Mobile Mark
antenna solutions

Antenna Factors That Drive Smart Grid Coverage

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Part I: Wireless System Characteristics

Smart grid technology holds great promise of cleaner air, more efficient power, and lower greenhouse gas emissions. In a smart grid system, the system itself will automatic self-correct and enhance the ability to detect power outrages ahead of time and correct any problems that persist. It provides real-time electricity cost and it allows consumers to alter their consumption pattern to avoid peak hour usage and saves money.

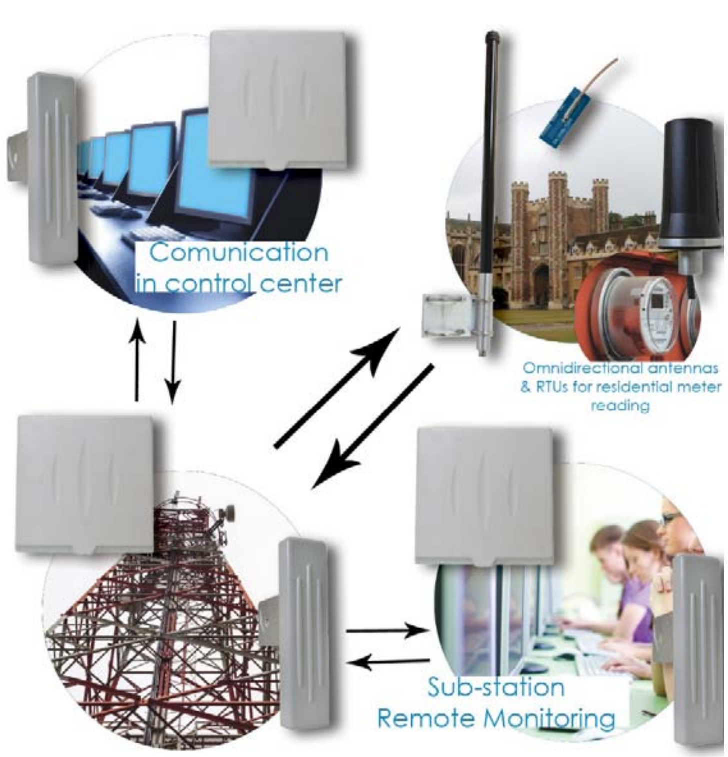


Fig. 1: Smart Grid wireless communication systems

Wireless connectivity is a cost effective solution to modernize the electrical grid by turning it into a smart grid system. It is easier to deploy a wireless communication systems to consumers than to install wired communication meters.

Wireless allows two-way digital communications by adding computer intelligence and data communications to the electricity distribution networks from non-renewable (coal and nuclear) and renewable energy (solar and wind) to smart appliances to plug-in cars.

Key components that enable smart grid to provide two-way wireless controls and communications are smart meters, backhaul site, utility pole radios, central utility communication center, and remote sub-stations.

Antennas made by Mobile Mark Inc. are already in use on commercial and residential smart metering, distribution utility poles, and utility company. Mobile Mark's experience in this area has given the company an appreciation for some of the wireless challenges these new networks are facing in their efforts to provide effective communications.

Some of these challenges can be addressed by choosing antenna types that matched the situation; other challenges require an examination of the antenna performance characteristics that come in to play. Different antenna styles are required at different points in the network: from cost effective fixed location antennas for smart metering, to robust high performance point-to-point, point-to-multipoint base station antennas for substation, remote monitor, and control utility infrastructure. Antenna styles under consideration include embedded antennas, surface mount antennas, omni-directional site antennas, as well as directional panel and yagi antennas.

A typical wireless system consists of many parameters and it is beyond the scope of this article to cover them all. Thus, we will focus on the wireless system's ability to digitally communicate over a wide distant in dynamic environments. We will examine, in the most optimistic view and under ideal conditions, the key wireless system characteristics that influence overall range performance as they are characterized and quantified using Friss transmission formula:

- Transmission RF power (1 Watt / 30 dBm)
- Antenna gain on transmitter and receiver
- Antenna radiation patterns and polarizations
- Frequency band (700 MHz to 5.85 GHz)
- Receiver Power sensitivity (-85 dBm)
- Path Loss

Each of these five areas will be examined in detail in Parts II – VII of this series.

Part II: Transmission RF Power

A key contributor to overall range performance is the transmitter radio frequency (RF) power as it applies to the antenna input. The higher the transmitter RF power going into the antenna the further the range will be increase. But there are limits to what is allowed. In the US, the Federal Communication Commission (FCC) set restrictions on the Effective Isotropic Radiated Power (EIRP) allowed on all frequencies for all wireless devices. If the wireless device is cellular, then additional PCTRB certification is required in order to be in compliance with many of the Cellular Carriers Networks (for example, AT&T, Verizon, T-Mobile, and US Cellular).

Effective Isotropic Radiated Power (EIRP) is determined by a combination of both the actual radio frequency power transmitted by the radio, as measured in watts or dBm, and the antenna gain at a typical 3m distant away.

If wireless systems operate within popular ISM unlicensed bands and utilized analog modulation and fixed radio frequency carrier, then the FCC under part 15 restricts RF power limit to 50,000 µV/m at 3m or EIRP power of -1.25 dBm at 3m. This EIRP RF power limit of -1.25 dBm at 3m is ideal for short range applications. A sample calculation with formulas below illustrates how to calculate and convert FCC EIRP limits from electric fields in µV/m at 3m to absolute RF power in dBm:

Calculate EIRP RF power in dBm:

FCC RF power limit to popular ISM band 902-928 MH, 2400-2485 MHz, and 5.725-5.850 GHz of electric fields E = 50,000µV/m at 3m. Convert E to dBm.

Solutions:

$\mathbf{r} := 3$ radius at 3m apart from source transmitter, in m

$\mathbf{E} := 50000 \cdot 10^{-6}$ Electric fields, in V/m at 3m FCC limit

$\mathbf{A} := 4\pi \cdot \mathbf{r}^2$ Effective aperature area, in m^2

$\mathbf{Z_o} := 120\pi$ free space intrinsic impedance of 377Ω

$\mathbf{P_r} := \frac{\mathbf{E}^2}{\mathbf{Z_o}} \cdot \mathbf{A}$ Calculated Receiver Power (Pr) density in watt (W) based on FCC limits

$\mathbf{P_r} = 750.000 \times 10^{-6}$

Convert EIRP power from Watt to dBm:

$\mathbf{P_o} := \mathbf{P_r}$ EIRP output RF power at 3m away from the source

$\mathbf{P_i} := 0.001$ Reference power, in 1mW

$$\mathbf{dBm} := 10 \cdot \mathbf{log}\left(\frac{\mathbf{P_o}}{\mathbf{P_i}}\right)$$

$\mathbf{dBm} = -1.249$

If wireless systems operate within popular ISM unlicensed bands and transmitters utilized spread spectrum technology then FCC EIRP restrictions under part 15 allow the transmission point to go up to 36 dBm. The two main spread spectrum types are frequency hopping, FHSS and digital modulation scheme, DSSS. These wireless transmitters are permit to transmit a maximum of 1 watt (or 30 dBm) into the 6 dBi gain Omni-directional or Directional antenna. However, this requirement is less restrictive if 2.4 GHz and 5.8 GHz wireless device are use for point-to-point applications.

The popular unlicensed ISM bands are:

- 902-928 MHz
- 2.400-2.4835 MHz
- 5.725-5.850 MHz

For 2.4 GHz band, the FCC allows the EIRP to be increased above 36 dBm but certain restrictions apply. The antenna must be directional and for every 3 dBi antenna gain increase, the RF transmit power applying into the antenna must be reduce by 1 dBm. The table 1 below shows combination of allowed transmit power / antenna gain and the resulting EIRP and range coverage up to 218 km for wireless point-to-point applications in free space. The range is the total distant between a transmitter and a receiver in meters. This range calculation is relatively lower compared to Friss formula since it includes a 20dB for wireless operating signal margin.

Transmit Power (dBm)	Transmit Antenna Gain, dBi	EIRP (dBm)	Receive Antenna Gain, in dBi	Calculated free space Range, in m
30	6	36	0 – 6 dBi	1,093 – 2,180 m
29	9	38	0 – 9 dBi	1,375 – 3,877 m
28	12	40	0 – 12 dBi	1,732 – 6,894 m
27	15	42	0 – 15 dBi	2,180 – 12,259 m
26	18	44	0 – 18 dBi	2,744 – 21,799 m
25	21	46	0 – 21 dBi	3,455 – 38,765 m
24	24	48	0 – 24 dBi	4,350 – 68,936 m
23	27	50	0 – 27 dBi	5,476 – 122,587 m
22	30	52	0 – 30 dBi	6,894 – 217,994 m

Table 1: FCC part 15 for 2.4 GHz RF power limit with spread spectrum transmitters for point-to-point applications.

The 5.8 GHz band used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in 1 Watt (or +30 dBm) conducted transmitter output power limit. Table 2 below shows combinations of allowed transmit power, antenna gain, the resulting EIRP, and calculated range coverage opportunity up to 229 km in free space. The range is the total distant between a transmitter and a receiver measured in meters. This range calculation is relatively low compared to Friss formula since it includes a 20 dB for wireless operating signal margin.

Transmit Power (dBm)	Antenna Gain, dBi	EIRP (dBm)	Receive Antenna Gain, in dBi	Calculated free space Range, in m
30	6	36	0 – 6 dBi	458 – 913 m
30	9	39	0 – 9 dBi	646 – 1,822 m
30	12	42	0 – 12 dBi	913 – 3,635 m
30	15	45	0 – 15 dBi	1,290 – 7,252 m
30	18	48	0 – 18 dBi	1,822 – 14,470 m
30	21	51	0 – 21 dBi	2,573 – 28,871 m
30	24	54	0 – 24 dBi	3,635 – 57,604 m
30	27	57	0 – 27 dBi	5,134 – 114,936 m
30	30	60	0 – 30 dBi	7,252 – 229,327 m

Table 2: FCC part 15 for 5.85 GHz RF power limit w/ spread spectrum transmitters for point-to-point applications.

The theoretical example given above ignores the impact of beamwidth. Increasing the RF power allows the radiation pattern to stay the same, whereas increasing the gain of the antenna results in a narrower beam-width. A narrower beam-width may make it harder to align the transmitting antenna with the receiving antenna, especially at long distances due to the earth curvature.

The responsibility for staying within FCC approved power limits falls on the operator or professional installer.

Part III: Antenna gain on transmitter and receiver

Antenna gain is a key characteristic to a wireless system design for overall range coverage consideration. In fig. 2, using Friss transmission formula (in free space), we present wireless range coverage calculations based on a 1 watts transmitter, -85 dBm receiver power sensitivity, system operating margin of 20 dB, for a range of frequencies from 700 MHz to 5.85 GHz. These are plotted for discreet antenna gain from 0 dBi to 10 dBi.

The calculated data is based on an ideal isotropic antenna. The VSWR is 1.0:1, antenna efficiency is 100%, the weather is perfect, and antennas are installed at least a 100m above ground. This theoretical calculation includes free space transmission loss but it does not account for other path losses. These theoretical calculations give designers a starting point.

The purpose is to aid wireless designers in the quick antenna selection process by comparing the combine impact of antenna gain and operating frequency.

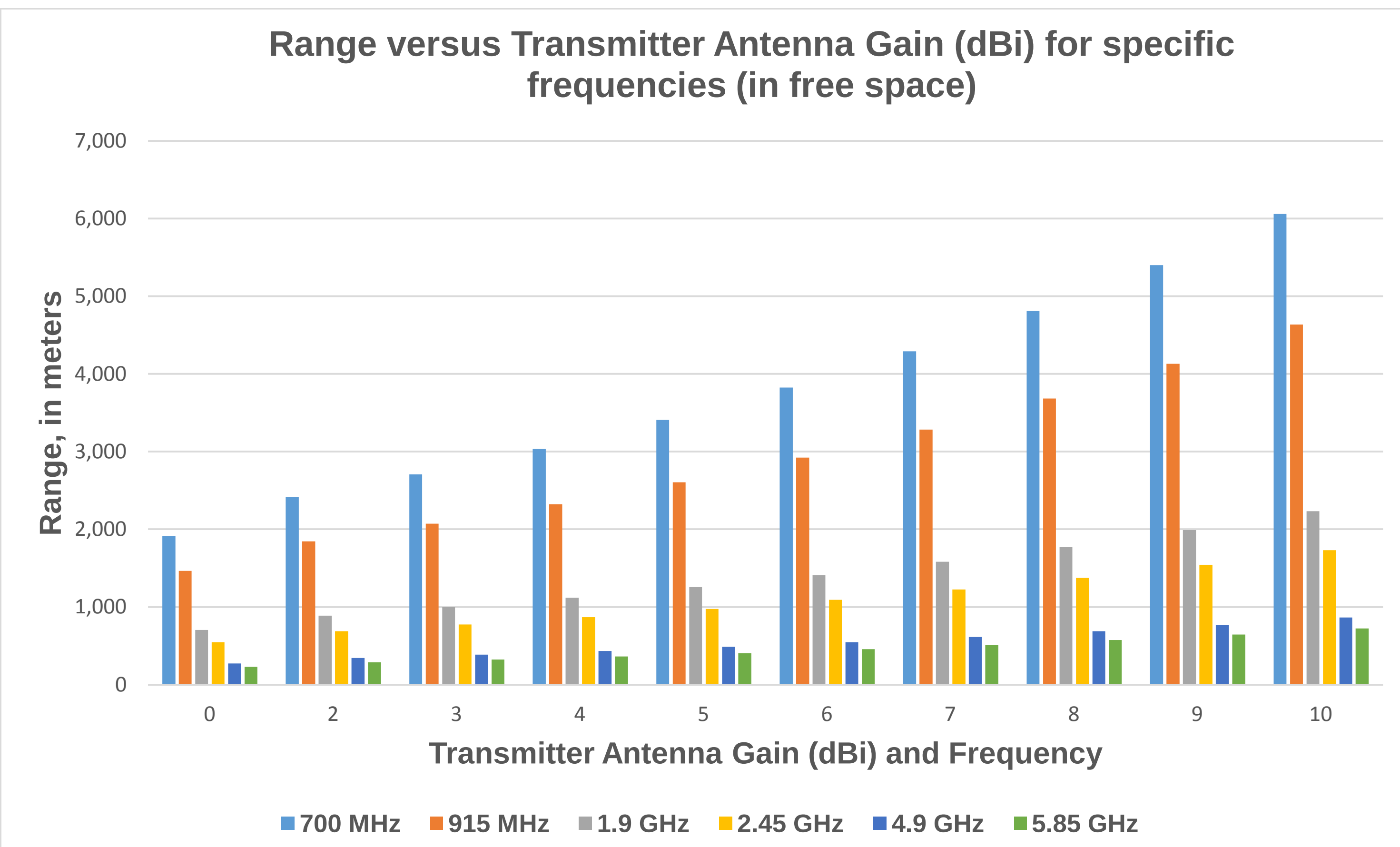


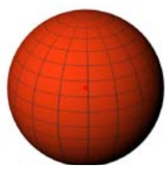
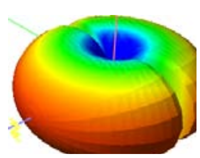
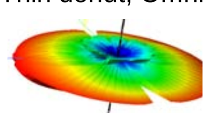
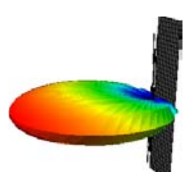
Fig. 2: Range based on antenna gain and frequency in free space

The vertical scale is range coverage, in meters, that a wireless system able to transmit and receive. The horizontal scale is antenna system gain in increments from 0 to 10dBi. The colored bars show the data for popular frequency sets from 700 MHz to 5.85 GHz

The antenna gain in dBi is a reference against an isotropic antenna. An isotropic antenna is defined as a “hypothetical” lossless antenna having equal radiation pattern in all directions (spherical) and its antenna gain is only 0 dBi or unity. Although it is ideal and not physically realizable, it is often taken as a reference for expressing the directive properties of actual antennas. An antenna with a 10 dBi gain is 10 dB better than an isotropic antenna. The graph in fig. 2 applies to both Omni-directional and Directional antenna types.

Part IV: Antenna Radiation Patterns and Polarizations

In table 3, the first antenna represents an Isotropic (ideal) antenna. Its 3D antenna pattern is a spherical shape and therefore it radiates electrically and magnetically uniformly in all XYZ planes or in all directions. It has an infinite number of principle E-planes and H-planes. The remaining antennas and its patterns in table 3 show deviations from this theoretically ideal antenna.

<table>
<tr><th>Antenna Types</th><th>Gain, in dBi</th><th>3D pattern</th><th>Beam-width</th><th>Range, in m (Free space)</th><th>Applications (Mobile Mark Antennas)</th></tr>
<tr><td>2.45 GHz Isotropic (ideal)</td><td>0 dBi</td><td>Spherical
</td><td>Uniformly in all directions</td><td>548m</td><td>Theoretical reference only</td></tr>
<tr><td>915 MHz Antenna</td><td>0 to 5 dBi</td><td rowspan="2">Donut, Omni
</td><td rowspan="2">360°Az x (30° to 78°) EL</td><td>1466 - 2607m</td><td rowspan="2">Point-to-multipoint (OD / RM / EM / PST / SM / LTM Series)</td></tr>
<tr><td>2.45 GHz antenna</td><td>0 to 2 dBi</td><td>548 - 689m</td></tr>
<tr><td>2.45 GHz antenna</td><td>8 dBi</td><td>Thin donut, Omni
</td><td>360°Az x 12°EL</td><td>1375m</td><td>Point-to-multipoint (OD series)</td></tr>
<tr><td>2.45 GHz 90° Sector antenna</td><td>8 dBi</td><td rowspan="2">Slice of donut, Directional
</td><td>90°Az x 22°EL</td><td>1375m</td><td rowspan="2">Point-to-point (PS / YAG / SCR series)</td></tr>
<tr><td>2.4 / 5.8 GHz Corner Reflector</td><td>9dBi / 12dBi</td><td>2.4: 45°Az x 35°EL
5.5: 35°Az x 25°EL</td><td>1545m / 913m</td></tr>
</table>

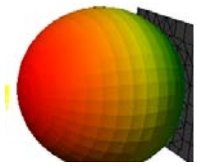
915 MHz RHCP /LHCP antenna	8 dBi	Directional 	70°Az x 70°EL	3683m	Point-to-point (PN & HD series)

Table 3: 3D Antenna patterns and range performance characteristics of various antenna types.

Spherical coordinate system is adopted to best describe antenna characteristics: antenna radiation patterns and polarization. Antenna polarization is defined as the curve traces by the instantaneous electric field radiated by the antenna in a plane perpendicular to the radial direction.

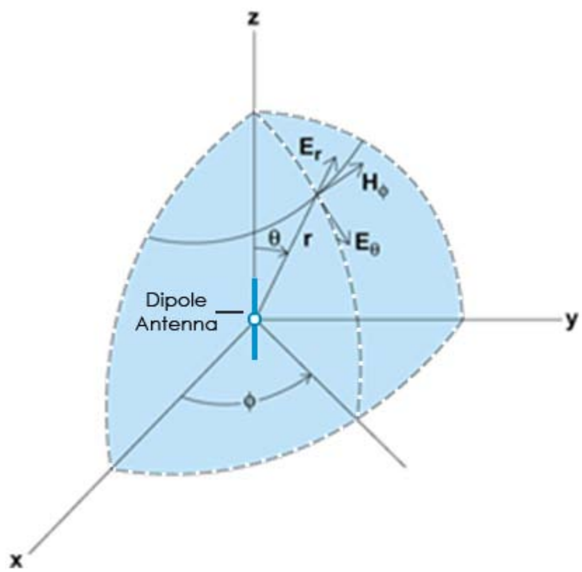


Fig. 3: Dipole antenna in spherical coordinate system

For example, in fig. 3, a half-wave dipole antenna is the Antenna Under Test (AUT) installed on the vertically on Z-axis (ie. vertically polarized) at coordinate X=0, Y=0, Z=0 in blue color. The following antenna patterns describe how to interpret this Dipole antenna characteristics:

Elevation Radiation Pattern: (Horizontal Polarization)

- The symbol theta “ϴ” is the elevation angle in the antenna elevation radiation pattern measurement.

- At elevation angle of ϴ = 0° and 180°, antenna radiation patterns point toward the sky and ground on Z-axis respectively. A half-wave dipole antenna has null radiation patterns of at least 20 dB in these two elevation angles.

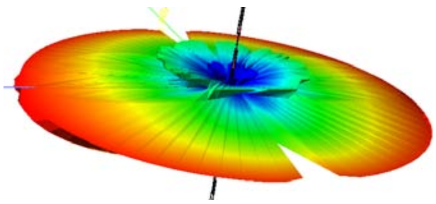
- At elevation angle of ϴ = 90° and 270° (or 90° and -90°), antenna radiation patterns point toward the horizon or flush to the earth surface. A half-wave dipole antenna gain is peak at 2.15 dBi at these two angles.

Azimuth Radiation Pattern: (Vertical Polarization)

- The symbol phi “∅ is the azimuth angle in the azimuth radiation pattern measurement.

- At azimuth angles ∅ = 0° to 360° in XY plane, its antenna radiation patterns point flush to the earth surface. A half-wave dipole antenna has gain of 2.15 dBi for all these azimuth angles. Therefore, it is called Omni-Directional pattern antenna.

Thus, the half-wave dipole antenna in Fig. 3 is a vertical polarization antenna since the electric fields radiates up and down along the antenna in Z-axis perpendicular to XY plane. The observation distant “r” is the located at some distant in meters away from the Dipole antenna. It has an infinite equivalent number of principle E-planes or electric fields (symbol “E_Θ”) as Phi “∅ varies from 0° to 360° and therefore it is called Omni-Directional antenna. The symbol “$H_\varnothing$” is the magnetic fields with one principle H-planes.



ECO8-2400 Series
Fig. 4a: 3-D Antenna Radiation Pattern

ECO8-2400 Series – Azimuth Plot

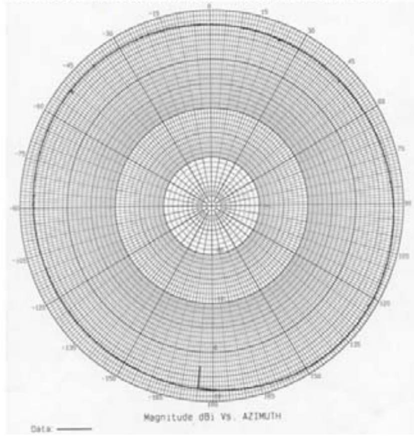


Fig. 4b: 2-D Azimuth Radiation Pattern

ECO8-2400 Series – Elevation Plot

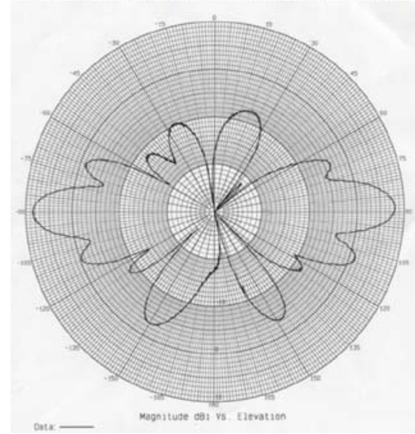


Fig. 4c: 2-D Elevation Radiation Pattern

For example, the third antenna in the table 3 (same as Fig. 4a) has an antenna gain of 8 dBi, 3D Omni-directional radiation pattern, and vertical polarization at 2.45 GHz. This same antenna measured using 2 dimensional (2-D) antenna patterns equipment is illustrated in Fig. 4b and Fig. 4c. An Omni-Directional antenna pattern has an infinite number of principle E-planes (Elevation planes on XZ axis, $\emptyset=\emptyset_c$) and only one principle H-plane (Azimuthal plane on XY axis, peaks at Θ = 90°and -90°). The antenna half power beam-width measured as 360°Az x 12°EL. At this antenna gain and frequency with 1 Watt RF power, the antenna can transmit up to 1,375m in 360° around the antenna along the earth surface. The 12°EL means the antenna radiation pattern is 12 degrees thick donut as it radiates 360° azimuth around the antenna peak point. The receiving antenna, whether omni-directional or directional, needs to be aligned with the transmitting antenna. Since the transmitter antenna is vertically polarized, the receiver antenna must aligned to vertical polarization. In addition, it must be mounted at the same height and its azimuth antenna pattern must be lined up with the transmitting antenna. Engineers refer to this as "antenna boresight" where the maximum signal is achieved. This may be challenging for long range communication systems since earth curvatures and terrains come into play.

When network developers are designing point-to-point networks, they typically use directional antennas and they consider both the azimuth and the elevation radiation patterns. Azimuth (Az) radiation patterns are typically Vertical polarization and elevation (EL) radiation patterns are Horizontal polarization. As we saw with the point-to-multipoint Omni-Directional antenna example, both transmit and receive antennas must be aligned to same vertical polarization. With directional antennas, the field of transmission is determined by both AZ and EL and must be matched-up with the AZ and EL of the partner antenna respectively.

For linear polarization antennas, the vector that describes the electric field at a point in space as a function of time is always directed along a line. Both transmit and receive antennas must be mounted at the same height and same polarization match-up for optimum performance as illustrated in Fig. 5:

- If transmit antenna aligned to Vertical Polarization, receive antenna must aligned to Vertical Polarization (Azimuth to Azimuth patterns).
- If transmit antenna aligned to Horizontal Polarization, receive antenna must aligned to Horizontal Polarization (Elevation to Elevation patterns).
- A minimum antenna performance if both transmit and receive antenna polarizations are mis-matched (Horizontal to Vertical Polarization).

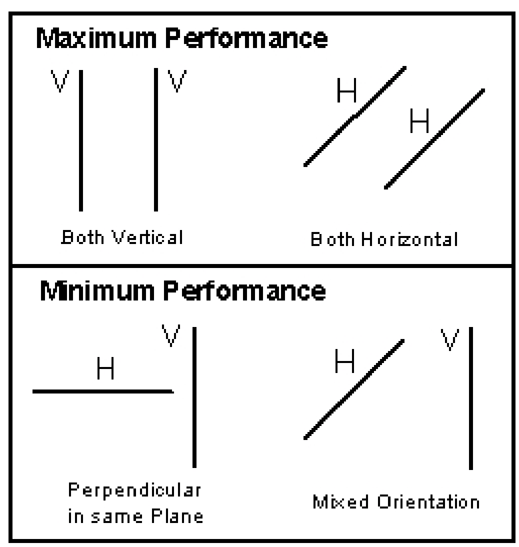


Fig. 5: Linear polarization antenna alignment

The fourth antenna in the table 3 is an example of a directional antenna that is used for point-to-point applications. It features 8 dBi gain at 2.4 GHz with a 90° (azimuth) and 22° (elevation) sector. It capable of transmitting up to 1,375m within only that 90° sector. This sector antenna pattern consist only ¼ slice of the donut. At this antenna gain and frequency, it radiates simultaneously 90° azimuth when align to Vertical polarization and 22° elevation when align to Horizontal polarization. If the transmit antenna is a sector install to same height and alignment to Vertical Polarization, the receive antennas and its antenna polarization alignment match-up at bore-sight choices can be as follows:

- Sector antenna (Rx) align to Vertical Polarization: angle of coverage is up to 90°
- Omni antenna (Rx) align to Vertical Polarization: angle of coverage is up to 90°
- Yagi antenna (Rx) align to Vertical Polarization: angle of coverage is up to 90°

The fifth antenna in the table 3 shows an example of directional circular polarization antenna that is used in point-to-point applications. It features 8 dBi gain at 915 MHz with 70°Azimuth (Az) x 70° elevation (EL). This antenna polarization is circular and its communication range coverage is up to 3683m. If this is transmit antenna aligned to Vertical Polarization, then the receive antenna and its antenna polarization alignment match-up at bore-sight choices can be as follows.

- Omni antenna (Rx) align to Vertical or Horizontal Polarization: angle of coverage is up to 70°
- RHCP antenna (Rx) is self-align: angle of coverage is up to 70°
- Yagi antenna (Rx) align to either Vertical or Horizontal Polarization: angle of coverage is up to 70°

Circular Polarization antenna is consider as an opportunistic antenna. It communicates simultaneously to both Vertical and Horizontal polarization antennas.

Part V: Frequency band

Radio frequency of operation is one key parameter that influence the range of coverage in a wireless system. Let's compare the range of four ideal antennas, by looking at different gains and frequencies, as summarized in the table below.

Antenna gain	**700 MHz**	**5.85 GHz**	**700 MHz to 5.85 GHz Antenna switch**	**5.85 GHz to 700 MHz Antenna switch**
0 dBi gain	1,917m	229m	-88% range decrease	737% range increase
10 dBi gain	6,061m	725m	-88% range decrease	736% range increase

Table 4: Radio frequency of operations

In table 4, an ideal antenna gain of 10 dBi at 700 MHz will result in range of 6,061m compares to 0 dBi at range of 1917m or a 216% increase in range coverage. Using the same ideal antenna system gain of 10 dBi at 5.85 GHz, the wireless system can only communicate up to 725m range and at 0 dBi ideal antenna transmits and receives up to 229m.

If one designer switch from 700 MHz to a 5.85 GHz antenna systems, the range decreases from 1917m to 229m or 88% for both 0dBi and 10dBi. In the reverse, if one designer switch from 5.85 GHz to 700 MHz antenna systems, the range is increase from 229m to 1917m or 737% range boost for both 0dBi and 10dBi. The antenna in frequency band used at 700 MHz has an advantage of 734% better range over the 5.85 GHz regardless of any antenna gain.

For long range wireless communication requirement, it is best to use lower frequency of operation at 700 MHz. For short range wireless communication requirement, it is best to use frequency of operation at 5.85 GHz.

Part VI: Receiver Power Sensitivity

Another, key characteristics affecting overall range performance is the radio receiver sensitivity under symbol Pr. Because receiver sensitivity indicates how faint or weak an input signal can be successfully received by the receiver, the lower the power level, the better. Lower power for a given S/N ratio means better sensitivity since the receiver's contribution is smaller. When the power is expressed in dBm the larger the absolute value of the negative number, the better the receive sensitivity. A table 5 below is good guideline to use for wireless design to select RF receiver sensitivity criteria based on range performance requirements.

RF Receiver Sensitivity @12dB SINAD	**Range Performance**
(-60 to -80) dBm	Low range
(-80 to -100) dBm	Mid-range
(-100 to -120) dBm	Best range

Table 5: Receiver sensitivity

Typically, a formalized RF receiver sensitivity measurement includes RF, audio, noise, and distortion and a published unit as for example in dBm at a threshold level at 12dB SINAD using a 1 KHz tone. For example, receiver sensitivity at 12 dB SINAD of −100 dBm is better than a receiver sensitivity of −97 dBm by 3 dB, or a factor of two better performance. In other words, at a specified data rate, a receiver with a −100 dBm sensitivity can hear signals that are twice the power of those heard by a receiver with a −97 dBm receiver sensitivity.

If the wireless system is designed for long applications, it is best to obtain RF detector for receiver design performance at least -100 dBm sensitivity or better.

Part VII: Path loss

Path loss is the reduction of the overall wireless system range by attenuating the electromagnetic wave while propagating through free space loss and obstacles loss. Obstacles loss is cause by object deflection and diffraction and it is measured by empirical method.

Free space path loss is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight (LOS) through air distant in meters, with no obstacles nearby to cause reflection or diffraction to further attenuate the signal. Free space attenuation is the theoretical calculation, in dB, depends on distant and frequency using speed of light in meters per second (m/s). A formula below shows the further the distant the higher the loss or attenuation in dB; the higher the frequency the higher the loss or attenuation.

$$\lambda := \frac{c}{f}$$

$$FSPL_{LOS} := \left(\frac{4\pi d}{\lambda}\right)^2$$

$$FSPL_{LOS} := 27.56 + 20\cdot\log(d) + 20\cdot\log(f)$$

Where

$FSPL_{LOS}$ = free space loss in decibels, dB
d = distant in meter between transmit and receive, in free space
l = wavelength in meter
c = speed of light in a vacuum at 2.99792458 × 10^8 meters/second
f = frequency in MHz

	Free space and Obstacles path loss (FSPL), in dB					
Distant (meter)	**700 MHz**	**915 MHz**	**1900 MHz**	**2.45 GHz**	**4.9 GHz**	**5.85 GHz**
100m	69.3 dB	71.7 dB	78.0 dB	80.2 dB	86.2 dB	87.8 dB
1,000m	89.3 dB	91.7 dB	98.0 dB	100.2 dB	106.2 dB	107.8 dB
Residential building loss (avg)	4 dB	6.5 dB	10.3 dB	12 dB	13 dB	13.8 dB
In-Vehicle loss (avg)	10.9 dB	6.5 dB	6.7 dB	8 dB	13 dB	-
Interior drywall				3.5 dB	4 dB	
Cubical wall				3.5 dB	6.5 dB	
Wood door (hollow)				3.5 dB	6.5 dB	
Glass/window				2.5 dB	7 dB	
Bullet proof glass				10 dB	20 dB	
Steel/fire exit door				16 dB	28.5 dB	
Brick/concrete wall				12 dB	20 dB	
All metals	26 dB					
Single tree foliage loss	10.8 dB	11.7 dB	14.1 dB	14.9 dB	17.2 dB	17.7 dB
CCIR forest loss	0.15 dB/m	0.2 dB/m	0.3 dB/m	0.35dB/m	~0.5dB/m	~0.6dB/m

Table 6: Free space path loss and obstacle path loss by empirical methods by COST 231 propagation model

In practice, the wireless signal travels through many obstacles prior before it arrives to the receiver. This theoretical calculations become empirical in nature which include free space path loss and all other additional loss (cable, connectors, and micro-strip, enclosures, walls, trees, and etc).

For example, a typical high level calculation of a 700 MHz wireless system transmits 1000m away which it needs to transmit through a residential building, a tree, a 100m forest, and a car is illustrated as follow:

Total Signal loss (@700 MHz) = 1,000m free space (89.3 dB) + Residential Building (4 dB) + In-Vehicle loss (10.9 dB) + Single tree foliage loss (10.8dB) + forest (0.15dB/m *100 = 15dB)
= 89.3 + 4 dB + 10.9 dB + 10.8 dB +15 dB
= 115 dB

The total RF signal attenuation for this 700 MHz wireless system is simply the sum of all the losses of 115 dB of signal upon arrival at the receiver. In table 6, free space and all other common obstacles path loss in dB at various frequency are illustrated and measured by researchers and scientists community. It is best to use as an aid and a starting point for wireless designers for their specific applications.

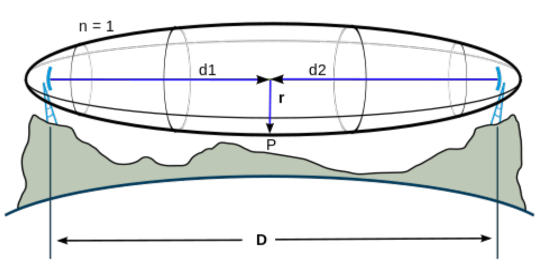


Fig. 7 (Fresnel zone):
D is the distance between the transmitter and the receiver; *r* is the radius of the first Fresnel zone (n=1) at point P. P is d1 away from the transmitter, and d2 away from the receiver. (Source: Wikipedia)

The unknown factor that causes range degradation is typical objects path loss and it can only be determine by empirical method. Object path loss (or path attenuation) is the complex reduction in power density of electromagnetic wave cause by refraction, diffraction, reflection, aperture-medium coupling loss, and absorption cause by objects. Path loss is also influenced by terrain contours, environment (urban or rural), propagation medium (dry or moist air), the distant the transmitter and the receiver, and the height and location of the antenna.

In practice, in Fig. 7, the wireless system designers need to install their antennas to a minimum radius height “r” above ground level or above objects of the first Fresnel zone requirement to ensure free space range performance.

Fresnel provided a means to calculate the zones, where a given obstacle will cause mostly in phase or mostly out of phase reflections between the transmitter and the receiver. Obstacles in the first Fresnel zone will create signals with a path-length phase shift of 0 to 180 degrees, in the second zone they will be 180 to 360 degrees out of phase, and so on. Even numbered zones have the maximum phase cancelling effect and odd numbered zones may actually add to the signal power.

$\mathbf{D} := 1000$ Total distance between Tx and Rx antennas installed in meters, m

$\mathbf{r} =$ Calculate 1st Fresnel zone radius needed to be away from obstacle or typically above ground

$\mathbf{f} := 700$ Frequency transmitted in MHz, Megahertz

$$\mathbf{r} := 8.657 \cdot \sqrt{\frac{\mathbf{D}}{\mathbf{f}}}$$

$\mathbf{r} = 10.347\text{m}$

For example, the minimum 1st Fresnel zone height distant “r” of 10.347m above ground level or above objects is required for 700 MHz wireless systems to operate close to free space performance operating at 1000m away. The 1st Fresnel distant “r” is located at middle point or at 500m between the two 700 MHz transceivers.

Fig. 5: Point-to-point directional antennas

Back haul sites and pole-mounts radios relay two-way wireless communication information in a mesh network connecting point-to-point and point-to-multiple-point applications. These sites relay two-way wireless communication data flows of utility customers, utility substations, and transmission line distribution back to utility headquarters within a smart grid system over thousands of miles.

To sum up, wireless communications transform from simple electrical grids to a smart electrical grid. It communicates digital data information upstream to utility provider for status report and downstream to give consumer incentive to alter and reduce energy consumption habits to save money. Wireless communication offers advantage of lower labor and components cost to quickly convert into a smart grid. This article has shown theoretically calculation that it is definitely meet a wireless communication range coverage. Smart grid range coverage is predominately driven by antenna factors: transmit power, antenna gain, frequency, receiver sensitivity, and path loss. To make the wireless communication as seamless and as efficient as possible, selecting the right antenna for the job is key.

About Mobile Mark, Inc.:

Tam Chau is an Antenna Design Engineer with Mobile Mark, Inc. The company designs and manufacture antennas for commercial and governmental wireless applications such as GPS Fleet Tracking, Cellular M2M (Machine-to-Machine), WiFi and RFID. The antennas are used in Public Transit, Trains, Mining, Local Vans, Long Distance Trucks, Police & Public Safety, Security, Military, and Smart Grids & Smart Meters. Engineering and custom design services are available. Mobile Mark’s global headquarters, which include research facilities and manufacturing plant, are located near Chicago, IL. An additional manufacturing and sales facility is located near Birmingham, UK. Complete information can be found on the website: www.mobilemark.com.

