Mobile learning and health-risk management of pulsed microwave technologies

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ABSTRACT

Many schools and educational institutions are using wireless Wi-Fi and Tablet technologies in their education. Recently WHO IARC classified radiofrequency (RF) radiation 'possibly carcinogenic to humans'. Currently guidance levels for electromagnetic fields (including RF) are based on thermal effects while effects have been reported on non-thermal levels. Possibly these biological, non-thermal effects are brain-related and affect cognition, memorizing and learning. We start by describing our measurement method used for Wi-Fi routers and laptop Wi-Fi antennas. Then a historical overview on thermal and non-thermal viewpoints is provided. The objective of this study is to quantify the actual RF radiation levels around Wi-Fi access points and laptop computers at educational facilities and to assess their compliance with the current thermal-only guidelines and also with precautionary, biological guidance levels. This paper ends to recommendations how to minimize radiation exposure in educational institutions.

Author Keywords
WLAN, Wi-Fi, health, learning, safety limit, radiofrequency, radiation, electromagnetic, risk management

INTRODUCTION

Mobile learning encompasses both learning supported by mobile technology and also learning in an era characterized by constant mobility of people and knowledge (Sharples *et al.,* 2011). This constant mobility is achieved using a network of mobile phone base stations, wireless routers, computers, mobile phones and, recently, tablet devices. However, several scientists, governments and the European Parliament have emphasized precautionary principle and indicated health risks in pulsed microwave technologies, including for example Wi-Fi (Wireless Fidelity) and UMTS (Universal Mobile Telecommunications System). In 2009 the European Parliament pointed out that the exposure limits for general public are obsolete, since they haven't taken into account the developments in information and communication technologies (European Parliament, 2009) The World Health Organisation (WHO) and it's International Association of Research on Cancer (IARC) classified 2011 radiofrequency radiation (microwave radiation) as 'possibly carcinogenic to humans', based on epidemiological evidence on the connection of glioma (brain tumour) and mobile phone use (WHO, 2011). The biological, non-thermal effects of electromagnetic fields (EMF) are documented in the BioInitiative Report (BioInitiative, 2007) and in the ICEMS Monograph (ICEMS, 2010). At the same time authorities and standard setting bodies (like ICNIRP (International Commission of Non-Ionizing Radiation Protection) and IEEE (Institute of Electrical and Electronics Engineers) have not officially recognized such risks. The current European safety limits (the directive 1999/519/EC) are solely based on ICNIRP recommendations and the thermal effects of the Wi-Fi-frequency EMFs, with the research data preceding the year of 1999.

The focus of this paper is to measure pulsed radiofrequency radiation of Wi-Fi technology, view results in light of the recent research and provide recommendations to manage a possible risk. The measurements are conducted in the Wi-Fi-router environment to illustrate the gap between the new research data (BioInitiative Report) and the old data (EU directive). There are articles that cover technical measurements of the Wi-Fi technology in schools (Peyman *et al*. (2011). Similarly, there are already some research papers inspecting the health-related effects of Wi-Fi technology on humans (Papageorgiou *et al.,* 2011; Havas *et al.,* 2010; Maganioti *et al.,* 2010). However, based on our literature search on Pubmed (http://www.ncbi.nlm.nih.gov/pubmed/) and EMF-Portal (http://emf-portal.org) there are not articles covering health effects and risk-management of Wi-Fi technology in schools, except a commentary by Watson (2011). So, in that sense our approach might provide new contributions both for science and practice.

The need for the research of non-thermal effects of EMFs has been pointed out by the high-level European bodies. In 2009 the European Parliament issued a resolution (2008/2211(INI)) emphasizing the need to encompass Wi-Fi-devices into EU indoor air quality policies. The Council of Europe committee examined the evidence and issued a statement in 2011 saying that wireless technology is "potentially harmful to humans". The committee concluded amongst other recommendations that wireless networks (including Wi-Fi and mobile phone use) should be removed from schools and replaced with wired, Ethernet infrastructure. (Council of Europe, 2011)

Next we will describe the method and measurement protocol we are using for Wi-Fi access points and laptops. Thereafter we will illustrate the difference between thermal and non-thermal effects and related guidelines. Health studies related to pulsed microwave technologies (including Wi-Fi) are thereafter described. At the end of this paper we will present our measurement results and point out safer practices of Wi-Fi use.

METHOD AND MEASUREMENT PROTOCOL

Several Wi-Fi access points and laptops were measured. Measurements were taken at Tallinn University of Technology and at Tampere University. The measurement instruments were Gigahertz Solutions HF59B meters (Langenzenn, Germany). These high frequency (HF) analyzers measure pulsed radiofrequency radiation in scale 800MHz-2500MHz with a directional antenna.

The instruments were selected over the use of spectrum analyzers because of their wide bandwidth measurement method. The HF59B HF analyzers allow to catch the whole Wi-Fi power density level at once, unlike spectrum analyzers that scan the given frequency range one frequency step at a time. The spectrum analyzer approach might therefore miss some of the signal resulting an inadequate reading.

Five Wi-Fi-routers were measured at both locations. An average and a maximum reading was recorded on each router site. Data was recorded with two signal processing modes: 1) RMS (root mean square) and 2) peak. A directional antenna HF800V2500LPE174 (frequency response 800-3000MHz) was used to provide the signal analyzer mainly with the signal of a target router. Measurements were taken from a perspective of a sitting student's head, at distances of 0.2, 0.4, 0.8, 1.2, 2, 3 and 4 meters from the Wi-Fi router (access point). Routers were put into constant download state. At each distance the analyzer was rotated on horizontal plane around the router, the maximum reading was recorded.

Five laptop computers were measured in order to compare them to Wi-Fi-router's emissions. The laptop computers were put into constant upload state to maximize the use of Wi-Fi-antennas. Also the laptop screens were tilted to a typical an angle of 115 degrees. Otherwise the same measurement protocol was applied as with the routers and measurements are done from similar distances.

The measurement results were compared with existing European legislation - the EU directive 1999/519/EC on the limitation of exposure of the general public to electromagnetic fields. It should be noted that current legislation in regard to the EMFs in Wi-Fi-frequencies was formed on the basis of the thermal effects. Much concern has been raised by both the general public and scientific community, whether the existing legislation provides adequate protection from EMFs exposure. Therefore the comparison of the measurement results was also done to non-thermal, biological recommendation levels of the BioInitiative Report (BioInitiative, 2007). Next the background of current thermal guidelines and the BioInitiative Report's safety levels are addressed to point out possible shortcomings in providing general public with adequate EMF safety levels.

GUIDELINES AND BIOLOGICAL EFFECTS

Currently, the health debate around mobile phones, base stations and power lines is heated in many countries (NRK, 2008). The authors will provide here two views, both with supporter groups. Thereafter we will illustrate the measurement results and risk management practices.

The thermal effects view

After the Second World War, a German biophysicist, Professor Herman Schwan moved to the USA to work for the US defense department contracts in the area of electro-magnetic fields. Like infrared radiation, radio waves and microwaves produce heat when they're absorbed in sufficient quantity. Although not a biologist, Schwan assumed this heating was the only effect EMR would have on living tissue.

Schwan then estimated danger levels based on how much energy was needed to measurably heat metal balls and beakers of salt water, which he used to represent the size and presumed electrical characteristics of various animals. Appreciable heating occurred in these models only at levels of 100.000 microwatts / cm2 or above, so, incorporating a safety factor of ten, Schwan in 1953 proposed an exposure limit of 10.000 microwatts / cm2 for humans. By showing soon afterward that it took more than this intensity to cause burns in real animals, Solomon Michaelson seemed to have confirmed the safety of "nonthermal" dosages. No one tested for subtler effects, and the 10,000-microwatt level was uncritically accepted on an informal basis by industry and the military. In 1965 the Army and Air Force formally adopted the Schwan limit, and a year later the industry-sponsored American National Standards Institute recommended it as a guideline for worker safety. (Becker and Selden, 305, 1985)

Currently, the guidance levels for non-ionizing radiation in most of the Western countries are based on thermal effects. In other words, the current guidelines only restrict the intensity of the radiation to prevent tissue heating in excess of what the body's thermoregulatory mechanism can cope with (Hyland, 2000). The exposure is measured after maximum 6 minutes exposure, no cumulative, long-term effects are recognized. A specific organization is responsible for maintaining these guidelines, namely ICNIRP (International Committee on Non-Ionizing Radiation Protection) (ICNIRP, 1998). The ICNIRP guidance level for 2400 MHz (including Wi-Fi) is 10 W/m2 = 10.000 mW/m2. Manufacturers are allowed to produced Wi-Fi routers with maximum 100 milliWatts.

Reference levels for the Wi-Fi frequencies (2GHz and more) set by the EU directive 1999/519/EC are expressed as Equivalent plane wave power density Seq and are 10W/m2 (RMS value). If this limit is exceeded the directive assigns more detailed investigation to find out if basic restrictions are met, expressed as whole body average SAR 0,08 W/kg and localized SAR (head and trunk) 2 W/kg applying to the range of 10 MHz-10 GHz.

The WHO (World Health Organization) International EMF Project and ICNIRP see that there are no other mechanisms than heating that may affect health and therefore current safety limits are valid. Military uses microwaves for crowd control and non-lethal weapons (Becker and Selden, 1985). Bone fractures are healed using special frequencies and polarities of electro-magnetic fields (Becker, 1990). Interestingly, both these activities take place at non-thermal levels and can not be explained through heating. The independence and neutrality of ICNIRP, IEEE and WHO have been occasionally questioned (NRK, 2008; Slesin, 2005)

The non-thermal effects view

In 1952 the German physicist, Professor W. O. Schumann of the Technical University of Munich showed that there are electromagnetic standing waves in the atmosphere, within the cavity formed by the surface of the earth and the ionosphere. There is a resonating electromagnetic oscillation between earth and ionosphere in the 10 Hz region (Schumann resonance, 7.83 Hz). The intensity and spectrum of the Schumann Resonances vary markedly from day to night and with solar activity. At night both the brainwaves of a human being (measured by EEG) and the Schumann Resonances are dominated by very low frequencies (<5 Hz).

Human brains detect, use and react to natural low frequency signals, the Schumann Resonances. 7.83 Hz is the same frequency at which the hippocampus, the area of the brain responsible for short term memory, vibrates. (Cherry, 2002). In 1960's it was demonstrated how human cells communicate electronically and how voltage and polarity is changed when for example wound healing is taking place (Becker and Selden, 1985).

Already in 1970s Russian doctors diagnosed an illness called microwave syndrome, where chronic exposure to artificial electro-magnetic fields weaken human immune system (Gordon, 1979).

If the non-thermal effects would be recognized officially, the ICNIRP guidance levels could be dropped perhaps to the 1/10.000 part of their existing value. Several French cities adopted in summer 2009 the 1 mW/m2 limit recommended by the BioInitiative (2007). The reason for these low levels is based on evidence on several animal studies where chronic exposure in levels below 10 mW/m2 produces harmful effects (see an overview in Levitt and Lai (2010). According to Otto and von Mühlendahl (2007) the reproducibility of these non-thermal effects is usually poor, and no physiologic or pathogenic mechanism, so far, has been accepted by all organisations to explain these effects. Similarly, Lin (1997, 439) sees, that better understanding is needed of the mechanisms of interaction between RF/microwave radiation and biological systems, and of the significance of any observed effects.

POSSIBLE HEALTH EFFECTS OF PULSED SIGNAL IN WI-FI AND RF TECHNOLOGIES

Generally, pulsed microwave radiation is more harmful than continuous wave microwave radiation (Creighton *et al.*, 1987). Pulsed microwave radiation is produced by several, modern technologies like Wi-Fi routers, Wi-Fi laptops, mobile phones and mobile phone base stations.

There are 10 epidemiological studies of mobile phone base stations. In their review, Khurana *et al.* (2010) found out that 8 out of 10 epidemiological studies indicate increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances < 500 meters from base stations. Here we need to understand, that an epidemiological study of a mobile phone base station is different from Wi-Fi technologies. There are no epidemiological studies of Wi-Fi. The exposure level, RF power density levels close to a mobile phone base station may be smaller than next to a Wi-Fi router / antenna, but the exposure time is often longer. Elliott *et al.* (2010) inspected the connection of mobile phone base station and childhood cancers and found no correlation. In Elliott's research power density values were modelled, not measured.

The basic frequency and the carrier wave in the Wi-Fi technology is 2450 MHz. Additionally, the signal is pulsed, information is encoded in pulses. These pulses are between 50-500 Hz. There is also a beacon signal; both the router and the gadget send their device ID (identification) number at 10 Hz. This might be problematic, because this is very close to the strongest Schumann Resonance. The human DNA itself is very sensitive to RF-radiation and human DNA can act as a fractal antenna (Blank and Goodman 2011). The newest research related to Wi-Fi points out to effects on brain, heart and fertility. Papageorgiou *et al.* (2011) noticed that a Wi-Fi base station affected short-term memory of humans. Maganioti *et al.* (2011) noticed that radiation from a Wi-Fi-base station affected brain-functioning deleteriously in the alpha- and beta-band. This change was visible in women but not in men. Havas *et al.* (2010) noticed that a Wi-Fi-like pulsed microwave radiation affected heart-rate variability (HRV) in some research subjects. Avendano *et al.* (2011) showed that the use of laptop computers connected to internet through Wi-Fi decreases human sperm motility and increases sperm DNA fragmentation.

In summary, there is very little evidence on harmful effects of Wi-Fi. However, there is much research is done on pulsed 2450 MHz technologies before Wi-Fi era (see for example EMF-Portal, http://www.emf-portal.org). Findings point out to the direction that human behavior, functionality and memory is affected by the pulsed nature of radiation.

RESULTS AND DISCUSSION

At two universities a total of five Wi-Fi access points are measured. Similarly, a total of five laptop computers are also measured. An average and a maximum power density of all five access points and laptops are presented in table 1.

Distance (m) from	Access point		Laptop (Wi-Fi adapter)	
	Peak value	RMS value	Peak value	RMS value
0,2	22,6 / 48,0	1,16 / 1,50	12,2 / 17,2	1,65 / 3,40
0,4	11,1 / 21,0	0,74 / 1,01	4,69 / 7,20	0,78 / 2,26
0,8	4,56 / 5,60	0,27 / 0,41	2,12 / 3,40	0,56 / 1,31
1,2	2,04 / 2,80	0,13 / 0,22	1,04 / 1,88	0,35 / 0,82
2	0,59 / 1,50	0,05 / 0,08	0,45 / 0,93	0,16 / 0,49
3	0,46 / 0,57	0,04 / 0,07	0,29 / 0,62	0,11 / 0,30
4	0,29 / 0,48	0,03 / 0,07	0,19 / 0,32	0,07 / 0,19

Table 1. Power density of five Wi-Fi access points and five laptop PCs (average/maximum), measurement unit: mW/m²

We compare our measurements to the measurements of Peyman *et al*. (2010) in a class-room situation: The maximum power density values for the laptops and access points at 0.5 m were 22 mW/m² and 87 mW/m² respectively, decreasing to 4 mW/m² and 18 mW/m² at 1 m distance (Peyman *et al*., 2010). By comparison Peyman *et al.*'s measurement results are higher about 3-4 times to ours. This is due to a specialized computer program used by Peyman *et al*. to maximize the Wi-Fi adapter radiation. We believe that using standard upload-download protocols produces more realistic results and basis for comparison.

Avendano *et al.* (2011) used a laptop computers with Wi-Fi and noticed decreases human sperm motility and increased sperm DNA fragmentation. Sperm were exposed to an average of around 6.8 mW/m² radiofrequency radiation for four hours. As seen from our measurement results, this level is easily outperformed by both Wi-Fi access points and laptop PCs. Avendano *et al*. measurements produce only one example of non-thermal effects of RF EMFs, well below official safety limits. Similarly, Atasoy *et al*. (2012) found out reduced fertility and structural changes on testes of rats when exposed chronically in close distance (25 cm) by Wi-Fi. However, animal-based research cannot be directly extrapolated to humans.

CONCLUSION AND RECOMMENDATIONS

To answer the question, do current safety limits protect public from all risks, the research of non-thermal effects suggests that all the factors related to possible Wi-Fi effects are not considered in current guidelines. If biological effects are taken into account for future safety limits, then the Wi-Fi technology is called for new innovative, less EMF-radiating solutions. Based on our results, we would recommend precautionary actions to reduce EMF exposure.

Recommendations for mobile learning environments at schools:

1. Keep the distance: place the devices away from student's head and body.
2. Minimise the exposure time: no base stations (incl. Wi-Fi) in classrooms.
3. Avoid continuous mobile data transfer, prefer synchronised, off-line services.
4. Anytime, anyplace is not realistic. Turn Wi-Fi off when not needed.
5. Designated Wi-Fi Zones by modifying and shielding antennas. Adjust power levels. in a Wi-Fi-router.

The comparison of the measurement results was done to EU directive 1999/519/EC which were set in action to protect the general public from adverse health effects from EMFs. Only thermal effects of the EMFs in Wi-Fi frequencies were accounted for in the directive, leaving the door open for future research. Therefore the directive is based on a research available by the time of it's approval by the European Parliament in 1999. Our measurements demonstrated that current Wi-Fi radiation in educational facilities is above established non-thermal health effects. This situation contradicts general EU occupational health and safety policy regarding EMFs that could be expressed as „better safe than sorry". The Bioinitiative Report (2007) points out several new health effect mechanisms of the EMFs. In our opinion these new mechanisms should be researched further. Therefore the aim of this article was to point out the gap between "old data" and the "new data" that inevitably has raised the concern amongst the general public and scientific community likewise.

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