This paper/presentation is intended for technical and semi-technical professionals that are or will be involved in the sales, engineering and/or integration process of Proxim Corporation products. It is intended as prerequisite material that should be reviewed and studied in advance of attendance in any technical course offered by Proxim or it’s partners.
It is critically important that students are completely familiar with the contents of this presentation/paper prior to the start of any Proxim technical course. Students are encouraged to bring any questions that arise from the review of this material to class; there will be an opportunity to clarify these concepts in the early stages of the training class.

This presentation/paper can also be treated as a stand-alone presentation or paper, unassociated with a Proxim training course, and used for the advancement of an individual’s technical understanding of Radio Frequencies applicable to Proxim Corporation products.

The author is always interested in the continuous improvement of this material. If you have any comments or suggestions for improvements, you are encouraged to e-mail these to Ken Ruppel: kruppel@proxim.com
This section is an introduction to technical concepts that are fundamental to the understanding of Proxim wireless devices and applications.
Point to point connections (also referred to as “PTP” or more rarely “PP”) are essentially similar to ‘leased lines’ between locations. All of the throughput assigned to the connections flows through from one place to another (in both directions). The utilization of the throughput typically has absolutely no impact on the performance of the system. That is, both ends of the system are fixed locations, and the throughput is defined either by the equipment deployed and/or the distance between the two locations. 100% of this throughput is available at all times to be utilized between both locations.

In some conditions, one or both of these locations may have several groups of users that are ‘sharing’ the total throughput of the connection. The connection is unaware of the sharing of data, however. Sharing policy is normally defined by external equipment, and not the connection itself. That is, if you have a wire or fiber going between buildings, the wire and fiber do not “know” anything about how many users are utilizing the connection, or, for that matter, if anyone is using the connection at all. The connection is there, and it will transport to it’s maximum capacity between the two end points whenever it is presented with information to transport.
Both indoor and outdoor wireless connections can be formed in a shared access environment. For example, most indoor wireless systems are point-to-multipoint (also referred to as “PTMP” or “PMP”), in that there are one or more central stations (typically called “Access Points” or “AP’s” and sometimes “Wireless Access Points” or “WAP’s”) and more than one user may connect to that AP and share the total capacity of that AP. Internet Service Providers (ISPs) often use outdoor PMP systems, as coverage can be provided to multiple user locations in a geographic area, and total system costs are lower compared to multiple point-to-point connections.

For ISP’s, it is extremely common to implement subscription services where the total throughput allocation is shared amongst many users and “over-subscribed” in that the promise to each customer with respect to total throughput available adds up to substantially more than the system can support. This is typically not problematic, as Internet traffic is extremely ‘bursty’ and it’s uncommon for multiple users at multiple locations to be requiring the maximum throughput connection simultaneously. Most people have experienced a noticeable drop in Internet access speeds at certain times of the day, as somewhere in the network, many people are competing for the total throughput of one element of the system at the same time. This is inevitable for any successful service, even if the connection from the ISP is not-oversubscribed, the backbone connections, or even central Internet servers or devices may be significantly taxed at certain times.

The important concept to understand here is that the total throughput of a PMP system is shared, not dedicated.
The Concept of Line-of-Sight (LOS)

- No obstructions between each end
  - No trees
  - No buildings
  - No mountains
  - Can you go through a window?
    - Probably, but with added losses that are hard to predict:
      » Plan on 10dB as an initial guess, can be greater for reflective (metallic) tinted glass

The term “line-of-sight” (sometimes referred to as “LOS”) can be a bit misleading. It does not necessarily mean that if you can see it, you have line-of-sight, and if you cannot, you do not. Instead, the basic concept is that if you could tie a string between locations and pull the string tight, the string would not be touching anything but air. Of course, the longer the distance, the harder this is to achieve, as more obstacles, including the earth curvature, terrain, buildings and trees may make this nearly impossible, impractical or extremely difficult. There is more to this concept than the simple string analogy. There are other requirements, such as “path clearance,” that are critical to most wireless systems. This is covered later in this document.

A common question about line-of-sight is if the wireless signal can go through a window, or potentially other materials (such as walls, or other materials). It’s important to understand that wireless signals will penetrate certain substances better than others, and in most cases the ability to accomplish this is a function of the frequency of operation, the substance material, the thickness and relative location to the wireless device, and the strength of the signal transmission. With enough energy, wireless signals can penetrate most everything. However, most wireless systems are designed to have minimal or no obstructions from one end of the system to the other. In the case of windows, most Proxim products will penetrate windows with little impact to performance, but certain reflective coatings on windows and/or lead-filled glass (virtually anything with metallic content) can hamper the abilities of the system, sometimes very significantly.
The Line-of-Sight Issue - raising one side

- A structure can be erected to establish line-of-sight over obstacles

In the case of many outdoor systems, especially for longer distances, line-of-sight may not be possible without increasing the height of one of the antenna locations to get over obstacles that might otherwise block the line of sight.

This diagram depicts the concept of raising the antenna at one end of a communications link to a position that establishes line-of-sight to the opposite end of the link. This drawing is exaggerated to illustrate this concept.
More common than raising the height of one antenna to establish line-of-sight over an obstacle is to raise the height of both antennas. Typically it is more reasonable to build two medium-height structures than it is to build one tall structure.
The Line-of-Sight Issue – using a repeater

- A system approach called a “repeater” can establish line-of-sight to go around or over obstacles
  - Active repeaters (two radio systems back-to-back)
  - Passive repeaters (one radio system redirected)

If building structures at the endpoints is not feasible or practical, one alternative configuration would be to use a ‘repeater.’ This example shows a repeater in an outdoor configuration, which is where this term is usually applied. However, you will find the term repeater also used in indoor wireless applications. Essentially, they are very similar.

A repeater utilizes a location where line-of-sight can be established to both endpoints. There are two types of repeaters, active and passive. An active repeater (which is the most common implementation) uses two radio systems in a “back-to-back” configuration, essentially two independent systems that are simply wired together at the data interfaces. A less common architecture is a passive repeater. A passive repeater is a single radio system, with a set of antennas or a “billboard” style reflector at the repeater site to “bounce” the signal between the two locations. Generally, passive repeaters are very difficult to engineer and implement. They often require extremely large antennas at all locations, and only can be applied to configurations where both legs of the link are rather short distances (generally less than 1 mile for outdoor systems).

More information on engineering repeater configurations is provided in technical classes. At this point it is important to simply understand the general concept that this approach is an additional method to overcome line-of-sight issues. Active repeaters can also be used to extend the distance capability of a system, even where no line-of-sight issue exists.
This section is intended as an introduction to radio wave behavior and some of the considerations that will be needed when designing and implementing wireless systems.
The Hertz Measurement of Frequency

- 1 Hertz (Hz) = 1 cycle/second
  - 1,000 Hz = 1 kHz
  - 1,000,000 Hz = 1 MHz
  - 1,000,000,000 Hz = 1 GHz

The Hertz is the unit of measure for frequency. Radio waves are typically described by their operating frequency.

You are probably familiar with numbering schemes for radio stations. For example, you may know a station that refers to itself as “95 point 7.” The number 95.7 is the frequency of the radio station in Megahertz (MHz), or millions of Hertz. That is, the transmitter tower that is broadcasting the radio signal is sending radio waves that are at 95,700,000 cycles per second, or 95.7 MHz.
A wave propagates in a repeating pattern (often represented as a sine curve, as shown above). This repeating pattern is of a fixed length, known as the wavelength. Wavelength is typically measured in forms of meters such as centimeters and millimeters.

Radio waves travel at the speed of light (c), which is roughly 300,000,000 meters per second. The expression for frequency and wavelength is \( c = f \times \lambda \), where \( f \) is the frequency in Hz and \( \lambda \) is the wavelength in meters. This equation illustrates that the higher the frequency, the smaller the wavelength.
At any point in time, the particular location of the traveling wave within its cycle is known as the phase. Phase is measured in either degrees or radians. 360 degrees and $2\pi$ radians make up 1 cycle.

At 0 or 360 degrees, the wave is in the starting position of the cycle. At 180 degrees, the wave is half-way through a cycle. The diagram above illustrates several phases within a cycle.
The Watt and the Decibel: Measurement of Power

- Watt (W)
- Decibel reference to 1 mW (dBm)
- Decibel (dB) - a ratio or difference in power
  > e.g. 20dBm is 3dB less than 23dBm

Conversion equations

\[
x_{(\text{dBm})} = 10 \log y_{(\text{mW})}
\]

\[
y_{(\text{mW})} = 10^{x_{(\text{dBm})}/10}
\]

Depending on how technical you are (or become!), you may eventually hear the terms “Watt” or “decibel” or “dB.” These terms all refer to power. In this case we are talking about the radio frequency (RF) energy (either transmitted or received).

You may have heard the terms Watt and decibel as other types of power, such as the term Watt used for power of appliances such as a light bulb or hair dryer, and decibel for audio power levels such as from a rock concert.

When referring to RF power, the equations provided above allow you to convert from dBm (decibels referenced to 1 milliwatt) to Watts, and vice-versa. The Watt and the dBm are precise power levels that have standard reference points. The term ‘dB’ is not a precise measurement, rather a measurement difference between relative power levels. The example shown is that 20dBm is 3dB less than 23dBm. The following page illustrates these relationships more logically than the equations.
As can be seen by the equations on the previous page, dBm’s are related to Watts in a logarithmic fashion. If you look carefully at the above diagram, these relationships can be easily seen.

First look at the 1 Watt line, which is equivalent to 30dBm. If you double the power (from 1 Watt to 2 Watts), this is equivalent to a 3dB increase in power. So, for every 3dB difference relative to one measurement, that is double or half the power. The next observation you may make is that is you increase the power (in Watts) by a power of 10 (such as from 1 Watt to 10 Watts) this increases the power by 10dB. Likewise you can see this as you decrease by powers of 10 and decrease power by 10dB.

Another factor that is illustrated here is that power measurement in dBm can be expressed as a negative value. As is shown, if you reduce power from 1 milliWatt (0.001 Watts) to a value one power of 10 less to 100 microWatts (0.0001 Watts), the power in dBm reduces by 10dB from 0dBm to –10dBm. It’s that simple! Values like the threshold specifications of Proxim radios are typically fractions of nanoWatts!

You might consider memorizing one point in the relationship, such as 1 Watt = 30 dBm, and then use the ‘rule of 10’s’ or the ‘rule of 3’s’ to make conversions without a calculator.
Just like light and sound, RF energy can be directed in a limited or narrow direction, rather than in a 360-degree sphere. In your technical advancement, you may hear the term “isotropic” which refers to a theoretical spherical energy source.

Again, like light and sound, the more energy that is applied the stronger it becomes (brighter, louder). Also, devices such as a reflector (such as the metallic silver surface behind a flashlight bulb in a flashlight), will increase the “volume” of light in a focused direction. The concept of focused energy is best related to an adjustable focus flashlight (such as the popular pen flashlights called ‘mag-lights’ or ‘mini-mag’) or a megaphone in front of your mouth (these are the cone-shaped devices that you speak into to direct your voice louder in one direction).

From time to time, you will hear the terms ‘power’ and ‘gain.’ These are related to one another, but not exactly the same. In our flashlight example, the batteries and the bulb make up the transmitted power. The reflector is the instrument providing gain of the signal in a focused direction. Power is a measure of strength - gain is a measure of amplification.

Relating this back to decibels, we can have a transmitter that has 20dBm of output power. This transmitter can be attached to an antenna that has 10dB of gain, and this results in 30dBm of ‘effective’ output power in the direction of the main beam of the antenna.
Most people are familiar with the term Watt, as it is used to describe many household devices, such as light bulbs, microwave ovens, stereo systems, etc. So how much power is a Watt? In RF energy terms (so you can relate this directly to radio communication systems later), a standard microwave oven has power between 700 to 1500 Watts. This is a fairly high amount of RF energy that is needed to cook your food quickly. Likewise, a standard cell phone has RF output in the neighborhood of 100mW to 200mW. This is comparatively much less energy than your microwave oven!

Most indoor and outdoor communication systems from Proxim Corporation have an output power in the range between 10mW (0.01 Watts) to no more than 1 Watt.
We discussed gain and directivity of RF waves and compared them to light and sound. You can further this concept by visualizing that they behave similar to light and sound in many additional ways.

For example, light, sound and radio waves all reflect off surfaces and are also partially absorbed by surfaces. They also diffuse (scatter) and refract (bend) like light and sound waves. You know from experience that an empty room with wooden floors and no curtains reverberates sound, similar to the sound of your singing in the shower! These reverberations are caused by the audio waves bouncing off the floors, walls and ceiling and returning to your ears multiple times from multiple directions. Likewise, light travels this way too, such as a light bulb in an empty room with white walls, versus in a room full of furniture and darker colored walls. You will see shadows and the overall light will be less bright into your eyes.

Think of your eyes and ears as receivers, and your voice as a transmitter. This is an accurate simplification of RF radio waves. In the way that sound and light behaves, you can draw the same conclusions for RF energy. However, the amount of reflection and/or absorption as well as diffusion or refraction is dependent on the surface or substance that it’s bouncing off, or flowing through. Eventually, you will become familiar with the effects of different substances on radio waves. For example, humidity and rain can have an effect upon the transmission and reception of radio waves at certain frequencies.
The graphic shows a common example of refraction. You’ve probably seen the apparently bent straw or spoon in a glass of water, or reached into water to touch something, and it’s not exactly where you think it is. This is because the light waves bend when they pass through water compared to air. Again, radio waves behave in a similar manner.

Scattering is best visualized by considering looking at a light source when it is foggy versus when it is clear. When it is foggy, you will see less energy overall (as some of it is absorbed and/or reflected away from you by the water molecules) and the light that you do see will be ‘fuzzy’ in comparison. Again, radio waves behave in a similar manner.
When we are considering line-of-sight, as well as other concepts such as ‘beamwidth’ (which is a term that will be used often in class), if you are having trouble with the concept, you can almost always relate RF concepts to light or sound. From the reception perspective, think of your eyes or your ears.

If you place blinders that block your peripheral vision, you will not be bothered by light sources (or seeing objects) to your side. Directional radio antennas have a similar ability, effectively blocking (or more accurately, reducing) the energy that can be received (‘seen’) in any angle other than the angle it is pointed. Similar to the directionality and relative directional gain that you would get by speaking into a megaphone, you would also get directional gain by placing a megaphone in front of your ear. The megaphone in both cases causes less energy from off-angles to be transmitted or received.

Likewise, bad weather or obstructions may limit your ability to see or hear, and this is likewise true for radio waves.
A common question regarding radio waves used for outdoor communications is in regards to the effect of rain (or snow or fog or any inclement weather). This chart helps illustrate the effect of rain on radio waves. As can be seen by the chart, there is a substantial difference in the effect of rain on systems operating at or below 6 GHz frequencies compared to 11 GHz or higher frequencies. In a cloudburst condition (this is typhoon-type rain), the attenuation (loss) of the signal level can be substantial. On a per-mile basis there is 8dB attenuation at 11 GHz compared to only 1dB attenuation at 6 GHz. This becomes fractions of a dB per mile at frequencies below 6 GHz - virtually ignorable.

Later we will discuss distance planning of radio systems. For radios operating at higher frequencies (such as 11 GHz and higher), planning for rain attenuation is critical. Using a 10 mile path for an example, a cloudburst condition will cause only 10dB of attenuation at 6 GHz compared to 80dB at 11 GHz. Remember that every 3dB is half the power! So, 10dB is a little less than 12% of the original power (half of half or half, if it were 9dB loss). Imagine the fraction for 80dB! As you will learn in the technical training courses, it’s completely impractical that a system can be designed to withstand 80dB of loss.
Again, like light and sound, radio waves can be blocked or partially blocked by obstructions. The effect will depend how much blocking is occurring as well as the nature of the blockage. You’ve seen this with cellular phones and AM/FM radio, where the reception gets very poor the closer to the center of the building you get, as the radio waves generated from outside the building must pass through more and more substances. The higher you go in frequency, the more critical this becomes. Virtually all of Proxim’s equipment works in “middle” frequency bands that are not ideal for penetrating through substantial barriers, but are able to penetrate some.

The above graphic is an excellent depiction of what happens to a light wave when it hits a sharp obstruction. You can see by the intensity at the right of the graphic that the overall intensity is ‘distorted’ even in the region where there is line-of-sight, and there is a little bit of ‘leakage’ into the area that didn’t have direct line-of-sight to the light wave.

This point is very important for communications systems. Because if the primary radio wave is even partially obstructed, not only will it be partially blocked, but it will also be ‘distorted.’ For communication systems, this can be much more critical than it might be with light or sound. For outdoor systems, it is generally intended that there will be no obstructions whatsoever between the ends of the the communication system. For indoor systems, this is less critical, as the endpoints of the communications connection are much closer (a matter of feet compared to potentially miles for the outdoor system), and therefore the received signal level will be stronger.
We discussed the bare room with wooden floors and the impact on reflections for light and sound. For radio waves, it’s again the same. Generally, for indoor systems, this is not an issue. In fact, most indoor technologies are designed to operate under conditions of many reflections and reflections can help the reception and transmission of the radio waves, as you might want the signal to bounce around a corner to get behind a wall, or into a hallway.

For outdoor systems, again it’s much different. We will want to minimize or eliminate potential sources of reflections. This concept will be discussed several times through the remainder of this paper as well as during the technical training courses.

Remember, that if a radio wave bounces off a reflection object, the direct radio wave and the reflected wave will arrive at the receiver at two different times. The reflected wave will have traveled a longer distance, passed through more air, some energy absorbed by the ‘extra’ air as well as the reflective substance, and therefore will be reduced in amplitude compared to the direct signal.
If two radio waves of the same frequency arrive at the reception point at the same time and in the same phase, the signal amplitude will be increased. That is, the phase will add and the signal will be stronger than the original signal. If several waves of the same frequency arrive at the same place in the same phase, they will all add together for greater total amplitude.

Recalling the previous page on reflections, you may conclude that certain positions for the reflective surface relative to the origination and reception point will cause additive phase, as the reflections will be delayed in time equal to a multiplier of the wavelength (in distance), and the reflected signal will arrive at the reception point perfectly in phase with the direct path. When this happens, the signal received will be stronger than if there was no reflection.
The opposite of the in-phase additive effect is the effect of signal phase cancellation. If two signals of the same frequency arrive at the reception point exactly 180-degrees out of phase with respect to one another, the amplitudes of the signals will cancel one another, or reduce signal amplitude, potentially to zero, as shown above if perfectly out of phase at the same amplitude and frequency.

Reflective substances at certain locations will result in signal amplitude reduction, and potentially, the complete cancellation of the signal reception. It’s probably somewhat obvious that it’s unlikely that reflections will cause complete cancellation since being perfectly out of phase and at equal amplitude would require near-perfect precision! However, it is VERY likely that a reflection will have SOME effect on the signal level, with some of the effect being additive and some of the effect being subtractive. In radio system design, we won’t be too concerned about improving the signal level, but we will be concerned about reductions in signal level – so reflection points will need to be eliminated, minimized and/or controlled, where possible.

As it has been illustrated, the position of reflective substances, and their effect upon reception, is directly related to the frequency of the signal that is being received. The distance that the wave travels when reflected is related to the wavelength, and if it’s an even number of half-wavelengths through the entire reflected path, the signal will arrive in phase where an odd number of half-wavelengths will arrive out of phase. As an example, the wavelength of a 5.8 GHz signal is approximately 2 inches, so a half-wavelength is only 1 inch. This means that if the reflected wave travels one inch further in one case compared to another case, it will have the opposite effect on cancellation or addition to the direct wave. One inch makes all the difference!
The understanding of the effect of reflections and signal phase additions or subtractions is the pre-cursor to a discussion of something called the “Fresnel Zone” (the “s” in Fresnel is silent). This concept primarily applies for outdoor wireless applications, where distances are longer and the effects of multipath reflections can be very serious. The Fresnel zone is an area that is defined by an ellipse whose edges are in the location where reflections will arrive exactly ½ wavelength out of phase (relative to the defined frequency). There are several Fresnel zones, that is, several elliptical boundaries, forming concentric ellipses. These ellipses are completely three-dimensional. That is, they have equal width as they do height.

When designing outdoor wireless systems, there should be an evaluation of the path clearance between the endpoints of the system to assure that not only line-of-sight is achieved, but that obstacles in the path do not cause reflections at Fresnel zone boundaries. In an improper design, when obstacles infringe upon the Fresnel zone boundaries, reflections will cause serious impact to signal reception, causing unreliable connections.

Remember that Fresnel zones are three-dimensional. When designing a link that goes down a street between buildings, or between groves of trees, these are also potential sources of reflection points and need to be evaluated in the design.
The *k* factor defines how the radio wave bends (due to refraction) in relation to the earth’s surface.

Refraction index variation results from changes in temperature, humidity, barometric pressure, and air density. These effects are most likely to occur in:

- The early morning (dark) hours
- The springtime and fall
- Still air environments
- Humid environments

Summarizing this slide and the previous slide, the earth curvature, the related *k* factor and the Fresnel zone all need to be considered when determining that line of sight, proper path clearance and no problems with reflections will occur during system operation. These factors should help illustrate that you can almost never depend on visual line-of-site to verify that you have radio line of site. Also, without evaluating the exact location of the antennas relative to the ground and obstacles on the ground below and around the radio path, it can be difficult to predict the impact of reflections on the radio signal.

It should be noted that these potential issues are often overlooked in many radio system designs and can be the source of many problems when improperly designed or ignored. Proper antenna placement is critical in EVERY system design to minimize these effects. Even short distance building-to-building applications can be effected by these issues. In some cases, positioning an antenna a few feet or even a few inches from one position to another can make substantial difference to the radio system reliability.
Polarization describes the orientation of the E (electrical) and H (magnetic) components of an RF wave front.

- Linear polarization (horizontal, vertical, slant linear)
- Circular polarization (right-hand, left hand)

RF can be transmitted (and received) with dominant polarization

- Polarization provides a level of discrimination (attenuation) against different polarization signals, especially "opposite" polarization (e.g. horizontal versus vertical)

Weather and multipath can "de-polarize" RF

There are two components to an RF signal: electric and magnetic. These components travel at 90 degrees relative to each other. The term “vertically polarized” means that the electric wave is traveling vertically and the magnetic wave is traveling horizontally. Most antennas are linearly polarized and can be configured for either vertical or horizontal polarization by selecting a particular physical mounting orientation 90-degrees relative to one another. In any wireless communication system, the transmitting and receiving antennas should ideally be oriented to have the same polarity. For outdoor systems, it is critical that they are matched.

Some antennas utilize circular polarization. The concept is no different, except that the signal polarization now travels in a ‘corkscrew’ fashion, either clockwise or counter-clockwise rotation.

You are probably familiar with the brand name “Polaroid”. This brand was originally applied to the sunglasses that were produced under this brand (before this brand was applied to instant film developing!). The brand name likely comes from the term polarization, in this case referring to light waves. These lenses are designed to reject some polarizations of light, while accepting others. This has the effect of reducing the light that passes through these lenses.
The terrain between two end points of a wireless communication system has an impact on the system performance. As you may guess by now, mountainous (or uneven) terrain is advantageous to signal reception. Many potential reflections are bounced away from the receiving antenna, therefore resulting in few, if any, reflected signals received at either end.

Likewise, flat terrain is more challenging for RF system design, as radio waves may easily reflect between the end points and these reflections may be received at either end.
Climate Effects on RF

- Humid climate is worst
  - More moisture = more ducting and refraction = more attenuation
- Dry climate is best
  - Reduced moisture = less ducting and refraction = less attenuation

You might have also already reached the conclusion that dry climates are advantageous to RF propagation compared to humid climates. Humid climates will impact radio waves by absorption, reflection and refraction of signals against the water molecules in the air between the end points.
This section describes the overall radio spectrum with focus on the radio frequencies that Proxim equipment utilizes.
This chart is a generalization of the different frequency bands, some with which you may already be familiar. The band names are shown in the middle stripe. The band names are not that important, but it is important to understand the relationship of one band as it relates to another.

Proxim’s products generally operate in the SHF (super high frequency) band. Some Proxim products operate just above or just below this band. The diagram illustrates other items that occupy some of these bands.
This difficult-to-read chart is provided only to illustrate one thing. That is, that radio frequencies are regulated by the government. In this case the chart illustrates the allocations that have been made of particular radio frequencies to different types of services and users within the United States by the Federal Communications Commission (FCC).

You will notice on the chart that at some locations, you see a ‘stack’ of 2 or more colored boxes. This illustrates that within these bands, more than one service is allowed to use this frequency band. Some frequency bands are wholly reserved for particular uses, such as government communications, radio and television.

To say that a particular frequency range is reserved for a particular service or set of services should accompany the statement that each frequency band has precise regulations for its use by different services. These regulations attempt to protect systems from causing harm or interference to one another and also address safety with respect to RF energy and health issues.
Virtually all the radio spectrum can be categorized into one of these categories. These are not ‘official’ categories of wireless services, more an interpretation by the author.

License-exempt (also known as license-free or unlicensed) spectrum is spectrum that is available for general commercial and consumer-based wireless devices. The user does not have to register the use of the wireless device with the government, and does not have to be in a particular location when operating the equipment. Most of Proxim’s systems are license-exempt; you have the freedom to install these systems wherever you wish, similar to remote controls and cordless phones.

Licensed spectrum is ‘coordinated’ with other users of the same spectrum in the same area. Licensing requires the user to register the intent to use a system at a particular location and the regulatory agency (or their agent) reviews the requirement and determines a configuration that can operate as desired with no impact on previously deployed systems. This process can be time consuming and fees are associated with this activity (including renewal costs). However, for systems carrying mission-critical information (such as emergency communications) or tied to significant revenue (such as the backbone for a cellular operator), licensing can be very comforting to the user.

AM/FM radio, television and cellular service fit into the “owned” category. This spectrum is allocated to a particular user in a particular area. This is not significantly different from licensed, except that the rights are to a large amount of spectrum for a significant period of time, and other users will not be granted overlapping licenses in the same region.

<table>
<thead>
<tr>
<th>Types of Spectrum</th>
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<tbody>
<tr>
<td><strong>License-exempt</strong></td>
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<tr>
<td>&gt; Anyone can use</td>
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<tr>
<td>&gt; No coordination or registration required</td>
</tr>
<tr>
<td>&gt; Opportunity for interference, which the user must work around</td>
</tr>
<tr>
<td><strong>Licensed (or ‘Leased’)</strong></td>
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<tr>
<td>&gt; Coordination required</td>
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<tr>
<td>&gt; Registration required</td>
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<tr>
<td>&gt; Interference is better controlled, but not completely eliminated</td>
</tr>
<tr>
<td>▪ Regulatory agency will assist with any interference cases</td>
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<tr>
<td><strong>Owned</strong></td>
</tr>
<tr>
<td>&gt; Purchased spectrum, usually in a given region, usually by auction</td>
</tr>
<tr>
<td>&gt; Owner needs to self-coordinate intra-system interference potential</td>
</tr>
<tr>
<td>&gt; Some coordination may be needed with neighboring owners</td>
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</table>
Three primary ISM (Industrial, Scientific, Medical) bands:

- “900” MHz
  - 902-928 MHz
- “2.4” GHz
  - 2400-2483.5 MHz
- “5.7” or “5.8” GHz
  - 5725-5850 MHz

Three primary U-NII (Unlicensed National Information Infrastructure) bands:

- “5.2” GHz (or “Lower 5”)
  - 5150-5250 MHz, indoor only
- “5.3” GHz (or “Middle 5”)
  - 5250-5350 MHz, indoor and low-power outdoor
- “5.7” or “5.8” GHz (or “Upper 5”)
  - 5725-5825 MHz (higher power, outdoor)

Many license-exempt systems utilize one of the ISM or U-NII bands, and this is true of most Proxim products. These bands have been designated by many countries for license-exempt use, and some standards have arisen for interoperability of certain devices from region to region to establish systems that will communicate with one another easily.

The U-NII bands have still not been recognized for unlicensed use in many countries, however this is changing rapidly with the deployment of increasing consumer devices in these bands. In countries outside of the USA, these bands may be designated by other names, such as LE-LAN (License Exempt Local Area Network) in Canada.

The purpose of this slide is to simply become familiar with these names and the designations of these bands. People may refer loosely to some of these bands as 2 GHz (in the case of 2.4 GHz ISM) and 5 GHz (meaning the collective bands in the 5 GHz range). Also, some people may equate the term “ISM” or even the term “license-exempt” with the term “Spread Spectrum.” The use of the term ‘spread spectrum’ to describe devices operating in these bands, as well as vice-versa is a misleading statement. In the early days of the ISM band regulations, a certain radio technology called ‘spread spectrum’ was required for operating in the ISM bands. This is no longer the case, and spread spectrum technology has never been required in the U-NII bands. Some devices that operate in these bands do utilize spread spectrum technology, although this does not represent all devices operating in these bands making this association less and less accurate.
The Concept of Interference

- Interference is the reception of signals from sources other than the intended source
  - The source of the interference may be from a closer and/or stronger signal level compared to the desired signal impacting the ability of the system to receive the desired signal properly
- Interference can be caused by energy that is at the same frequency as the signal that you wish to receive, or can be at a nearby frequency with enough energy to ‘leak’ into the receiver
- Interference can also be caused by energy that is a completely different frequency from that which you wish to receive. High-powered transmitters can radiate ‘harmonics’ where they are also inadvertently transmitting energy that is a multiple of the intended transmitter frequency

All radio reception can suffer from interference. Other systems operating at the same or similar frequencies, usually nearby your system or pointed at your antennas, can cause interference into your system. Interference can also be caused by unintentional transmissions, such as signals that ‘leak’ from electronic equipment that are nearby your radio equipment. In many cases, interference will not cause disruption to the radio system. Generally the interference must present strong enough energy at the intended receive frequency to cause issues. The amount of energy depends upon the technology that is applied and its ability to operate under adverse conditions such as interference. For example, some systems may change frequencies when performance is inhibited, others may have circuits or algorithms that are designed to counter interference.

One practical example is that of a conversation that you might be having in a crowded noisy room. You may have to raise your voice or turn your ear towards the speaker to provide intelligible reception in the presence of the other noise that is being received by your ear.

The most common cause of interference for Proxim’s systems is self-interference. That is, our customers may be deploying several devices that operate in the same frequency band at the same location. This is allowed, but in all cases, the system design must take into consideration the selection of frequency channel plans, locations for antennas, power output and other related issues when designing and deploying the system so as to minimize the effects of the interference on the intended level of performance.
This section describes some of the basic product technology concepts that will be required to understand during the Proxim training course.
### Methods of Two-Way Communications

- **Frequency Division Duplex (FDD)**
  - Communications in one direction are at a different frequency than in the other direction, transmitting and receiving in both directions at the same time
    - Can establish high speeds in both directions (usually equivalent speed)
    - No substantial time delays (latency) for communication, as no information is buffered
    - The difference in frequency can be small (a few MHz) or large (100's of MHz), in the same frequency band or different bands altogether
- **Time Division Duplex (TDD – or ‘Ping Pong’)**
  - Communications in one direction are at a different time than in the other direction, transmitting and receiving at the same frequency but in succession
    - Can provide unbalanced communications when desired (e.g. more download than upload, or variable to demand)
    - Has an impact on latency

Most PMP systems utilize TDD approaches for establishing two-way communications. This is an efficient use of throughput and spectrum for shared-access systems. Outdoor point-to-point systems are known to use either TDD or FDD, depending on the application and requirements of the system.

For Internet-style communications, TDD systems are well suited. Internet traffic is very resilient to delays as well as having built-in protocols for retransmission of information. TDD technology is generally lower cost, as it utilizes a single radio circuit chain for both transmitting and receiving. TDD systems can result in delays to the information that can be too great for certain applications. Voice, for example is an application that is not very tolerant to high latency. You have probably experienced a long-distance call where when the person spoke, there was a large delay before it was heard at the other end. This is caused by latency. As you know, it makes it difficult to carry a conversation. Likewise, you may have used a speakerphone where one person keeps talking and they cannot hear you, as the microphone turns off when the speaker is being used. This is similar to the transmission of signals using TDD, except that the TDD systems can often coordinate inbound and outbound communications with great precision.

FDD systems are used more for voice traffic and/or longer distance connections where latency cannot be tolerated and full throughput is needed in both directions simultaneously. This is especially critical for system implementations that use several links to establish communication from the edge of the network to the core. While latency of a single TDD system may not be significant to a system, when several systems are connected together, the latency may be too great to tolerate. FDD systems will not exhibit these issues.
It is important to understand the configuration of the equipment that you are considering. Every radio system requires antennas at both ends. In some cases, these antennas are integrated into the product. In some cases, integrated antennas allow for alternative antennas to be connected instead. In other cases, there is no antenna provided and a choice of antennas is available.
For outdoor applications, some radio systems are designed in a one-piece chassis, normally designed for mounting indoors or in an enclosure. In these configurations, a cable is used to remotely locate the antenna from the radio hardware. The advantage of this approach is that the radio hardware is in a location where it is easy to install and easy to access for maintenance. The potential disadvantage of this approach is that it can result in higher cost cabling for the antenna system, and the longer cable length may introduce more loss and impact system performance. In many applications, this impact is minor or can easily be overcome in the system design.

Other outdoor applications use radio systems that are designed in a two-piece configuration. These configurations allow for a portion of the radio system to be mounted outdoors, near the antenna. This packaging approach has the potential advantage of reducing the length and associated loss of the cable that connects the antenna to the radio, thus improving performance or resulting in smaller antennas. However, this approach has the potential disadvantage of a more difficult installation and maintenance (as part of the radio system is mounted outdoors, potentially high on a pole or tower).
Antennas come in many different shapes and sizes. Omni-directional antennas are intended to provide circular, or semi-spherical coverage. Directional antennas range from sector antennas (intended to provide a certain sector of coverage) to highly-directional antennas (providing precision beamwidth for point-to-point applications).

Every antenna has a specified gain measured at it’s primary direction. This gain figure (in dB) will be used to determine the strength of the signal from the transmitter (output power minus any cable loss plus antenna gain) as well as the received signal gain.

Every antenna also has a specified coverage or gain pattern (as shown above in the graph for a directional antenna). The antenna pattern illustrates the directional gain (or attenuation) of the antenna. Antennas also have a dominant polarization relative to their physical mounting. Linearly polarized antennas can be changed from vertical to horizontal by simply rotating the entire antenna 90-degrees or by rotating the ‘feed’ of the antenna (where applicable).

It is important to understand that the more directional an antenna is, the higher the gain of the antenna in the direction desired. So an omni-directional antenna has fairly low gain, where a point-to-point highly-directional antenna has high gain, and sector antennas are in-between. For highly-directional antennas, the larger the antenna, the higher the gain and the more narrower the beam pattern (beamwidth).
This section is intended to familiarize the reader with the concepts of transmission engineering. That is, the engineering that goes into determining if a system configuration is going to operate, or configuring a system to accomplish a particular application.
The primary objective of radio system design is to establish connections between certain locations. RF signals dissipate while traveling through the air and they change their behavior while traveling over or bouncing off nearby objects and through changing air density. All of these factors may impact system performance. The fundamental objective is to design the system to provide the coverage or the distance desired.

As mentioned earlier, the radio technology (such as TDD or FDD) may have an impact on distance. Of course, the strength of the transmitted signal and the ability of the system to ‘hear’ (receive) the signal are the cornerstone of the abilities of the system. Clearly, if something is louder, you can hear it from further away. Also, if you have a better sense of hearing, you can also be further away.

The frequency of the system also has an impact on the distance or coverage. As mentioned earlier, higher frequencies generally do not travel as far (under equal conditions) as lower frequencies. However, governmental regulations may apply to certain frequencies which may limit or extend distance capability at particular frequencies. The effect of obstacles, climate and terrain on distance was discussed earlier.

The antenna pattern is also a critical element of the system design. For point-to-point outdoor communications, highly directional antennas are usually implemented, which helps to ‘focus’ the transmitted and received energy only in the direction desired. For indoor systems, omni-directional antennas, or large beamwidth sector antennas are typically used to provide coverage over the area desired relative to the location of the antenna. For outdoor point-to-multipoint configurations, a similar approach is used to the indoor environment, choosing antennas that provide the coverage footprint desired.
For any radio system the ability to receive the signal from the other end, over a given
distance, is a simple equation of gains and losses. Using the diagram above you can
follow the signal from the left to the right and see the different gain and loss elements.
Fundamentally, if the signal level that arrives at the input of the receiving radio is higher
than it’s threshold (it’s minimum discernable signal level without significant error), then
the signal will be received. The level of that signal is called the “Received Signal Level”
and commonly is referred to as “RSL.”

Generally, you wish to optimize this signal level as high as possible so that any issues
with the path (obstructions, reflections, etc.) have less impact. Also, a higher received
signal level will mean that the reception will be more robust against interference, as
interference must compete with the intended signal level.
System Gain is a critical factor for radio systems. Considering the diagram from the previous page, the output power and the threshold are the two radio specifications that are part of the distance planning mathematics. High system gain has the potential advantages of:

• Allowing longer distance connections
• Allowing smaller antennas with less gain
• Overcoming cable loss
• Creating higher received signal level
  • Better system performance
  • Better immunity to interference

Fade Margin is the difference between the RSL and the Threshold. This term gets its name from the concept that the signal level may ‘fade’ (reduce) due to atmospheric effects. The stronger the RSL, the more reliable the system will be, therefore, fade margin should be maximized in all wireless designs, especially outdoor links, and most importantly for longer distances.
The term “Availability” is commonly applied to outdoor wireless systems and usually only for dedicated connections. In simple terms, the higher the fade margin, the higher the availability. However, availability equations include other factors such as the specific frequency, terrain, climate, and the distance of the wireless connection. The equations that have been developed for these predictions are of reasonable accuracy for high-quality wireless link designs and are the standards upon which most telecommunication infrastructures depend.

Proxim believes that outdoor wireless links should be designed (and then implemented) to the desired availability standard that the customer wishes to achieve. There are no actual standards for availability, but Proxim has developed the following general guidelines:

- 99.995% or greater for telephone circuits
- 99.950% or greater for IP-based data connections

These standards are very general. Clearly, the network design and the nature of the information being carried over the connection can change these numbers to be more or less conservative. For example, an IP-data circuit that has an alternate route with spanning tree may not be seen to require as high of an availability standard as an IP-data circuit that is the only connection for a large business to their servers or the Internet. Likewise, a high-capacity voice circuit may be desired to operate at a higher availability standard than a lower-capacity link. That is, more revenue and more calls are being supported by the higher capacity link, and therefore the reliability is more critical.
The author hopes that this tutorial is helpful to your general understanding of wireless concepts. The information contained in this paper/presentation is intended to be general, but also aimed at the specific concepts that are required for a baseline understanding of wireless technology required prior to entry into any Proxim technical training course. If you have any questions or comments about this content, please bring them to class, as there will be an opportunity for discussion. Also, the class will cover some of these concepts much more deeply where needed. If you are reading this paper and do not plan to attend a Proxim class, your comments may be forwarded directly to the author, Ken Ruppel, Director of Systems Engineering at Proxim, via e-mail at: kruppel@proxim.com