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Electromagnetic Radiation Measurement of a High Power Wireless Network Adapter

Yasin Karan[1,*], Nilüfer As[1]

[1]Department of Physics, Recep Tayyip Erdoğan University, Rize, 53100, Turkey

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*Correspondence E-mail: yasin.karan@erdogan.edu.tr

ABSTRACT Electromagnetic pollution is an active research area, especially after the widespread deployment of Global System for Mobile Communications (GSM) base stations in the environment. Numerous studies on electromagnetic pollution of base stations are available in literature. Health effects of GSM base station and signals are engrossing and researches in this field have been going on. In this particular study, electromagnetic radiation (EMR) of wireless network adapters with high gain antenna is analyzed and compared with other electromagnetic radiation sources. The measurements are realized in long and short distances from the transmitter. The results indicate that the high power wireless network adapter radiation is significantly higher than the other electromagnetic sources in residential environment, especially compared with GSM signals and common wireless network adapters.

Keywords: Wireless network adapter, Electromagnetic radiation, Electromagnetic pollution, IEEE 802.11 standard, Selective radiation measurement.

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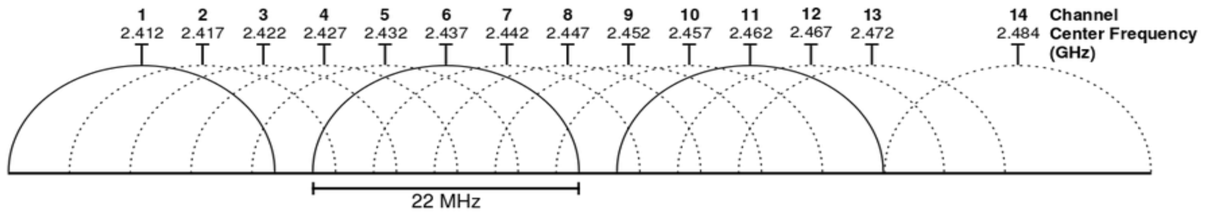
1. INTRODUCTION

The base stations came into our lives with GSM technology development in the beginning of 1990s. That caused the public to worry about the electromagnetic pollution radiated from cell phones, base stations especially close to their home and also TV/Radio transceivers. The limitations of the emitted power are regulated by related authorities. Nevertheless, today almost every home has its own electromagnetic sources which are wireless network routers and adapters.

There have been many studies about measurement of electromagnetic radiation [1-10]. The electric field strength level in the schools, hospitals, dormitories, residences and high towers around city center of Ankara was measured 1.64 V/m (max.) with a mean of 0.32 V/m, and standard deviation of 0.255 V/m in GSM frequency bands [2]. The electric field strength of base stations in the city of Nablus, Palestine was measured in different distances and the maximum value was found to be 3.49 V/m at 10 m distance [3]. In another study, electromagnetic field exposure level of main streets in Diyarbakır city was analyzed statistically and it is seen that the results are not in normal distribution [4]. A base station in Rize, Turkey was measured and maximum1.114 V/m in terms of electric field strength and 3.248mW/m^2 in terms of power density were found in [5-7]. 60 base stations measurements were carried out in Australia and the maximum power density value was found to be 7.8 mW/m^2 [8].
In another study, electromagnetic field strengths in different European cities were investigated and it was found to be below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) limit values [9]. TV/Radio transmitter towers in Trabzon city were investigated in terms of electric field and it was found that the maximum value was 0.4732 V/m in FM band [10]. In a different approach to base stations, the ϒ radiation dose levels were measured with the samples taken from different distances from a base station, and the results showed a higher value in the base station environment compared to the non-base station environment [11]. The simulation and real environment measurements of electromagnetic propagation for Wi-Fi access points were compared and 3 dB differences were found in [12].

The effect of electromagnetic field on human health was also studied by several researchers. For example,



(b)

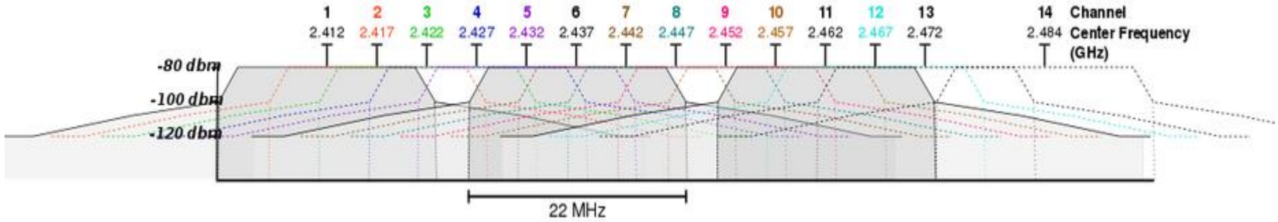


Fig. 1. Channel specifications in IEEE 802.11 standard (a) channels frequency bands, (b) channels power figure [16]

variation of temperature around human ear and head exposed to electromagnetic radiation was analyzed in another study. It was noted that electromagnetic field effect using cell phone resulted in temperature change of 0.22 - 0.39 °C on ear and 0.07 - 0.17 °C on head [13]. The effect of 900 MHz electromagnetic field on cortisol and testosterone level was analyzed to examine the effect of Electromagnetic Radiation (EMR) on organic tissues. The rats were exposed to electromagnetic wave of 1 mW/cm^2 for 30 min/day in 4 weeks. Consequently, cortisol values were found higher and the testosterone level was lower in the rats exposed to electromagnetic field compared to the electromagnetic free rats [14].

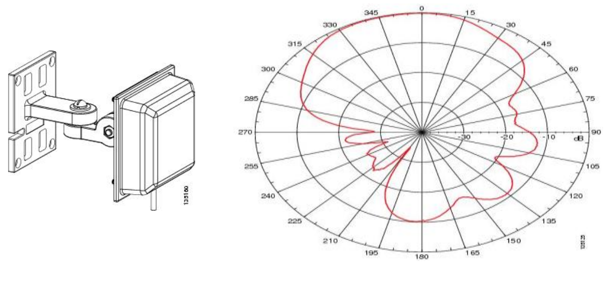
In our study, the electric field strength of a wireless network adapter for wireless local area network (WLAN) is investigated. In the literature, while experimental data for GSM base stations and TV-radio transmitters is present, no experimental data for the wireless network adapter for WLAN especially with high gain antenna is available yet. Since the internet usage has expanded in all environments and accessing to internet service has certain cost, some people tend to access free internet from public internet suppliers even from long distance. In order to do that, a high power wireless network adapter with high gain antenna can be used to have long distance communication without considering the electromagnetic field strength of the device. In this study, the electric field strength of a high power wireless network adapter was measured by internet usage and transmission distance. The results were compared with other wireless systems and with random network adapters.

1.1 IEEE 802.11 Standard

IEEE 802.11 is wireless local area network standard published by IEEE community. This standard includes the media access control (MAC) layer and Physical layer properties of the WLAN. Industrial, Scientific and Medical (ISM) radio frequency bands are used in IEEE 802.11 standard. ISM bands are the reserved radio bands for public use. IEEE 802.11 has some types named as IEEE 802.11x where x is a, b, g, n, ac, ad, etc. for different types. These types are differentiated mainly by frequency, data rate and modulation type. While IEEE 802.11a uses 5 GHz ISM band, b and g use 2.4 GHz ISM band, and n uses both 2.4 and 5 GHz bands.

In Turkey, where the experiments carried out, only 2.4 GHz band is allowed to be used for WLAN. Therefore, 802.11 b/g/n standards are allowed to be used in Turkey. These standards have 14 channels. These 14 channels are shown in Figure 1 (a) with central frequencies. The bandwidth of each channel is 22 MHz and each channel is 5 MHz apart from the next channel except the 14th one. This channel is 12 MHz apart from the previous channel. As seen in the Figure 1, adjacent channels are interfering with each other. Because of that, non-interfering channels should be used for the same time to avoid the interference. The channels 1, 6 and 11 or the channels 2, 8 and 11 can be used at the same time. The 14th channel is restricted by many countries and the channels 12 and 13 can be used with a lower power according to the some country regulations [15].

Figure 1 (b) shows the spectral mask of IEEE 802.11 channels. For a reliable data transfer, each channel needs to be attenuated at least 20 dB from central frequency power in the edge frequencies.



(a) (b)

Fig. 2. (a) Cisco AIR-ANTM5560P-R Antenna, (b) its E-field radiation pattern (Cisco guideline, Cisco Multiband Wall-Mount Antenna (AIR-ANTM5560P-R)", 2007)

Antennas are used to radiate and capture RF energy with some gain. Directional antennas radiate and capture more power in a specific direction. Therefore, its radiation pattern shows higher power in some direction and a lower power in other directions, while omnidirectional antenna pattern shows equal power in every direction in one plane. Figure 2 (a) shows an example of a directional antenna and its radiation pattern. As in the Figure 2 (b), the frontal area has more coverage (power) than other sides. The wireless network adapter that was used in the experiment has a directional antenna.

1.2 ICNIRP and ICTA Standard

The maximum limit values of exposure to electromagnetic field are imposed by country regulators. The International Commission on Non-Ionizing Radiation Protection (ICNIRP), an independent organization, sets the limits and updates them. Most of the countries set their rules based on ICNIRP limits. For instance, the limits in Turkey were quarter of the ICNIRP limits. With last updates, now, the limits are even lower than the quarter of ICNIRP limits. The Information and Communication Technologies Authority (ICTA) is a legal institution in Turkey and it is responsible for deciding the limit values of electromagnetic exposure values. These limits differ due to occupational exposure and public exposure. Occupational exposure limits are kept higher than public exposure limits. Table 1 shows the limit values of ICNIRP and ICTA for electric field, magnetic field and power density [17-19]. Electromagnetic field strength limits of ICTA were updated in 2015 [19].

Table 1. Reference levels for general public exposure to time-varying electric and magnetic fields

Frequency range (MHz)	E-field strength (V/m)		H-field strength (A/m)	
	ICNIRP	ICTA	ICNIRP	ICTA
400–2000	$1.375f^{1/2}$	$0.305f^{1/2}$	$0.0037f^{1/2}$	$0.00082f^{1/2}$
900	41.25	9.15	0.111	0.0246
1800	58.34	12.94	0.157	0.0348
2000-60000	61	13.5	0.16	0.035

Additional to E-field strength limitations, ICNIRP defines Specific Absorption Rate (SAR) limits. SAR is the absorbed amount of electromagnetic energy per kg by a normal human body. SAR is proportional with E-field strength. Mobile phones use SAR values as E-field limitations. The calculation of SAR is simplified by the equation;

$$\mathbf{SAR} = \boldsymbol{\sigma}\mathbf{E}^2/\boldsymbol{\rho} \qquad (1)$$

where σ is conductivity in *S/m*, *E* is electric field in *V/m* and ρ is density in *W/kg* [17]. As seen in Equation 1, SAR is related with conductivity and density of human body or tissue. Since conductivity and density of tissue are flexible, obtaining precise SAR value is not feasible.

2. EXPERIMENTAL

In the experimental setup, the wireless network adapter is in a 10-story apartment flat and 180 meter away from an access point which is located in a university campus. From this distance, it is not possible to make a reliable connection and access to internet with a common wireless network adapter. However, the connection can be successfully made with high power 802.11b/g network adapter which is equipped with a high gain directional antenna.

Figure 3 shows the measurement point (access point shown as “AP”) and the network adapter place (red dot). As seen in the figure, the distance is roughly 180 m. Also there are obstacles between them such as two apartment corners, walls and windows. These obstacles attenuate, reflect and scatter the electromagnetic waves and that have a bad influence on reliable wireless communication. When there is line of sight (LOS) between transmitter and receiver, wireless communication can be successful in longer distances, compared to when there is non-line of sight (nLOS). The wireless network adapter is inside of the apartment as seen in Figure 4 (a). Figure 4 (b) shows the measurement points around the antenna. The antenna and network adapter were chosen as high gain and powered. Those devices are OEM (Original Equipment Manufacturer) devices and commonly available in electronics markets.

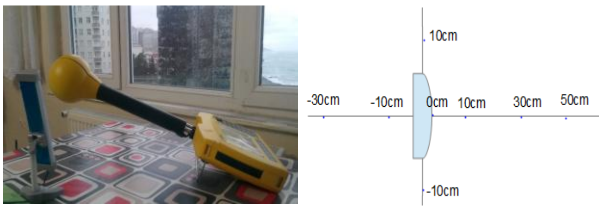
Electromagnetic field measurements were realized with a compact spectrum analyzer device (SRM 3006, Narda Safety Test Solutions GmbH, Pfullingen, Germany). It measures the electric field in the 420 MHz- 6 GHz frequency range with a triaxial coil antenna. Electric field can be converted to both magnetic field and power flux density values using Equation 2 and 3 assuming in far field measurement. The measurement results were recorded in the device and uploaded to a computer using its software [5].

$$\mathbf{E} = \eta_0\mathbf{H} \qquad (2)$$

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \qquad (3)$$

where *E* is electric field strength in *V/m*, η_0 is free-space impedance equal to 377 Ω, H is magnetic field strength in *A/m*, *S* is power flux density in W/m^2.

Fig. 3. The measurement point and with roughly distance; AP and Red dot are the access point and measured antenna locations



(a) (b)

Fig. 4 (a) Measured antenna and measurement view. (b) The measurement points around measured antenna

3. RESULTS

The results are given based on distance between the access point and the wireless network adapter: in-campus and off-campus and in case of the internet usage: active-use and passive-use parts. The distance between access point and the adapter is short in in-campus measurements and long in off-campus measurements. There was continuously file downloading and video streaming in the active-use, however there was not any file downloading but just internet surfing in passive-use. The transmitted power and duration vary due to the transmission distance and usage. The measurement points are kept in a short distance from the antenna because wireless network adapter antennas are used as attached to computer, so they can be next to human body.

Table 2. The electric field strengths (V/m) of measured points

Distance (cm)	Off-campus active-use		Off-campus passive-use		In-campus active-use		Home Wi-Fi router active-use	
	Max. peak	Max. mean	Max. peak	Max. mean	Max. peak	Max. mean	Max. peak	Max. mean
-120	0.20	0.03	-	-	-	-	-	-
-100	-	-	-	-	-	-	1.49	0.08
-50	0.53	0.07	-	-	0.38	0.02	-	-
-30	1.01	0.18	-	-	0.55	0.03	2.99	0.12
0	11.8	1.61	5.45	0.17	5.62	0.24	3.39	0.20
10	9.77	1.11	5.49	0.15	-	-	-	-
20	-	-	-	-	4.38	0.19	0.72	0.11
30	3.67	0.60	2.71	0.06	-	-	-	-
50	2.19	0.35	1.61	0.04	2.66	0.09	0.65	0.08
70	0.99	0.17	0.79	0.02	1.31	0.07	0.79	0.06

Table 2 shows the results of all measurements cases. At long distance, both active and passive usages were investigated and the results are shown as off-campus active-use and off-campus passive-use in Table 2. By using the same wireless network adapter, another measurement was realized in the campus where the access point is close to the network adapter. The results of in-campus measurements are given in in-campus active-use part of Table 2. Another measurement was carried out in a house with a common use wireless network router. The measurements were carried out at different times and measurement distances could vary in each experiment. Therefore, only measured data and distances were given in the table.

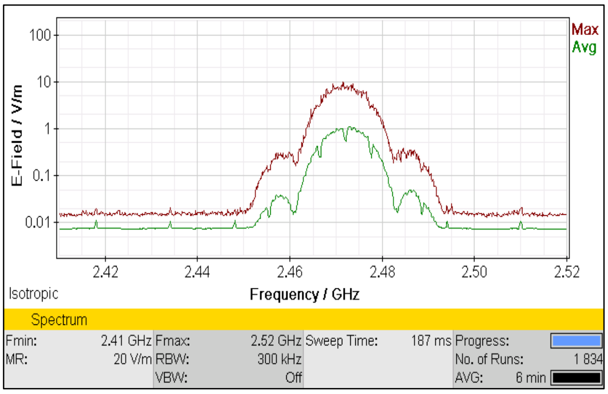
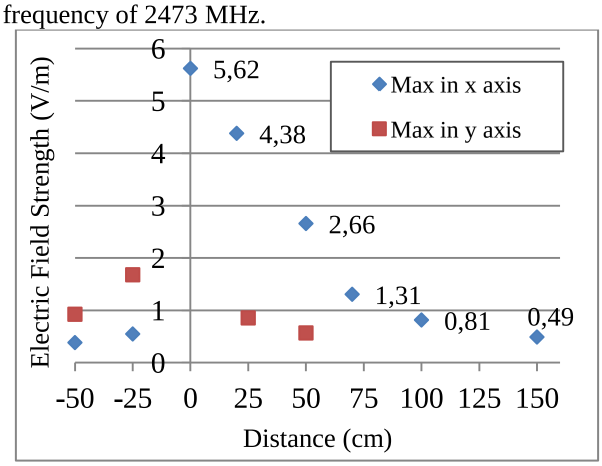
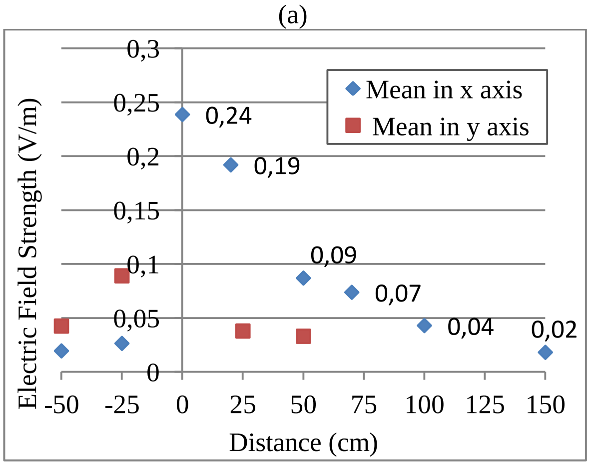


Fig. 5. One of the throughputs from spectrum analyzer in the measurement of out of campus active used at 10 cm distance

Figure 5 shows one of throughput of the spectrum analyzer measurements. It is the electric field strength in the 2.4 - 2.52 GHz band at 10 cm distance from directional antenna in the out of campus active downloading usage. The center frequency seems 2.472 GHz, so the channel number of this channel is 13 as seen in Figure 1 (b). Maximum electric field strength is 9.77 V/m in the frequency of 2471.6 MHz. Among the average values, the maximum average value is 1.11 V/m in the frequency of 2473 MHz.



(a)



(b)

Fig. 6. (a) The maximum peak and (b) the maximum of mean values of electric field strength values in two directions for in-campus active-use

Figure 6 (a) and (b) show the maximum peak of electric field strength and maximum mean values in the 2.4-2.5 GHz range for in-campus active-use, respectively. In both figures, antenna is measured in x and y directions as shown in Figure 4 (b). Since the antenna is directional, the electric field strength is lower in the lateral and back side than the front side of the antenna. The same measurement was performed in off-campus measurement, and similar results; lower intensity in the back and lateral side than the front side were obtained as expected. The data in Figure 6 (a) shows the maximum peak values of measurements in the 2.4 - 2.5 GHz band while the data in the Figure 6 (b) shows the maximum value of the mean values of the same measurements. Each measurement was realized in at least six minutes time interval.

Figure 7 compares the maximum electric field strengths of four measurements and Figure 8 compares the maximum mean values of electric field strengths of four measurements. These data can also be seen in Table 2. Both figures show that the electric field is the highest in off-campus measurements when there is a continuous downloading. Its values are fairly higher than the others especially in maximum of mean values. When there is not continuous downloading in off-campus measurements, the electric field strength is less than the continuous downloading in-campus measurements. The home measurements with a common router showed the minimum electric field strength among the continuous downloading measurements. Also, since its antenna is not directional, the electric field is similar in positive and negative directions. As expected, the electric field strength gets lower with the increasing distance except in the last data of home measurement with the common wireless router. The reason of this data is that the second wireless receiver (computer) started to access to the router and began downloading a file at that time.

If the results of these measurements are compared with the references given in the introduction, it can be interpreted that the electric field strength of high gain antenna in wireless adapters is more dominant than the base stations, because they are closer to human body. In this study, measured electric field strength values are much higher than the measured electric field strength values in references, even the measurements are realized in residential environment. Since WLAN adapter’s antennas could be located inside of a room and close to the users, near and far field of the antenna was measured. These high power adapters can be used to access to WLAN routers at long distances. Nonetheless, since the measurements of high power adapters showed much higher EMR than the common wireless router, it is suggested locating the antenna outside the room.

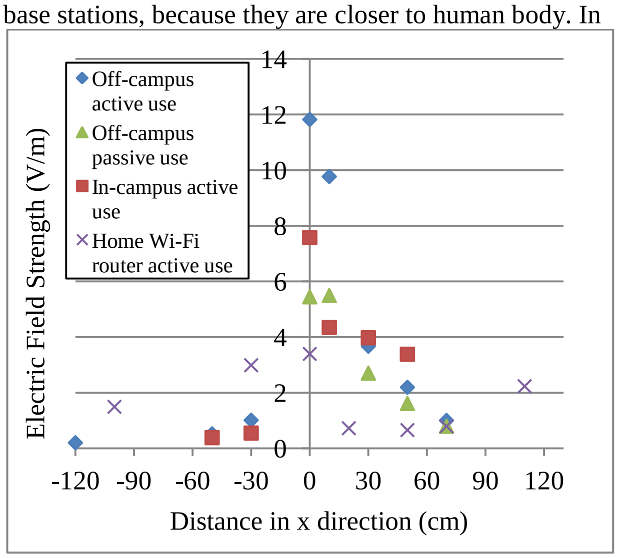


Fig. 7. The maximum electric field strengths in four measurements

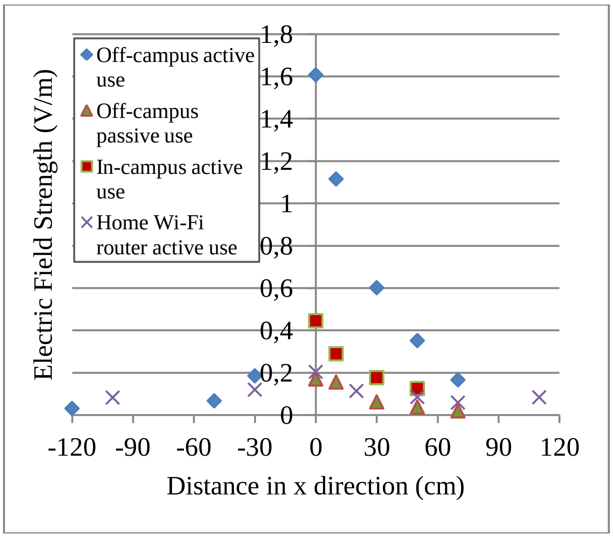


Fig. 8. The maximum mean values of electric field strengths in four measurements

In Figure 9, 700 MHz – 2.5 GHz band was measured, as well when there is a phone calling and the phone was next to the spectrum analyzer; also the spectrum analyzer was 10 cm away from the directional antenna of the wireless network adapter. Additionally, the mobile operator used in the measurement uses the 1800 MHz band. From the figure, it is seen that the electric field strength of wireless network adapter is much higher than other active bands. Especially, when mean powers of EM sources are compared, wireless network adapter is multiple times higher than other sources.

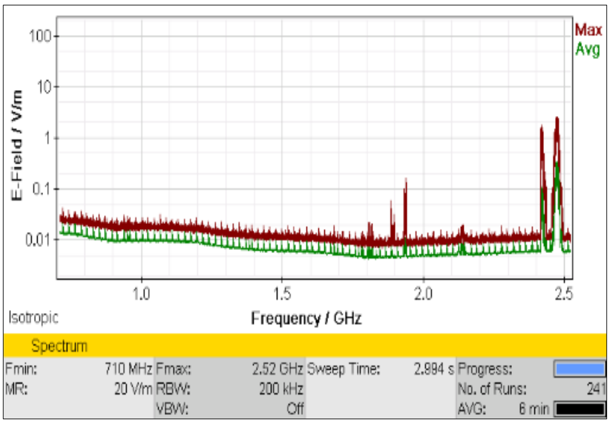


Fig. 9. A general view of the spectrum when there is a cell-phone calling and wireless internet usage (the measurement distance is 10 cm)

4. CONCLUSION

In this study, the electromagnetic pollution of the wireless network adapter with a high gain antenna in long distance was analyzed in terms of electric field strength. The measurements were realized in short distance and long distance from WLAN access point during continuous downloading and no downloading. Also, one of the common used wireless router's electric field strength was measured to compare with a network adapter. The result showed the wireless network adapter with high gain causes considerably more electromagnetic pollution compared to the standard home wireless router because of the transmission in longer distance. Also, when the distance between transceivers is getting longer, emitted electromagnetic signal strength increases. The amount of the difference is significant around the antenna. Therefore, high gain wireless antenna of wireless network adapters or router is better to be kept out of the rooms. At least, it is better to be kept the antenna in longer distance from human body. By comparing measured EMR with the limitations of ICNIRP and ICTA regulations, those are below, yet close to the ICTA limitation values in some cases. Also, the overall results showed that EMR of wireless adapters and routers is higher than the base-stations' EMR given in the references, because base-station antennas are far from human active life, but adapters and routers are close. Thus, it is better to use them cautiously.

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Biographies

Yasin KARAN was born in Istanbul, Turkey. He received his B.Sc. degree in Electronics and Communication Engineering from Kocaeli University, M.Sc. degree from University of Rochester, NY, USA in 2006 and 2009, respectively. He is currently continuing his doctoral studies at Karadeniz Technical University. He is currently a lecturer in Physics Department at RTE University. His main research interests are wireless communication, microcontroller systems.

E-mail: yasinkaran@gmail.com

Nilüfer AS was born in 1970 in Çanakkale, Turkey. She received her B.Sc. degree, M.Sc. degree, Ph.D. degree in Physics from Uludağ University (U.U.), Bursa, Turkey in 1992, 1994 and 2002, respectively. She is currently an Assistant Professor in Physics Department at RTE University. She was worked Faraday Effect, Electromagnetic Wave Analysis in Fiber Wave Guides, Non-Ionizing Electromagnetic fields measurements and several topics in the field of General Physics. She was worked at different projects on Solid State Physics, Nuclear Physics and General Physics areas. She has been a member of Turkish Physical Society (TFD). She is currently manager of RTE University Electromagnetic Pollution Center.

E-mail: nilufer.as@erdogan.edu.tr