SEAWIND

FP7-ENV-2009-1

Sound Exposure & Risk Assessment of Wireless Network Devices

Call: FP7-ENV-2009-1

Grant agreement no.: 244149

Final Summary Report

Executive Summary

Wireless network devices have become an integral part of modern society as they facilitate our lives by offering a broad range of capabilities oriented toward greater user mobility, flexibility, and productivity. Along with this development, our daily exposure to radio frequency (RF) electromagnetic fields (EMF) where we live, work, and play is rapidly increasing. During the course of SEAWIND project, the technology has become even more pervasive due to the growing popularity of smart phones and tablet computers, which had already reached the milestone of 1 billion users in October of 2012 and is expected to double over the next 3 years.

The primary objectives of SEAWIND were to close the knowledge gaps regarding the sequelae of exposure to wireless network devices. First, we analyzed exposure signals of the wireless network devices and identified the most relevant technologies with respect to exposure, which is currently dominated by the systems (GSM, UMTS, LTE, and WiFi) integrated in smart phones and tablet computers; wireless metropolitan area networks (WiMAX) and body area networks (BAN) are not being exploited as heavily as expected. Thus, we focused our analysis on the GSM, UMTS, LTE, and WiFi data networks, as well as on exposures related to RFID applications.

As exposure patterns change continuously with different usage patterns, we assessed not only the exposures found with today's devices but developed methodologies (novel propagation models inside rooms) and instrumentation (measurement protocols, novel calibration methods) that are generally applicable to current and future technologies for assessing the maximum and typical exposures to the primary RF sources inside buildings. The improved calibration methods, which provide precision increased by a factor of 20 (uncertainty of > 100% to < 5% ($k = 2$)) and, therefore, increased confidence in exposure assessments and in the demonstration of compliance of wireless network devices within safety limits, have already been adopted by standards and regulatory agencies. We have generated a translation matrix from incident fields (external to the body) to induced fields (internal to the body) in the various tissue types from more than 7000 simulations involving the complex anatomies of the Virtual Population. The new methods and tools have been applied to measure spatial and temporal RF exposures from wireless network technologies in typical indoor microenvironments (schools, crèches, offices, and homes) in Belgium and Greece and have also been used to estimate the maximum and typical exposures from other technologies. They also have been experimentally validated by near-field measurements and in anechoic chambers.

One of the main results is the estimations of the mean and the range of the exposures from the various wireless network devices and the comparison to the exposures from other wireless technologies. This is summarized in Figure 1. The highest exposures found were due to the use of a mobile phone as a wireless access point with the phone in contact with the body (e.g., inside the trouser or shirt pocket), i.e., via tethering. In this configuration, the maximum exposure may even exceed safety limits by a factor of two or more, depending on the phone

model (while always compliant when used at the ear, many phones today comply with safety limits for partial body exposure only when at a distance of 15 mm with their rear-sides towards the body). The estimated mean exposure at the highest data rate is also higher than that of the phone used in talk mode. Therefore, the most effective way for people to reduce exposure is to keep the phone, while tethering, at least 50 mm away from the body (e.g., in a bag) or, even better, more than 200 mm away (e.g., on the table). At distances larger than 200 mm from the body, mobile phone exposure is reduced by a factor of 400 compared to the maximum when operated at the ear or body. When the distance is more than one meter, exposures are reduced by an additional factor of 25 compared to the expected exposure to base stations. With these simple measures, exposures to wireless network devices can be kept significantly far below that of mobile phones operated at the ear. Exceptions are the use of the wireless data network for phone-like usage at the ear, e.g., Skype telephony. Similarly, the exposure of the head during talk-mode can be reduced by the use of hands-free kits. It should also be noted that exposures of the hands might be high for handheld devices like smart phones, tablet computers, etc., during wireless data uplink via mobile or wireless networks and when using a phone hand-held with a hands-free kit. Another measure to reduce the exposure is the choice of communication technology. The use of the more modern UMTS technology in talk-mode reduces mean exposure levels by a factor of 100 compared to GSM. When considering cumulative exposure for transmission of a fixed size data packet, UMTS and WiFi rank approximately equal, while with GSM, which has much lower data transfer rates, the exposure duration will be longer by a factor 10 – 100 with concomitantly higher cumulative exposure.

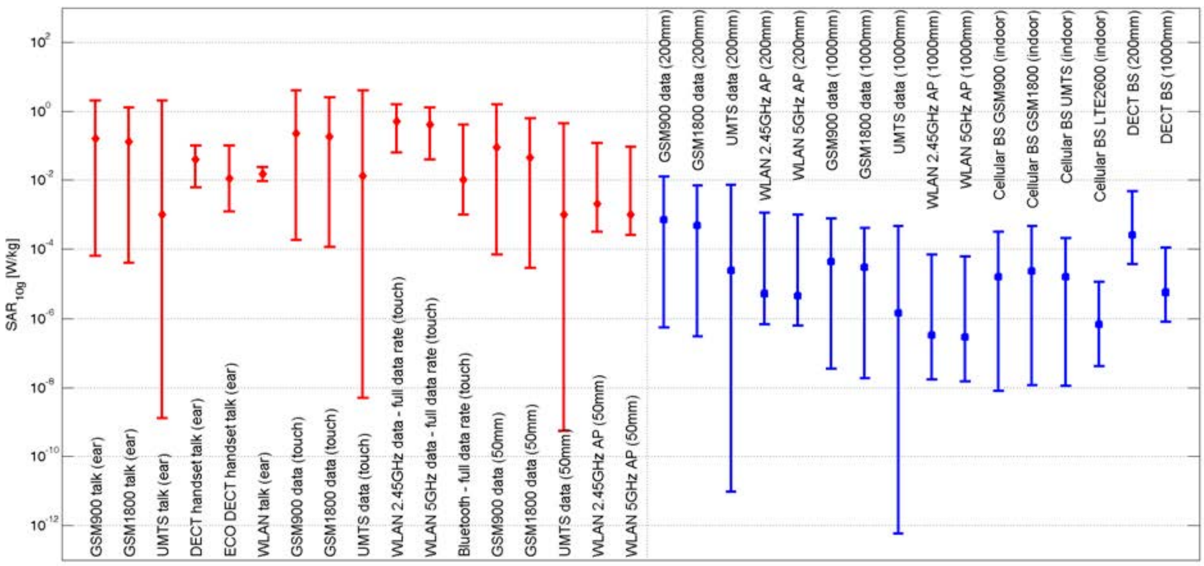

Figure 1: Estimated mean and maximum and minimal exposures of wireless network devices compared to other wireless sources (red: near-field sources; blue: far-field sources). These were compiled for the purpose of comparison at the end of the project and are subject to technology, usage, and implementation changes.

Based on these results and considering the quality of the communication links, guidelines for exposure minimization at user terminals and access points, as well as a web-based tool for optimal placement of the access point for minimized exposures in apartments and houses, were derived.

The secondary objectives aimed to develop exposure systems and tools for screening the potential impact of wireless network exposures on genome integrity. Based on our analysis of exposure systems, we have synthesized four test signals that represent today's variety of exposures (GSM, UMTS, WiFi, RFID) with characteristics that maximize the likelihood of evoking a biological response (high amplitude, high peak-to-average ratios, high periodicity of the ELF power variations) based on current information from genotoxicity screening. Using carefully controlled *in vivo* and *in vitro* experimental systems and approaches, we could not reproduce previously reported induction of DNA damage by mobile-phone-specific signals. In addition, we found no indication of a direct DNA-damaging potential by the newly explored signal modulation used in modern data transfer technologies. On the basis of our investigations, however, we cannot exclude modulation-specific interferences as some of our findings provide hints about how EMF may interfere with cellular homeostasis other than by damaging the DNA. Altogether, these results clarify current uncertainties regarding the interactions of wEMFs with the human genome and they advance the conceptual framework for future investigations into their potential health impacts. In particular, their implications will stimulate and guide experimental research into the role of EMFs as a putative co-carcinogen or co-stress factor that might under specific circumstances potentiate adverse health effects. These contributions will also be of great value for the further development of tools for the screening and assessment of the biological effects of wEMF exposure and, hence, the safety of future wEMF technologies.

In the third part of the project, guidance and recommendations were developed for appropriate risk governance for government officials. This was done based on eight focus groups (four in Switzerland, four in Greece) and one group Delphi to balance undue precaution (rejection of beneficial technology) with carelessness about risks (focus on benefits only and neglect of scientific uncertainties).

In summary, the SEAWIND project has not only met all objectives of the call by closing the knowledge gaps in the exposure assessments of wireless network devices as used today, but went further to develop methodologies and instrumentation to enable rapid and cost-effective exposure evaluations of any future technologies operating at frequencies of 0.8 – 6 GHz. Novel tools for genotoxicity screening for any RF signal have also been developed. The screening we performed on selected signals did not reproduce previous findings of DNA damage induction by wEMF exposure but provide convincing arguments for the absence a direct DNA damaging potential of such exposure. Preliminary findings on modulation dependent interferences with cellular processes provide an important lead for future research that should be focused on the finding the site and mechanism of interaction of these external wEMF with the biology.

Table of Contents

Summary Description of Project Context and Objectives

Wireless devices are an integral part of modern society that have become ubiquitous in our homes, schools, hospitals, and workplaces in the last decade, as the populace becomes increasingly mobile and technologically sophisticated. Although wireless communications facilitate our lives by offering a broad range of capabilities oriented toward greater user mobility, flexibility, and productivity, our daily exposure to electromagnetic fields (EMF) is rapidly increasing where we live, work, and play. Among the main sources of exposure are wireless local area networks (WLAN), wireless metropolitan area networks (WMAN or WiMAX), and body-mounted and body-worn wireless personal area networks (WPAN). Another rapidly evolving technology is radio frequency identification (RFID).

The exponential growth of wireless network device usage necessitates that the scientific basis for assessment of potential health risks due to EMF exposure in everyday life be broadened, especially since the International Agency for Research on Cancer (IARC) has classified radiofrequency (RF) EMF as possibly carcinogenic to humans (Group 2B) based on studies that show increased incidence of glioma, a malignant type of brain cancer, associated with wireless phone use (http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf).

The three-year initiative SEAWIND (***S****ound* ***E****xposure & Risk* ***A****ssessment of* ***Wi****reless* ***N****etwork* ***D****evices*) aimed to address the questions concerning the impact of exposure to novel wireless technologies on health by (1) providing comprehensive measurements of public exposure, (2) characterizing the fields induced inside the body, (3) evaluating the effects of specific exposures on cells and DNA, and (4) combining the findings of this project with available scientific knowledge to further enlighten policymakers.

In ten scientific work packages under the umbrella of an eleventh work package devoted to management, SEAWIND addressed the entire scientific spectrum from dosimetry to biology with the aim to satisfy the following objectives:

1. In a comprehensive literature review on *in situ* and laboratory incident exposure evaluations as well as experimental dosimetric evaluations of wireless networks (Work Package 1: 'Review of exposure assessment and dosimetry of wireless networks'), shortcomings and knowledge gaps should be identified at the outset of the project. The literature is monitored throughout the lifetime of the project and subsequently updated at the end of the project.
2. Investigation of current and future wireless network systems from device and system points of view (Work Package 2: 'Review of communication systems, signals, and power modulations'): The most important aspects to consider were power classes and power envelopes of systems as a function of traffic. The former is important for evaluation of compliance and worst-case exposure, whereas the latter is relevant for assessment of average exposure strength and exposure signal characterization.

3. Development of instrumentation and procedures for the accurate exposure assessment of these devices (Work Package 3: 'Development of instruments and calibration techniques'). The knowledge gained is disseminated via Work Package 9 ('Dissemination to standards') to the appropriate standardization groups.
4. Assessment of worst-case exposures required to demonstrate compliance with safety limits as well as for risk assessment (Work Package 4: 'Incident field evaluations for whole-body exposure'). This needs to be performed for the far-field exposure scenarios and for the near-field exposure scenarios (Work Package 5: 'Dosimetry for worst-case partial body and local exposure') are evaluated.
5. Assessment of typical daily-life exposure scenarios (Work Package 6: 'Organ specific dosimetry') by selection of source models and postures to represent exposure of the general population and the generation of anatomical models in appropriate postures and dosimetric evaluations for adults, children, and pregnant women.
6. Development of theoretical propagation models to characterize the exposure, which are thoroughly validated with respect to epidemiological considerations.
7. Testing of the models with various technologies to check that they accurately predict exposure to wireless devices.
8. Derivation of simplified exposure prediction models that can be used by non-engineers and that nevertheless permit reliable determination of exposure for any multi-system/exposure situation.
9. Derivation of guidelines for optimal installation and usage, to maximize connectivity and minimize exposure
10. Translation of the above-mentioned exposure scenarios to organ-specific exposures in the time domain for the entire user population (Work Package 6), which is necessary for accurate risk evaluations (the use of the incident field strength only is too inaccurate for risk evaluations).
11. Application of standardized procedures and development of advanced biological models and experimental procedures to sensitively and quantitatively measure transient and persistent molecular and cellular responses due to EMF exposure; the concerted approach focuses on *in vitro* and *ex vivo* analyses of cells with genotoxicity and genomic instability as endpoints (Work Package 7: 'Genotoxicity screening *in vivo* and *in vitro*').
12. Evaluation of the four most-dominant signals that address the biological relevance of real-life exposure scenarios (Work Package 7), which is finalized at the end of the project.
13. Development of novel exposure systems for the biological screening of wireless EMF exposures. Three exposure systems in total, two for *in vitro* and one for rodent exposure, should be produced (Work Package 8: 'Exposure systems and quality control').
14. Dissemination of the instrumentation, calibration techniques, and assessment procedures developed to the relevant international standardization groups (CENELEC, IEC, ICES, ARIB, etc.) (Work Package 9: 'Dissemination to standardization agencies').
15. Performance of a comprehensive risk-governance protocol to integrate the scientific risk assessment results, the risk perceptions by key stakeholders and users, and the wider social and ethical concerns. The goal is to provide society with all the relevant data and background information to make prudent choices and to have a firm basis for making

tradeoffs between benefits and risks (Work Package 10: 'Risk governance, integrating assessment, perception, and communication').

16. Development of communication and dissemination tools for improving risk communication practice, which is finalized at the end of the project.
17. The communication systems considered should focus mainly on systems for data communication with special attention to lower-range systems (e.g., WiFi, WPAN, and BAN), which are foreseen as being employed everywhere indoors, e.g., the IEEE 802.11, IEEE 802.15 and IEEE 802.16 families. The exposure characteristics are compared to mobile systems for well-known telephony as well as for data, including GSM, UMTS and its extensions, 4G LTE, DECT systems, Bluetooth, etc. The systems will be grouped according to exposure characteristics, e.g., power levels, bandwidth, duty cycle, modulation, spectrum of the power, frequency, etc. (e.g., Ultra Wide band (UWB) systems, RFID systems, etc.).

The SEAWIND effort consisted of eight expert groups (including SMEs) from five European countries, all with internationally recognized competence in their respective fields. The contributing scientists offered a wide range of expertise in exposure assessment, dosimetry, biology, and risk assessment. The consortium was supported by two external advisors with excellent reputations for their achievements in risk-assessment processes within public institutions.

A Description of the Main S&T Results/Foregrounds

Description of Wireless Network Devices and Systems

Technological progress has led to rapid changes in the situation with regard to wireless network exposure due especially to the transition from simple mobile phones, used for speech and short messages, to complex “smart phones”, which offer high rate data communications. Progress has continued apace even during the lifetime of the SEAWIND project. The main exposure factor of concern remains the use of devices in speech mode with the device (phone) close to the head. This is by far the largest exposure in terms of specific absorption rate (SAR) values in the head. Body-supported or hand-held usage during speech mode, e.g., by means of a hands-free kit, causes similar high exposures of body regions close to the phone. High exposures also occur when the phone is used as data network terminal over mobile networks (tethering). There is also growing public concern related to remote access points in offices and homes. However, not only is the average power of an induced field important for full characterization of exposure, but also the envelope of the frequency- and time-domain power variations play a role. The following is a brief overview of the systems described in lay terms to the best of our ability.

a) Global System for Mobile Communications (GSM)

GSM is also known as second generation (2G) mobile communication, a digital system, whereas the first generation (1G) is the now obsolete analog system. The system is imbedded as a choice in all modern phones, and it is a matter of coverage and network provider settings whether or not 2G is used (the user may also choose the system via the mobile phone settings). GSM, counting billions of users, is the most widely used system. In GSM, power is not constantly delivered but is transmitted in short bursts on the order of milliseconds (0.57 ms), allowing multiple users (up to 8) to share frequency band channels between the bursts. The frequencies, which are different for uplinking (from device to base station) and downlinking (from base station to device), lie in Europe in the 900 MHz and 1800 MHz bands. The data rate is small, on the order of tens of kilobits per second (kb/s). Mobile stations have peak powers of 1 W at 1800 MHz and 2 W at 900 MHz. In speed mode, only 1 of 8 time-slots is used during uplink, thus, the frame-average maximum output power is approximately 1/8 of the aforementioned peak power levels. Base stations transmit depending on the cell size up to several hundreds of watts. The dominant modulations of the output power are at frequencies of 2, 8, and 217 Hz and their harmonics. The antenna input power of the mobile unit, which is controlled by the base station over a range of 30 dB, start at maximum power upon handovers between base stations. In the real world, the average output power is dominated by the handovers, resulting in an average of 30 – 50% of the frame-averaged maximum output power (Kuhn, S.; Kuster, N., IEEE Transactions on Electromagnetic Compatibility 99: 1 - 13 (2012)).

b) Universal Mobile Telecommunications System (UMTS)

UMTS, also known as wideband code division multiple access (WCDMA), is the 3G system that is gradually replacing GSM. It is technically very different, as it uses a code technique that allows multiple users to simultaneously access the same frequency bands and time slots. The advantage is obtained through use of a wider bandwidth than in GSM, i.e., 5 MHz, with the additional advantage of a "processing gain" (due to intelligent encoding of the data and speed communication) of up to a factor of ten thousand in power. This has the important consequence that, although the maximal values of output power are similar to those of GSM, the mean value in practice may be in the micro to low milliwatt range, typically between a factor of 50 – 100 below the maximum output power (Kuhn, S.; Kuster, N., IEEE Transactions on Electromagnetic Compatibility 99: 1 - 13 (2012)). Of course the mean value of the specific absorption rate (SAR) is reduced accordingly. Power variations in the low frequency range, below 1000 Hz, are more noise-like and do not conform to specific frequencies like GSM signals.

c) Long Term Evolution (LTE)

The quest for higher wireless data rates has pushed the development of 4G, LTE, with promised downlink rates of up to 100 Mbps under good propagation conditions. Clearly, the emphasis is not on speech, but rather data communication to laptops and tablets, where the distance to the head is large with ensuing low SAR values. Voice communication in LTE is foreseen via Voice-over-IP (VoIP) technologies, similar to the well-known Skype service. The nature of the signal and access techniques are complicated, adaptive, involving both the frequency-domain (narrow bandwidth slots) and time-domain slots. One novel feature is the adoption of multiple antennas at both transmitters and receivers. LTE has not been studied further in the SEAWIND project.

d) WiFi Local Area Networks (LANs)

Wireless LANs are highly pervasive in the field of short-range wireless data communications and are partially replacing not only cellular solutions like 2G and 3G but also wired LANs. They exist now in many private homes, schools, hotels, trains, buses, airports, etc. The maximum power is 100 mW in the 2.45 GHz band and up to 1 W in the 5 GHz band. Personal exposure levels are, in general, very low, except when very close to an access point or a mobile device using WiFi. In the latter case, the maximum SAR levels can be as high as levels from mobile phones. The maximum data rate is 54 Mbit/s for commonly used devices and up to 600 Mbit/s for modern devices. Exposure is highly dependent on the usage scenario with respect to the body, e.g., head-mounted, front-to-face, hand-held, body-worn etc. Average exposure is also heavily dependent on the actual data throughput. Although exposure is often low, the pervasiveness warrants inclusion of the system in the SEAWIND studies.

e) Digital Enhanced Cordless Telecommunications (DECT)

DECT is a cable-replacing radio technology suited for voice, data, and networking applications with range requirements of up to a few 100 m. Its use in cordless phones is widespread in many homes. ETSI specified frequency bands between 1800 – 2500 MHz. The peak output power of the portable part, the phone handset, which is typically used close to the head, is 250 mW; however, the mean value when only one timeslot is used is 10 mW. In standby mode, the fixed part transmits a short packet-bearer beacon for an average power of 2 mW. Like for GSM, there are power bursts, in this case at 100 Hz and harmonics.

f) Bluetooth

Bluetooth is a high-speed, low-power wireless link technology operating in the 2400 MHz band typically used to connect phones, laptops, personal organizers, printers, and other portable devices. There are three possible power levels, 100, 2.5, and 1 mW with bursts frequencies of 1600 Hz and harmonics. Devices with a peak output power of 100 mW have to implement a power control to limit the output power to typically less than 2.5 mW. Like WiFi, the actual average output power depends heavily on data throughput. In most cases, the average output power is at least a factor of 10 smaller than the reported maximum output power levels. The low power levels and similarities to DECT and GSM justify that no further studies are performed.

g) Radio Frequency Identification (RFID)

RFID is a fairly recent technology, which is assumed to soon migrate to an even wider range of applications, where objects (e.g., pets, luggage, people) are equipped with an integrated unique RF tag that communicates with a remote reader. Many different frequency ranges are used, the common one being the 866 MHz band. In many cases, the tag has no internal energy source, and all the necessary energy for communication, typically 2 W, comes from the reader. A short burst of energy is often sufficient for establishing the identification.

Choice of signals for biological experiments

Based on a thorough analysis, it was decided that the GSM, UMTS, WiFi, and RFID communication systems would be investigated. Representative signals were created for both *in vivo* and *in vitro* exposure systems, the details of which are described below.

Assessment of Exposure

a) Measurement Techniques, Instrumentation and Procedures

With the introduction of modern communication technologies in our everyday life, the mobile communication industries and government agencies have been confronted with the task to accurately assess human exposure to EM fields from wireless devices. At the beginning of the SEAWIND project, existing measurement equipment had been optimized for only 1G and 2G wireless technologies, which limited accuracy for exposure assessment of modern communication technologies. In the course of the project, we have conducted research and implemented methods to overcome these insufficiencies and to re-establish measurement uncertainties for internationally unified standards.

Initially, we determined the requirements for field probes with respect to linearity, sensitivity, and acceptable uncertainty and defined requirements for calibration systems and experiments to characterize the dynamic response of broad-band probes and narrow-band receivers to modern communication signals. A total of more than 100 communication signal waveforms, representing the worst-case signals emitted from wireless communication devices during compliance testing for SAR and incident field measurements, have been generated. The generated waveforms include signals for WiFi, LTE and WiMAX devices as well as 2G mobile and cordless communication technologies. The signals were based on test modes or typical test scenarios defined after a review of the underlying communication standards. Where multiple communication signals, e.g., multiple modulation types in WiFi, were possible, signals for all possible modes of a communication system were generated. In a second step, numerical models of broad-band EMF probes and frequency selective receivers were developed and implemented as simulation tools. These tools facilitated simulation and evaluation of the response of the measurement system to the communication signals. A measurement setup to experimentally assess the system response was developed. The system was based on well-characterized EMF sources, a waveform signal generator, a power amplifier, and a highly linear power sensor to allow determination of the system transfer function over the full dynamic range required of the field probes. The signals defined previously were used to validate numerical models against measurements of realistic probes and receivers. The system responses were evaluated for various types of dosimetric (SAR) near-field probes and free-space EMF probes as well as different types of frequency selective spectrum analyzers (narrow-band receivers). Based on the findings, novel calibration and linearization methods were developed and a fully automated calibration system for near-field broad-band probes was implemented. The proposed methods were extensively validated with communication signals emitted from real mobile communication devices.

Detailed uncertainty budgets for the proposed probe calibration and measurements techniques were evaluated and the contributions of the individual uncertainty sources determined. Our newly developed methods allowed the overall linearity error to be kept below +/–0.2 dB (5%) when measuring modern communication signals, compared to greater than 3 dB (100%) by older approaches.

The novel measurement methods assure the industry, government agencies, and the public that human exposure to EMFs can be accurately assessed and compliance with respect to safety standards reliably tested.

b) Fields in the Environment or Incident Fields

At the beginning of the SEAWIND project, there existed several reports in the literature in which exposure levels had been studied in different countries and for different scenarios by means of personal exposure meters (PEMs). The disparate methodologies used in these investigations and the considerable variation in some of the results render the findings to be of limited value. It is clear that, to be able to reliably compare exposure levels across Europe, the same measurement methodologies (protocols) must be used. Campaigns in Belgium and Greece were initiated calling for the same procedures and, in some cases, even the same equipment models, to be employed.

The spatial and temporal variations in RF exposure was studied in typical indoor microenvironments (schools, crèches, offices, and homes) in Belgium and Greece (Figure 2). These microenvironments could be further classified as urban, suburban, and rural environments. On the whole, 153 measurements of electric fields were conducted in the two countries. According to the protocol developed, initial scanning with a broad-band radiation meter was performed in the microenvironment of interest to locate the position of the maximum electric field. Subsequently, a narrow-band (frequency selective) measurement was performed at the spot and a PEM was placed as closely as possible to it to record the electric fields in various frequency bands for several hours (3 – 4 days). At the end of this monitoring period, a second location in the same microenvironment (usually in a vicinity where people spend a lot of time, like a bed, cradle, sofa, etc.) was also monitored by a PEM for the length of time. In this project, using the wealth of the measurements obtained, we were able to develop and validate a method to extrapolate instantaneous exposure to maximum daily exposure by combining spatial-field values and 24-hour time-evolution of the electric fields.

Figure 2: Measurements in offices, schools and crèches.

With respect to the results of the measurement campaign, it should first be noted that all instantaneous and maximum exposure values satisfy international exposure limits, i.e., were below the reference levels specified in guidelines. Mobile telecommunications and radio broadcast reception (FM) were present in nearly all indoor microenvironments. In both countries, we found the highest average exposure values in office environments (1.1 V/m in Belgium and 0.7 V/m in Greece), and the lowest in homes (0.3 V/m in Belgium and 0.4 V/m in Greece) and in schools (0.4 V/m in Greece). Exposure in offices was mainly due to mobile telecommunication systems, whereas, in home environments, DECT and WiFi 2G were the dominant contributing sources. In homes, the average contribution to the total electric field values was more than 28% for DECT and 6.7% (Belgium) and 30.1% (Greece) for WiFi 2G. We measured the highest electric-field values in urban environments and the lowest in rural environments. The contribution of cellular phone networks (GSM and UMTS) to the total electric field values was, on average, 48.3% in Belgium and 53.8% in Greece, i.e., the latter remain a significant source of exposure indoors. During the measurement campaign in Greece, an extension of the initial procedure, whereby narrow-band measurements were conducted at the windows and center of a room with a stencil of points at some distance between them, was implemented. This procedure also showed that, for a room, the exposure to mobile phone networks radiation is dominated by the signals entering through the windows.

Concerning temporal measurements, the total signal variance over 24 hours was mainly due to mobile telecommunication signals. However, TV signals also influenced the time behavior of total signals in offices, as did indoor signals (DECT and WiFi 2G) in crèches (Belgium) and homes. The total signal varied the most in Belgian crèches (39.3 %) and in Greek homes (58.2 %).

The characterization of exposure in various indoor microenvironments and the determination of diurnal variation were not the only achievements of the project regarding incident fields on humans. Within the SEAWIND project, it was possible to formulate and validate a novel method for evaluation of whole-body absorption of electromagnetic energy by people inside a room. The method is based on the theory of *room electromagnetics*, which has been used successfully for acoustics applications, whereby a closed room environment is considered a lossy cavity characterized by a line-of-sight component (where it exists) and diffuse scattering components from walls and internal obstacles. The method starts with assessment of the reverberation time in an empty room by means of either channel sounders or virtual multiple-input-multiple-output channel systems. Then, the same measurement is performed with people inside the room. The two measured times combined with some geometric characteristics, like distance from the transceivers and the volume of the room, can result in the total whole-body antenna cross-section (ACS), i.e., humans in the room are treated like receiving antennas. The average whole-body SAR is derived by dividing the total ACS by the number of people in the room, multiplied by the power density at a point in the room. The method has been validated at WLAN frequencies in realistic environments, and the absorption cross-sections calculated were in excellent agreement to those reported in the literature that had either been measured or assessed with numerical techniques. At frequencies of 2.3 and 3 GHz, average ACS values of 0.34 and 0.36 m^2, respectively, were measured, with a range of 0.24 –0.43 m^2 at the point of measurement. Variability in body surface area (BSA) as well as in illumination response to radiation by the subjects in the room accounts for observed range in ACS values. For example, the Visible Human (VH) numerical model illuminated by a plane wave at 2.1 GHz for three orientations (front, right side, and oblique) results in illuminated surfaces of about 0.44, 0.23, and 0.39 m^2, respectively.

To facilitate the above method of *room electromagnetics* for determinations of power density needed for evaluation of whole-body SAR, a new numerical method (software code) based on radiosity for estimating the diffuse multipath components has been developed and implemented. The tool has been tested against full-wave methods of computational electromagnetics in complex realistic indoor environments with acceptable accuracy and reduced CPU times. The average deviation of the calculated from the measured field at 15 points inside a teleconference room (used for distance learning) was 3.7 dB at a frequency of 2.75 GHz.

c) Fields in the Body

Although incident fields can give an indication of exposure level for comparison to reference levels defined in exposure guidelines, the actual physical quantities related directly to biological effects are the electric and magnetic fields inside human tissues that cannot be readily measured. There are two approaches to the assessment of these fields, namely, via experiment and numerical dosimetry. The former entails the use of phantoms that represent worst-case conditions of maximal exposure, and the latter can be used to simulate realistic exposure situations from which results can be deduced and statistically analyzed. Before the SEAWIND project, the majority of research efforts focused on dosimetric characterization of mobile phones for voice communication, i.e., next to the user's head. However, mobile phones are being replaced by smart phones and laptops by tablets that are used mainly for data communication (including VoIP for conversation) and tethering (i.e., as an access point to the internet). In SEAWIND, the use of these devices as terminals for wireless data transfer with currently available technologies, as well as with emerging telecommunication protocols (including those at higher frequencies), has been studied, whereby it was assumed that the devices are located next to the body rather than the user's head.

In the area of experimental dosimetry, new measurement setups were developed. Generic sources that can be used to mimic the exposure from commercially available devices were constructed and placed against a flat phantom filled with tissue simulating liquid having the same properties as human tissues across a wide range of frequencies. The generic sources that were manufactured within the project included dipoles, a patch antenna for circularly polarized RFID readers, and a laptop with printed antennas at different positions representative of the location in real devices (Figure 3). The generic sources were placed close to the phantom (touching it when possible, but also at distances up to 10 cm from the phantom surface), and the peak spatial SAR averaged over 10 g was measured with state-of-the-art instrumentation, according to the procedures developed within the SEAWIND project and disseminated to international standardization bodies. The measurements were then compared with those obtained with commercially available devices in the same configuration.

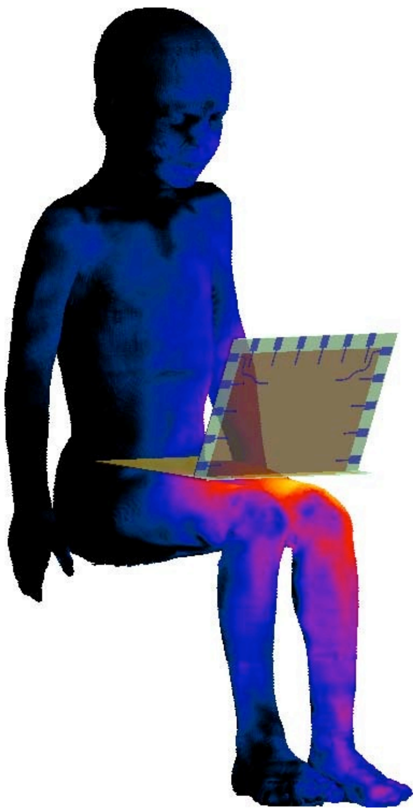

Figure 3: Dosimetry of the exposure caused by generic laptop during data upload via the WLAN.

It was found that the generic sources resulted in peak spatial SAR values that were similar to (in the case of RFID the deviation was –0.27 dB) or larger than (in the case of the laptop by up to 6.05 dB) the values for the commercial devices. Moreover, the latter were detuned when placed next to the flat phantom, whereas the generic devices exhibited a more broadband behavior. This conservative approach is always necessary, to allow use of the computational model of a generic source in numerical dosimetry for investigation of exposure from real devices. The computational models of the sources were created and tuned in such a way that, in simulations of the experimental setup, the calculated SAR distribution in the phantom matches as closely as possible the measured one. Having validated the sources, these were placed at several locations next to the numerical phantoms of humans to assess exposure in typical situations.

A total of eight human models of the Virtual Population (ViP) were used to represent both sexes and various age groups, i.e., Thelonious (male, 6 years), Billie (female, 11 years), Louis (male, 14 years), Duke (male, 34 years), Fats (obese male, 37 years), and, Ella (pregnant female, 26 years, in 3 gestational stages: 3, 7, and 9 months). The positions of the sources (quarter-wavelength dipoles) were chosen to simulate real life exposure situations:

- The wireless device placed inside the trousers pocket (back and front sides); in these cases, the generic source was 5 mm away from the body
- The wireless device placed inside the jacket pocket; in this case, the source was placed 20 mm away from the body
- The wireless device placed in a bag (backpack or "side-carry" bag); in these cases, the source was placed 50 mm away from the trunk of the body.

The dipoles were placed on the left and right sides of the phantom for each of the above situations, at several heights and positions, and in planes that conformed to the body surface, to account for the variability of, e.g., the way people carry bags or the diverse types of clothing (Figure 4). For all frequencies of current and emerging communications systems (866, 2000, 2450, 3500, and 5500 MHz) to be considered, a large number of simulations, on the whole, 7,600, were performed, amounting to several days of CPU time. Simulations were carried out with the state-of-the-art finite-difference time-domain (FDTD) software package SEMCAD X, backed by hardware acceleration with GPU arrays. More than 15 TB of data were generated and post-processed to assess correlations between maximum absorbed power in the tissues (peak spatial SAR averaged over 10g) with respect to frequency, sex, age or organ.

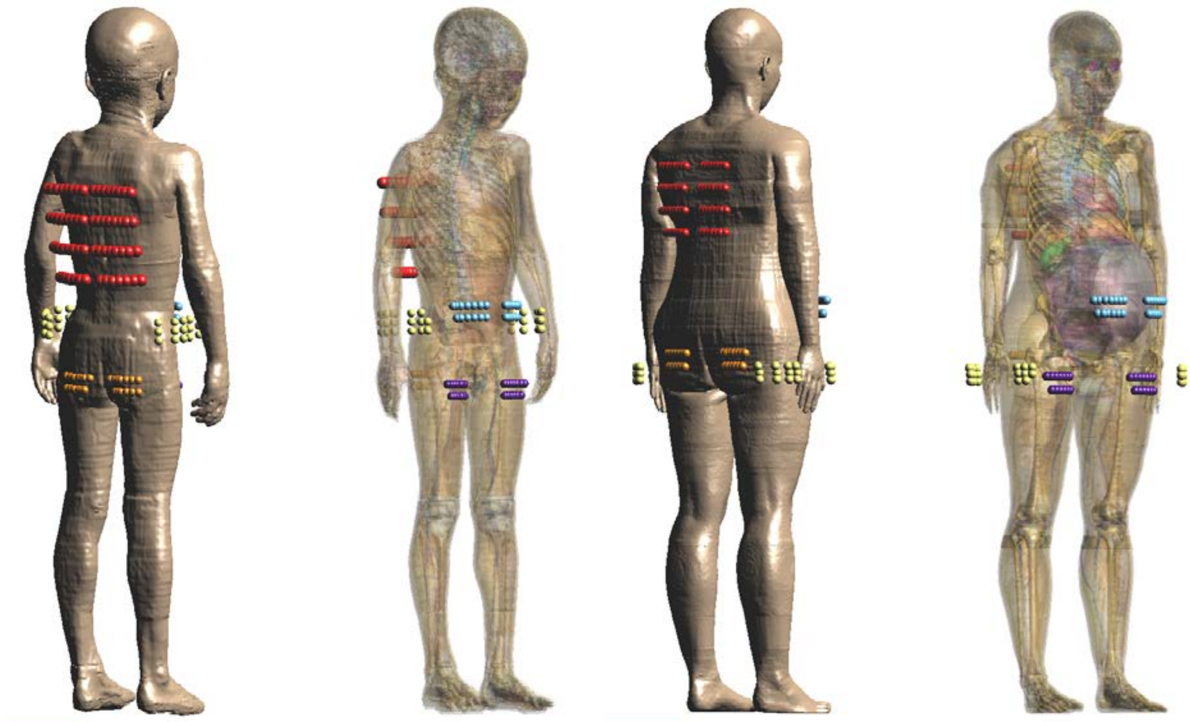

Figure 4: RF sources positions around Thelonious and a 9 months Pregnant Woman (back and front views); front trousers pocket (purple), back trousers pocket (orange), jacket pocket (blue), side-carry bag (yellow), and backpack (red).

The variability in calculated peak spatial SAR values, which usually occurred in the skin, was large (up to 3.33 dB) at lower frequencies and became smaller at higher frequencies. The value depended on the tissue stratification next to the position of the generic source, i.e., the device; no specific correlation of SAR with gender or age could be found. This result was confirmed for the RFID source: the spread in the distribution of peak spatial SAR values when the RFID antenna was next to the pelvic area was larger than that next to the head. During movements in front of the pelvic area, the antenna illuminated several tissues with different dielectric properties, leading to large variation in the amount of absorbed energy as a function of position. By contrast, in the head area, tissue stratification differs less, leading to a smaller variation in SAR values.

When the duty cycle (percentage of time of radiation emission) and the realistic radiated power of the devices are taken into account, the calculated peak spatial SAR values are several times lower than the basic limit for the respective body area in the ICNIRP guidelines. This is true even in the case of a baby monitor placed in the vicinity (10 cm) of a newborn’s head (simulated with a model of an eight-week-old female infant created within the SEAWIND project).

The fields inside the body are of interest not only for the use of wireless devices but also as resultant incident fields, i.e., generated in the body by wireless networks fields in the environment. In the SEAWIND project, significant progress was made in the assessment of the worst-case SAR from incident fields, as well. Figure 5 shows the exposure for fields incident on the right side of the body. An eigenvector approach was proposed for the first time to maximize the absorption of RF energy based on the incidence of twelve plane waves (front, left, back right, top, and bottom for two different polarizations). According to this approach, it is possible to determine the amplitude and phase of the twelve incident waves that result in the highest energy deposition in the body. The results were compared with those obtained by statistical multi-path exposure (SME) analysis, an accepted assessment approach. The new SME tool takes amplitudes and phases from given distributions (depending on the particular environment investigated, namely, indoor, outdoor, macrocell, microcell, etc.) for randomly incident plane waves, to formulate a cumulative distribution function (CDF) for the exposure characterized by statistical parameters, e.g., mean, median, and n-th percentile values. The novel SME eigenvector method was used to acquire worst-case whole-body SAR values for the 99th-percentile in two different anatomical models, Duke and Thelonious (see above) at two frequencies (950 and 2450 MHz) reliably with less than 0.5 dB deviation; this was achieved with considerably less computational expenditure than required by SME tools or the five-random-plane-wave-exposure method thus far described in the literature.

Figure 5: Far field exposure of the Virtual Family (Duke, Ella, Thelonious)

These findings have been validated by an alternative technique of assessing the total absorption from handheld devices used by real persons. A test person was holding a device with the hands in the lap and the total absorbed power was found as the difference between the input power and the radiated power, measured in an anechoic room, Figure 6 (top). Figure 6 (bottom) shows the relative absorptions for a smart phone for four test persons. The absorptions vary between 5 and 25 %, the largest being at the highest frequencies. Note that although there are differences between persons, they are minor for the same position and device, the exposure is dominated by the antenna technology and placement in the device.

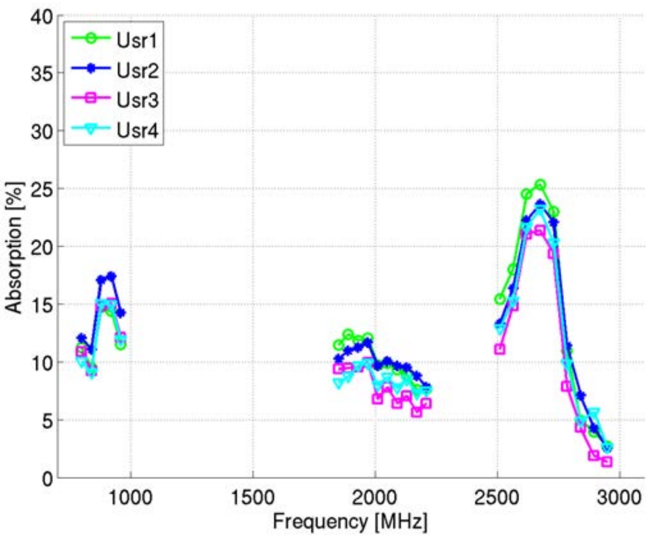

Figure 6: Experimental setup in anechoic room, where a test person holding a device on the lap is rotated around a vertical axis. The total radiated power is found by integration over all angles (top). Absorption of power in a person relative to input power as a function of frequency (bottom).

d) Guidelines for Exposure Minimization

The research results also allowed derivation of guidelines on how exposure to wireless networks can be minimized. In the close vicinity to a wireless network device, exposure is dominated by the device itself and is only minimally influenced by the environment. Farther away, the environment is an important exposure factor, i.e., diffuse incident EM fields from an access point (base station) in the room determine the exposure.

Exposure by Body-Mounted Devices

Both measurement and simulation results show that there are several critical factors that affect personal exposure, i.e., the fields induced in the body, which are, for the sake of discussion, expressed in terms of energy absorbed in tissues by body-mounted devices.

The most important factor is, as expected, the radiated power of the device. It is preferable to use wireless terminals of communications systems that incorporate a power control mechanism, i.e., can change output power according to the quality of the signal at point of use. The quality of the signal is influenced mainly by the distance to the access point (base station), the type of the environment, the proximity to dielectric objects, and the technical characteristics, e.g., the antenna, of the device itself. It is known that, during voice communication with a mobile telephone, good quality of reception is associated with reduced radiated power from the phone, and, therefore, lower absorbed power in the tissues. *It is advisable that consumers adopt the use of terminal devices that implement telecommunication protocols with power control, when these are available, e.g., ECO DECT instead of DECT.*

However, signal quality can influence exposure in other ways, too, for example, when WLAN signal quality becomes poor, lower modulations will be used to maintain a stable connection at the expense of a lower physical data transfer rate. But, for lower modulations (and, thus, lower physical data transfer rates), higher duty cycles (i.e., percentage of the time that the wireless device radiates) will result because the time to transmit data and control packets will be longer (e.g., 248+24 μs for 54 Mbps becomes 2072+44 μs for 6 Mbps), while the idle durations remain the same. Therefore, *it is important that transfer of large data files or multimedia streaming should be performed only when the established connection between the portable device and the access point in a room is of good quality*.

Another important factor for limiting exposure is the distance of a device from the body. We have estimated with numerical calculations in SEAWIND that moving a device from the trousers pocket (where the distance to the skin is assumed to be 5 mm) to the jacket pocket (with an assumed distance to the skin of 20 mm) reduces the peak spatial SAR value averaged over 10g by up to 10 times, depending on the frequency. Moreover, tissue stratification in the vicinity of the device position is also significant. Placement in the back trousers pocket compared to in the front pocket, although assumed to be 5 mm away from the skin in both cases, results in higher peak spatial SAR values due to the larger fat content in the back. Nevertheless, in the front pocket, the device radiates more towards thermosensitive organs, e.g., testes, compared to the back trousers pocket. *It is obvious from the above that carrying the wireless network device at a higher distance from the body (e.g., in a bag instead of the pocket) when it is communicating with an access point (base station) can significantly reduce exposure.*

Exposure by Access Points

In the SEAWIND project, we investigated the exposure to access points (base stations) of wireless networks by measuring the fields emanating from them. It is clear from the measurement results that, for distances of up to 1 m, the EM source determines the field strength and exposure level. It is known from EM theory that the decay of an electric field close to a RF source is inversely proportional to the distance from the source raised to the power of 2 – 3. This behavior of the electric fields was confirmed by measurements during SEAWIND. The impact of the orientation of the antenna is large, as well. Close to the access point, there are hardly any depolarization effects, meaning that, when the antenna of an access point is vertically oriented, the electric field values in the vertical direction are much higher than those in the horizontal direction. Therefore, fields couple better to standing persons. Beyond a distance of 1 m, the reflections in the room produce a depolarization effect, i.e., the energy carried from the source to a person in the room is the same for both polarizations. Therefore, *it is clear that a simple measure to reduce the exposure from access points is to place them at least one meter away from locations where people remain for a longer time, e.g., beds, tables, sofas, play areas, etc.*

Another factor that needs to be considered is the duty cycle, i.e., the percentage of time that a device is emitting a signal. The root mean square (rms) electric field scales with the square root of the duty cycle and, therefore, the power density at a point scales with the duty cycle itself. Therefore, to find the electric field level for a 50% duty cycle (i.e., the device transmitting only half of the time), the electric field level measured at a 0.5% duty cycle is multiplied by 10 ($\sqrt{50/0.5} = \sqrt{100} = 10$). Thus, the duty cycle has a huge impact on the electric field level. In locations with poor coverage (low maximum field value), the duty cycle can increase tremendously due to the increased bit error rate, which results in data retransmission and an increased rms electric field value. Conversely, exposures are lower where coverage is good. *So, a second exposure guideline is that, at locations where a WiFi connection is used frequently, the coverage should be sufficiently good to avoid retransmissions, which lead to higher duty cycles and higher exposures.*

To determine optimal placement of an access point inside a flat, we designed within SEAWIND a web-based exposure tool (see Figure 7) that provides exposure estimations of an indoor wireless network with a single access point. The tool consists of a graphical user interface (GUI) that provides the necessary tools to configure a floor plan – with assignment of appropriate materials to the walls, doors, and windows – position the access point, and calculate the estimated exposure in the room. The exposure can be evaluated in terms of incident electric field as well as whole-body absorption (SAR). The incident electric field is calculated based on heuristic indoor propagation models, whereas the whole-body absorption is based on *room electromagnetics* theory developed in the SEAWIND project. The tool can be used to predict the impact on exposure of moving the access point to other locations. Currently, we designed the web-based tool for a single access point (i.e., wireless router) radiating at 2450 MHz (WiFi). The tool does not consider the exposure of other (mobile) wireless devices, such as mobile phones, laptops, DECT phones, etc. Furthermore, the tool does not take into account intermittent usage of the network as it assumes that the WiFi radiates permanently at maximum output power, an assumption that grossly overestimates the usage of the network. Based on several measurement campaigns in indoor and outdoor environments, we observed that WiFi has a duty cycle of less than 11% in 95% of the cases. However, when slow connections are present, the duty cycle of a

WiFi access point might become as high as 94%, e.g., when multiple mobile devices are connected to the access point or the connection (the signal at the position) of a mobile device is poor. A web-service based on this tool will be freely accessible to the public.

A third, more evident, guideline is that access points should be switched off when not in use, because, even when the WiFi connection is not used, the access point sends beacon signals about every 102 ms.

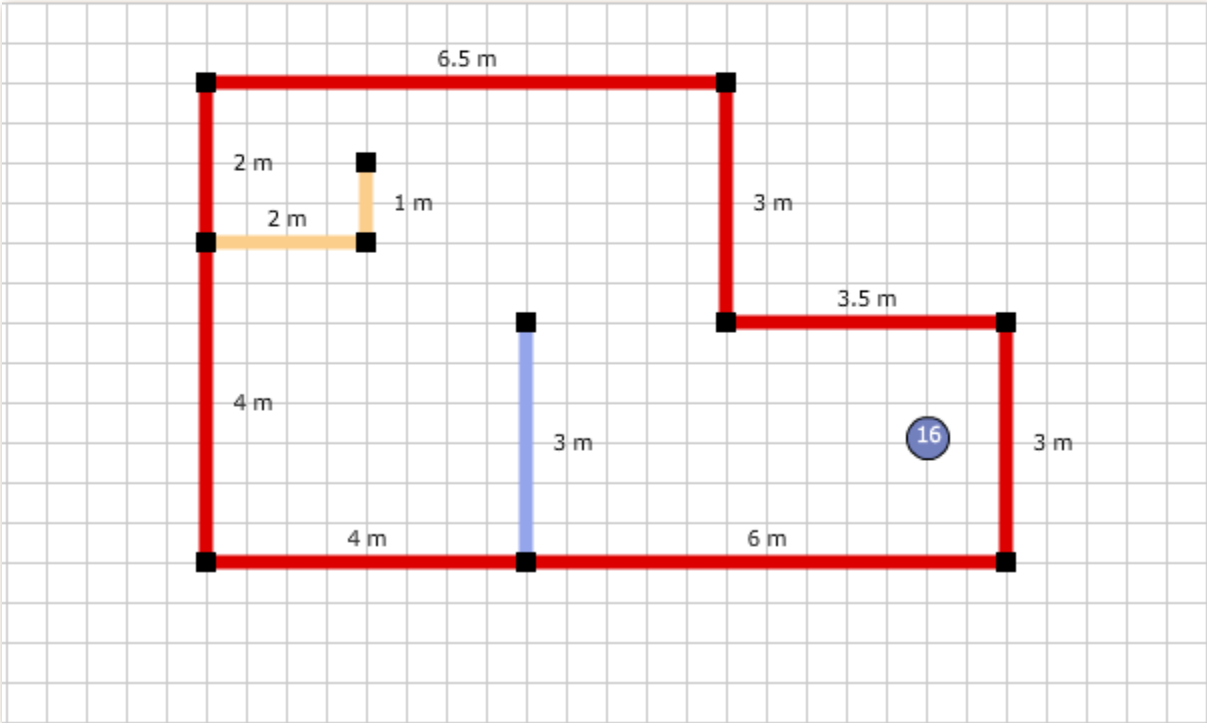

Figure 7: Typical interface of an office designed with the interactive WHIPP tool (Wireless & Cable Heuristic Indoor Propagation Prediction Tool, University of Ghent). The tool predicts the exposure and guides the user to optimize the placement of rooters, etc.

Assessment of Genotoxicity and the Potential Contribution of Oxidative Stress

It is well established that higher-energetic EMFs such as the ultraviolet (UV)-component of sun light or ionizing radiation have a potential to directly damage the chemical structure of the DNA. The spectrum of damage induced is wide and includes a variety of DNA base modifications, crosslinks and strand breaks. As such alterations affect the function of the DNA as a carrier of genetic information, EMFs in this energy range are considered “genotoxic”. Consistently, there is ample evidence for exposure of cells or organisms to high-energetic EMFs causing genetic mutation and increasing the risk of malignant cell transformation and cancer. Theoretical considerations predict that the energy transmitted by low-level or weak EMF (wEMF) in the frequency range used in wireless data transfer is far below the level sufficient to inflict direct damage to the DNA. Still, wEMF exposure was suspected to impact the integrity of the human genome due to indirect effects, as some laboratory studies reported positive effect in genotoxicity tests. Although these observations remained a subject of controversy due to reproducibility issues, they nevertheless raised public concern regarding the safety of wEMF based communication technology.

a) Exposure Systems

The history of bioelectromagnetic research, i.e. research on the interactions of EMFs with biological systems, is scattered with reports of effects that were notoriously refractory to independent reproduction by other independent researchers, thus casting doubt on whether any effect was there at all. Unfortunately, experiments and exposures were not sufficiently well controlled or described, such that the precise exposure conditions were poorly defined; furthermore, artifacts and stray exposures were not properly accounted for or characterized, or were minimized, adding to the uncertainty surrounding the observed effects. With this in mind and with reference to the literature, we set out to design experimental approaches and equipment to perform *in vivo* and *in vitro* genotoxicity screening according to the best practices. The systems we used provided the tools to allow well-characterized and controlled exposure of cells and rodents. Of particular note is the live cell imaging system, which allowed for the first time a direct, real time insight into cellular response to wEMFs of different modulation characteristics. This application of this system is likely to generate a significant impact in wEMF research. Whereas the types of signals present from GSM and 3G mobile phones are easily characterized and show specific characteristics in terms of their temporal signal variations, signals from WiFi, RFID, and other signals display more random variation as a function of the data traffic being sent over the link. Within the project, the exposure systems were equipped with advanced signal sources capable of reproducing this randomness, while maintaining characteristics compatible with well-defined SAR doses. Furthermore, the new instrumentation was presented at the premier conference for bioelectromagnetics to allow other researchers in the field to share the new developments. The exposure systems developed and delivered, described in the following sections, can all provide a variety of signals including continuous wave (CW), GSM, UMTS, WiFi, and RFID.

In Vitro Exposure Systems

In vitro exposure systems are used for controlled experiments with cultured cells (Figure 8). Existing systems were equipped with the new signals for emerging wireless technologies, namely for WiFi and RFID and delivered to Fraunhofer ITEM in Hannover and to the University of Basel. Two exposure units were installed in a cell culture incubator to control accurately the ambient environment. It is well known that changes in culture conditions (e.g. temperature) can have a profound effect on human cells and hence must be minimized such that the EM interaction can be evaluated. The systems were designed such that the maximal difference between sham and exposure is always less than 0.1K. An additional consideration of importance is that the experimenter should not know which of the two chambers is exposed and which remains unexposed (also referred to as sham). This is known as experimental blinding and ensures that any preconceived bias of the experimenter as to what they expect to observe can be eliminated from the analysis. Blinding is very important where changes are small or subtle.

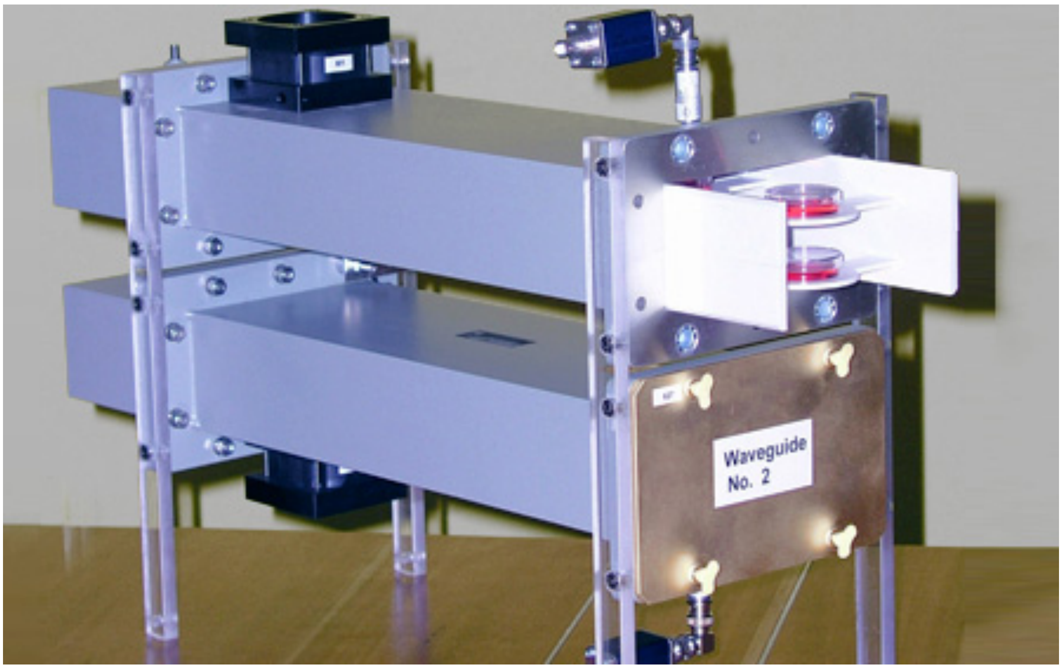

Figure 8: In vitro exposure system for exposure of cells, which is installed in an incubator.

In Vitro Exposure System for Live Cell Imaging

The live cell exposure system is a miniature RF exposure system normally operating at 2450 MHz, which is integrated with a live cell imaging microscope (Figure 9). State-of-the-art microscopic techniques, including confocal scanning and fluorescence microscopy can be performed, allowing live cell observation during exposure. In contrast to the classic approach of post exposure analysis of cells, the instrument enables direct insight into the cellular response to EMF in real time. This computer-controlled setup allows different signals to be selected, as well as the monitoring of exposure and environmental conditions. The system also provides the ability to blind the experiments such that the experimenter does not know if a given exposure in a sequence is sham or exposed.

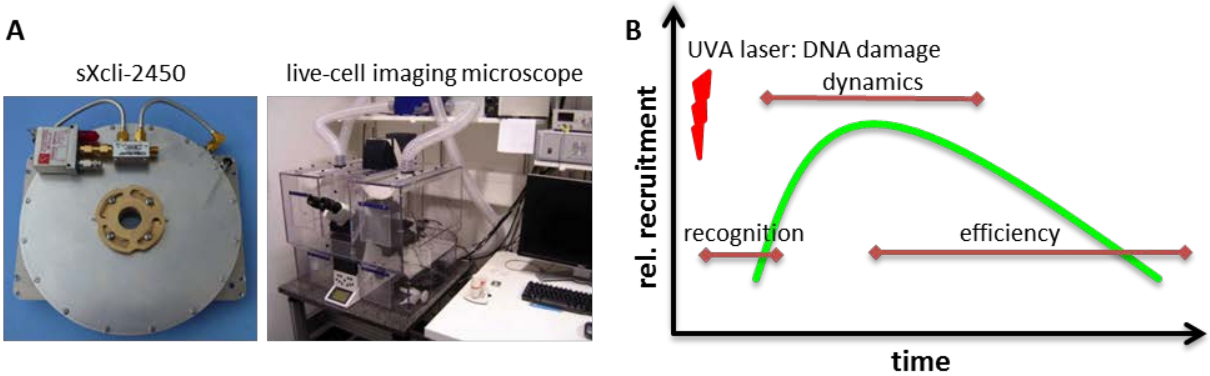

Figure 9: sXc-2450-Live Imaging Exposure System setup to study DNA repair dynamics. A: Pictures of the live-cell imaging wEMF exposure chamber sXcli-2450 (left), which can be introduced into the microscope table of a live-cell imaging epifluorescence microscope (right). **B:** Depiction of the theoretical recruitment dynamics of a repair protein to the sites of DNA damage induced by UV-A laser exposure. Analysis of different repair phases permit conclusion about impacts of the treatment on parameter such as DNA damage recognition or repair efficiency.

In Vivo Exposure Systems

An *in vivo* exposure unit was designed to provide an efficient and flexible setup with maximum exposure homogeneity for mice housed singularly within standard cages (Figure 10). Homogeneity of the exposure is required for an accurate prediction of what each individual mouse has been exposed to and, hence, to relate any possible effects to a given dose. Exposure to SARs well beyond those seen in real life scenarios was made possible to maximize the chance of inducing some effect, however always taking care not to expose at too high a level such that thermal effects become dominant. Exposure was at 2450 MHz with the various modulation schemes defined and agreed on by the consortium. As well as monitoring the EM exposure, environmental parameters were also recorded throughout to have a full record. The system consisted of two reverberation chambers that could be allocated by the user to sham (no exposure) and expose or both to different exposure levels.

Figure 10: Exposure system for rodents.

Dosimetry

Central to the analysis of experimental results is knowledge of the dose – not just the overall dose but also the dose to individual tissues or organs of the mouse. Dosimetry was performed to determine how the dose varies according to the different tissues and anatomy inside the mouse. To achieve this, a male mouse model with a weight of 28 g was used for the numerical dosimetry by computer modeling, and a simple homogeneous phantom was used to verify the results experimentally. Thermal modeling was also performed to assess temperature rise in different tissues.

Exposure Signals (Rationale & Description)

Exposure was performed with various modulation schemes, including CW, GSM, UMTS, WiFi, and RFID. These modulations were chosen from the range of possible signals as having the characteristics that best represent today's variety of exposures, whereas the average power and the ELF power envelopes were synthesized to maximize the likelihood of engendering biological effects, based on current best hypotheses regarding interactions of weak RF exposures with organisms.

CW, continuous wave, simple sinusoidal signals of constant amplitude, phase, and frequency that do not, as such, convey any information, was included as a form of active sham exposure, i.e., without ELF spectral components of the power envelope but generating the same temperature load.

GSM and DECT belong to a class of signals that use constant envelope modulation schemes – there is no amplitude modulation, only phase or frequency, but with time division multiple access (TDMA), i.e., a time slot is allocated to each user during which power is transmitted by that user´s device. This results in an additional 100% amplitude modulation (on-off) of the transmit power, so the power is present in bursts only, which results in significant differences between the maximum and average power transmission levels, i.e., the pronounced ELF spectrum of the power envelope typical of GSM and DECT. In the SEAWIND project, we included GSM because of previously reported effects and because it has coherent 2 Hz, 8 Hz, and 217 Hz components and harmonics. DECT was not chosen, as its predominant 100 Hz bursts are also simulated by the WiFi signal.

The next class of signals applied use what is known as WCDMA that are characteristic of many third generation mobile communication standards. WCDMA uses a mathematical property of what are known as pseudo random sequences (noise-like signals) to enable several users to simultaneously utilize the same channel at the expense of increased bandwidth. The signals from or for individual users can be recovered only by the use of the same pseudo random sequence as used to encode the signal, this process in addition rejects all other signals. In WCDMA, the information is typically encoded with a combination of phase and amplitude modulation, which gives an inherently "non-periodic", random-like variation of output power as a function of time that is faster and less pronounced than the TDMA signals. The predominant WCDMA, UMTS – the 3rd generation system – was chosen within the study for this class of signals.

To represent the WLAN, we chose the IEEE 802.11b/g standard, as it is the most widespread technology. The signal synthesized is based on measurements of throughput in a typical network where the data packets have a statistical or random character imposed on a regular beacon or network identification burst; the random nature is, however, constrained in this context to allow good dose characterization. IEEE 802.11g also adds to the health risk assessment an important new modulation type, orthogonal frequency division multiple access (OFDMA), where the data is split for transmission in parallel on many different carriers. Additionally, the data is sent in bursts by TDMA, where the preamble of each burst and the identification beacon is IEE 802.11b-compatible and uses a simple form of CDMA, and the data in each burst is OFDMA, to allow many users on one wireless LAN.

The final signal type is that generated by RFID tag readers, which are optimized to maximize energy transfer and, hence, have high average powers compared to peak power. An RFID tag has no battery or power source and uses the transmitted energy from the reader to power its circuits and transmit identity data back to the reader. The reader transmits data to the tag by means of digital modulation of the amplitude known as amplitude shift keying, which essentially switches the signal on and off rapidly. Again, the signal is transmitted in bursts with the minimum allowable period between the bursts.

b) Genotoxicity Testing in cultured human cells (*in vitro*)

Evidence for a potential genotoxic effect of wEMF at 0.1 to 2 W/kg was obtained mostly from the so-called "Alkaline Comet assay", a classical experimental test to evaluate and quantify the level of DNA damage, in particular DNA strand-breaks and alkaline labile sites, in cell populations. In the SEAWIND project, we made use of this assay to re-visit the potential of wEMFs to induce DNA damage in *in vitro* cultured human cells. In addition to the standard test, we applied a modified version of the assay that allows a specific and more sensitive detection of oxidative DNA base lesions. Moreover, to address potential wEMF effects more comprehensively, the SEAWIND project not only tested previously reported observations but extended the investigation to a wider range of wEMF signals and modulations that have become important for wireless data transfer in recent years and to the exploration of potential co-genotoxic effect.

The SEAWIND consortium thus decided to perform a systematic as well as an explorative genotoxicity assessment of wEMF signal modulations relevant to the exposure of the public. As outlined above, the signals included were GSM, UMTS, WiFi and RFID and the unmodulated continuous carrier wave (CW) at 1.95 GHz. These were applied under strictly blinded experimental conditions to two human cell lines previously reported to be responsive to EMFs. Induction of DNA damage by wEMFs was analyzed in dependency of the time of exposure- (1, 4, and 24 hrs) and the applied SAR dose (0.5, 2, and 4.9 W/kg SAR). The first series of experiments focused on the replication of previously reported observations with the alkaline Comet assay that indicated an induction of DNA damage by mobile phone-specific UMTS and GSM signal modulations in primary human fibroblast and immortalized human trophoblast cells (HTR-8/SVneo cells). Despite considerable efforts to optimize the sensitivity of our assays, however, these effects could not be confirmed in the two SEAWIND partner laboratories. Likewise, the subsequent systematic testing of potential effects of the WiFi, RFID and CW exposure signals in the Comet assays failed to produce evidence for DNA damage induction.

To validate these results and to address the hypothesis that wEMFs might alter intracellular levels of reactive oxygen species (ROS), we systematically assessed the wEMF signals for induction of oxidative DNA damage. For this purpose, we applied the enzyme-modified version of the Comet assay, designed to specifically detect a common oxidative base modification with high sensitivity. As the standard alkaline Comet analyses, however, this assay produced no evidence for increased oxidative DNA base lesions in the two cell types tested. Consistent with this lack of effect in the enzyme-modified Comet assay, we did not observe any EMF-induced change in intracellular ROS using a highly-sensitive, fluorescence microscopy-based method that traps the short-living

ROS and converts it into a more persistent fluorescence signal. Notably, this assay was negative, even if it was performed under 50Hz EMF exposure that previously produced a measurable effect in the alkaline Comet assay. Thus, as both the intracellular ROS detection and the oxidative Comet assay are very sensitive methods, we conclude that ROS-mediated oxidative DNA damage is not an important contributor to potential genotoxic effects related to wEMF exposure under the experimental conditions.

The development and application of standardized experimental procedures, including the blinded exposure and evaluation as well as the independent confirmation of key findings in the two partner laboratories, was an important conceptual strength of this part of the SEAWIND project, meant to avoid eventual inconsistencies in reproducibility that often occurred in this field of research. Minor variations of experimental conditions, due to differences in the technical infrastructure between laboratories, however, are difficult to eliminate and may have contributed to the contradictory outcome of similar experiments in the past. We addressed the issue of experimental variation, focusing on the consistency of results generated by different Comet analysis pipelines. This showed, not unexpectedly, that the methods used in the two partner laboratories produced slightly different results from otherwise identical experiments or even data sets. Thus, minor technical issues like this may add up in the multistep protocol of the Comet assay and culminate in an overall experimental variation that, if the effect under investigation is small, may produce small positive results in some analyses and negative outcomes in others. This is a negligible issue if the agent assayed is clearly DNA toxic and affects homogeneously most cells in a population with a consistent dose-dependency. EMF exposure, however, has never produced strong dose-dependent responses and the data underlying positive effects (e.g. ELF-EMF exposed human cells) suggest that only a subpopulation cells in a culture may be affected. All considered, the inconsistent nature of EMF effects in the Comet assay strongly suggests that this type of exposure does not damage the chemical structure of the DNA. It may, however, affect certain aspects of cell physiology in a way that alters the steady-state level of naturally occurring DNA strand breaks in some cells. Cells undergoing DNA synthesis, for instance, have intrinsically increased levels of DNA strand breaks that are picked up by the Comet assay, and there is evidence from ELF-EMF studies that the dynamics of such processes might be influenced under exposure. Interesting and consistent with such indirect effects, the results of our experiments addressing the potential co-genotoxicity of wEMFs indicated that UMTS exposure may slightly modulate the response of MRC-5 cells to a known genotoxin. The significance of this observation, however, needs clarification by further investigation. Hence, while the classical genotoxicity assays are well suited to measure biologically relevant DNA damage, they were not capable of reliably detecting effects of wEMF exposures tested in the SEAWIND project. This strongly suggests that the wEMF exposures applied did not generate direct DNA damage. Yet, as the Comet assay has the potential to pick up subtle changes in the DNA structure associated with environmental impacts on cell physiology, including those possibly induced by wEMFs, we believe it may mislead under certain circumstances and generate inconsistent results and interpretations as observations in EMF research. Therefore, novel experimental approaches need to be developed to investigate the real targets of the interaction of EMFs with biological processes (see below).

In conclusion, considering both the results reported in the literature and the observations of the biological *in vitro* part of the SEAWIND project, there is no evidence for a direct DNA damaging potential of wEMFs. However, wEMF exposure might impact cellular processes that, in combination with other environmental stressors, could result in molecular readouts resembling those of genotoxins. Such effects could explain the occasionally reported positive result with the Comet assay.

c) Genotoxicity Testing Exposed Mice *(in-vivo; ex-vivo)*

To address persistent *in vivo* genotoxicity and co-genotoxic effects of wEMF exposure in living animals, this part of the SEAWIND project examined micronucleus (MN) formation in bone marrow and peripheral blood erythrocytes (PB) and also in keratinocytes of mice. Male B6C3F1 mice were exposed to the 1.95 GHz CW and the three wEMF signals UMTS, WiFi, and RFID. For each signal, exposure levels in terms of average whole body SAR of 0 (i.e., sham), 1.6, 4.0 and 10 W/kg were used. Groups of 6 mice were exposed in reverberation chambers for 2 weeks, 20 h/d to the CW and wEMF signals and SAR levels. In addition, the well-characterized cyclophospamide monohydrate (CP) was used for co-exposure experiments with 1.95 GHz CW signal to investigate a potential co-mutagenic effect. Finally, malondialdehyde (MN) levels were evaluated in the erythrocyte fraction as a measure for lipoperoxidation, a signal of oxidative stress.

No significant increase in micronucleus formation was notable in CW, WiFi, or RFID exposed mice. However, a slight but significant increase in MN frequency was obvious in PB erythrocytes after UMTS (10 W/kg) exposure. In addition, the clastogenic activity of cyclophosphamide in the bone marrow was significantly decreased by CW pre-exposure (10 W/kg), and MDA levels were altered by WiFi and RFID. In conclusion, none of the tested RF-EMF signals revealed evidence for direct DNA-damaging potential. There are, however, indications of slight wEMF-mediated co-mutagenic effects *in vivo*, which need to be confirmed.

d) Development and Application of Novel Assays

Beyond applying classical cytogenetic tests to assess the genotoxic potential of EMFs, an important objective of the SEAWIND project was the development and application of advanced experimental procedures to elucidate putative interactions between wEMFs and DNA-related cellular processes.

DNA modifications including strand-breaks naturally occur through a variety of DNA transactions associated with cell metabolism and proliferation. In general, these are efficiently repaired and therefore not detectable as DNA damage or genetic alterations by classical tests that require the DNA repair capacity to be saturated by induced DNA damage. Thus, modulation of DNA repair capacities either genetically or by chemical inhibition of repair enzymes may increase the sensitivity of these assays towards minor changes in the steady-state of endogenously occurring DNA lesions, e.g. by accumulation of unrepaired DNA damage. As EMFs were proposed to induce low levels of DNA single strand-breaks and ROS-triggered oxidative DNA damage, we considered the inactivation of respective DNA repair activities a promising approach towards enhancing the sensitivity of the alkaline Comet assay for the detection of potential wEMF damage.

To this end, we evaluated a series of PARP1/2 inhibitors with respect to cytotoxicity and impairment of DNA repair in the two cell models used in the SEAWIND project. The activity of PARP proteins play a key regulatory role in the recognition and processing of DNA base damage and strand-breaks. Alkaline Comet assays performed with wEMF exposed and PARP inactivated cells indicated a slight accumulation of DNA damage in UMTS exposed cells, while the GSM, WiFi and RFID signals had no such effect. Although both, the signal dependency of this effect and the question whether it indeed reflects DNA damage accumulation requires confirmation, these results underline the feasibility and power of the modulation of DNA repair capacity for future research into the potential DNA directed effects of EMFs.

Effects of EMFs on cellular processes appear to be generally subtle and transient, impeding any kind of endpoint analysis. The SEAWIND project intended to develop equipment and experimental procedures to investigate molecular and cellular responses in real-time under wEMF exposure, allowing the detection of small and transient effects. We thus designed, developed and applied a wEMF exposure chamber for live cell imaging microscopy (sXclive-2450) as described under "Exposure Systems" (see above).

One application of such a tool (see Figure 11) is the tracing of DNA damage by detecting the transient appearance of DNA repair proteins in focal nuclear structures representing sites of ongoing repair, so-called repair foci. To explore the potential of such an approach, we established human cells lines expressing a fluorophore-tagged XRCC1 protein. XRCC1 is a key regulator of the repair pathway that fixes DNA single-strand breaks and oxidative DNA base modifications and is known to be rapidly recruited to sites of damage. Remarkably, we noticed that the monitoring of the XRCC1 repair activity under the fluorescent microscope significantly increased foci formation, suggesting that the excitation of GFP-fluorescence at about 488nm is sufficient to induce simple DNA base damage and strand-breaks. While this is an observation to be taken seriously by the research community, as the technology has been widely used to address the kinetic and dynamic aspects of cellular DNA damage response, the high background of repair activity induced by the observation made an assessment of transient induction of repair foci in wEMF-exposed cells impossible. Nevertheless, the results highlight the sensitivity and the feasibility of live cell imaging of cells under EMF exposure, which can be applied to monitor virtually any cellular process that can be tracked microscopically (e.g. the real-time assessment of ROS formation described before). We also used the technology to investigated a putative impact of wEMF exposure on the dynamics of DNA repair processes, as changes in repair activities might explain transient disturbances of genome integrity as well as co-genotoxic effects described in some studies. Again, we took the key factor XRCC1 as a readout but this time monitored the recruitment and persistence of XRCC1 to and at artificially induced DNA damage (UV-microlaser-irradiation), eliminating the problem of observation triggered damage. However, neither recruitment nor persistence of XRCC1 protein at laser-induced sites of DNA damage was altered in UMTS-exposed cells when compared to non-exposed cells. This suggested that XRCC1 dependent DNA repair activities were not affected by the wEMF exposure, consistent with an absence of effect in the Comet assays. Nevertheless, our experiences with the application of the live cell imaging technology emphasize the versatility of the newly developed wEMF exposure system for future investigations into any cellular processes that might become important in terms of cellular EMF response.

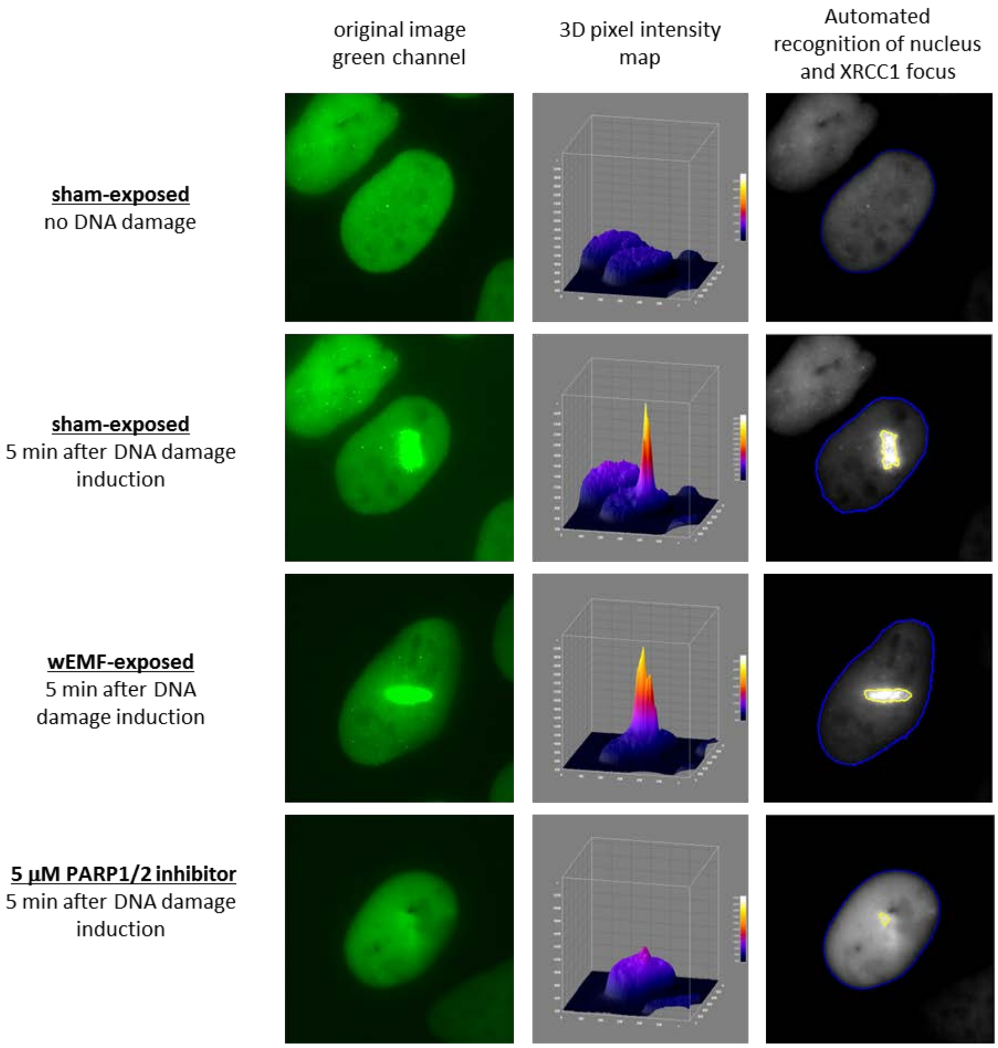

Figure 11: Quantification of XRCC1 recruitment to DNA damage by automated image processing. Representative images of XRCC1-GFP expressing cells before and 5 min after the induction of DNA damage by a UV-A laser at 355 nM, taken with a filter set specific for the green GFP fluorescence (left column). Based on the pixel intensity maps of 16-bit grayscale images (middle column), the open source software CellProfiler determines automatically the nucleus (blue outlined) and the XRCC1-GFP focus (yellow outline) and measures the pixel intensities of the detected regions (right column).

Risk Communication

a) Insights about Concerns and Risks from Lay People

Eight focus group exercises were conducted – 4 in Switzerland and 4 in Greece – with lay people to gather insights about concerns, risks, and benefits of wireless network devices. A focus group is a moderated and structured process of debate involving some 6 to 15 participants representing a social group or a relevant selection of stakeholders, designed to explore the social resonance of arguments for and against certain controversies or value conflicts, to better understand patterns of perception and potential concern, and to anticipate demands for communication and information. In total, about 90 persons attended the focus groups in Switzerland and Greece. Please note that these results are not representative!

In their assessment of sources, channels, and information requests, the focus groups in Switzerland and Greece revealed five user types: (1) sceptical users, (2) "convinced" frequent and pragmatic careless users, (3) "interested" frequent users, (4) adaptable users, (5) low-tech non frequent and non-users.

The focus groups also produced basic recommendations on an integrated policy of communication. Focus group participants demonstrated a preference for a centralized information source integrating different independent (scientific) sources and channels, and "authorized" by a trustworthy central institution (such as the European Union). The provider should also be obliged to provide reliable information about potential health risks and recommend precautionary measures. The information supplied by the provider merely constitutes one element of an integrated communication policy.

The participants were of the opinion that political decision-makers should be encouraged to initiate a set of international and long-term studies on the issue. Independent international studies by scientists were judged by the respondents to be the most reliable source. This was true for all types of users. Studies should be written or translated into everyday language accessible to a lay readership. The information should also be published on the website of every EU member country.

The participants would also appreciate risk comparisons with other familiar risk situations (i.e. smoking, use of mobile phones).

The participants of the focus groups expected any communication to address the different types of users mentioned above, with the message targeted to the needs of each of the user groups (by modifying message framing, channel, frequency, information type, language).

The scope of communication favoured by the participants ranged from a) providing full information on technology, spatial diffusion, exposure-related health effects, exposure, protective action (including precautionary measures), public policies and standards, to b) limited communication about health effects, or only when health risks are clearly indicated (supported by "pragmatic careless users", who feel unable to change their habits without good reason).

The highest consensus on communication strategy was achieved in the focus groups with relation to the integration of health information into a single format, including physical risks, psychological online addiction, data security, social exposure, pressure, social fragmentation, monitoring juvenile Internet use, etc.

The focus groups also made some demands and offered concrete political recommendations, e.g., providers should not only release information on risks, but should also be encouraged/obliged by law to reduce exposure. Participants also suggested that school curricula should include information (similar to traffic safety information) on the risks associated with wireless network devices (health as well as other).

Other suggestions included that the best knowledge available be summarized in the form of a leaflet and / or a YouTube video sponsored by the EU Commission, providing EMF measurement tools (i.e., exposure calculators) in public places such as schools and online, installation of a common regional network (there should be one single wireless network per region instead of a variety of overlapping signals), and production of urban risk maps featuring telephone antennas, high voltage power lines, and radio amplifiers, not to mention publication of information brochures and online articles.

Several focus groups had the chance to examine a web tool created by iMINDS for the prediction of indoor exposure.

b) Communication Strategy and Strategy to Communicate Uncertainty

DIALOGIK conducted a group Delphi to devise the best strategy for communicating the IARC 2b classification of agents (c.f., International Agency of Research on Cancer (IARC) 2012). The group Delphi was also designed to develop approaches on how to communicate uncertainty to a lay audience.

It must also be mentioned here that the results of a group Delphi cannot be representative; the statistical values simply serve as a guide for discussion. In the SEAWIND Delphi, 14 experts participated in the group (in total, over 130 experts were requested to participate in the group Delphi)! These participants were experts in EM compatibility, technology assessment, radiation protection, risk research, EMFs and microwaves, public health, information technology and society, medical radiation biology, future studies and technology assessment, mobile communication, etc.

Between the participating experts there was broad consensus (1) that public authorities, health related organizations and scientists, and consumer associations are the most relevant communicators to supply the public with risk classification information.

There was also broad consensus during the first round of the group Delphi (2) that national agencies and scientists should cooperate. During the second round, the experts argued that the national agencies and scientists should be complemented by a tandem of scientists and journalists to ensure that expert information is presented in an understandable and comprehensible way. The experts also agreed about (3) the need for risk avoidance/benefit recommendations that should form the content of the communication. Regarding the objectives of the communication (4), there was consensus between the participating experts about the need for transparency when evaluating and managing risks. They also agreed that there is no need to present just one position, and instead favored a presentation of the arguments for each of the conflicting positions (with strong emphasis on communication of uncertainties).

For the experts, the most effective communication channels (5) depend on the communication objective and the target group. Effective communication channels could be websites, press conferences, scientific publications, TV, and radio. In terms of credibility (6), there was consensus that the most credible communication channels are scientific publications and information supplied by the relevant authorities.

According to the experts, risk awareness (7) can be enhanced by apps and product labelling. Mobile measurement instruments were rejected as inappropriate, so more research is needed here.

The last question (8) dealt with whether uncertainty should be communicated at all. In this instance, the participating experts were unable to reach agreement, and concluded that uncertainty should not always be communicated. However, there was consensus that uncertainty is a key element of risk communication, and that it is important to achieve a balance between the desire to provide people with the information necessary to enable them to evaluate and assess risks on their own, and the potential for causing undue fear, incurring more damage by cementing risk aversion, which, in turn, can lead to missed opportunities.

The qualitative studies of this part of the project aimed at understanding perceptions about, concerns associated with, and the need for information on wireless network devices and the corresponding technological infrastructure. They focused on two specific characteristics: a) that devices are frequently used by large sections of the population – and even have an impact on those not engaged in active use – and b) that the uncertainty surrounding long-term health risks is ongoing.

This constitutes an extraordinary challenge to political planning, both in terms of risk governance and risk communication. The main strategic communication recommendation foresees integration of information from a unified, independent, and credible source, and tailoring information and communication programmes to the needs of the different user types. These recommendations exceed the context of SEAWIND technologies, since the same communication problems also apply to various other technologies that remain shrouded in uncertainty, such as nano-particles, genetically modified organisms, dosimetry, and others.

Many experts felt that the general public's sense of risk awareness was underdeveloped. Some people overestimate while others underestimate risk, and there is a lack of judgement when it comes to appropriately balancing risks and benefits.

During the group Delphi, two opposing opinions emerged, concerning how and when uncertainty should be communicated: one group favored full disclosure of comprehensive information, including guidelines for prevention, while the other favored a more limited information approach, whereby all information that could cause unnecessary fear and worry is filtered. Which of these two opposing strategies is more appropriate is likely to depend very much on the individual situation. It is important to achieve a balance between causing undue worry and concern on the one hand and a careless approach to risk on the other. Communication should aim to provide people with the background information, thus allowing them to judge for themselves how much protective action they need/want to take.

The Potential Impact and the Main Dissemination Activities and Exploitation of Results

Potential Impact

The potential impact of SEAWIND is expected to be on several levels, the societal impact being the most important. Until recently, research has concentrated on mobile phones while less attention was paid to the pervasive exposure of wireless local or metropolitan area networks, body-mounted and body-worn wireless personal area network devices, and specific wireless applications in industry, e.g., novel RFID logistics applications. However, that people are increasingly exposed to these signals during their daily life causes considerable public concern about the safety of these technologies. The most significant impacts are seen in the following areas:

Exposure Signals

The exposure signal has been analyzed, in particular with respect to daily-life and maximum exposures. The main characteristics and differences have also been summarized in layman terms. This will allow technical experts, communication experts, politicians, and the public to rationally discuss the different technologies (Work Package 2: Review of communication systems, signals, and power modulations).

Based on this analysis, signals designed and applied (Work Package 7: Genotoxicity screening *in vivo* and *in vitro*) well represent the technology but also maximize the likelihood of generating effects. The rationale is also provided. It is suggested that these signals shall be used or at least considered for any future biological experiments.

Measurement Technology

The methodologies and instrumentations were developed to reduce the uncertainties of exposure assessment (Work Package 3: Development of instruments and calibration techniques). These results were disseminated to the standards agencies (Work Package 9: Dissemination to standards) and have already been adopted. This enables reliable exposure assessments that are of great importance for industry, regulators, and health agencies for industry. It also had a significant economic impact for the participating SME, as it could demonstrate its lead in providing exposure assessment technologies.

Incident and Induced Field Exposures

For the first time, the exposures due to wireless networks were systematically analyzed. The spatial and temporal RF exposures at typical indoor microenvironments (schools, crèches, offices, and homes) were measured in Belgium and Greece. Furthermore, methods to extrapolate instantaneous exposure to maximal daily exposures were developed. These values are important today to enable quantitative exposure values (Work package 5: Dosimetry for worst case partial body and local exposure & 6: Organ specific dosimetry).

More important is the novel propagation model that enables estimation of the exposures inside closed rooms. This model will be widely used in the future for exposure estimations and wireless network optimizations (Work package 4: Incident field evaluations for whole-body exposure).

Also for the first time, a comprehensive analysis for induced fields was performed. This allows estimation of the maximum tissue and organ-specific exposures based on frequencies and antenna input power and distance or incident field strengths. This not only enables assessment and comparison of the exposures related to today's technologies but of any future technologies (Work package 6: Organ specific dosimetry).

All of the above findings have also been experimentally validated.

Exposure Systems

Several exposure systems (*in vitro* system, novel table-top reverberation system for mice, and a live-cell imaging system) were developed or have been adapted for the purpose of this study. In particular, the live imaging system, which allows direct real-time insight into cellular response to EMFs of different modulation characteristics, which could have a significant scientific impact, is the first of its type to be reported. The output from Work Package 8 (Exposure systems and quality control) was instrumentation that was exploited directly by the partners in the project.Furthermore, the new equipment was presented at the foremost conference for bioelectromagnetics, to allow other researchers in the field to share the new developments. It is expected that one of the partners will offer a version of these systems for investigations of impact of RF on other biological endpoints.

Genotoxicity Screening *In Vivo* and *In Vitro*.

Based on epidemiology and supported by some laboratory studies, EMFs were classified as possibly carcinogenic (2B) by IARC. Although many cellular pathways may promote the formation of cancer, agents that directly attack the DNA exhibit in general a carcinogenic potential. Therefore, the SEAWIND project aimed at systematic re-evaluation of the potential impact of wEMF signals on genome integrity, which was previously very controversially discussed in both the scientific and the public community. By carefully controlled experimental *in vivo* and *in vitro* systems and approaches, previously reported induction of DNA damage by mobile phone-specific signals could not be reproduced. In addition, there was no indication for a direct DNA-damaging potential of the newly explored signal modulations used in modern data transfer technologies. However, our investigations revealed novel hints about modulation-specific multifactorial effects and how EMF may interfere with cellular homeostasis. These results clarify and advance the scientific understanding about potential health impacts of EMFs and, in particular, will stimulate and guide future investigations into the role of EMFs as a putative co-carcinogen or co-stress factor. Such research will be supported by the novel tools developed during the SEAWIND project. Hence, the outcome of the present project will direct future biological investigations towards a better understanding of the interactions between EMFs and biological systems, which will facilitate the risk assessment concerning health effects of EMF exposure (Work package 7: Genotoxicity screening *in vivo* and *in vitro*).

Risk Governance: Integrating Assessment, Perception and Communication

In communicating uncertainty, the dilemma of finding the appropriate balance between undue precaution (rejecting a beneficial technology) and carelessness about risks (focusing on benefits only) must be addressed. The panelists recommended: Integrate information about health risks in a broader information context about social risks and benefits of WLAN and mobile internet use in general, take advantage of different channels, vary the frequency with which information is given, and experiment with different formats and frames in line with the needs and concerns of the various user-typed identified above. The focus groups also recommended establishing a centralized structure for authorized independent information (e.g., by EU institutions).

Furthermore, on the practical side, the EU was advised to produce YouTube videos on the issue and to consider establishing awareness programs at schools. These measures should be augmented by installing radiation measurement devices in computer rooms, to create exposure and risk maps about radiation exposure, and to invest in a single common wireless network to minimize exposure to radiation from overlapping EMFs caused by a variety of parallel wireless networks.

Standards

The following standards greatly benefit from the outcomes of this project:

- IEEE 1528: Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques (adopted the methodology developed in Work Package 3)
- IEC 62209-1: Human Exposure to Radio Frequency Fields from Hand-Held and Body-Mounted Wireless Communication Devices: Human Models, Instrumentation and Procedures - Part 1: Procedure to determine the specific absorption rate (SAR) for devices used in close proximity to the ear (frequency range of 300 MHz to 6 GHz). (adopted the methodology developed in Work Package 3)
- IEC 62209-2: Human exposure to radio frequency fields from hand-held and body mounted wireless communication devices – Human models, instrumentation, and procedures – Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz) (adopted the methodology developed in Work Package 3)
- IEEE C95.3: Recommended Practice for Measurements and Computations of Electric, Magnetic and Electromagnetic Fields With Respect to Human Exposure to Such Fields, 0

Hz to 300 GHz (is currently under revision and adaption of the methodology is also tabulated)

Dissemination

The SEAWIND dissemination aimed to promote knowledge sharing among the scientific community and standardization bodies and to increase awareness of the project results on the part of the public. Various instruments were and are used to reach that goal.

A project website was established at the beginning of the SEAWIND project and was continuously updated during the course of the project. The purpose of the website was to exchange information and share confidential data within the consortium as well as to promote the project and its activities to the wider scientific and user communities. It, therefore, consisted of public and private sections. The public section comprised all material accessible to the general public, whereas the private section is intended for the internal organization of the project and could only be accessed via login with a username and password. The structure of the SEAWIND website at http://www.seawind-fp7.eu was designed in a clear and consistent way so that visitors and users could easily locate all information intended for them. The main sections were listed in the left navigation pane.

In the public domain, the opening page referred to "News and Events" to clearly highlight the latest developments regarding the project and project-related issues. Events, such as a workshop in which the SEAWIND experts reported project results in the course of a public event, were announced there. Detailed information about the project aims, the deliverables of the project and management structure, the consortium partners, and external advisors were provided on linked pages.

A project leaflet written in generally understandable language, containing a summary of the main objectives and methodology and the project partners, was developed. The leaflet aimed not only to promote the project to the public, but was also used to inform people who were affected by the studies, e.g., pupils (and their parents) of the schools and other facilities where measurements were performed. For that purpose, the leaflet was translated also in Greek. The leaflet is available for download from the project website and was distributed in printed form at conferences and other events during the lifetime of the project.

Dissemination activities of SEAWIND towards the scientific community included various channels, such as participation in scientific meetings, conferences, and workshops, publications, and liaisons with other research projects. The SEAWIND project and its results have been presented at around 20 national and international scientific meetings, conferences, and workshops in the form of posters and oral presentations and distribution of the project leaflet.

Dissemination of the project results to the scientific community and industry and general public has also been established via a workshop. The IT'IS Foundation, coordinator of SEAWIND, organized a scientific workshop covering, among other topics, SEAWIND-related research results. The workshop "EMF Health Risk Research - Lessons Learned and Recommendations for the Future – 7 years later" took place in Autumn 2012 (October 21 – 26, 2012) at the Center Stefano Franscini, in Monte Verità, Ascona, Switzerland. The workshop brought together world-renowned researchers in the field of EMF and health as well as government health protection experts and standardization committees to analyze and synthesize newly available research results. It provided a forum for extensive discussions that has been available neither at scientific meetings nor at official standard/assessment group meetings, namely, to focus on those experiments that are not in line with current understanding of EMF interaction with biological systems. In the frame of the workshop, a public event was held for local people entitled "Health Risk from of Exposure to Wireless Network Devices?", which focused on SEAWIND research. For the first time, the principal investigators of the SEAWIND consortium presented the results and conclusions of the project to the general public. The researchers and representatives of health agencies were available to answer questions asked by the public. The event has been videotaped for dissemination and is available on the SEAWIND webpage, the Monte Verita webpage and other related sites.

The SEAWIND consortium is closely liaised to the European Framework Programme 7 project ARIMMORA ("Advanced Research on Interaction Mechanisms of electroMagnetic exposures with Organisms for Risk Assessment"), which deals with the exploitation of biophysical mechanisms that could explain the effects of weak environmental extremely low frequency (ELF) fields in support of a possible causal relationship between cancer and ELF magnetic field (ELF MF) exposure. Four SEAWIND Partners are also members of the ARIMMORA consortium.

The objective of Work Package 9 ("Dissemination to Standards") was the direct dissemination of the results of the Work Package 2 ("Review of communication systems, signals, and power modulations"), Work Package 3 ("Development of instruments and calibration techniques"), Work Package 4 ("Incident field evaluations for whole-body exposure"), Work Package 5 ("Dosimetry for worst-case partial-body and local exposure"), Work Package 6 ("Organ specific dosimtery") to the relevant standard committees, with the advantage that the findings could be evaluated at the earliest possible opportunity by academic, industrial, and governmental experts and adopted as soon as possible. The dissemination work began in early 2010, with presentation to the standards committees, first of the open questions and then the results. The work has a direct impact on measurement standards where complex signals must be accurately measured.

List of SEAWIND Deliverables

Work package 1: Review of exposure assessment and dosimetry of wireless network
D1.1: Literature review of exposure assessment and dosimetry of wireless networks
D1.2: Update on literature review

Work package 2: Review of communication systems, signals and power modulations
D2.1: Report on exposure signals characterized to give basis for WP3 requirements (duty cycle, bandwidth etc.)
D2.2: Report on communication systems and the signal characteristics relevant for exposure assessment
D2.3: Selection of four generic power envelopes to be used in WP7 and WP8

Work package 3: Development of instruments and calibration techniques
D3.1: Requirements on probe systems that are suited for exposure assessments of wireless network devices
D3.2a: Recommended probe calibration procedures for type approval of wireless network devices (broad-band probes)
D3.2b: Recommended probe calibration procedures for type approval of wireless network devices (narrow-band probes)

Work package 4: Incident field evaluations for whole body exposure
D4.1: Description of locations for frequency-selective and personal exposimeter measurements
D4.2: Description of the simulation cases
D4.3: Statistical data set of incident exposure measurements for different scenario's and different sources that produce a far-field exposure
D4.4: Comparison of measured and simulated electromagnetic fields
D4.5: Statistical SAR data set derived from the statistical incident field set for sources that produce a far-field exposure combined with the results of WP6

Work package 5: Dosimetry for worst case partial body and local exposure
D5.1: Description of worst-case set-up for each source
D5.2: SAR measurement set-ups

Work package 6: Organ specific dosimetry
D6.1: Anatomical models in all necessary postures and validated source models
D6.2: Preliminary evaluation of exposure as a function of posture and technology
D6.3: Report/publication on the cumulative exposure including assessment of uncertainty and variability

Work package 7: Genotoxicity screening in vivo & in vitro
D7.1: Report of the MN studies
D7.2: Report of the comet assays in DNA SSB repair proficient and deficient human fibroblasts
D7.3: Report on SCE and chromosomal aberration tests in repair proficient and deficient fibroblasts
D7.4: Report on real-time ROS measurements
D7.5: Report on SSB repair foci formation under wEMF exposure
D7.6: Report on XRCC` localization dynamics under wEMF exposure

Work package 8: Development of exposure systems and quality control
D8.1: In vitro exposure system xXc1950 adopted including dosimetry
D8.2: sXcli2450 system developed including dosimetry
D8.3: sXv2450 system including dosimetry
D8.4: Report on quality control

Work package 9: Dissemination to standards
D9.1: Report on the dissemination to standard committees

Work package10: Risk governance: Integrating assessment, perception and communication
D10.1: Report on risk profiles for selected technologies
D10.2: Report on the results of the group Delphi process
D10.3: Report on the results of the Focus Groups
D10.4: Report on decision support tools for risk evaluation

Work package 11: Project Management
D11.1: Minutes of the General Assembly (months 1, 12, 24, 36)
D11.2: Establishing a project website and publication of project leaflet
D11.3: Plan for the dissemination of results (month 3) and updates (months 12, 24, 36)
D11.4: Information sheets and informed consent forms approved by competent national body (Greece)
D11.5: Permit for the animal experiments from the local authority in Germany
D11.6: Status report on exploitable results (month 12, 24), and final exploitation plan (month 36)
D11.7: Status report on access rights and IPR issues (months 12, 24, 36)

List of SEAWIND Journal Publications

J. B. Andersen, K.L Chee, M. Jacob, G.F. Pedersen, T. Kürner, "Reverberation and Absorption in an Aircraft Cabin With the Impact of Passengers," IEEE Transactions on Antennas and Propagation, vol. 60, pp. 2472 – 2480, May 2012.

A. Bamba, W. Joseph, J.B. Andersen, E. Tanghe, G. Vermeeren, D. Plets, J.O. Nielsen, L. Martens, "Experimental Assessment of Specific Absorption Rate Using Room Electromagnetics," IEEE Transactions on Electromagnetic Compatibility, vol. 54, pp. 747- 757, August 2012.

A. Bamba, W. Joseph, G. Vermeeren, E. Tanghe, D.P. Gaillot, J.B. Andersen, J.O. Nielsen, M. Lienard, L. Martens, "Validation of Experimental Whole-Body SAR Assessment Method in a Complex Indoor Environment," Bioelectromagnetics, vol. 34, pp. 122 – 132, August 2012.

J. Nadakuduti, S. Kühn, M. Fehr, M. Douglas, K. Pokovic, N. Kuster, "The Effect of Diode Response of Electromagnetic Field Probes for the Measurements of Complex Signals," IEEE Transactions on Electromagnetic Compatibility, vol. 54, pp. 1195 – 1204, December 2012.

I. Markakis, T. Samaras, "Radiofrequency Exposure in Greek Indoor Environments," Health Physics, vol. 104, pp. 293 – 301, March 2013.

M. Capstick et al., "2.45GHz In-vitro Exposure System for Use During Live Cell Imaging," publication in preparation.

M. Capstick et al., "In-vitro Exposure System for Live Cell Imaging at 2.45 GHz," publication in preparation.

M-C. Gosselin et al., "SAR Exposures by Wireless Network Device," publication in preparation.

J.O. Nielsen et al., "On Polarization and Frequency Dependence of Diffuse Indoor Propagation," publication in preparation.

D. Schürmann, et al., "Combined about PARP & co-genotoxicity," publication in preparation.

D. Schürmann, et al., "Other approaches: SCE, life-cell imaging," publication in preparation.

C. Ziemann, et al., "In vitro, Comet data," publication in preparation.

C. Ziemann, et al., "In Vivo Studies," publication in preparation.