Radiation Mitigation Techniques for Mobile Radio Base Stations

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ABSTRACT
Growing demand for mobile communication services results in a continuous increase in the number of base stations over a limited area, accompanied by public concern for possible health and ecological effect of these systems.
In this paper, the factors that controlling the power density around base stations on the ground level are presented and discussed.
Many techniques to mitigate the electromagnetic exposure levels in the vicinity of base stations are discussed. Using phased array antenna as an efficient approach for RF radiation reduction in the near of the base stations is analyzed and compared with cell splitting technique. The required base station numbers in both techniques are calculated and compared.

تقنيات تقليل ألإشعاع لمحطات الجوال الراديوية

الخلاصة
أن نمو الطلب على خدمات الأتصالات المحمولة (الجوالة) أدى إلى استمرارية الزيادة في عدد المحطات وفي نطاق مساحة محدودة .رافق ذلك قلق واهتمام عام بخصوص احتمالات تأثير تلك المنظومات على الصحة والبيئة .
في هذا البحث تم مناقشة عدد من التقنيات وتقليل مستويات الإشعاع الكهرومغناطيسي بالقرب من المحطات باستخدام هوائي المصفوفة ألطوري كتقنية كفوءة لتقليل الإشعاع بالقرب من المحطات وتم التحليل والمقارنة مع تقنية شطر الخلايا وتم حساب ومقارنة عدد المحطات المطلوبة في كلا التقنيتين .

INTRODUCTION
The rapid diffusion of cellular wireless communication systems has caused an increased concern for the potential detrimental effects on human health resulting from exposure to electromagnetic fields radiated by the antennas of these systems. This problem should be viewed in two different aspects. The first one contains possible health hazards due to cell phone devices usage, and the other relates to electromagnetic (EM) fields emitted by the base station antennas[1].

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Electromagnetic radiation can be described as waves of electric and magnetic energy moving together through propagation mediums. Electromagnetic waves can be characterized by their wavelength, frequency, or energy, and according to these characteristics, electromagnetic waves can be classified into ionizing, and non-ionizing radiations.

Ionizing radiations are extremely high frequency (EHF) electromagnetic waves that have enough energy to produce ionization and break the atomic bonds, such as X-rays and gamma rays. Non-ionizing radiations are electromagnetic waves that have weak photon energies to break atomic bonds such as radio waves[1].

Radio waves are used for providing radio broadcasting and various types of communication at radio frequencies (RF), produce electromagnetic energy that is insufficient to cause ionization and to break the chemical bonds, so, they are classified as non-ionizing radiation[2].

The increasing use of cellular phones leads to a growing number of mobile base stations, and increases the public concern for their possible effects on human health. The concerns have related to the emissions of radio frequency (RF) radiation from both cellular phones and base stations[3].

In order to avoid any probable biological and health effects from short- and long-term exposure to RF radiation, several guidelines and standards have been issued by many national and international organizations. These guidelines express the intensity of the RF fields in terms of their components (electric and magnetic field), in terms of the power density (power per unit area) in the far-field zone of the radiation source, or in terms of the energy absorbed by an element of biological body mass, i.e., called the specific absorption rate (SAR)[4][5].

Cellular Telephone Networks

The cellular mobile communication systems were developed much like radio or television broadcasting systems. Instead of using a single powerful transmitter in television broadcasting systems to achieve the largest possible coverage area, the cellular mobile telephone networks employ many low-power transmitters throughout a coverage area, by dividing a given region into sub-areas called **cells** as shown in Figure 1.

Cellular telephone networks allow two-way communication between the fixed part of the system (base station), and mobile phones moving in the area covered by the base station[6].

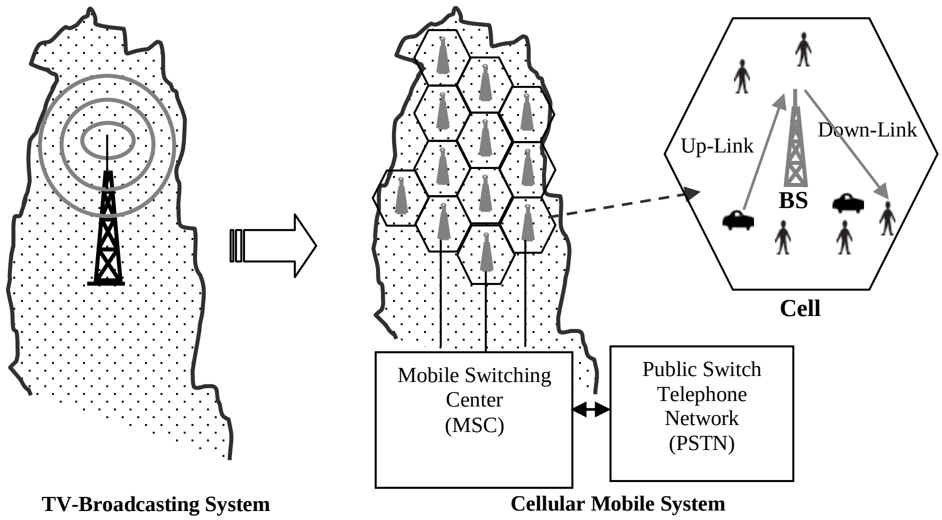


Figure (1): Radio Broadcasting and Cellular Mobile Radio Systems

The base station (BS) connects the simultaneous mobile calls via telephone lines, microwave links, or fiber-optic cables to the mobile switching center (MSC), that coordinates the activity of all of the base stations and connects the entire cellular system to the public switch telephone network (PSTN).

The channels used for transmission from the base station to the mobile units are called forward or downlink channels, and the channels used for transmission from the mobiles to the base station are called reverse or uplink channels.

Once a call is in progress, the switching center adjusts the transmitted power of the mobile (in power control process) to maintain call quality as the mobile unit moves in and out of range of a given base station (cell) [7].

Exposure to cellular base station radiation emitted continuously (even when nobody is using the phone), has raised public concern regarding possible health effects to people exposed to such radiation[3]

Radiation Exposure Calculation

The radiation exposure caused by base stations is measured in terms of power density or field intensity. To evaluate the power density at any location, it is necessary to understand how signals propagate in the particular environment.

In free space, at regions far away from the transmitter (far-field regions), the power density (S) from an isotropic point source may be thought of as the effective isotropic radiated power (EIRP) divided by the surface area of a sphere with radius r [7].

$$S = \frac{EIRP}{4\pi r^2} \quad ....(1)$$

maximum radiated power due to radiation of P_t watts by a distant antenna with a In practice, Effective Radiated Power (ERP) is used instead of EIRP to denote the gain of G_t , so equation 1 can be written as

$$S = \frac{ERP}{4\pi r^2} = \frac{P_t G_t}{4\pi r^2} \qquad ....(2)$$

where r
is the distance between the radiation center of the transmitting antenna and the exposure point .

Equation 2, implies that the power density from a transmitter decreases rapidly as one moves away from the antenna($S \propto 1/r^2$).

In urban environments, the Line Of Sight (LOS) path between the base station and the mobile units is mostly blocked as the height of the mobile unit antennas may be smaller than the surrounding structures. Hence, the cellular radio signals propagate by means of reflection, diffraction, refraction, and scattering on the building surfaces resulting a decay of the power density that is inversely proportion to r^γ.

$$S \propto \frac{1}{r^\gamma} \qquad ...(3)$$

Where
γ is the path loss exponent value which is typically between 2 and 6. Larger values of power exponent correspond to more obstructions and hence faster decrease in power density as the distance r becomes larger[8].

At ground level, in the vicinity of a base station tower, RF exposure is inversely proportional with the distance measured from the antenna to the point at which the power density exists. Hence, the power density at the ground level can be determined in terms of the horizontal distance from the tower to the point of exposure(d), and the antenna heights using the geometry shown in Figure 2. It can be given as

$$S = \frac{P_t G_t}{4\pi r^\gamma} = \frac{P_t G_t}{4\pi \left(\sqrt{(h_b - h_m)^2 + d^2}\right)^\gamma} \qquad ... \quad (4)$$

Where
h_b denotes the height of the base station antenna above the ground, and h_m is the exposure point height[2][3].

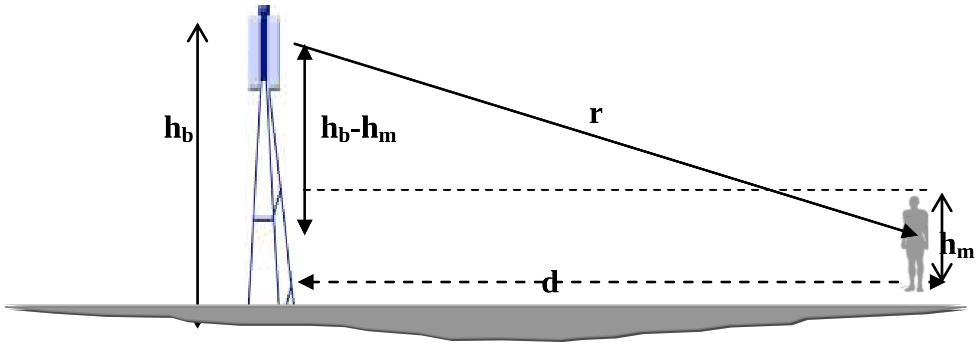
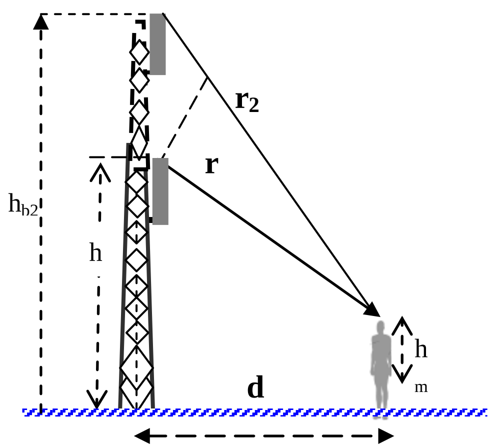


Figure (2): Power Density Calculation at Ground Level.

Base Stations Radiation Mitigation Techniques

There are various techniques can be applied to avoid excessive radiated power density absorbed by the general public who are exposed to the electromagnetic radiation emitted by cellular base stations.

Figure 3 shows that increasing the base station antenna height(h_b), results in radiation exposure reduction as the signal path to the exposure point will be increased. In Figure 4, the power density against the transmitting antenna height is drawn for a point 1.5 m above the ground, 30 m, and 50 m away from the base station. The figure shows that the power density can be significantly reduced by increasing the transmitting antenna height.



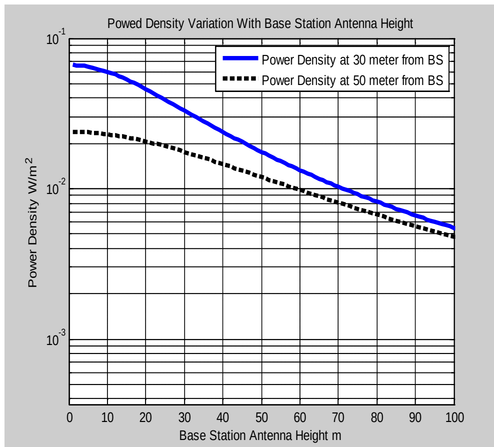


Figure (3) Effect of Antenna Height **Figure (4) Power Density against Antenna Height**

Equation 4, implies that transmitting power reduction lead to reduce the actual radiation received by the people close to wireless base stations. Therefore, a lowered exposure in the vicinity of base station can be accomplished by reducing the effective radiated power (ERP) through many techniques.

One of these techniques is to transfer to smaller cells (microcells) without affecting the size of the entire service area. The other technique is to use base stations with directed high gain antennas that lead to less number of base stations, and low actual transmitting power.

Cell Splitting Technique:

The process by which the congested cells are split into smaller cells (microcells), with its own base station and the same number of channels as the original large cells is called cell splitting.

Assuming that the original cell base station has a transmit power of P_{t1}, and its antenna has a gain of G_{t1}, the power density (S_1) at the cell border in the main beam can be obtained by neglecting the term (h_b-h_m) in equation 4 :

$$S_1 = \frac{P_{t1}\, G_{t1}}{4\,\pi\,(R_{c1})^{\gamma}} \qquad \dots \quad (5)$$

where (R_{c1}) is the distance from the cell border to the base station tower that is assumed to be in the center of the area covered by the cell. This distance represents the maximum communication range (the original cell radius, that can be given as

$$R_{c1} = \left(\frac{P_{t1}\, G_{t1}}{4\,\pi\, S_1}\right)^{\frac{1}{\gamma}} \qquad \dots. \quad (6)$$

In general, the area covered by a hexagonal cell (A_c) can be determined by[9]:

$$A_c \approx \;\; 2.6\,(R_c)^2 \qquad \dots \quad (7)$$

Therefore, the area covered by the original cell is:

$$A_{c1} \approx \;\; 2.6\; \left(\frac{P_{t1}\, G_{t1}}{4\,\pi\, S_1}\right)^{2/\gamma} \qquad \dots(8)$$

In order to test the properties of cell splitting technique, let us assume that the original cells are subdivided into smaller cells each of a radius that is equal to half of the original cell radius(0.5 R_{c1}). For the new smaller cells, the communication range is decreased and the transmitted power must be reduced to P_{t2}. The power density (S_2), and the coverage area of each microcell will be given as

$$S_2 = \frac{P_{t2}\, G_{t2}}{4\,\pi\,(0.5 R_{c1})^{\gamma}} \qquad \text{....(9)}$$

$$A_{c2} \approx \; 2.6 \left(\frac{P_{t2}\, G_{t2}}{4\,\pi\, S_2}\right)^{2/\gamma} \qquad \text{...(10)}$$

The transmitted power of the new cells, can be found by examining the power density at the boundaries of the new and original cell and setting them equal to each other (same coverage must be obtained in both cases). Assuming same antennas are used in both cases:

$$S_1 = S_2 \quad \Rightarrow \quad \frac{P_{t1}\, G_{t1}}{4\,\pi\,(R_{c1})^{\gamma}} = \frac{P_{t2}\, G_{t2}}{4\,\pi\,(0.5 R_{c1})^{\gamma}} \qquad \ldots (11)$$

$$\boldsymbol{P_{t2} = P_{t1}\,(0.5)^{\gamma}} \qquad \ldots (12)$$

For standard urban environment ($\gamma = 4$), then the transmitted power of the smaller cells (microcells), can be given as

$$P_{t2} = \frac{P_{t1}}{16} \qquad \text{....(13)}$$

It can be concluded that transition to microcells level can help in transmitted power reduction to (1/16) of the power required for original cells to serve the same coverage area. In other words, the transmitted power can be reduced by 12.04 dB, while maintaining the signal to interference ratio(S/I) that is required to fill in the original cell. At the same time, this transition process will increase the number of cells **four** times as each new cell area will cover (1/4) of the area covered by the original cell as shown in Figure 5.

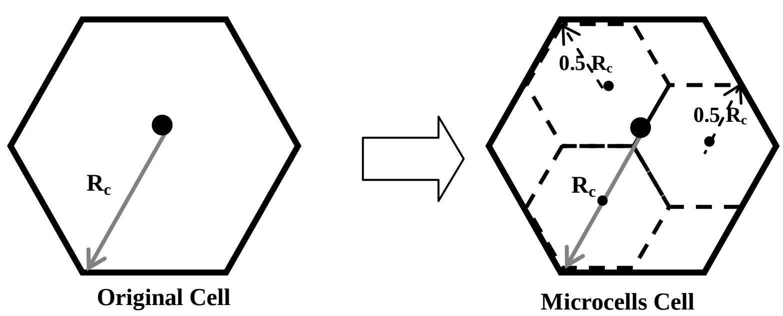


Figure (5): Cell Splitting Technique

Phased Array Antenna:

Traditional array antennas, where the main beam is steered via phase shifters to directions of interest, are called **phased arrays**. The principle of this technique depends on changing the phase of the signal at each antenna element electronically.

Phased array antenna as shown in Figure 6, is an array consists of two or more homogenous radiating elements that are spatially arranged to provide fixed phase to each element by placing phase shifter on each element so that signals received or transmitted from all elements will be in phase in a particular direction.

Phased arrays are commonly used in many practical applications including cellular mobile communications due to their the higher gain they can provide in comparison with conventional antennas[11][12].

This technique uses directional antennas to reduce the actual radiated power while the service area of a base station may retain its size so that the effective radiated power (ERP) will be constant.

The constant coverage area or the cell radius (R_c), determines the constant character of the effective radiated power.

$$ERP = P_t\, G_t = const. \quad \ldots \quad (14)$$

where P_t is the transmitter power, and G_t is an antenna gain. This follows that during using an omnidirectional antenna in the horizontal plane, the actual required transmitter power will be

$$P_t = \frac{ERP}{G_t} \quad \ldots.(15)$$

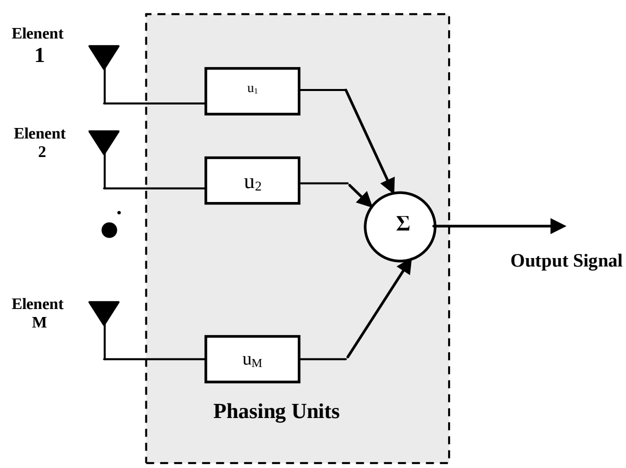


Figure (6): Phased Array Antenna

As an example, the required transmitter power during using a dipole antenna with a gain of 1.64 will be (ERP/1.64). In general, replacing an antenna with a gain of (G_{t1}) by another antenna with a gain of (G_{t2}) allows to reduce the actual transmitting power from (P_{t1}) to (P_{t2}), while keeping the same effective radiated power.

$$\boldsymbol{P_{t1} = \frac{ERP}{G_{t1}} \quad , \quad P_{t2} = \frac{ERP}{G_{t2}}} \qquad ...(16)$$

Therefore, the advantage due to reduction of power radiated by the transmitter K, can be found as

$$K = \frac{P_{t1}}{P_{t2}} = \frac{ERP}{G_{t1}} \div \frac{ERP}{G_{t2}} = \frac{G_{t2}}{G_{t1}} \qquad ...(17)$$

If a phase array antenna that contains M antenna elements each with a gain of (G_{t1}) is used, the gain of the base station transmitting antenna (G_{t2}) will be equal to the gain of one element multiplied by the number of elements in the array (M) ($G_{t2=}$ M G_{t1}). If each antenna element used in the array have a gain of 1.64 gain, the ratio K in equation 17, will be equal to(K= M G_{t1}/G_{t1}) then K= M and the required transmitted power will be (P_{t1}/ M).

Thus the use of phased array for the base station transmitter facilitates reduction of transmitted power radiated by M^{-1}, and that satisfy the cellular mobile system requirements without increasing the number of base stations.

Figure 7, shows that the power density at a distance of 50 m from the tower is equal to 0.0788 $\mu W/cm^2$ when one dipole antenna is used in transmitter, while it decreases to 0.0394 $\mu W/cm^2$ when an array of two elements is used. Hence, using phase array decreases the radiation exposure due to the high antenna gain obtained.

With the same effective transmitted power, the coverage can be increased by using a base station with phase array antennas. The approximate relationship of coverage area to antenna gain can be derived using equations 8, and 10.

$$A_{c1} \propto \quad (G_{t1})^{2/\gamma} \quad , \quad A_{c2} \propto \quad (G_{t2})^{2/\gamma} \qquad ...(18)$$

where

A_{c1} is the coverage area of the base station that uses one dipole antenna and A_{c2} is the coverage area of the base station uses phase antenna array. As G_{t2} is (M) times G_{t1}, the coverage area will be increased by $M^{2/\gamma}$.

$$\frac{A_{c2}}{A_{c1}} = \left(\frac{M\ G_{t1}}{G_{t1}}\right)^{2/\gamma} = (M)^{2/\gamma} \qquad ... \quad (19)$$

Assuming that the base stations are distributed uniformly in the considered area (A) that is the cellular system is designed to cover, then the required base stations number will be reduced according to the reduction factor (ρ) that is given by:

$$\rho = \frac{A/A_{c2}}{A/A_{c1}} = \left(\frac{G_{t1}}{G_{t2}}\right)^{2/\gamma} = \left(\frac{1}{M}\right)^{2/\gamma} \qquad ...(20)$$

Equation 17, implies that using phased array antenna results in reduction of the base stations number by ($1/M^{2/\gamma}$). In Figure 8, the number of base station reduction factor (ρ) is drawn as a function of the number of phased antenna array elements (M), in free space environment ($\gamma = 2$), and in standard urban environment ($\gamma = 4$). It can be noticed that in urban areas, one would use one base station with phase antenna array of eight elements instead of three conventional base stations that are close proximity. As a result, this will contribute in decreasing the total power density caused by the sources (base stations) in a certain area as the total power density (S_t) caused by n-sources (channels or base stations) can be determined by summing up all the power densities at that point using superposition theorem. So, more base stations number leads to higher exposure[2][13].

$$S_t = \sum_{i=1}^{n} S_i \qquad ....(21)$$

Where

(S_i) is the power density due to the i-th radiating antenna.

The power reduction obtained during the use of phase array antenna, can be expressed as a higher (SIR) signal to interference ratio and a reduction in RF pollution during transmission between the base station and the mobile cellular phone.

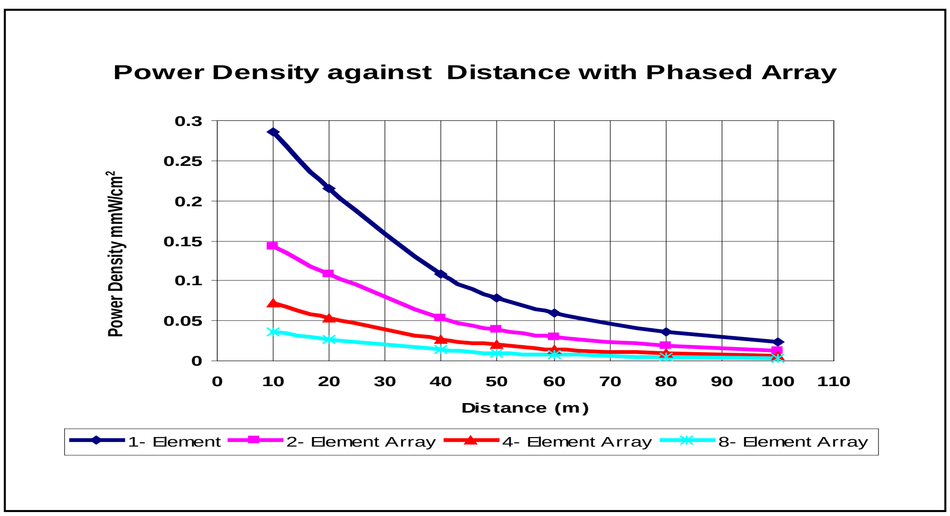


Figure (7) Power Density with Phase Array Antenna

It can be concluded that both cell splitting and phase-array antennas are effective methods to reduce power densities in the vicinity of cellular base stations as both technique has the ability to reduce the transmitted power. The cost to perform cell splitting is very high as more base station must be added while using phase array antennas help in reducing the number of base stations as they can be placed further apart in the entire coverage area, and this in turn decreases the total power density.

CONCLUSION

Cellular base stations are one of the main sources of RF radiation that may affect the public health. In order to reduce the total exposure received by the general public from wireless communication systems, many techniques can be applied. Increasing the transmitting antenna heights is one possibility to reduce the exposure in the vicinity of a base station.

Many alternative effective techniques can be applied to reduce base stations power densities such cell splitting or using efficient antenna systems.

Transition to microcells (cell splitting) is one of effective possibility to reduce the exposure in the vicinity of a base station as this technique can help in transmitted power reduction. Unfortunately the cost to perform cell splitting is very high as it is required to increase the number of base stations to fill in the same coverage area.

Using phased array antennas in mobile communication systems is very promising as they can provide a substantial reduction radiated power and RF pollution. When the base station effective radiated power is held constant, using phased array antennas can results in power density reduction around the base stations. The use of phased array antenna with an array of M elements in base stations facilitates reduction of transmitted power by M^{-1}, and reduction in base station number by $M^{2/\gamma}$.

REFRENCES

[1] Cleveland, Robert F., and Ulcek , Jerry L., “ Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields”, Issued by (Federal Communications Commission Office of Engineering & Technology), August. 1999.

[2] Dawoud, Mahmoud M. ," High Frequency Radiation and Human Exposure", Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN (ICNIR 2003).

[3] Abdelati, Mohammed, “ Electromagnetic Radiation from Mobile Base stations at Gaza”, Journal of The Islamic University of Gaza (Natural Sciences Series) Vol.13, No.2, 2005,PP 129-146.

[4] ICNIRP Statement on the “Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz)”. 2009. http://www.icnirp.de/documents.

[5] Ahma Luan, Ibrani Mimoza, and Hamiti, “ Computation of SAR Distribution in a Human Exposed to Mobile Phone Electromagnetic Fields”, PIERS Proceedings, Xi'an, China, March, 2010, PP 1580-1582.

[6] Miceli, Andrew, “ Wireless Technician’s Handbook”, Artech House, Norwood, Second Edition, 2003.

[7] Rappaport, T. S., “Wireless Communications Principles and Practice”, Prentice Hall, Upper Saddle River NJ, Second Edition, 2002.
[8] Seybold, John S., “ Introduction to RF Propagation”, John Wiley & Sons, Inc., New Jersey , First Edition, 2005.
[9] Garg ,Vijay K., “ Wireless Communications and Networking”, Morgan Kaufmann Publishers, USA, First Edition, 2007.
[10] Bond, Sandy, “The Impact Of Cellular Phone Base Station Towers On Property Values”, Ninth Pacific-Rim Real Estate Society Conference, Brisbane, Australia 19-22 January 2003.
[11] Y. Cengiz and H. Tokat, “ Linear Antenna Array Design With Use of Genetic , Memetic And Tabu Search optimization Algorithms”, Progress In Electromagnetics Research C, Vol. 1, 2008, PP 63–72.
[12] Gross, Frank B, “Smart Antennas for Wireless Communications”, McGraw- Hill, First Edition,2005.
[13] Sallomi, Adheed H., Salim, Sana R." Range-Coverage Extension Using Smart Antennas in Mobile Communication Systems", Iraqi Journal of Applied Physics, Vol. 5, No.2, April, 2009, PP 25-28.