Technical Brief
AN119

Wireless System Design
Top-Level Issues

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Abstract

Raveon specializes in wireless data communication products with a keen focus on system requirements and long-range communications. When creating a new wireless system, there are many technical issues to consider. This paper outlines the major issues Raveon evaluates to create a product fit for its market as well as an overview of how Raveon's made its system decisions for its *LandScape™ System* of wireless products.

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Introduction

"*How far will a radio communicate?*" and "*Which frequency is best?*" are two of the most common questions one faces when developing a new radio system. It is easy to find general answers to these questions, and this paper attempts to present them, but in the end, the solutions to both questions are too complex for a simple answer. Wireless system design is a very complicated balancing act — balancing market expectations with the realities of the technological solutions. In balance are product performance, cost, size, power, government regulations, antenna location, environment, microprocessor speed, development schedules, and circuit complexity.

Communication range is dependent upon many things, but in order of how they impact your system, the main ones are:

1. *Terrain*
2. *Antenna height above the terrain*
3. *Frequency used*
4. *Antenna performance*
5. *Transmit power*
6. *Receiver sensitivity*
7. *Data Rate*
8. *Protocol*

This paper will discuss the impact each of these have on the system, and the trade-offs involved when choosing a wireless system architecture.

Link Budget

System design begins with quantifying the "*link margin*" of the system. The link budget is the difference between how much RF power a transmitter radiates, to how much power a receiver needs to reliably work. Knowing the link-budget is key to understanding how far the product will wirelessly communicate. Because the math involved with computing it is much easier when using power in dB, most link budget computations are done in decibels (dBs) instead of power in watts.

For example, a 915MHz transmitter may radiate 2mW of power (3dBm), and its companion receiver that it communicates with may have a receive sensitivity of –95dBm. This will give a link-budget of approximately 98dB. In real-world cases, the antenna gains of the system must to be carefully studied and included as well.

Once we know the link budget of the system, we can compare it too the power loss between the transmitter and the receiver, and verify that there is adequate "*link margin*". A properly designed system will have 10-25dB of extra signal at the receiver, so in this example with 98dB of link budget, the system should bw designed to work reliably as long as there is no more than about 70-80dB of loss between the transmitter and the receiver.

The concept of link-margin is simple, but in the beginning of a system design, it is often difficult to predict. Link-margin depends upon so many different aspects of the system. The frequency, the terrain, the transmitter power, the receiver sensitivity, the protocol, and the antenna gain. All are factors in determining the link margin. Deciding upon the proper link margin is an iterative process, but as the system design progresses, it will become a benchmark for the total system solution to be measured against.

BASIC HIGH-FREQUENCY RADIO PROPAGATION:

Propagation at higher frequencies (above 30MHz) is different from propagation at lower frequencies in several major respects. While all radio waves tend to move in straight lines, higher frequencies are blocked more sharply by terrain or buildings, and they can be focused more easily by high-gain antennas. Because wavelengths are shorter at higher frequencies, higher frequencies can move more easily through small openings (like windows and hallways in buildings, or into tunnels). On the other hand, higher frequencies suffer more loss between omni directional antennas.

The most basic model of radio wave propagation involves so called "free space" radio wave propagation. Free space path loss is proportional to $1/F^2$, where F = frequency. For example, the use of a frequency that is twice as high will result in only 1/4 as much energy being available at the receiver (assuming the use of omni directional antennas, with other factors kept the same). The increased path loss at higher frequencies may also be described as a “20dB/decade” loss: the path loss increases 20 dB (a factor of 100) for a decade (a factor of 10) increase in frequency. In freee-space (and in most real-world cases), <u>the lower-the frequency, the better the propagation!</u>

In this model, radio waves emanate from a point source of radio energy, traveling in all directions in a straight line, filling the entire spherical volume of space with radio energy that varies in strength with a 1/(range)^2 rule (or 20 dB per decade increase in range).

The free-space loss (the difference between the transmitter power and the received power for isotropic antennas) is:

$$36.56 + 20 \mathrm{Log} D(mi) + 20 \mathrm{Log} F(MHz)$$

Real world radio propagation rarely follows this simple model. The three basic mechanisms of radio propagation are attributed to reflection, diffraction and scattering. All three of these phenomenon cause radio signal distortions and give rise to signal fades, as well as additional signal propagation losses.

Outdoors, with mobile and portable units, movements over very small distances give rise to signal strength fluctuations, because the composite signal is made up of a number of components from the various sources of reflections (called "multipath signals") from different directions as well as scattered and / or diffracted signal components. These signal strength variations amount to as much as 20 to 40 dB and account for some of the difficulty presented to the designer of reliable a radio communications system. The basic signal attenuation noticed in the real world gives rise to what are termed "large scale" effects, while the signal strength fluctuations with motion are termed "small scale" effects.

Indoors the situation is even worse. It is very difficult to design an "RF friendly" building that is free from multipath reflections, diffraction around sharp corners or scattering from wall, ceiling, or floor surfaces (let alone operate perfectly in a randomly chosen building location). The closest one could probably get to an "RF friendly" building would be an all wooden or all fiberglass structure -- but even this must have a structurally solid floor of some kind and this more ideal RF building will still have reflections, multipath and other radio propagation disturbances (as the materials properties section below shows) which will prove to be less than ideal. Indoors then, the simple free space model fails to account for the small and large scale fading that is observed in real world radio links as Figure 1 (ref. 1) below readily shows.

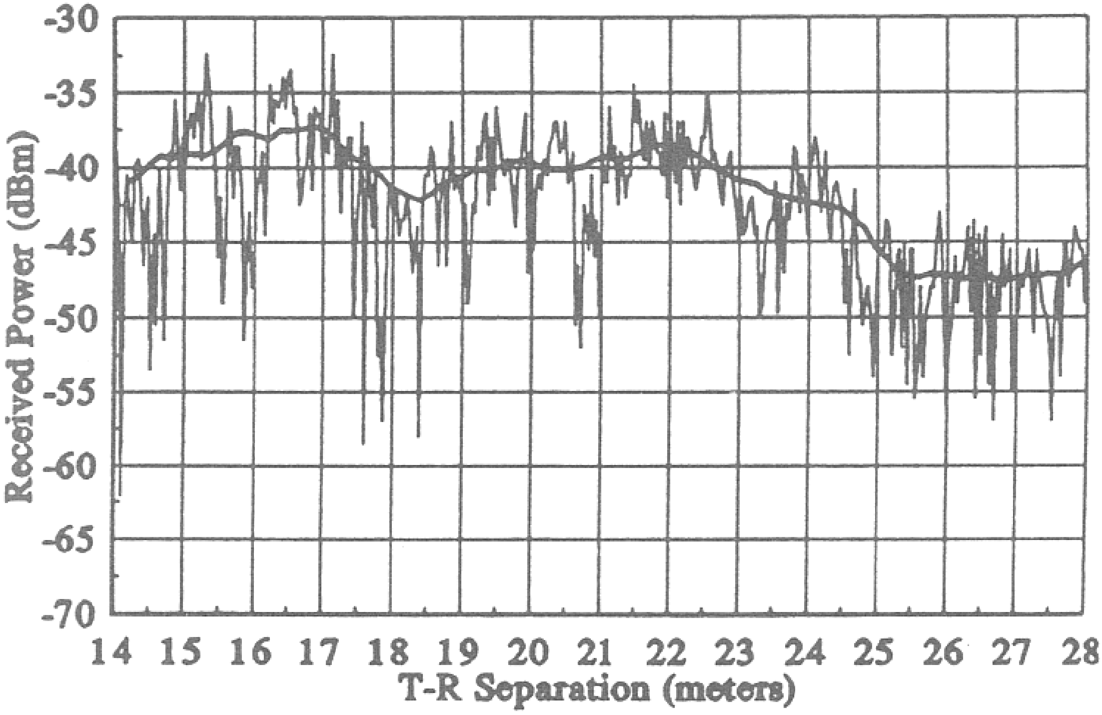


Figure 1 - Received RF Power plot indoors versus range in meters.

Radio wave propagation inside smooth walled metal buildings can be so bad that radio "dead spots" can exist where the signal is virtually non-existent. These dead spots arise because of almost perfect, lossless reflections from smooth metal walls, ceilings or fixtures that interfere with the direct radiated signals. The dead spots exist in 3 dimensional space within the building and motions of only a few inches can move from no signal to full signal.

If the penetration is through a foliage obstruction block,an approximation of the "excess" path attenuation using the Wiessberger model [2] as follows:

$$L_f = 1.33 \cdot F^{0.284} \cdot D_f$$

where

L_f is the "excess" attenuation in dB due to signal propagation through the foliage obstruction block
D_f is the distance that the signal propagates through the foliage obstruction block (meters)
F is the RF frequency (GHz)

The term "excess" attenuation refers to the additional attenuation above the basic transmission loss, for a given path length, in the absence of foliage.

ABOUT MULTIPATH:

A communications system can interfere with itself when multiple versions of the transmitted signal arrive at the receiver via different paths. These “multipath” signals with different directions-of-arrival, amplitudes, and propagation delays arise from the reflection of radio signals off various objects, such as mountains and buildings. Depending on the relative amplitudes and time delays between them, the signals can constructively add or destructively subtract from each other. Multipath is one primary limitation in wave propagation, with destructive cancellation causing occasional unexpected signal loss (called frequency-selective fading.) Multipath can also cause data errors (intersymbol interference) when the time delay differences are on the order of the time duration of a transmitted symbol.

Intersymbol interference tends to become a greater problem when data rates are higher, when higher-order efficient modulations are used, or when the radio is in motion.

In the real world, multipath occurs when there is more than one path available for radio signal propagation. The phenomenon of reflection, diffraction and scattering all give rise to additional radio propagation paths beyond the direct optical "line of sight" path between the radio transmitter and receiver. As Theodore S. Rappaport describes the phenomenon in *Wireless Communications — Principles and Practice* (ref.2):

> *"Reflection occurs when a propagating electromagnetic wave impinges upon an object which has very large dimensions when compared to the wavelength of the propagating wave. Reflections occur from the surface of the earth and from buildings and walls.*
>
> *Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver. At high frequencies, diffraction, like reflection, depends on the geometry of the object, as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction.*
>
> *Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel. In practice, foliage, street signs, and lamp posts induce scattering in a mobile communications system."*

In practice, not only metallic materials cause reflections, but dielectrics (or electrical insulators) also cause reflections. Drywall, concrete, and even wood will reflect radio signals.

The actual signal levels reflected from insulators depends in a very complicated way on the above characteristics as well as the geometry of the situation. Suffice it to say, that insulators are not as good at reflecting radio signals as metal surfaces, but even common insulating materials do cause some reflection of radio waves. Multipath occurs when all the radio propagation effects combine in a real world environment. In other words, when multiple signal propagation paths exist, caused by whatever phenomenon, the actual received signal level is vector sum of all the signals incident from any direction or angle of arrival. Some signals will aid the direct path, while other signals will subtract (or tend to vector cancel) from the direct signal path. The total composite phenomenon is thus called multipath.

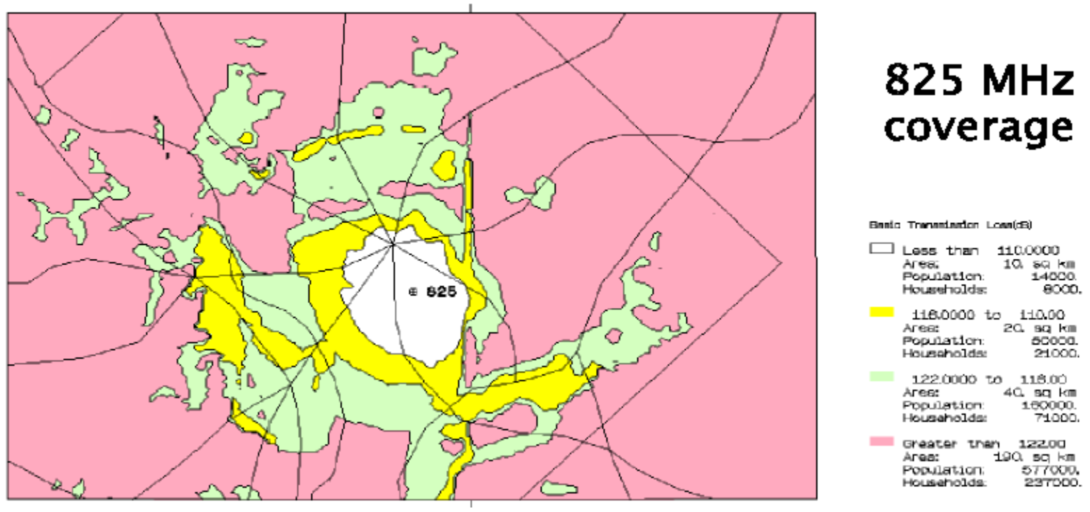
Two kinds of multipath exist: *specular* multipath -- arising from discrete, coherent reflections from smooth metal surfaces; and *diffuse* multipath -- arising from diffuse scatterers and sources of diffraction (the visible glint of sunlight off a choppy sea is an example of diffuse multipath).

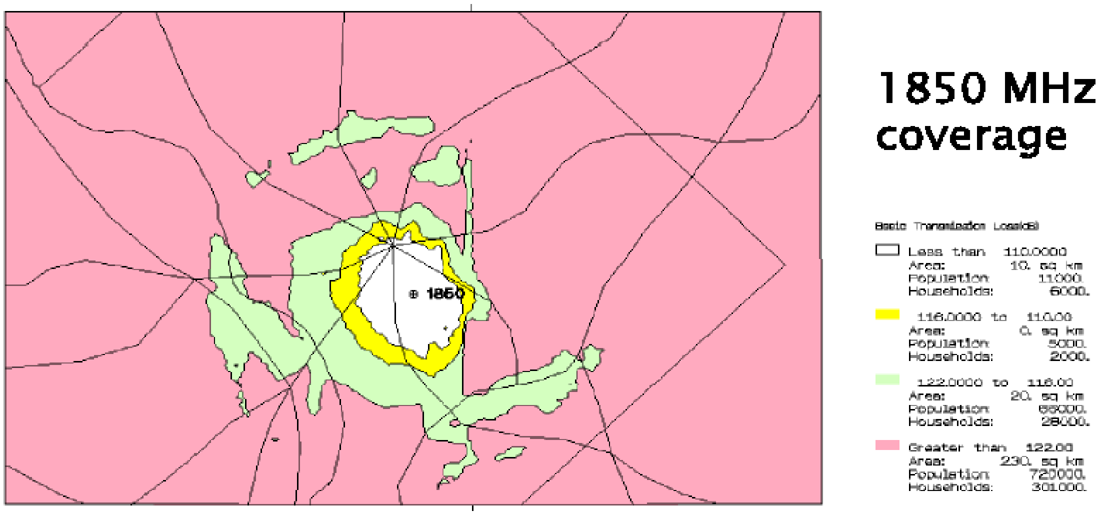
Both forms of multipath are bad for radio communications. Diffuse multipath provides a sort of background "noise" level of interference, while specular multipath can actually cause complete signal outages and radio "dead spots" within a building. This problem is especially difficult in underground passageways, tunnels, stairwells and small enclosed rooms. The proper functioning of the radio communication link requires that multipath be minimized or eliminated.

OUTDOOR RF PROPAGATOIN

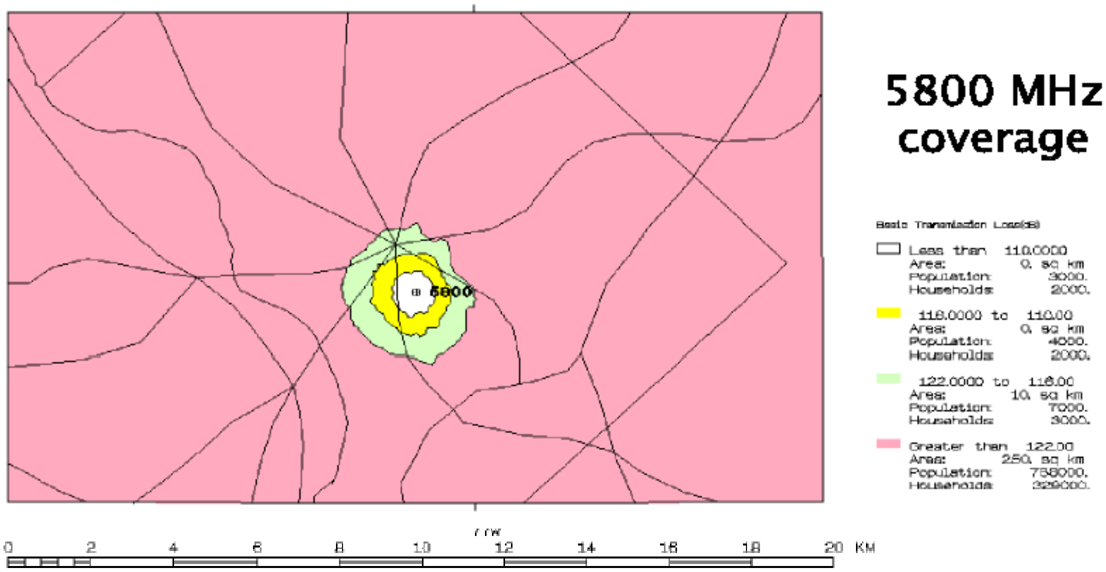
Although the formulas are useful in some circumstances, the actual range of a VHF or UHF signal is affected by reflections from the ground and surrounding objects. The path lengths of the reflected signals differ from that of the line-of-sight signal, so the receiver sees a combined signal with components having different amplitudes and phases.

A number of computer simulation tools consider these propagation phenomena and are used to design radio systems. The three figures below illustrate example outputs of transmission path losses for a hypothetical station in Washington, DC, using the Communications System Performance Model (CSPM) which is based on NTIA's Irregular Terrain Model [3]. Inputs to the program include transmitter latitude and longitude (CSPM uses digital terrain databases), transmitter frequency, antenna height, polarization, mobile station antenna height, and other factors.





1850 MHz coverage

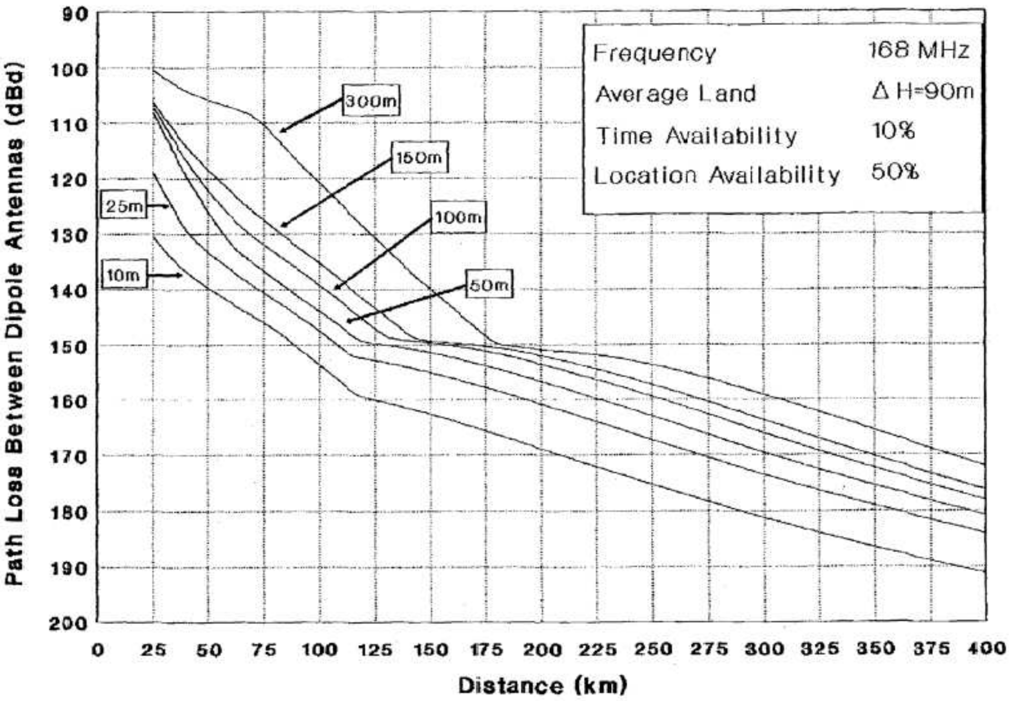


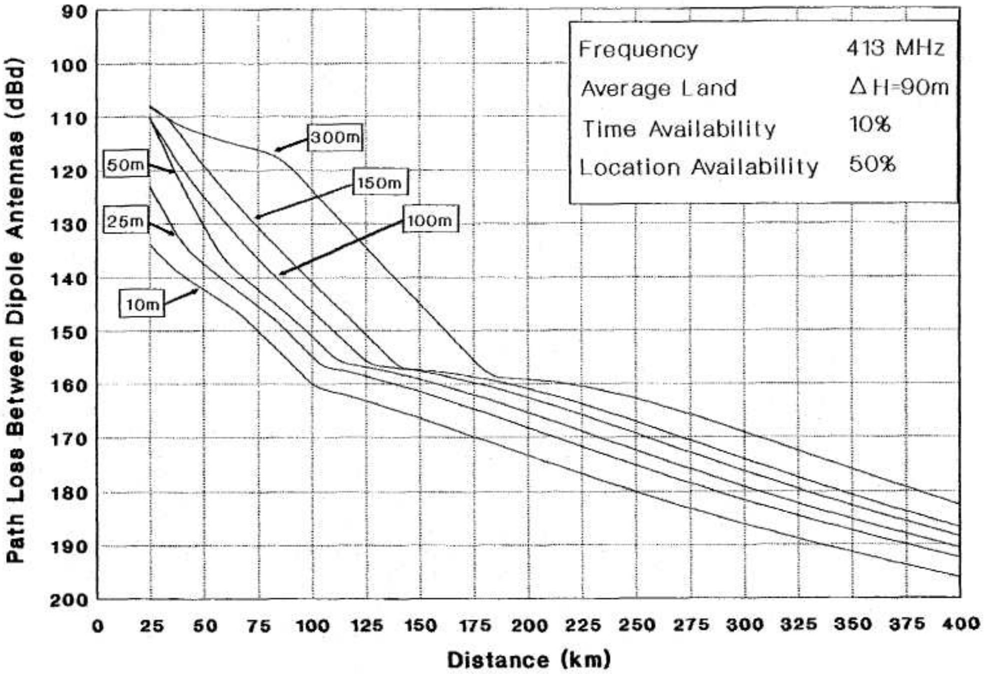
5800 MHz coverage

It is clear from these examples that as frequency increases, radio coverage decreases (assuming fixed antenna gain and other factors held constant). What should not be assumed, however, is that this decreased coverage is necessarily detrimental to the operation of a radio system that is properly designed to accommodate these losses. Various engineering solutions are available to compensate for increased transmission losses, if required. In addition, many modern radio systems depend on smaller coverage zones (cells) to increase frequency reuse (which enables more clients to be served simultaneously).

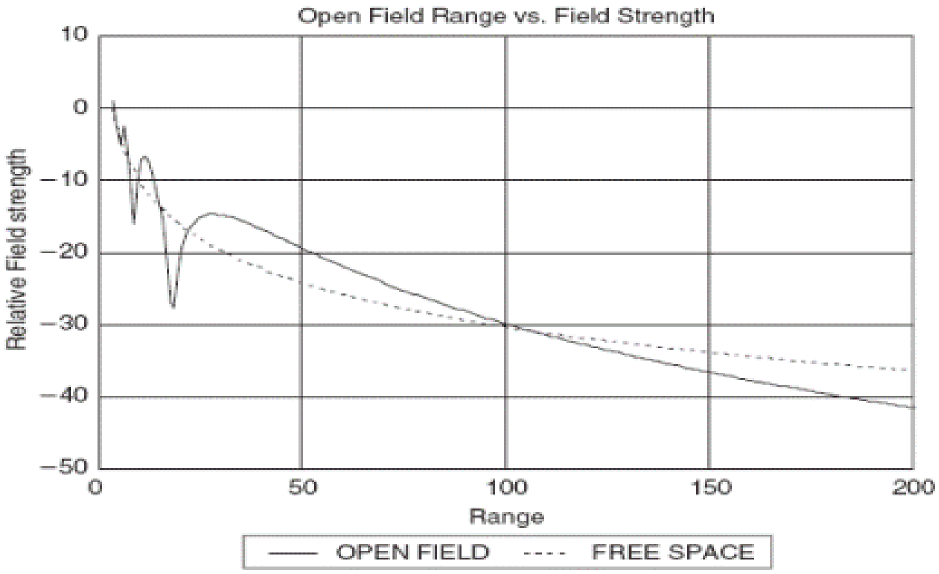
The NTIA publishes some VHF and UHF range approximations used for their system planning. The graphs below are from their Redbook.

VHF Outdoor Propagation with various Antenna heights





The real-world path loss combined with multipath fading makes predicting signal strength (communication range) a real challenge. For example, the plot below shows the RF fields strength for a 300MHz radio system, with antennas 10’ above the average terrain. The standard math formulas would predict field strengths as shown in the dotted line. Actual field strength is shown in the solid line. One can easily see the signal dips due to multi-path around 20 meters, and that the field strength drops at almost 12dB when the distance is doubled, instead of the 6dB the math formulas predict.



UHF Outdoor Propagation with various Antenna heights

INDOOR RF PROPAGATION:

Remember that in free space, an additional signal loss of 20 dB is incurred for each 10 to 1 increase in radio range. Thus, an obstacle with a measured loss of 20 dB or more from its materials is a significant loss!

We probably cannot do anything about the buildings, building materials or structures a system will be used in, however, we must still explore the realm of overall macroscopic signal propagation in a typical building. Radio engineers would like to be able to predict the signal levels and range of signal losses present in a building. To enable this prediction a number of studies and measurements have been made which grossly characterize in building signal propagation. Figure 2 below shows scatter plots of radio path loss as a function of distance in a typical office building for propagation through one through four floors. Figure 3 below shows measurements made at another "typical" building. Observe that both sets of data were taken at 914 MHz, not 2400 MHz and that data is shown for propagation on the same floor as well as between floors.

We can extrapolate this data for use at 2400 MHz with a fair amount of certainty, if we add a few dB (perhaps 5 to 6 dB) to account for the higher frequency we will use to each graph point.

Interpretation of this data provides a level of understanding of the potential problem at hand. Figure 2 shows losses ranging from about 50 dB to over 80 dB for a transmitter-receiver separation of only 10 meters. Figure 3 shows even higher losses, extrapolating to our frequency range gives us over 50 dB to over 90 dB attenuation in a 10 meter separation!

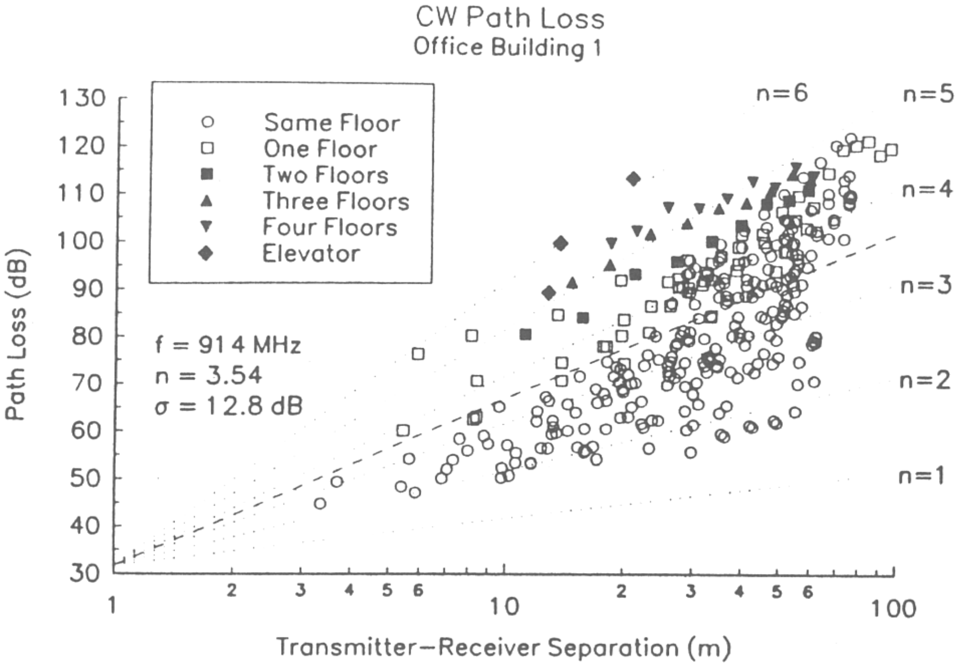


Figure 2 - Path Loss Scatter Plot in a Typical Building.

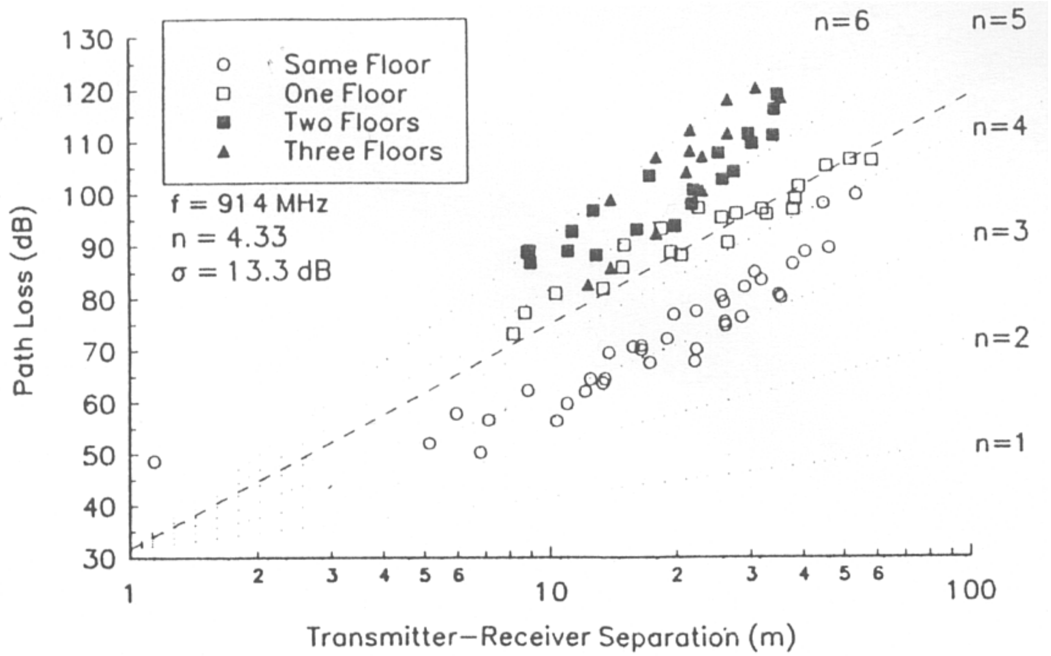


Figure 3 - Path Loss Scatter Plot in Another Typical Building.

Given that the entire loss budget for the typical indoor wireless link is in the neighborhood of 90-120 dB, most of our losses seem to be expected in the very first 10 meters! However, this interpretation of the data presented in Figures 2 and 3 takes the entire realm of multi-story building propagation into account. This is perhaps not fair in the current context. If we confine ourselves to same floor only propagation, then losses at 10 meters can be expected to be about 60 dB. However, going out to a 50 meter range between transmitter and receiver causes losses as high as 110 dB -- almost all of our loss budget will disappear by 50 meters!

ESTIMATING / PREDICTING INDOOR PROPAGATION LOSS:

As an approximation to estimating indoor path losses, if we assume that propagation follows an approximate 1/(range^3.5) power rule, rather than 1/(range^2), we can predict propagation losses with the following relationship (at 2.4 GHz):

*Path Loss (in dB) = 40 + 35 * [LOG (D in meters)]*

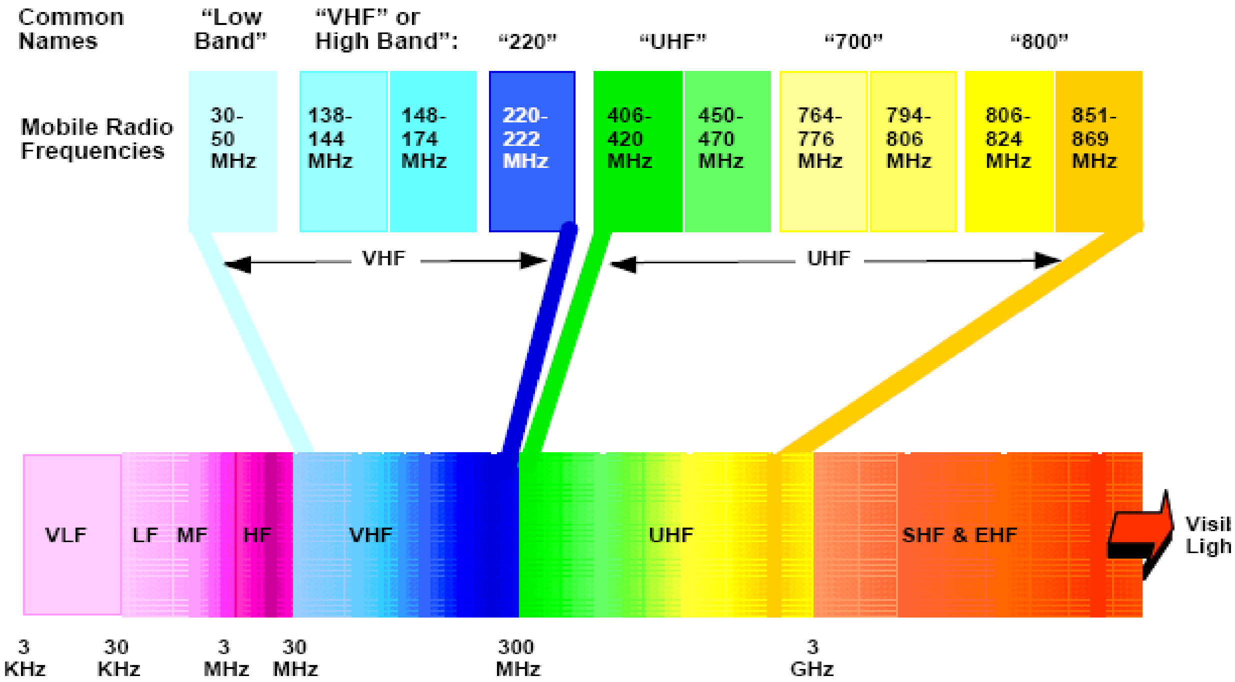
Thus a 10 meter path will give a loss of about 75 dB and a 100 meter path gives a path loss of about 110 dB. If the data above are fairly accurate, we can expect a large-scale signal fluctuation of about 13 dB (or the estimated path loss will have a variance of about 13 dB).

In the real world then, it is probably optimistic to expect in-building links to work well beyond about 100 meters!

DETERMINING THE FREQUENCY BAND

The first step in designing a radio system is to decide the frequency band(s) to be used in the system. Determining the proper frequency band to use could be limited to licensing, environmental or existing system considerations. The frequency bands differ in noise levels, ranges, skip, and other factors.

Licensing requirements are the first consideration in determining frequency band. The different frequency bands available for licensing are determined by a government agency that usually covers site licensing and frequency coordination. The FCC (Federal Communications Commission) and Industry Canada are the government agencies in the United States and Canada respectively.



Lowband (29 to 50 MHz)

This band is subject to heavy skip – signals bounce off the ionosphere and travel great distances. There are frequent dead spots, and the signal does not bounce off hills or buildings. It has the most range and the highest noise level. The antenna structures can become quite large (many meters long).

VHF Highband (132 to 170 MHz)

There is much less skip, very good range, and less noise in this band than Lowband. This band also has fewer dead spots than the VHF low-band. There is no atmospheric skip to worry about, and natural and man-made background noise is low.

UHF band (406 to 512 MHz)

This band's range is less than in VHF highband. The signal bounces off hills and buildings well and has practically no skip interference. It also has fewer dead spots and less noise. The physical size of UHF antennas can be attractive as they are 1/3 smaller than VHF antennas.

800 / 900 MHz band

The signal bounces off buildings and metal objects extremely well and presents little noise. The range is less than UHF and there is more absorption by foliage. Generally, radios operating at 800 or 900MHz have longer range than the comparable equipment using 2.4GHz or higher frequencies. However, the 2.4GHz ISM band has more bandwidth to support higher data rates and number of channels, and is available worldwide. At times, cell-phone and paging systems create considerable noise in this band.

2.4GHz band

The signal bounces off buildings and almost any hard object. The path-loss is three-times that of 900MHz and 20 times that of a VHF system, so this band is used primarily for short-range high-speed data links such as wireless LAN. The band has considerable noise from cordless phones and micro-wave ovens, although the interference is often negligible as the propagation is shorter than lower-frequencies. The range is less than UHF and there is much more absorption by foliage.

5 GHz band

While free space propagation losses will be much higher at 5GHz than 2.4GHz, propagation losses through most construction materials are virtually identical. This makes 5GHz wireless potentially the better choice for building automation applications.

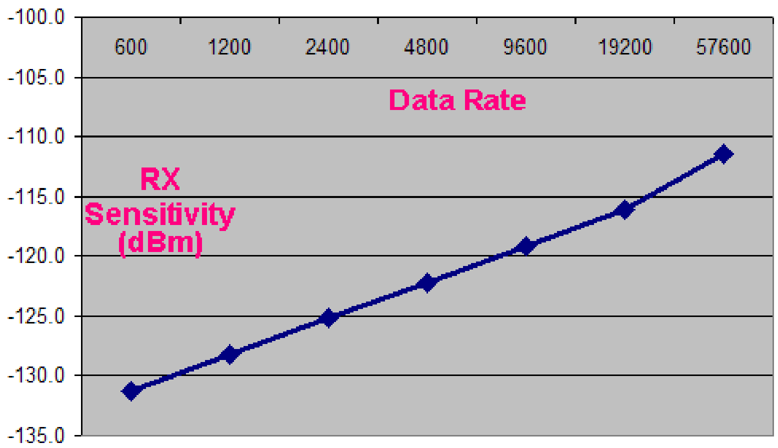
Frequency band selection can also depend on the environment in which the radio system will be operating. VHF lowband is used in many industrial applications (eg. gas and oil companies) as well as some law enforcement applications (eg. highway patrol). VHF highband is widely used in forested or wilderness areas and for public safety applicaitons. UHF and 800 / 900 MHz are typically used in urban areas and to link VHF sites together. The government licensing agency can help you determine the proper frequency band if you are unsure of which band to use.

Data Rate

An important and overlooked aspect of a data radio system is the over-the-air data rate it uses. The over-the-air data rate is the data rate the radios send and receive data between them at. The user’s interface may be 10Mbps Ethernet, or 1200 baud RS-232. This will not mater. It is the rate over-the-air that affects communication range.

All things being equal, slow data rates will have better communication range than fast data rates. It is a 1:1 relationship. A signal sent at a rate 2X that of another will also have ½ the amount of power-per-bit of information. This is because with slower data rates, the bits are longer and they more RF power is in each bit. This 1:1 relationship goes hand-in hand with transmit power. Increasing the RF transmit power 10X has the exact same effect on communication range as slowing the data rate 10X. Either way will increase the range, although slower data will often cost nothing in hardware, where 10X more RF power can be costly.

The following chart shows how receiver sensitivity is effected by data rate.



At very low data rates such as 600bps, a typical well-designed receiver can receive a signal as weak as -130dBm. At a higher data rate, of say 57.6k, the receiver would need -112dBm to receiver, an 18dB difference (60X the power!)

For system with low transit power, battery operation, or ultra-long range requirements, it is important to use low data rates for best system performance.

RADIO SYSTEM DESIGN

The performance and synergy of individual components in a wireless system are critical to the overall system performance. Great receivers with poor antennas are poor receivers. The overall system design approach must be balanced. All radio systems are constrained by some combination of: size, power consumption, cost, antenna configuration, and frequency choices.

There are numerous ways the radio system designer can maximum the link-margin while balancing the system trade-offs. It is often not a matter of choosing one technology over another, but of balance—balancing the market needs with the technical constraints. Successful products are technologically well balanced. They may not have the best of any one technology, but the combination of the trade-offs can make outstanding performers. Conversely, some very well-designed products fail because they neglect to account for some fundamental restraint to their application. Following is a list of the main parameters the system architect must address.

Frequency Band

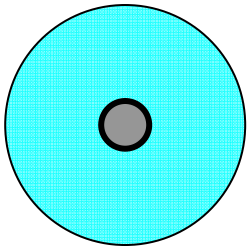
As discussed, different frequencies will propagate differently, and choosing one that performs best in the environment it is used in will increase range. Given equal signals, lower frequencies often work better and further. This is at the expense of larger circuits and physically larger antenna structures. Government regulations will limit the choice of frequencies bands. Some frequencies require a license to operate on, other are license-free, and others may not be used at all for private use. Lower-frequencies have much tighter restrictions on data-rate and bandwidth. Once a suitable band is identified, the technical regulations governing its use must be carefully studied to ensure the federal constraints are workable in the system.

Antennas

The various frequency bands have many different antenna options. The antenna construction techniques used in different bands allow for optimal antennas to be used for the application. For some systems, the choice of antenna actually drives the frequency band of choice. For example, point-to-point link antennas are smaller and easier to build at microwave frequencies compared to those at VHF or UHF. Radio location and ranging is much more accurate at microwave frequencies. Conversely, ¼ wavelength omni-directional antennas receive more signal power at lower frequencies, causing this type of antenna to be very inefficient at microwave frequencies. The challenge is to make an efficient radiating structure that puts power out in a direction that the designer desires. For fixed antennas, this is simple, but in hand-held and mobile devices, it is often not possible to radiate a signal in an optimal way. Antennas are always a trade-off of size, pattern, and esthetics, but <u>money spent on a good antenna is often dollar-for-dollar the best return in a system</u>.

Fundamentally, there are two types of antennas to choose from: *Omni-directional* and Directional.

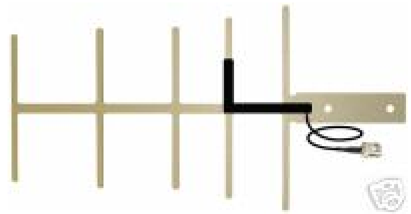
Omni-Directional Antennas.



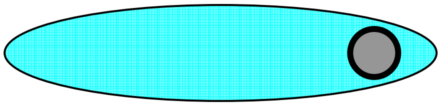
Because it transmits and receives in all directions, the omni-directional antenna is used on mobile and portable radio systems. Looking at its radiation pattern from above, it looks like a circle, radiating energy in all directions.

Omni antennas are required when radios must talk between moving locations, or when the direction of communication path is not known or changing. They come in many shapes and mounting configurations, but most all are a 1.4 or 5/8 wavelength rod positioned above a ground plane. If a ground-plane is not available, then ground radials are added to the bottom of the antenna, as shown in the picture to the right. Other more advanced mechanical configurations are used for operation without a ground-plane or obtaining slightly higher performance.

Directional Antennas



A directional antenna is one that directs its signals in only one direction. Antenna gain are commonly 6-10dB, and 20dB is not unusual. They have a “Gain” specification, but “Gain” is a bit of a misnomer. They will effectively boost their signals by their gain spec, but only in one direction. This is how they achieve “gain”. The radiation pattern is, as viewed from above, is no longer a 360 degree circle, but a beam, with a width inversely proportional to the gain. The send signals farther, but only in one direction, that is why they are unsuitable for mobile applications.



When comparing communication systems and radio specifications, it is very important to understand what type of antenna was used, as it is not unusual for manufacturers to quote performance with a very-high gain directional antenna, making range specifications look better.

Antenna System Quality

When designing a communication system, the quality of the antenna system is very important. The qperformance of the antenna system is determined by three main factors: gain, height, and installation.

Gain

The simple "rubber-duck" type antennas is used what a small may actually have a signal loss of 5-10dB. A ¼ wave whip antenna or even better, 5/8 wave whip antenna with a good ground plane makes a good general-purpose antenna. Tall base-station antennas ar available with 5-10dB of gain, but they are quite tall, and often heavy. Directional Yagi antennas with 6-12dB of gain are available, offering the most gain. Use an antenna with the most gain, that still meets your size and cost goals. Remember every 3dB is a 2X power multiplier!

Height

The height above average terrain where the antenna is located is very important. A few feet can make a big difference if there are obstructions in the area, and obstructions can be located hundreds of meters from the antenna and still interfere. Mount the antenna as high-off the ground as possible. There are simple propagation range calculators on the internet that will predict system range, and you will quickly see that height is a major factor in determining how far a system will go.

Installation Quality

Most all antennas needs a good "ground" to work properly, so mounting them according to the manufactures instructions is important. The ground of the antenna must be adequate, and the coaxial feed-line to the antenna should have low-loss. If the antenna coax run is long (more than 30 feet at VHF or 10 feet at UHF), then the feed-line should be of higher-quality (lower-loss) type, which is more expensive, but still less-costly than adding power amplifiers to the system.

Modulation

There are dozens of common modulation techniques used in modern communication systems. AM, FM, OOK, MSK, GFSK, PSK, π/4 (and the spread-spectrum variants of these) all have advantages and disadvantages. The choice of modulation directly effects cost, power-consumption, bit-error-rates, and CPU processing power. Many radio system designers choose their modulation type based solely upon whatever is available from their semiconductor supplier. The performance and advantages of all classical modulation types is well understood, so often the modulation choice will come down to cost and complexity. PSK may be better than AM, but a PSK transmitter will cost many times that of an AM. As the system designer has little choice in this, this paper will not address the relative merits. The system engineer can determine how well a particular modulation scheme works by looking at a receiver's *Sensitivity Specification*. The receiver sensitivity specification shows the engineer how well the modulation works as well as how well it was implemented in the product they are considering.

Protocols

The radio protocol is used by the system designer to offset many of the other limitations of the system. Weaknesses in the modulation method, antenna performance, frequency band, and power constraints can all be offset with a proper protocol. Many standard protocols address common data communication issues.

802.11, Zigbee, AMPS, and BlueTooth are just a few examples of the literally hundreds of radio protocols available to the system engineer. When the application is unique, and the standards don't fit, a custom protocol designed for the system in mind may be the path to a successful product.

A Forward Error Correction (FEC) protocol may be overlaid onto any modulation scheme to improve its immunity to interference and reduce bit-errors. It does this at the expense of data throughput.

Automatic Request (ARQ) is a handshaking protocol that enables modems to re-transmit data that does not get thorough the first time. Transparent to the user, it enables wireless modems in noisy environments to work error-free.

A cellular hand-off protocol, message repeaters, and access-points also may be added to the system design to increase its wide-area coverage. This is often implemented in systems that must cover rolling terrain, very wide areas, and even areas as large a nation.

A Case Study:

At Raveon, we began the development of a new wireless remote control system for outdoor landscape systems by lining up and prioritizing the main system requirement. By doing this, we could determine the driving factors in choosing which technologies to implement in the system.

Raveon's *LandScape™ System* Requirements:

1. **Low Cost.** The product technology must have a path to very low unit costs, to meet the expectations of the consumer market.
2. **500-5000 ft communication range.** The competition works over 50-200 ft, and we feel this is inadequate for a modern wireless system.
3. **Ultra-low power.** The technology must support products capable of operating 10 years off of D cells, and 1-3 years off of AA battery packs. This enables truly wireless products (no power cords) for rain sensors, weather stations, moisture sensors, security sensors,…
4. **Unlicensed Frequency Bands.** The radio must not require the end-user to obtain a license to use the radio. This is too costly and complex for most consumers.

There are dozens of other concerns, but these 4 were our most important issues. Each of the 4 requirements above were analyzed with regards to all of the technological solutions, and our conclusions were as follows:

1. **Cost.** Low-cost meant using off-the-shelf components, and low-power. By utilizing highly-integrated components off-the-shelf components, the solution will be lower-cost than one that used custom components, or a discrete design. The highest-volume integrated solutions are in the ISM frequency bands, so chipsets in used in these bands were studied. There are 3 basic ISM bands (900MHz, 2.4GHz, and 5.8GHz). Within these bands, a user may operate in low-power mode (non spread-spectrum) or a high-power mode (spread-spectrum). By keeping the RF transmit power level very low, there is no need for an RF power amplifier, and the costs associated with it and its supporting circuits. All vendors of transceiver chipsets in the ISM bands were studied, and the

merits of each compared. The merits of each were compared to the next 3 issues to yield the best chipset choice.

2. **Range.** To achieve the desired range, a link budget of 100 to 110 dB is needed. Because the cost has driven the RF transmit power to be as low as possible, a high-sensitivity receiver is required. None of the available low-power integrated solutions could meet the cost and sensitivity goals. Numerous high-power spread-spectrum chipsets and modules are available, but some chipsets would not meet the cost goals, and none of the available spread-spectrum modules would.
3. **Ultra-low power.** The need to operate years off of simple batteries disqualified the spread-spectrum solutions. But high-power spread-spectrum was needed to get the desired range. This presented the system designers with a classical dilemma. To achieve the desired range, something else was needed, and this something came in two parts. One part was an enhanced receiver design to improve the fundamental performance of the integrated chipset. And the other part was FEC and a custom protocol to increase the range of the system without increase RF power out. FEC and a reverse error correction were added to the system. Both of these are software solutions that increase the performance, with no impact to product cost.
4. **Frequency Band:** The 2.4GHz bands and 5.8GHz band were disqualified as candidates for this application because of the severe range limitation these microwave frequencies have when using omni-directional antennas. The 915Mhz ISM band was chosen for its superior range and low-cost implementation potential.
   After studying the RF environment in this band, as well as the out-of-band interference, additional interference rejection circuitry was added to the design to ensure the nearby paging and PCS signals to not interfere with the operation of the system.

This *LandScape System* has since been designed and constructed, and the desired system goals have been realized. The range of the system is similar to systems costing 3-5X more money, and the low-power, low-cost, and long range allow for the creation of new products that have not been possible before.

CONCLUSIONS:

So, how does one go about designing the ideal RF communication system? The trade-offs are complex and in many cases, one could make a career out of studying them. Lacking the time to do this, the best way is to step back, and look at ***all*** the constraints. Matrix these, and many of the decisions will become obvious. The remaining issues can be solved by careful evaluation of the technologies along with consulting experts in the field. Fortunately, many of the most complex issues have been solved by companies such as Raveon, who can offer complete wireless solutions.

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