A Novel Theoretical Model for Cellular Base Station Radiation Prediction

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***Abstract* - The number of cellular base stations placed in urban areas are continuously increasing to face the continuous demand for cellular wireless services. Mounting base stations in an uncontrolled way has raised the concern of people living or working around base station towers about the probable health effects associated with base station radiations. In this study, a theoretical mathematical prediction model to estimate the exposure level due to cellular base station radiations is proposed. The objective is to check how various parameters such as base station density, path loss exponent value, base station antenna heights, and cell radius can control the power density induced at the exposed objects in urban areas.**

Keywords - Non-ionizing radiation, Cellular base station radiation, Power density, Electromagnetic effects on human health. Path loss exponent.

I. INTRODUCTION

In the last decade, the cell phone usage has grown in extraordinary rates, and becomes a fundamental part of people lifestyle [1]. Despite the great benefits presented by cellular communication technology, there is major concern about the negative biological effect of long-term exposure to Radio Frequency (RF) radiations that may be resulted with the wide spread of cellular base stations [2].

Placing base stations in urban areas is necessary in locations at which cellular communications demand is high to maintain the connection between cell phones (subscribers) and the cellular network. Therefore, it became popular to see cellular base stations placed close to commercial and crowded residential areas to achieve the required coverage and capacity[3] [4].

The electromagnetic radio frequencies used in mobile communications are located at the non-ionizing part of the electromagnetic spectrum. The Electromagnetic Radiation (EMR) produced by cellular base stations may pass through human biological tissues causing some harmful effects to the people living close to base stations [5]. The well known effect of exposure to microwave is the thermal effect as the microwave energy is absorbed by the exposed tissues resulting in body temperature increasing as occurs in microwave ovens [6]. The human body acts as a grounded monopole antenna that can absorb the EMR energy in a level depending on the induced power density and the exposure interval [7] [8] .

In order to assess the probable effects of cellular network on human health, many studies have been done in to extract formulas to estimate the Radio Frequency (RF) power density, and the specific absorption rate (SAR) due to exposure to base-station radiations [9-12].

The main objective of this paper is to derive a mathematical model that can be implemented to compute the expected power density induced due to multi RF sources. The proposed model considers the cellular base station density at a certain area which can be easily estimated with the use of the Geographical Information System (GIS) software. The model may be preferable for RF pollution level prediction because of the direct relationship between the induced power density and the number of RF sources.

In the following section, the physical quantities used to evaluate the RF exposure level will be explained in brief. The proposed mathematical model that can be implemented to predict the expected power density at different scenarios will be presented in section 3. Section 4 describes the results of our model simulations. Section 5, concludes the paper.

II. CELLULAR BASE STATIONS AND RF RADIATIONS

The most important dosimetric physical quantity used to characterize the EMR exposure level and set the safety guidelines is the power density. The radial component of the power density (S) at the distance r from the base station antenna that represent the rate of energy flow per unit area measured in watts per square meters, can be expressed as[13] [14]:

$$S = \frac{P_t\, G_t(\theta,\phi)}{4\pi r^2} \tag{1}$$

where Pt denotes the net power radiated by the base station transmitting antenna, and Gt(θ,ϕ) is the antenna gain in the direction specified by spherical co-ordinates.

Radio signals emitted by cellular base stations propagate through space, the power density induced at the exposed object will be decreased due to free space attenuation, absorption, and obstacles existence. The radio signal transmission is heavily affected by the buildings and other high surrounding structures in urban environment causing to block the Line of Sight (LOS) path. Therefore, the power density will decay in a magnitude that is inversely proportional to rn where n is the power exponent that depends on the propagation environment nature. As a result equation 1, can be modified to take the form [15]:

$$S = \frac{P_t\, G_t(\theta,\phi)}{4\pi r^n} \tag{2}$$

The typical value of the power exponent is 2 for free space where there are no obstacles could block the line-of-sight between the base station antenna and the exposed objects (receivers). In practice, the power exponent value is more than 2 in urban areas [13] [15].

The electric field E (V/m) and the magnetic field H (A/m) are related to the corresponding far field incident power density through the free-space impedance (Zo) by the relation [16] [17].

$$S = E \times H = \frac{E^2}{Z_o} = H^2 Z_o \tag{3}$$

Where Zo is the free space impedance (120 π ohms).

III. PROPOSED MODELS FOR POWER DENSITY PREDICTION

A. Theoretical Approach Derivation for Power Density Prediction

The scenario shown in Figure 1 is chosen to estimate the power density due to single cellular base station. With the use of eq.1, the induced power density at the exposed body S can be derived as:

$$S = \frac{P_t\, G_t}{4\pi\, r^n}$$

$$S = \frac{P_t\, G_t}{4\pi\,(\sqrt{d^2 + (H-h)^2}\,)^n} = \frac{P_t\, G_t}{4\pi\left(d^2\,(1 + \frac{(H-h)^2}{d^2}\right)^{n/2}}$$

$$S = \frac{P_t\, G_t}{4\pi d^n\,\left((1+\tan^2\theta_i\right)^{n/2}} = \frac{P_t\, G_t}{4\pi d^n\,(\sec^2\theta_i)^{n/2}}$$

$$S = \frac{P_t\, G_t}{4\pi d^n}\cos^n\theta_i \tag{4}$$

where H is the height of the base station transmitting antenna, h is the exposed object height, d is the horizontal distance between the tower base and the exposed object, and θi is the incidence angle of the radial component of the power density at any point of the exposed object:

$$\theta_i = \tan^{-1}\left(\frac{H-h}{d}\right) \tag{5}$$

The incidence angle θi is varying along the exposed object from θ1 at the ground level to θ2 at the tip of the exposed object. At each point along the exposed body, the distance r travelled by the emitted signal varies as the incident angle (θi) varies. Therefore, the effective height of any point along the exposed body can be seen as a function of (θi).

It can be noticed that the power density induced at the exposed object depends on the effective radiated power (Pt Gt), the horizontal distance (d) in addition to the incidence angle (θi).

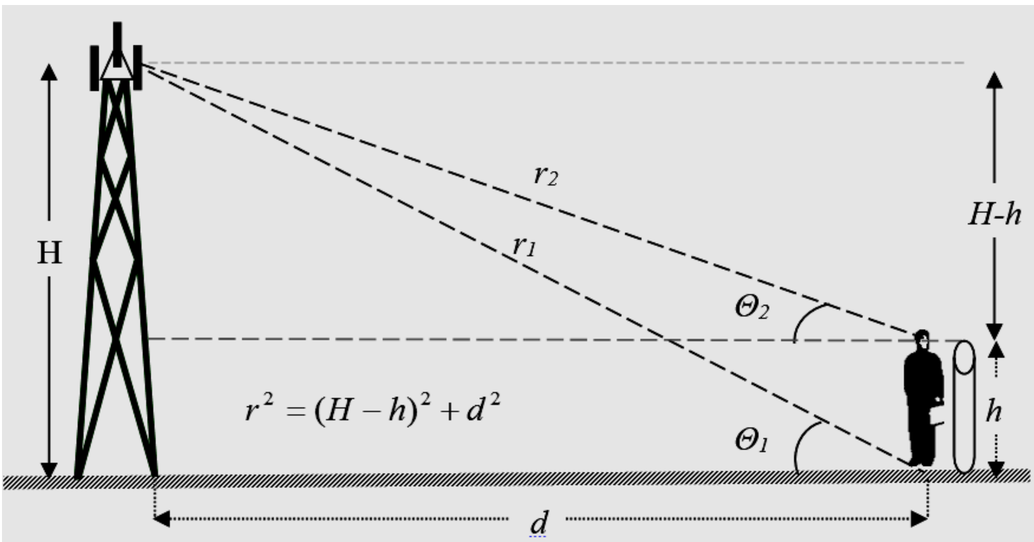

Figure 1. Power Density Evaluation Geometry

If (Sk) is the power density due to the k-th radiating source (base station), the total induced power density (St) due to K sources can be expressed using superposition theorem as:

$$S_t = \sum_{k=1}^{K} S_k = \frac{P_{tk}\, G_{tk}}{4\pi\, r_k^{\,n}} = \sum_{k=1}^{K} \frac{P_{tk}\, G_{tk}}{4\pi\, d_k^{\,n}} \cos\theta_k \tag{6}$$

where Ptk , Gtk denote the radiated power and the gain of the k-th radiating antenna respectively, θk is the incident angle of the power density component directed toward the exposed object, and dk is the horizontal distance between the k-th tower base and the exposed body.

B. Theoretical Approach Derivation for Multiple RF Sources Power Density

In the second scenario, a theoretical approach for power density due to the radiation emitted from all of the network base stations will be derived. This will be achieved by assuming the cellular configuration shown in Figure 2. All cells in the system are assumed to have identical base stations that are uniformly distributed over the network entire coverage area. The network cells are approximated by circles, each with a radius of Rc and the network coverage area is assumed to have a circular shape with radius of Rca and a base station density (ρBS).

The object at distance r from the central base station located at the center of Figure 2 is exposed to multiple RF sources (cellular base stations). Therefore, the total induced power density equation should consider all the contributing base stations, especially in urban areas with high base station density. The power density induced due to the base station O can be expressed as:

$$S = P_t\, G_t / (4\pi\, r^n)$$

The other base stations contribution can be determined by multiplying the power density caused by one base station by the number of these base stations. The number of these base stations can be obtained by integrating the elementary surface (z dzdθ) located at a distance z from the exposed object. Each elementary surface (z dzdθ) contains (ρBS zdzdθ) base stations that contribute in total induced power density. The total power density then can be expressed as:

$$S_t = \frac{P_t\, G_t}{4\pi\, r^n} + \int_0^{2\pi} \int_{z=R_c-r}^{R_{ca}} \frac{P_t\, G_t}{4\pi\, z^n} \rho_{BS}\, z\, dz\, d\theta$$

$$S_t = \frac{P_t\, G_t}{4\pi\, r^n} + \frac{P_t\, G_t}{4\pi} \rho_{BS} \int_0^{2\pi} \int_{z=R_c-r}^{R_{ca}-r} z^{1-n}\, dz\, d\theta$$

$$S_t = \frac{P_t\, G_t}{4\pi\, r^n} + \frac{P_t\, G_t}{4\pi} 2\pi\, \rho_{BS} \left[\frac{z^{2-n}}{2-n} \right]_{2R_c-r}^{R_{ca}-r}$$

$$S_t = \frac{P_t\, G_t}{4\pi\, r^n} + \frac{P_t\, G_t}{4\pi} 2\pi\, \rho_{BS} \left[\frac{(R_{ca}-r)^{2-n}}{2-n} - \frac{(2R_c-r)^{2-n}}{2-n} \right]$$

$$S_t = \frac{P_t\, G_t}{4\pi\, r^n} + \frac{P_t\, G_t}{2n-4} \rho_{BS} \left[\frac{1}{(2R_c-r)^{n-2}} - \frac{1}{(R_{ca}-r)^{n-2}} \right]$$

When the effect of the first two tiers surrounding the central cell is considered the distance Rca -r will be equal to 4Rc-r , and when three tires is considered the distance will be 6Rc-r and so on. For large networks the distance Rca is too large compared to the cell radius Rc, therefore the equation can approximated by:

$$S_t = \frac{P_t\, G_t}{4\pi\, r^n} + \frac{P_t\, G_t}{2n-4} \rho_{BS} \left[\frac{1}{(2R_c-r)^{n-2}} \right] \tag{7}$$

Where n is the power exponent value that is assumed to be more than two for urban environments.

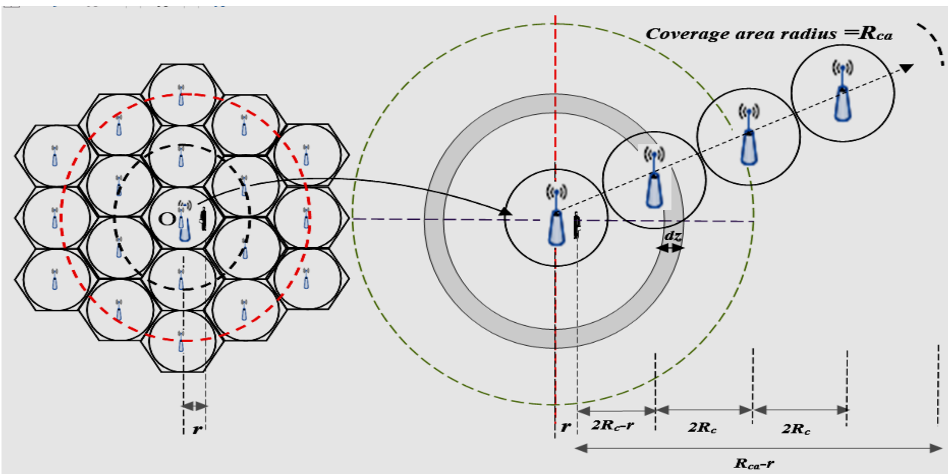

Figure 2. Circular Approximation for Cellular Configuration

IV. MODELS SIMULATION

The proposed models are simulated with a cellular network of a base station of a transmitted power of 10 W, and a transmitting antenna of 17 dB gain. These values were used as they are mostly used by many cellular service providers. The power density was evaluated at a horizontal distance of 50 m from the base station in our simulations.

Figure 3 shows that as the transmitting antenna height increases, the power density will decrease. This is due to further attenuation of the transmitted signal that take longer path to reach the exposed object. The variation of the induced power density at the exposed object with the angle of incidence is illustrated in Figure 4. It can be noticed that the power density at the base of the base station tower is zero as the angle is 90, while it will be at the peak where the exposed object face the directed power density or the main lobe of the transmitting antenna. That means people living in buildings with the same height of base station antenna are exposed to higher level of radiation.

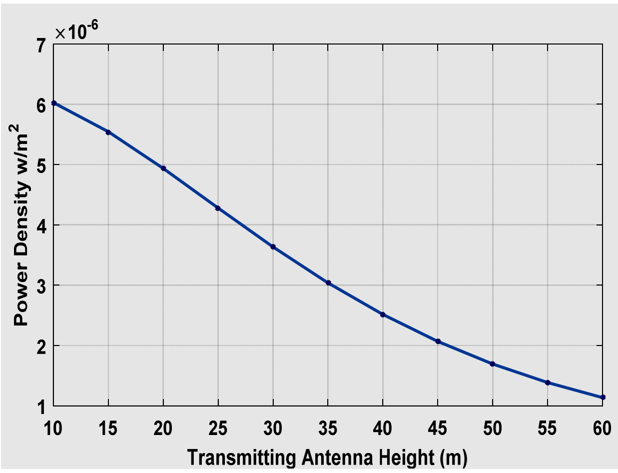

Fig. 3. Power Density with BS Antenna Height

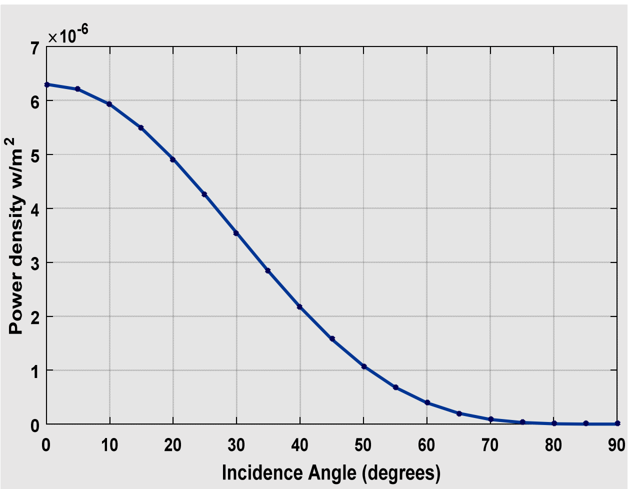

Fig. 4. Power Density with Incidence Angle

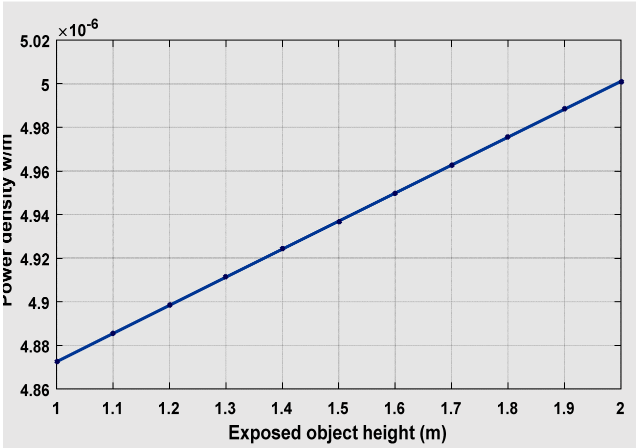

Fig. 5. Power Density with Exposed Object Height

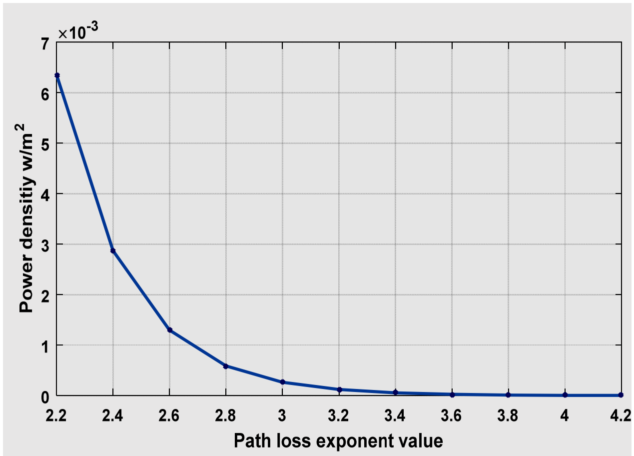

Fig. 6. Power Density with Power Exponent

It can be seen from Figure 5 that the induced power density at the top of the exposed object is higher than that in lower points, so, the power density increases as the exposed object height increases as it will closer to the radiation center.

Figure 6 shows the variation of power density with path loss exponent value. It can be concluded that higher values of power exponent means higher attenuation and then lower induced power density.

V. CONCLUSIONS

A theoretical model to predict the power density induced in urban areas close to human dwellings centers has been proposed. The model simulation results show that the base station density, the transmitting antenna height, the angle of incidence, and the RF propagation environment nature can contribute in power density controlling. From the simulated results, it was proved that the increasing of base station antenna height and antenna tilt can be considered as active techniques in EMR reduction. Furthermore, with using the proposed model, the effect of the exposed object height is very small, and can be considered negligible.

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