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RF Radiation Distribution & Corresponding Exposure Levels Due to Mobile Base Stations in Sri Lanka

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I. INTRODUCTION

Significant concerns are raised on possible health effects due to exposure to radiofrequency (RF) electromagnetic fields, especially after the rapid introduction of the mobile telecommunication systems [1]. People who live within 100 m – 300 m from the base of mobile phone telecommunication masts (when the mast is clearly visible), are generally more concerned about possible health effects associated with living close to them.
It is believed that radiation levels from the foot of the antenna to a distance of 50 m is due to minor lobes and this is expected to be very small and therefore, it will not be a threat to the public health [2]. From real life assessments of RF intensity around base station antennas, the situation is quite different because the distribution of RF is influenced by nearby base station antennas and other structures. Some studies have shown that there may be an association between some health effects and living very close to GSM (Global System for Mobile telecommunication) base station antennas [3, 4]. In many of these studies carried out at different places around the world to assess the level of RF exposure to the populace, low power densities were found around the base stations. But despite the low exposure obtained from these RF radiation sources, effects on well-being and performance cannot be ruled out as shown by recently obtained experimental results [3, 5, 6].
In Sri Lanka, more base stations are being installed in every part of the country and according to a survey conducted by the TRCSL's (Telecom Regulatory Commission in Sri Lanka), the estimated number of mobile phone subscriptions in March 2017 was around 27.2 millions. Base stations operating in densely populated cities in the GSM) 900, 1800 and UMTS (Universal Mobile Telecommunication System) 2000 MHz frequency bands are continuously evolving due to the conditions of the competition and the need for a better response to increasing customer demand. Up to now, over 7000 mobile base station antennas has been installed in the country by five main network providers. These installations give rise to widespread concerns among the population regarding possible detrimental effects on human health due to the exposure to the electromagnetic waves emitted by these base station antennas. Therefore, it is necessary to determine the exposure levels of main cities due to RF radiation transmitted by the mobile base station antennas (downlink stream) with respect to the three frequency bands. Finally,these exposure levels are compared with the international standards for RF safety issues. This paper also aims to provide RF radiation propagation due to mobile base station antennas in major cities with respect to each network provider.
Studies carried out by other countries, such as Saudi Arabia, maximum and minimum power densities in the reported sites were 0.0981 W/m^2 and 0.0007 W/m^2, respectively [7]. Based on those results, the maximum electromagnetic radiation was approximately 4.9% of the national guidelines of Saudi Arabia [7]. In the United Kingdom, from 118 locations maximum power density reported was 8.3 mW/m^2 [8].

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ELECTRIC FIELD INTENSITY AND POWER DENSITY

The electric field intensity, *E*, and power density, *S*, of an electromagnetic field are two quantities whose limiting values are specified by international standards for public safety. If the maximum electric field at a particular location due to all RF sources in the environment can be obtained by measurement, then the power density, of the electromagnetic field at that location can be estimated from the equation (1).

$$S\ (\mathrm{W/m^2}) = \frac{E^2}{\eta} \quad (1)$$

where η is the intrinsic impedance of free space = 377 Ω.

The electromagnetic radiation reference levels of power density are given in Table 1 [9]. In Sri Lanka, the TRC uses the FCC standards for RF safety issues.
If the experimental values of *E* and *S* are less than the safety standards specified by the accepted international organizations, then it is assumed that there is no health risk.

Table 1. Electromagnetic radiation reference levels for General public according to FCC standards.

Frequency Bands	EMR Reference level Power Density, S ($\mathrm{W/m^2}$) [frequency f in MHz]
900 MHz	$f/150$
1800 MHz	10
2 GHz	10

In order to ensure compliance with the Maximum Permissible Exposure (MPE) for the environment, a dimensionless quantity known as the *exposure quotient* is calculated [10]. This quantity is expressed in terms of the calculated power density *S* from measured results of the field strength and the MPE in power density. Thus,

$$\text{exposure quotient} = \frac{S}{MPE} \quad (2)$$

For a certain location, all the signals from different networks with respect to those three frequency bands were considered. The sum of the ratios of the measured power density to the corresponding MPE of the power density should not exceed one [11] to ensure safety. That is

$$\sum_{i=1}^{n} \frac{S_i}{MPE_i} \le 1 \quad (3)$$

where,
S_i - Power Density at the i^{th} frequency, frequency given in MHz
MPE_i - Reference level of the Power Density at the i^{th} frequency
n - Total number of transmitting signals

If this condition is not met, the environment may be at a risk in future.

II. METHODOLOGY

The measurements of field intensity were made at different locations, which represent highly populated flat urban environment, such as Colombo, Gampaha, Jaffna and Kurunegala. Further, along the coastal belt from Jaffna to Trincomalee which are urban. Kandy, Matale, Nuwara-Eliya, Badulla and Bandarawela are hilly areas at high elevation and measurements were taken from other areas of the country as well. These cities are shown in Fig.1. The measurement set up used is shown in Fig. 2.

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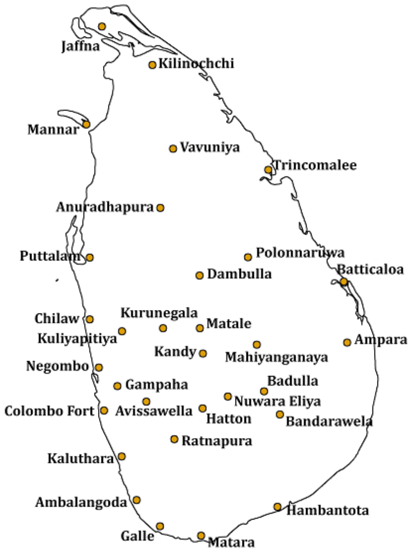

Figure 1. Site survey map

Figure 2. Measurement set-up

It consists of standard Yagi-antenna (Telewave product – USA) of different frequency ranges and a spectrum analyzer (Anritsu MS 2712 E – 100 kHz to 4 GHz). Three different antennas were used to measure the signals in 900 MHz, 1800 MHz and 2 GHz bands.

All measurements were taken during the day time when most of the mobile phones are normally in use. For measuring the field strength in each city, a particular location was selected by considering the most populated areas such as public bus stands, railway stations, playgrounds, etc. This location was selected by avoiding large buildings where interferences might be caused. The antenna was mounted 1.4 m above the ground level (i.e., the approximate height of all human beings) and it was replaced according to the frequency band considered. Figure 3 shows the frequency slots allocated to the network providers in downlink stream by the TRCSL in three frequency bands [12].

For a particular network provider, operating in a certain bandwidth, the maximum voltages received were obtained with respective to the different channels operated in that frequency slot from the spectrum analyzer. This was done by rotating the antenna in 360^0 in 8 steps as 45^0 divisions. The approximate time spent for a one step was two minutes. Then finally it gave the maximum voltages received for the corresponding channels belonging to the network provider. Likewise for one frequency band, all signals received belong to different network providers within the allocated frequency slots were scanned at a particular location. This was repeated for other two frequency bands as well. The total time spent for location was approximately five hours.

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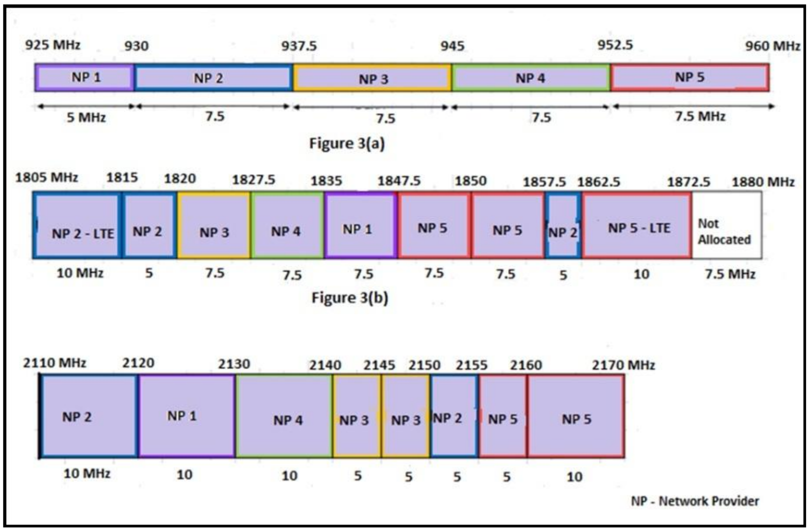

Figure 3. Frequency slots allocated for the network providers in downlink stream [Figure (a) in 900 MHz band, Figure (b) in 1800 MHz band, Figure (c) in 2 GHz]

For a particular city, a large number of signals was considered. A typical spectrum analyzer measurement is shown in Figure 4.

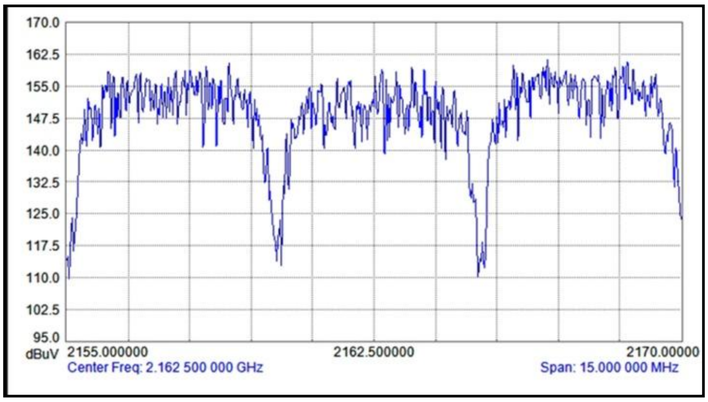

Figure 4: Spectrum analyzer measurement of 2 GHz frequency band signal at Galle

The measured value of V_m was converted to field intensity E (dBμV/m) using Eq. (5). Then it was converted into the numerical value.

$$E\ (\text{dB}\mu\text{V/m}) = K\ (\text{dB/m}) + V_m\ (\text{dB}\mu\text{V}) + L\ (\text{dB}) \qquad (5)$$

Where, K (dB/m) is the antenna factor which is the ratio of electric field strength at the antenna to the voltage produced at the antenna connector. The value of K is given by the antenna manufacturer. The corresponding antenna factors for the frequency bands of 900 MHz, 1800 MHz and 2 GHz are 17.7 dB/m, 24.1 dB/m and 33.4 dB/m respectively. Here L (dB) is the total system loss. The system loss was measured experimentally using a synthesized signal generator and it was observed as L = 8 dB.

The measured signal field strength is only from one direction and it is in the direction of maximum field strength received for that signal. For the **worst case** (maximum possible) situation we suppose that this field comes from three orthogonal directions. This will be added as an additional safety factor for the exposure level. Hence,

$$E_{Worst}^2 = E_X^2 + E_Y^2 + E_Z^2 \ ; \ E_X = E_Y = E_Z = E_{Max}$$

Therefore,

$$E_{Worst}\ (\text{V/m}) = \sqrt{3}E_{Max} \qquad (6)$$

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From eqn. (1), the power density in **worst-case** situation becomes,

$$S_{Worst}\ (\text{W/m}^2) = \frac{E^2_{Worst}}{\eta} \qquad (7)$$

The Electric field strength and the Power density were calculated using Eq. (5) to (7). For instance, measurements taken at Vavuniya showed the highest strength for 2 GHz band and the value is 79.185 dBµV. The calculation process for that signal is as follows.

From equation (5); E_{max} = 24.1+79.185+8 = 111.285 dBµV/m
Converting dBµV/m to V/m;
E_{max} = 0.3666 V/m
From equation (6); $E_{worst} = \sqrt{3} \times 0.3666$
E_{worst} = 0.63497 V/m
From equation (7); $S_{worst} = (0.63497)^2 / 377$
$S_{worst} = 1.0694 \times 10^{-3}$ Wm^{-2}
From equation (2); Exposure Quotient (E.Q) = $1.0694 \times 10^{-3} / 10$
E.Q = 10.694×10^{-5}

Likewise the total exposure quotient was calculated by considering all signals received. The calculated values of field intensity and power density were compared with the FCC standards given in Table 1.

III. RESULTS AND DISCUSSION

Table 2 shows the exposure quotients in different cities for different frequency bands in the descending order and RF radiation distribution in these cities with respect to mobile base station antennas belonging to five network providers. These measurements were based on the frequency spectrum allocated for the mobile cellular network providers in Sri Lanka by the TRC as in Figure 3.

The values in Table 2 show the maximum possible exposure levels because these results are based on the worst-case condition and they are below the FCC guidelines.
The results are illustrated in Figure 5. Among the cities considered, the highest exposure level was at Vavuniya and measurements were taken at a place close to the public bus stand. This may be due to the fact that the two network providers established their base station antennas more recently and transmitted high power levels to have a maximum coverage area. The highest contribution to RF absorption by the human body at this site was due to 2 GHz band. However the exposure level was approximately one third of the accepted limits and therefore it was not much less than the specified limits.
The minimum exposure level was reported in Puttalam and it was 1220 times lower than the prescribed permissible level. From Table 2, it can be observed that in 19 sites out of 30, the major exposure contribution is due to the 2 GHz mobile base stations. This may be due to the fact that almost all the network providers were upgraded their systems to higher frequency bands because of the additional features given. The other significant point is that in the most populated areas such as Colombo Fort and Jaffna, the exposure level is more than 100 times below the limits. That is due to the installation of micro cellular base station antennas by replacing macro cellular base station antennas. By this they can reduce the coverage area thereby reducing the transmitting power.
At the hilly areas such as Badulla, Bandarawela, Nuwara Eliya and Hatton, most of the base station antennas are mounted on top of the hills and comparatively higher power levels are transmitted to cover the town limits.

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Table 2: Exposure quotients and Maximum average values of indicated signal voltage of all signals from a given network provider with respect to different frequency bands.

City	Exposure Quotient $\times 10^{-3}$				Leading Network Provider with Maximum average signal voltage in dBµV		
	900 MHz	1800 MHz	2 GHz	Total	900 MHz	1800 MHz	2 GHz
Vavuniya	6.52	31.78	240.48	278.78	169.32-**NP 5**	161.74-**NP 5**	163.02-**NP 5**
Ratnapura	0.27	4.92	74.83	80.01	154.61-**NP 2**	150.38-**NP 2**	161.22-**NP 2**
Kilinochchiya	0.27	13.11	62.79	76.17	158.86-**NP 5**	151.97-**NP 5**	161.21-**NP 5**
Mannar	14.66	28.26	24.58	67.49	164.98-**NP 5**	158.01-**NP 2**	163.74-**NP 5**
Gampaha	8.14	26.54	9.87	44.55	165.88-**NP 4**	166.77-**NP 2**	165.69-NP 2
Badulla	18.29	1.01	19.68	38.98	167.75-**NP 1**	150.94-**NP 2**	160.74-**NP 2**
Polonnaruwa	0.17	8.72	23.56	32.44	142.35-**NP 1**	153.12-**NP 1**	160.95-**NP 1**
Kandy	13.28	7.37	8.28	28.93	174.20-**NP 1**	168.70-**NP 4**	161.66-**NP 2**
Kalutara	4.03	8.46	12.68	25.18	158.66-**NP 1**	155.13-**NP 5**	161.11-**NP 5**
Hambantota	9.12	1.31	11.00	21.43	160.37-**NP 2**	156.69-**NP 4**	158.13-**NP 5**
Baticaloa	0.15	4.21	15.60	19.96	148.90-**NP 5**	151.92-**NP 5**	159.87-**NP 5**
Kurunegala	4.15	2.19	13.52	19.86	171.90-**NP 4**	162.85-**NP 5**	163.73-**NP 5**
Anuradhapura	7.03	1.91	10.06	19.00	161.45-**NP 5**	151.96-**NP 2**	159.00-**NP 3**
Galle	2.20	1.85	13.82	17.87	160.86-**NP 1**	150.91-**NP 5**	159.81-**NP 1**
Ambalangoda	1.41	2.09	11.46	14.95	161.16-**NP 5**	152.81-**NP 5**	157.66-**NP 5**
Matara	0.48	12.89	1.21	14.58	159.43-**NP 5**	149.87-**NP 2**	151.58-**NP 5**
Bandarawela	2.26	1.30	10.41	13.97	163.31-**NP 5**	152.43-**NP 5**	160.67-**NP 5**
Ampara	10.75	0.47	2.24	13.47	167.69-**NP 1**	146.01-**NP 1**	152.14-**NP 4**
Trincomalee	5.42	0.36	6.97	12.75	163.33-**NP 1**	144.34-**NP 5**	159.84-**NP 1**
Hatton	1.63	6.89	3.50	12.02	154.43-**NP 1**	145.20-**NP 5**	154.72-**NP 5**
Nuwara Eliya	1.84	0.44	9.06	11.33	165.96-**NP 1**	149.67-**NP 5**	159.67-**NP 5**
Colombo Fort	0.79	3.79	1.76	6.34	167.16-**NP 3**	161.12-**NP 2**	168.33-**NP 5**
Matale	3.11	0.40	1.98	5.49	169.05-**NP 1**	155.65-**NP 5**	159.50-**NP 5**
Jaffna	0.10	1.57	2.88	4.55	149.66-**NP 5**	152.01-**NP 5**	153.05-**NP 5**
Negombo	1.89	0.39	1.33	3.61	171.58-**NP 1**	153.03-**NP 5**	158.12-**NP 5**
Dambulla	0.89	0.30	2.23	3.43	152.77-**NP 5**	145.92-**NP 5**	158.32-**NP 5**
Awissawella	0.30	1.74	1.37	3.41	154.29-**NP 1**	141.39-**NP 2**	152.06-**NP 5**
Chilaw	1.60	0.64	1.10	3.34	165.15-**NP 5**	154.09-**NP 1**	157.56-**NP 5**
Mahiyanganaya	0.23	0.12	1.43	1.78	154.38-**NP 5**	138.12-**NP 4**	150.57-**NP 4**
Puttalam	0.37	0.04	0.41	0.82	160.28-**NP 5**	144.57-**NP 1**	148.31-**NP 2**

From Table 2, we can have an idea about the RF strength distribution with respect to five network providers in each city. Maximum average RF strengths in all cities with respect to each frequency band were also tabulated. This gives the highest average values of signal voltages indicated of all signals from a given network provider in that frequency band. This is important because all the signals belonging to a certain network provider in that location were considered. These average RF strengths were calculated by assuming the signals received from exact frequencies of 900 MHz, 1800 MHz and 2 GHz. Location wise in all frequency ranges, NP 5 dominates at Vavuniya, Kilinochchi, Baticaloa, Ambalangoda, Bandarawela, Jaffna and Dambulla while NP 2 dominates at Ratnapura and NP 1 dominates at Polonnaruwa. The maximum received signal from all considered cities with respect to each band is given in table 3;

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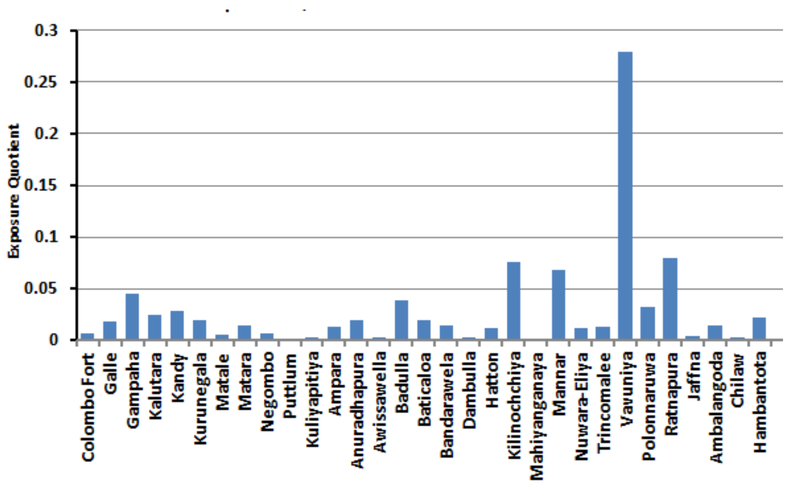

Figure 5: Exposure Quotients of main cities in Sri Lanka.

Table 3: Maximum signal received voltages in all measured cities.

Frequency Band	Location	Signal Frequency (MHz)	Signal voltages (dBμV)	Network Provider
900 MHz	Gampaha	946.4	93.513	NP 4
1800 MHz	Galle	1816.7	89.137	NP 2
2 GHz	Vavuniya	2110.7	79.185	NP 2

Table 4 shows the maximum average signal strengths from all cities considered in each frequency range.

Table 4: Maximum average signal voltages received in all measured cities.

Frequency Band	Location	Signal voltage (dBμV)	Network Provider
900 MHz	Kandy	67.211	NP 1
1800 MHz	Kandy	61.710	NP 4
2 GHz	Colombo Fort	61.340	NP 5

Data gathered reveal that in major cities comparatively higher strengths could be found and as predicted, rural places such as Polonnaruwa, Mahiyanganaya and Puttalam showed the minimum strengths with respect to 900 MHz, 1800 MHz and 2 GHz bands respectively.

Figure 6 shows the total number of cities that each of these network providers dominates in maximum average strengths with respect to each frequency range;

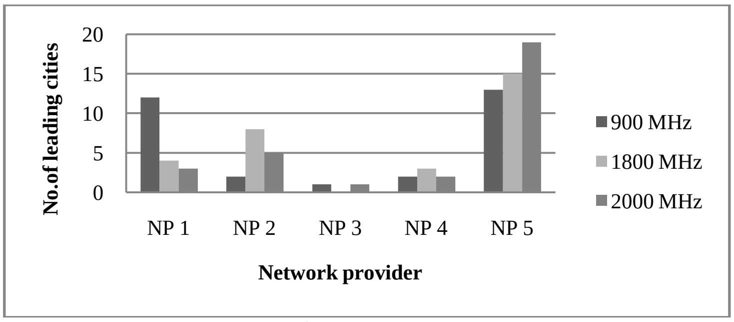

Figure 6: Total number of leading cities in each network provider w.r.t. each frequency band.

Figure 6 clearly shows that among the network providers, NP 5 leads in all frequency ranges at those cities considered in maximum average strengths. NP 3 dominates in only two cities in two frequency ranges and normally it provides comparatively lower strengths. In most of the cities, one network provider shows the maximum strength but not the maximum average strength. For instance, in 900 MHz band, maximum strength showed at Gampaha by NP 4 but the average maximum showed at Kandy by NP 1.

IV. CONCLUSION

Measurements indicate that the exposure levels due to all mobile cellular network providers as at August 2018 for the general public in locations considered in this work are below FCC specified safety standards. In some cities of Northern Province comparatively higher exposure levels have been shown. Colombo and Jaffna show comparatively lower values due to the installation of micro cellular base station antennas. From among the sites measured, the highest exposure level was reported at Vavuniya mostly due to the 2 GHz band but it was still one-third of the permissible level. About 75% of the total exposure from all sites considered, is due to the 2 GHz band. Some of the hilly areas show comparatively higher exposure levels than flat terrains. According to the analyzed data, exposure levels of places such as Vavuniya, Ratnapura and Kilinochchiya are not very much below the standards. Therefore this kind of exposure assessment should continuously be done at least once in two years since mobile base station antennas are being built at a rapid rate. It is advisable to build micro cellular base station antennas by replacing macro cellular base station antennas to have a good coverage without interferences and to minimize the exposure levels.
According to the RF radiation distribution with respect to the mobile base station antennas from the cities considered in the country, NP 5 leads in all frequency ranges. That evaluation was done based on maximum average strengths received. Also in all cities considered, NP 3 provides comparatively lower strengths. Major cities show considerable higher strengths and as predicted some rural areas with low capacity show lower RF strengths.

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REFERENCES

[1] Wolf, R., and D. Wolf. 2004. "Increased Incidence of Cancer near a Cell-Phone Transmitter Station". *International Journal of Cancer Prevention*. 1(2):1- 19.
[2] M.A.A. Karunarathna and I.J. Dayawansa, "Human Exposure to RF radiation in Sri Lanka", Sri Lankan journal of Physics, vol.6, pp19-32, March 2005.
[3] Hutter, H.P., H. Moshammer, P. Waller, and M. Kundi. 2006. "Subjective, Sleeping Problems, and Cognitive Performance in Subjects Living Near Mobile Phone Base Station". *Occup. Environ. Med*. 63:307-313.
[4] Santini, R., P. Santini, J.M. Danze, P. Le Ruz, and M. Seige. 2003. "Symptoms Experienced by People Living in Vicinity of Cell Phone Base Station: Incidence of Distance and Sex". *Pathol. Biol.* 50:369-373.
[5] E. Singh, "Cell phone hazards and recommendations", *J. Telecommunications (India)*, Vol.59, no.6, pp. 44-50, 2011.
[6] James C.Lin, "Biological Bases of Current Guidelines for Human Exposure to Radio-Frequency Radiation', *IEEE Trans. Antennas Propagat*, Vol.45, No.3, June 2003.
[7] M. Nahas, T. Mohammed and Simsim, "Safety Measurements of Electromagnetic Fields Radiated from Mobile Base Stations in the Western Region of Saudi Arabia", *Wireless Engineering and Technology*, Vol. 2, pp. 221-229, 2011.
[8] S.M. Mann, T.G. Cooper, S.G. Allen, R.P. Blackwell and A.J. Lowe, "Exposure to Radio Waves near mobile Phone Base Stations", NRPB-R321, June 2000.
[9] FCC Std.,Guidelines for Evaluating the Environmental Effects of Radio Frequency Radiation, FCC 96-326, Washington,DC,1996.
[10] ICNIRP Std., Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and electromagnetic Fields (Up to 300 GHz), Health Physics, 74, 1998,pp.494-522.
[11] IEEE International Committee on Electromagnetic Safety, "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300GHz," (IEEE C95.1-2005) 2006.
[12] Consultation document (2018, August), Radio Frequency spectrum allocations of Sri Lanka, Telecommunications Regulatory Commission of Sri Lanka (TRCSL). Available: http://www.trc.lk