Review of EMR Monitoring Systems Developed by the Mobile Radiocommunications Laboratory, National Technical University of Athens

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Abstract: The purpose of this paper is to present fully automated systems that monitors on a real time basis the non-ionizing electromagnetic radiation emitted by wireless networks. The presented radio monitoring systems aim to perform repetitive and reliable measurements by using a well-defined measurement algorithm as well as high quality calibrated equipment and to inform the public – using the widespread web technologies – about the levels of the electromagnetic radiation emitted by any wireless telecommunication system.

Keywords: Non-ionizing electromagnetic radiation, Automated monitoring systems, Field strength measurements, Power density measurements

1   Introduction

During the last years, the installation and operation of wireless networks, has lead to increasing public concern about the exposure to electromagnetic radiation (EMR) emitted by such sources. In addition with traditional broadcasting systems (FM radio and VHF-UHF television), radar systems, etc, these concerns call for the continuous information of the public regarding their exposure to electromagnetic radiation levels. On site "ad-hoc" measurements are the first step for estimating the exposure levels. Nevertheless, ad-hoc measurements refer to a specific time period (usually 1-2 hours). On the other hand, the notion of continuous measurements of electromagnetic radiation levels on a 24-hour basis is more appealing to the concerned public [1]. This is due to the fact that the recorded values can be directly compared to the public exposure safety values, called reference levels, which are set by the relevant organizations, such as the EC [2] and local government authorities [3]. Therefore, a network for the measurement and recording of non-ionizing electromagnetic radiation levels on several sites and on a 24-hour basis is one of the best solutions for keeping the public informed. Another important parameter of such a network is to present the result of the measurements to the public via a user-friendly web site [1].

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Monitoring networks are a valuable tool in attempting to deal with public concerns about the potential health effects of non-ionizing electromagnetic radiation. As a result, several monitoring systems are implemented all over Europe and Africa [4 – 7]. Moreover, network deployment implies a number of challenges in terms of hardware certification, network control and daily maintenance. With all the above considerations in mind, electromagnetic radiation monitoring networks have been deployed in Greece. "Hermes" network [8] started its operation in November 2002, while "pedion24" network [9] (where pedion is the Greek word for field) on November 2005 [1]. So far, 329 continuous monitoring stations have been installed in urban and rural areas of Greece and more than 73 000 000 measurements have been conducted and stored.

We present the design aspects of such monitoring networks developed by the Mobile Radiocommunications Laboratory of the National Technical University of Athens, Greece, regarding the hardware and software, overall measurement results conducted up-to-date.

2   Web-based Radio Monitoring

An automated web-based radio monitoring system has been developed in the Mobile Radiocommunications Laboratory, situated at the National Technical University of Athens, Greece. The measurement system is able to monitor whichever frequency band we choose, such as FM, TV, GSM, DCS, radar signals, etc. Concisely, the developed system [10]:

(a) monitors the frequency bands by turns,

(b) computes the quantities Field Strength and Power Density,

(c) compares the extracted quantities with the electromagnetic limits [3],

(d)   monitors in real time the spectrum on the clients' web browsers.

The application (see Fig. 1) consists of two parts: the main measurement system and the part that controls and processes the measurements through a computer network. In the first part, the core of the measurement system is a spectrum analyzer, which is controlled by a PC via a developed software application. The software application controls the measurement procedure, receives the measurement data and sends it to the server. In the second part the server which is installed on a PC, provides in real time any computer connected to the Internet with the measurement data. The communication interface between the users and the server provides the users with a friendly environment with the purpose of viewing the measured quantities [10].
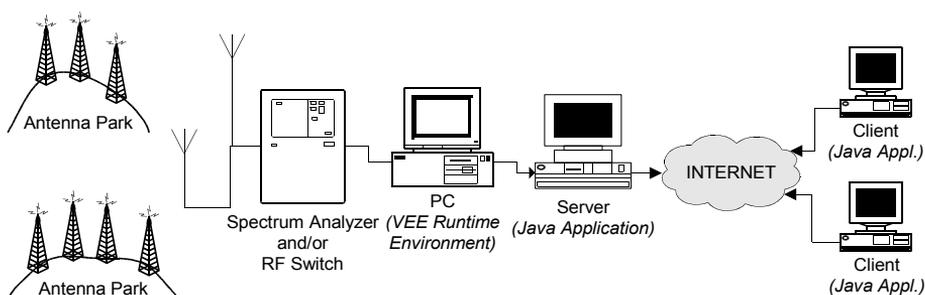
Fig. 1 – *General configuration of the web-based radio monitoring system.*

2.1 Measurement procedure

i) Measurement set-up

The measurement set-up is shown in Fig. **2**. The measurement set-up consists of [15]:

- ➢ Omni directional wideband antenna,
- ➢ Antenna power supply unit,
- ➢ Spectrum analyzer,
- ➢ Personal Computer (PC1), which is connected to the spectrum analyzer and communicates with it through a developed software application (Network Radio Monitoring),
- ➢ Personal Computer (PC2), which is connected to the former PC through Ethernet (Local Area Network) and acts as a server for the application.

ii) Measurement algorithm

In this section the methodology of the measurement procedure is described. The services that are included in the application are shown in Table 1, where the characteristics and the electromagnetic levels of each service are also presented. The electromagnetic radiation levels have been extracted from the limits that the Greek Common Ministerial Decree proposes [11].

According to the measurement algorithm, the system sweeps the bands successively. In each band there are carried out N measurements every T seconds. These parameters can have different values at each band and are controlled by the administrator, therefore, the total time devoted to a specific time, that is, $N \times T$ [s], can be altered according to the administrator's needs [10].

Table 1
Telecommunication services included in the application.

| Service	Spectrum characteristics		EMR reference levels	
	Frequency band	Modulation	Field Strength E [V/m]	Power Density S [W/m^2]
Radio (FM band)	87.2-107.9 MHz	FM	22.4	1.6
Television (UHF-1)	465-688 MHz	AM-VSB FM	23.7 – 28.9	1.9 - 2.8
Television (UHF-2)	688-855 MHz	AM-VSB FM	28.9 – 32.2	2.8 – 3.4
Mobile Telephony (GSM 900 Downlink)	935-960 MHz	GMSK	33.6 – 34.1	3.7-3.8
Mobile Telephony (DCS 1800 Downlink)	1885-1880 MHz	GMSK	47.8 – 47.7	7.5
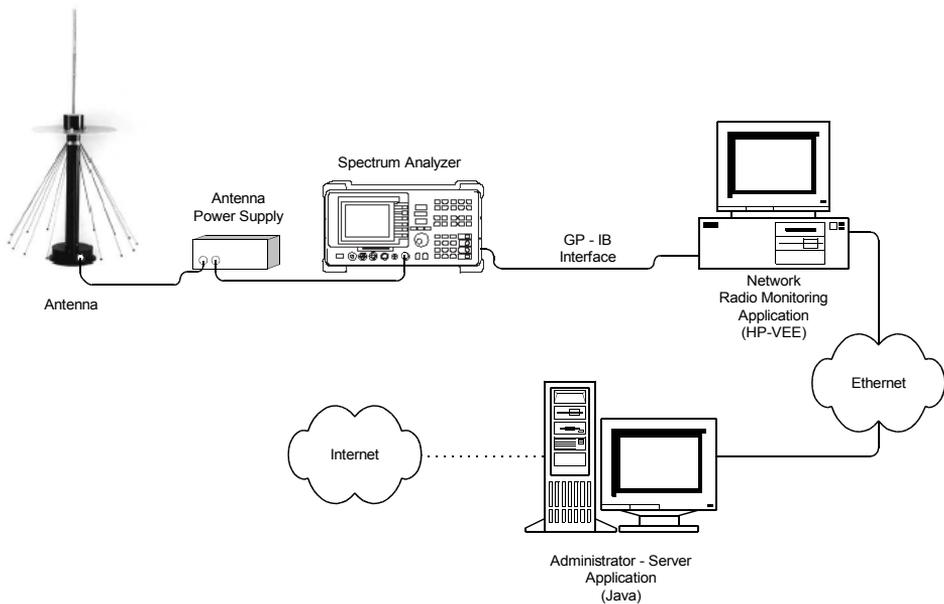
Fig. 2 – *Measurement set – up.*

Each measurement consists of the following stages [10]:

(a) Initially, the spectrum analyzer – which is the measurement device – carries out a power measurement, by dividing the frequency range in 400 spaces that are called bins and sampling the received signal in these spaces. Therefore, each measurement consists of 401 values of the power (P_{SA} in dBm) in the input of the spectrum analyzer.

(b) The former values are processed in order to distinct the peak values and reject the others, since only the peak values express the contribution of each signal to the electromagnetic pollution.

(c) The remainder values (power levels in the input of the spectrum analyzer) are converted into field strength (E in dBμV/m) and power density (S in dBW/m^2) levels in the output of the antenna. For this purpose, we take into account the total loss of the configuration (L_{conn}) and the antenna factor (K). The system loss was measured experimentally, whereas the antenna factor was given by the manufacturer. The conversion is done according to the following equations [12]:

$$E\left[\frac{\text{dBμV}}{\text{m}}\right] = K\left[\text{dB/m}\right] + P_{SA}\left[\text{dBm}\right] + L_{conn}\left[\text{dB}\right] + 107\,\text{dB}, \qquad (1)$$

$$S\left[\frac{\text{dBW}}{\text{m}^2}\right] = K\left[\text{dB/m}\right] + P_{SA}\left[\text{dBm}\right] + L_{conn}\left[\text{dB}\right] - 38.76\,\text{dB}. \qquad (2)$$

(d) The values are combined in order to extract the electromagnetic field levels per band and quantity and estimate how many times the electromagnetic field levels are below the limits (Times Below Limits – TBL). These quantities are computed according to the following equations:

$$TBL \text{ for field strength} = \frac{1}{\sum\limits_{i>1\text{MHz}}^{300\text{GHz}} \dfrac{E_i^2}{E_{Li}^2}}, \qquad (3)$$

$$TBL \text{ for power density} = \frac{1}{\sum\limits_{i>1\text{MHz}}^{300\text{GHz}} \dfrac{S_i^2}{S_{Li}^2}}, \qquad (4)$$

where:

− E_i, S_i are the field strength and the power density at the frequency of i MHz,

− E_{Li}, S_{Li} are the reference level of the field strength and the power density at the frequency of i MHz.

2.2 Software applications

In this section are described the developed software applications which implement the measurement algorithm and present the results to the internet. There have been developed [10]:

 ➢ An application in the HP-VEE[TM] visual programming language, in order to communicate with the measurement device (spectrum analyzer) and control its parameters,

 ➢ Two applications in the Java[TM] textual programming language, in order to control the whole system, define the operational parameters and provide the public with the measurements, through the internet.

2.2.1 HP-VEE application

The specific application is installed on PC1 and aims to set the measurement parameters (frequency range, resolution bandwidth, video bandwidth), implement the repetitive measurement algorithm that was described in the previous section, receive the measurements from the spectrum analyzer and send it to the server. The application has the feature of being automatically restarted after a power failure or when the server halts [10].

2.2.2. Java Applications

The process of the measurements and their presentation using the internet are implemented in two separate applications: (i) Server – Administrator application and (ii) Client – User application [10].

(i) Server – Administrator application

The specific application (see Fig. 3) controls the measurement system and shows the extract quantities. The administrator is able to start and stop the measurement procedure, edit and view the operational parameters and view a log file which records the users that were connected to the system, via special buttons. The administrator is able to alter the values of the following operational parameters (see Fig. 4) [10]:

 ➢ Spectrum analyzer parameters, such as the start/stop frequency, the resolution bandwidth, the video bandwidth, the sweep time and the scaling,

 ➢ Measurement parameters, such as the number of measurements (N) and the measurement period (T) in each band,

 ➢ Configuration parameters, such as the IP port address of the PC, in which the HP-VEE application is running, the antenna factor and the loss of the connection between the antenna and the measurement device.

 ➢ General parameters, such as the name and the corresponding frequency/channel of the various radio and television stations.
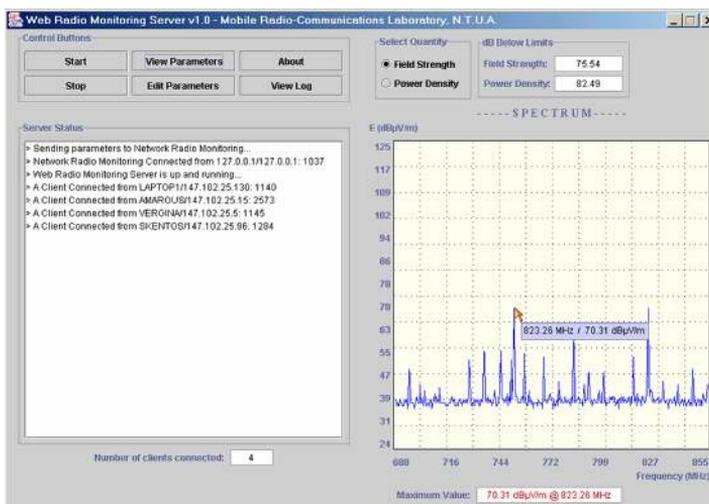
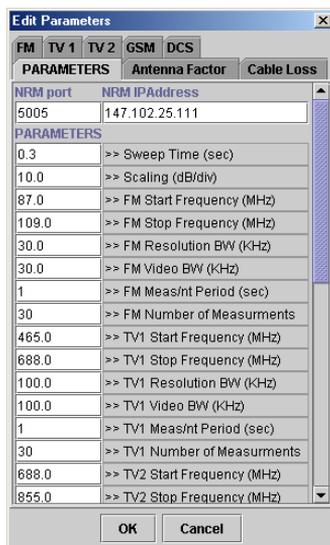**Fig. 3** – *Server – Administrator application.*

Fig. 4 – *Operational parameters.*

(ii) Client – User Administrator application

The application (Java applet – see Fig. 5) has been developed and running on a web page providing the users with the ability to watch the electromagnetic spectrum of the measured telecommunication services (see **Table 1**) and the contribution of each service to the electromagnetic pollution. It is accessed by every computer connected to the internet, provided that its browser is Java

enabled. It is developed with the same programming techniques as the Server – Administrator application [10].

The user is able to:

➢ Choose the language of the presented application,

➢ View the spectrum of the measured telecommunication services in different frames

➢ Choose to view a significant telecommunication service,

➢ View the field strength or the power density

➢ View the current maximum value of the signal in each band, the frequency in which the maximum value occurs and the Times Below Limits (see (3) and (4)) for both the field strength and power density,

➢ Choose between absolute and logarithmic (dB) units for the extracted quantities,

➢ View the channels (e.g. radio, TV) corresponding to each frequency, by moving the mouse over the peaks of the spectrum.

➢ Be informed about the proposed limits for each band from a relevant table
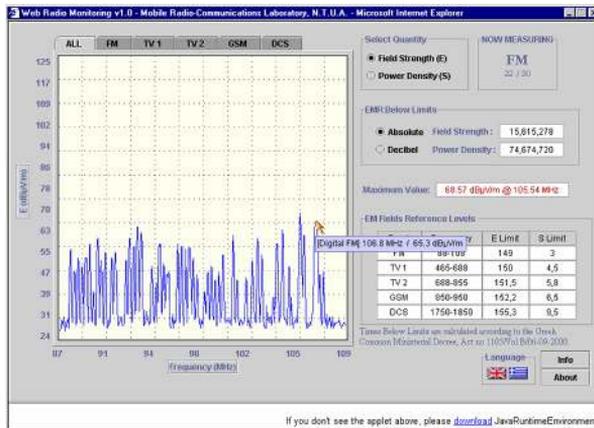

Fig. 5 – *Client – User application.*

3 A distributed MultiInstrument RF Radiation Measurement System

A project implemented by the Mobile Radiocommunications Laboratory of the National Technical University of Athens for the Hellenic Civil Aviation Authority is the design, development and installation of an automated

monitoring system of the radiofrequency radiation levels in two terraces of corresponding buildings of the authority, located on Immitos Mountain, Attica region, Greece.

The first building houses radar (see Fig. 6), while the second a set of antennas used for the control of the Greek airspace (see Fig. 7). Furthermore, the surrounded area contains a plethora of electromagnetic radiation sources, such as radars, broadcasting antennas, mobile telephony antennas, microwave links, etc, which burden the environmental electromagnetic pollution at the specific sites.

Fig. 6 – *Radar building*.

Fig. 7 – *TYM Building*.

Previous measurements conducted by the Mobile Radiocommunications Laboratory have confirmed the expected high intensity of the electromagnetic field values at these sites. The fact that these areas are accessible by the working staff necessitates the installation of an automated measurement system of the electromagnetic radiation levels able to inform the staff for the electromagnetic radiation levels on a 24-hour basis and alert it when a measured value exceeds the safety reference levels according to the Greek legislation [3].

A multitude of devices [13 – 15] and measurement configurations [4 – 9] are commercially available and being widely used to monitor the electromagnetic field strength levels. In such systems, the key feature should be the end-to-end automation, from the automated identification of the measurement devices, the data acquisition and the online distribution and presentation of the results to the interested party. The described system suggests a scenario where the measurements are transferred to the end-user immediately after they are carried out, which is in contrary to the typical configurations where the devices store their measurements and transmit them at predefined

times instances to the control unit. Additionally, the end-user application is independent of the hardware configuration, that is, if the measurement device change or a hardware failure occurs to one or more instruments, the application is automatically adjusted and need not to be updated.

The system is based on the client – server architecture, while a lot of parameters have been taken into account during the design, such as its fully configurability via a local computer network, its flexibility regarding the type and the number of the measurement devices operating and the measurement procedure parameters.

3.1 Hardware architecture of the system
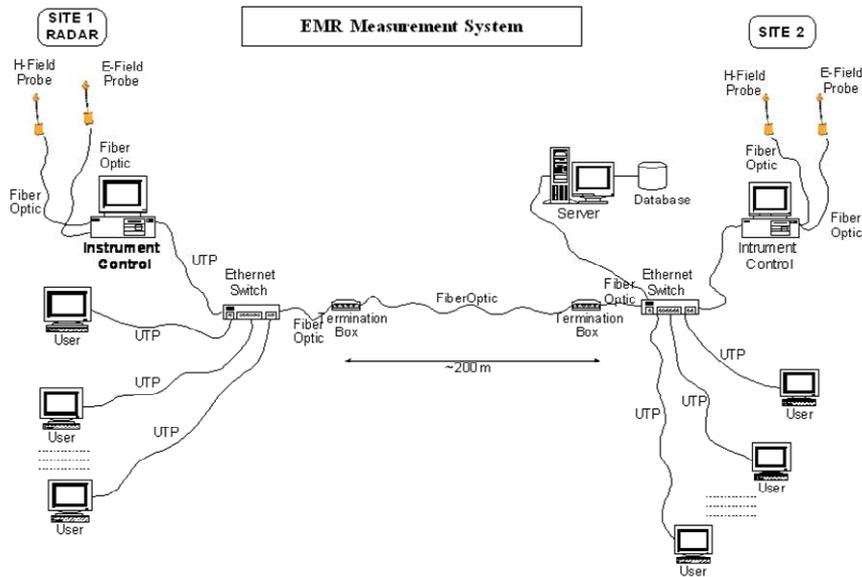
The system structure is presented in Fig. 8.

Fig. 8 – *System architecture.*

As far as the hardware architecture the system is comprised of the following parts:

  i) The measurement devices, which are wideband, triaxial and excellently isotropic electromagnetic field sensors and controlled via their optical interface. An electric and a magnetic field sensors are installed at each site, giving the electric field strength value (E in V/m) and the magnetic field strength value (H in A/m) respectively. The frequency range is 3 MHz – 18 GHz for the electric field sensor and 27 MHz – 1 GHz for the magnetic field sensor, thus covering the majority of possible electromagnetic radiation sources.

444

ii) The two instrument controller computers (instrument server PCs) which are connected to the instruments via their optical interface. One server is installed per building and is responsible for the transmission of the measurement commands to the instruments and the collection of the measurement data from them.

iii) The central server computer, which communicates with the instrument controller PCs through the local area network and is responsible for the whole control of the system and the measurement data collection and storage. It is also committed to distribute the data to the clients of the system.

3.2. Software architecture of the system

As far as the software architecture is concerned, three applications have been developed, based on the client – server model:

i) The Instrument Server application, which runs on the Instrument Controller PC and is responsible for the full control of all the measurement devices connected to it. It is developed in the Java programming language and enables the administrator of the system to determine the measurement parameters, namely, which instruments are active, the measurement refresh period and the full-duplex communication parameters via a graphical user interface. Each instrument oriented command, such as an instrument type query or a measurement query is passed to it through the Java Comm API [16], which, therefore, enables the administrator to talk to the specific instruments. The corresponding responses are received from the application in a similar way. While the application is in a continuous communication with the instruments, it is in a waiting mode, waiting for the central control station to connect to it via the local area network, in order to pass to it the collected data.

ii) The Central Server application runs on the Central Server PC and it is also developed in Java. Through this frame application the administrator can set the instrument server PC parameters, such as their IP addresses, ports and identification strings. The connection is achieved via the local area network. The first packet received contains identification information concerning the number and the type of operating instruments and also where the specific instruments are installed. The next packet contains the measurement data plus their identification data, attached to them as headers. The Central Server is also in waiting mode, waiting for users' requests for connection. Finally a developed RDBMS stores the measurement data for further processing.

iii) The End – User application, which runs on the user – client PC and is responsible for the presentation of the measurement results on an online mode. That means that every time the measurement devices carry out a

new measurement, it is automatically previewed on this application. Through its graphical user interface one can monitor the electromagnetic field measurements from all the devices, regarding all the measurement sites. Moreover, a comparison with the safety reference level is done on the fly and a graphical indication reflects the result of this comparison.

4 Hermes and Pedion24 Systems – Continuous Monitoring of EMR

4.1 System architecture – design aspects

A typical system architecture of a centralized monitoring network is depicted in Fig. 9.

The network consists of the Remote Measurement Stations (RMS) and one or more Control Units (CU). Each remote measurement station communicates with the control unit via a public wireless network such as GSM, GPRS or UMTS. Such a wireless interface allows the installation of a measurement station practically everywhere as long as the area is covered by any cellular operator. The control unit controls the remote units, stores the measurement data and hosts the web site. Any interested party can access the results through an internet gateway [1]. A detailed description of each part of the system follows.
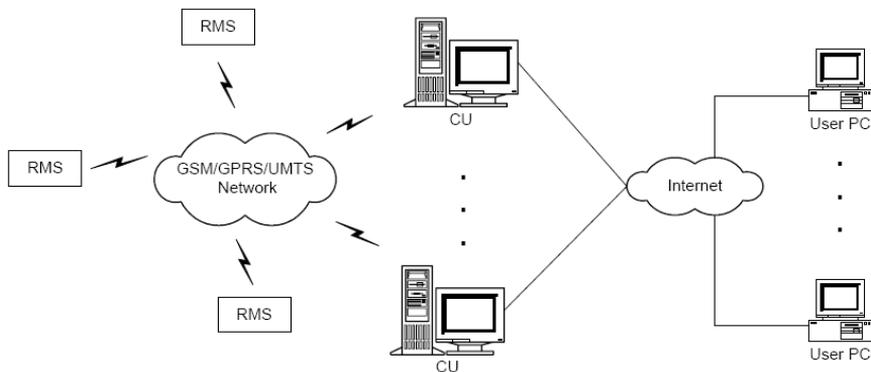

Fig. 9 – *System architecture.*

4.1.1 Remote measurement station

The measuring equipment must be a fully autonomous unit able to [1]:

− operate continuously (on a 24-hour basis),
− perform electromagnetic radiation measurements in the frequency range of interest covering the main sources that contribute to the total electromagnetic pollution,

- store the measurements in its internal memory and transmit them to the control unit via a wireless interface for further elaboration,
- be supplied by the main power supply or a solar panel (preferable),
- be fully remote controlled,
- detect abnormal operation of any kind (self diagnostics such as power loss and overheating problems) and report it to the control unit.

In order to fulfill these requirements a remote monitoring station would consist of a broadband isotropic and triaxial electric field sensor, a GSM/GPRS/UMTS modem, as well as temperature and humidity sensors. A major problem encountered in this system is the periodic calibration of the monitoring stations. Regarding the measurement quantities, either broadband or narrowband measurements can be conducted. Broadband measuring stations record the electrical field strength and/or the power flux density for a given frequency range. A range of 100 kHz – 3 GHz is usually enough in order to take into account the vast majority of sources. Other possible ranges are for example 880 – 960 MHz (GSM900), 1880 – 2100 MHz (GSM1800 plus UMTS band), etc. In [17 – 19] the interested reader can find a plethora of commercially available monitoring units. Recently, selective monitoring systems became commercially available [20]. The referred stations are fully autonomous and can be remotely controlled via the GSM/GPRS protocol [1]. Nevertheless, there exist some limitations regarding this type of device. Basically, the contribution of each frequency band or equivalently radiation source cannot be estimated, as the measurement probes of the stations have a broad frequency response. In addition, only one spot of the whole inspected site is actually measured, which renders the final installation spot selection a critical manner. To overcome these limitations, we have decided to perform additional on-site or "ad-hoc" measurements using different equipment on each site every 6 to 12 months. These measurements do not replace the continuous measurements but they complement them. The scope is twofold. First, by using either a spectrum analyzer or a highly selective radiation meter, we accomplish to distinguish between the radiation sources. Moreover, a verification of the accuracy of the continuous measurement result is available by simply comparing the total exposure levels of the two methodologies [1].

4.1.2 Control units

The control unit is a server computer equipped with a wireless modem and the necessary software applications for [1]:

i) controlling the remote monitoring stations and configuring the operational parameters,
ii) downloading the measurement data via the wireless interface,
iii) storing the data in its hard disk,

iv) processing the measurement results and publish them to the corresponding web site.

Usually the remote measurement station manufacturer provides a software application for the control of the units and the data collection. Through this application the system administrator is able to change the measurement and communication parameters. The data is collected and exported in formatted text file. Moreover, a graphical user interface is provided for plotting the measurement values. The measurement data is stores in a database therefore a full historical record for every measurement site is kept on the control unit. An administrative tool (desktop- or web-based) is developed in order to perform the above operations. Finally, a web server running on the control unit hosts the web site [1]. A more detailed description of the hardware and software architecture can be found in [21 – 24].

4.2 Operating networks in Greece

Two electromagnetic radiation networks have been deployed in Greece. These electromagnetic radiation monitoring networks share a common scientific goal, that is, to conduct accurate, long-term, continuous measurements of the non-ionizing electromagnetic radiation in Greece and to determine and understand trends and variability of the field [1].

4.2.1 Hermes monitoring network

In November 2002, the Mobile Radiocommunications Laboratory of the National Technical University of Athens, commenced the operation of the first electromagnetic radiation monitoring network in Greece, named "Hermes". The development of this network was motivated by the lack of previous systematic measurement and recording of electromagnetic field strength levels over the country and aimed at providing valid, up-to-date information to citizens about the results of these measurements, namely, the exposure level to non-ionizing electromagnetic radiation [1].

The system at its present state (May 2014) comprises 124 remote monitoring stations spread all over Greece and two control unites located in two University laboratories (National Technical University of Athens, NTUA and Aristotle University of Thessaloniki, AUTH). The Mobile Radiocom-munications Laboratory controls stations located in the Southern part of Greece, while the AUTH in the northern part. The stations are located at schools, universities, public authorities' buildings and private flats. There are multiple criteria for the selection of the measurement sites. High population concentration is among the most important ones. The special features of each location, such as the presence of buildings of particular interest for the local community (e.g. schools and hospitals) and the existence of antennas in the close vicinity of the sites are also taken into account. It should be explicitly

noted that the aim of this monitoring network is to provide the public with accurate information about the electromagnetic radiation at sensitive areas all over Greece rather than to measure the radiation emitted from specific antennas. As a result, the technical characteristics (emitted power, main lobes, etc) of the nearby antennas are not a priori known, as we do not focus on distinctive antennas. From now on, we will only refer to the stations that are under the control of the Mobile Radiocommunications Laboratory.

The measurement results are open to the general public through a devoted web site (see Fig. 10).
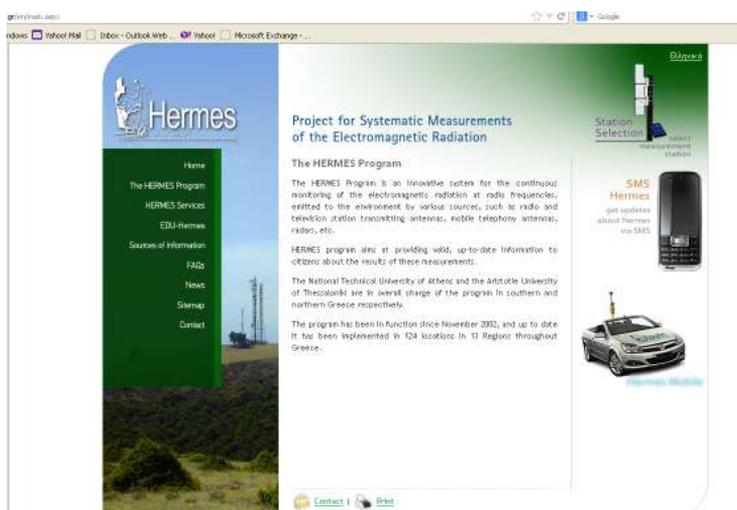

Fig. 10 – *Hermes monitoring network*.

The web site contains both static and dynamic pages and aims at presenting the measurement results for all the monitored sites. It also provides information concerning the non-ionizing electromagnetic radiation exposure issue. Through the web site, the visitor may view graphs of the measured values for custom date/time interval selection. Furthermore, a comparison of the measured values with the Greek legislation reference levels is presented. A feedback form is also available to the public in order for them to express questions or comments to the system administrators. Although the electric field strength is recorded by the remote measurement stations, power flux density values are presented on the web site [1]. Detailed description of the "Hermes" network and the results of the measurement can be found in [8].

4.2.2 "Pedion24" monitoring network

In November 2005, Mobile Radiocommunications Laboratory started the operation of a second monitoring network, named "pedion24" network, Fig. 11.

The design and operating principle of this network are similar to those of "Hermes" network. "pedion24" network at its present state (May 2014) consists of 205 remote monitoring stations. Locations of monitoring stations are carefully chosen to cover places of special interest such as schools, hospitals, nurseries, areas with high population density, and also private flats in Attica and 39 other prefectures of Greece. The network is continuously expanded throughout Greece. Detailed description of the "pedion24" network and the results of the measurements can be found in [9].

Fig. 11 – *"Pedion24" monitoring network.*

4.3 Measurement methodology

The described technical background regarding the measurement methodology is common for both presented networks.

4.3.1 Broadband measurements

Fully autonomous and remotely programmable measurement stations have been chosen as the measuring equipment of the continuous monitoring measurement procedure. Four different models have been used, developed by two manufacturers [19, 25]. The stations differ in the number and the frequency range of the bands they measure and record [16]:

− EE4070-WB model that records the electromagnetic field strength in the frequency band 100 kHz – 3 GHz (Fig. 12a),
− EE4070-SL model hat records the field strength for three frequency bands: 100 kHz – 3 GHz, GSM-900 band GSM1800 + UMTS band,
− MCE-410 model that records the field strength for two frequency bands: 100 kHz – 3 GHz and 900 MHz – 3 GHz (Fig. 12b),

    − PMM-8057 model with EP–3B-01 probe model that records the field strength in three frequency bands: 100 kHz – 3 GHz, 100 kHz – 862 MHz and 933 MHz – 3 GHz (Fig. 13).

(a)

(b)

Fig. 12 – (a) EE4070-WB *station at Koskinou, Rhodes*;
(b) MCE-410 *station at Heraklion, Crete*.

    The measured quantity is the electric field strength and the sensors are isotropic tri-axial E-field probes. Currently, the vas majority of the remote measurement stations used for the two networks are MCE-410 and PMM-8057 models, as the other two models have been discontinued by the manufacturers. The main technical characteristics of these two stations and a detailed description of the measurement methodology can be found in [7].

Fig. 13 – PMM8057 *station at Kipseli, Athens.*

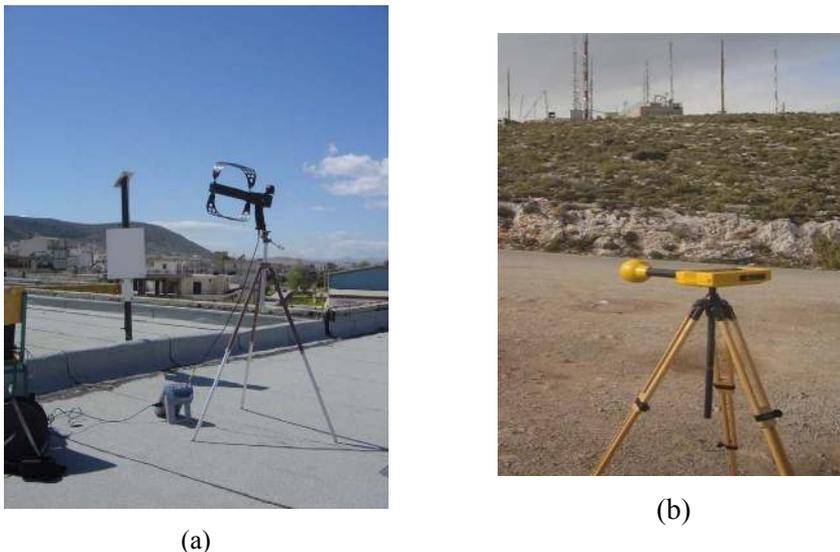### 4.3.2 Ad-hoc frequency selective measurements

(a)

(b)

Fig. 14 – *Narrowband measurement setup*: (a) *Spectrum analyzer*;
(b) *Selective radiation meter.*

The necessity of these measurements has been explained in a previous section. Either a portable spectrum analyzer equipped with a set of antennas [26] or a selective radiation meter [17] with a broadband probe can be used to measure the electric field strength/power flux density values of every radiation source. Then, the measured data are processed and grouped in sub-bands such as FM, UHF, GSM-900, etc. The calculation of the total exposure level is based on the formula given in [2] and [27]:

$$SI = \sum_{i>20MHz}^{300GHz} \left(\frac{E_i^2}{E_{\lim,i}^2} \right) = \sum_{i>20MHz}^{300GHz} \left(\frac{S_i}{S_{\lim,i}} \right) < 1 \text{ for safe exposure,} \qquad (5)$$

where:

− SI is the safety index and must be lower than the unit for safe exposure

− E_i and S_i are the measured values for each frequency source i,

− $E_{\lim,i}$ and $S_{\lim,i}$ are the corresponding reference levels.

The lowest measured frequency is 20 MHz for the spectrum analyzer set-up and 75 MHz for the selective radiation meter set-up and not 100 kHz as in continuous monitoring due to the lack of an antenna for measuring such a low band. Therefore, we must be careful when comparing these results with the broadband monitoring results due to this difference in the measured bands.

Another commonly used measure of the exposure level is the inverse of the safety index, which shows how many times below or above the safety limits is the measured field. The contribution of each formed sub-band to the total exposure is also calculated based on the individual safety indexes (by summing the corresponding terms of the summation). Typical ad-hoc measurements set-ups and two representative graphs from the web site are given in Fig. 14 and Fig. 15 and Fig. 16 correspondingly.
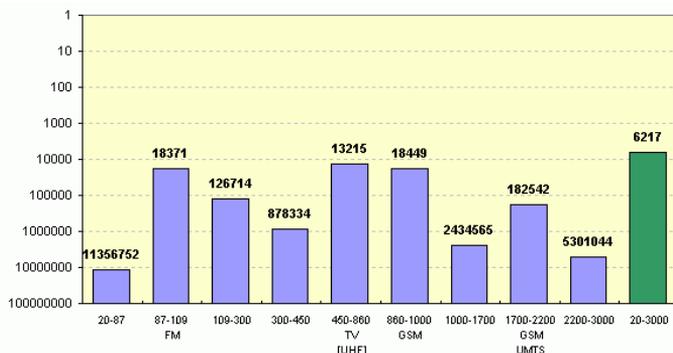

Fig. 15 – *Power Density measurement results conducted with a spectrum analyzer (narrowband). The bold indicates how many times below the limit the measured levels are.*
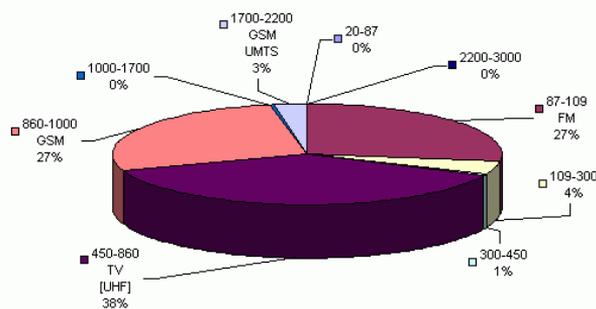

Fig. 16 – *Contribution of each band to the total electromagnetic radiation calculated by spectrum analyzer measurements.*

5   Conclusion

In this paper we have presented three non-ionizing electromagnetic radiation monitoring networks designed and implemented by the Mobile Radiocommunications Laboratory of the National Technical University of Athens, Greece.

In the first network, a developed software application performs radio monitoring in order to inform the general public about the levels of the electromagnetic radiation from antenna parks. The application implements a robust algorithm based on the functions of the spectrum analyzer. The public, through a web-site, gets informed with the issues regarding the electromagnetic radiation produced by wireless telecommunication systems.

The second radio monitoring network presented is a fully automated distributed multiinstrument RF radiation measurement system that monitors on a real time basis the electromagnetic radiation emitted by antenna parks. The key feature of this system is the online operation capability, its easy configurability through a computer network and the automatic adaptation of the running software application to any configuration change.

The third presented case is the design and development of automated nationwide monitoring systems of the non-ionizing electromagnetic radiation in Greece. The system uses reliable hardware based on electric field strength probes and the measured data is presented openly to the public using the Web. Two independent networks, called "Hermes" and "pedion 24" have been operating since November 2002 in several areas of Greece, and more than 73 000 000 electric field strength measurements have been recorded up-to-date in our database and 350 ad-hoc measurements have been conducted. Since the commencement of operations the measured electromagnetic radiation levels are significantly below the required reference levels. We are currently planning the installation of more remote stations in dense urban and rural environments.

6   References

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