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Assessment of short/long term electric field strength measurements for a pilot district

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Abstract: The level of electromagnetic radiation (EMR) exposure increases day by day as natural consequences of technological developments. In recent years, the increasing use of cellular systems has made it necessary to measure and evaluate EMR originating from base stations. In this study, broadband and band selective electric field strength (E) measurements were taken at four different times in order to evaluate the change of short term E in Atakum district of Samsun, Turkey. The measurements were collected from 46 different locations using a SRM 3006 and a PMM 8053 EMR meter in a band from 100 kHz to 3 GHz, and the maximum E (E_{max}) and the average E (E_{avg}) were recorded. The highest values have been noticed in these measurements at 9.45 V/m and 17.53 V/m for E_{avg} and E_{max} respectively. Apart from these measurements, 24 hour long term E measurements were taken at a location where the highest value was observed and analyzed, to observe the change of Es during a day. At the end of the study, a tentative mathematical model that helps in computing the total E of the medium with 95% accuracy, was obtained.

Keywords: Electric field strength, electromagnetic (EM) radiation, EM measurement, base station, statistical analysis

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Introduction

With the rapidly evolving technology, the use of wireless communication systems increases day by day. Devices using wireless systems use electromagnetic waves for communication, and these systems conduce toward an increase in the use of electromagnetic radiation (EMR). Cellular systems occupy a large part of our daily lives in wireless systems and cellular systems users communicate with each other with the help of base stations. Users demanding communications from anywhere, increase of multimedia usage, and the ability of base stations to operate a limited number of users at the same time, force operators to install more base stations. Established base stations are actively broadcasting EMR for 24 hours a day so that people living in these areas are exposed to EMR radiation of the base stations even if they do not want to be. Each base station behaves like an EMR source, and this increase in base stations causes the level of EMR that is exposed to increase daily.

There are a number of limitations and standards that have resulted from some research by certain international organizations that are examining the effects of EMR on human health. These limitations are specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1], which is based on the assumption of 24 hour exposure recognized by the World Health Organization (WHO). In Turkey, restrictions and regulations related to exposure to EM fields are established by the Information and Communication Technologies Authority of Turkey (ICTA) [2]. In Turkey, 75% of ICNIRP's restriction values are applied by ICTA. The electric field limit values determined by ICTA and ICNIRP are shown in Table 1. The values in this table are the average values given after EMR exposure for six minutes. There are 3 communication operators in Turkey currently used by the users and they use 2G (second generation), 3G (third generation) and 4G (fourth generation) systems. According to [2], the electric field strength (E) limits are 30.9 (V/m) for 900 MHz base station, 43.7 (V/m) for 1800 MHz base station, 45.75 (V/m) for 3G systems, which is 2100 MHz, and also 45.75 (V/m) for 2600 MHz base station.

Obtaining EMR values in crowded settlements, especially where there are too many cellular systems, is very important to be able to examine the effects of EMR on human health. For this reason, a number of studies have been conducted in the literature [3–13] to measure EMR contamination from base stations and to investigate the effects of these measurements on human health. Therefore,

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Table 1: Reference EMR levels of ICNIRP and ICTA

Frequency range (MHz)	E (V/m)	
	ICNIRP	ICTA
0.010 – 0.15	87	65.25
0.15 - 1	87	65.25
1 - 10	$87/f^{1/2}$	$65.25/f^{1/2}$
10 - 400	28	21
400 - 2000	$1.375f^{1/2}$	$1.03f^{1/2}$
2000 - 60000	61	45.75

f is frequency in MHz

in this study, E measurements were taken at four different times in order to examine and evaluate the change of E in Atakum district which is one of the most crowded districts of Samsun, Turkey.

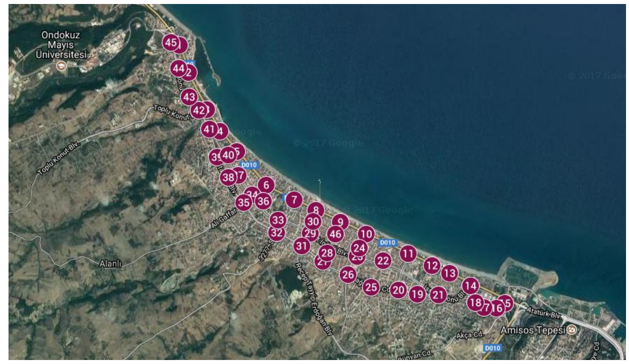

Figure 1: Measurement locations in Atakum district

1 Electrical field strength measurements

In this study, the E measurements were conducted using a SRM-3006 and a PMM 8053 EMR meter in Atakum district at 46 different locations considering the number of users, distance from base stations and line of sight. In the measurements, the maximum E (E_{max}) and the average E (E_{avg}) were recorded. The total E in the band between 100 kHz – 3 GHz is measured using the PMM–8053 with the EP-330 isotropic electric field probe [14] twice in August 2015 named as M1, M2, and in December 2016, named as M3, and M4 respectively, while band selective measurements are conducted using the Narda SRM–3006 with the 3501/03 isotropic E-field probe [15] in February 2017. The E measurement locations are shown in Figure 1, and visuals of the measurements using the PMM-8053 and SRM-3006 are shown in Figure 2.

(a)

(b)

Figure 2: Taking measurement with a-) PMM 8053, b-) SRM 3006 EMR meter

2 Measurement results

The changes in the E_{max} and the E_{avg}, which were measured at 46 different locations, are given in Figure 3a and Figure 3b respectively. As seen from Figure 3a, the maximum E_{max} acquired is 3.72 V/m at location 26 for the second measurement (M2), while maximum E_{avg} acquired is 2.67 V/m at location 26 for the third measurement (M3). The reason for the high E values observed at this point may be due to the fact that the location has a high user density and

Table 2: Statistical characteristics of the measured values

	E_{max} (V/m)			E_{avg} (V/m)		
	Max.	Mean	Std.	Max.	Mean	Std.
M1	3.65	1.22	0.56	1.85	0.45	0.41
M2	3.72	0.86	0.63	2.10	0.40	0.43
M3	3.32	0.91	0.78	2.67	0.57	0.62
M4	3.48	0.94	0.83	2.41	0.53	0.58

is close to one of the base stations. The statistical characteristics of measured values are specified and listed in Table 2.

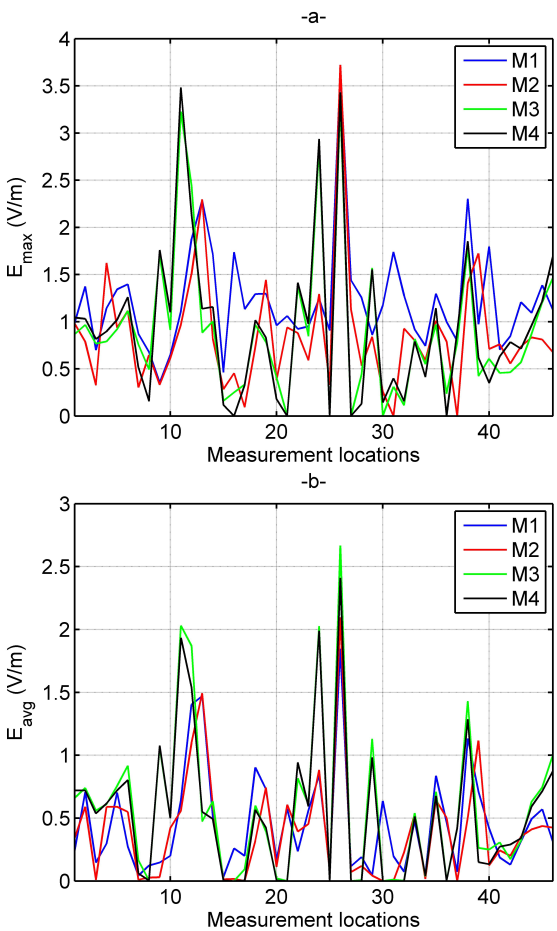

Figure 3: a) Maximum (E_{max}) b) Average (E_{avg}) Es versus locations

Band selective measurements were fulfilled at all locations using the Narda SRM 3006 to specify the effect of E sources into the total E. All band selective measurements are shown in Figure 3. An example of the details of the SRM–3006 measurements, which involve the E sources (frequency ranges, service name etc.), caused pollution as shown in Table 3 for location 26. In the table, each E source has a specific index number and the 23rd index is the representation of E levels inclusive of undefined frequency bands, and the 24th index is the representation of total E (E_T) values of the medium.

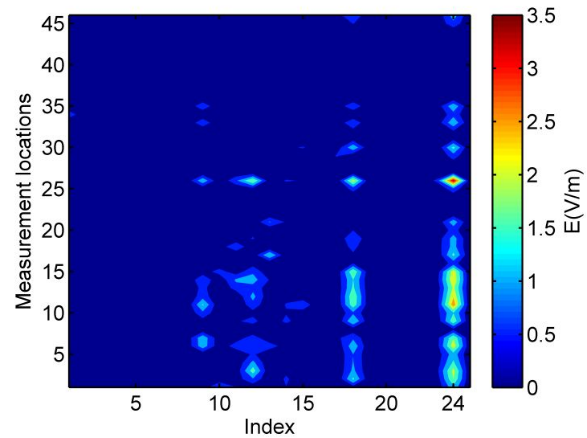

Figure 4: Band selective E values

It is seen from Table 3 that the primary sources of E are LTE900, LTE800, GSM1800, GSM900, LTE1800, and UMTS2100 bands. When total E is 3.616 V/m, 2.243 V/m of this value is produced by UMTS2100, while 2.048 V/m, 1.402 V/m, and 0.913 V/m are produced by GSM900, LTE800, and LTE900 respectively. The total E of medium is computed as follows:

$$E_T = \sqrt{\sum_{i=1}^{23} (E_i)^2} \tag{1}$$

where E_i is the electric field for i^{th} band. The other transmitters excluding 18 bands give rise to E_{23}. The contribution percentage (P_i) of each band is computed as in Eq. 2.

$$P_i = \frac{E_i^2}{E_T^2} \times 100 \tag{2}$$

The pie chart illustrating the divisions of all E sources is given in Figure 5 for location 26. As seen from Figure 5, 88.7% of total E in the medium is emitted by base stations which use LTE800, LTE900, GSM900, LTE1800, UMTS2100, and the other frequency bands. Among these systems, UMTS2100 has the most contribution with 43.6%.

Long term E measurements were taken to determine the change of E values measured at location 26 during a day, and the results are given in Figure 6. Figure 7 shows the measurement location 26. Measurements started at 6pm and continued until the next day. Figure 6 shows a

Table 3: Frequency selective E values

Index	Service Name	Lower Frequency	Upper Frequency	E (V/m)
1	Low Band	30 MHz	87.5 MHz	0.133
	FM Band	87.5 MHz	108 MHz	0.021
3	Air Band	108.1 MHz	136 MHz	0.022
4	Land Band-I	136.1 MHz	173 MHz	0.021
5	TV VHF Band	173.1 MHz	230 MHz	0.023
6	Land Band-II	230.1 MHz	400 MHz	0.026
7	Land Band-III	400.1 MHz	470 MHz	0.015
8	TV UHF Band	470.1 MHz	790.9 MHz	0.084
9	LTE800	791MHz	820.9 MHz	1.402
10	ETC1	821 MHz	925 MHz	0.057
11	LTE900	925.1MHz	935.1 MHz	0.913
12	GSM900	935.1 MHz	961.0 MHz	2.048
13	ETC2	961.1 MHz	1.805 GHz	0.147
14	GSM1800	1.805 GHZ	1.820 GHz	0.554
15	LTE1800	1.820 MHz	1.879 MHz	0.456
16	DECT	1.880 GHz	1.899 GHz	0.024
17	ETC3	1.899 GHz	2.010 GHz	0.067
18	UMTS2100	2.010 GHz	2.170 GHz	2.243
19	ETC4	2.171 GHz	2.399 GHz	0.034
20	WLAN	2.400 GHz	2.483 GHz	0.314
21	ETC5	2.484 GHz	2.569 GHz	0.031
22	LTE2600	2.570 MHz	2.660 MHz	0.082
23	Residual services			0.598
24	Total			3.616

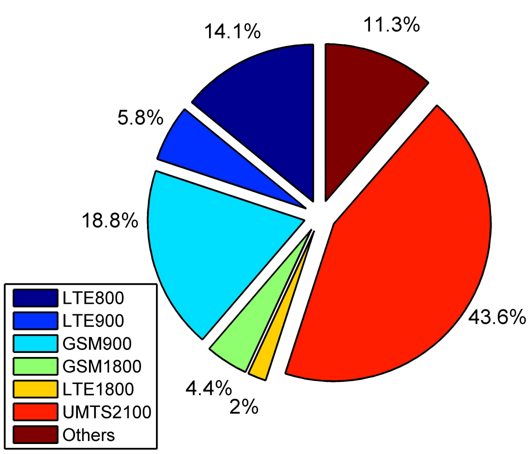

Figure 5: Pie chart of E

great variation depending on the measurement hours. It is seen that the number of users actively using the base station is the main factor influencing the E. Low E values were measured between the hours of 05:00–07:00 in the morning (mean E is 7.05 V/m), and very high E values between 12:00 and 18:00 hours (mean E is 10.5 V/m). The highest measured E value was 17.53 V/m while the 24 hour average was 9.45 V/m. The standard deviation value is 2.02 V/m for this 24 hour measurement.

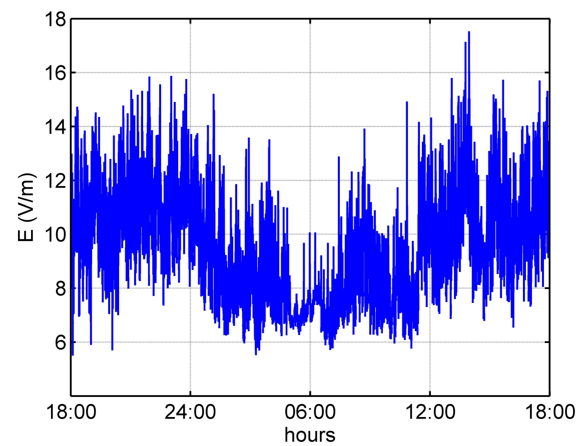

Figure 6: E levels measured for 24 hour at location 26

Figure 7: A picture of location 26

3 Analysis

Total E value of medium is calculated with Eq. 3 with the use of band selective measurements. In this equation, all service names' E value will be represented with an index number (e.g. E_{10} for GSM900) throughout the rest of the paper. The estimated total E of the medium (E_T) can be computed with Eq. 3 using the six bands which consist of 88.7% of total E.

$$\hat{E}_T = \sqrt{E_9^2 + E_{11}^2 + E_{12}^2 + E_{14}^2 + E_{15}^2 + E_{18}^2} \tag{3}$$

In order to evaluate the performance of the method Normalized Root Mean Square Error (NRMSE) is computed

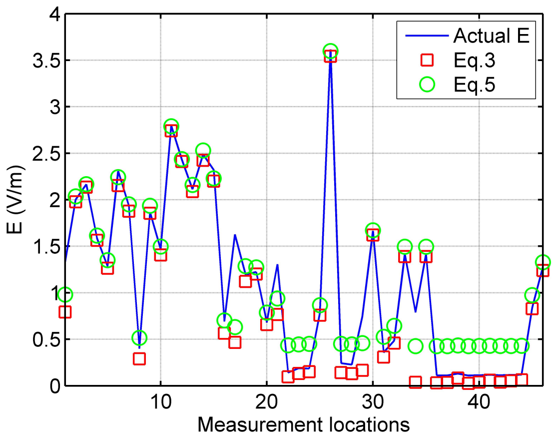

Figure 8: Multilinear regression analysis

as follows:

$$NRMSE = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_{T,i} - \hat{E}_{T,i})^2}}{\max(E_T) - \min(E_T)} \quad (4)$$

where $E_{T,i}$ is actual E value, $\hat{E}_{T,i}$ is estimated E, i is measurement location, and N is the number of measurements locations.

The NRMSE is 0.0729 between E_T and $\hat{E}_T$ for Eq. 3. In order to obtain lower NRMSE multilinear regression [16] was implemented and total E in medium is estimated as follows;

$$\hat{E}_T = \Big(0.01810 + 1.0448E_9^2 + 1.2804E_{11}^2 + 0.9814E_{12}^2 + 1.3335E_{14}^2 + 0.9655E_{15}^2 + 0.9768E_{18}^2\Big)^{1/2} \quad (5)$$

NRMSE between between E_T and $\hat{E}_T$ is calculated as 0.0705 using this equation. Figure 8 shows estimated E values using Eq. 3, and Eq. 5, and actual E values of corresponding measurement locations. It is seen from Figure 8, Eq. 3 gives the best performance especially actual E values lower than 0.5 V/m, while Eq. 5 gives better performance for high E values. Therefore a new empirical E estimation model can be proposed combined of Eq. 3 and Eq. 5 and given in Eq. 6. The NRMSE is 0.0538 between E_T and $\hat{E}_T$ for Eq. 6.

$$\hat{E}_T = \begin{cases} \sqrt{E_9^2 + E_{11}^2 + E_{12}^2 + E_{14}^2 + E_{15}^2 + E_{18}^2} & E < 0.5 \\ (0.01810 + 1.0448E_9^2 + 1.2804E_{11}^2 + 0.9814E_{12}^2 + 1.3335E_{14}^2 + 0.9655E_{15}^2 + 0.9768E_{18}^2)^{1/2} & E \geq 0.5 \end{cases} \quad (6)$$

4 Conclusion

In this study, for observing the change of E in Atakum district of Samsun, Turkey, three stage measurements were conducted. In the first stage, short term E measurements were taken at four different times and at 46 different locations. It can be seen from the measurements that E values may change with time and the measurement locations. It can be inferred from the measurements results that the maximum recorded E_{max} is 17.53 V/m while the maximum E_{avg} is 9.45 V/m which are below the limits determined by the ICTA and ICNIRP. It is also seen from the results that E_{avg} has increased within measurement periods. In the second stage, in order to define the main E source in Atakum district, band selective E measurements were performed at the same locations using the SRM 3006. An extensive analysis of band selective measurements demonstrates that the primary E sources in Atakum district are the base stations which use LTE800, LTE900, GSM900, LTE1800, UMTS2100 frequency bands, and 2100MHz has the most contribution to total E value with 43.6%. In the third stage long term E measurements were recorded to assess the changing of E during the day. It is seen from the results that the E level in the morning increases by 48.9% compared to the measurements in the afternoon. At the end of the study a tentative mathematical model was obtained to estimate E in the medium with an accuracy of up to 95%.

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