were started at 08.00 and stopped at 07.59 each day at a 4 sec. sampling period [5], and results were graphed in Fig. 4.

It is clearly seen from Fig. 4 (a), that the number of users affects E significantly. The max. E value was recorded as 4.20 V/m on campus during midday. After 16:00, when students started to leave campus, the E value decreased. It is also shown in the figure that at class break times, such as 10:00 and 11:00, the measured E levels increased. The E level dropped between 02:00 and 04:00, as the base stations does not fully operate. The min, mean and standard deviation of the measurement are 0.74 V/m, 1.324 V/m and 0.508. Long term E measurement results are given in Fig. 4 (b) for the hospital. There are no sudden fluctuations in E in the hospital as compared to Fig. 4 (a). Having constant visitors and patients because they are in service throughout the entire may be raised as a reason. The max., min, mean and standard deviation of the measurement are 2.38V/m, 1.03V/m, 1.378V/m and 0.229.

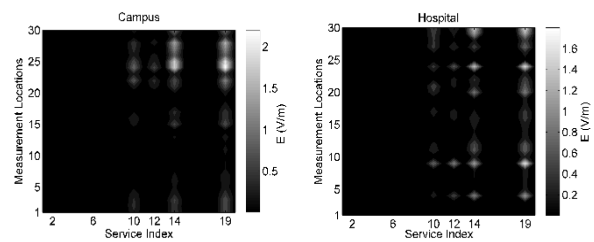

Fig. 3. Band selective E values for campus and hospital.

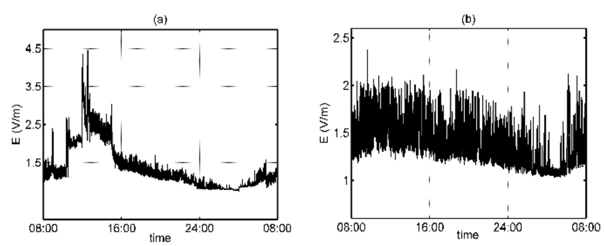

Fig. 4. Long term measurements for: (a) LC24 and (b) LH9.

IV. ANALYSIS

The measurement results for each pollution source were compared and their contributions to the combined E were analyzed. R^2 values, correlation coefficients between E_{19} and E_1-E_{18} and pie chart were used to determine the main E sources. As seen in Fig. 5 (a), E sources that have lower than 0.5 R^2 and correlation can be neglected. Furthermore, it is also seen in Fig. 5 (b) that basic E sources are E_{10}, E_{12} and E_{14} to a significant percentage (98%). On this basis, E_{10}, E_{12} and E_{14} can be determined as the main sources of pollution.

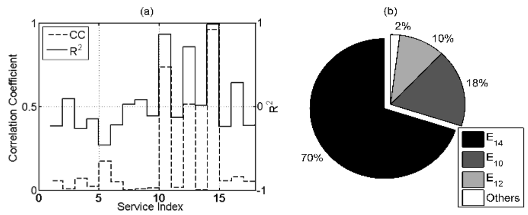

Fig. 5. (a) Correlation coefficient (CC) and R^2 values, and (b) the pie chart of E.

To model total E in medium with E_{10}, E_{12} and E_{14} multilinear regression [10] was applied and total EMR was defined ($\hat{E}_T$) as in Eq. 2:

$$\hat{E}_T = \sqrt{0.0157 + 0.9895E_{10}^2 + 1.0122E_{12}^2 + 1.0015E_{14}^2}\,. \quad (2)$$

The performance of the method was compared in terms of Normalized Root Mean Square Error (NRMSE), which is defined by the following:

$$\text{NRMSE} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_{T,i} - \hat{E}_{T,i})^2}}{\max(E_T) - \min(E_T)}\,, \quad (3)$$

where $E_{T,i}$ is actual E values, $\hat{E}_{T,i}$ is estimated E, *i* is measurement location, and N is the number of total measurement locations. The NRMSE is 0.0023 between E_T and $\hat{E}_T$.

Since determining the distribution of total E needs specific band selective EMR meter, which is not generally accessible, calculating the main pollution source from the total becomes more crucial. For this reason, linear regression [10] was applied to the same data and the estimated E_{10} ($\hat{E}_{10}$) was calculated easily with the use of Eq. 4. The NRMSE between E_{10} and $\hat{E}_{10}$ is 0.1187:

$$\hat{E}_{10} = \sqrt{0.0202 + 0.1508E_T^2}\,. \quad (4)$$

Similarly $\hat{E}_{12}$ and $\hat{E}_{14}$ can be estimated by using the following equations. The corresponding NRMSEs are 0.1238 and 0.0480:

$$\hat{E}_{12} = \sqrt{-0.0017 + 0.1006E_T^2}\,, \quad (5)$$

$$\hat{E}_{14} = \sqrt{-0.0339 + 0.7478E_T^2}\,. \quad (6)$$

For E_{14}, the reason for yielding the highest accuracy was having the highest correlation (0.95), while for E_{12} low correlation (0.52) led lower accuracy.

V. CONCLUSION

In this study, EMR levels in Samsun Ondokuz Mayıs University's Kurupelit Campus and Faculty of Medicine Hospital were measured between years 2013 and 2015, and the values were compared with limits determined by ICNIRP. The maximum measured E value was 4.20 V/m for all medium. Comparing this value with the limit shows that there is not significant electromagnetic pollution in Kurupelit Campus and the hospital. The results also show that measured E vary by time and an increase in number of users cause significant increase in E levels. Based on band selective measurements and statistical analysis main reason of EM pollution is determined as UMTS2100. A novel empirical model was proposed for characterizing the total E of medium with 99.7% accuracy. In order to predict the band selective E values from the total E; other new models were suggested. Using these models allow determining each main sources' E and they can be calculated without using any band selective EMR meter.

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