PLANTRONICS.
SOUND INNOVATION™

Roaming Range: Understanding Wireless Headset Performance in the Real World

EXECUTIVE SUMMARY

Many factors affect the performance of a wireless headset system and how far a headset can roam from its base. So many factors come into play, in fact, that it's difficult to give distance estimates without the use of sophisticated measurement and analysis tools. This paper will help users understand the reasons that they might experience either differences in roaming performance from product to product, or different roaming performance than estimates provided in manufacturer documentation. Note that the frequency band (such as 900MHz) is only one in a whole range of factors, and cannot be considered predictive of performance.

There are two major categories of influential factors:

1. The **design** of the wireless headset system's transmit and receive radio, including:
   - Antenna design—to optimize the radio coverage between headset and base
   - Transmitter output power: balanced between battery size, circuitry cost and heat generated
   - Radio frequency band: such as 900MHz, 2.4GHz, Bluetooth™, and 1.9GHz DECT 6.0—performance varies in terms of range and behavior around obstacles
   - Multipath design—how a wireless device handles the radio signals that reflect off surfaces in an office building, allowing a user to roam further from the base

2. The **environment** in which a wireless system is used—both solid, physical environment and radio environment play a role. While *outdoor* range is predictable and easy to calculate, *indoor* range varies greatly. Major contributors to indoor range degradation include:
   - Attenuation, or weakening of the radio signal, as it passes through building materials, people and other objects
   - Signal reflection as a radio signal bounces around inside, hitting solid objects and reflecting in other directions—making the primary signal more difficult to detect
   - Interference from other devices: the presence of other transmitters in a shared and crowded radio band
   - Density of wireless headset installation—as the number of installed headsets in a given area increases, roaming range decreases

All manufacturers balance these factors in the design of a headset, to deliver the best performance possible given diverse circumstances and preferences. Because indoor roaming range is so difficult to pin down, manufacturers quote the outdoor/unobstructed roaming distance in literature.

INTRODUCTION

Increasingly, companies are turning to wireless headsets connected to land-line desk phones as a way to improve productivity—by affording workers the mobility to do their jobs in new and more efficient ways. This commonly involves multi-tasking that takes employees away from their workstations—often into different areas of a building. Precisely how far users will be able walk from their desks and still communicate on their headsets is a common question buyers ask when considering the purchase of a wireless headset system.

Major manufacturers of wireless headsets build their products around industry standards, making the performance relatively similar from maker to maker for products built on a given standard. Based on the specifications of these standards, manufacturers also commonly publish typical operating ranges. However, in the real world, users find the actual usable range of a device can vary considerably from the typical operating range the manufacturer specifies. The distance that the headset and base station can connect with acceptable voice quality is called the *roaming range*. This distance is a function of two main factors:

1. The design of the radios employed in the headset system
2. The radio frequency environment that these radios use

This paper will explain the factors that impact the operating range of wireless headset systems in common environments.

RADIO DESIGN

Wireless headset/base systems incorporate a pair of two-way radios, each consisting of a transmitter, a receiver and antenna. The headset transmitter digitally encodes the user's voice and sends it through an antenna to the wireless base station. The base station receives the signal through its similar antenna, then sends the signal to a connected telephone. Incoming conversation is handled in precisely the opposite way. Throughout the back-and-forth process between headset and base, several factors affect performance—which can be grouped into two simple categories:

1. Maximum RF output power out of the transmitter antenna
2. Minimum discernable signal into the antenna of the receiver

Basically, the more RF output power out of the transmitter antenna, the farther the maximum distance the headset can operate away from the base station. The smaller the minimum discernable signal the receiver is capable of operating at before unacceptable voice quality occurs, the farther the maximum distance the headset can operate away from the base station.

Maximum RF Output Power

Maximum radio frequency (RF) output power is the largest transmit signal that the system is capable of producing. A number of elements in the radio transmitter contribute to the transmit power at the output of the antenna. Among these elements are:

1. Antenna design
2. Transmitter output power
3. Radio frequency band

PLANTRONICS
SOUND INNOVATION

Minimum Discernible Signal

At the other end of the system, the single metric that defines sensitivity of the receive subsystem is the *minimum discernible signal*. This is the smallest signal—present at the input to the antenna—capable of delivering adequate voice quality required to carry on a conversation. There are many elements in the radio receiver that contribute to how well it can use the RF power present at the receiver antenna, and thereby determine the minimum discernible signal. These include the same factors as the Maximum Output Power factors, with an additional final factor:

1. Antenna design
2. Transmitter output power
3. Radio frequency band
4. Multipath design

1. Antenna Design

Different shapes and attributes of wireless antennas produce different "shapes" of radiation patterns. Choosing the antenna that delivers the most appropriate transmit directionality and field curve affects the ability of a wireless headset to roam within range of its base to maximum distance. Since all wireless headsets, by their nature, require *omnidirectional* antennas that produce basically a 360 degree signal—the trick is how to adapt an antenna to produce a 360 signal despite the fact it's attached to a large signal-blocking object: the human head. An antenna that would perfectly create that 360 pattern would be a long antenna sticking up over the user's head—but few of us would don such a headset. So, to create more stylish and comfortable headsets, creative antenna design becomes critical.

2. Transmit output power

Boosting radio power results in stronger signal and hence, greater range. This requires circuitry that operates safely and effectively at high power, and does not spark, short circuit or damage the equipment. Lower power radios may have reduced signal strength and range, but operate safely and generate less heat—making the system safer, smaller and lighter.

3. Radio frequency band

Different radio frequency bands are available to wireless systems of all kinds, and affect range performance indoors. There are two principle factors to consider:

- Basic physics
- Regulation of devices within a band

Simple Equation for Electromagnetic Physics

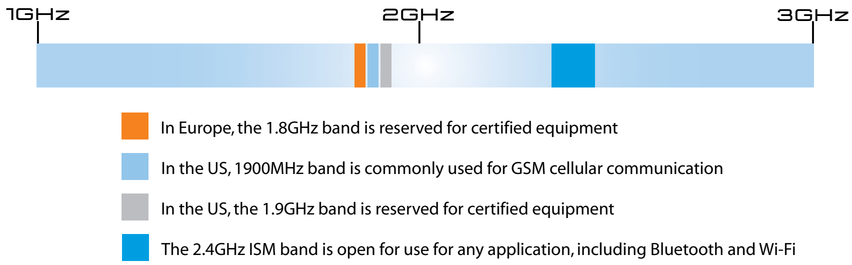
Radio frequency band and roaming range have an inversely proportional relationship. In a free space environment (outdoors, in line of sight), if the radio frequency design parameters of output power and receiver sensitivity are held constant, but radio frequency band is doubled, then the range will be cut in half.

In an indoor environment, the physical effects of doubling the radio frequency band will have a lesser degradation on range. It is difficult to precisely predict the actual performance the physical effects of doubling the radio frequency band because of building materials and obstacles encountered indoors. Different radio frequencies respond differently to the materials in a building.

Also, manufacturers do not make these band changes in isolation and will offset the difference in frequency by altering antenna design or output power to compensate for the difference in behavior. So, changes in radio frequency alone do not predict the range of a product.

Regulation of Devices in an RF Band

Wireless headsets operate in frequency bands worldwide which are commonly known as "unlicensed" frequency bands. This means that the government does not require a specific license for each transmitter of operation. Most worldwide unlicensed bands, such as 2.4GHz, allow a range of different types of radio transmission schemes to operate in the band. The different types of transmissions are not required to cooperate with one another, which means they are free to cause mutual interference. The further away from its base a headset is located, the more susceptible it is to the effects of interference from the devices in a crowded band—hence, roaming range is limited by the presence of devices causing interference.



By contrast, for DECT 6.0 (or 1.9GHz), the government includes protocol requirements that forces cooperation between radios in the band. This means that wireless headsets or other transmitting devices are required to "listen" on a desired channel within the band and determine no other transmitters are using the channel before the transmitter can "talk" (transmit). This prevents interference—and hence, extends roaming range.

DECT 6.0 prevents interference—and hence, extends roaming

Further, the DECT 6.0 band is limited to two-way voice isochronous communications. This results in a cooperative environment of like-designed devices which more effectively mitigate contention for the frequency channels when higher numbers of devices are deployed in a given area. In other words, devices in this band and protocol offer higher capacity usage of given spectrum than other unlicensed spectrum—and greater roaming range.

4. Multipath design

When a transmitter sends out a radio signal to a receiver, the signal can reflect off surfaces indoors, creating an effect called *multipath* (discussed in detail on page 7). Given that the shortest distance between two points is a straight line, reflected signals are taking the long route to the headset—and arrive later than non-reflected, primary signals. This can cause problems for the receiver, which must cope with multiple signals arriving at different times. How a headset system handles this situation will affect how far a headset can roam from its base.

A Balance of Design Factors

Given the importance of these two main radio design factors, one might think that headset system manufacturers could improve roaming range simply by designing the radio so that transmit power is extremely large and minimum discernible signal is extremely small.

However, transmit power is limited by government safety *regulatory requirements* for maximum output power*. Higher transmit power also consumes more battery power to provide the RF power, thereby reducing talk time. The system's *price point* is also a factor, as higher power amplifiers, greater battery power, and other associated circuit design issues required to boost output power and improve range would add cost.

The minimum discernible signal is also constrained by the size of *circuit elements* such as filters. As a result, decreasing the minimum discirnable signal would increase the size of the headset and cost if the system. Higher-performance circuit elements—such as low noise preamplifiers—can also improve minimum discernible signal. But these, too, require a trade off with regard to the cost of the system.

RADIO FREQUENCY ENVIRONMENT

The second major category of factors affecting roaming range is the *radio frequency environment*. Simply put, the environment in which a wireless headset system is used will impact the performance of the system—in conjunction with the design elements already discussed. The main force at work is called *path loss*—the amount that an RF signal is weakened as it travels the distance between headset and base, reducing the roaming range of the system.

Received Signal Power

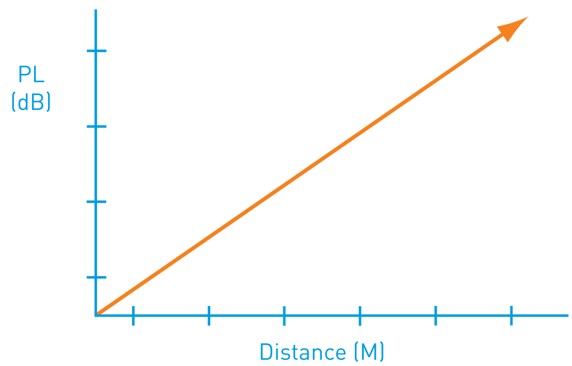
To describe the effects the radio frequency environment has on range, it helps to look at a simple model of a one-way RF communications link.

In a radio "vacuum" or perfect environment, the equation below describes how radio signal power is attenuated (reduced) relative to the distance it must travel before it is received at the other end of the radio link.

RF power at the receiver antenna =
RF power transmitted from the transmitter antenna minus
Path Loss

Basically, as the receiver gets farther away from the transmitter, the path loss increases and the received signal power decreases. Received signal power varies as path loss varies—that is, as the environment changes.

Path Loss vs Distance at 1.90GHz



RF energy can become a factor to human safety at highest signal powers; although this does not ordinarily become a concern in wireless headset systems, which are designed to produce much less output power than long-range devices such as cell phones

PLANTRONICS
SOUND INNOVATION™

Signal Power And Voice Quality

As with cell phones and other radio communications, it takes a large enough received signal in order to hear good-quality voice. At some signal levels the voice degrades, but is still intelligible. There is an RF signal level at the at the receiver antenna (RPrx) that provides this audio "minimum acceptable" quality voice signal. The specific received power level that produces the minimum acceptable quality voice signal is the *minimum discernible signal* defined previously (see page 2).

Using the equation above, this wireless headset system can be said to provide minimum acceptable voice for path loss up to:

Maximum path loss = Transmitted signal power minus Minimum Discernible Signal received

Manufacturers commonly use the outdoor range as the stated maximum roaming range for a wireless headset system.

Path Loss And Range In An Outdoor Environment

In an outdoor radio system, when the antennas are high above the ground and there are no obstacles in between the transmit antenna and receive antenna, the *Path Loss* (PL) is very well defined and easy to predict. This environment is known as *Line of Sight* (LOS).

The maximum range in an outdoor LOS environment is easy to predict since path loss is well defined and accurately estimated. For this reason, manufacturers commonly use the outdoor range as the stated maximum roaming range for a wireless headset system.

Path Loss And Range In An Indoor Environment

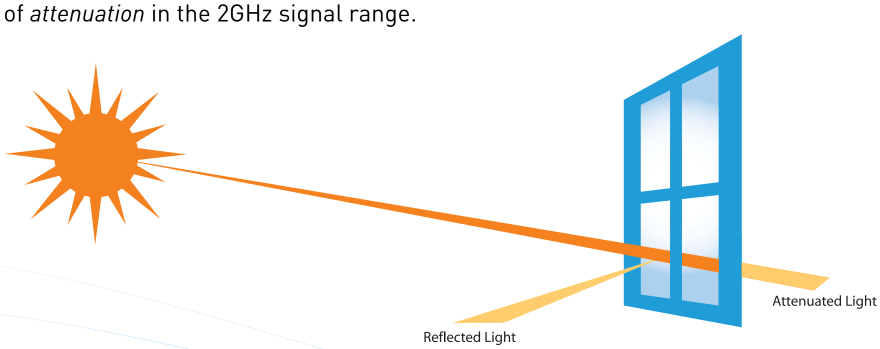
The indoor RF environment is very different than an outdoor LOS environment. The path loss between transmitter and receiver is no longer easy to predict because the environment is not unobstructed, as it is in the LOS as defined above. Furniture, building materials, and even people have effects on the RF electromagnetic wave. Additionally, other sources of RF energy (such as Wi-Fi networks, cellular transmission towers, security systems, scientific or medical instruments) can affect the radio receiver's ability to receive the desired signal. The path loss can no longer be modeled according to a neat mathematical equation.

The most common path loss, or reduced signal power, are:

1. Attenuation from indoor materials
2. Multipath from signal reflection
3. Interference from other radios
4. Density of wireless headset installation

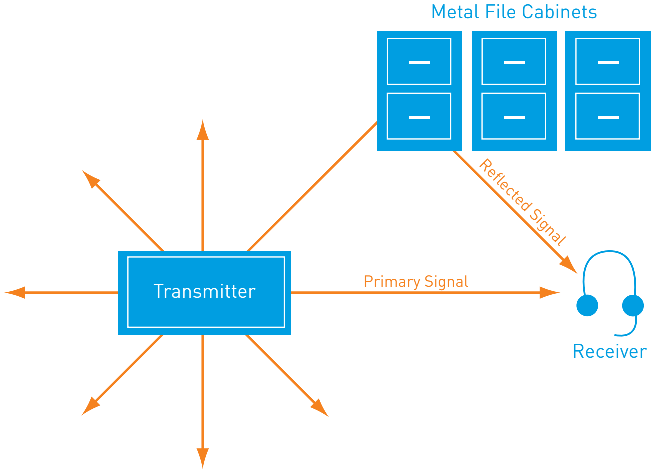
1. Attenuation

When a material (furniture or building material) is in the path of the RF signal between the transmitter and receiver, it will have effects that attenuate (reduce) the RF signal, reflect the RF signal, or both. For example, a rule of thumb used by radio engineers is that an indoor wall made of two layers of modern *fireproof gypsum material* will result in approximately 6 db of *attenuation* in the 2GHz signal range.



2. Multipath

When the furniture or building material is *metallic*, it provides a *reflective* environment to the signal. Wireless headset system antennas attempt to radiate in all directions equally (creating an omnidirectional radiation pattern) since the headset can be located in any direction relative to the base. The transmitted signal will then reflect off many objects indoors. These reflected transmitted signals may arrive at the receive antenna later than the primary signal, causing signal distortion.



However, since the reflected signal must travel a longer path than the direct signal, it will arrive at a later time than the direct signal. When the reflected signal arrives later in time it will be out of sync with the principal signal—causing signal distortion. This distortion effect is known to the communications systems engineer as *multipath*. The impact of indoor multipath on voice quality increases as the headset user walks away from the base—hence limiting roaming range.

3. RF Interference

The discussion on multipath above describes how the desired transmitter's signal can become distorted due to reflections. Similarly, RF signals in the RF frequency band can distort the desired direct path RF signal at the receive antenna. This effect is common on wireless headset systems used in the popular 2.4GHz unlicensed frequency band where WiFi, Bluetooth™ and microwave ovens operate. These devices are more commonly found indoors and therefore further degrade range from the maximum range RF environment of LOS. DECT and DECT 6.0 systems operate in a more protected environment, which minimizes the likelihood of this effect (discussed in detail on page 2).

Unintentional radiators can also produce unwanted energy in the radio frequency band used in wireless headset systems. Electric motors in fans and machinery found indoors can sometimes produce interfering signals in wireless headset system frequency bands and also cause distortion of the received RF signal.

Generally, all of these interference sources have a higher likelihood of producing distortion of the RF (and hence audio) signals as the headset gets farther from the base station. When received signal power is smaller, the interfering signal is more likely to be large by comparison, distorting the received RF signal.

4. Density

If many additional wireless headset systems in the same RF band are used in the close proximity (same or adjacent rooms) there is also the possibility of these systems degrading the headset system performance. DECT 6.0 and DECT 900 wireless headset systems select a clear RF channel within the frequency band to operate in. This is called the *listen before talk* protocol. The more crowded the frequency, the longer a system must "listen" before talking—and the higher the likelihood of two users attempting to use same channel. This may cause either interference or delays to the headset user. And like many of these effects, the larger the distance between headset and base, the greater the problem.

As a general rule, the larger the number of systems, the smaller the range. And the further the roaming distance, the more audio disruption occurs. The most prominent disruption occurs when a headset user is distant from the system base but close to another user's wireless headset system that is presently using the same frequency channel.

PRACTICAL IMPLICATIONS

What does all this mean for an end user of wireless headset systems in an office?

1. Performance in a "perfect environment" (that is, outdoors with headset and base in line-of-sight) is what's written on the box, but indoors it can be different
2. Manufacturers balance a number of factors in headset design which affect range—cost of components, battery life, radio power and comfort
3. When you change RF technologies—like when you upgrade from 900MHz to DECT 6.0—you may notice some changes in performance, and this is normal
4. DECT 6.0 provides the best protection from interference, though it offers slightly less range in some environments

SUMMARY

Comparing indoor and outdoor performance: while range in an outdoor line of sight (LOS) environment is easy to predict based on factors such as output power and sensitivity of the receiver, predicting range in an indoor environment is much more difficult. Attenuation of the signal, multipath effects, interference from separate radio systems, interference from unintentional RF noise sources, and proximity of other headsets all work to reduce the range achieved in an outdoor LOS environment. In addition, the indoor range achieved will vary considerably from location to location based on the building construction, size of rooms and furnishings.

Comparing different systems: separate from environmental factors affecting roaming range of wireless headset systems, technology and design difference between models will play into the equation. The RF frequency, antenna design, output power, and many other factors combine to make each headset model slightly different than the next. Manufacturers must carefully balance the cost, comfort and performance to find the "sweet spot" that meets the most user needs for business communication and personal preference.