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ELECTROMAGNETIC RADIATION FROM MOBILE PHONE BASE STATIONS AT GAZA*

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ملخص: لقد زاد القلق في منطقتنا لدى عامة الناس من احتمالات الضرر الناتج عن إشعاعات الهواتف المحمولة و محطاتها و خصوصاً لدى الأطفال. و رغم وجود إرشادات و معايير دولية لحدود تعرض الأفراد لتلك الإشعاعات إلا أنه لم تقم أي دراسة لقياس شدة تلك الإشعاعات في غزة. و نتيجة لذلك و بتحفيز من الجمهور و سلطة جودة البيئة في فلسطين بدأت هذه الدراسة. و يهدف البحث لتوضيح الجهود الدولية المتظافرة في هذا المجال إضافةً لتطوير برنامج محوسب يسهل عملية تقدير و قياس مستويات الإشعاع في غزة. و يتم في هذا البرنامج تخزين بيانات محطات الهواتف المحمولة و إحداثياتها في قاعدة بيانات و من ثم حساب مستويات الإشعاع نظرياً و إخراج الجداول و الخرائط التى توضح ذلك. و بالإضافة لذلك يستطيع البرنامج التواصل مع جهاز قياس الإشعاع و تخزين القياسات الفعلية في قاعدة البيانات و من ثم استخراج الخرائط و الجداول. و لقد وجدنا أن القياسات الفعلية في عينة الدراسة تتوافق مع القيم النظرية و هي ضمن المعايير الدولية المسموح بها.

Abstract: The general public through our region is concerned that exposure to electromagnetic fields (EMF) from mobile telephones and their base stations could be a hazard to health, especially in children. While there are guidelines on the limitation of human exposure to EMF, no measurements have been done to evaluate compliance with the limits on exposure in the vicinity of any base station in Gaza. In response to public concerns shared by the environmental quality authority in Palestine this research is initiated. It aims to highlight relevant international work and develop computer tools which simplify estimating and measuring EMF levels in our city. The implemented software package stores the base stations' parameters and coordinates in a database and then generates tables and maps that illustrate EMF levels estimated theoretically. Moreover, it can communicate with a measuring device and store actual measurements in the database so that it is used to generate maps and tables. It is found that real measurements are consistent with theoretical ones and they are much lower than the exposure limit recommended by the international health organizations.

1. Introduction

The radio waves used in mobile telephony are, like visible light and X-rays, electromagnetic waves that consist of both an electric and a magnetic component which vary periodically in time. The frequency of variation determines the wave properties and uses. Radio waves, which can be used for various types of communication, are found in the lower part of the spectrum and classified as non-ionizing radiation.

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The early mobile telephony systems such as NMT, TACS, and AMPS, use analog telephony while newer systems such as GSM (global system for mobile) use digital technology. Digital systems have several advantages compared with analog systems: for example, higher user capacity, increased privacy, lower power consumption, and better immunity to interference [1].

The GSM is adopted by Jawwal Company which is the unique national mobile phone service provider in Palestine. The overall system is made up of a network of radio base stations, each of which covers a certain geographical area (called a cell) and which together provide coverage for a larger area. The base stations, which continuously send and receive signals, are linked by cable or radio links to the fixed network via mobile exchanges that direct traffic and keep track of where in the network each activated mobile telephone is located [1].

The cells are grouped into clusters. The number of cells in a cluster must be determined so that the cluster can be repeated continuously within the covering area. The typical clusters contain 4, 7, 12 or 21 cells. The total number of channels per cell depends on the number of available channels and the type of cluster used. The GSM system operates in either the 900 MHz or 1800 MHz band. The 900 MHz band is utilized in Palestine. This band is divided into two regions: The uplink band (890 MHz to 915 MHz) which is used by the mobile phones and the downlink band (935 MHz to 960 MHz) which is used by base stations. Each link band is divided into 200 KHz channels, thereby, providing 124 channels for communications and one needed for technical reasons. Time Division Multiple Access (TDMA) is employed to allow each channel to be used by eight simultaneous sessions. Out of the 124 channels, only 24 are allocated for Jawwal Company, while the rest are reserved for other networks. The signals transmitted by Jawwal towers are within the frequency band 955.2 MHz to 960 MHz while the signals transmitted by Jawwal mobile phones are within the frequency band 910.2 MHz to 915 MHz [2].

When a mobile phone initiates a call session, the phone sends radio signals to the closest radio base station, which in turn sends the call on to a mobile switch. If the destination uses an ordinary wired telephone, the mobile switch sends the call to the fixed network. Otherwise, the switch routes the call to another base station, whose antenna sends the call as radio signals to the other user's mobile phone. When a call is terminated, the mobile telephone goes into idle mode, in which it will only transmit information when necessary or at regular intervals.

As more and more people use mobile telephones, more base stations are required to handle more calls. Therefore, base stations are being placed closer to mobile phone users allowing denser re-use of frequencies. As towers are being placed within meters of homes, schools, and other sensitive areas, this is causing anxiety in the community. The radiations from these towers have been associated with a range of health problems including birth defects, brain tumors, lymphomas, and memory problems [3-10].

Some governmental agencies and organizations around the globe have established guidelines, good practices and recommendation regarding exposure to EMF. These organizations study the effect of EMF on the human body, and specify a number of basic restrictions on the amount of electromagnetic energy which can be absorbed by the human body without ill effects [11-14].

While there are many guidelines for exposure limits to EMF field, there are no international standard measurement procedures to evaluate the compliance with the limits of exposure. Many rigorous measurement campaigns have been developed in some places around the world such as Engadine [15], La Trobe University [16], and the main cities at the Mediterranean coastline of Spain [17]. The measurements obtained by all these studies are well below the standard levels.

The aim of this paper is to summarize important work done on the health effects of mobile phone networks, initiate measuring campaigns in Palestine by starting a pilot one in Gaza, and develop a helpful software package that simplifies the auditing procedures of mobile phone base stations. The rest of this paper is organized as follows: In Section 2 important work done on health effects of EMF is reviewed and the standard limits specified by the international health organizations are summarized, in Section 3 the theoretical calculations used to estimate EMF parameters are presented, in Section 4 the experimental results are detailed, in Section 5 the implemented software package is described, and finally in Section 6 comments, conclusions, and suggestions for future work are given.

2. Health effects and standard limits

The hypothesis that exposure to radio waves might produce health damage has been analyzed mainly from several epidemiological studies [3-10]. Especially leukemia in children and brain tumors were the clinical entities often described. To date these studies do not provide enough information to allow a proper evaluation of human cancer risk from RF exposure because the results of these studies are inconsistent. This can be explained by differences in the design, execution and interpretation of these studies. Cancer studies using animals have not provided convincing evidence for an effect on tumor incidence.

The radio waves penetrate exposed tissues and cause thermal biological effects. The force produced by an electric field on charged objects, such as the mobile ions present in the body, causes them to move, resulting in electric currents, and the electrical resistance of the material in which the currents are flowing results in heating. This heat input causes the temperature to rise and it continues to do so until the heat input is balanced by the rate at which it is removed, mostly by blood flowing to and from other parts of the body [7].

It is very well established that electromagnetic radiation can only be absorbed in quanta of energy. The energy quanta of radiation at 0.9 and 1.8 GHz equal 4 and 7 μeV. Both these values are extremely small compared with the energy of around 1 eV needed to break the weakest chemical bonds in genetic molecules (DNA). Therefore, GSM radiations can't ionize atoms and molecules and is described as non-ionizing radiation (NIR). However, higher frequency radiation, such as far-ultraviolet radiation and x-ray, has energy quanta bigger than 1eV and so can readily ionize atoms and molecules, and produce some damage to biological tissues even at very low intensities. This is referred to as ionizing radiation [18]. The intensity determines the number of quanta striking the body per second and, even though this is small at low intensities, each quantum still has a certain probability of ionizing and so damaging biological molecules. Non-ionizing electromagnetic radiation, however, is believed to be harmless at very low intensities, although it can be damaging at high intensities [19]. For example, light at modest intensities produces useful biological effects which allow us to see illuminated objects. However if the intensity of the light becomes too large, the eye can be seriously damaged. Very high intensity RF radiation can also be damaging as is clear from the strong heating effects produced in a microwave oven. So one need to know at what intensity the radiation starts to produce damage; this might usually be expected to be higher than the lowest intensity at which biological effect can be detected.

The rate at which the energy is absorbed by a particular mass of tissue m is $m\sigma E^2/\rho$, where σ and ρ are, respectively, the conductivity and density of the tissue and E is the rms value of the electric field. The quantity $\sigma E^2/\rho$ is called the specific energy absorption rate or SAR and is measured in watts per kilogram. The SAR produced by a particular value of electric field is larger in children than in adults because their tissue normally contains a larger number of ions and so has a higher conductivity [20]. Figure 1 shows a computer model that illustrates the SAR distribution due to a mobile phone.

Figure 1. A computer model that illustrates the SAR distribution.

There is also data regarding the biochemical and molecular mechanisms of cells both *in vitro* and *in vivo* with effects independent of thermal phenomena [21]. The fact that EMF can produce thermal phenomena does not depend on the grade of power density field administered

A recent study on 12 human volunteers exposed to continuous cell phone emission for up to 4 hours showed a slight (but statistically-significant) oxidative stress response and a consistent rise in plasma-levels of lipid peroxidases with the duration of exposure. At the same time levels of antioxidases in the erythrocytes decreased [22]. Oxidative stress is typically induced by ionizing radiation through direct homolysis of chemical bonds. In the case of non-ionizing radiation such as RF-fields, another mechanism must be involved, e.g. by stabilizing the reactive species or by destabilizing the parent molecule.

In summery, RF-fields can produce a very wide range of measurable biological effects. In addition to what can be measured at the present stage of scientific investigation, it is likely that other completely unknown effects remain to be discovered. A full review of all biological effects of RF-fields, and their implications for effects on human health far exceeds the scope of this paper and the interested reader is referred to the literature (see for example Refs. [23,24]).

There are a number of national and international regulations, standards and recommendations dealing with electromagnetic exposure in the radio frequency range. The limits are generally very similar and are usually based on recommendations from the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), Federal Communication Commission (FCC), the International Radiation Protection Association (IRPA), and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) [11-14]. Based on established scientific studies, it is claimed that the limits have been set with a wide margin in order to protect people from any *known* negative health effects of both short- and long-term exposure to electromagnetic fields. Basic restrictions on exposure are provided for both general public and workers exposed in the workplace. Occupational exposure limits are generally less restrictive than non occupational since some control can be applied over the condition and duration of exposure. In Palestine the relevant safety limit is laid down by the Environmental Quality Authority (EQA). They have adopted the FCC limits which are illustrated in Figure 2.

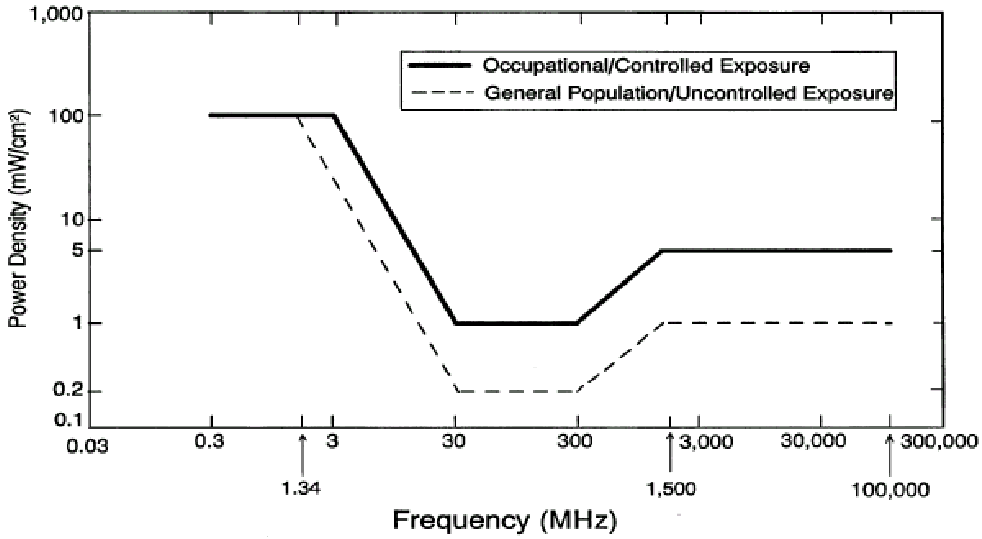


Figure 2. The FCC recommended RF exposure limits

It is seen from the figure that the recommended exposure limit to the Jawwal network radiation, which is around 0.9 GHz, is 0.45 mW/cm^2. This standard limit, although international, is not universally adopted. In UK the limit is 0.4 mW/cm^2, Australia 0.2 mW/cm^2, Switzerland 0.0042 mW/cm2 and Italy 0.01 mW/cm^2. The Salzburg Resolution recommended an outdoor exposure level of less than 0.1 µW/cm^2 in publicly accessible areas around a base station. This is 4500 times lower than the FCC guideline value for 900MHz emissions. The Salzburg Resolution is the intensity below which no health effects have been published [25].

3. Mathematical calculations

Assume that there are *n* antennas as illustrated in Figure 3. The i^{th} one may be characterized by its power (P_i), gain relative to the isotropic antenna in a given direction (G_i), and coordinates relative to a certain origin (x_i,y_i,z_i), where $i \in \{1,2, .., n\}$.

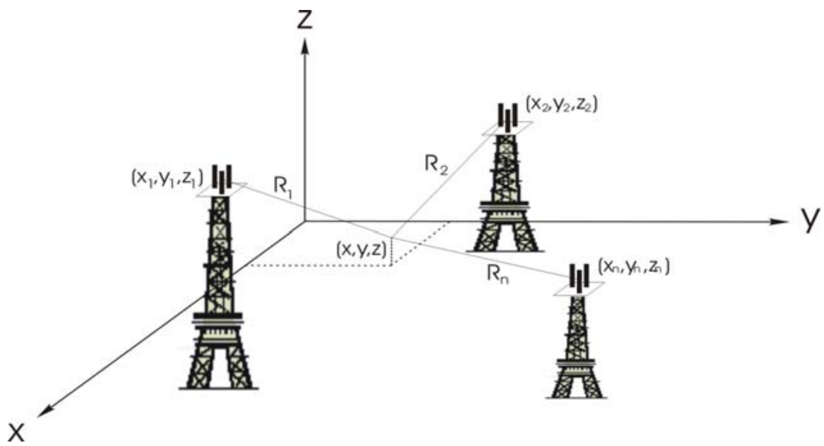


Figure 3. Antennas contributing to RF field at point of interest

Although the quantity G_i is generally a function of coordinate variables, it may be safely treated as a constant to simplify calculations. The electromagnetic power density (S_i) due to the i^{th} radiating antenna at point (x,y,z) located in the far field free space is given by the general equation

$$S_i = \frac{EIRP_i}{4\pi R_i^{2}}$$

where R_i is the distance to the antenna and $EIRP_i$ is the Equivalent Isotropic Radiated Power of the antenna. It is given by the product of the antenna power and its gain, i.e.

$$R_i^2 = (x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2$$

and

$$EIRP_i = P_i * G_i$$

The total power density due to all antennas is given by super position as

$$S = \sum_{i=1}^{n} S_i = \sum_{i=1}^{n} \frac{P_i \, G_i}{4\pi[(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2]}$$

The magnitude of the electric field strength (E) and magnetic field strength (H) are related to the power density as follows:

$$S = E^2/377 = 377H^2$$

It should be mentioned that these equations are approximate as they assume far-field free space and neglect the reflection effects. However, they provide tolerable prediction for the radio frequency radiation levels [26].

4. Experimental results

The measurements of RF emissions are usually conducted in two different stages; broadband and narrowband measurements. A basic broadband measuring instrument comprises an electric field meter equipped with a broadband probe. Only if the measured values in the broadband stage surpass the decision level will the narrow-band stage be necessary. This stage is made with spectrum analyzer or selective frequency instrumentation necessarily.

In this work a "Narda EMR-20" measuring device with probe 100 MHz to 3 GHz is used. It is manufactured in Germany and came with a calibration certificate from the official department in charge there. The device measures the directional components of both electric and magnetic fields as well as the magnitude of the power density [27]. These measurements may be transferred to a personal computer for processing through the standard RS232 serial interface. We wrote professional software using Visual Basic language to communicate with the device and store the measured values in a *Microsoft Access* database. The software provides full remote control of the system's operation and allows reporting the results online. It is also possible to generate offline tables and figures. The equipment setup is illustrated in Figure 4.

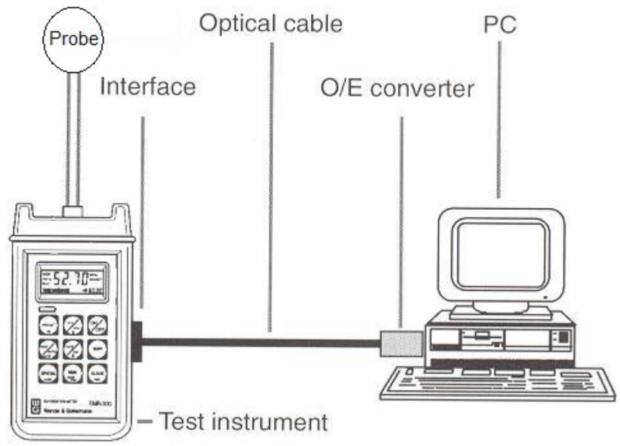


Figure 4. Broadband measuring equipment layout

Broadband levels obtained in our work have not made it necessary to go into the second stage. Levels measured are well below decision levels; therefore the broadband measurement is enough to guaranty the conformity. Three separate measurements are performed in this research as detailed in the following subsections.

4.1. Mapping the strength of signals along the major roads in Gaza

Electric field signals from mobile telephone base stations and all other significant signals from such sources as TV and FM radio were measured along the major roads in Gaza. The measurements were taken in three different days around noontime. If possible, measurements were made in locations that maintain direct line-of-sight with known RF source, at height of approximately 1.7 m above ground. Where practical, the measurement antenna was positioned in open areas away from likely sources of reflection. The antenna was positioned and oriented so as to obtain maximum signal strength. Figure 5 shows the electric field levels on a color-coded map. The larger colored circles indicate higher signal levels, while progressively smaller circles indicate decreasing levels.

There are some comments on the results of this experiment: First; it is found that the measured values are in general consistent with their mathematically predicted ones. Second; at rare places, the measured values are found quite higher than calculated ones. After short investigation, these unexpected results are justified by the existence of other nearby radiation sources such as FM transmitters. Last; it is noticed that the measurements of radiation levels in our area of study due to mobile phone base stations as well as other RF broadcast sources are well below the reference levels established by the international health organizations.

4.2. RF EME exposure levels from a typical JAWAL tower

The second experiment was to monitor closely a typical GSM tower. The selected one was on the Daoor building rooftop which is close to the researcher's residence home. The measuring device was mounted at a distance one meter from one of the sector antennas[1]. The 24 hour measurements of the power density are illustrated in Figure 6.

The variation of the power density along the time is due to the variation of the number of active time slots. With most sector antennas used in Jawwal network, each one has two transmitters. Each transmitter has a bandwidth of 200 KHz generated from multiplexing 8 slots in the time domain. The minimum operation of a base station requires one transmitter to be in operation for each sector antenna. This transmitter operates at full power even when not handling any calls. This usually occurs after midnight on most sites. As more people use the network, the second transmitter is

[1] The cell coverage area is usually divided into three sectors. Each of them is 120^{o} and covered by an array of monopole directional sector antenna.

turned on allowing up to another eight simultaneous telephone calls. It may be observed from Figure 6 that the peak hour of the network is, as expected, between 7 and 8 o'clock in the evening. As the power density at that interval is almost twice its corresponding after midnight, it is concluded that the specific sector antenna operates at its full capacity at the peak hour. To reduce the call blocking probability the cell capacity may be enhanced by increasing the number of transmitters. If four transmitters are used to power the sector antenna instead of two, then it can handle up to 32 simultaneous calls allowing probable duplication of current RF levels.

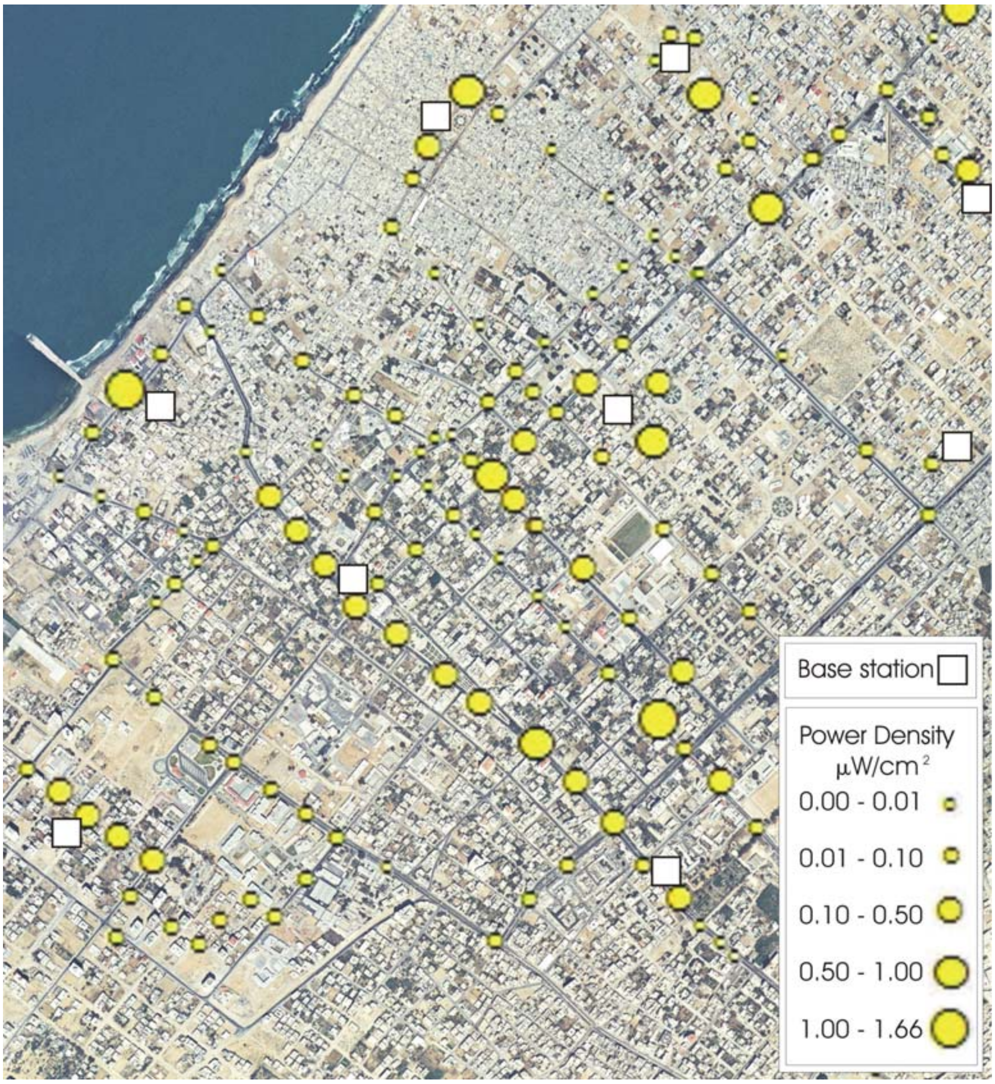


Figure 5. RF Electrical Field levels along Gaza main roads.

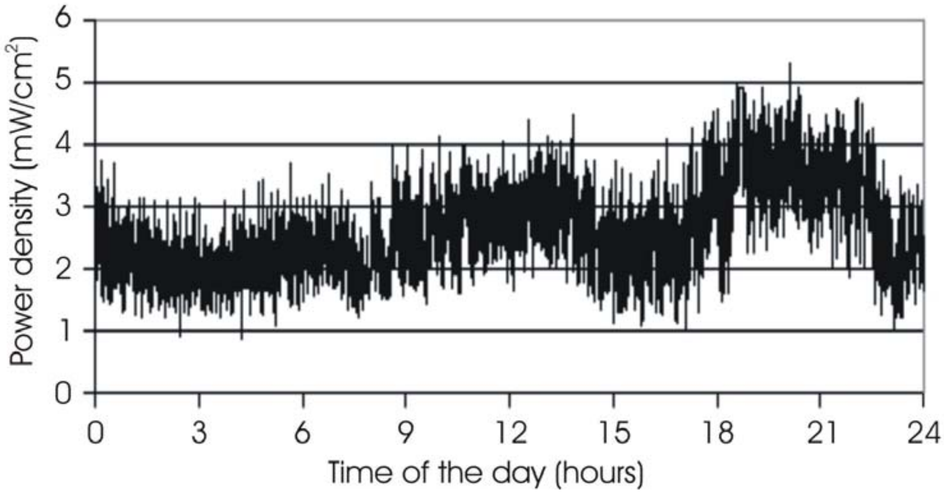


Figure 6. The activity of a typical base station antenna.

4.3. RF EME Exposure from a typical GSM phone

The considerations in this subsection are restricted to the fields produced by GSM mobile phones. The maximum powers that 900 MHz GSM mobile phones are permitted to transmit by the present standards are 2W. However, because TDMA is used, the average powers transmitted by the phone are never more than one-eighth of this maximum value (0.25W) and are usually further reduced by a significant amount due to the effects of adaptive power control and discontinuous transmission. Adaptive power control means that the phone continually adjusts the power it transmits to the minimum needed for the base station to receive a clear signal. Discontinuous transmission refers to the fact that the power is switched off when a user stops speaking. The level of radiation at call setup is much larger than that during conversation. During this phase the phone starts by checking all control channels in order to determine the substation with the strongest signal and hence will give the best connection. Then the phone sends the origination message which is a very short message (about 0.25 second). After the cellular service provider verifies that caller is valid, the base station sends a channel assignment message to the phone. This message informs the phone on which channel the conversation will take place. Consequently, the phone turns to the assigned channel and begins the call. At this step, the ring back signal or busy signal is heard. Both of these are transmitted by the base station as an audio signal just like the voice of the person on the destination.

An experiment is performed to highlight the variation of the radiation levels during the call progress. The electric field at a point 1 cm from a typical phone is measured. The result is shown in Figure 7.

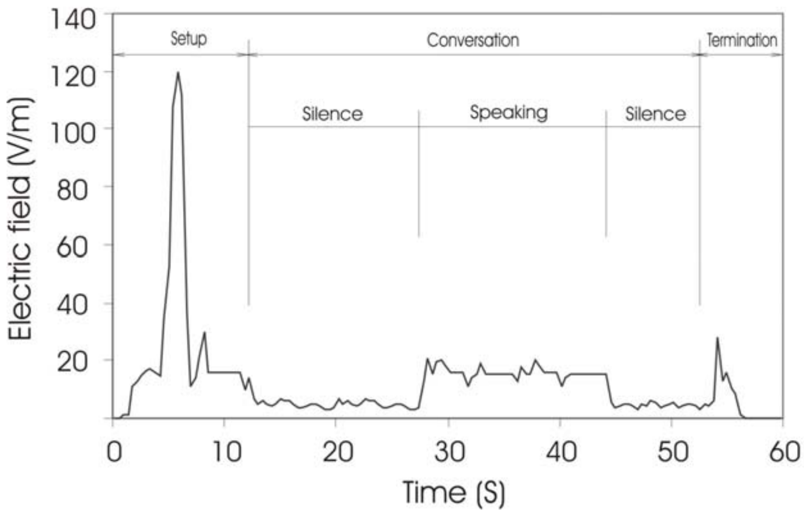


Figure 7. Electric field levels emitted from a typical GSM phone.

As indicated earlier in this subsection, the magnitude of the signal may vary depending on the phone model and its location relative to the base stations. However, the experiment provides deeper insight knowledge and concludes with some advice of keeping the phone away from our head during call setup.

5. Description of the implemented software package

The software is composed of three parts: The first one calculates radiation theoretically at any point in the map and it stores the results on a table and displays it as coded colored circles on the map. The second part communicates with the measuring instrument and stores the measured values in a database table. The last part gives the user the ability to manage the database tables. Therefore, the main window of the software, which is shown in Figure 8, has three menus; calculation, measurement, and tables.

The *calculation* menu enables the user to calculate the power density at any point on the Gaza city map. It contains many tools; view, colors, zoom, snapshot, save, and calculation. The view tool shows a view of Gaza strip map. Snapshot tool determines and stores the points of interest on database for calculating the power density. Calculate tool calculates the radiation for the stored points on the database and shows the values of radiation as circles, the size of each circle is proportional to the power density as illustrated in Figure 9. The colors tool calculates radiations all over the map and colors it according to the rate of radiation as illustrated in Figure 10. The user has the ability to specify the radiation levels and their corresponding colors.

Figure 8. Main Window of the Software

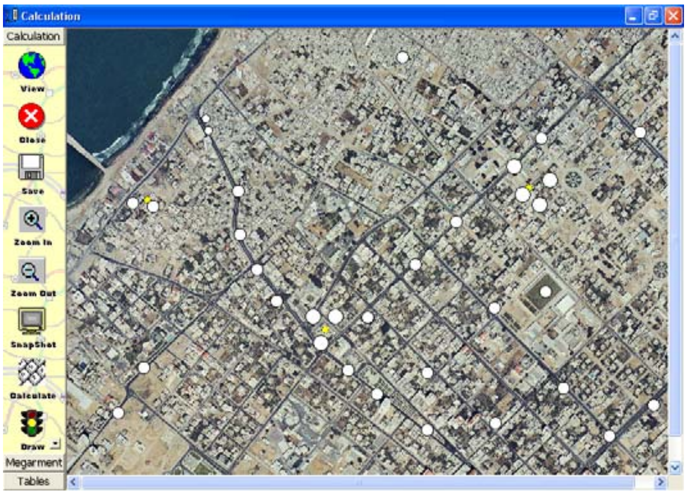


Figure 9. Radiation Calculation

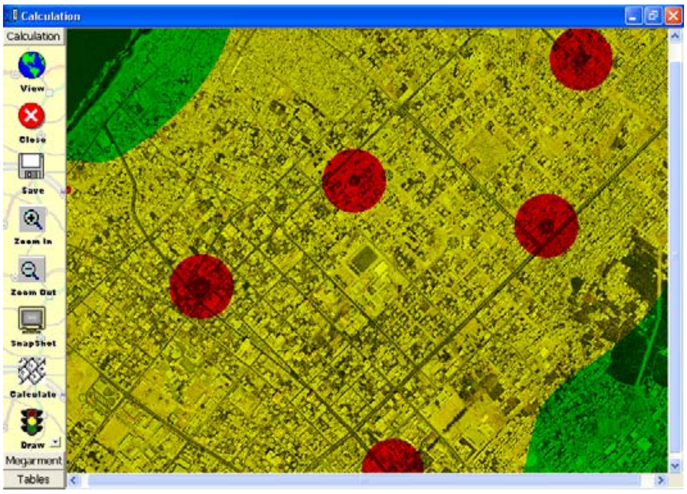


Figure 10. Color coding of radiation levels

The *measurement* menu provides full remote control of the measuring device and allows storing the measurements on the database. These measurements may be monitored online as shown in Figure 11 or they may be exported offline to customized tables and figures. The measuring device is commanded by the software to read electric field, magnetic field or power density.

The *tables* menu has helpful tools for managing the database. The user may add base stations and specify their parameters as illustrated in Figure 12. Moreover, the measurement tables may be displayed and user-defined reports may be generated.

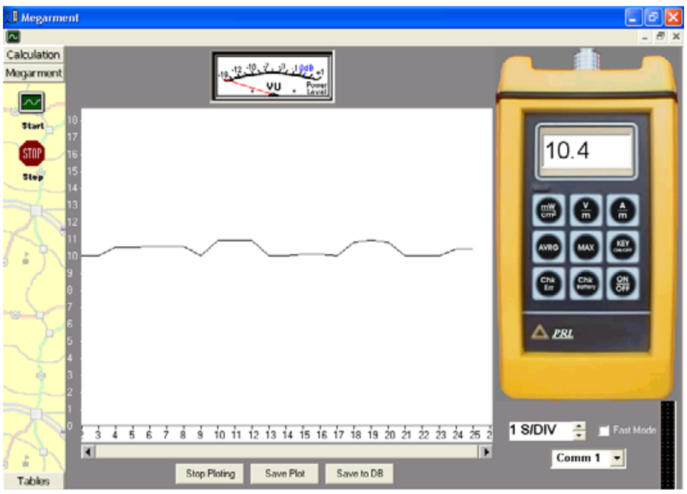
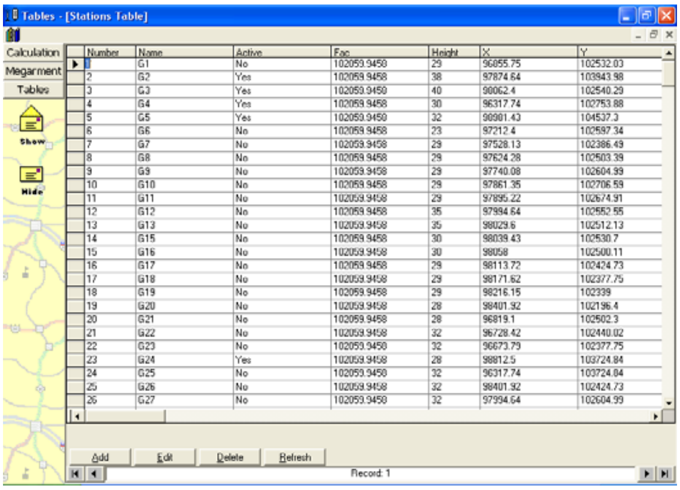


Figure 11. Measurement Window



Number	Name	Active	Fac	Height	X	Y
1	G1	No	102059.9450	29	96855.75	102532.03
2	G2	Yes	102059.9458	38	97874.64	103943.98
3	G3	Yes	102059.9450	40	98062.4	102540.29
4	G4	Yes	102059.9458	30	96317.74	102753.88
5	G5	Yes	102059.9450	32	98981.43	104537.3
6	G6	No	102059.9458	23	97212.4	102597.34
7	G7	No	102059.9458	29	97528.13	102386.49
8	G8	No	102059.9458	29	97624.28	102503.39
9	G9	No	102059.9458	29	97740.08	102604.99
10	G10	No	102059.9458	29	97861.35	102706.59
11	G11	No	102059.9458	29	97895.22	102674.91
12	G12	No	102059.9458	35	97994.64	102552.55
13	G13	No	102059.9458	35	98029.6	102512.13
14	G15	No	102059.9458	30	98039.43	102530.7
15	G16	No	102059.9458	30	98058	102500.11
16	G17	No	102059.9458	29	98113.72	102424.73
17	G18	No	102059.9458	29	98171.62	102377.75
18	G19	No	102059.9458	29	98216.15	102339
19	G20	No	102059.9458	28	98401.92	102196.4
20	G21	No	102059.9458	28	96819.1	102502.3
21	G22	No	102059.9458	32	96728.42	102440.02
22	G23	No	102059.9450	32	96673.79	102377.75
23	G24	Yes	102059.9458	28	98812.5	103724.84
24	G25	No	102059.9450	32	96317.74	103724.04
25	G26	No	102059.9458	32	98401.92	102424.73
26	G27	No	102059.9450	32	97994.64	102604.99

Figure 12. A View of Tables Menu

6. Comments, conclusions, and suggestions for future work

Most of the evidence for adverse effects from mobile phone and base stations is circumstantial and statistical. Studies that show reproducible results require considerable time and scientific training. People and governments often don't realize that cause-and-effect is not necessarily immediate and obvious. Brain tumors and adult leukemia are rare, and may have very long incubation period. In other words, the GSM system has not been in use long enough to allow for a comprehensive epidemiological assessment of their impact on health. It is stressed that further studies are needed to draw a more complete picture of health risks from exposure to low-levels of RF radiations.

In any case, the radio frequency measurements in our area of study due to mobile phone base stations as well as other RF broadcast sources are much lower than the exposure limit recommended by the FCC.

In this research the measurements of RF signals in Gaza is done during noontime as it is a convenient time for the female team who carried the experiment. This experiment was intended to provide an estimate of RF signal levels where the focus was on the special distribution. The second experiment focused on the activity of a typical GSM tower to provide an idea of the time variation of GSM signal levels during the day. The ratio of signals in the obtained chart may define an activity factor for the GSM network which may be used to normalize the measurements of the first experiment at any time point during the day.

GSM signals are not continuous but sporadic in nature. The measuring devices of these signals (similar to most sensing devices) require a time window to sense and process the measured physical signal. As the time window shrinks, the complexity and cost of the measuring device increases. The device used in this research has a cost around 8500$ and requires a time window of 0.2s for measuring and transmitting the signal record. Although this may seem inconvenient to provide real time measure of signals, it meets the scope of this research by being able to provide average measures in a relatively small time window. Moreover, the summation of many sporadic-behavior sources results in a more smooth output signal.

Suggested future work is to investigate each base station in Gaza individually. Attention must be given to suspicious base stations whose antennas are oriented directly and close to occupied buildings. The signal levels in these seriously exposed regions should be monitored along the day in order to judge the safety level taken in placing these base stations.

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