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Electrical Engineering & Computer Science Practice

Radiofrequency Fields in the Environment and from Advanced Metering Infrastructure

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Prepared for

British Columbia Utilities Commission

At the Request of

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Acronyms and Abbreviations

AM	Amplitude modulated
CDMA	Code-division multiple access
EIRP	Equivalent isotopically radiated power
FM	Frequency modulated
FSK	Frequency-shift-keying
Gateway	Sensus FlexNet Gateway
GSM	Global system for mobile communications
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
ISED	Innovation, Science and Economic Development Canada
MHz	Megahertz
MoM	Middle-of-minute
ms	Millisecond
mW/cm^2	Milliwatts per square centimeter
RF	Radiofrequency
SAR	Specific absorption rate
SC6	Safety Code 6
SentryPoints	Sensus FlexNet SentryPoints™
SmartPoints	Sensus FlexNet SmartPoint® modules
Sonix IQ gas meter	Sensus Sonix IQ™ advanced meter
W	Watts
W/cm^2	Watts per square centimeter
W/kg	Watts per kilogram
W/m^2	Watts per square meter

Limitations

At the request of FortisBC Energy Inc. (FEI), Exponent prepared this summary report on the types of common environmental exposures to radiofrequency electromagnetic fields and exposure to FEI advanced metering infrastructure. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Executive Summary

Similar to other utility companies (both electric and gas) throughout Canada and the United States, FortisBC Energy Inc (FEI) is in the process of modernizing their infrastructure with the proposed upgrade of natural gas meters as part of the Advanced Gas Meters project. Similar to the existing meters, these new meters will record gas consumption over time and will have the added ability to communicate that usage information through a dedicated wireless network. The gas meters will be battery-powered and in addition to communicating gas consumption information, will also allow FEI to remotely detect and respond to gas leaks, including a remote shutoff capability in the event of an emergency.

FEI has selected the Sensus USA Inc. Sensus Sonix IQ™ advanced meter (hereafter, Sonix IQ gas meter) as the equipment to upgrade the gas metering system. The Sonix IQ gas meter will be a component of the FlexNet communication network that operates on a dedicated licensed portion (approximately 900 Megahertz) of the radio spectrum, a different type of operation than the FEI electric meter network, which operates in a license-free mesh network.

The purpose of this report is to describe the radiofrequency (RF) signal technology used by the FlexNet network. The Sonix IQ gas meter is the component of the network proposed to be most widely deployed, so the analysis focuses on the Sonix IQ gas meter, but the report also provides information about RF exposure levels from other components of the FlexNet network and how the exposures from these components compare to RF limits from Health Canada Safety Code 6 (SC6). In addition, this report provides context by describing some other RF sources encountered in daily life from both natural and man-made sources and compares the relative strength of these natural and man-made sources to those of the network components.

In typical operation, the Sonix IQ gas meter transmits RF energy for a total of approximately 0.34 seconds per day. This very low transmission time also means that the exposures in general are also low, especially the indoor RF exposure from the Sonix IQ gas meter, which is about 24 million times below the SC6 exposure limit, and substantially less than RF exposures from common natural and man-made sources.

1. Basic Physics of Electromagnetics

There are many natural and man-made sources of electromagnetic fields. Although not widely recognized, naturally occurring visible light is one of the most common electromagnetic fields to which we are exposed every day. Man-made electromagnetic fields include extremely low frequency sources such as the fields from power transmission and distribution lines, as well as higher frequency sources that are associated with transmission of radio and television broadcast signals and various wireless personal communication devices.

The primary defining characteristic of electromagnetic fields is their frequency. The frequency of an electromagnetic field is determined by the number of times it oscillates (i.e., changes direction) each second, and frequency is what governs how these fields interact with humans.[1]

Electromagnetic Waves

Electromagnetic waves are intuitively difficult to understand since most are invisible to the human eye and cannot be heard, tasted, touched, or smelled. Water waves, on the other hand, are quite familiar and can be used through analogy to illustrate some of the relevant properties of electromagnetic waves. For instance, when one drops a rock in a pond, the rock creates a water wave, which expands outward from the source. The wave propagating on the surface of the pond does not actually carry water molecules with it, rather the wave spreads to adjacent water molecules (propagates) when adjacent water molecules move up-and-down. The wave with the highest amplitude (i.e., height above the pond's surface) is at the source, and as it spreads outward, the height of the waves gets successively smaller. Figure 1, taken with a high-speed camera, illustrates how the up and down motion of the wave is highest at the source and diminishes as it expands outward.

[1] Both electromagnetic fields and electromagnetic waves are used concurrently in this report depending on which is more intuitive and more readily understandable, but in all instances, their meaning is the same.

Figure 1. Illustration of the concept of wave energy movement from a source.

Electromagnetic waves are made up of individual electric fields and magnetic fields and, similar to water waves, as electromagnetic waves propagate away from the source, the amplitude (i.e., the strength of the constituent electric and magnetic fields) decreases.

The Electromagnetic Spectrum

Although often assumed to include only radiofrequency (RF) fields, the electromagnetic spectrum in fact includes all forms of electromagnetic fields. As shown in Figure 2, electromagnetic fields are broadly classified as either *non-ionizing radiation* or *ionizing radiation*.[2] *Non-ionizing radiation* in the radio portion of the electromagnetic spectrum includes RF broadcast signals from amplitude-modulated (AM) and frequency-modulated (FM) radio stations and from television broadcasts, while light from the sun or from a flashlight are common examples of electromagnetic fields in the visible portion of the electromagnetic spectrum. These non-ionizing fields are described in the left side of Figure 1, shaded in light blue. The microwave (sometimes included in the definition of RF) and infrared portions of the electromagnetic spectrum fall between the radio and visible portions of the electromagnetic spectrum. All these non-ionizing fields are too weak to break the bonds within atoms or

[2] The term radiation simply means "energy propagated through space." It is used to describe energy emitted from any particular source such as heat from a campfire, light from a flashlight, acoustic energy from a stereo system, or the broadcast signal from an FM radio antenna (http://er.jsc.nasa.gov/seh/e.html#electromagnetic radiation and http://er.jsc.nasa.gov/seh/r.html#radiation).

molecules. In contrast, *ionizing radiation* such as from X-rays or gamma rays (described in the right side of Figure 1, shaded in purple) is strong enough to break molecular or atomic bonds.[3]

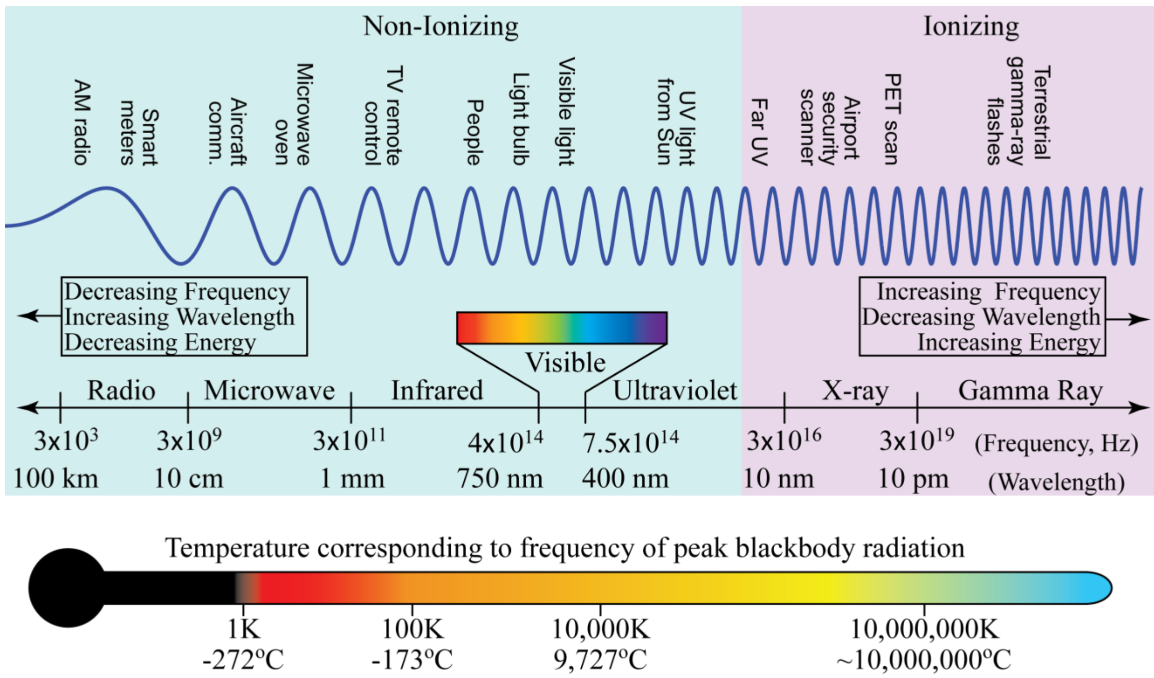

Figure 2. The electromagnetic spectrum and the relationship between frequency, wavelength, energy, and temperature.

Common Sources of Electromagnetic Fields

Technologies such as broadcast transmissions, radar, cell phones, and Wi-Fi are some of the most common man-made sources of electromagnetic fields, but in fact natural sources of RF are far more common and include lightning, the earth itself, and even other organisms, including humans.

The concept that the earth and humans, as well as virtually all objects, are sources of electromagnetic fields warrants additional attention. Extremely hot objects such as the sun produce electromagnetic fields primarily in the visible and ultraviolet portions of the spectrum,

3 http://www.who.int/ionizing_radiation/about/what_is_ir/en/

while colder objects such as the earth produce fields primarily in the infrared portion of the spectrum. This phenomenon is called thermal radiation or heat radiation, while scientists refer to it as blackbody radiation.

Blackbody Radiation

Any object (i.e., blackbody) that has a temperature above absolute zero[4] gives off electromagnetic energy; the temperature of the object determines the frequency at which most of the electromagnetic energy is produced. Hotter objects emit both more energy and energy at higher frequencies than colder objects.

Blackbody radiation from man-made sources

An electric stove provides a good example to illustrate how electromagnetic energy emitted by a blackbody changes at colder and hotter temperatures. When the stove burner is first turned on, it begins to heat up and produces stronger electromagnetic fields in the infrared portion of the spectrum than in the visual portion. This means that the burner still appears the same (black) but the electromagnetic energy can be felt by placing a hand nearby and feeling the infrared heat. As the burner gets hotter, it begins to glow reddish-orange, which is electromagnetic energy in the lower part of the visible spectrum. Household burners cannot heat beyond this point; however, if the temperature did increase further it would begin to glow a yellowish-white color (in the higher portion of the visible spectrum). At still hotter temperatures, such as from a welder's torch, the light would become bluish (the highest part of the visible spectrum), and at even higher temperatures, the light from the welder's torch would be in the ultraviolet range.[5] The same description applies to a gas-stove burner but the transition to blue light is more rapid.

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4 Absolute zero is the temperature at which the motion of molecules theoretically stops, which is 0 on the Kelvin scale and equivalent to about -273 degrees Celsius or about -460 degrees Fahrenheit.

5 The emission of this intense heat and ultraviolet light are among the reasons that welders wear protective glasses when performing their work.

Blackbody radiation from natural sources

As noted above, any object that has a temperature above absolute zero radiates electromagnetic energy and it does so at all frequencies (although very small amounts at very low or very high frequencies). Since humans and the earth both have a temperature of ~300 Kelvin, most of their emitted energy is in the infrared portion of the electromagnetic spectrum (i.e., it can be seen with the use of infrared imaging devices), but a very small portion of that energy is also emitted in the radio and microwave portions of the electromagnetic spectrum. Humans and the earth are therefore sources of RF energy (albeit very small sources).

Radiofrequency Communications

RF fields are an integral part of modern technology, particularly wireless communications; they are used in emergency beacon services, air traffic control systems, cell phones, and advanced metering infrastructure, to name a few. RF fields are also widely used in scientific research and many more industrial, commercial, medical, and personal applications. In addition to frequency discussed above, **power, duty cycle, modulation, frequency, reflection, and attenuation** are concepts common to most RF communication systems including the Sensus Sonix IQ™ advanced meter (hereafter, Sonix IQ gas meter) and associated FlexNet End Points supplied to FEI for their proposed gas network by Sensus USA Inc. (Sensus). These concepts are therefore discussed in greater detail below.

Power

The importance of power transmitted by devices is obvious; higher output power leads to higher RF signal levels and thus higher potential RF exposure. The other factors are discussed in greater detail below.

Duty Cycle

An important way man-made sources differ from one another is how often and in what patterns they transmit. Some sources transmit all the time at relatively constant power levels (e.g., FM radio and television broadcasts), while others transmit all the time but vary as to how much power is transmitted (e.g., Wi-Fi routers, AM radio). Intermittent operation is used by technology that only transmits based on data transfer needs and user demand. For example, advanced meters transmit only when they need to transfer data; cell phones transmit based both on user demand and when they interact with the mobile network; and microwave ovens only produce RF fields when they are used.[6]

RF exposure to a particular source based on transmission patterns can be simplified into the source's "duty cycle." Duty cycle is determined as a percentage of time the source transmits information. For example, sources that transmit continuously, whether at constant or varying power, have a duty cycle of 100%. The duty cycle of a device that utilizes an intermittent transmission pattern can be reported as either an operational duty cycle or an average duty cycle.

Since AM/FM radio and TV transmitters transmit continuously, they have a 100% duty cycle. The duty cycle of a Code Division Multiple Access (CDMA) cell phone, however, will vary based on how often the owner of the phone uses it—a 6-minute CDMA cell phone call in a 30-minute period has as an *operational* duty cycle of 20%, while a 1.5-minute call in a 30-minute period has an *operational* duty cycle of 5%.[7] Global System for Mobile (GSM) is another communication protocol commonly used by cell phones in Canada. Rather than transmitting continuously, a GSM phone transmits only $1/8^{th}$ of the time (but generally at 8 times the power of a CDMA transmission). The duty cycle of the *RF transmission signal* from a GSM phone call is therefore 12.5%. For 6-minute GSM phone call in a 30-minute period, the total duty cycle is the product of the *operational* duty cycle and the duty cycle of the transmission: 20% × 12.5% = 2.5%. The FlexNet End Points send very short transmissions (typically about 55 milliseconds) at regular pre-programmed intervals of once every 4 hours. As discussed in more detail in Section 3, the typical duty cycle is 0.00039% (about 0.34 seconds per day).[8]

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6 Some cell phones may also change transmission power output based upon circumstances, while all the FlexNet End Points always transmit with the same power output.

7 When a call is made on a CDMA cell phone, it transmits continuously. This calculated *operational* duty cycle example should not be confused with the *actual* duty cycle of the emission of a CDMA cell phone.

8 This information was provided by Sensus.

Modulation and Carrier Frequency

Radio broadcasting provides an easily understood example of the concepts of modulation and carrier frequency. The call number of the radio station, such as 88.1 FM or 690 AM in Vancouver, is actually a designation of the carrier frequency (i.e., the carrier signal). The frequency is modulated (i.e., changed) in order to send information on the carrier signal. In AM radio, the frequency of the signal is constant and the amplitude (i.e., strength) of the signal varies (as shown in Figure 3a).[9] This variation in strength is a code that the receiver (i.e., the radio in your car or home) decrypts to receive the information. In FM radio broadcasting, the strength of the signal is constant and the frequency of the signal varies (as shown in Figure 3b).[10] In this case, the variation in frequency is the code for information transfer.

In digital transmission, frequency-shift-keying (FSK) is a modulation scheme where, similar to FM, the frequency of the signal varies, but the variation is only between discrete frequencies (as shown in Figure 3c).[11] The amplitude of the signal in an FSK-modulated system (such as used by FlexNet End Points) does not depend on the transmitted information since only the frequency of the signal varies. This is important in an RF exposure assessment because it means the output power of an advanced meter does not change (it is either on or off) when transmitting.[12]

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9 http://www.its.bldrdoc.gov/fs-1037/dir-002/_0277.htm

10 http://www.its.bldrdoc.gov/fs-1037/dir-016/_2377.htm

11 http://www.its.bldrdoc.gov/fs-1037/dir-016/_2347.htm

12 This is in contrast to many cell phones in which the power output of the phone may vary from one call to another and even within the same call.

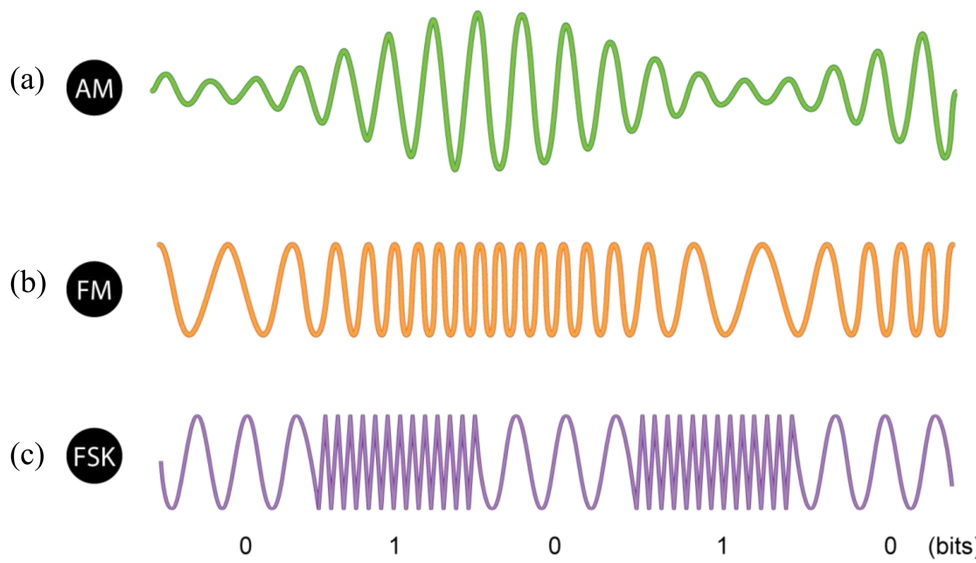

Figure 3. Examples of theoretical AM, FM, and FSK-modulated signals.

Reflection and Attenuation

When an electromagnetic wave reaches a boundary (such as the ground or a wall), part of the energy from the wave will reflect from that boundary and some will be transmitted through (attenuated to a lower level). The amount of energy reflected and the amount that passes through depends both on the frequency of the electromagnetic wave and on the material properties of the boundary.

The building materials of an individual's home therefore can have a significant effect on a person's RF exposure from external sources. For example, at the frequency of FlexNet communications or cell phones, a 20-centimeter-thick concrete wall allows less than 1% of incident RF energy through; a 9-centimeter-thick brick wall allows about 45% of the energy through; and a 1.9-centimeter-thick plywood wall allows over 80% of the energy through (NIST, 1997).[13]

[13] At lower frequencies, such as those used in television or radio broadcasting, the fraction of energy that passes through these materials is substantially higher.

Distance from the Source

While a boundary will cause some of the energy in an electromagnetic wave to reflect and attenuate, the signal strength also diminishes with distance from the source, even if the wave does not pass through any material that causes it to lose energy. This attenuation is due simply to the expansion of the wave, similar to the motion of a water wave described above. When the electromagnetic wave is transmitted, a finite amount of energy is released at the source. As the wave expands, this same amount of energy is spread out over a larger and larger area so that the amount of energy in any particular location decreases as the wave gets farther from the source. The power density of the RF field decreases with the square of the distance from the source according to the inverse-square law.[14] So, an individual located 10 meters away from a source will be exposed to 100 times less RF energy than an individual located 1 meter away from the same source.

[14] A discussion of the inverse square law specific to the FlexNet End Points is provided in Section 3.

2. Health Canada Safety Code 6

History of Safety Code 6

Health Canada is the Canadian federal agency responsible for setting limits on human exposure to RF energy. The health risk assessment of RF exposures performed by the agency and its limits are summarized in Safety Code 6 (SC6). The purpose of SC6, originally published by Health Canada in 1991, is to *"establish safety limits for human exposure to radiofrequency (RF) fields in the frequency range from 3 kHz [Kilohertz] to 300 GHz [Gigahertz]"* (p. I) to protect workers and the general public[15] from RF fields. Innovation, Science and Economic Development Canada (ISED), formerly Industry Canada, published standards for certifying equipment that meets SC6 limits and methods for demonstrating compliance (ISED, 2015a, 2015b, 2015c, 2016).

Since its initial publication, Health Canada periodically updates SC6 as new scientific literature becomes available; these updates published in 1999, 2009, and 2015 include a number of revisions with new versions, and each time give consideration to reviews of scientific research prepared for Health Canada by panels of scientists convened by the Royal Society of Canada (RSC, 1999, 2001, 2007, 2009, 2013). As stated in SC6 (2015):

> *The exposure limits specified in Safety Code 6 have been established based upon a thorough evaluation of the scientific literature related to the thermal and non-thermal health effects of RF fields. . . . The exposure limits in Safety Code 6 are based upon the lowest exposure level at which any scientifically established adverse health effect occurs. Safety margins have been incorporated into the exposure limits to ensure that even worst-case exposures*

[15] The standard discussed in this report is designed to protect the general public including "*[i]ndividuals of all ages, body sizes and varying health status, some of whom may qualify for the conditions defined for the controlled environment in certain situations*" (p. 13). SC6 also applies separate guidelines for persons in controlled environments (e.g., certain workplaces, not discussed herein) where RF fields have been characterized, persons are aware of high strength RF effects, and they can apply mitigation strategies to avoid potential exceedance of exposure limits.

> *remain far below the threshold for harm. The scientific approach used to establish the exposure limits in Safety Code 6 is comparable to that employed by other science-based international standards bodies. … At present, there is no scientific basis for the occurrence of acute, chronic and/or cumulative adverse health risks from RF field exposure at levels below the limits outlined in Safety Code 6. The hypotheses of other proposed adverse health effects occurring at levels below the exposure limits outlined in Safety Code 6 suffer from a lack of evidence of causality, biological plausibility and reproducibility and do not provide a credible foundation for making science-based recommendations for limiting human exposures to low-intensity RF fields (pp. 1–2).*

RF Exposure Limits

The limits for human exposure to RF are specified as Basic Restrictions by SC6. The Basic Restriction is measured in terms of the specific absorption rate (SAR), which is the rate of RF-energy absorption by bodily tissues. Estimating or measuring the SAR from a particular source is quite complex and is not easily accomplished outside a controlled laboratory environment. Therefore, to simplify the safety assessment, SC6 developed Reference Levels in units of power density (e.g., watts per square meter [W/m^2]) that are easy to compute and measure for a comparison to safety limits.[16] SC6 also notes that "*safety factors have been incorporated into the exposure limits*" to ensure that demonstrated health effects are avoided and that "*[t]he protection factors … are a factor of 10 (controlled) and 50 (uncontrolled)*" (RSC, 2014).[17]

Other organizations such as the Institute of Electrical and Electronics Engineers (IEEE) and the European-based International Commission on Non-Ionizing Radiation Protection (ICNIRP)

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[16] SC6 also notes that "*[w]hile compliance with the basic restrictions is required, non-compliance with the reference levels does not necessarily mean that the basic restrictions are not respected. In such cases, additional measurements or calculations may be required to assess compliance*."

[17] As noted above, Health Canada provided SC6 revisions in 2009 and 2015. The basic restrictions (i.e., SAR limits) in both standards are the same, only the reference levels in the 2015 edition have been changed to provide a more conservative level at which comparison with Basic Restrictions is required.

similarly developed exposure limits for electromagnetic fields based on lengthy and comprehensive assessments of the scientific literature. The SC6 limits for the general public at frequencies of FlexNet transmissions (approximately 900 Megahertz [MHz]) are summarized in Table 1, along with the current IEEE and ICNIRP standards. To determine compliance of either SAR or power density limits with SC6 limits, the source exposure must be averaged over a 6-minute period.

Table 1. Exposure reference values and limits specified by SC6, IEEE, and ICNIRP at 900 MHz

	Reference Level Power Density		
Agency	**(W/m^2)**	**(mW/cm^2)**	**Basic Restriction SAR Limit (W/kg)**
Health Canada SC6 (2015)	2.7	0.27	0.08 (whole body) 1.6 partial body, (over any 1 gram of tissue) 4 (over any 10 grams of tissue in the limbs)
ICNIRP (2020)	4.5	0.45	0.08 (\whole body) 2 (partial body, over any 10 grams of tissue) 4 (over any 10 grams of tissue in the limbs)
IEEE, C95.1 (2019)	4.5	0.45	0.08 (whole body) 2 (partial body, over any 10 grams of tissue) 4 (over any 10 grams of tissue in the limbs)

mW/cm^2 = milliwatts per square centimeter; W/m^2 = watts per square centimeter; W/kg = watts per kilogram; and 1 mW/cm^2 = 10 W/m^2.

3. FlexNet Network and Sonix IQ Gas Meter

Information about all aspects of the design and operation of the FlexNet network were provided to Exponent by Sensus including transmission schedule, duration, modulation and protocol, as well as meter antenna pattern, number of endpoints, and base stations, etc.

The FlexNet communication network operates on a dedicated licensed radio spectrum, which differs from some other network architectures, such as the FEI electric meter network, that operate using a mesh network. Among other benefits, the use of a dedicated licensed portion of the radio spectrum limits external interference sources and limits how often data need to be communicated from individual meters. Each individual meter or module (collectively referred to as End Points) communicates directly with a base station (i.e., it does not relay messages from one device to another) and messages from the meter or module to the base station or vice versa are sent using very brief transmissions.

There are two versions of the FlexNet communication protocol, both of which use short messages of approximately 55 milliseconds and each End Point communicates on a fixed schedule, most typically every 4 hours. The Sonix IQ gas meter communicates using FlexNet version 2 protocol—a spread-FSK type modulation—while all other End Points (discussed in greater detail below) communicate using the FlexNet version 1 protocol—an FSK modulation. An overview of the FlexNet architecture is shown in Figure 4, which indicates that the residential gas meters are installed at the residence, while the other elements of the network are generally located very far from residences.

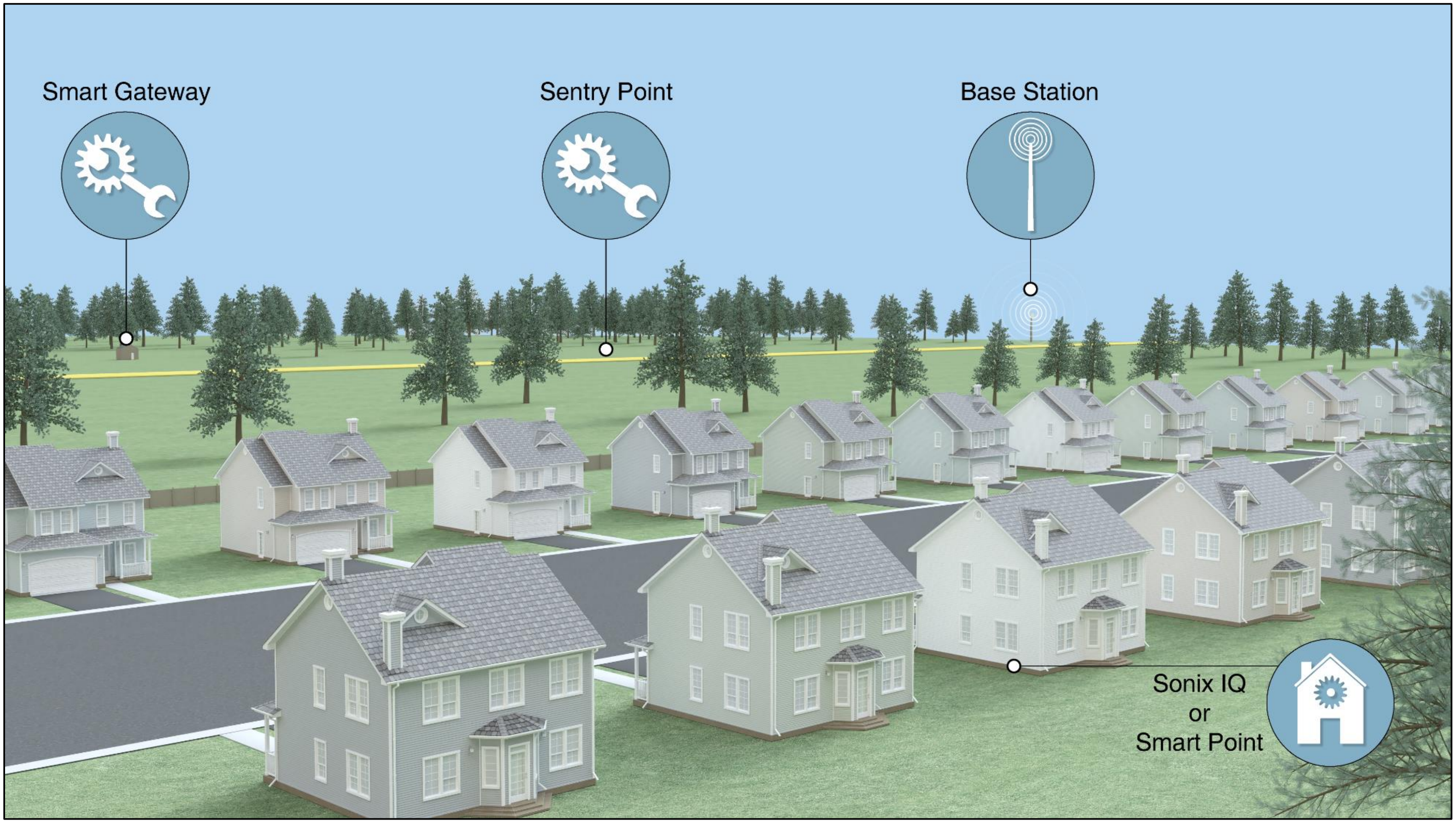

Figure 4. Illustrative overview of the Sensus FlexNet communication network.

End Points

As discussed above, FEI proposes to use several different types of End Points throughout the FEI gas service territory; these End Points will be connected together through the Sensus FlexNet network. There are four primary devices to be deployed:

- Sonix IQ gas meters;
- Sensus FlexNet SentryPoints™ (hereafter SentryPoints);
- Sensus FlexNet Gateways (hereafter Gateways); and
- Sensus FlexNet SmartPoint® modules (hereafter SmartPoints).

Sonix IQ gas meters are proposed to constitute more than 90% of the approximately 1 million End Points anticipated to be deployed. The focus of the assessment is therefore on the Sonix IQ gas meters, but information regarding the other End Points is provided as well. The following list provides a brief introduction to each End Point, and each is also discussed in greater detail below.

- Sonix IQ gas meters are the residential gas meters that will comprise the vast majority of the total FlexNet End Points. These units communicate customer usage data once every 4 hours.
- SentryPoints (cathodic protection units) will be installed far from residences and businesses on gas pipelines to collect and record data to monitor cathodic protection systems on the pipelines. SentryPoints communicate data once every 6 hours.
- Gateways are stand-alone, battery-powered radio transceivers that will be attached to a variety of sensors and equipment (also generally far from residences and businesses) to allow them to remotely connect with the FlexNet network. These devices typically communicate data once per hour, but can be programmed to transmit as often as once per minute.
- SmartPoints will be mounted directly on existing gas meters in cases where the existing meter will not be replaced with a Sonix IQ gas meter. SmartPoints communicate customer usage data once every 4 hours.

Sonix IQ Gas Meter

The Sonix IQ gas meter is a residential gas meter that operates using ultrasonic sound to measure gas flow and has an integrated communication system, an enclosed battery, and an automatic shutoff option. These meters generally will be mounted outside residences or other buildings and will run on the FlexNet version 2 protocol. Similar to the other End Points, the Sonix IQ gas meter will communicate bi-directionally, directly with a base station, on a pre-defined schedule.

Since the FlexNet network uses a licensed band with limited bandwidth, it is important that not all meters transmit at the same time. If all meters transmitted simultaneously, messages could interfere with one another and get lost in the noise. Therefore, each Sonix IQ gas meter is configured to transmit every 4 hours on a pseudo-random schedule of ±20% of the transmission period, which results in a constantly shifting but regular transmission schedule. Using the 4-hour transmission period, for example, if a transmission occurs at 4 AM, the next transmission will occur during a window 48 minutes before to 48 minutes after 8 AM (i.e., 7:12 AM to 8:48 AM), and so on.

It is estimated that in addition to the transmission sent every 4 hours for data reading, approximately three extra status messages will be sent in a given week. The duty cycle of the Sonix IQ gas meter is therefore highly regular and controlled. The maximum duty cycle will occur during the initial installation of the Sonix IQ gas meter at which time it will connect with the base station and establish itself as part of the network. During this process, the meter will send seven different messages, each three times, and these transmissions will occur spaced every 2 minutes. This results in a maximum of 21 messages sent over the course of 42 minutes. This only occurs once when the meters initially connect to the network.

SentryPoints

FEI monitors the operation of safety systems, called cathodic protection, installed to protect gas pipelines from corrosion using SentryPoints. The purpose of these units is to measure and collect data at points of installation to provide that data to central monitoring locations that can evaluate the data and check on the operation of the protective voltage cathodic protection system. SentryPoints represent only a small fraction of the total End Point units. Additionally, unlike Sonix IQ gas meters, these units are not installed at residences.

As discussed above, the SentryPoints will communicate using the FlexNet version 1 protocol. Since cathodic protection needs to be addressed over year-long timescales, data are not required as often, so SentryPoints will communicate with the base station at 6-hour intervals (i.e., four messages each day). The version 1 protocol also uses very brief transmissions occurring on a pseudo-random schedule of ±20% of the transmission period. For example, if transmission occurs at 12:00 AM, the next transmission would occur during a window 72 minutes before to 72 minutes after 6 AM (i.e., 4:48 AM to 7:12 AM), and so on.

Gateways

Gateways are battery-powered communication devices that will be attached to sensors or other units in the field and serve as a hub to connect those sensors (for instance in locations without a power source) to the FlexNet network so that the data provided are available without sending personnel to read the instruments. Gateways are capable of transmitting and forwarding alarms to utility systems or individuals. Approximately 10,000 Gateways are proposed to be installed throughout the system (generally away from residences or buildings), so represent only a small fraction of the total units.

Because the Gateways can be connected to a variety of different sensors, they can also be configured to read and transmit that data at a variable rate. The most common read/transmission rate is expected to read data every 15 minutes and transmit data every hour, but they can be configured to read data every 12 seconds and to transmit every minute.[18] Similar to SentryPoints, Gateways will operate using the FlexNet version 1 protocol with very brief transmissions sent on a schedule based upon ±20% of the chosen transmission period, similar to that described above for the SentryPoint.

SmartPoints

SmartPoints are communication devices that can be mounted directly on existing gas meters in cases where the existing meter will not be replaced with a Sonix IQ gas meter. SmartPoints generally will be located outside residences or other buildings and will operate on the FlexNet version 1 protocol, but will otherwise operate almost identically to the Sonix IQ gas meters with an hourly read schedule and a 4-hour transmission schedule. Approximately 24,000 existing gas meters are expected to need a SmartPoint rather than being replaced with a Sonix IQ gas meter.

Base Station

While approximately 1 million End Points will be installed, the amount of data and total transmission time from the End Points is low enough that only approximately 170 base stations are required to collect the transmitted data. Each base station will be custom engineered for the area in which it is installed (e.g., urban, suburban, rural). They are designed to be mounted high above the ground (typically 20 meters high or more) on poles, towers, buildings, and other structures, similar to existing cell tower installations. The majority of base stations will transmit

[18] Since these are battery-powered units, the limiting factor in transmission schedule is battery lifetime. A unit that transmits once per hour will have a lifetime between 8.7 and 12.25 years (depending on how many sensors are connected). A unit that transmits once per minute will have a lifetime of between 2 to 3 months.

equally in all directions (isotropic antennas), although some will transmit only in specific directions (directional antennas), and each is designed to communicate with up to approximately 60,000 End Points.

While the End Points transmit very infrequently, as described in more detail below, the base stations will typically send four messages per minute with a minimum of one message per minute for synchronization of devices.[19] While the base stations transmit much more frequently than the various End Points, there are very few of them and they are all located tens of meters above ground. Base stations operate at similar power levels as many cell phone transmitters, but there will be only 170 in the entire FEI network area compared to approximately 68,000 cell phone transmitters at more than 6,900 locations throughout British Columbia (see Appendix A, Figure A-1).[20] The relatively short transmission times and limited number mean that base stations will contribute little to overall RF exposures.

RF Characteristics of End Points

End Point Transmission Parameters

Information about the power and gain of the End Point antennas is available from regulatory filings. RF certification documents are available online with each end point assigned a unique identifier code as summarized in Table 2. The effective radiated power of these devices is the product of the power applied to the antenna and the gain of the antenna. All End Points have an equivalent isotopically radiated power (EIRP) of 2 Watts (W) or less.

[19] There is a separate dedicated radio channel used for critical data like alarms, which would be used infrequently.

[20] Source: Government of Canada Spectrum Management System Data (http://sms-sgs.ic.gc.ca/eic/site/sms-sgs-prod.nsf/eng/h_00010.html); SCADACore Canadian Cell Tower Map (https://www.scadacore.com/tools/rf-path/cell-tower-map-canada/). Accessed April 27, 2021.

Table 2. RF certification summary of FlexNet End Points

FlexNet Device	ISED Identification No.	Federal Communications Commission Identification No.	Power (W)	× Gain =	EIRP (W)
Sonix IQ Gas Meter	2220A-SONIXIQV2	SDBSONIXIQV2	0.982	1.995	2.0
SentryPoint	2220A-BHRM100	SDBBHRM100	0.813	1.585	1.3
SmartPoint	220A-GFL3	SDBGFL3	0.776	1.585	1.2
Gateway	2220A-SGW100	SDBSGW100	0.893	1.585	1.4

End Point Duty Cycle

In the FlexNet network, each End Point transmits a fixed amount of data during each transmission on a highly regular transmission schedule. This in turn means that the duty cycle of each End Point is well defined and controlled. The typical duty cycle and total transmission time per day for all endpoints is summarized in Table 3. During typical operation, the Sonix IQ gas meters transmit only for about 0.34 seconds per day total, with similarly short total transmission times for the other End Points. The total transmission time remains very short, even under the maximum expected duty cycle when an End Point goes through startup and connection to the network (see Appendix B, Table B-1).

Table 3. Transmission time and duty cycle of FlexNet End Points under typical operation

End Point	Seconds per day	Duty Cycle (δ)
Sonix IQ Gas Meter	0.34	0.00039%
SentryPoint	0.23	0.00026%
SmartPoint	0.36	0.00042%
Gateway	1.40	0.0016%

Example RF Exposure from End Points

Using the information in Table 2 and Table 3, it is possible to calculate the RF exposure from the various End Points at any particular distance based upon the formula:

$$S = 2.56 \frac{PG}{4\pi R^2} \delta TF \qquad \text{(Equation 1)}$$

where *S* is the power density of a signal at a distance *R* from the transmitter, with an input power *P*, an antenna gain *G,* and a duty cycle of δ. A transmission coefficient, *T*, can be used to account for any applicable attenuation or reflection from boundary materials, and the factor *F* can be used to account for the preferential transmission of a signal forward away from the device rather than backward.[21] Finally, the factor of 2.56 is used to include the potential reflection of the signal from the ground that may increase the exposure above that calculated using the standard inverse square law.[22] In order to calculate the RF exposure from the various End Points, it is therefore necessary to know the power and gain of the antenna as well as the duty cycle (other factors, such as distance *R* and transmission coefficient *T*, depend on a particular exposure scenario).

Using this approach, the RF signal from a Sonix IQ gas meter at several distances both indoors and outside a building for a typical duty cycle was calculated for a variety of exposure scenarios (see Appendix B, Table B-2). As an example, the indoor exposure was calculated at a distance of 1 meter behind the Sonix IQ gas meter using a typical duty cycle of 0.00039%. This calculation accounts for the preferential transmission in the forward direction so that the amount of energy directed toward the residence is approximately one-tenth that transmitted away from the residence. The calculation also accounts for attenuation of the signal when passing through the walls of the structure (assumed in this example to be plywood and drywall, which absorbs

[21] Sensus measurements demonstrate that the power transmitted in the backward direction (e.g., indoors) is approximately 1/10th of the power transmitted in the forward direction.

[22] This factor of 2.56 is sometimes applied to far-away sources such as television or radio broadcast signals (ISED, 2015c) and is not generally applicable to the signal from the end points. It is included here, however, to conservatively overestimate the RF exposure from the various FlexNet end points.

about 26% of the signal).[23] Similar estimates also were calculated for the other End Points for outdoor exposure at a distance of 1 meter in front of the unit at a typical duty cycle. The calculated power density (*S* in the second to last column in Table B-2) is calculated using Equation 1 above and then converted to a percent of the SC6 limit using the appropriate value (i.e., as listed in Table 1).

These calculations show that for the typical duty cycle (one transmission every 4 hours) at a distance of 0.25 meters immediately in front of the Sonix IQ gas meter, the RF exposure would be approximately 13,000 times below the SC6 limit. At the maximum duty cycle (during the one-time meter startup and network connection), at a distance of 0.25 meters immediately in front of the Sonix IQ gas meter, the RF exposure would be approximately 1,000 times below the SC6 limit.

At a distance of 1 meter behind the Sonix IQ gas meter (indoors) and a typical duty cycle (one transmission every 4 hours) the exposure would be approximately 24 million times below the SC6 limit. At distances greater than 1 meter, where persons would be expected to spend more time, exposures are far lower. Results for the SmartPoints are similar, but lower than the Sonix IQ gas meter, and exposures from the more distant SentryPoints and Gateways (e.g., outdoors and 10 meters away) range from approximately 60 to 400 million times below the SC6 limit.

[23] Both indoor and outdoor calculations also include a conservative ground reflection factor of 2.56 (ISED, 2015c).

4. Sources of Radiofrequency Fields

There are numerous natural and man-made sources of RF fields. As discussed in the Introduction, some of the natural sources of RF fields are produced by blackbody radiation from warm objects such as the earth and humans; the representative RF exposure values for these natural sources are summarized in Table 4. Common man-made devices include those used for communications and many other purposes. Communication devices used in the home, such as cell phones, Wi-Fi, and Bluetooth devices produce relatively weak fields; however, they are often used in very close proximity to the individual and may therefore result in higher exposures than remote (but more powerful) sources such as radio or television broadcast signals. Other devices . like microwave ovens and radar guns, use RF fields for non-communication purposes such as heating food or measuring speed and distances.

The frequency and representative RF exposure values for some common man-made RF sources are also shown below Table 4. Table 4 provides an estimate for the specific exposure conditions listed, but it is important to recognize that there are wide variations in each of these estimates based on different exposure scenarios. It is also important to note that a majority of sources listed in Table 4 operate continuously or at the very least operate for substantially longer time periods than the few seconds per day the Sonix IQ gas meters will transmit. While Table 4 provides a list of some of the common sources, it is only a very small subset of all RF sources. Figure A-2 in Appendix A shows the many hundreds of RF communication bands, as defined by ISED, used in modern society, all of which have the potential to contribute to electromagnetic field exposure.

Table 4. Frequency and representative RF exposure values for common man-made RF sources[24]

Source	Frequency (MHz)	Reported Value (% of SC6 Limit)*	Exposure Conditions
Blackbody radiation from the earth	0.003 – 3,000	0.009	Typical
Blackbody radiation from humans	0.003 – 3,000	0.018	Typical
Cell Phone	800 – 1,900	5 – 12†	Personal Call
Cordless Phone / Handheld Unit	1,880 – 1,900	0.5 – 3.8	Handheld Unit
Wi-Fi	2,400 – 2,484	0.00007 – 0.75	Typical
Bluetooth	2,400 – 2,484	0.002 – 0.31	At 0.25 – 3 meters
Microwave Oven	2,450	0.01 – 2.4	At 1 meter

* RF exposure is presented as a percentage of the SC6 limit to keep these exposure values both consistent and accurate. The SC6 limit is defined as the applicable SAR limit, wave power density limit, or square of the field magnitude limit, all for uncontrolled environments. Both whole body exposure and spatial peak SAR for the head are used where appropriate.

† An average value based upon Abdulla and Badra (2010) is approximately 7.6% (*see* e.g., Figure 5).[25]

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[24] RF exposure can be heavily dependent upon situation, so exposure conditions are provided for each exposure value. For reference, see Mantiply et al. (1997); Foster (2007); Valberg et al. (2007); HPA, (2008); ICNIRP,(2009); Viel et al. (2009); and Abdulla and Badra (2010).

[25] The Abdulla and Badra (2010) study covers phone calls that typically result in higher exposure than texting or data services because these modes of operation generally have lower power output, lower operational duty cycle, and the device is used at greater distance from the head and trunk than phone calls.

5. RF Exposure Comparisons

Evaluating RF Exposure

Sections 3 and 4 discuss the typical RF power and transmission characteristics of various network End Points and various common natural and man-made sources, respectively. These data can be used to describe the power density from the various sources, but the *exposure* of a person involves not just how much energy is absorbed by a person, but also how long or how often that absorption occurs. Although a full RF exposure assessment requires the evaluation of the total RF exposure of a person to all RF sources in his or her environment, such an analysis generally needs to be done on an individual basis, or somehow limited to assess the potential contributions of particular sources. Examples below show the relative strength of various potential exposures but do not constitute full exposure assessments.

Example Exposure Scenarios

The discussion in Section 3 provided example RF calculations for the FlexNet End Points and Section 4 detailed other common natural and manmade sources of RF fields. Comparison of these results shows that End Points in the FlexNet network are both very low power and also operate very infrequently. As a result, the RF exposure from these devices will be extremely low. To illustrate this further, Figure 5 shows a graphic comparison of exposure from a Sonix IQ gas meter to exposures from other common RF sources. The exposure of each source relative to the SC6 limits (sorted from smallest to largest) is shown beneath a graphic of each source, as well as the factor describing how much larger that exposure is than the exposure from a typical Sonix IQ gas meter. This figure demonstrates that not only does the RF exposure from a Sonix IQ gas meter inside a residence represent a tiny fraction of the SC6 allowable limit, but that the exposure from other sources both inside and outside a residence are many times greater than that from the Sonix IQ gas meter.

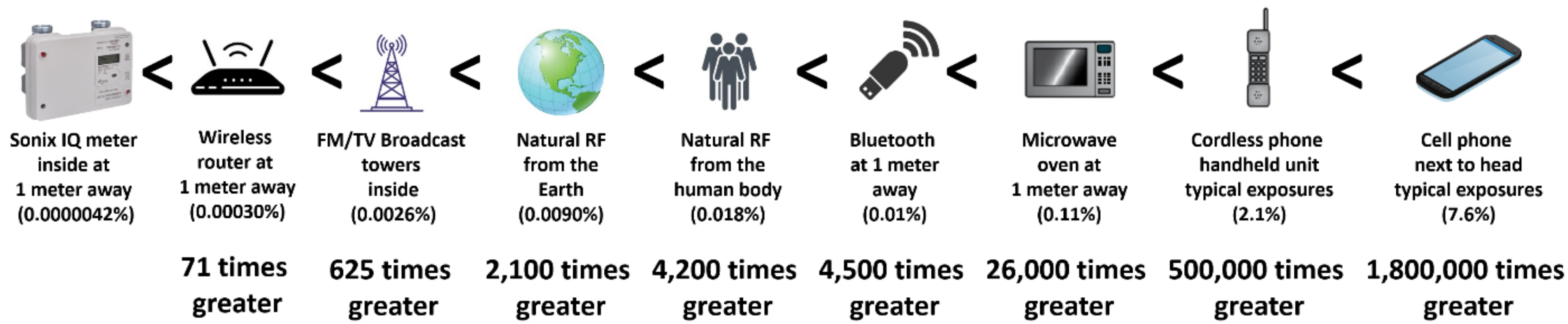

Figure 5. RF exposure of a Sonix IQ gas meter relative to other RF sources.

The RF exposure as a percentage of SC6 limits is shown beneath each graphic in parentheses and a comparison of how much greater each exposure is than that from a Sonix IQ gas meter is shown below that in bold font.

The comparison of exposures shown in Figure 5 represents a simple comparison of some of the relevant potential exposures. A more detailed description is shown below in Figure 6 in which RF exposures are plotted as a percentage of the SC6 limit in a bar graph. In order to show the very small exposure sources on the same scale as the larger exposure sources, the results are presented on a logarithmic scale where each vertical tick in the axis represents an increase by a factor of 10. The graphic is divided into two sections. The portion labeled *RF Exposures in General Environments* shows the general background of RF energy encountered in rural, suburban, and urban environments, and is included to provide context of typical background levels reported in peer-reviewed literature (Joseph et al., 2012). The portion labeled *Typical RF Sources* compares the RF exposure from each of the items shown in Figure 5. In Figure 6, scenarios for the Sonix IQ gas meter are shown for potential exposure outdoors, as well as potential exposure outdoors from the other FlexNet network components. A black line shows the example cell phone exposure is 1.8 million times higher than typical indoor exposure from a Sonix IQ gas meter. Full details of the RF exposure calculations for the End Points are provided in Appendix B, Table B-2.

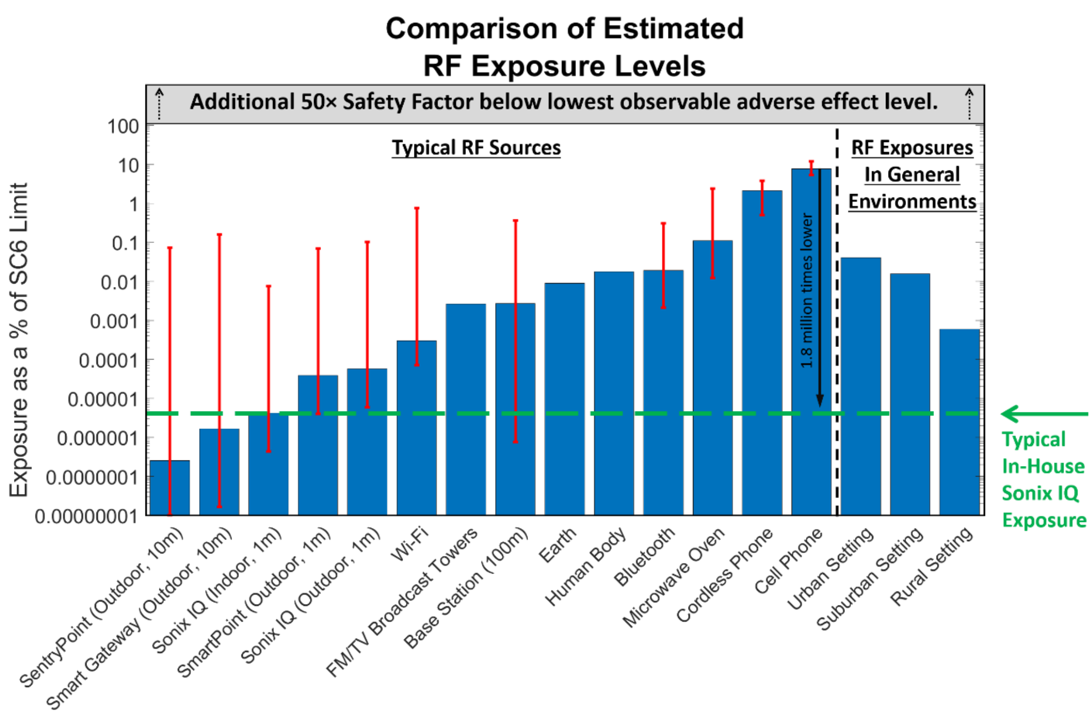

Figure 6. Comparison of RF exposure from End Points to other sources under typical use. The red lines show variability of some man-made sources. Exposures in general environments are from Joseph et al. (2012). Other data sources are from those listed for Table 4.

A red line is shown overlaid on the bar for most man-made sources in Figure 6 to provide an indication of the potential variability in the exposures for these sources. As an example, the exposure from the Sonix IQ gas meter (both indoors and outdoors) is detailed in Appendix B, Figure B-2. The "Indoor, 1m" exposure (third bar from the left in Figure 6) is calculated inside the building at a distance of 1 meter behind the gas meter using a typical duty cycle of 0.00039%. In addition, this calculation accounts for the Sonix IQ gas meter preferentially transmitting in the forward direction so that the amount of energy directed toward the residence is approximately one-tenth of that transmitted away from the house. The calculation also accounts for attenuation of the signal when passing through the plywood and drywall from the walls of the example residence (only about 74% of the signal passes through the combination of plywood and drywall).[26] Similar variability estimates are also provided for other man-made sources based on the peer-reviewed references detailed in Table 4.

Additional Discussion

The RF exposure from the communication of Sonix IQ gas meters is extremely small due to the low power output and very infrequent transmissions. The transmissions are so infrequent and so short that for the approximately 0.34 seconds of transmission per day (*see* Table 3) of the Sonix IQ gas meters, it will take more than 2 years and 5 months (~890 days) until the gas meter transmits for the same amount of time as a 5-minute call on a cell phone.

Another way to put into context the very low total exposure level is to compare the RF power density indoors from a typical Sonix IQ gas meter (i.e., 0.00000011 W/m^2)[27] to a well-known source. The CBC television broadcasting station in Vancouver (call sign CBUT-DT) operates at a frequency of about 600 MHz and a transmitter power of 88.5 kilowatts.[28] Using the same approach as described in Equation 1 above, it is possible to calculate the distance at which the average RF power density from the CBUT-DT broadcast station is the same (indoors) as the

[26] Both indoor and outdoor calculations also include a conservative ground reflection factor of 2.56, as noted in ISED (2015c).

[27] *See* Appendix B, Table B-2.

[28] https://www.fcc.gov/media/television/tv-query. Accessed April 27, 2021.

indoor exposure from the gas meter; a distance as far as approximately 340 kilometers.[29] In other words, residents of British Columbia from Vancouver nearly to Castlegar are currently exposed to a greater power density from the Vancouver CBUT-DT television broadcast station than they would be 1 meter away from a Sonix IQ gas meter installed outside their home.

[29] The CBUT-DT television broadcast station does not transmit the same power in all directions. The maximum transmission power occurs in a direction due east of the station. https://www.fcc.gov/media/television/tv-query. Accessed April 27, 2021.

6. Conclusions

This report describes the basic physics of RF fields in general and outlines characteristics of RF fields important for understanding human exposure to these fields. It also includes a detailed description of the potential exposure to the various End Points of the FlexNet communication network with a focus on the Sonix IQ gas meter, which will constitute approximately 90% of all installed End Points. The report also describes a variety of natural and man-made RF sources and provides a comparison of the potential RF exposure levels from these sources in relation to the Sonix IQ gas meters, as well as to the SC6 limit.

Under typical operation, the Sonix IQ gas meter transmits RF energy a total of approximately 0.34 seconds per day. This very short transmission time also means that the indoor RF exposure from the Sonix IQ gas meter is about 24 million times lower than the SC6 exposure limit, and substantially lower than the RF exposures from common natural and man-made sources. The typical exposure from other End Points are still lower, and hence all End Points of the proposed FEI network will result in exposure levels millions of times lower than the SC6 exposure limit.

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Appendix A

Number of Cell Phone Base Stations and Radiofrequency Usage Spectrum Chart (ISED)

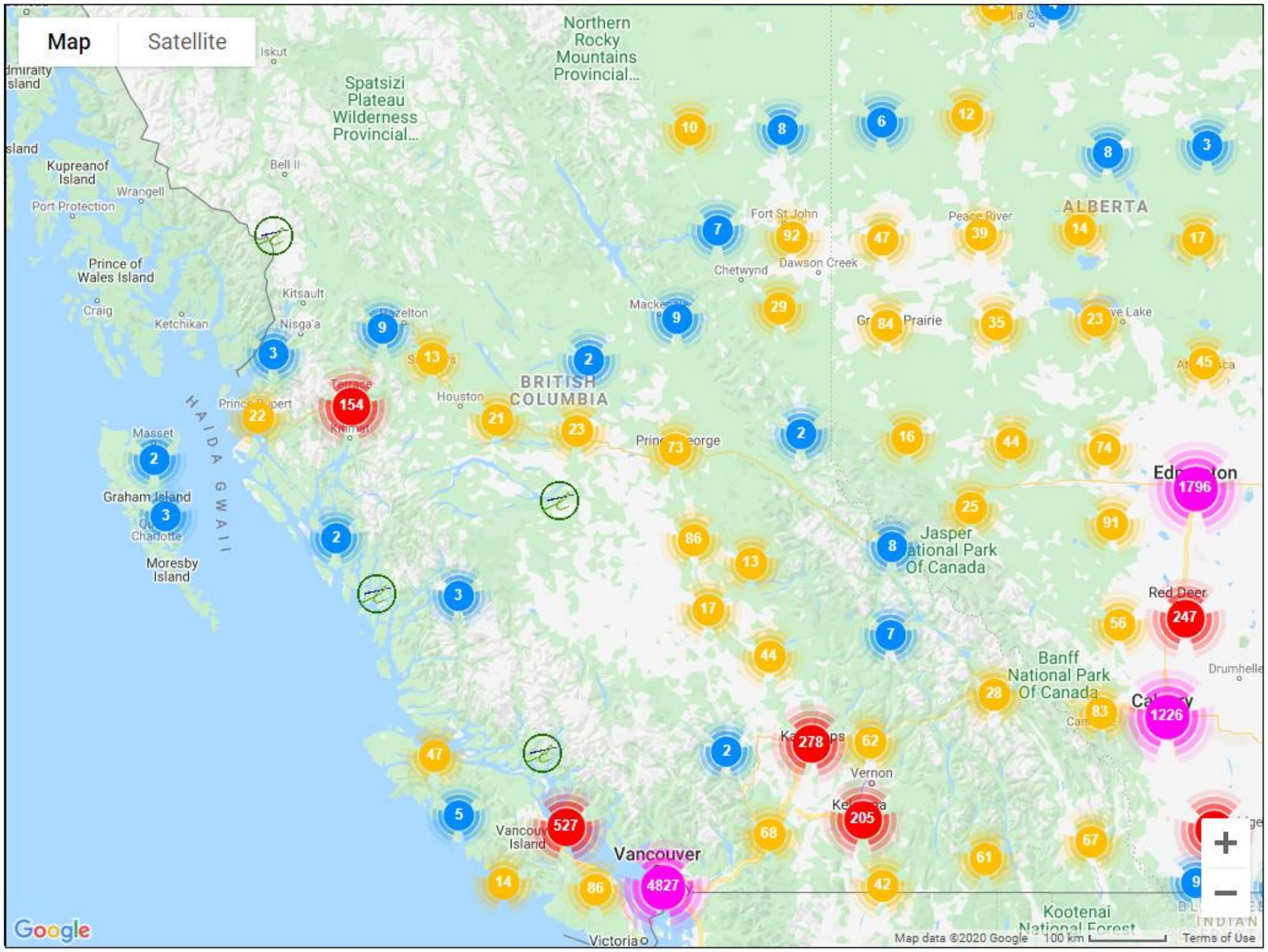

Figure A-1. Locations of cell towers in British Columbia.

Source: Government of Canada Spectrum Management System Data (http://sms-sgs.ic.gc.ca/eic/site/sms-sgs-prod.nsf/eng/h_00010.html); SCADACore Canadian Cell Tower Map (https://www.scadacore.com/tools/rf-path/cell-tower-map-canada/). Circles indicate the number of cell towers in the specified geographic region. Accessed April 27, 2021.

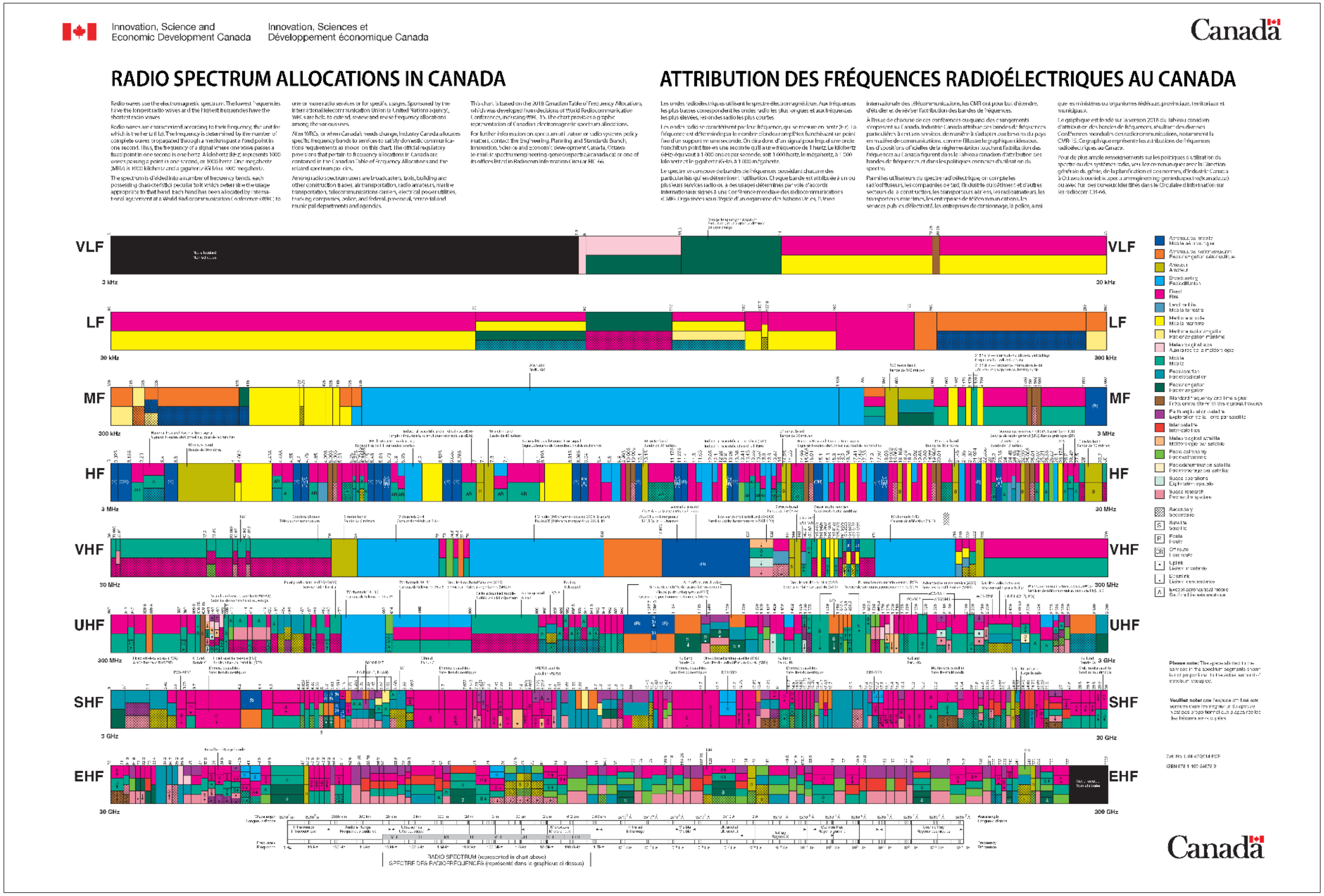

Figure A-2. Radio Spectrum Allocations in Canada.

Source: ISED. https://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/2018_Canadian_Radio_Spectrum_Chart.PDF. Accessed April 27, 2021.

Appendix B

Example Exposure Calculations for FlexNet End Points

As discussed above, the Sonix IQ gas meter sends one message that lasts 52.48 milliseconds every 4 hours, while the message length of the remaining End Points (SentryPoint, SmartPoint, and Smart Gateway) is a similarly short at 56.7 milliseconds (though each transmits on a different schedule). The message length, duty cycle, and total transmission times per day are summarized in Table B-1.

Table B-1. Duty cycle of FlexNet End Points*

		Typical Operation†		Short-Term Maximum§	
End Point	Message Length (millisecond)	Duty Cycle (δ)	Seconds Per Day	Duty Cycle (δ)	Seconds Per Day
Sonix IQ Gas Meter	52.48	0.00039%	0.34	0.044%	1.4
SentryPoint	56.7	0.00026%	0.23	0.047%	1.4
SmartPoint	56.7	0.00042%	0.36	0.047%	1.4
Gateway	56.7	0.0016%	1.4	0.095%**	81.6**

* Information was provided by Sensus.

† Under typical operation, Sonix IQ gas meters send one message every 4 hours, as well as about three additional status update messages per week.

§ Sonix IQ gas meters, SentryPoints, and SmartPoints operate at this duty cycle only during the initial installation and connection to the FlexNet network. The initial connection lasts a total of less than 1 hour.

** Gateways can be programmed to read and report data at a variety of intervals. The shortest interval is one transmission per minute. A Smart Gateway could be operated in this manner for the lifetime of the battery (estimated to be approximately 2 to 3 months).

During the short time that one of the FlexNet End Points (Sonix IQ gas meter, SentryPoint, SmartPoint, or Gateway) is transmitting, the power of that transmission is constant and so the potential exposure level (excluding the effect of any external environmental factor such as walls or distance) is determined by the duty cycle of each End Point. The typical and maximum duty cycles of the various End Points are detailed Table B-1. Using these duty cycle numbers, it is possible to calculate exposure levels from an example End Point based upon the duty cycle (at a particular distance).[30]

The formula for calculating the exposure is provided and described at the end of Section 3 in the body of the report and selected results using this formula are provided in Table B-2.

[30] A Sonix IQ gas meter transmits about one-tenth as much power in the backward direction as in the forward direction. (The measurement information was provided by Sensus).

Table B-2. Example calculations of RF exposure from FlexNet End Points

Scenario (Location, Distance in meters [m] or kilometers [km])	Power (*P*) (W)	Gain (*G*)	Ground Reflection Factor	Forward/Back Transmission Factor (*F*)	Transmission through Wall Material (T)	Distance from Source (R)	Duty Cycle (δ)	Power Density (*S*) (mW/cm^2)	% of SC6 Limit
Sonix IQ Gas Meter (Indoors, 3 m)	0.98	2.00	2.56	0.1	0.736	3 meters	0.00036%	0.0000000012	0.00000043%
Sonix IQ Gas Meter (Indoors, 1 m)	0.98	2.00	2.56	0.1	0. 736	1 meter	0.00039%	0.000000011	0.0000042%
Sonix IQ Gas Meter (Indoors, 25 cm)	0.98	2.00	2.56	0.1	0. 736	0.25 meters	0.044%	0.000021	0.0075%
Sonix IQ Gas Meter (Outdoors, 3 m)	0.98	2.00	2.56	1	--	3 meters	0.00036%	0.000000016	0.0000059%
Sonix IQ Gas Meter (Outdoors, 1 m)	0.98	2.00	2.56	1	--	1 meter	0.00039%	0.00000016	0.000057%
Sonix IQ Gas Meter (Outdoors, 25 cm)	0.98	2.00	2.56	1	--	0.25 meters	0.044%	0.00028	0.10%
SmartPoint (Indoors, 3 m)	0.78	1.58	2.56	0.1	0.736	3 meters	0.00039%	0.00000000081	0.00000029%
SmartPoint (Indoors, 1 m)	0.78	1.58	2.56	0.1	0. 736	1 meter	0.00042%	0.0000000078	0.0000028%
SmartPoint (Indoors, 25 cm)	0.78	1.58	2.56	0.1	0. 736	0.25 meters	0.047%	0.000014	0.0051%
SmartPoint (Outdoors, 3 m)	0.78	1.58	2.56	1	--	3 meters	0.00039%	0.000000011	0.0000040%
SmartPoint (Outdoors, 1 m)	0.78	1.58	2.56	1	--	1 meter	0.00042%	0.00000011	0.000039%
SmartPoint (Outdoors, 25 cm)	0.78	1.58	2.56	1	--	0.25 meters	0.047%	0.00019	0.069%

Scenario (Location, Distance in meters [m] or kilometers [km])	Power (*P*) (W)	Gain (*G*)	Ground Reflection Factor	Forward/Back Transmission Factor (*F*)	Transmission through Wall Material (T)	Distance from Source (R)	Duty Cycle (δ)	Power Density (*S*) (mW/cm^2)	% of SC6 Limit
SentryPoint (Outdoors, 50 m)	0.81	1.58	2.56	1	--	50 meters	0.00026%	0.000000000028	0.000000010%
SentryPoint (Outdoors, 10 m)	0.81	1.58	2.56	1	--	10 meters	0.00026%	0.00000000069	0.00000025%
SentryPoint (Outdoors, 25 cm)	0.81	1.58	2.56	1	--	0.25 meters	0.047%	0.00020	0.072%
Smart Gateway (Outdoors, 50 m)	0.893	1.58	2.56	1	--	50 meters	0.00039%	0.000000000045	0.000000017%
Smart Gateway (Outdoors, 10 m)	0.893	1.58	2.56	1	--	10 meters	0.0016%	0.0000000045	0.0000017%
Smart Gateway (Outdoors, 25 cm)	0.893	1.58	2.56	1	--	0.25 meters	0.095%	0.00044	0.16%
Base Station (Outdoors, 3 km)	40.36	16.41	2.56	1	--	3,000 meters*	0.14%	0.0000000021	0.00000076%
Base Station (Outdoors, 100 m)	40.36	16.41	2.56	1	--	100 meters*	0.56%	0.0000073	0.0027%
Base Station (Outdoors, 0 m)	40.36	16.41	2.56	1	--	0 meters*	1.67%	0.0010	0.36%

* Value indicates the horizontal distance from the base station, but includes an antenna height above ground of 15 meters, representative of the minimum expected antenna height above ground.