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Earthlink-Proposed San Francisco-Wide Wi-Fi Network:
Observations and Calculations for Relation to Exposure Limits

Executive Summary

Relative exposure due to the proposed Earthlink Wi-Fi network is calculated to be less than the near-consensus limit of 1 mW/cm^2 for thermal exposure at reasonable distances. Background radiation levels remain unmeasured; field measurements are needed to determine if the addition of this system would drive absolute exposures beyond the limit.

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Modern conveniences enhance nearly every aspect of our daily lives. Wireless video baby monitors keep tabs on our infants. Remotely-operated automatic garage door openers keep us dry when arriving home on a rainy day. Radio-frequency toll tokens allow us to breeze through toll-booths. Are these luxuries truly innocuous, or are there downsides we don't realize? Baby monitor cameras send an unencrypted signal, allowing tech-savvy neighbors a camera in our own homes. Prior to recent safety measures, several children were killed every year by closing garage doors. A log of toll transactions can detail where a motorist has been, when, and how fast he was driving between toll-booths. Yes, life in the current-day is easier than ever, but this life of ease is paid for with our privacy, our safety, and our health.

What is Radiation?

Ask a physicist to explain the nature of radiation and he may say that it is simply energy in motion. This energy is able to travel in many modes, with some interesting characteristics. Since early in the last century, scientists have observed that radiation exhibits the properties of both waves and particles; sometimes particles have the properties of waves and sometimes waves have the properties of particles. This may seem counter-intuitive, but using this theory of 'wave-particle duality' makes the mathematics fit experiment.

Some familiar types of radiation are solar radiation from the sun, infrared radiation from heat lamps, and microwave radiation used by microwave ovens, cellular phones, and Wi-Fi networks. These are forms of 'electromagnetic radiation,' which refers to lower-frequency waves and pseudo-particles generated by changing electrical or magnetic fields. 'Nuclear radiation' refers to high-frequency energy waves and particles generated by structural changes in atoms. Three Mile Island and the currently-debated food irradiation programs are examples which involve nuclear radiation.

These different types of radiation are further classified as 'ionizing' and 'non-ionizing' forms. When a wave with enough energy hits an atom, it can knock a piece off the atom. This particle can in turn hit another atom and knock a piece off of it. In this way, one or many atoms are changed into 'ions' when their electronic charge is changed through the loss. A particle instead of a wave hitting the first atom can also make this change. This is called 'ionizing radiation' and only waves and particles with enough energy, such as gamma rays and x-rays, can change atoms in this way. 'Non-ionizing radiation,' by contrast, occurs at much lower frequencies and does not affect atoms in this manner. The electromagnetic radiation used by the proposed Earthlink San Francisco Wi-Fi network falls into this non-ionizing category.

How is Radiation Measured?

Measuring waves is much like measuring the energy of some everyday objects. Amplitude and frequency or wavelength are enough to define a wave's form. The kinetic energy of a bowling ball is determined by its mass and its velocity. With enough of either, it can knock down a bowling pin. Likewise with a wave, greater energy comes from increased frequency or increased amplitude. Unlike a bowling ball, electromagnetic waves only travel at one speed. It's commonly known as "the speed of light" and is known by physicists as the universe's speed limit because nothing can go faster. Associated with energy and mass, it is represented by the familiar "c" in Einstein's "$E=mc^2$". Because of this speed limit, either the frequency or the wavelength is sufficient in quantifying a wave. The other can be found through the wave equation: Speed = Wavelength * Frequency. Wavelength is specified in any distance measure, usually meters (m). Frequency describes the number of cycles or undulations of the wave every second. The unit for frequency is Hertz (Hz), after a noted scientist. Radio frequency (RF) is the portion of the electromagnetic spectrum between audio and infrared. At the low end around 10 kHz, the waves are kilometers long; at the upper end near 100 GHz, they are only millimeters. Some familiar frequencies are 88 to 108 megahertz (MHz) for FM radio or 900 MHz or 2.4 gigahertz (GHz) for cordless telephones. The proposed Earthlink network operates using frequencies near 2.4 GHz, 5.2 GHz, and 5.7 GHz

Who and what governs these airwaves?

Many organizations have an interest in keeping human use of the electromagnetic spectrum in order. The first in any American's mind is the Federal Communications Commission[A] (FCC). Among other things, they are tasked by the United States government with keeping all broadcasters in-line. From the television station in the largest market to the smallest of household walkie-talkie units, they decide who can transmit what, on which frequency and with what strength. Officially, their interest is in keeping one broadcast from interfering with another. Another U.S. entity is the National Institute for Occupational Safety and Health[B] (NIOSH), charged with trying to keep the workforce working. Accidental exposures to high voltage or harmful radiation concern them. A counterpart across the Atlantic Ocean is the European Committee for Electrotechnical Standardization[C] (CENELEC). The World Health Organization[D] (WHO) is interested in keeping denizens of the planet free from AIDS or starvation, but also safe from possible carcinogens and mutagens, as some radiation can be considered. One last less-familiar group is the International Commission on Non-Ionizing Radiation Protection[E] (ICNIRP). They help to inform the public about radiation by assembling published science into Exposure Guidelines to distribute through the WHO. Even the smallest of governments also participate in control over the electromagnetic spectrum through their grants of right-of-way, contribution of local services and permits for pole space, towers, and antennas. Many thoughtful hands guide electromagnetic waves through the air indirectly.

One of the most direct methods that an agency can use to control radiation is an official regulation. The Code of Federal Regulations[F] (CFR) number 47 addresses some of the FCC's goals. Part 15 of that code number is specific to radio frequency devices. At a sub-national level, state and local governments have the power to affect transmissions through their ordinances. Zonings may restrict placement of transmitters. Housing commissions may disallow antennas. These persons always act with the thoughtful best interest of their citizens, but may not always execute all the stipulations available to them.

Many entities have put forth their ideas about radiation. The FCC's Office of Engineering and Technology (OET) has issued Bulletin 65[G], with guidelines for human exposure to electromagnetic fields. The American National Standards Institute[H] (ANSI) joined with the Institute of Electrical and Electronics Engineers[I] (IEEE) to publish C95.1, most recently updated in 2005. It is titled "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields 3 kHz to 300 GHz". The WHO contributes to scientific knowledge through their Environmental Health Criteria (EHC) Monographs. The EHC numbered 137 addresses "Electromagnetic Fields (300 Hz to 300 GHz)."[J] Europe's CENELEC utilizes ENV 50166-2 finalized in 1995: "Human exposure to electromagnetic fields - High frequency (10 kHz to 300 GHz)." Understanding this plethora of opinions necessitates some calculations.

What limits exist?

The near-consensus limit due to thermal effects for exposure to radio-frequency electromagnetic radiation in the range including 2.4 GHz is generally 1 mW/cm^2, where a milliwatt (mW) is one thousandth of a watt. The prime source cited is the FCC's limitation on radiated power for radio frequency devices, which are outlined in Part 15.247 of CFR 47. Obviously, manufacturers are also concerned about radiation exposure. The Alvarion equipment that Earthlink proposes to co-locate with the Tropos node exhibits this admonition, titled "FCC Radiation Hazard Warning"[K]: *(emphasis added)*

> To comply with FCC RF exposure requirements, the antenna used for this transmitter must be fixed-mounted on outdoor permanent structures with a separation distance of *at least 2 meters* from all persons and *must not be co-located* or operating in conjunction with any other antenna or transmitter.

Single-device exposure for this specified equipment at 2 m is about 32 μW/cm^2, Alvarion's implicit limit. This is about 3% of or 32 times less than the 1 mW/cm^2 limit above. A microwatt (μW) is one thousandth of a milliwatt (mW), one millionth of a watt. For reference, EHC 137 gives the threshold of warmth on human tissue due to thermal effects[L] as 27 mW/cm^2. This monograph also gives an exposure limit of 1 mW/cm^2 and goes on to qualify that as being derived from a Specific Absorption Rate (SAR) of 0.08 W/kg for humans. The limit references "exposure from either continuous or modulated electromagnetic fields from one or more sources, averaged over any 6-min period during the 24-h day."[M] The ICNIRP concurs, with a limit of 1 mW/cm^2 over 6 minutes, with a peak level of not more than 1000 times the average. The ultimate reference for electronics engineers is the IEEE, who with ANSI declare in C95.1 that the limit for 30 minutes exposure to the general population is a function of frequency (f[MHz]/1500). For the Wi-Fi 2.4 GHz, this limit is 1.6 mW/cm^2 . For 5.2 GHz and 5.7 GHz, it would be 3.5 and 3.8 mW/cm^2 respectively. A limit for related equipment is provided by the FDA in their 21 CFR Chapter I, Sub J, 1030.10 Power Limits for Microwave Ovens[N]: 1 mW/cm^2 at 5 cm before purchase, 5 mW/cm^2 after purchase. One of the rare standards with a differing opinion is OSHA's quite old (dated 1966) "Non-Ionizing Radiation" 1910.97(a)(2)(i)[O]. It gives a limit of 10 mW/cm "as averaged over any possible 0.1-hour period." It also states that, "This guide applies whether the radiation is continuous or intermittent."

How much exposure?

Determining *absolute* exposure to radiation is difficult through calculations alone because it is nearly impossible to account for *every* source of radiation, including background. This silent, invisible, but ubiquitous background radiation originates from microwave ovens, cordless phones, laptop computers, radio/television broadcasts, even the sun and cosmic radiation from the Big Bang. San Francisco-specific sources include 138 transmitters on Sutro Tower[P], over 2,500 licensed cellular phone transmitters[Q] at 530 sites[R], public service communications transmitters, and the wi-fi hotspot in every coffee house. Sources even closer in proximity include the laptop in everyone's bag and the phone clipped to everyone's belt. *Relative* exposure, with a few simplistic assumptions, is nearly trivial to calculate. It consists of all the radiation calculated from chosen sources in the environment. All sources not chosen to be included in the calculation are included in the background radiation. Background levels can be determined empirically through taking actual field test measurements with special equipment. Absolute exposure equals relative exposure calculated plus the background exposure measured. Without field tests in the actual equipment environment, relative exposure *increase* is all that can be meaningfully calculated.

The first decision to make when calculating electromagnetic radiation levels is whether to use the equations and assumptions for near-field or far-field propagation. The electromagnetic wave behaves differently very close to its source; although there is some debate, a good demarcation distance is $\lambda/2\pi$. This equals 1/k, where 'k' is known as the "wavenumber." Others put the near-field propagation limit within $\lambda/2$, or half the wavelength. Some say a tenth of the wavelength while others say a full wavelength. For signals at 2.45

GHz, the wavelength is 12 cm (4¾ inches) giving a 1/k near-field transition at 19 mm (¾ inch). Other signals higher frequencies are even shorter. In any case, interest lies in the far-field thus the standard equations apply.

The main equation used is one for the intensity or power density level. The Equivalent Isotropic Radiated Power (EIRP) constitutes the output power of the electronics increased by the gain of the antenna. It is usually specified by the manufacturer in equipment literature. The "equivalent isotropic" part of the radiated power means that we can consider this to be a point source of radiation, thus the power is distributed evenly across a sphere containing the unit. The radius of the sphere is the distance of measurement away from the unit to the test point. For the power density at this distance, divide the EIRP from the antenna by the surface area of the sphere for watts per unit of area. All the following calculations standardize on milliwatts per square centimeter (mW/cm^2) and use this equation[S].

$$Power\ Density = \frac{EIRP}{4\pi r^2}$$

Earthlink proposes roughly 2,200 total node locations on light and utility poles throughout the city[T]. Approximately two thirds of these locations will utilize a Tropos 5210 unit with no other co-located equipment ('node-only'). The Tropos 5210 has a range of EIRPs, with the highest being given as 36 dBm (4 W)[U]. The 1 mW/cm^2 maximum permitted exposure (MPE) range for a node-only installation of 4 W is 18 cm (7 inches). Approximately one third of the total locations[V] will feature both a Tropos unit connected to a subscriber unit (SU) Motorola Canopy 5750SM, 5250SM, **or** Alvarion BreezeACCESS™ VL as the gateway to an area access point (AP). These gateway units have maximum EIRPs of 1 W[W], 1 W[X], and 16 W[Y] respectively. In the best case, there would be only 5 W broadcasting at this location with a gateway and a node; in the worst case, while very unlikely that the full power would be directed at the test point, there would be 20 W. The combined MPE limit radius for 20 W is 40 cm (16 inches) away from the node/gateway co-located installation. Once data has moved from a user to the node, to a gateway, and along to an area AP, it must still get to the Internet at Earthlink's San Francisco point of presence (POP). This traverse from AP to POP is known as "backhaul." The details of the network backhaul are not discussed by any document publicly available. This communication link could be provided via copper, fiber, or even fixed, point-to-point wireless. Should Earthlink choose the wireless option, background radiation measurements will be required to assure that no public areas are exposed to total radiation levels over the proscribed limit.

If an unsuspecting San Francisco resident were sitting on her street balcony for a morning cup of coffee while reading SFGate.com on her laptop computer, she might be a minimum of 5 m (16 ft) from a standard streetlight node location containing only a Tropos 5210. Her *relative* exposure from the common-case node in this scenario would be 1 µW/cm^2. Her laptop is also transmitting back to the node, with the internal laptop antenna 30 cm (1 foot) away. It is transmitting at a strong 20 dBm (100 mW) with a 6 dBi gain antenna for an EIRP of 400 mW. The computer adds 35 µW/cm^2 to the 1 for a total *relative* exposure of 36 µW/cm^2 *in addition to any other radiation she is already experiencing from other sources as described above*.

Every third node location has a gateway co-located. The same resident at the same distance as above now is exposed to the worst-case 20 W node/gateway combination. Her network exposure in this case would be 6 µW/cm^2 due to the network node location. The computer again adds 35 µW/cm^2 to the 6 for a total *relative* exposure of 41 µW/cm^2. This constitutes 4% of the 1 mW/cm^2 limit.

Another San Francisco resident sleeps against an exterior wall facing the street, on the top floor of a mid-rise apartment building. This buildings in his area are in a prime location for an access point and most are an excellent height. The Earthlink project places a Motorola Canopy two-band access point antenna site on the roof of the building across the street. Both buildings are the same height and are 15 m (50 ft) apart. Each of the 14 access points may have up to twelve antennas on a mast, six for each band, arrayed so that their 60 degree coverage will receive from all 360 degrees. Since the Internet operates in two directions, they are also capable of transmitting the same levels as the subscriber units described above. If the resident is in the center of the main lobe of one of the six antennas, he is also receiving some exposure from the antennas on either side of that one. Add a very small amount radiating from the back side of the antenna pointing directly away and the resident could conservatively be experiencing an effective two total antenna radiation amounts. Scattering dissipates some of the signal and losses through a brick wall can be around 4 dB. Combined with any infrastructure in the wall and interior wall treatments, a reasonable attenuation might be as much as 8 dB. In fact, wireless link providers recommend wireless modems for indoor use of this proposed system. With two bands transmitting and two effective antennas in the equation, the total would be (2 bands) * (2 effective antennas) * 1 W each = 4 W. After incorporating the wall attenuation, this resident would have a relative exposure of 22 nW/cm^2. A nanowatt (nW) is a thousandth of a microwatt (μW) and a billionth of a watt. Recall that exposure decreases proportionally to an inverse square of the distance. Again, this 0.0022%-of-limit exposure is relative and must be added to what the resident is already receiving.

A city employee works at a desk with a wireless router near his keyboard. His office is on the other side of the wall from the break room microwave. His router transmits an EIRP of 18 dBm. At 60 cm (2 feet) away, that constitutes 1.4 μW/cm^2. Add that to the microwave, which is at its FDA limit (2 dBW) of 5 mW/cm^2 at 5 cm distant. The microwave is 2 m (6.5 feet) away, but the emission also experiences loss through the wall of 10 dB. The exposure would be 3 μW/cm^2, but 0.3 μW/cm^2 with the wall. Together, that's 1.7 μW/cm^2 above what he is already receiving from background radiation.

In each of these situations, the calculated relative exposure is low, but the absolute exposure is still uncertain. Exposure from all sources is what the limit aims to curtail. Without direct measurements in the actual environment, total exposure and relation to the limit remains unknown.

Conclusion

The relative exposure that would be presented by the proposed Earthlink network does not approach the near-consensus thermal-exposure limit of 1 mW/cm^2. It may, however, contribute to the existing background radiation sufficiently to place the total RF exposure over that limit. Only field measurements can determine whether the network would push absolute exposure levels above the limit or whether the limit is already exceeded in some publicly accessible locations in San Francisco.

Endnotes

A. Federal Communications Commission http://www.fcc.gov/oet/rfsafety
B. National Institute for Occupational Safety and Health http://www.cdc.gov/niosh
C. European Committee for Electrotechnical Standardization http://www.cenelec.org
D. World Health Organization http://www.who.int/peh-emf/en
E. International Commission on Non-Ionizing Radiation Protection http://www.icnirp.de
F. Code of Federal Regulations http://www.gpoaccess.gov/cfr
G. http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf
H. American National Standards Institute http://www.ansi.org
I. Institute of Electrical and Electronics Engineers http://www.ieee.org
J. Available at: http://www.inchem.org/documents/ehc/ehc/ehc137.htm
K. Alvarion BreezeACCESS™ VL Subscriber Unit Quick Installation and System Manual
L. WHO EHC 137 Table 30: "Cutaneous Perception in Humans"
M. WHO EHC 137 Table 35: "IRPA General Population Exposure Limits for RF Fields"
N. http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=1030.10
O. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9745#1910.97(a)(2)(i)
P. Sutro Tower Antenna Inventory as of 05 December 2006
Q. San Francisco Planning Commission 2004 Inventory of Existing Cellular Antennas
R. San Francisco Planning Commission Wireless Telecommunications Services Guidelines Presentation
S. Benson, H. 1991. University Physics. Wiley & Sons, New York. pp. 348-349
T. Categorical Exemption from Environmental Review; Project Case Number 2007.0097E: San Francisco Citywide Wireless Broadband Internet Access Network
U. Tropos 5210 Outdoor MetroMesh™ Router datasheet
V. Categorical Exemption from Environmental Review; Project Case Number 2007.0097E: San Francisco Citywide Wireless Broadband Internet Access Network
W. Motorola Canopy 5750SM Specifications Sheet
X. Motorola Canopy 5250SM Specifications Sheet
Y. Alvarion BreezeACCESS™ VL datasheet: 21 dBm (1/8 W) (max at antenna port) with a 21 dBi antenna

Also:

Committee on Man and Radiation (COMAR) http://www.ewh.ieee.org/soc/embs/comar/
National Council on Radiation Protection and Measurement (NCRP) http://www.ncrponline.org
Bioelectromagnetics Society http://www.bioelectromagnetics.org
European BioElectromagnetics Association http://www.ebea.org