

# RuggedWireless™ “The Wireless Guide”



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# 1 Overview


This document is aimed at operational managers and engineers tasked with creating, extending, or modernizing their existing communication structure to include 802.11 Ethernet-based wireless technologies. The factors involved in designing, maintaining and understanding 802.11 communications networks will be addressed, in the hopes of making transitions toward new wireless installations smooth and efficient.

## 2 A Basic Introduction to IEEE 802.11 Radio-Frequency and Antenna guidelines


### 2.1 IEEE 802.11 Spread Spectrum technologies

The RS900W RuggedWireless family utilizes the IEEE 802.11g standard for wireless communications. This standard describes a mode of radio-frequency communications mode which in turn utilizes underlying spread-spectrum technology. The advantages of spread spectrum technology include the ability to allow multiple users to occupy the frequency band with a minimum of interference to other users (i.e. very tolerant to interference sources).

Conventional spread-spectrum technologies rely on single carrier modulation schemes, such as Frequency-hopping spread-spectrum (FHSS) – whereby a narrowband carrier changes frequency in a pattern known to both the transmitter and the receiver. With proper synchronization the sustained effect is to create a single logical data channel. To an unintended receiver FHSS appears to be short-duration impulse noise. Another type of wireless spread-spectrum technology is the Direct-sequence spread-spectrum (DSSS) – which generates called a very short duration *chip* (often called a chipping or a chirping code). Direct-sequence spread-spectrum transmissions multiply the data being transmitted by a "noise" signal built from these *chirping* codes. This noise signal is a pseudorandom sequence of 1 and -1 values, at a frequency much higher than that of the original signal, thereby "spreading" the energy of the original signal into a much wider band. To an unintended receiver DSSS energy appears as low-power wideband (i.e. "white") noise and is rejected by most narrowband receivers.

 *The original 802.11 (2 Mbps) and the 802.11b (11 Mbps) standards utilize the DSSS mode of communication.*

Orthogonal Frequency Division Multiplexing (OFDM) is differentiated from other spread-spectrum technologies because it is a multi-carrier modulation scheme. Instead of transmitting the data serially over a single fast channel, it relies on multiple carriers to transmit data in parallel using the entire allocated channel bandwidth. By utilizing a large number of closely spaced but orthogonal (i.e. independent) sub-carriers, these individual sub-carrier are individually modulated with a conventional modulation scheme (such as QAM – quadrature amplitude modulation) at a low symbol rate maintaining (aggregate) data rates similar to conventional *single-carrier* modulation schemes in the same bandwidth. In practice, OFDM signals are generated using the (Inverse) Fast Fourier Transform algorithm. The primary advantage of OFDM over *single-carrier* modulation schemes is its ability to cope with severe channel conditions — for example, multipath and narrowband interference — without complex equalization filters. Channel equalization is simplified because OFDM can be modeled as having many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. OFDM generally has a nearly 'white' spectrum, giving it benign electromagnetic interference properties with respect to other co-channel users.

 *The 802.11a and 802.11g standards (54 Mbps) utilize the OFDM mode of wireless communication.*

### 2.1.1 Spread Spectrum radio performance factors

Spread spectrum technology almost exclusively utilizes the frequency bands that have been (internationally) reserved for unlicensed applications. This means that in order to operate a spread spectrum device, no transmit license is required. The bands currently authorized for spread spectrum emissions are: 902-928 Mhz, 2400-2483.5 Mhz and 5725-5850 Mhz.

 It must be noted, that the user is not guaranteed exclusive use of these frequencies, as is the case with licensed frequencies

Frequency Range	Band	Comments
900-928 MHz	ISM	Limited availability: US, Canada, Australia, parts of South America, 868 MHz in EU
2400-2483.5MHz	ISM	Used by 802.11b and 802.11g
5725-5850 MHz	ISM	Used by 802.11a

Table 14 - Unlicensed spectrum frequency bands

ISM – Industrial, scientific and medical

EIRP – Effective isotropic radiated power

	Frequency Band		
	900 MHz	2.4 GHz	5.7 GHz
Interference levels (current crowding)	Highest	Median	Lowest
Bandwidth	28 MHz	83.5 MHz	125 MHz
Free space attenuation	Lowest	Median	Highest
Antenna gain/size ratio	Lowest	Median	Highest
Antenna mounting and feed considerations	Lowest	Median	Highest
Atmospheric effects	Lowest	Medium to High	Highest
Multipath fading	Median	Lowest	Highest

Table 15 - Comparison of the ISM frequency bands

	FHSS	DSSS	OFDM
Basic spreading strategy	Interference avoidance	Interference minimization	Data rate maximization
Spectrum Utilization	Lowest	Median	Highest
Range	Lowest	Median	Highest
Multipath fading rejection	Median	Lowest	Highest
System Complexity	Lowest	Median	Highest
Maximum data rate	Limited by FCC rules	Median	Highest
Latency	Highest	Median	Median
Power Consumption	Lowest	Median	Highest
In-band interference behavior	Dynamic data frame dropout on occupied channels	Graceful degradation until jamming margin is exceeded followed by total link failure	Adaptive data rate reduction
Loss of synchronization (penalty)	Highest (seconds)	Lowest	Low
Out of band interference rejection	Lowest	Highest	Medium to High

**Table 16 - Comparison of RF modulation technologies**

FHSS – Frequency Hopping Spread Spectrum

DSSS – Direct Sequence Spread Spectrum

OFDM - Orthogonal Frequency Division Multiplexing

## 2.2 IEEE 802.11 Antenna topologies

The single most important item affecting radio performance is the antenna system. Careful attention must be given to this part of an installation, or the performance of the entire system will be compromised. High quality, gain antennas should be used at all master and remote stations. The antennas should be specifically designed for use at the intended frequency of operation.

Antennas are made by a number of manufacturers and fall into two general categories: *omni-directional* and *directional*. An omni-directional antenna provides equal radiation and response in all directions and is therefore appropriate for use at master stations, which must communicate with an array of remote stations scattered in various directions. At remote stations, a directional antenna such as a yagi is typically used. Directional antennas confine the transmission and reception of signals to a relatively narrow lobe, allowing greater communication range, and reducing the chances of interference to and from other users outside the pattern. It is necessary to aim these antennas in the desired direction of communication (i.e., at the master station).

Antennas used for 802.11g (OFDM) applications include parabolic dish, yagi, and dipole. Dish and Yagi antennas are directional, so they are typically used in point-to-point radio applications. Dipole antennas are omni-directional, so they are typically used in short-range multi-point radio applications, or at master stations in multi-point communication systems. Yagi antennas are also polarized, so the orientation of the antenna becomes important.

### 2.2.1 Antenna Characteristics

If you were planning to cover an office--or an even larger area, such as a campus or a utility sub-station--you will almost certainly want to use external antennas for your access points. When considering specialized antennas, there are only a few specifications that you need to pay attention to:

#### 2.2.1.1 Type (radiation pattern)

The antenna type determines its radiation pattern--is it omni-directional, bidirectional, or unidirectional? Omni-directional antennas are good for covering large areas; bidirectional antennas are particularly good at covering corridors; unidirectional antennas are best at setting up point-to-point links between buildings, or even different sites.

#### 2.2.1.2 Gain

The gain of the antenna is the extent to which it enhances the signal in its preferred direction. Antenna gain is measured in dBi, which stands for decibels relative to an isotropic radiator (which has a unity gain i.e. 0 dBi). An isotropic radiator is a theoretical beast that radiates equally in all directions. dBi is the true gain the antenna provides to the transmitter's output. Gain is also reciprocal--it applies to (both) signal transmitting and receiving. An easy way to remember gain basics is that every 3 dB of gain added doubles the effective power output of an antenna. The more an antenna concentrates a signal, the higher the gain it will have. Simple external antennas typically have gains of 3 to 7 dBi. Directional antennas can have gains as high as 24 dBi.



*Higher gain means stronger (both) sent and received signals*

### 2.2.1.3 Half-power beam width

This is the width of the antenna's radiation pattern, measured in terms of the points at which the antenna's radiation drops to half of its peak value. Understanding the half-power beam width is important to understanding your antenna's effective coverage area. For a very high-gain antenna, the half-power beam width may be only a couple of degrees. Once you get outside the half-power beam width, the signal typically drops off fairly quickly, though that depends on the antenna's design. Don't be fooled into thinking that the half-power beam width is irrelevant for an omni-directional antenna. A typical omni-directional (vertical) antenna is only omni-directional in the horizontal plane. As you go above or below the plane on which the antenna is mounted, the signal decreases.



*A typical omni-directional (vertical) antenna is only omni-directional in the horizontal plane.*

### 2.2.1.4 Polarization

This is the direction in which the antenna radiates wavelengths, either vertically, horizontally, or circularly. Vertical antennas have vertical polarization and are the most common. For optimum performance, it is important that (both) the sending and receiving antennas have the same polarization.

### 2.2.1.5 VSWR

Voltage Standing Wave Ratio (VSWR) measures how well the antenna is matched to the RF-network at the operating frequency being used. It indicates how much of the received signal won't reach either the transceiver or receiver.

## 2.2.2 Antenna Types

We've discussed antennas entirely in terms of their properties for transmitting, largely because most people find that easier to understand. Fortunately, an antenna's receiving properties are identical to its transmitting properties--an antenna enhances a received signal to the same extent that it enhances the transmitted signal.

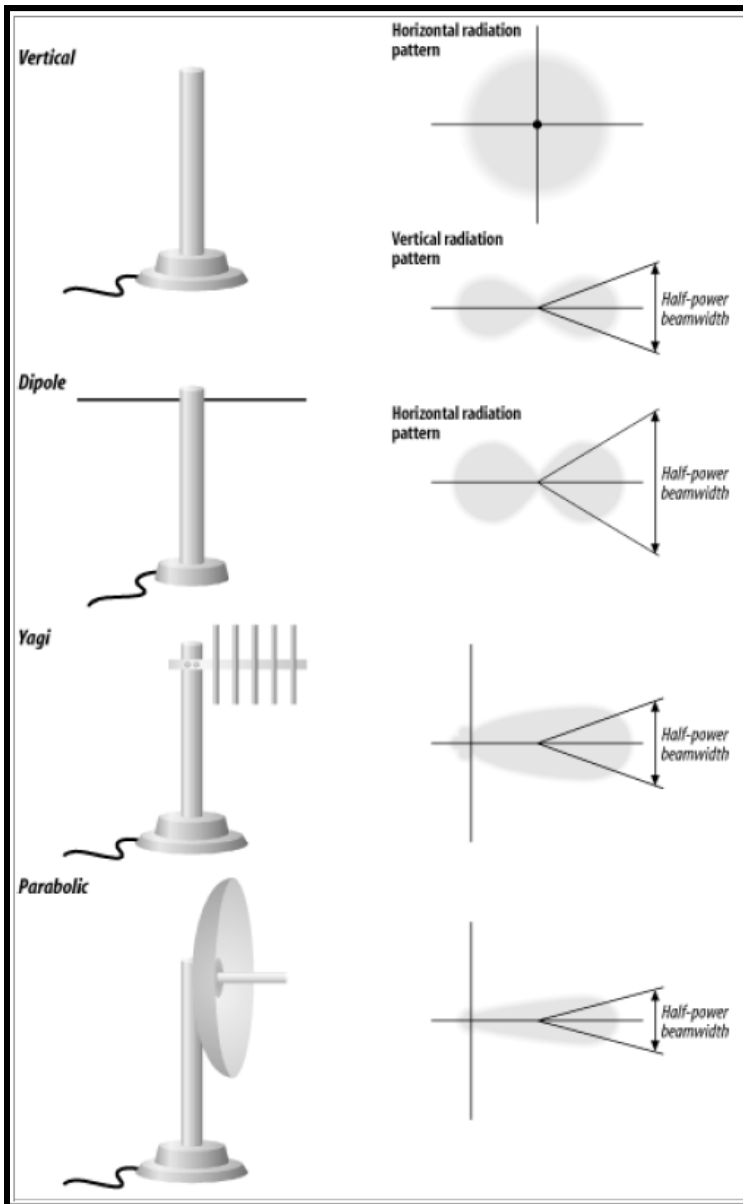


Figure 11 - Some (basic) Antenna types

### 2.2.2.1 Vertical (omni-directional)

This is a garden variety omni-directional antenna. Most vendors sell several different types of vertical antenna, differing primarily in their gain; you might see a vertical antenna with a published gain as high as 10 dBi or as low as 3 dBi. How does an omni-directional antenna generate gain? Remember that a vertical antenna is omni-directional only in the horizontal plane. In three dimensions, its radiation pattern looks something like a donut. A higher gain means that the donut is squashed...so that the outer circumference of the doughnut extends farther. It also means that the antenna is larger and more expensive, though no antennas for 802.11 service are particularly large.

If you want to cover a confined outdoor area--for example, a yard between several buildings of a utility substation--note that the half-power beam width means that a roof-mounted vertical antenna might be less than ideal, particularly if the building is tall. Vertical antennas are good at radiating out horizontally; they're not good at radiating down. In a situation like this, you would be better off mounting the antenna outside a first- or second-story window.

### 2.2.2.2 Dipole (omni-directional)

A dipole antenna has a figure eight radiation pattern, which means it's ideal for covering a hallway or some other long, thin area. Physically, it won't look much different from a vertical--in fact, some vertical antennas are simply vertically mounted dipoles.

### 2.2.2.3 Yagi (directional)

Yagi antennas were the design of two Japanese people, Hidetsugu Yagi and Shintaro Uda, and are sometimes referred to as Yagi-Uda antennas. They were originally designed for radio, but are now also used for 802.11 systems. A Yagi antenna is a moderately high-gain, unidirectional (i.e. very directional) antenna, and are often used for point to point, or to extend the range of a point to multi-point system. It looks somewhat like a classic TV antenna. There are a number of parallel metal elements at right angles to a boom. However, you are not likely to see the elements on a Yagi for 802.11 service; the commercially made Yagis that I have seen are all enclosed in a *radome*, which is a plastic shell that protects the antenna from the elements in outdoor deployments. Yagi antennas for 802.11 service have gains between 12 and 18 dBi; aiming them is not as difficult as aiming a parabolic antenna, though it can be tricky. They have excellent signal strength and in the right circumstances can communicate for miles!

### 2.2.2.4 Parabolic (directional)

This is a very high-gain antenna. Because parabolic antennas have very high gains (up to 24 dBi for commercially made 802.11 antennas), they also have very narrow beam widths. You would probably use a parabolic antenna only for a link between buildings (or utility sub-stations); because of the narrow beam width, they are not very useful for providing services to end users. Vendors publish ranges of up to 20 miles for their parabolic antennas. Presumably, both ends of the link are using a similar antenna. Do not underestimate the difficulty of aiming a parabolic antenna properly--one commercial product has a published beam width of only 6.5 degrees. If you decide to install a parabolic antenna, make sure that you have it mounted firmly. You do not want a bad storm to nudge it a bit and take down your connection.

Some vendors make an issue of the distinction between "mesh" or "grid" parabolas (in which the antenna's reflector looks like a bent barbecue grill) and solid parabolas. Don't sweat it--if the antenna is well-designed, the difference in performance between a mesh and a solid reflector is not worth worrying about.



*A Parabolic mesh antenna does have an advantage, in areas subject to high winds.*

### 2.2.2.5 Backfire (directional)

This small directional antenna looks like a cake pan with a tin can in the middle. It's designed to be compact, often under 11" in diameter, making it unobtrusive and practical for outdoor use. These

antennas also offer excellent gain, and can be used in both point-to-point or point-to-multipoint systems.

### 2.2.2.6 Panel or Patch (directional)

These antennas are often square or rectangular, and they're frequently hung on walls. They're designed to radiate horizontally forward and to the side, but not behind them. Sometimes they're called "picture-frame" antennas. Panel antennas are ideal in applications where the access point is at one end of a building. They're good for penetrating a single floor of a building, and for small and medium-size homes and offices. Because panel antennas can be easily concealed, they're a good choice when aesthetics are important.



*Since a Panel/Patch antenna might not have much vertical radiation, it might not be a good choice for multifloor applications.*

### 2.2.2.7 Sector (directional)

A sector antenna can be any type of antenna that directs the radio waves in a specific area. They are often large, outdoor flat-panel or dish-type antennas mounted up high and tilted downward toward the ground. These antennas are often used in sprawling campus settings to cover large areas.

#### Note 1:

Parabolic and Yagi antennas are useful primarily for links between buildings. The biggest problem is aiming them properly. If the two sites are visible to each other, you can play some tricks with gunsights--though if you can see one site from the other, you probably don't need such a sophisticated antenna system. Otherwise, buy a good compass and a topographical map from the U.S. Geological Survey, and compute the heading from one site to the other. Remember to correct for magnetic north. If you can spend some extra money, you might be able to simplify the setup by installing a high-gain vertical antenna at one site; then you need to aim only one antenna. If the signal is marginal, replace the vertical with a parabolic antenna once you have the first antenna aimed correctly.

#### Note 2:

High-gain antennas can become a regulatory problem, particularly in Europe (where power limits are lower than in the U.S.).

## 2.2.3 Antenna Installation

Spread spectrum radios are inherently line-of-sight systems due to the high-frequencies that they tend to operate in. Line of sight in this case is not only defined as a straight line between two points (i.e. optical), but rather a three-dimensional area between two points defined to include the Fresnel Zone. The Fresnel Zone can be viewed as a signal cone surrounding the entire radio path with the largest diameter in the center between the two antennas as shown in figure 6-3.

✓ *For a reliable link, at least 60% (or greater) of the Fresnel Zone must remain clear of obstructions.*

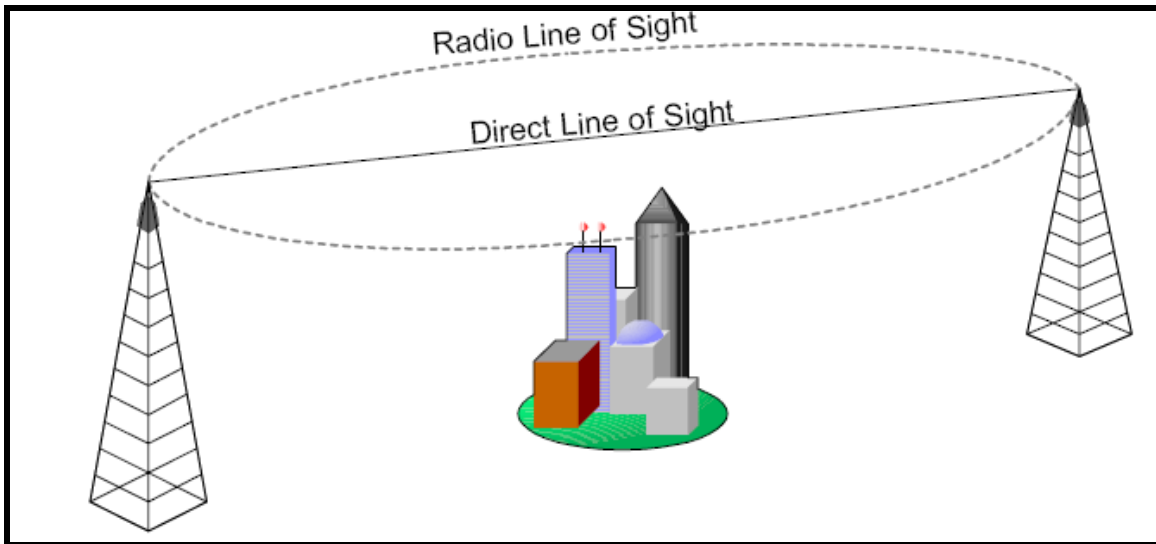


Figure 12 - The difference between Radio Line-of-Sight vs Direct (optical) Line-of-Sight

### 2.2.4 Antenna Mounting

The antenna manufacturer's installation instructions must be strictly followed for proper operation of a directional or omni-directional antenna. Using the proper mounting hardware and bracket ensures a secure mounting arrangement with no pattern distortion or de-tuning of the antenna. Mount the antenna in the clear, as far away as possible from obstructions such as buildings, metal objects, dense foliage, etc. Choose a location that provides a clear path in the direction of the associated station. The end of the antenna (furthest from the support mast) should face the associated station. Final alignment of the antenna heading can be accomplished by orienting it for maximum received signal strength. Most radio equipment includes provisions for measuring signal strength.

Polarization of the antenna is important. Systems that use a vertically polarized omni-directional antenna at the master station must use vertically polarized (elements perpendicular to the horizon) remote antennas. Cross-polarization between stations can cause a signal loss of 20 decibels (dB) or more.

### 2.2.5 Feed lines

The importance of using a low-loss antenna feed line is often neglected during radio installation. Using the wrong cable can cause huge reductions in efficiency and these losses cannot be recovered with any amount of antenna gain or transmitter power. For every 3 dB of feed line loss, half the transmitter power will be lost before reaching the antenna. To illustrate the importance of this loss, consider the following: At 950 MHz, a 100-foot/30.5m length of RG-8A/U coaxial cable (commonly used at VHF and lower frequencies) introduces a loss of about 8.5 dB. A 5 Watt transmitter operating into such a feed line would produce only 700 milliwatts at the antenna, and a similar loss in receive sensitivity would occur.



*For every 3 dB of feed line loss, half the transmitter power will be lost before reaching the antenna.*

On the other hand, a 100 foot/30.5m length of 7/8 inch semi-rigid coaxial cable operating under the same conditions will introduce only 1.28 dB of insertion loss, and will deliver 80% of the transmitter's power to the antenna.

The choice of which feed line to use depends on: the length of cable required to reach the antenna, the amount of signal loss that can be tolerated, and cost considerations. For long-range transmission paths, where signals are likely to be weaker, a low-loss cable type is recommended, especially if the length of the cable must exceed 50 feet/15m. For a short-range system, or one that requires only a short antenna feed line, a less efficient cable may be acceptable, and will cost far less than large diameter semi-rigid

## **2.2.6 Radio Path Quality**

Except for short-range paths that can be visually evaluated, a path study is generally recommended for new installations. A path study predicts the signal strength, reliability and fade margin of a proposed radio link. While terrain, elevation and distance are the major factors in this process, a path study must also consider antenna gain, feed line loss, transmitter power, and receiver sensitivity to arrive at a final prediction.

Path studies are normally performed by a communications consultant or a system integrator who uses topographic maps or a software program to evaluate the feasibility of a proposed path. Computer-assisted studies have become very popular in recent years and greatly simplify the process of path planning. Although path studies provide valuable assistance in system planning, they are not infallible. It is difficult, for example, to consider the effects of man-made obstructions or foliage growth without performing an actual on-the-air test. Such a test can be done using temporarily installed radio equipment. Ideally, a radio site will provide enough natural elevation to clear surrounding terrain without the need for a tall antenna tower. In these cases, the station antenna can often be mounted to a short mast and affixed to the equipment building or to an existing utility pole. If site elevation is not sufficient, a tower or other support structure must be used to raise the antenna above surrounding obstructions.

### *How strong is strong enough?*

The strength of radio signals in a well-designed system must exceed the minimum level needed to establish basic communication. This excess strength is known as the fade margin, and it compensates for variations in signal level, which may occur from time to time due to foliage growth, minor antenna misalignment, or changing atmospheric losses.

While the required amount of fade margin differs from one system to another, experience has shown that a level of 20 to 30 dB above the receiver sensitivity threshold is sufficient in most systems. Manufacturers of radio telemetry products often provide a means for direct measurement of received signal strength using a DC voltmeter, terminal, or diagnostic software. Consult equipment manuals for details.

## 2.3 IEEE 802.11 Operating guidelines (FCC)

There are two distinct classes of (operating) users prescribed by the FCC for Spread Spectrum devices that exist for 'intentional radiators' (i.e. radio transmitting equipment). The first category is referred to as "Consumers and IT Professionals Operating Spread Spectrum (DSSS) gear" while the second class is referred to as "Amateur Radio Operators operating under licensed spectrum". The RuggedWireless RS900W family of devices operates under the first category.

Users who operate under the "Consumers and IT Professionals Operating Spread Spectrum (DSSS) gear" category are bound by the following:

- Users must comply with FCC Part 15 rules and regulations
- Frequencies include 902-928 Mhz, 2400-2483.5 Mhz and 5725-5850 Mhz
- Maximum Transmitter Power Output (TPO) is 1.0 watt (30 dBm).
  - NOTE: The RS900W TPO is rated for 100 mw (20 dBm)
- The formula for converting antenna gain from dBi (i.e. relative to isotropic element) to dBd (relative to a dipole element) is  $\text{dBi} - 2.2 = \text{dBd}$

There are two different topologies for wireless operation under these rules. The topologies are referred to as either (i) "Point-to-Point" (PTP) or (ii) "Point-to-Multi-Point" (PTMP). A PTP topology is created by a direct wireless connection which exists only between two wireless nodes. A PTMP topology is formed when a single node is enabled to wirelessly communicate with multiple (i.e. more than 1) remote nodes at the same time. Each of these specific topologies has different Effective Isotropic Radiated Power (EIRP) limitations.

### 2.3.1 Point to Multi-Point (PTMP) topology

- The maximum EIRP power allowed is 36dBm (4 watts).

✓ NOTE: This means that the combination (sum) of the TPO and the Antenna Gain is not allowed to exceed 36dBm.

✓ NOTE: Typically (although certainly not always) an omni-directional antenna type is used by the central node in a PTMP topology to maximize the coverage radius.

Transmitter RF output (TPO)	Antenna Gain	EIRP in watts
30 dBm, 1W	6 dBi	3.98
27 dBm, 500mW	9 dBi	3.98
24 dBm, 250mW	12 dBi	3.98
20 dBm, 100mW	16 dBi	3.98
17 dBm, 50mW	19 dBi	3.98
14 dBm, 25mW	22 dBi	3.98
10 dBm, 10mW	26 dBi	3.98

Table 17 – PTMP: Maximum transmitter power versus antenna gain

- Any losses from the transmitter due to cabling (attenuation), lightning suppression, filtration etc. can be subtracted from the transmitted power dBm figure.

✓ **EXAMPLE:** From the table above, we can see that when utilizing the RS900W (which is rated for 20dBm or 100 mw TPO) with any external antenna of less gain than 16 dBi will safely fall below the EIRP limit (of 4 watts) as set by the FCC.

- The only justification for using the RS900W (in a PTMP topology) with an antenna with a higher gain ( $> +16$  dBi), would be to compensate for losses from the transmitter. It is important to realize that the EIRP is not allowed to exceed 36 dBm (4 W) in a PTMP topology.

✓ **EXAMPLE:** In a realistic scenario which utilizes the RS900W (which is rated for 20dBm or 100 mw TPO) with 100ft of LMR400 (at 6.7dB of loss due to cable attenuation) will bring the transmitter power down to 13.3dBm (i.e. 20dBm minus 6.7 dB). This allows the installation of (up to) a 22dBi antenna (13.3 dBm plus 22 dBi = 35.3 dBm) to maximize the EIRP.

### 2.3.2 **Point to Point (PTP) topology**

- Higher EIRP levels are allowed if the antennas are directional in nature.

✓ **NOTE:** This is because with antennas of higher gain, comes a “narrowing” of the beam width, and less potential for unintended interference.

✓ **NOTE:** Typically a highly directional antenna type is used by both ends of a wireless link in a PTP topology, which will focus the wireless signal beam.

- Any systems which operate in a point-to-point configuration are allowed to employ transmitting antennas with directional gain that is greater than 6dBi, provided the maximum output power of the transmitter (TPO) is reduced by 1 dB for every 3 dBi of the directional gain of the antenna which exceeds the maximum EIRP. By following this calculation, the maximum EIRP power allowed remains uncapped, because it is limited in practice by the increasingly “difficult to aim” behaviour of the (increasingly highly directional) antennas.
- Any losses from the transmitter due to cabling (attenuation), lightning suppression, filtration etc. can be subtracted from the transmitted power dBm figure.

Transmitter RF output (TPO)	Antenna Gain	EIRP in watts
20 dBm, 100 mW	16 dBi	3.98
19 dBm, 79 mW	19 dBi	6.35
18 dBm, 63 mW	22 dBi	10.14
17 dBm, 50 mW	25 dBi	15.81
16 dBm, 40 mW	28 dBi	25.23
15 dBm, 32 mW	31 dBi	40.28
14 dBm, 25 mW	34 dBi	62.79
13 dBm, 20 mW	37 dBi	100.2
12 dBm, 16 mW	40 dBi	....

Table 18 – PTP: Maximum transmitter power versus antenna gain

✓ **EXAMPLE:** From the table above, we can see that when utilizing the RS900W (which is rated for 20dBm or 100 mw TPO) with any external antenna of less gain than 16 dBi will safely fall below the EIRP limit (of 4 watts) as set by the FCC.

- The justifications for using the RS900W (in a PTP topology) with an antenna with a higher gain (> +16 dBi), would be:
  - (i) To increase the range (distance) between the wireless nodes.
  - (ii) To exercise a degree of control over the measurable RF signal “footprint” of the link between wireless nodes. This is done by intentionally decreasing the RF signal aperture (measured as the “half-power beam-width”), thereby reducing the likelihood of unintended interception of the wireless signal by unintended wireless nodes.
  - (iii) To increase the “link budget” between the wireless nodes. This serves to add a measure of reliability (sometime called the “fade margin”) to the wireless link, by allocating signal 9dB) headroom, to accommodate signal fading due to atmospheric and other transitory disturbances.

✓ **EXAMPLE:** Always remember that by increasing the antenna gain, the effect will be measured on both the transmitted output AND on the receiver sensitivity. For every +1 dB of antenna gain, this will contribute independently towards the TX and the RX budget, yielding an overall +2 dB increase in the “link budget”.

✓ **EXAMPLE:** To use an antenna with 25 dBi gain, the TPO for the RS900W must be reduced by 3 dB to 17 dBm (50mW). This will provide an overall transmit power level of (17 dBm + 25 dBi) 42 dBm (15.8 W). In addition, the receiver sensitivity will also be boosted by +25 dBi for an overall increase of +50dB in the wireless “link budget”.

### 3 RuggedWireless Frequently Asked Questions (FAQ)

#### What factors can affect wireless coverage/range?

Range estimates are typical and require line of sight. Basically that means you will need a clear unobstructed view of the antenna from the remote point in the link. Keep in mind that walls and obstacles will limit your operating range and could even prevent you from establishing a link. Signals in the 2.4 Ghz generally will not penetrate metal or concrete walls. Trees and leaves are also obstructions to 802.11 frequencies so they can partially (or even entirely) block the signal. Other factors that will reduce range and affect coverage area include metal studs in walls, concrete fiberboard walls, aluminum siding, foil-backed insulation in the walls or under the siding, pipes and electrical wiring, furniture and sources of interference. Other sources of interference include the microwave oven, other wireless equipment, cordless phones, radio transmitters and other electrical equipment. Due to the increased gain, installing range extender antennas in the presence of interference could actually yield either no improvement or worse range.

#### Which WiFi (802.11) Antenna type should I choose? Patch/Directional Antennas

Choose a patch if you want the signal more focused than from an omni-directional antenna . Patch antennas typically transmit the signal with approximately a 30 degree beam width. This is ideal for use in office locations, ie placed at one end of room to provide coverage for it's entire length. They can also be used outdoors to provide short distance point to point links.

#### When would I choose a Parabolic Grid Antenna?

These antennas have a very narrow beamwidth and are ideal for point-to-point bridge links. Grid antennas are highly directional and they should only be chosen to aim at one small (i.e. concentrated) spot.

#### When would I choose an Omni-Directional Antenna?

Choose an Omni-directional antenna to provide a signal over a full 360 degree radius.

#### How many clients can associate with an access point?

An Access Point is a shared medium and acts as a wireless hub. The performance of each user decreases as the number of users increases on an individual AP. Ideally, not more than 24 clients should associate with the AP because the throughput of the AP is reduced with each client that associates to the AP.

#### How do I convert between power expressed in 'milliwatt' and power expressed in 'dBm' units?

The formula used to convert stated 'power' levels to decibels (dBm – milliwatt @ 50 or 600 ohm impedance) is given as:  $\text{dBm} = 10 * \text{Log} (\text{Power in mW} / 1 \text{ mW})$

Conversely, the formula used to convert stated 'power' levels to milliwatts when expressed in dBm is given as:  $\text{Power (mW)} = \text{anti-log} (\text{dBm} / 10)$

**What is the definition of “Attenuation”?**

Loss of power expressed in dB. Attenuation is expressed in dB as follows:  $PdB = 10 \times \text{Log} (P_{out}/P_{in})$ . For example: If, due to attenuation, half the power is lost ( $P_{out}/P_{in} = 2$ ), attenuation in dB is  $10 \times \text{Log} (2) = 3dB$ .

**What is the definition of “Path Loss”?**

Path loss is the loss of power of an RF signal travelling (propagating) through space. It is expressed in dB. Path loss depends on:

- (1) The distance between transmitting and receiving antennas.
- (2) Line of sight clearance between the receiving and transmitting antennas.
- (3) Antenna height.

**What is the definition of “Free Space Loss”?**

Attenuation of the electromagnetic wave while propagating through space. This attenuation is calculated using the following formula:  $\text{Free space loss} = 32.4 + 20 \times \text{Log} F(\text{MHz}) + 20 \times \text{Log} R(\text{Km})$  F is the RF frequency expressed in MHz. R is the distance between the transmitting and receiving antennas. At 2.4 Ghz, this formula is:  $100 + 20 \times \text{Log} R(\text{Km})$ .

**What is the definition of an “Isotropic Antenna”?**

A hypothetical, lossless antenna having equal radiation intensity in all directions. Used as a zero dB gain reference in directivity calculation (gain). The sun is often given as an example of an isotropic radiator.

**What is the definition of “Antenna Gain”?**

Antenna gain is a measure of directivity. It is defined as the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna was radiated equally in all directions (isotropically). Antenna gain is expressed in dBi.

**What is the definition of the antenna “Radiation Pattern”?**

The radiation pattern is a graphical representation in either polar or rectangular coordinates of the spatial energy distribution of an antenna of the electromagnetic wave while propagating through space.

**What is the definition of “RF Power Level”?**

RF power level at either transmitter output or receiver input is expressed in Watts. It can also be expressed in dBm. The relation between dBm and Watts can be expressed as follows:  $PdBm = 10 \times \text{Log} P_{mw}$ . For example: 1 Watt = 1000 mW;  $PdBm = 10 \times \text{Log} 1000 = 30 \text{ dBm}$  100 mW;  $PdBm = 10 \times \text{Log} 100 = 20 \text{ dBm}$ . For link budget calculations, the dBm convention is more convenient than the Watts convention.

**What the definition of antenna “Side Lobes”?**

The radiation lobes in any direction other than that of the main lobe.

**What is the definition of an “Omni-Directional” antenna?**

This antenna radiates and receives equally in all directions in azimuth.

**What is the definition of “Directional” antenna”?**

This antenna radiates and receives most of the signal power in one direction.

**What is the definition of “Antenna Beamwidth”?**

A measurement of the directivity of a directional antenna. Defined as the angle between two half-power (-3 dB) points on either side of the main lobe of radiation.

**What is the definition of “Receiver Sensitivity”?**

The minimum RF signal power level required at the input of a receiver for certain performance (e.g. > BER).

**What is the definition of “EIRP (Effective Isotropic Radiated Power)”?**

Equal to the transmitted output power minus cable loss plus the transmitting antenna gain.  $EIRP = P_{out} - C_t + G_t$   $P_{out}$  = Output power of transmitted in dBm  $C_t$  = Transmitter cable attenuation in dB  $G_t$  = Transmitting antenna gain in dBi  $G_r$  = Receiving antenna gain in dBi  $PI$  = Path loss in dB  $C_r$  = Receiver cable attenuation is dB  $S_i$  = Received power level at receiver input in dBm  $P_s$  = Receiver sensitivity is dBm  $S_i = P_{out} - C_t + G_t - PI + G_r - C_r$  Example: Link Parameters: Frequency: 2.4 Ghz  $P_{out} = 4$  dBm (2.5 mW) Tx and Rx cable length ( $C_t$  and  $C_r$ ) = 10 m. cable type RG214 (0.6 dB/meter) Tx and Rx antenna gain ( $G_t$  and  $G_r$ ) = 18 dBi Distance between sites = 3 Km Receiver sensitivity ( $P_s$ ) = -84 dBm.

Link Budget Calculation  $EIRP = P_{out} - C_t + G_t = 16$  dBm  $PI = 32.4 + 20 \times \log F(\text{MHz}) + 20 \times \log R(\text{Km}) @ 110$  dB  $S_i = EIRP - PI + G_r - C_r = -82$  dBm In conclusion, the received signal power is above the sensitivity threshold, so the link should work. The problem is that there is only a 2 dB difference between received signal power and sensitivity. Normally, a higher margin is desirable due to fluctuation in received power as a result of signal fading.

**What is the definition of “Signal Fading”?**

Fading of the RF signal is caused by several factors:

(1) Multipath: The transmitted signal arrives at the receiver from different directions, with different path lengths, attenuation and delays. The summed signal at the receiver may result in an attenuated signal.

(2) Bad Line of Sight: An optical line of sight exists if an imaginary straight line can connect the antennas on either side of the link. Radio wave clear line of sight exists if a certain area around the optical line of sight (Fresnel zone) is clear of obstacles. A bad line of sight exists if the first Fresnel zone is obscured.

(3) Link Budget Calculations

(4) Weather conditions (Rain, wind, etc.) At high rain intensity (150 mm/hr), the fading of an RF signal at 2.4 Ghz may reach a maximum of 0.02 dB/Km. Wind may cause fading due to antenna motion.

(5) Interference: Interference may be caused by another system on the same frequency range, external noise, or some other co-located system.

**What is the definition of “Line of Sight” concept?**

An optical line of sight exists if an imaginary straight line can be drawn connecting the antennas on either side of the link. Clear Line of Sight: A clear line of sight exists when no physical objects obstruct viewing one antenna from the location of the other antenna. A radio wave clear line of sight exists if a defined area around the optical line of sight (Fresnel Zone) is clear of obstacles.

**What is the definition of “Fresnel Zone”?**

The Fresnel (pronounced: fruh nell) zone is the area of a circle around the line of sight. The Fresnel Zone is defined as follows:

$R = \frac{1}{2} \sqrt{\lambda D}$  where R is the radius of the first fresnel zone, where  $\lambda$  is the wavelength, where D is the distance between sites.

<b>dBm</b>	<b>Watts</b>	<b>dBm</b>	<b>Watts</b>	<b>dBm</b>	<b>Watts</b>
0	1.0 mW	16	40 mW	32	1.6 W
1	1.3 mW	17	50 mW	33	2.0 W
2	1.6 mW	18	63 mW	34	2.5 W
3	2.0 mW	19	79 mW	35	3.2 W
4	2.5 mW	20	100 mW	36	4.0 W
5	3.2 mW	21	126 mW	37	5.0 W
6	4 mW	22	158 mW	38	6.3 W
7	5 mW	23	200 mW	39	8.0 W
8	6 mW	24	250 mW	40	10 W
9	8 mW	25	316 mW	41	13 W
10	10 mW	26	398 mW	42	16 W
11	13 mW	27	500 mW	43	20 W
12	16 mW	28	630 mW	44	25 W
13	20 mW	29	800 mW	45	32 W
14	25 mW	30	1.0 W	46	40 W
15	32 mW	31	1.3 W	47	50 W

Table 19 - dBm to Watt Conversion Table

**3.1 References**

## 4 Wireless (and related) LAN Terminology

**802.11** - *IEEE 802.11* ([IEEE Std. 802.11-1999](#)) is a medium access control ([MAC](#)) and physical layer ([PHY](#)) specification for wireless connectivity for fixed, portable, and moving stations within a local area. It uses direct sequence spread spectrum (DSSS) in the 2.4 GHz ISM band and supports raw data rates of 1 and 2 Mbps. It was formally adopted in 1997 but has been mostly superseded by [802.11b](#). IEEE 802.11 is also used generically to refer to the family of [IEEE](#) standards for wireless local area networks

**802.11a** - *IEEE 802.11a* ([IEEE Std. 802.11a-1999](#)) is a [PHY](#) standard that specifies operating in the 5 GHz U-NII band using orthogonal frequency division multiplexing (OFDM). It supports data rates ranging from 6 to 54 Mbps.

**802.11b** - *IEEE 802.11b* ([IEEE Std. 802.11b-1999](#)) is an enhancement of the initial [802.11 PHY](#) to include 5.5 Mbps and 11 Mbps data rates. It uses direct sequence spread spectrum (DSSS) or frequency hopping spread spectrum (FHSS) in the 2.4 GHz ISM band as well as complementary code keying (CCK) to provide the higher data rates. It supports data rates ranging from 1 to 11 Mbps.

**802.11g** - *IEEE 802.11g* (IEEE Std. 802.11g-2003) is a higher speed extension (up to 54 Mbps) to the [802.11b PHY](#), while operating in the 2.4 GHz band. It uses orthogonal frequency division multiplexing (OFDM). It supports data rates ranging from 1 to 54 Mbps.

**802.11i** - *IEEE 802.11i* is a comprehensive [IEEE](#) standard for security in a wireless local area network ([WLAN](#)) that describes [Wi-Fi Protected Access 2 \(WPA2\)](#). It defines enhancements to the [MAC](#) Layer to counter some of the weaknesses of [WEP](#). It incorporates stronger encryption techniques than the original [Wi-Fi Protected Access \(WPA\)](#), such as Advanced Encryption Standard ([AES](#)). The original [WPA](#), which can be considered a subset of 802.11i, uses *Temporal Key Integrity Protocol (TKIP)* for encryption. WPA2 is backwards-compatible with products that support the original WPA. *IEEE 802.11i / WPA2* was finalized and ratified in June of 2004.

**802.1x** - As the IEEE standard for access control for wireless and wired LANs, 802.1x provides a means of authenticating and authorizing devices to attach to a LAN port. This standard defines the Extensible Authentication Protocol (EAP), which uses a central authentication server (e.g. RADIUS) to authenticate each user on the network.

**Access Point (A/P)** - An *access point* is the communication hub for the devices on a [WLAN](#), providing a connection or bridge between wireless and wired network devices. It supports a [Wireless Networking Framework](#) called [Infrastructure Mode](#). When one access point is connected to wired network and supports a set of wireless stations, it is referred to as a basic service set ([BSS](#)). An extended service set ([ESS](#)) is created by combining two or more BSSs.

**Ad hoc mode** - This is a [Wireless Networking Framework](#) in which stations communicate directly with each other, without the aid of an Access Point. It is useful for quickly establishing a network in situations where formal infrastructure is not required. Ad hoc mode is also referred to as *peer-to-peer mode* or an independent basic service set ([IBSS](#)).

**AES** - The *Advanced Encryption Standard* (AES) is a symmetric 128-bit block data encryption technique developed to replace DES encryption. AES works at multiple network layers simultaneously. Further information is available on the [NIST Web site](#).

**Beacon** - Beacon frames provide the "heartbeat" of a [WLAN](#), announcing the existence of the network, and enabling stations to establish and maintain communications in an orderly fashion. It carries the following information (some of which is optional):

- The Timestamp is used by stations to update their local clock, enabling synchronization among all associated stations.
- The Beacon interval defines the amount of time between transmitting beacon frames. Before entering power save mode, a station needs the beacon interval to know when to wake up to receive the beacon.
- The Capability Information lists requirements of stations that want to join the [WLAN](#). For example, it indicates that all stations must use [WEP](#).
- The Service Set Identifier ([SSID](#)).
- The [Basic Rate Set](#) is a bitmap that lists the rates that the [WLAN](#) supports.
- The optional Parameter Sets indicates features of the specific signaling methods in use (such as frequency hopping spread spectrum, direct sequence spread spectrum, etc.).
- The optional Traffic Indication Map (TIM) identifies stations, using power saving mode, that have data frames queued for them.

**BSS** - A *basic service set* (BSS) is an [Infrastructure Mode Wireless Networking Framework](#) with a single access point. That is, a set of 802.11 compliant stations which operate as a connected wireless network. Also see extended service set ([ESS](#)) and independent basic service set ([IBSS](#)).

**BSSID** - In [Infrastructure Mode](#), the *Basic Service Set Identifier* (BSSID) is the 48-bit [MAC](#) address of the wireless interface of the [Access Point](#). This identifier is used by all stations within a BSS, within the frame headers (usually the MAC address).

**CSMA/CA** - Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is a low-level network arbitration/contention protocol. A station listens to the media and attempts to transmit a packet when the channel is quiet. When it detects that the channel is idle, the station transmits the packet. If it detects that the channel is busy, the station waits a random amount of time and then attempts to access the media again. CSMA/CA is the basis of the IEEE 802.11e Distributed Control Function ([DCF](#)). See also [RTS](#) and [CTS](#). The CSMA/CA protocol used by [802.11](#) networks is a variation on CSMA/CD (used by [Ethernet](#) networks). In CSMA/CD the emphasis is on collision detection whereas with CSMA/CA the emphasis is on collision avoidance.

**CTS** - A *clear to send* (CTS) message is a signal sent by an [IEEE 802.11](#) client station in response to an *request to send* ([RTS](#)) message. The CTS message indicates that the channel is clear for the sender of the RTS message to begin data transfer. The other stations will wait to keep the air waves clear. This message is a part of the IEEE 802.11 [CSMA/CA](#) protocol. (See also [RTS](#).)

**dBi** - The decibel units used to calculate the gain of an antenna. The change in power is referenced against an isotropic radiator, which is a theoretical ideal transmitter that produces a perfect electromagnetic field output. The sphere would extend in all directions with equal intensity, and at 100% efficiency, in 3-dimensions, similar to the rays of light produced by the sun.

**dBm** - A dBm measurement is a measurement of absolute power based on the reference of 1 milliwatt (1 mW).

**EAP** - The *Extensible Authentication Protocol* (EAP) is an authentication protocol that supports multiple methods, such as token cards, Kerberos, one-time passwords, certificates, public key authentication, and smart cards. Variations on EAP include EAP Cisco Wireless (LEAP), Protected EAP (PEAP), EAP-TLS, and EAP Tunnelled TLS (EAP-TTLS).

**ESS** - An *extended service set* (ESS) is an [Infrastructure Mode Wireless Networking Framework](#) with multiple access points, forming a single subnetwork that can support more clients than a basic service set ([BSS](#)). Each access point supports a number of wireless stations, providing broader wireless coverage for a large space, for example, an office.

**ERP** - The *Extended Rate Protocol* refers to the protocol used by [IEEE 802.11g](#) stations (over 20 Mbps transmission rates at 2.4GHz) when paired with Orthogonal Frequency Division Multiplexing (OFDM). Built into ERP and the IEEE [802.11g](#) standard is a scheme for effective interoperability of IEEE 802.11g stations with IEEE 802.11b nodes on the same channel. Legacy IEEE 802.11b devices cannot detect the ERP-OFDM signals used by IEEE 802.11g stations, and this can result in collisions between data frames from IEEE 802.11b and IEEE 802.11g stations. If there is a mix of 802.11b and 802.11g nodes on the same channel, the IEEE 802.11g stations detect this via an ERP flag on the access point and enable *request to send* ([RTS](#)) and *clear to send* ([CTS](#)) protection before sending data. See also [CSMA/CA](#) protocol.

**Fresnel Zone** - (pronounced 'fre-nel') The area around the line-of-sight between WLAN bridge antennas that radio waves spread out into after they leave the antenna. This area must be kept clear or the strength of the signal will be weakened.

**Gain** - The measurement used to indicate the frequency and range for the WLAN bridge antenna. As the number increases in a WLAN bridge antenna, the coverage area becomes more narrow and the distance of the coverage area becomes longer.

**Gateway** - A *gateway* is a network node that serves as an entrance to another network. A gateway also often provides a proxy server and a firewall. It is associated with both a router, which use headers and forwarding tables to determine where packets are sent, and a switch or bridge, which provides the actual path for the packet in and out of the gateway. Before a host on a [LAN](#) can access the Internet, it needs to know the address of its *default gateway*.

**IBSS** - An *independent basic service set* (IBSS) is an [Ad hoc Mode Wireless Networking Framework](#) in which stations communicate directly with each other. This is an IEEE 802.11 based wireless network that has no backbone infrastructure and consists of at least two wireless stations.

**Infrastructure Mode** - This is a [Wireless Networking Framework](#) in which wireless stations communicate with each other passing data through a central [Access Point](#). In this mode, the wireless stations can communicate with each other or can communicate with hosts on a wired network. The access point not only mediates wireless network traffic in the immediate neighborhood, but also provides communication with the wired network. An infrastructure mode framework can be provided by a single access point ([BSS](#)) or a number of access points ([ESS](#)).

**Power over Ethernet (PoE)** - A method of delivering DC power to the Wireless Access Point or Bridge devices, through CAT5 Ethernet cabling. Typically used in installations where AC power is not available to achieve the optimum positioning (placement) of the devices.

**PSK** - Pre-Shared Key (*PSK*) also known as “personal mode”. see [Shared Key](#).

**Public Key** - A *public key* is used in public key cryptography to encrypt a message which can only be decrypted with the recipient's private or secret key. Public key encryption is also called asymmetric encryption, because it uses two keys, or Diffie-Hellman encryption. Also see [Shared Key](#).

**RADIUS** - Remote Authentication Dial-In User Service (RADIUS) is a ‘backend’ server that performs authentication and accounting services using the Extensible Authentication Protocol (EAP). This server is required by the 802.1x security standard.

**RC4** - A symmetric stream cipher provided by [RSA Security](#). It is a variable key-size stream cipher with byte-oriented operations. It allows keys up to 2048 bits in length.

**RSSI** - The *Received Signal Strength Indication* (RSSI) an [802.1x](#) value that calculates voltage relative to the received signal strength. RSSI is one of several ways of measuring and indicating *radio frequency* (RF) signal strength. Signal strength can also be measured in mW (milliwatts), dBm (decibel milliwatts), and a percentage value.

**RTS** - A request to send (RTS) message is a signal sent by a client station to the access point, asking permission to send a data packet and to prevent other wireless client stations from grabbing the radio waves. This message is a part of the IEEE 802.11 CSMA/CA protocol. (See also RTS Threshold and CTS.)

**RTS Threshold** - The parameter specifies the packet size of a request to send (RTS) transmission. This helps control traffic flow through the access point, and is especially useful for performance tuning on an access point with a many clients.

**Shared Key** - A *shared* key is used in conventional encryption where one key is used both for encryption and decryption. It is also called secret-key or symmetric-key encryption. Also see Public Key.

**SSID** - The Service Set Identifier (SSID) is a thirty-two character alphanumeric key that uniquely identifies a wireless local area network. It is also referred to as the Network Name. There are no restrictions on the characters that may be used in an SSID. All radios and access points within the same BSS must use the same SSID or their packets will be ignored.

**STP** - The Spanning Tree Protocol (STP) an IEEE 802.1 standard protocol (related to network management) for MAC bridges that manages path redundancy and prevents undesirable loops in the network created by multiple active paths between client stations. Loops occur when there multiple routes between access points. STP creates a tree that spans all of the switches in an extended network, forcing redundant paths into a standby, or blocked, state. STP allows only one active path at a time between any two network devices (this prevents the loops) but establishes the redundant links as a backup if the initial link should fail. If STP costs change, or if one network segment in the STP becomes unreachable, the spanning tree algorithm reconfigures the spanning tree topology and reestablishes the link by activating the standby path. Without spanning tree in place, it is possible that both connections may be simultaneously live, which could result in an endless loop of traffic on the LAN.

**TKIP** - The Temporal Key Integrity Protocol (TKIP) provides an extended 48-bit initialization vector, per-packet key construction and distribution, a Message Integrity Code (MIC, sometimes called "Michael"), and a re-keying mechanism. It uses a RC4 stream cipher to encrypt the frame body and CRC of each 802.11 frame before transmission. It is an important component of the WPA and 802.11i security mechanisms.

**WDS** - A *Wireless Distribution System* (WDS) allows the creation of a completely wireless infrastructure. Typically, an Access Point is connected to a wired LAN. WDS allows access points to be connected wirelessly. The access points can function as *wireless repeaters* or *wireless bridges* in this configuration.

**WEP** - Wired Equivalent Privacy (WEP) is a data encryption protocol for 802.11 wireless networks. All wireless stations and access points on the network are configured with a static 64-bit (40-bit secret key + 24-bit initialization vector (IV)) or 128-bit (104-bit secret key + 24-bit IV) Shared Key for data encryption. It uses a RC4 stream cipher to encrypt the frame body and CRC of each 802.11 frame before transmission

**Wireless bridge (or wireless repeater)** - See WDS.

**WLAN** - *Wireless Local Area Network* (WLAN) is a LAN that uses high-frequency radio waves rather than wires to communicate between its nodes.

**WPA** - Wi-Fi Protected Access (WPA) is a Wi-Fi Alliance version of the draft IEEE 802.11i standard. It provides more sophisticated data encryption than WEP and also provides user authentication. WPA includes TKIP and 802.1x mechanisms.

**WPA2** - *WiFi Protected Access* (WPA2) is an enhanced security standard, described in [IEEE 802.11i](#), that uses Advanced Encryption Standard ([AES](#)) for data encryption. The original [WPA](#) uses Temporal Key Integrity Protocol ([TKIP](#)) for data encryption. WPA2 is backwards-compatible with products that support the original [WPA](#). WPA2, like the original [WPA](#), supports an *Enterprise* and *Personal* version. The Enterprise version requires use of IEEE [802.1x](#) security features and *Extensible Authentication Protocol* ([EAP](#)) authentication with a [RADIUS](#) server. The Personal version does not require IEEE [802.1x](#) or [EAP](#). It uses a *Pre-Shared Key* ([PSK](#)) password to generate the keys needed for authentication.

## 5 About RuggedCom Inc.

RuggedCom Inc. designs and manufactures industrially hardened networking equipment including 802.11 based wireless Switches, IP Routers, and Gateways suitable for the harsh environments of the electric power utility substation or industrial factory floor. Founded by individuals with strong backgrounds in utility and industrial automation and a passion for developing innovative technology, RuggedCom is well suited for providing the right solutions to address the needs of our customers.

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