Review Paper

WI-FI AND HEALTH: REVIEW OF CURRENT STATUS OF RESEARCH

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Abstract—**This review summarizes the current state of research on possible health effects of Wi-Fi (a commercial name for IEEE 802.11-compliant wireless networking). In response to public concerns about health effects of Wi-Fi and wireless networks and calls by government agencies for research on possible health and safety issues with the technology, a considerable amount of technology-specific research has been completed. A series of high quality engineering studies have provided a good, but not complete, understanding of the levels of radiofrequency (RF) exposure to individuals from Wi-Fi. The limited number of technology-specific bioeffects studies done to date are very mixed in terms of quality and outcome. Unequivocally, the RF exposures from Wi-Fi and wireless networks are far below U.S. and international exposure limits for RF energy. While several studies report biological effects due to Wi-Fi-type exposures, technical limitations prevent drawing conclusions from them about possible health risks of the technology. The review concludes with suggestions for future research on the topic.**
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Key words: exposure, radiofrequency; health effects; radiation protection; radiofrequency

INTRODUCTION

WITHIN THE past two decades, Wi-Fi© [a trademarked name for wireless networking products that are certified to be compliant with the Institute of Electrical and Electronics Engineers' (IEEE) 802.11 family of standards (IEEE 2009) by the Wi-Fi Alliance (http://www.wi-fi.org), an industry group] has become omnipresent in modern society. Wi-Fi devices contain low-powered radiofrequency (RF) transceivers that support wireless local area networks (WLANs). Their most familiar (but not only) use is to provide access to the Internet by laptop computers, although IEEE 802.11 protocols are used for other communications devices, including some electric utility meters.

Initially developed as a wireless replacement for Ethernet cable to connect computers to local area networks, IEEE 802.11 is now the basis of virtually all wireless local area networks present in homes, offices, and other environments. At present, virtually every laptop computer and SmartPhone comes equipped with a Wi-Fi client, and one recent study estimated that 61% of American households presently have Wi-Fi for Internet access (Thota 2012). Increasingly, household devices are incorporating Wi-Fi interfaces to allow remote programming and data acquisition: bathroom scales, gaming devices, audio equipment, household thermostats, and running shoes. While numerous wireless networking technologies are available, virtually all of the WLANs with which an ordinary citizen would be familiar are configured around IEEE 802.11 using Wi-Fi certified devices.

Under any plausible exposure scenario, the levels of RF exposure from a WLAN (either from the client card in a laptop or the access point located in a house) are far below major international limits, in particular those of IEEE (IEEE 2005) or the International Commission on Nonionizing Radiation Protection (Vecchia et al. 2009), as well as national limits [in the U.S., those of the Federal Communication Commission (FCC 1997)]. Health agencies have not expressed concern about possible health hazards from such exposures (e.g., WHO 2006). Nevertheless, public controversy persists about possible health effects of the technology, particularly related to the presence of WLANs in schools. A few authors have recommended against the use of Wi-Fi in schools on precautionary grounds (Sage and Carpenter 2009).

In response to public concern, some agencies have called for research on possible health effects of the technology. For example, the European Parliament in a 2009 resolution called for study of "'wireless' domestic appliances, which, like Wi-Fi for Internet access … have been widely adopted in recent years in public places and in the home, with the result that citizens are being continuously exposed to microwave emissions" (European Parliament 2009).

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This review examines the current state of research on possible biological effects/health effects of RF energy emitted by Wi-Fi devices and comments on future directions of such research. The topic is important because, apart from the immense research literature on biological effects of RF energy in general, the literature on Wi-Fi has been developed in response to calls for technology-specific studies involving particular forms of RF emitting devices. Many more wireless technologies are on the horizon that will present similar exposure and risk perception issues as Wi-Fi, and it is worthwhile to review critically the research that has developed so far with respect to this particular wireless technology.

METHODS

A systematic search was conducted in September-November 2012 (updated in March 2013) to identify literature that specifically pertained to possible health risks from exposures to RF signals emitted by Wi-Fi equipment. Searches included general scientific databases (Medline and ISI Web of Knowledge) as well as specialized databases [EMBASE and the database of RF bioeffects literature maintained by the IEEE ICES standards group (http://ieee-emf.com/)].

In addition, the FCC Equipment Authorization database (https://apps.fcc.gov/oetcf/eas/reports/GenericSearch.cfm) was searched to characterize operating power levels of Wi-Fi equipment. This database lists every grant (a prerequisite for sale) from the FCC to a vendor of a device. For any device, the database typically includes user manuals, photographs of intact and sometimes disassembled devices, and RF test results on the device.

RESULTS

Engineering/exposure limits

Frequency and modulation. The IEEE 802.11 family of communications standards, a subset of which is used by Wi-Fi devices, was originally approved in 1997; but it has been updated and extended numerous times since then (Table 1). The frequency of transmission, channel width, and data rate (number of bits s^{-1} that can be transmitted), as well as modulation characteristics, vary with the version of IEEE 802.11 that is being used. The frequencies allocated for Wi-Fi and other digital communication devices vary somewhat with country but in most cases are similar to those used in the U.S.

Most Wi-Fi devices operate in the unlicensed spectrum at 2.400–2.4835 GHz (2.412–2.462 GHz in the U.S.). This is a part of the industrial-scientific-medical (ISM) band at 2.4–2.5 GHz that is used for many other purposes, including a variety of digital communication devices commonly found in the home (Bluetooth and ZigBee wireless interfaces, some cordless telephones) as well as noncommunications devices (household microwave ovens). This ISM band is also used for many industrial heating and medical appliances.

In recent years, Wi-Fi devices have appeared that operate using IEEE 802.11a or n, which allow transmission near 5 GHz either in the ISM band at 5.725–5.850 GHz or in a different band at 5.15–5.35 GHz. Most Wi-Fi devices transmit on channels of 20 MHz width, although IEEE 802.11n provides for transmission in two channels with a total bandwidth of 40 MHz to increase the rate of data transmission. The transmissions consist of trains of pulses of RF energy ranging in duration from a few tenths of a ms to 10 ms or so, depending on the amount of data being carried by a burst. The pulses are modulated using digital techniques, Direct Sequence Spread Spectrum, Frequency Hopping Spread Spectrum, or Orthogonal Frequency Division Multiplexing (DSSS, FHSS, or OFDM), depending on the variant of IEEE 802.11 that is being used. These different modulation techniques result in signals with somewhat different spectral characteristics within the channel being used by the device at the time.

As can be seen from Table 1, the data rate supported by WLANs varies considerably depending on the version of IEEE 802.11, from 1–2 Mbit s^{-1} for the legacy (original) version of the standard to a maximum of 600 Mbit s^{-1} for IEEE 802.11n. The actual transmission rate from a given device will vary with time, depending on the software protocol used by the computer, signal quality, network congestion, and other factors. Data rate in part determines the number of pulses (and hence the total amount of RF energy) required to transmit a given number of bytes of data. Unlike

Table 1. Versions of IEEE 802.11 used with Wi-Fi devices.

IEEE 802.11 version (date released)	Frequency (GHz)	Bandwidth of channel (MHz)	Data rate per stream (MB s^{-1})	Modulation[a]
IEEE 802.11 (original version) (1997)	2.4	20	1–2	DSSS/FHSS
IEEE 802.11a (1999)	5	20	6–54	OFDM
IEEE 802.11b (1999)	2.4	20	1–22	DSSS
IEEE 802.11g (2003)	2.4	20	6–54	OFDM/DSSS
IEEE 802.11n (2009)	2.4/5.3,5.8	20/40	7–600	OFDM

[a] DSSS-direct-sequence spread spectrum; FHSS-Frequency-hopping spread spectrum; OFDM-Orthogonal frequency-division multiplexing (different modulation techniques used for digital data).

mobile telephones, Wi-Fi does not use adaptive power control (adjusting the transmitted power from the client according to the signal from the base station).

Peak output power. The peak output power of Wi-Fi transmitters is subject to national regulation; in the U.S., these are the FCC rules as provided in Title 47 of the Code of Federal Regulations (47CFR). Most Wi-Fi devices are regulated under part 47CFR15.247. This part limits the intentional emissions from devices that operate in the unlicensed Industrial-Scientific-Medical (ISM) bands at 2.45 or 5.8 GHz to a maximum conducted power (power into the antenna) of 1 watt, provided that the gain of the antenna is less than 6 dBi (decibels with respect to an isotropic radiator). Devices with higher gain (more highly directional) antennas have lower limits on conducted power to limit the effective isotropic radiated power (EIRP, which is the input power to the antenna times the antenna gain relative to an isotropic radiator) to 4 W peak.

The emission limits for Wi-Fi devices vary somewhat across the world. Canadian limits are the same as those in the U.S. Limits in the European Union are significantly lower, with a maximum peak EIRP of 0.1 W for Wi-Fi devices operating in the 2.45 GHz band (Standard EN 300328 2006, ETSI 2006) and 0.2 or 1 W for devices in the 5.2 and 5.5 GHz bands, respectively (Standard EN 301893 2007, ETSI 2012). This corresponds to substantially lower power levels, in terms of conducted power, than allowed in the U.S. and Canada.

In the U.S., different devices are governed by different rules in 47CFR, depending on their frequency and modulation characteristics and other factors (see Foster 2013 for a summary). However, most of the common digital communications devices encountered in modern society [including mobile phone handsets, many cordless telephones, and SmartMeters (wireless-enabled utility meters)], are subject to similar limits on peak operating power.

Microwave ovens are another common source of RF energy in the home. While the ovens are designed to keep the energy in the oven, invariably a small amount of RF energy leaks from the seals in the doors. In the U.S., the maximum RF power density outside of a microwave oven is comparable to that from a dipole antenna radiating at about 1 W. However, microwave ovens operate at nearly full duty cycle (while the oven is turned on) as opposed to pulsed operation at low duty cycle, as is the case with Wi-Fi and most digital communications equipment.

In short, Wi-Fi operates under similar power constraints and in similar frequency bands as many other digital communications devices found in the consumer environment; microwave ovens in the home can radiate at similar peak power levels. These devices vary widely in modulation characteristics, pulse widths, and duty cycle of transmission. All are localized sources of energy whose intensity falls off rapidly with increasing distance from the device, which complicates exposure comparisons.

Fig. 1 shows the distribution of operating power (in terms of peak conducted power) of Wi-Fi devices from the FCC Equipment Authorization Database. Most U.S. approved devices operate at levels considerably below the FCC limit (most commonly at 0.03–0.1 W), although some may operate at peak conducted power levels as high as 1 W. The effective isotropic radiated power would be higher by a small factor equal to the antenna gain.

Fig. 1 also shows the rapid increase in number of FCC grants for Wi-Fi devices beginning in the early 2000s as Wi-Fi clients began to be included in laptop computers,

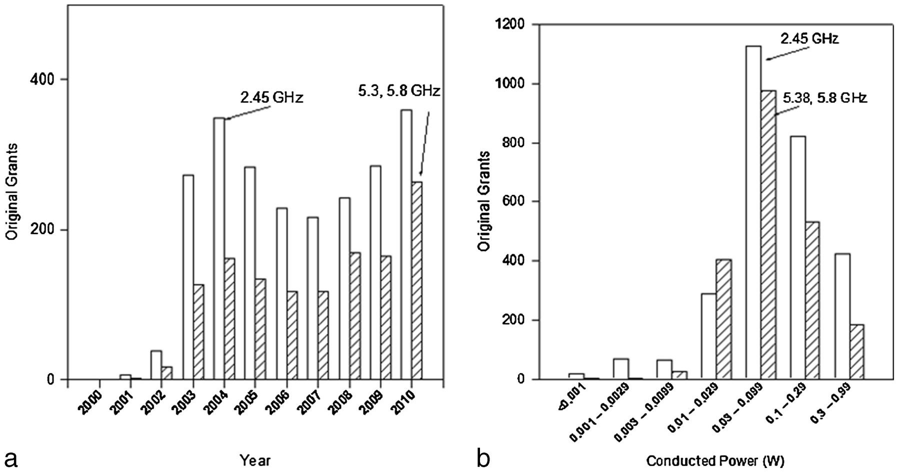

Fig. 1. (a) New FCC grants for Wi-Fi (IEEE 802.11) equipment by year of grant and by conducted power in each of the two frequency ranges (2.45 and 5.3–5.8 GHz) used by the technology in the United States. Each grant refers to one device submitted to the FCC for authorization. (b) Distribution of power in terms of conducted power to antenna for Wi-Fi devices. From the FCC Equipment Authorization database; figures adapted from Foster (2013).

somewhat later in smartphones, and still later in other household devices. This increase parallels the massive shift in communication technology toward digital techniques that has taken place over the past decade. During this period, most of the low-power (Part 15C) devices approved by FCC employ digital communications techniques and transmit RF pulses at similar frequencies and are subject to similar power limits as Wi-Fi (Foster 2013). Presently, the home of a typical middle class consumer in a developed country may have dozens of wireless devices: Bluetooth headsets for phones or Bluetooth enabled keyboards; Bluetooth or ZigBee-enabled devices for remote control of thermostats or entertainment electronics; and Wi-Fi-enabled electronic books, games, or household appliances, such as bathroom scales. All of these devices produce some level of RF exposure to users at levels that vary widely but which are invariably far below U.S. and international safety limits.

Incident power density. The FCC limits on Wi-Fi devices are stated in terms of conducted power from the internal circuits in a device that is applied to the antenna, which (neglecting losses and mismatching of the antenna) is equal to the amount of RF power radiated from the device. By contrast, major international and national guidelines provide exposure limits in terms of absorbed power in the body expressed as the Specific Absorption Rate or SAR in W kg^{-1} (basic restrictions) or as incident power density S (W m^{-1}) that impinge on a person's body (reference levels).

A simple free-space propagation model gives an order of magnitude estimate of RF exposure from a Wi-Fi device. For an antenna radiating power P into free space (neglecting reflections from other surfaces), the power density S at a distance R is

$$S = \frac{PG}{4\pi r^2} = \frac{EIRP}{4\pi r^2}, \qquad (1)$$

where G is the gain of the antenna in the direction of interest relative to an isotropic radiator, and EIRP is the effective isotropic radiated power, which is defined as PG. For a simple lossless dipole antenna that approximates the antenna in many Wi-Fi transmitters, $G = 1.65$. Eqn (1) does not consider reflection of the energy from surfaces or multipath effects, which are significant effects when RF signals propagate through buildings; nevertheless, this free-space model is a reasonable approximation in an indoor environment within a few meters of the antenna (Bach Andersen et al. 2007).

According to eqn (1), a typical Wi-Fi device operating at a conducted power of 0.1 W using a lossless half-wave dipole antenna (EIRP of 0.16 W) would produce a peak field intensity of approximately 330 mW m^{-2} at a distance of 20 cm and about 13 mW m^{-2} at a distance of 1 m. As shown in Fig. 1 and by others (Peyman et al. 2011), most Wi-Fi transmitters operate at considerably lower power levels than this.

Exposure limits. Table 2 compares human exposure limits in effect in the U.S. (FCC) and IEEE and ICNIRP exposure standards at the frequencies used by Wi-Fi. The ICNIRP guidelines have been adopted by most countries; the limits in the U.S. and Canada (and in a few other countries) are based on the similar IEEE standard. The limits in Table 2 are reference levels for whole-body exposure and can be exceeded in both the IEEE and ICNIRP guidelines as long as the basic restrictions are satisfied. For an antenna located very close to the body, a more relevant limit would be the localized SAR (2 W kg^{-1} in the head and trunk in any 10-g contiguous mass of tissue in ICNIRP).

Exposure assessment

RF exposure from Wi-Fi devices in real-world environments. Considerable effort has been spent assessing the real-world RF exposures from WLANs, Wi-Fi -equipped laptops, and Wi-Fi access points, using both experimental measurements (Schmid et al. 2007; Peyman et al. 2011; Lunca et al. 2012) and numerical simulation (Martinez-Burdalo et al. 2009). Several groups have also refined the methodology for exposure assessment from WLANs (Verloock et al. 2010; Bechet et al. 2012) or for developing

Table 2. Exposure limits for RF energy at frequencies used by Wi-Fi.

Limit[a]	Exposure limit W m^{-2}	Averaging time min	Exposure limit W m^{-2}	Averaging time min
	2.45 GHz		5.8 GHz	
FCC Occupational	50	6	50	6
General Public	10	30	10	30
IEEE C95.1-2005 Controlled (equivalent to occupational)	82	6	100	3.4
Uncontrolled (equivalent to general public)	10	30	10	26
QICNIRP Occupational	50	6	50	6
General Public	10	6	10	6

[a] Reference level, plane wave equivalent power density, whole body exposure.

numerical models of WLANs to reduce exposure (Koutitas and Samaras 2010). Because of the nature of the emissions (pulse RF energy with low duty cycle), specialized (and expensive) equipment is required for accurate measurements of RF exposures from Wi-Fi equipment. Inexpensive RF detectors on the consumer market, which typically consist of sensitive peak detectors with audio output (producing sounds reminiscent of Geiger counters), are misleading in several respects.

A 2007 survey by Foster of Wi-Fi signals in diverse environments (offices, shops, healthcare, educational institutions) reported median time-averaged RF power densities in the range of 0.001–0.010 mW m^{-2} at distances of about 1 m from a laptop when its Wi-Fi client was communicating with the network (Foster 2007). Even when the laptop was uploading a large file via file transfer protocol (FTP) to a server at a remote location, the time-averaged power levels that were measured corresponded to duty cycles of transmission from the laptop considerably below 1%, apparently limited by the rate at which the network connected to the WLAN could accept the data. The signal intensity from the devices fell off as the inverse square of distance from the antennas. A recent survey (Lunca et al. 2012) of (peak) RF emissions from laptops and client cards in typical office environments found exposure levels comparable to those expected from Eq. 1. For example, Lunca et al. (2012) reported a peak power density of 54 mW m^{-2} at a distance of 1 m from a Wi-Fi access point operating at 2.45 GHz, which would correspond to an EIRP from the access point of about 0.6 W.

By far the most extensive study of RF exposures from Wi-Fi access points and client cards used in schools in the UK was reported by Peyman and colleagues (Peyman et al. 2011; Khalid et al. 2011). The survey found a mean (peak) power density of about 5 mW m^{-2} at a distance of 1 m from 28 access points or laptops (2.45 GHz) and approximately 2 mW m^{-2} at a distance of 1.5 m from 14 devices (5.8 GHz). These peak field intensities are considerably below those expected on the basis of eqn (1) from a device operating at the European limits of 100–200 mW EIRP (2.45 and 5.2 GHz, respectively), again reflecting the fact that most devices operate at considerably lower levels than allowed by law. [The measurements by Lunca et al. (2012) on a device in Romania suggest an EIRP considerably above EU limits; however, in private correspondence (December 2012), Lunca described the measurements as "preliminary." The device in question is no longer available, preventing an independent check of its operating characteristics in the FCC database.]

In their 2011 study, Peyman et al. surveyed six primary and secondary schools in the UK, in classrooms where students were "logging in and out of the Wi-Fi enabled laptops, [engaging in] web based interactive learning applications, browsing the internet, email applications, file transfers, downloads and video streaming." The duty cycles of transmission from the Wi-Fi client cards in the children's' laptops ranged from 0.02–0.91%; that of the access points in the classrooms ranged from 1.0–11.7%. The investigators estimated that the "maximum time-averaged power density from a laptop would be 220 μW m^{-2} at a distance of 0.5 m, and the peak localized SAR predicted in the torso region of a 10-y-old child model at 34 cm from the antenna would be 80 μW kg^{-1}." Needless to say, these levels are a tiny fraction of UK exposure limits, which are based on ICNIRP.

Recently, Joseph et al. (2013) studied the duty cycle of operation of WLANs (representing the combined emissions from access points and clients) at 179 locations in different environments (urban areas, homes, offices) with users engaged in different activities (surfing news sites, downloading YouTube videos, etc.). The median duty cycle of the WLANs over all of the measurements was 1.4%; but the actual duty cycle varied widely, depending on the network speed and the load on the network. The maximum recorded duty cycle of the WLAN ranged up to 91.4% while a client was sending a large file over a slow network. These duty cycles pertain to all transmissions on the WLAN, not to those of any particular device.

Members of the public often ask about the cumulative exposure that a person receives when using a Wi-Fi device in a room in which multiple users are also accessing the WLAN. Malone and colleagues (Malone and Malone 2009; Fang and Malone 2010) developed and experimentally tested a model to predict the total radiated power from all nodes (including the access point and clients) in a WLAN as a function of the total load on the network. If the network is unsaturated (operating below maximum capacity), the total radiated power is proportional to the load. However, as the usage of the network approaches its maximum capacity (the network becomes saturated), the total radiated power in the WLAN approaches the power transmitted by a single node. This behavior is a consequence of collision avoidance protocols in IEEE 802.11, which are designed to ensure that only one node will transmit at a time.

One can contrive operating conditions in which this limiting behavior does not occur. For example, if every node in the network transmits packets simultaneously without waiting for acknowledgment pulses and without using collision avoidance protocols, the total radiated power in the network would scale roughly as the number of nodes, hypothetically without limit. For a hypothetical group of 500 nodes, each transmitting 0.1 W in broadcast mode, the total radiated power in the WLAN can be as high as 3 W theoretically (Malone and Malone 2009). However, real networks seldom, if ever, operate this way.

Moreover, a network with this many nodes would be spread over a large area, and the average RF power density at any place would be quite low.

In a more possible (but still unrealistic) scenario, with a roomful of schoolchildren all simultaneously uploading large files over a single WLAN, the total transmitted power, summed over all nodes, might approach 100 mW—roughly similar to that radiated by a single mobile phone handset. When downloading files, most of the transmissions will be from the access point, not the students' computers, and any particular device will spend a large fraction of its time waiting for its turn to transmit or for acknowledgment pulses from other devices. In a mixed usage scenario (students browsing web pages, reading and writing email, downloading YouTube videos, touching up Facebook pages, playing online games), only a fraction of the maximum capacity of a network would be used even in a classroom filled with users. Because the network divides transmissions among its various nodes, the RF exposure to the user of a WLAN would consist of sequential exposures from all active devices in the WLAN, most of which are located at some distance from the individual. The level of exposure to individuals in the room, while low with respect to exposure limits, will vary with many factors including the network configuration and location of emitters through the room.

SAR produced by Wi-Fi devices. Findlay and Dimbylow (2010) calculated the specific absorption rate (SAR) produced by Wi-Fi antennas in a child, using the finite difference time domain (FDTD) method and numerical models of a child. For a "a worst case exposure configuration" (Wi-Fi antenna located 3 cm from the face), the maximum SAR over a 10-g contiguous volume of tissue in a 10-y-old child was 817 mW kg^{-1} peak SAR (during a RF pulse). Assuming a realistic 1% duty cycle of transmission, this corresponds to a time-averaged SAR of 8.17 mW kg^{-1}, a factor of nearly 250 below the 2 W kg^{-1} basic restriction in ICNIRP for localized RF absorption.

Other exposure scenarios likewise result in SAR values that are very low compared with the ICNIRP basic restrictions. Parazzini et al. (2010) calculated the SAR produced by a WLAN near a cochlear implant in a person. The investigators reported "localized differences" of up to an order of magnitude in SAR near the implanted electrode array of the implant, compared to the SAR produced in the same location in the head without the implant. However, the actual SAR levels produced by the WLAN were very small compared to the limits. For example, the 99th percentile SAR near the electrodes of the implant was about 90 mW kg^{-1} at 2.45 GHz and 0.3 mW kg^{-1} at 5.8 GHz, assuming an unrealistically high incident RF power density of 10 W m^{-2}.

Most of the studies cited report Wi-Fi exposures under unrealistic worst-case conditions, often in terms of peak power densities (during a pulse) rather than time-averaged values that would be pertinent to hazard assessment. Even with this tendency to overstate exposures compared to real-world levels, the results show that RF exposures from Wi-Fi devices are far below regulatory limits under any plausible exposure scenario.

In summary, engineering studies have shown that: (a) the peak power density from Wi-Fi devices has been well-characterized, both by test data submitted to the FCC and by direct measurements; and (b) the power density averaged over times specified by exposure limits is highly variable, but as a consequence of the low duty cycle of operation, it is always a small fraction of the peak power density. Consequently, the RF exposures to an individual from a WLAN under any realistic conditions will be a tiny fraction of IEEE/FCC or ICNIRP limits. The studies cited above do not consider exposures resulting from direct contact of an individual with the antenna of a Wi-Fi device, but the low operating power and low duty cycle of transmission would seem to guarantee compliance with SAR limits for localized exposures.

Exposures from Wi-Fi networks compared to other sources of RF exposure in the environment. Recently, Joseph et al. have reported extensive surveys of RF exposures in typical (European) environments (Joseph et al. 2010, 2013; Viel 2009a and b). These surveys were conducted using personal RF dosimeters that had tuned filters to sort signals according to the technology that produced them. The dosimeters sampled the ambient RF fields at 90-s intervals for up to 7 d with the subjects located in various non-occupational environments. These studies provide undoubtedly the best available data on the time-average exposures of individuals to ambient RF fields, at least in urban areas in Europe.

Table 3, based on Joseph et al. (2010), compares average RF exposure levels measured in five European countries from various sources in different settings (office, home, car/bus). In this table, "uplink" and "downlink" refer to signals from a cell phone handset or cellular base station; the survey did not measure exposures to users of the handsets themselves (which would be much higher than reported in the Table) but only to bystanders.

In these surveys, the highest time-averaged ambient RF fields were produced generally by mobile phone handsets used by individuals in a room. Wi-Fi contributed only a small fraction to the ambient RF background in the environment at levels below or comparable to those from digital cordless (DECT) portable phones, wireless base stations, and broadcast transmitters from sources outside

Table 3. Range of time-averaged exposures to RF energy in typical environments[a] by technology.

Technology	Frequency, MHz	Range of time-averaged exposures, mW m^{-2}
FM Broadcast	88–108	0.01 – 0.02
TV Broadcast	174–830 (several bands)	0.005 – 0.02
Mobile Phone Downlink (from Base Station)	925–2,170 (several bands)	0.02 – 0.2
Mobile Phone Uplink (from Handset) — Exposures to Other than User	880–1,980 (several bands)	0.05 – 0.9
DECT Cordless Phone	1,880–1,900	0.001 – 0.05
Wi-Fi	2,400–2,475 (and less commonly 5,200 or 5,800)	0.001 – 0.008

[a] Range of averages of many measurements in outdoor locations, offices, trains, cars or busses, and homes in urban areas. Based on Joseph et al. (2010).

the home. They were also comparable to fields from operating microwave ovens in the homes.

Except for FM and TV broadcast, most of the sources of exposure indicated in Table 3 have only become commonplace in modern society within the past decade. It seems that population exposure to RF energy has increased significantly in recent years, and wireless networks represent, by all appearances, only a small part of the total increase.

Some citizens have expressed concerns about possible interference between emissions from Wi-Fi equipment and medical devices. This issue has been investigated extensively, primarily in connection with mobile phone radiation (Carranza et al. 2011), and the issues should be similar. The few confirmed instances of potentially harmful interference to medical devices from mobile phones involve scenarios in which the handset is located very close to the device, which is unlikely to occur with Wi-Fi routers or access points. To avoid the possibility of such problems, medical device companies typically specify minimum separation distances to be maintained between RF transmitters, including Wi-Fi devices, and potentially vulnerable devices such as implantable defibrillators or cochlear implants.

Biological effects

The possible biological effects of RF energy have been investigated by numerous investigators since the 1950s or even before, and now a massive literature exists on the subject. The IEEE ICES database (http://ieee-emf.com/studysearch.cfm) currently lists 4,408 studies of varying relevance covering the range 300 kHz–300 GHz, going back to the late 1950s.

Many earlier studies are not included in this database. This includes a substantial literature from the former Soviet Union and its Warsaw Pact allies, as well as a substantial body of research generated by the Tri-Service program that began in the late 1950s. This program, which was originated and supported by the U.S. military, funded projects in 10 U.S. universities and led to numerous publications (Michaelson 1971). Its goal was to address occupational safety concerns related to the presence of high-powered RF transmitters in many military environments and also to address public concerns about the safety of military transmitting facilities to the nearby population. There is thus a large, very diverse, and uneven literature on biological effects of RF energy, spanning disciplines ranging from biophysics to epidemiology and engineering going back to the mid-20th century and even before.

Until the mobile phone controversy erupted in the early 1990s, the largest number of RF bioeffects studies used exposures in the two ISM bands at 0.915 or 2.45 GHz, using either continuous-wave or pulsed (radar-type) signals with high peak power but low duty cycle. More recently, many studies have been conducted using RF energy in frequency ranges used by mobile phone systems (chiefly at 0.9 or 1.8 GHz), often using modulation characteristics similar to those used by mobile phones (which are quite different from those used by radar).

Consequently, there exists a massive scientific literature on biological effects of RF energy in the same general frequency range used by Wi-Fi, although few studies have used IEEE 802.11 waveforms explicitly. These studies have been analyzed repeatedly by health agencies; for a review and cites of 33 recent expert reviews, see Verschaeve (2012).

The overwhelming consensus of these reviews is that present evidence does not show the existence of health hazards from exposures below present limits (ICNIRP or IEEE). However, in 2011 the International Agency for Research on Cancer (IARC, a component of the World Health Organization) determined that RF fields were a "possible" (class 2B) human carcinogen. According to the decision rules employed by IARC, this indicates some level of suspicion of carcinogenicity with insufficient evidence to conclude that RF fields are "probable" (group 2B) or "known" carcinogens (group A). The IARC decision was based on "limited evidence" for human carcinogenicity based on epidemiology data, "limited evidence" from long-term animal studies, and "weak mechanistic" evidence (Baan et al. 2011). This decision, which was taken in the context of long-term use of mobile phones, has no relevance to possible health effects of Wi-Fi, for which the exposure conditions are very different, nor does it imply a conclusion by IARC that RF fields actually do cause cancer at any exposure level.

Mechanistic considerations. The question of possible health hazards of Wi-Fi and other low level signals turns on whether mechanisms might exist that would produce biological effects of such radiation at exposure levels that are too low to be thermally significant. The biophysical mechanisms of interaction between RF energy and biological systems have been studied intensively since early in the 20^{th} century. Classic studies by physicists and biophysicists such as Peter Debye (1884–1966) (on electrically induced forces on molecular dipoles), K. S. Cole (1900–1984) (on electrical properties of cells at RFs to study membrane characteristic), and Herman Schwan (1915–2005) (on interactions between RF fields and tissues and cells to address a variety of scientific and health-related issues) provided the theoretical understanding of the interaction of RF fields with biological systems. Schwan and Foster (1980), Foster (2000), and more recently Challis (2005) and Sheppard et al. (2008) have published comprehensive reviews of interaction mechanisms as related to biological effects. Others have evaluated the bioeffects literature with respect to possible modulation-dependent effects (Foster and Repacholi 2004; Juutilainen et al. 2011).

The only unequivocal mechanism for bioeffects of RF energy at realistic exposure levels in the low-GHz frequency range involves heating of tissue. Several nonthermal (not heat-related) mechanisms of interaction have been well established and explored theoretically. These are generally related to forces exerted by RF electric fields (and to a much lesser extent, RF magnetic fields) on charges, induced charges, or magnetic dipoles in biological matter. However, quantitative analysis shows that very high field levels (which would be very hazardous thermally) would be needed to produce biologically observable effects through these mechanisms. A few authors have published theories for possible "nonthermal" mechanisms in an attempt to account for biological effects of fields in the GHz range at low exposure levels, but these have been open to challenge on various grounds, typically because the theories are formal and do not yield quantitative predictions or because the perturbations to the system produced at realistic exposure levels would be swamped by far larger levels of random thermal agitation (Foster 2000).

There is thus an extensive understanding of mechanisms of interaction (both thermal and nonthermal) between RF fields and biological systems that comes from research traditions extending back for many decades. Nothing has emerged, however, that would anticipate biological effects from RF fields at levels characteristic of Wi-Fi exposures, which are well below those capable of producing biologically significant heating. "Impossibility" arguments are difficult to sustain in biology; but the lack of a generally-accepted mechanism by which low-level (below ICNIRP and IEEE limits) RF fields in the GHz frequency range could produce biological effects, after many years of sustained efforts to uncover such mechanisms, makes it increasingly unlikely that any mechanism will be found.

Wi-Fi specific studies. A search of the literature for studies that assessed the effects of Wi-Fi exposure on animals and humans directly, focusing on studies that were peer-reviewed and that had well defined exposure systems and dosimetry, resulted in only seven studies (Sambucci et al. 2010; Ait-Aissa et al. 2012a, 2012b, 2013; Laudisi et al. 2012; Poulletier de Gannes et al. 2012; Poulletier de Gannes et al. 2013) that met these criteria (Table 4).

Given this small number, the search was expanded to include studies that were not peer-reviewed or which had apparent technical deficiencies (typically, lacked well defined exposure systems and dosimetry). This yielded an additional six studies (Oni et al. 2011; Papageorgiou et al. 2011; Atasoy et al. 2013; Avendano et al. 2012; Maioli et al. 2012; Maganioti et al. 2010) that are shown in Table 5. While relevant to the topic, these deficiencies limit what can be concluded from them.

All of the studies were evaluated with respect to blinding in exposures and analyses (7/7 in Table 4, 1/6 in Table 4 had explicitly blinded design), whether the possibility of thermal effects had been addressed explicitly (3/7 in Table 4, 1/6 in Table 5), whether they included positive controls (3/7 in Table 4, 0/6 in Table 5) and whether they included sham-exposed controls (7/7 in Table 4, 1/6 in Table 5). These features (blinded design, control for thermal effects of exposure, positive controls, sham-exposed controls) are, in the views of the present authors, minimum requirements for valid studies on bioeffects of RF energy.

All of the studies in the first group (Table 4) focused on the effects of Wi-Fi exposure on fetal and neonatal rats. The endpoints included fertility, pregnancy outcome, fetal and neonatal development, immune system development, brain development, and elevation of stress markers. Dose (SAR) in these studies ranged from 0.08–4.0 W kg^{-1}, all well above real-world Wi-Fi exposures. However, the studies had reasonably long exposure durations (1–2 h per day for 10–50 d).

None of the more than 150 endpoints assessed in the studies in Table 4 showed statistically significant effects.

Table 4. ***In vivo*** **studies of Wi-Fi exposure done with well-characterized exposure systems.**

Source	Model system (endpoints)	Exposure system[a]	SAR (W kg^{-1})	Duration	Outcome	Thermal issues[b]	Blinding[c]	Controls[d]
Laudisi et al. (2012)	Immune system of fetal rats (*n* = 7)	TEM cell (Ardoino et al. 2005)	4	2 h d^{-1}, 26 d	No effects	No	Yes	+positive +sham
Sambucci et al. (2010)	Fetal development and immune system of rats ($n \geq 20$)	TEM cell (Ardoino et al. 2005)	4	2 h d^{-1}, 14 d	No effect	No	Yes	−positive +sham
Poulletier de Gannes et al. (2013)	Fertility and fetal development in rats (*n* = 6)	Reverberation chamber (Wu et al. 2010)	0.8, 4.0	1 h d^{-1}, 30–36 d	No effects	uncertain	Yes	−positive +sham
Ait-Aissa et al. (2012a)	Brain development in fetal and neonatal rats (*n* = 3)	Reverberation chamber (Wu et al. 2010)	0.08, 0.4, 4.0	2 h d^{-1}, 10–35 d	No effects	uncertain	Yes	+positive +sham
Poulletier de Gannes et al. (2012)	Fetal and neonatal development in rats ($n \geq 12$)	Reverberation chamber (Wu et al. 2010)	0.08, 0.4, 4.0	2 h d^{-1}, 18 d	No effects	uncertain	Yes	−positive +sham
Ait-Aissa et al. (2012b)	Immune system in fetal and neonatal rats ($n \geq 15$)	Reverberation chamber (Wu et al. 2010)	0.08, 0.4, 4.0	2 h d^{-1}, 15–50 d	No effects	uncertain	Yes	−positive +sham
Ait-Aissa et al. (2013)	Stress markers in neonatal rats ($n \geq 90$)	Reverberation chamber (Wu et al. 2010)	0.08, 0.4, 4.0	2 h d^{-1}, 15–50 d	No effects	uncertain	Yes	+positive +sham

[a] All done in the 2.4 GHz ISM band.
[b] Could heating of the animals be an issue?
[c] Were exposures and analyses done in a blinded fashion?
[d] Positive controls present (+positive) or absent (−positive); sham-exposed controls present (+sham) or absent (−sham).

Table 5. Studies of Wi-Fi exposure done with incompletely characterized exposure systems and/or in vitro model systems.

Source	Model system (endpoints)	Exposure system[a]	SAR (W kg^{-1})	Duration	Outcome	Thermal issues[b]	Blinding[c]	Controls[d]
Papageorgiou et al. (2011)	Human EEG and performance on attention and memory tasks ($n \geq 30$)	Wi-Fi access point	uncertain	uncertain	Effects on most endpoints	unlikely	unknown	−positive −sham
Maganioti et al. (2010)	Human EEG (*n* = 8)	Wi-Fi access point	unknown	45 min	Some changes in males, none in females	unlikely	unknown	−positive −sham
Avendano 2012; Avendao et al. 2012; Freour and Barriere 2012	In vitro human sperm (*n* = 3)	Laptop computer	unknown	4 h	Decreases sperm mobility and increased DNA fragmentation	probably not	yes	−positive +sham
Oni et al. (2011)	In vitro human sperm (*n* = 4)	Wi-Fi access point + laptop computer	unknown	1 h	Effects on 3 of 4 endpoints	unknown	unknown	−positive −sham
Atasoy et al. (2012)	Testicular oxidative stress in rats ($n \geq 7$)	Wireless gateways	0.091[e]	24 h d^{-1}, 140 d	Oxidative stress in some assays	unknown	unknown	−positive −sham
Maioli et al. (2012)	Gene expression in mouse embryonic stem cells in vitro ($n \geq 40$)	Radioelectric asimmetric conveyer[f]	<0.01	24 or 48 h	Altered expression of most genes	unknown	unknown	−positive −sham

[a] All done in the 2.4 GHz ISM band.
[b] Could heating be an issue?
[c] Were exposures and analyses done in a blinded fashion?
[d] Positive controls present (+positive) or absent (-positive); sham-exposed controls present (+sham) or absent (-sham).
[e] Dosimetry methods not described.
[f] US Patent #7333859 19-Feb-2008 (Rinaldi et al. 2010).

The lack of teratogenic effects is consistent with the vast majority of previous studies on teratogenic effects of RF exposure (Jauchem 2008; Habash et al. 2009; Lee et al. 2009; Ogawa et al. 2009; Sommer et al. 2009; Vecchia et al. 2009; Takahashi et al. 2010), which found few teratogenic effects of RF energy in the absence of significant (a degree or more) increases in body temperature.

It is not clear why the studies in Table 4 focused on fertility and fetal development, as there are no clear biological or biophysical reasons to expect that Wi-Fi or any other type of nonthermal RF exposure would be likely to affect these endpoints. In part, these studies may have been responding to calls by the World Health Organization for reproductive studies with RF exposures, although not specifically with respect to Wi-Fi exposures (van Deventer et al. 2011).

The studies in the second group (Table 5) encompass a much wider range of biological effects, ranging from effects of Wi-Fi signals on human performance and EEG (Maganioti et al. 2010; Papageorgiou et al. 2011) to effects of Wi-Fi exposure on sperm (Oni et al. 2011; Atasoy et al. 2013; Avendano et al. 2012) and on gene expression in embryonic stem cells (Maioli et al. 2012).

Several of these studies reported effects of Wi-Fi-like exposures on human performance (e.g., a decrease in amplitude of the P300 wave in young men and an increase of that in women, while carrying out a task using working memory, interpreted as an effect on performance) or EEG (reduction in alpha and beta waves in female subjects but not in males) (Papageorgiou et al. 2011; Maganioti et al. 2010). Some previous studies have also reported effects of low-level RF exposures other than Wi-Fi on brain activity or EEG, but generally these effects have been small and difficult to confirm independently (Vecchia et al. 2009; Röösli et al. 2010; Kwon and Hämäläinen 2011). Kwon and Hämäläinen (2011) noted that, “The inconsistent findings [with respect to effects of RF fields on the EEG] suggest possible false positives due to multiple comparisons and thus replication is needed.” That recommendation would apply to these studies involving Wi-Fi exposures as well. The possible biological significance of the reported effects (small changes in amplitude of the EEG or P300 evoked response, for example) is unclear in any event. Moreover, interpreting small changes in the EEG associated with RF exposure is complicated by potential artifacts associated with the interaction between the applied RF field and EEG electrodes and to the sensitive amplifiers used with EEG measurement systems (Angelone et al. 2010).

A somewhat related topic is reports in the mass media and on the Internet that Wi-Fi exposure causes subjective symptoms in humans (e.g., headaches, fatigue, skin sensations), an effect popularly called “electrohypersensitivity” or “electrical hypersensitivity” (EHS). No reports were identified in the peer-reviewed scientific literature that examined electrical hypersensitivity and Wi-Fi exposures specifically. However, a number of challenge studies, in which hypersensitive individuals were exposed in a blinded way to RF energy, have demonstrated that such individuals are unable to identify exposure to RF energy at low (not thermally significant) levels (Habash et al. 2009; Vecchia et al. 2009; Baliatsas et al. 2012a and b; Rubin et al. 2005). In addition, the possibility must be considered that the media and Internet reports themselves may lead people to experience these types of subjective symptoms (Witthöft and Rubin 2013).

Several studies in Table 5 reported deleterious effects of exposures to RF energy from Wi-Fi devices on sperm function (Oni et al. 2011; Atasoy et al. 2013; Avendano et al. 2012). This work appears to be driven by the assumption that Wi-Fi laptop computers are actually used on peoples’ laps, and consequently that testes may be exposed to biologically significant levels of RF exposure. That assumption can be challenged for several reasons. First, it is not clear how many people actually use laptops on their laps, in part because many laptops generate an uncomfortable level of heat from the power supply and other circuits not related to RF energy (Sheynkin et al. 2005; Mohr et al. 2007; Paulius et al. 2008). Moreover, the RF exposure to the testes is uncertain. Wi-Fi antennas in a laptop (but not a tablet) are typically mounted inside the upper case of the computer directly beneath the screen, and in use, the case top would be oriented vertically so that the antennas would direct most of their energy away from the body.

The three studies showing effects of Wi-Fi exposure on sperm (Oni et al. 2011; Atasoy et al. 2013; Avendano et al. 2012) were done under very different conditions, with poorly characterized exposure systems, and with doses that ranged from uncertain to unknown (Table 5). Endpoints ranged from sperm motility to oxidative stress. By contrast, the one study of the effects of Wi-Fi exposure on male fertility that was done with a well characterized exposure system found no effects (Poulletier de Gannes et al. 2013). The literature related to effects of low-level RF exposure other than with Wi-Fi waveforms on the testes is diverse and inconsistent and does not make a convincing case for biologically significant effects of RF radiation at levels that do not cause significant temperature increases (Jauchem 2008; Merhi 2012). Before the studies in Table 5 on effects of Wi-Fi on sperm and sperm function can be used in risk assessment, they need to be repeated with better study design including blinding, sham-exposed controls, and better exposure assessment.

A different sort of bioeffects study was reported by Maioli et al. (2012), who exposed mouse embryonic stem cells to “Wi-Fi RF of 2.4 GHz” from an otherwise poorly characterized exposure system said to produce an SAR of 0.128 mW kg^{-1} in the exposed preparation. The pulses were produced by a medical device called a “Radioelectric Asymmetric Conveyer” that was designed to treat psychological stress (Rinaldi et al. 2010). The authors reported up- and down-regulation of numerous genes with a dose (in SAR) that was very small compared to ambient RF exposures from many technologies (as summarized in Table 3). While no other strictly analogous studies have been done with nonthermal RF exposure, similar studies have been done with higher RF doses, and no consistent effects have been found (Habash et al. 2009; McNamee and Chauhan 2009; Juutilainen et al. 2011). As with other effects of Wi-Fi that have been reported in single studies, this study needs to be repeated with a standard exposure system and with blinding and sham-exposed controls.

The same group has published a variety of other studies involving the “Radioelectric Asymmetric Conveyer” device (which members of the group developed and are promoting commercially), with endpoints as diverse as depression in humans and fertility in stallions (Rinaldi et al. 2010; Collodel et al. 2012). Some publications from this group identify the RF energy used in the studies as “RF waves from Wi-Fi,” and the device has output characteristics reminiscent of a Wi-Fi access point (although more recent papers mention output at 10.5 GHz as well). While the work may lead to information relevant to possible health effects of Wi-Fi, the extreme deficiencies in exposure assessment (together with other problems) limit what can be concluded from the work at present.

Biological studies of the different ISM bands. All of the biological studies using Wi-Fi exposures identified in this review (Tables 4 and 5) used the 2.4 GHz ISM band, and none used the 5.2 or 5.8 GHz bands. The major biophysically relevant difference between these frequencies is a shorter penetration depth of energy at the higher frequency; i.e., 0.4 versus 1.1 cm in muscle at 2.45 versus 5.8 GHz (based on Gabriel et al. 1996). There are no other apparent biological or biophysical reasons to expect the biological effects of Wi-Fi radiation to be different for the 2.45 and 5 GHz bands.

Summary of the biological studies. Several studies summarized in Table 5 reported diverse biological effects of Wi-Fi radiation. However, as a group the studies are weak, variously lacking blinding, adequate dosimetry, sham controls, adequately characterized exposure systems, and/or control for possible heating artifacts. The reported effects are also uncertain as to their health significance. With the possible exception of the EEG studies (Papageorgiou et al. 2011) all of the studies in Table 5 that reported effects of Wi-Fi exposure are also inconsistent with similar studies using nonthermal RF exposures of other waveforms.

Nevertheless, despite the apparent weaknesses of the studies, the reported effects from Wi-Fi exposures have been invoked widely on the Internet to justify claims of hazard from the technology, even as they have been given little weight in risk assessments by health agencies and expert groups. The lack of an apparent biophysical mechanism of interaction and the generally negative results of other studies using RF exposures at similar levels as Wi-Fi (Jauchem 2008; Habash et al. 2009; Vecchia et al. 2009; IARC 2011) provide no basis to anticipate that Wi-Fi exposure will cause any biological effects. The overwhelming consensus of health agencies around the world is that RF exposures below international (ICNIRP or IEEE) exposure limits have not been shown to produce any health hazard (Verschaeve 2012). That conclusion would not be changed by the Wi-Fi–related studies reviewed here, some of which indeed were already considered in these expert reviews.

CONCLUSION AND RECOMMENDATIONS

At present, the engineering aspects of Wi-Fi exposure are complex but well understood, and a series of high-quality studies have provided a good (but not complete) understanding of the exposures that these devices produce in users. The biological literature is much more scattered, both in endpoint and in quality. While some effects have been reported, technical limitations in the studies make them difficult to interpret, and artifacts cannot be excluded. The larger bioeffects literature and mechanistic considerations provide no basis to anticipate any biological effects from Wi-Fi exposures in users. However, the body of literature on the topic (considered separately from the far larger body of literature on bioeffects of RF energy in general) is very scant.

The question arises how health agencies should respond properly to public concerns about the safety of Wi-Fi technology. Some research to address these concerns—but not necessarily bioeffects studies—is clearly warranted. A full-scale research program in search of bioeffects of Wi-Fi exposures, such as undertaken with mobile telephones, is neither necessary nor likely to yield useful results. On the other hand, a limited number of biological studies of very mixed quality that pursue a variety of endpoints and are exploratory in nature (the current situation) rather than hypothesis-driven are not helpful either.

If further biological studies of Wi-Fi are to be done, they should be done in vivo, with endpoints that have a plausible connection to human health risk. The lack of any known mechanism for non-thermal effects of RF exposure in the relevant frequency range makes in vitro studies nearly impossible to interpret. The model systems chosen should take into account the limited penetration of Wi-Fi signals in the body; there is little point in evaluating organ systems in rats or mice that are too deep in humans to receive any real exposure from a Wi-Fi device. Studies should also use well characterized exposure systems; actual laptop computers should not be used as exposure systems because of difficulty of exposure assessment and thermal control. Studies should be planned with attention to elements of good study design: blinding, use of positive and sham-exposed controls, adequate dosimetry, and control for thermal artifacts. Rigorous methodology is particularly important in exploratory studies in search of small effects, which is the case of most of the studies reviewed here.

Future studies should use SAR levels and other exposure parameters that are relevant to Wi-Fi, and testing should be done at both the 2.4 and 5 GHz bands. Engineering technology is available to enable well controlled and precisely determined Wi-Fi-type exposures to be carried out, but it is expensive and out of reach for many research groups that might wish to enter the field. Nevertheless, funding agencies and journal editors need to insist on high quality studies with adequate exposure assessment.

The larger problem when planning bioeffects studies with Wi-Fi is the dearth (or arguably, complete lack) of unequivocal biological effects from low-level RF exposures and lack of a biophysical or biological basis for expecting any such effects. Moreover, the large parameter space with Wi-Fi (modulation, pulse parameters, and frequency) and the rapidly evolving nature of wireless networking technology would make it impossible to design comprehensive bioeffects studies that would convince all critics that all bases had been covered. This same problem will arise with other wireless technologies, many more of which are coming in the near future.

Perhaps the most useful approach of health agencies would be to monitor the bioeffects literature carefully. In the increasingly unlikely event that a mechanism for low-level effects were identified or a biological effect at low exposure levels were demonstrated, then a useful research program would be easier to plan. Apart from bioeffects studies, other kinds of studies involving Wi-Fi or other wireless technologies might be desirable and more likely to be productive. In its 2010 research agenda for RF fields (van Deventer et al. 2011), the World Health Organization called for a variety of studies. Among its "high priority" goals are to "assess characteristic RF EMF emissions, exposure scenarios and corresponding exposure levels for new and emerging RF technologies…" With Wi-Fi, this has already been addressed by a number of excellent studies that are summarized above. While more such studies could still be done with Wi-Fi, it is unclear what they could add to the issue. Newly emerging wireless communications technologies might create new exposure issues, however.

Another research goal of WHO is to gain a better understanding of "the determinants and dynamics of RF EMF-related health concerns and perceived health risks." Many wireless devices are already in use apart from Wi-Fi, including many in ordinary residential environments (Foster 2012). These include SmartMeters for utility metering (which are intensely controversial in some areas), Bluetooth and ZigBee devices for remote control of devices, and a host of Wi-Fi enabled devices for Internet access and other purposes. New wireless technologies are emerging, including body-area networks to connect physiological sensors on the body (Hao and Foster 2008) and wireless monitors of human activity for eldercare and other applications (Mo et al. 2012). These new wireless technologies may raise new issues related to risk communication and risk perception that involve RF exposures as well as other considerations.

Finally, it is noted that Wi-Fi and WLANs can raise immediate and urgent safety issues apart from possible RF bioeffects. Wireless networks, depending on how they are configured, are more or less susceptible to privacy invasion and hacking. The Internet, which many individuals access via WLANs, raises a number of safety issues (particularly with children) that have nothing to do with RF exposure. Excessive concern about speculative health hazards from RF exposures to Wi-Fi, without concern for these more immediate potential hazards, is comparable to worry about health effects of using mobile phones without concern for hazards of texting while driving.

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