EMF Exposure Reduction Using Weighted Angle Model for Multi-Technology Sectorized BS

Original Scientific Paper

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Abstract *– Mobile networks are now growing quickly due to major advancements in wireless technology especially with the introduction of the Fifth Generation New Radio (5G NR). A greater risk of exposure to electromagnetic field radiation (EMF) is being raised by the widespread deployment of base stations (BSs). Standard guidelines are set to control the amount of EMF radiation. This paper proposed a design model to de-concentrate and reduce the total exposure of the multi-technology BS with no drawbacks on network coverage level and key performance indicators (KPIs). The proposed solution applies the concept of weighted antenna's azimuth to spread the total exposure by separating the antennas in the same sector. A set of simulations is carried out to calculate the reduction in total exposure ratio (TER) and the Compliance Distance (CD). Also, A field measurement test was done in a life network to validate and evaluate the proposed model under real conditions. Furthermore, the network operation support system (OSS) records were analyzed to evaluate the impact on the network coverage and capacity behavior. The pre- and post-results demonstrate that using the proposed model enhanced the CD and TER., the results show using two azimuths reduces the CD by 23% and by 43.4% when using six antennas. Also, the field test result demonstrated a 19.23% reduction in the Total Exposure Ratio. Overall, the system records show no significant impacts were registered on network coverage level and capacity performance for the sites involved in the test.*

Keywords*:* *mobile wireless network, antenna sectorization, mobile coverage planning, EMF compliance distance*

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1. INTRODUCTION

Rapid development and extensive installation of mobile wireless networks increase the number of BSs that transmit data. enormous numbers of site BSs have been connected to provide the network with enough coverage and boost resource capacity. This has led to extremely enormous data transfers via mobile wireless networks, which will expand significantly by 2030 [1]. 2G Global System for Mobile Communication (GSM), 3G Universal Mobile Telecommunications System (UMTS), 4G Long-Term Evolution (LTE), and most recently, 5G NR, are the most widely used technologies in mobile wireless networks. Concerns regarding the negative effects on human health are addressed due to the rise in electromagnetic fields as a result of the development of new technologies [2].

Predictions state that 5G technology will evolve into an all-purpose system [3] because it provides high capacity and enables rich features and services that expand the number of business prospects and strengthen the global economy. For 5G development, NR BSs must be installed in higher frequency bands [4], mostly by colocating them with current 2G, 3G, and 4G technologies.

A group of technologies and solutions in one place needs an examination of the overall accumulated radiation and the exposure level in relation to standard limitations. Many studies indicate this evaluation even should take place during the design stage of the network before deployment as EMF is a constraint in network planning especially for 5G [5, 6].

Nearly all cellular network operators use sectorized base stations with directional antennas. The 3-sector model is particularly useful for optimizing load balancing, capacity resource management, inside and outdoor coverage, and interference reduction. Furthermore, various technologies spreading in the same directions as co-located are carried by the same sectors. Depending on the operator's design strategy [7], the group of technologies either be connected to one multi-band antenna, or might be installed into separate antennas, but all antennas of one sector are directed in the same azimuth.

The investigation of EMF for multiple technologies is a crucial topic that aims to enhance the assessment of the compliance distance and to introduce models to minimize it, especially since it requires the operators to identify the compliance distances and mark them as exclusive zones and should be not accessible for the general public.

The contribution of this study lies in providing a simple design solution to reduce the total exposure emitting from sectorized antennas of the multi-technology BS by applying horizontal separation angles between the antennas in the sector to de-concentrate the total accumulated exposure in the same direction, while maintaining the network performance with almost no impact on the coverage signal levels and performance. This model can be practically applied to the widely commonly used antennas that are currently installed for multi-technology BSs.

This manuscript is structured into nine sections including the introduction in Section 1. In Section 2, the total exposure ratio related to standard limits is briefed. The literature review and related work are discussed in Section 3. In Section 4, the proposed model is explained in detail. In Section 5, the simulation setup and results are presented and discussed. In Section 6, the in-situ assessment is explained and the results are discussed. Section 8 gives recommendations for the potential application of the proposed model. At last, Section 9 summarizes the paper's conclusion.

2. TOTAL EXPOSURE IN STANDARDS

The Federal Communication Commission (FCC), which establishes regulatory criteria in the USA [8], and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) which is established in Europe [9] are two well-known organizations that have established and published standard recommendations. Governmental and national authorities in many nations have utilized these guidelines to manage the installation of EMF transmitters and the activities associated with them [10, 11]. The FCC and ICNIRP standards make a distinction between the technical occupational workers (OW) and the general public (GP). The OW refers to the staff members who are well-trained to be aware of potential EMF hazards and are exposed to certain related scenarios, and the GP are characterized as being normal people who are exposed to electromagnetic fields and are not aware of the dangers associated with them.

The whole-body radiation reference levels have been set by ICNIRP for both the occupational workers and the normal general public under the transmitting frequency, as listed in Table 1.

Table 1. ICNIRP Reference Limits for OW and GP

Exposure Boundary	Frequency Range	E - field (V/m)	H - field (A/m)	PD (W/m²)
OW	0.1 - 30 MHz	$660/f_M^{0.7}$	$4.9/f_M$	NA
	>30 - 400 MHz	61.0	0.16	10.00
	>400 - 2,000 MHz	$3\ f_M^{0.5}$	$0.008\ f_M^{0.5}$	$f_M/40$
	>2.0 - 300 GHz	N/A	N/A	50.00
GP	0.1 - 30 MHz	$300/f_M^{0.7}$	$2.2/f_M$	NA
	>30 - 400 MHz	27.70	0.073	2.00
	>400 - 2,000 MHz	$1.375 f_M^{0.5}$	$0.0037\ f_M^{0.5}$	$f_M/200$
	>2.0 - 300 GHz	N/A	N/A	10.00

Also, the FCC standard has defined the maximum limits of exposure as the maximum permitted exposure (MPE) levels for the GP and OW according to the transmitting frequency band as listed in Table 2.

Table 2. The FCC exposure limits for 0.3 MHz to 100 GHz, for OW and GP

Exposure Boundary	Frequency Range	E - field (V/m)	H - field (A/m)	PD (W/m²)
OW	0.3-3.0 MHz	614.0	1.630	100.0
	3.0-30 MHz	$1842/f$	$4.89/f$	$900/f^2$
	30-300 MHz	61.40	0.163	1.00
	0.3-1.5 GHZ	-	-	f/300
	1.5-100 GHz	-	-	5.00
GP	0.3-1.34 MHz	614.0	1.630	100
	1.34-30 MHz	$824/f$	$2.19/f$	$180/f^2$
	30-300 MHz	27.50	0.0730	0.20
	0.3-1.5 GHz	-	-	$f/1500$
	1.5-100 GHz	-	-	1.00

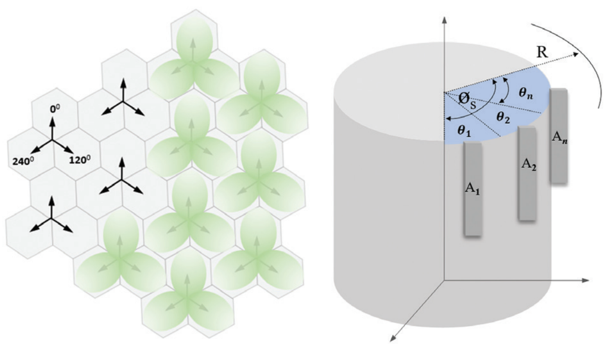
3. LITERATURE REVIEW

Owing to the significance of this subject, a great deal of research and studies have been done, and more is still being done. Aiming to examine the EMF exposure inquiry and evaluation, the recently published results in worldwide organizations concerning this topic are examined and presented from a number of viewpoints and aspects. This section evaluated a few examples that were recently published, and explored their work methods, conclusions, and outcomes. The following summaries are for those works that focused on determining the total exposure and compliance boundaries:

- The authors of [12] suggested conservative formulae to calculate the whole-body and localized SAR for the main beam exposure from the BS. The heuristic nature of the proposed formulas, their applicability to a class of typical base station antennas, their creation from multiple physical observations, and the results of a comprehensive literature review, measurements, and numerical simulations of typical exposure scenarios all lend support to their creation.
- The compliance distance for 2G GSM operating at 1800 MHz was calculated by the authors in [13] based on field measurements they conducted in various locations within the university (Symbiosis International University campus Pune, India). The calculated compliance distance is 8.4 meters.
- A novel technique for measuring 5G NR exposure based on user actions, including the evaluation of auto-included exposure of base stations and user phones, was suggested by the authors in [14]. Their study is based on information from earlier RF-EMF exposure research as well as certain studies that simulate NR base stations and readings close to test sites.
- In [15], the authors measured the 4G LTE TDD mMIMO in situ while accounting for 100% traffic load and maximum system utilization. The findings indicate that the EMF level was between 7.3 and 16.1% of the ICNIRP occupational reference level, as opposed to 79.3% based on traditional conservative calculations, and that the actual compliance boundaries were reduced by 2.2–3.3 times the conservatively calculated boundaries. The authors explain this drop by pointing to the irregular and unique conduct of mMIMO beamforming. They also point out that a further fall in the compliance barrier is anticipated because actual RBS traffic loading is typically substantially lower than 100%. Pinchera et al. analyzed the power levels surrounding the 5G antenna array in [16] to determine the compliance boundary and appropriately evaluate the exposure level. Using a statistical method, the authors presented a measure called normalized average power pattern (NAPP) for determining the average power density surrounding the antenna. Their findings illustrate the compliance distances that were computed using various power reduction factor values.
- In [17], Thielens et al. (at Ghent University) used finite-difference time-domain (FDTD) simulations for a 4G LTE base station antenna at 2,600 MHz to establish the EMF exposure compliance bounds. Their findings demonstrate that when the antenna is only partially radiating, the reference levels are not conservative for the different fundamental limitations and reference levels. Furthermore, their findings demonstrate that the compliance boundaries for fundamental restrictions at lower antenna powers are provided by the 10g averaged SAR in the head and trunk of the body.
- In [18], Heliot et al. used a commercial 5G BS operating at 3.6 GHz and a mMIMO customizable testbed operating at 2.6 GHz to examine the nature of mMIMO exposure and its effects on the compliance boundary. Their statistical exposure-based exclusive zone definition results are intriguing. According to their investigation, there are considerable changes in exposure depending on the direction of the beams. Additionally, assuming a fixed traffic load, the variance of exposure tends to decrease as the number of users increases. Conversely, regardless of the user numbers, the exposure rises sublinearly with traffic load.

4. TER DE-CONCENTRATION FOR THE BS

More effective coverage planning is possible when the cell site coverage is divided into sectors, which means dividing the coverage area into smaller sectors served by individual antennas. RF engineers adjust the signal propagation to reflect the geographic distribution of mobile users by concentrating the coverage in particular directions as shown in Fig. 1. (A) which represents (as an example) the three-sector model with 0/120/240 degrees as antennas' azimuth for the horizontal directions. Within the same cell site, the available frequency spectrum can be utilized numerous times with sectors remaining unaffected. This expands the cell site's total capacity and enables the simultaneous service of additional customers. Also, improved load distribution throughout the cell site is made possible by antenna sectorization. Traffic can be dynamically forwarded across sectors during high usage periods to reduce congestion and guarantee that all users receive sufficient service quality. The RF engineers may simplify their planning and deployment process according to the area's nature, and they focus on improving every region separately, accounting for variables like topography, population density, and anticipated traffic patterns. Generally, sectorization is a commonly used technique in the construction and optimization of mobile cellular networks because it offers a balance between coverage, capacity, and interference control overall [19].



(a) (b)

Fig. 1. (a) The three-sector model with 0/120/240 degrees is commonly used in mobile networks. (b) One sector in sectorized cells with i number of antennas.

While sectorization can enhance network performance and capacity, it increases the EMF radiation by concentrating the radiated signals from all technologies in the antenna's directions. Upon the guiltiness of ICNIRP and FCC, the total exposure should be calculated considering the accumulated power density from the transmitting sources.

Fig. 1. (b) shows a sectorized cell with n number of antennas in one sector. From [8, 9] the exposure ratio for each transmitter can be calculated using Equation (1).

$$ER_f = \frac{S_{inc,f}}{S_{inc,RL,f}} \tag{1}$$

Where ER_f is the Exposure Ratio at distance R from the antenna transmitting at frequency f. $S_{inc,f}$ and $S_{inc,RL,f}$ are the incident local power densities and their reference level at frequency f listed in Tables 1 and 2.

The $S_{inc,f}$ can be calculated using Equation (2)

$$S_{inc,f} = \frac{P_{T,f}\,.\,G_{A,f}}{4.\pi.R^2} \tag{2}$$

Where P_T is the transmitted power in watts, and G_A is the antenna's gain of the transmitter at frequency f.

By substituting Equation (2) in the nominator of Equation (1) ir gives Equation (3) as:

$$ER_f = \frac{P_{T,f}\,.\,G_{A,f}}{4.\pi.R^2.S_{inc,RL,f}} \tag{3}$$

Reference to [8, 9] The total exposure ratio of n number of transmitters in one antenna TERn can be calculated using Equation (4) as:

$$TER_n = \sum_{n,f} ER_f \tag{4}$$

Furthermore, the total exposure ratio of N sectors in one site TER_N can be calculated using Equation (5) as:

$$TER_N = \sum_{n=1}^{N} TER_n \tag{5}$$

Thus, by substituting Equation (4) in Equation (5), the TER_N can be calculated using Equation (6) as:

$$TER_N = \sum_{n=1}^{N}\sum_{n,f} ER_f \tag{6}$$

Although the three-sector model is commonly used for cell sectorization, this study considered the general case of N_s number of sectors of one BS in the proposed model. Assuming each sector contributes equally in the TER of one BS, thus, the total exposure of one sector comes through angle width $\emptyset_s$ which can be calculated simply using Equation (7):

$$\emptyset_s = \frac{360}{N_s} \tag{7}$$

Within one sector, the total exposure TERN can be distributed among the whole $\emptyset s$ by azimuth shifting the direction of each antenna towered separate sub-angle, each sub-angle has an angle width θ_n where n is the number of antennas in one sector. Each θ_n to have an angle width based on the TER_n weight out of the TER_N, which means the θ_n is the weighted angle proportional to TER_n. Of course, this manner is to be applied for other sectors in the same site to have repeated antenna's azimuth arrangement in the way for one technology to have the same antenna angle separation between all sectors. Thus, this approach gives a model to deconcentrate the total exposure (as spreading) in sub-directions rather than having all antennas transmitting toward one direction. So, the θ_n can be calculated using Equation (8).

$$\theta_n = \emptyset_s * \frac{ER_n}{TER} = \frac{360}{N_s} * \frac{TER_n}{TER_N} \tag{8}$$

Finally, by substituting Equations (3, 4, 6) into Equation (8), it gives Equation (9) to calculate the θ_n

$$\theta_n = \frac{360}{N_s} * \sum_{n,f} \frac{P_{T,f}\,.\,G_{A,f}}{\mathrm{S_{inc,RL,f}}} \Bigg/ \left(\sum_{n=1}^{N}\sum_{n,f} \frac{P_{T,f}\,.\,G_{A,f}}{\mathrm{S_{inc,RL,f}}} \right) \tag{9}$$

In the assessment section (section 7), will discuss in detail the results that show this model doesn't affect the base station performance in terms of coverage level and capacity. However, it is important to mention this model is applicable for macro sites that serve in areas where continuous coverage is required around the whole site area, and it's not applicable for below such cases:

- For sites that have sector's azimuths intentionally are directed toward certain locations for special coverage and capacity requirements such as highway road sites.
- For sites that use one antenna for all technologies such as penta-band and hexa-band antennas.

5. CD FOR SECTORIZED BASE STATION

IEC62232 has stated in their guidelines the most precise compliance border possible as an iso surface pattern that may be contained in a simpler shaped volume to create more restricting parameters, such as the box-shape (horizontal, vertical, and side) that is appropriate for the sectorized site with the vertical and horizontal boundaries of the coverage antenna. The box-shape compliance range is taken into consideration in this work to assess the exposure in the two primary directions facing the horizontal and vertical beams of the antenna. Similar to related studies found in the literature [12, 13], as shown in Fig. 2 the R_{CD} is used as the distance from the transmitter at which the entire TER equals one as per ICNIRP and FCC guidelines.

The R_{CD}, where TER =1, can be calculated using Equation (10) as:

$$R_{CD} = \left(\frac{1}{4\pi} \sum_{n=1}^{N} \sum_{f\,>\,30\,MHz}^{300\,GHz} \frac{P_{T,f}.\,G_{A,f}}{S_{inc,RL,f}} \right)^{1/2} \tag{10}$$

As 5G uses highly massive Multi Input Multi Output (mMIMO) systems that reduce interference and boost the cell capacity, more factors and variables were taken into account in several recent investigations of EMF exposure [12, 13, 20-22], such as the system load, actually emitted power, duty cycle, and spatio temporal. Additionally, the EMF evaluation might be carried out for actual circumstances. In [23], their results found that the actual exposure level is quite lower compared to the theoretical exposure for 5G mMIMO. In this investigation, the power weight ρ_w is added as a reduction in the entire used power P_T which is used to calculate the power density [24, 25].

Thus, Equation. (10) changed to Equation. (11) which presents the compliance distances RCD.

$$R_{CD} = \left(\frac{1}{4\pi} \sum_{n=1}^{N} \sum_{f > 30\,MHz}^{300\,GHz} \frac{\rho_{w,f} . P_{T,f} . G_{A,f}}{S_{inc,RL,f}} \right)^{1/2}$$

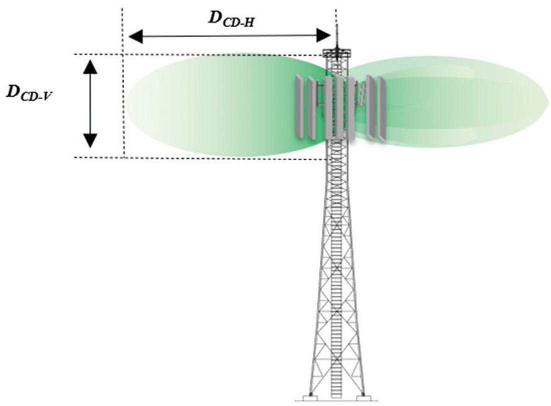


Fig. 2. Illustration of the Horizontal RCD-H and Vertical RCD-V compliance distances for macro site installed on the rooftop tower.

6. TER AND CD SIMULATION FOR 3-SECTORS BS

In the three-sector model, the sector's directions are horizontally separated by 120 degrees, so in this study, the model uses 0/120/240 degrees for sectors 1/2/3. This section discusses the theoretical TER and CD figures calculated for different scenarios of BSs that use a three-sector and examines the de-concentration options by using different azimuths for antenna directions. Table 3 lists a typical configuration for a three-sector site used for the TER and CD calculations. The BS is equipped with 6 technologies that transmit at the same time (GSM at 900 MHz, UMTS at 900 MHz, LTE at 800/1800/2100 MHz, and NR at 2600 MHz). In many countries, some operators run the 5G NR at higher frequencies such as 3.5GHz, or millimeter waves (mM) 28/39 GHz, but here the 5G NR is taken at 2.6 GHz because the calculations are validated in real-life sites operating with the frequencies and configurations listed in Table 3, and this is described in detail in next section.

Mathematical simulations are carried out to determine the TER and CD results for the proposed model using Equation (9) for the antenna's azimuths compared to the normal default azimuths where all antennas have the same direction. In this simulation, the TER & CD are calculated for different scenarios as described in the below paragraphs.

Scenario A: Applying the default azimuth, where all the antennas (of one sector) are directed in the same azimuth angle, this includes all technologies that transmit toward one direction. This design is commonly deployed in life networks where all technologies in one sector are connected to one multi-band antenna, or separate antennas but directed in one direction. For both, all transmitters radiate in the same sector direction as illustrated in Fig. 3.

Table 3. The configurations of 3-Sector BS site with 6 Technologies

Site Setting	2G 900	3G 900	4G 800	4G 1800	4G 2100	5G 2600
Freq. Band (MHz)	900	900	800	1800	2100	2600
Freq. BW (MHz)	4	4.2	10	10	20	60
Number of Tx	2T	1T	2T	2T	4T	64T
Number of Rx	2R	2R	2R	4R	4R	64R
Tx Power (Watt)	40	40	40	60	60	200
System Load	95%	95%	95%	95%	95%	95%
Ant. Gain (dBi)	16.6	16.6	16.2	16.5	17	24.8
Horizontal BW	60o	60o	65o	65o	65o	65o
Vertical BW	7.5o	7.5o	7.8o	6o	6o	6.5o
Ant. Tilt Angle	-6o	-6o	-6o	-6o	-6o	-6o
Ant. Height	35 m	35 m	35 m	35 m	35 m	35 m

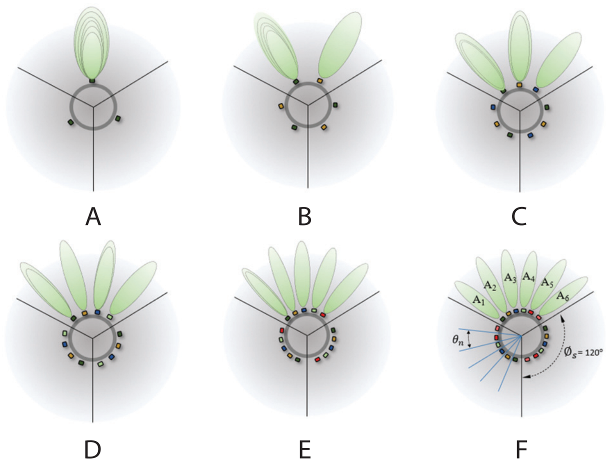


Fig. 3. Illustration of using different number of antennas in one sector in the 3-sectors model. A: 1 azimuth, B: 2 azimuths, C: 3 azimuths, D: 4 azimuths, E: 5 azimuths, F: 6 azimuths

Scenarios B, C, D, E, F: Applying the proposed model by using different azimuths, the angle separation for each technology is calculated using Equation (9). In B, two antennas are used per sector, the first antenna transmits the 900/800/1800/2100 MHz, and the second antenna transmits the 2600 MHz. In C, three antennas are used per sector (1: G900/U900/L800, 2: L1800/L2100, 3: N2600). In D, four antennas are used (1: G900/U900, 2: L800, 3: L1800/L2100, 4: N2600). In E, five antennas are used (1: G900/U900, 2: L800, 3: L1800, 4: L2100, 5: N2600). In F, six antennas are used (1: G900, 2: U900, 3: L800, 4: L1800, 5: L2100, 6: N2600). Practically, the RF engineers design the antennas according to the site requirements and of course consider the company's strategy for deploying the technologies as most of the networks start with the classic system (2G, and 3G), then grow to advanced solutions including 4G and 5G.

The simulation results are concluded in Table 4 which lists the θ_n values for each technology (antenna) calculated for the corresponding scenario. Also, it shows the CD distances (in meters) reference to ICNIRP for the general public, also it lists the reduction percent compared to the default setup using one direction for all technologies of scenario A. The results show that using 2 azimuths in scenario B gives less compliance distance by 23.3% compared to scenario A which has one direction. The 3 azimuths in scenario C give 35.9% less CD, the 4 azimuths in scenario D gives 39.8% less CD, the 5 azimuths in scenario E gives 41.3% less CD, and the 6 azimuths in scenario F gives 43.4% less CD compared to scenario A. Furthermore, Table 5 lists more detailed results of the horizontal and vertical compliance distances for the mentioned six scenarios references to both standards ICNIRP and FCC limits.

Table 4. The configurations of the 3-Sector BS site that is equipped with 6 Technologies

Antenna's Azimuths	Separation Angles θ_n (degrees)						CD (m)	CD Reduction (%)
	G9	U9	L8	L18	L21	N26		
1 Azimuth	120.0°						15.58	0.00%
2 Azimuths	70.3°					49.7°	12.63	-23.3%
3 Azimuths	47.9°			22.4°		49.7°	11.45	-35.9%
4 Azimuths	30.4°		17.5°	22.4°		49.7°	11.13	-39.8%
5 Azimuths	30.4°		17.5°	11.2°	11.3°	49.7°	11.02	-41.3%
6 Azimuths	15.2°	15.2°	17.5°	11.2°	11.3°	49.7°	10.85	-43.4%

Table 5. The horizontal and vertical compliance distances for the general public and occupational workers referenced to ICNIP and FCC limits

Antenna's Azimuths	ICNIRP GP (m)		ICNIRP OW (m)	
	CDH	CDV	CDH	CDV
1 Azimuth	15.58	2.51	6.97	1.12
2 Azimuths	12.63	1.92	5.34	0.86
3 Azimuths	11.45	1.60	4.46	0.72
4 Azimuths	11.13	1.51	4.19	0.67
5 Azimuths	11.02	1.47	4.09	0.66
6 Azimuths	10.85	1.42	3.94	0.63

7. IN SITU ASSESSMENT FOR TER DECONCENTRATION

A field experiment is done in a life network to examine the results of the proposed model by applying the antenna's azimuths with angles calculated using Equation (9). To have an accurate result, the experiment is done for 4 Macro-BS sites (one cluster) that service a residential populated district at Khubar city in the Kingdom of Saudi Arabia as shown in Fig. 4. The 4 sites belong to one public land mobile network operator (PLMN), all sites have the same configuration of three-sector, and each is equipped with 6 systems that transit as co-located in a multi-technology site.

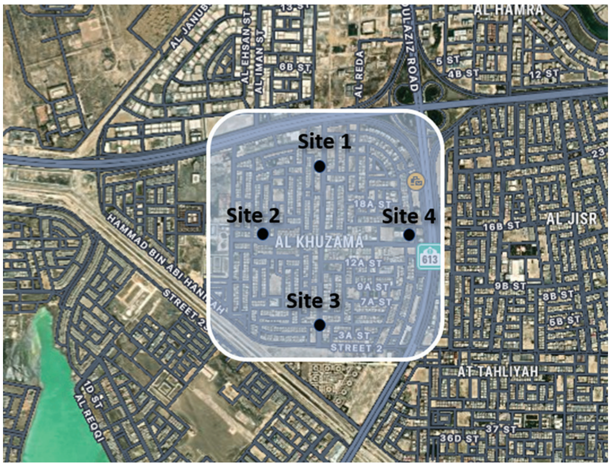


Fig 4. Google Earth map for the 4 sites where the field experiment is done

The 4 sites use 0/120/240 degrees for the sector's azimuths, where the 0 degrees starts from the north geographical direction and increases clockwise. All the sites were deployed with scenario B using two antennas, one for G9/U9/L8/L18/L21, and the second antenna for N26. Initially, all antennas were directed toward the same azimuth and were transmitted in the same direction. Then, the 2nd antennas of all sectors are redirected (rotated) to new directions with azimuths 60/180/300 degrees which gives 60 degrees as horizontal separation angles between the two antennas in each sector.

Two types of data are collected to assess the total exposure before and after applying the antenna azimuth changes, and also to evaluate the effects (impact) on the coverage signal level and capacity, as follows:

- Power density field measurement (radiation meter).
- TER from Geo-location data (system records).
- Signal level field measurements (drive test).
- Network's OSS KPIs data (system records)

7.1. POWER DENSITY FIELD MEASUREMENT

Field measurements are conducted to measure the power densities at two points in Site 1 (P1 and P2) as shown in Fig. 5. (A) and (B). Location P1 is intentionally selected facing the initial direction of the antennas at 0/120/240 degrees, and location P2 is selected facing 60/180/300 degrees.

The SRM-3006 radiation meter was configured to scan the downlink (DL) frequency ranges, the team collected approximately 7,200 measurement samples for each system technology at each point with a scan rate of 0.67 sample/second. All measurements were conducted at the same time during the highest hours of traffic (from 07:00 to 10:00 pm). For each point, the measurements are done twice, before the antenna's azimuth changes (Pre), and after the azimuth change (Post). The results show that TER decreased at P1 by -5.41% while it increased at P2 by 5.95% referenced to the ICNIRP limit.

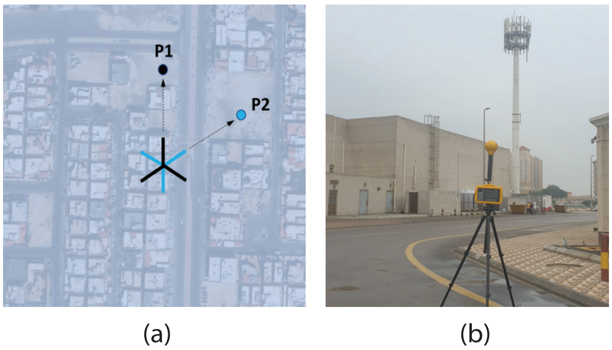


Fig. 5. (a) The measurement locations P1 and P2 at site 1, and (b) the radiation meter position which is in-front of the antenna's main direction.

7.2. TER EVALUATION FORM SYSTEM RECORDS

The network Operation Support System (OSS) contentiously records and archives the statistics and information about network traffic and performance. The TER is evaluated for the whole cluster before and after the antenna changes (Pre-and-Post) using the geo-location data recorded in the OSS system.

The received levels of all technologies from all devices in the cluster are recorded before and after the azimuth changes, and it's used to calculate the TER. The geo-location system gives the data as average for pixels of 50x50 meters each, the area under this test consists of 954 pixels within the cluster polygon of 2.3 Km2. The geolocation data is collected and calculated for two weeks period, one week before and one week after the antenna azimuth change. Fig. 6. summarizes the results which show the average Pre TER is 23.4x10-6, and it decreased to 18.91x10-6 after antenna azimuth is changed, this reduction is an improvement of -19.23% in average TER.

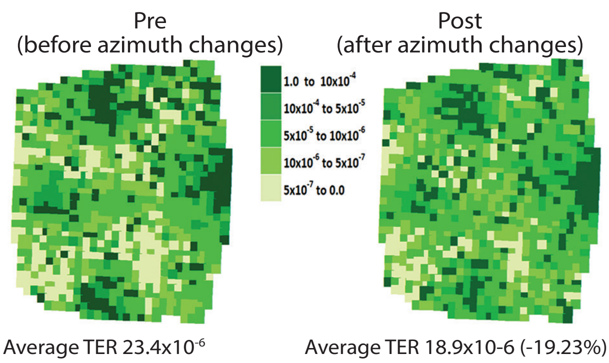


Fig. 6. The Pre and Post average TER from the geo-location records

Also, the TER distribution is evaluated and the results show that the higher range of TER (1.0 to 10x10-4) was counted for 17.0% on total pixels before the antenna changes, and it decreased to 2.7% after antenna azimuth was changed.

The above results are compared with similar related work found in [26], where a research group from Ericsson proposed an average power feedback controller to reduce the total transmitted over a specified time for the 5G MIMO system which reduces the total exposure ratio, their results show the power density becomes 25 % of the peak power after applying their power control solution. Such a solution gives 15.1% reduction in overall TER assuming the 5G contributes 20% from the total TER.

7.3. SITE'S COVERAGE PERFORMANCE

Drive test field measurements were conducted to evaluate the effect of azimuth rotation on the network received signal levels of all technologies. The team used TEMS Investigation v20 drive test tool which was installed on a laptop PC and connected to GPS and mobile user equipment (UE), as seen in Fig. 7. The measured samples were taken every 0.5 seconds, with over 3,290 measurement samples for each technology.

Fig. 7. The TEMS tool setup for field drive test measurements

The collected measurements include the Rx signal level in dBm of the Broadcast Common Control Channel (BCCH) for 2G, the Received Signal Code Power (RSCP) for 3G, the Reference Signal Received Power (RSRP) for 4G, and the Secondary Synchronization Reference Signal Received Power (SS-RSRP) for 5G. Table 6 summarizes the results that show the average coverage level in dBm and the delta of Pre vs Post, it indicates that there is no major drawback in signal level in the whole cluster for all technologies.

Table 6. The Pre and Post Rx Levels from Drive Test measurements

Measurement Layer		G 900	U 900	L 800	L 1800	L 2100	N 2600
		BCCH	RSCP	RSRP	RSRP	RSRP	SS-RSRP
Average Rx Level (dBm)	Pre	-68.9	-72.1	-77.6	-82.9	-83.3	-79.2
	Post	-69.3	-71.3	-77.0	-82.0	-82.6	-79.6
	Delta (dB)	0.4	-0.8	-0.6	-0.9	-0.7	0.4

For example, in Fig. 9 and 10, the Rx levels are plotted in the cluster map to display the details of the coverage levels and distribution for L800 and N2600 technologies. The results show the RSRP for L800 almost remains at the same average levels with -77.6 dBm at Pre and -77.0 dBm at Post with -0.6 dB delta, and have the same RSRP accumulated distribution among the cluster area. Also, the same results are obtained for N2600, the SS-RSRP almost remains at the same levels with -79.2 dBm at Pre and -79.6 dBm at Post with 0.4 dB delta.

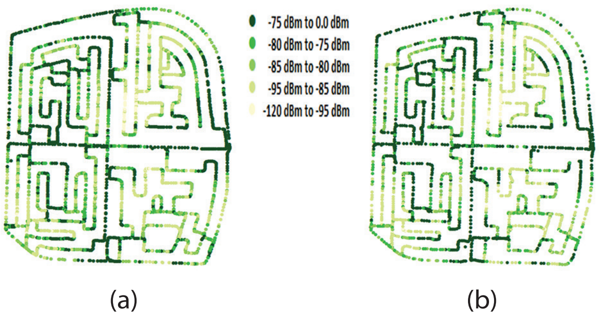


Fig. 8. 4G L800 Pre and Post RSRP levels;
a) Pre: Average RSRP = -77.6 dBm,
b) Post: Average RSRP = -77.0 dBm

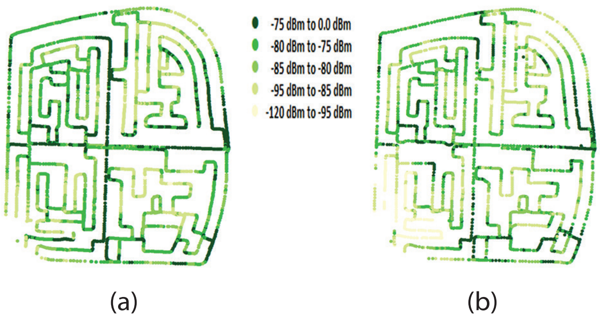


Fig. 9. 5G N2600 Pre and Post SS-RSRP levels;
a) Pre: Average SS-RSRP = -79.2 dBm
b) Post: Average SS-RSRP = -79.6 dBm

7.4. OSS PERFORMANCE RECORDS

Operation support system for mobile networks often use system row counters and statistics typically refer to a variety of metrics and data records that aid in network performance management and monitoring. In this work, some of OSS key performance indicators are employed to evaluate the behavior of the cluster under this study before and after applying the antenna azimuth changes which were implemented on the 09th of January 2024. The daily data were recorded for a continuous six weeks, three weeks pre, and three weeks post to the date of the change.

Fig. 10. shows the total daily carried traffic by the 5G N2600 for the whole cluster (4 sites), and also the system load percentage recorded based on the physical resource block (PRB) utilization. The traffic trend shows no significant change after the implementation date where the average traffic was 1.16 TB and became 1.18 TB, and the PRB utilization was 14.4% and became 14.5% with 0.7% increment.

Also, for N2600, Fig. 11. shows the daily total number of active connected users (simultaneous connection) and the user's throughput, the trend shows a very slight increase in connected users from an average of 295 to 305 users per day. And, there was almost no significant change in the user's throughput which was 78.7 Mbps and became 78.3 Mbps with -0.6% reduction.

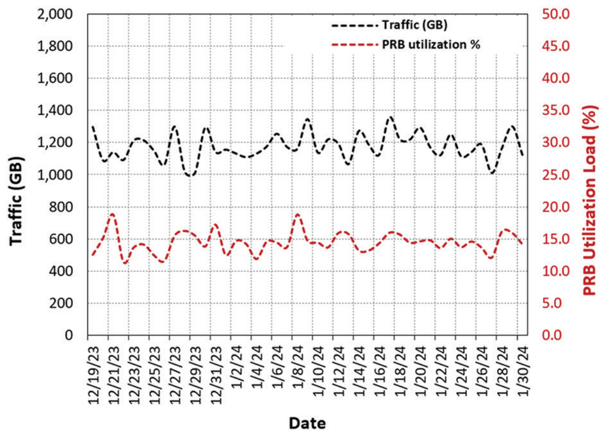


Fig 10. The daily total carried traffic and PRB utilization of the 5G N2600 for the whole cluster

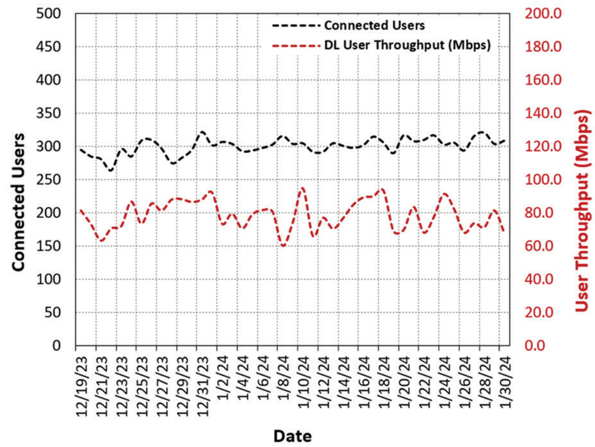


Fig.11. The daily total active connected users and throughput of the 5G N2600 for the whole cluster

8. RECOMMENDED APPLICATIONS OF THE PROPOSED MODEL

Reducing the TRE is the goal of the suggested method, and doing so will inevitably shorten compliance distances. On the other hand, neither the site performance nor the site coverage levels are impacted by the suggested approach. Nearly all national regulators require that the compliance borders be exclusive, inaccessible areas for the general public and shall be marked with warning signs or other obstacles to keep people out. To implement the compliance requirement, it is necessary to determine the compliance distances. The easier it is for mobile operators to meet the standards, the lower the compliance limits. The authors see these requirements can be assessed in the design phase before implementation, and small adjustments to the antenna orientations can be made using the proposed model to shorten the compliance distances for the necessary cases, particularly for wall-mounted and rooftop sites where the antennas usually will be placed in close proximity to accessible areas.

Also, the mobile operators continue expanding their networks by adding and deploying new technologies such as the 5G NR into the existing on-air sites following the current sector's direction, this approach increases the total exposure ratio and consequently extends the compliance boundaries. For some sites, extending the compliance boundaries to bigger ranges might reach accessible areas specifically for some rooftop and wall-mounted sites. in these kinds of situations, the authors believe that the proposed solution is advantageous and can assist in reducing the compliance distances without affecting network performance or coverage.

9. CONCLUSION

The growing deployment of mobile base stations raises concerns about electromagnetic field radiation. This study proposes a model to reduce total exposure by adjusting antenna azimuths to spread exposure horizontally within sectors. Simulations for a 3-sector base station with six technologies showed that using two azimuths cut compliance distances by 23%, while six azimuths reduced them by 43.4%. A field test in a cluster of four live sites demonstrated a 19.23% reduction in the Total Exposure Ratio (TER) after modifying antenna azimuths using the proposed model. Performance analysis revealed no significant impact on network coverage or capacity across all technologies tested.

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