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Assessment of Indoor-Outdoor Wi-Fi Radiation on Human Body and its Precise SAR Measurement

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There has been a lot of awareness concern about the health hazards of RF electromagnetic radiation on the human body, the radiofrequency electromagnetic field (RF-EMF) exposure assessment needs attention. This paper reports experimentally measured electromagnetic radiation emission from public place Wi-Fi devices. Indoor and outdoor measurements are done at different geographic locations in India. For the indoor assessment, the experiment was carried out in the national physical laboratory (NPL) New Delhi for 1-4 antennas Wi-Fi routers at a distance of 0-10-meter range are taken into consideration. The power density and electrical intensity were measured using a spectrum analyzer with isotropic E-field probe TSEMF-B1. For the outdoor measurements, four different Delhi metro stations Wi-fi devices at a distance of 20-meter range towards the train coach and below the Wi-fi routers have been considered. In this experiment, we used an instrument is Narda NBM-550 E-field probe for electric field and radiated power density estimation. In addition, the human whole body 3D model has been simulated in a free space environment, the measured outcome of indoor-outdoor electromagnetic radiation and specific absorption rate (SAR) is compared with the ICNIRP, FCC guideline limits at 2.45-5.87 GHz and precise SAR has been evaluated.

Keywords: Wi-Fi, SAR, Radiation, Human body, E-field probe

1 Introduction

Since the last decades, increased demand for high data rates has necessitated the advancement of the 5G communication, Internet of things (IoT) hardware lead machine to machine communication. This leads to the tremendous use of wireless signals. With the advent of smart homes, smart communication, smart city, and the need to connect multiple devices, wireless devices became a centre point to provide quality and faster communications. The use of cell phones, Wi-Fi and wireless communication devices leads to serious health hazards[1,2], most of the public Wi-Fi placed at different public places such as a university, offices, home, railways station, airport, bus stop, metro stations, hotels, schools, etc. Mobile phones, mobile base stations, and Wi-Fi devices are the main sources of exposure population to RF electromagnetic fields[3]. The wireless devices such as Bluetooth, personal computer, laptop, tablet, wireless router, audio player, connected to 5G, IoT devices, and the cell phones[4], Wi-Fi devices, the emerging technology operating at 0.8 GHz[5,6] to 5.8 GHz.

Electromagnetic energy exposure is reported to cause some serious health hazards such as cellular DNA damage, oxidative stress in tissues, blood antioxidant level changing[7], the adverse impacts on the human body organs *i.e.* brain, liver, kidney[8-10] and heart, pancreas[11,12], reproductive system and blood[13,14]. Larc *et al*. have reported regarding electromagnetic fields possibly carcinogenic to humans[15], Ibrahim *et al*. reported Wi-Fi radiation on rats[16], and Zhang *et al*., Dalyo *et al*. have reported regarding campus, school Wi-Fi radiations, Fathihah, *et al*. reported regarding the Adverse Effects of Wi-Fi Radiation on Male Reproductive System[17-19], Amani, *et al*. presented about the evaluation of Short-Term Exposure to 2.4 GHz Radiofrequency radiation emitted from Wi-Fi routers on the antimicrobial susceptibility of pseudomonas aeruginosa and Staphylococcus aureus[20]. Celaya-Echarri *et.al*. reported the Environmental Indoor RF-EMF Assessment in Complex High-Node Density Scenarios, Public Shopping Malls Case Study[21].

As per the international commission on non-ionization radiation protection (ICNIRP), electromagnetic radiation frequencies from 100 to 300 GHz can

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affect the biological system through thermal effect due to electromagnetic energy, this energy absorbed by biological tissue is measured in specific absorption rate (SAR)[22-24]. In the practical evaluation of the electromagnetic radiation in terms of an electric field in volt per meter (V/m) based on this parameter SAR values have been investigated as well as radiated power density watt per square meter (W/m^2) is a reference for the given frequency range, the exposure level varies from country to country. The ICNIRP introduction Guidelines for the 2.4 GHz, 5.88 GHz primary current Wi-Fi band E-field is 61 volts per meter (V/m) arrived at the midpoint over any 6 minutes, the power density is 10 W/m^2 at the middle point over any 6-minute time frame >1952 (V/m) is permitted in short pinnacles 10000 (W/m^2) arrived at the midpoint intensity of any short heartbeat signal levels from the Wi-Fi. Compared to earlier studies some of the researchers reported regarding schools, campus, etc[17,18].

Scientific knowledge on the long-term or multi-year exposure, especially in chronic environments, is limited and still indecisive[25-29]. Moreover, occupational radiofrequency electromagnetic field (RF-EMF) exposure assessment in worst-case conditions needs attention and must be accurately analyzed[30]. The particular situations in the context of the EMF safety vulnerable population[31]and hence, to prevent adverse health effects and safety issues of RF-EMF exposure, as per WHO further studies are required[32]. We reported regarding metro stations Wi-Fi devices radiation in terms of electric field and radiated power density, in addition, precise specific absorption rate (SAR) have been estimated.

2 Theoretical Consideration

To evaluate the wireless communication devices exposure, the two parameters that have been taken into account are power density and electric field, for the detailed understanding of signal transmitting and receiving in the free space medium we considered antenna 1 as isotropic *i.e*. transmitter antenna (Tx) and antenna 2 is the receiving antenna (Rx) with a distance of R and transmitted power P_t, transmitted gain G_t as shown in Fig. 1. The relation between electric field (E) and radiated power density(S) is as follows[33]

The power density S at receiving antenna 2 (Rx) is

$$S = \left(\frac{P_t G_t}{4\pi R^2}\right) Watt/_{m^2} \quad \ldots (1)$$

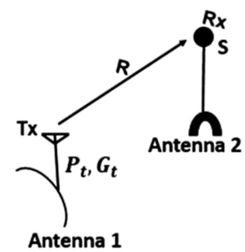

Fig. 1 — Isotropic Tx, Rx antennas.

From the Poynting vector theorem

$$S = \frac{E^2}{120\pi} \quad \ldots (2)$$

Where in equation (2) 120π *is the free space impedance near 377 ohms*

From equations (1), (2) the electric field (*E*) is

$$\frac{E^2}{120\pi} = \frac{P_t G_t}{4\pi R^2} \quad \ldots (3)$$

$$E = \frac{\sqrt{30 P_t G_t}}{R}\ V/_m \quad \ldots (4)$$

Antenna 1 (Tx) is the isotropic antenna so gain equal to one G_t =1, the Effective Isotropic Radiated Power (EIRP) and the power that would be radiated from a transmitter of Power P_t

$$E = \frac{\sqrt{30 P_t}}{R}\ V/_m \quad \ldots (5)$$

$$P_t = \frac{E^2 R^2}{30} \quad \ldots (6)$$

EIRP=Output Power-Cable Loss Gain

As per theory concern, there is no such loss exist, but in the practical situation there is some free space path loss (*PL*) exist between transmitting antenna (Tx) and receiving antenna (Rx) as shown

$$PL = \left(\frac{4\pi R}{\lambda}\right)^2 = \left(\frac{4\pi R f}{C}\right)^2 \quad \ldots (7)$$

Where λ is a wavelength, f is frequency, C is the speed of light, R distance between TX and RX. In the practical concern transmitting antenna (Tx) is Wi-Fi devices and receiving antenna is E-field probe TSEMF-B, Narda NBM-550 probe for the indoor-outdoor measurements locations as shown in Fig. 2-4.

3 Measurements and Test Locations

For the traceable and accurate wireless communication devices exposure measurements, we used spectrum analyzer R&S FSH8 with isotropic E-field probe TSEMF-B1 for indoor measurements, the

Narda NBM-550 Probe for outdoor measurements, the scheme of the measurement setup is shown in Fig. 2b,3. The measurements are taken for electric field strength (mV/m) and radiated power density (mW/m^2) in the averaging mode of 6-minutes duration. The measurement locations are NPL workplace apex metrology building shown in Fig. 2a, and four metro station locations are given in Table 1 with respective Fig. 3, 4. The measurement distance from the source point (Wi-Fi routers-1,2,3,4) antennas, was at 10m for an indoor and the outdoor respectively 20 meters. The measurements setup layout as shown in Fig. 3, the traceability chart of measuring types of equipment are E-field probe TSEMF-B1 with a spectrum analyzer and Narda NBM 550 probe as shown in Fig. 5, this equipment was traceable to microwave metrology standard[34]. The indoor and outdoor measurement results as shown in section 4 and also the precise SAR estimation has been presented in section 4.1, the simulated whole human body model as shown in Fig. 9 and measured values are presented in Table 3.

Fig. 2(a) — Indoor measurement location.

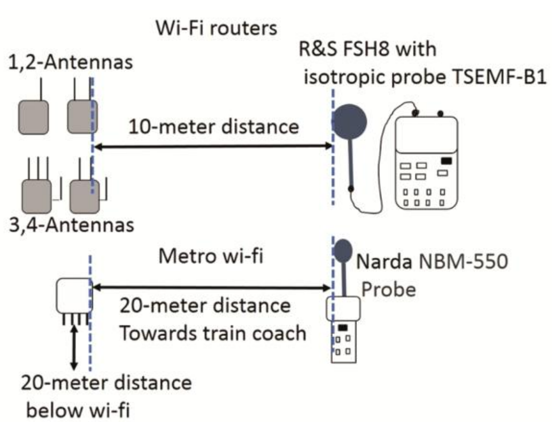

Fig. 2(b) — Measurement setup layout of 1,2,3,4 antennas Wi-Fi at 0 to10 ,20-meters rang.

4 Indoor-Outdoor Measurement Results Discussion

Fig. 6(a,b) and Fig. 7(a,b) represent the 1-4 Antennas Wi-Fi devices electric field strength and radiated power density respectively with a distance of 0 to 10-meter range. from the observations of both parameters, gradually declining with the distance in the order of $1/R,/R^2$ as shown in the theoretical consideration equation no (1,4). It indicates that the wireless communication devices radiation decreases per the distance of $1/R,1/R^2$.

Figures 8 (a-d) shows the outdoor locations B, C, D, E, *i.e.* four metro stations, towards the train coach

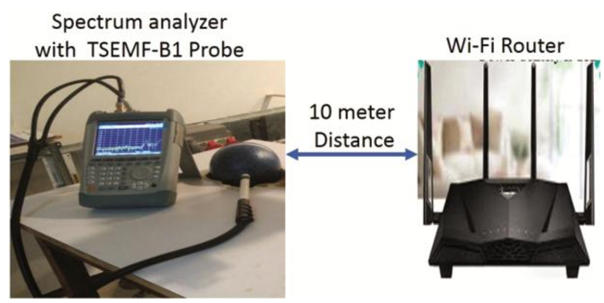

Fig. 3 — Measurement setup in NPL Apex Metrology building New Delhi.

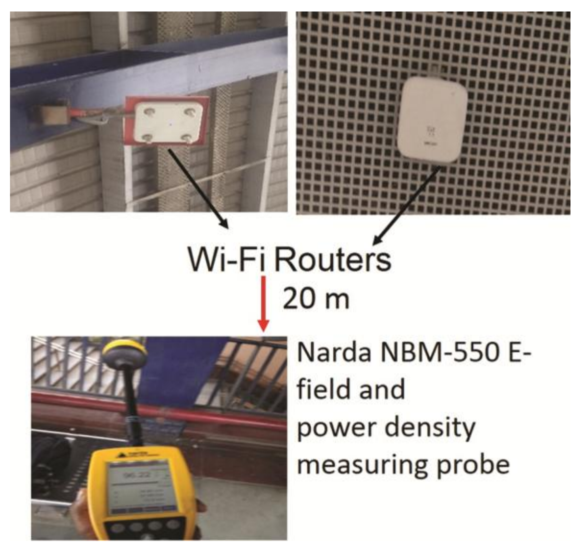

Fig. 4 — Measurement locations (B, C, D, E) of the metro station, source point to towards the train coach and below Wi-Fi at a distance of 20-meter range by using Narda NBM-550 Probe.

Table 1 — Distance Between the Test Probe with Respective Locations and Wi-Fi Router

Location Name	Distance from Wi-Fi router in (meters)
A	10
B	20
C	20
D	20
E	20

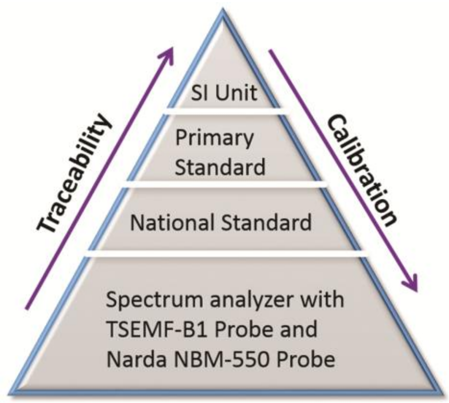

Fig. 5 — Traceability Chart.

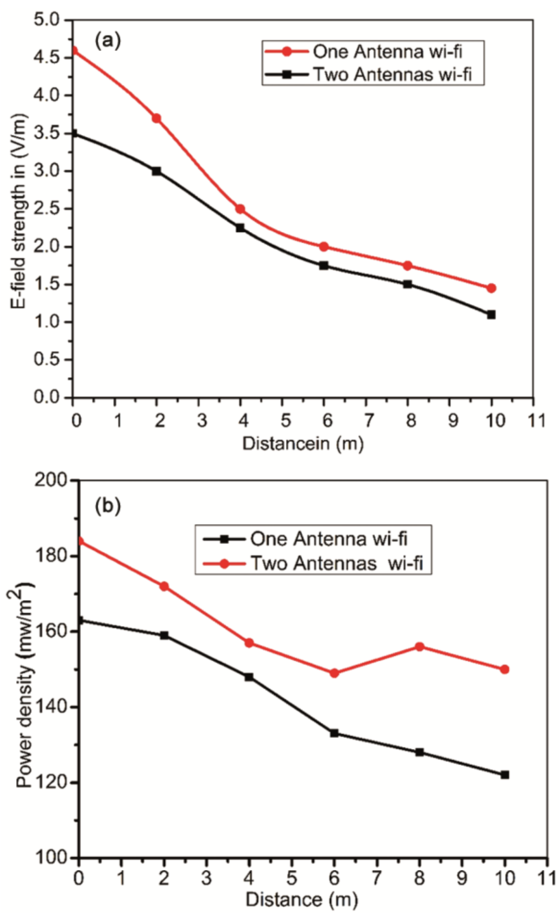

Fig. 6 (a, b) — E-filed strength, radiated power density of 1,2 antennas Wi-Fi router at a distance of 10 meter range.

and below the Wi-Fi router with a distance of 0 to 20-meter range. It can be seen in Fig.8 (a-d) that the Electric field and Power density measured at these locations are decreasing with distance in the order of $1/R, 1/R^2$, as expected equations (1,4).

Table 2 shows indoor measurements comparison of E-field and power density with standard guideline

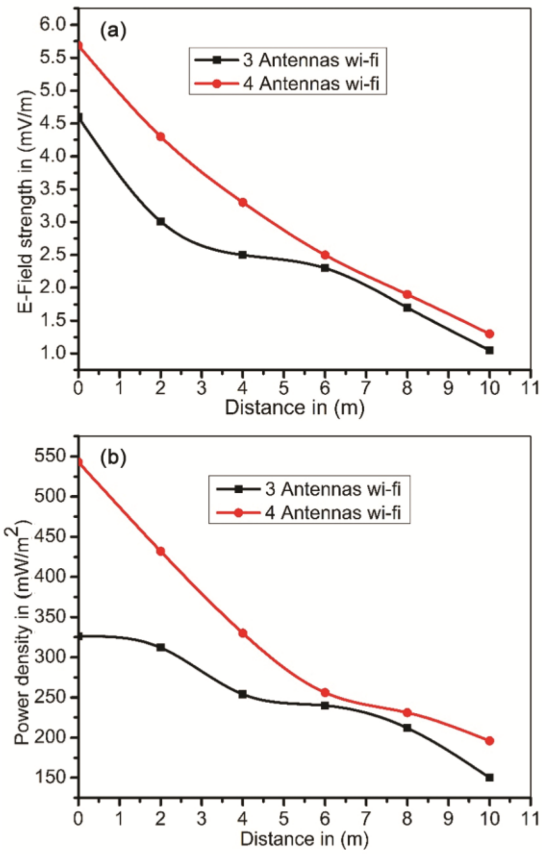

Fig. 7(a, b) — E-filed strength and Radiated power density of 3,4 tower Wi-Fi router at a distance of 0 to10-meter range of 0 to the 10-meter range.

limit, in both cases, the values are within the standard limit. Table 3 describes the comparison of the outdoor measurement of B, C, D, E, E-field, and power density with the standard guideline *i.e.*, the international commission on Non-ionizing radiation protection (ICNIRP), Federal Communication Commission (FCC).

The outdoor measurement values are within FCC, ICNIRP guideline limits towards the train coach and below Wi-Fi, as shown in Table 2, some times the concertation of people using mobile phones near the Wi-Fi routers, the mobile phones uplink communication leads the higher exposer, and thus it may need further deep investigation for the concrete conclusions**.** To overcome the higher exposure the people should observe the public place Wi-Fi devices etc. and maintain the distance of 30 meters away from the RF sources and the people should not wait for more than 5 minutes near wireless devices and using metalized shielding windows to the trains, cars, buses etc. are may protect from the higher exposure.

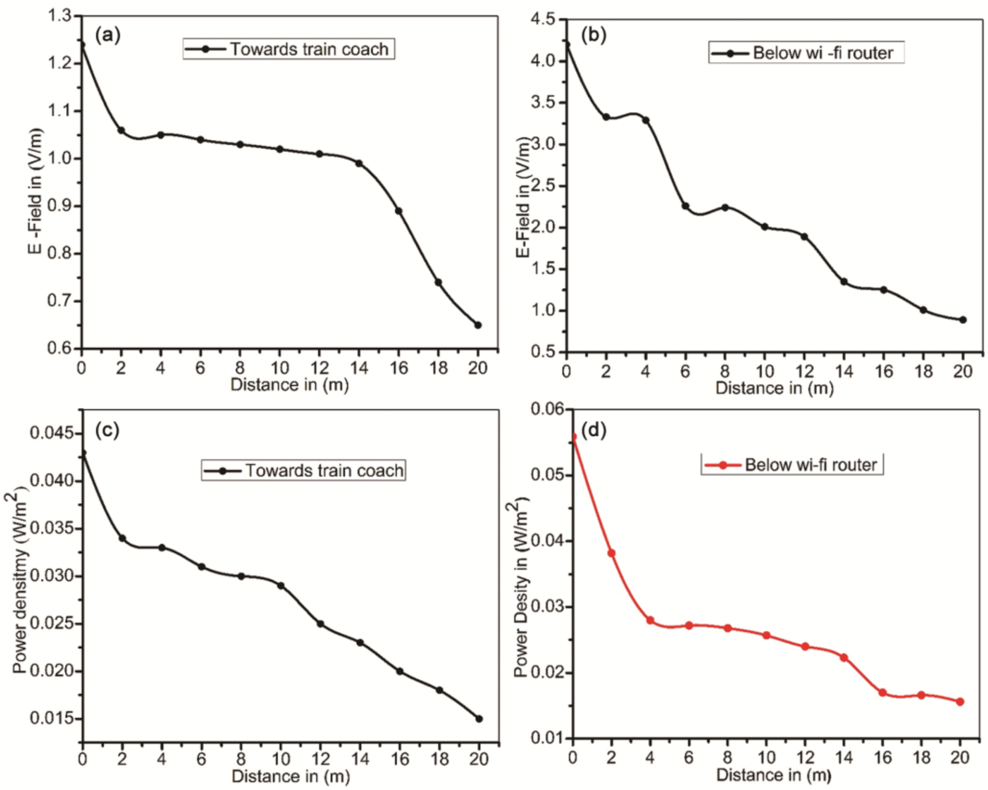

Fig.8 (a, b) — E-filed strength and c, d is Radiated power density towards the train coach and below Wi-Fi at a distance of 20 meter range.

Table 2 — Measured E-field and Power density at indoor-outdoor locations

Indoor locations (A)	E-Field (mV/m)	Power Density in (mW/m^2)	ICNIRP,FCC[47,48] E-field - Power Density
NPL -1,2 Antenna routers	0.7-4.7	182.29-115	0.1 to 6V/m - 10W/m^2
NPL -3,4 Antenna routers	0.5-4.5	555-162.3	0.1 to 6V/m - 10W/m^2
Outdoor locations	Below Wi-Fi - towards the train (V/m)	Below Wi-Fi - towards the train (W/m^2)	
B	4.2 - 45	0.0165-0.0105	61 V/m -10W/m^2
C	3.62 -50	0.0249-0.0103	61V/m -10W/m^2
D	4.89-46	0.0559- 0.0103	61 V/m -10W/m^2
E	1.24 -1.05	0.0066-0.0430	61 V/m - 10W/m^2

Table. 3 — Measured and Standard SAR

Freq. in (GHz)	ϵ'	ϵ''	E-field (V/m)	ω	ϵ_0	σ (S/m)	SAR (W/kg)	Standard SAR(W/kg)
			0.7	1.54E+10	8.85E-12	1.94	0.000951	
2.45	52.68	14.30	4.7	1.54E+10	8.85E-12	1.94	0.042855	1.6,2
			0.5	1.54E+10	8.85E-12	1.94	0.000485	
			4.5	1.54E+10	8.85E-12	1.94	0.038475	
			4.2	3.64E+10	8.85E-12	6.3	0.111132	
2.45-5.87	-	-	3.62	3.64E+10	8.85E-12	6.3	0.082558	
			4.89	3.64E+10	8.85E-12	6.3	0.150646	
			1.24	3.64E+10	8.85E-12	6.3	0.009687	

4.1 Specific Absorption Rate (SAR) Analysis

Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed per unit mass by a human body when exposed to a radio frequency (RF) electromagnetic field, as per IEEE 1528, it is as follows

$$\mathrm{SAR} = \frac{\sigma E^2}{\rho}\ \frac{\mathrm{W}}{\mathrm{kg}} \quad \ldots (8)$$

Where σ is tissue conductivity (S/m), E is the electric field (V/m) and ρ is the mass density of the tissue (kg/m^3)

In the present era of wireless communication, antennas are needed for daily life communication. Guidelines have been issued for the safety of the human body from electromagnetic radiation by concerned organizations *i.e*. Federal communication commission (FCC)[35-39], European international electro technical commission (IEC) and IEEE 1528, ICNIRP has set the safety limit of 1.6W/kg absorbed by 1-gram tissue and 2W/kg for 10-gram tissue. The main important parameters in this problem are human tissue-equivalent complex permittivity *i.e*.

$$\epsilon^* = \epsilon' - j\epsilon'' \quad \ldots (9)$$

where ε′ are the real part or energy absorption (storing) and ε′′ is its imaginary part or loss factor is $j = \sqrt{(-1)}$,generally, the loss factor expressed in terms of loss tangent is

$$\tan\delta = \frac{\epsilon''}{\epsilon'} \quad \ldots (10)$$

in the biomedical application measurement tissue conductivity, also play a wider role with a respective frequency band that is in terms of the imaginary part of tissue *i.e*.

$$\sigma = \omega\epsilon''\epsilon_0\ S/m \quad \ldots (11)$$

Where $\omega = 2\pi f$ *is the measurement frequency and* ϵ_0 *is the permittivity of free space.*

To investigate the SAR experimentally, the human tissue-equivalent liquid (TEL) is essential, for that four ingredients are needed *i.e*. DGBE is 7.99%, Triton x-100 is 19.97%, NaCl is 0.16 and distilled water is 49.75, these ingredient weights of percentage varies with respective frequencies, the TEL prepared as per IEEE1528, the human tissue-equivalent liquid complex permittivity and conductivity measured by using DAK 3.5 dielectric probe[40]. Table 3 shows measured and standard limits of the SAR for indoor and outdoor locations. For the sake of better understanding, the whole human body 3D model has been simulated in a free space environment with help of the Ansys high-frequency structure simulator (HFSS), the SAR variation low to high at below Wi-Fi and towards the train coach as shown in Fig. 9.

Table 4 is the comparison of earlier researcher reported SAR values and current existing precise SAR values has been presented, Findlay, R. P et. al., De Gannes FP et. at. and Foster KR et.al. are reported SAR values[41-43] are 8W/kg,4 W/kg. As per the ICNIRP guidelines, higher SAR values suggest that it

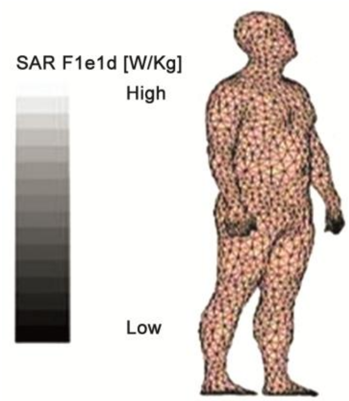

Fig. 9 — Simulated whole-body 3D model with SAR Field [W/kg].

Table 4 — Comparison of previous and existing SAR

Reference	Study of population	2.45 GHz Wi-Fi (SAR) W/kg	2.45-5.87 GHz Metro station Wi-Fi (SAR) W/kg	Outcome
[41]	Full body	8.170	-	The highest SAR value reported
[42,43]	Full body	4.0	-	Cellular DNA damage
[44]	Full body	0.80	-	Risk of pregnant women and children
[45]	cord blood and placenta	0.62	-	studied oxidative stress parameters
[46]	Full body	0.10	-	Study on children and adolescents,
[47,48]	Full body	0.08	-	No effect
[49]	Full body	0.049	-	No effect
Proposed study	Full body	0.042	0.15	Precise low SAR value reported

may harm the biological body. In the present study, we got a much lower SAR value of 0.42W/kg, furthermore, the metro stations Wi-Fi devices precise SAR estimation have been done, this could be an advancement of the study.

5 Conclusions

The radiofrequency electromagnetic field exposure assessment experimental and simulated study has been performed at indoor-outdoor public Wi-Fi devices in five different locations in the Delhi metro stations and offices. The measured results are traceable to the national standards and obtained results of indoor-outdoor locations an electric field, radiated power density both are within and below the limits of the ICNIRP standard at 2.45GHz and 2.45-5.87 GHz.Moreover, the evaluated specific absorption rate values are also within the ICNIRP guidelines.

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