Selection of Antenna for Wireless Communication System

Abstract: *The vehicular cellular phone systems initiated a rapid growth of wireless communication .However, with the growth of these systems cell sizes are made smaller and smaller to increase user capacity. Meanwhile along with this growth in outdoor communication the interest in indoor systems like telephony (cordless phones and wireless PABX-es) and data services (e.g. Wireless LAN's) also started. Today as the size of hand-held devices is growing small there is a need to have so many antenna designs which fulfills this demand for ultra-thin, compact sizes and high-performance devices that have the ability to meet multiple standards. This led to the need of designing different types of antenna as per different requirement from the user. To successfully implement a reliable, robust, and high-performing wireless system it is necessary to thoroughly consider the antenna selection and review the requirements of the system in the very early design stages of the hand-held device. This will avoid numerous iterations and unnecessary system redesigns. The objective of this paper is to compare various antennas on the basis of their parameters and applications so that planning for the antenna selection and determining the best one becomes easy .It ensures that the antenna will function optimally .From the perspective of system planning, the choice of antenna selection and deployment options depends on the current and future demand for system performance and the financial resources available. In any wireless communication system, the antenna plays a major role in the reliability and performance of the system.*

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Index terms: *Wireless communication, Types of antenna, base station, antenna parameters, polarization, radiation pattern and microstrip patch antenna.*

1. INTRODUCTION

The optimal placement of base stations has been an important parameter which is used to maximize performance of wireless systems [1, 2]. However, the deployment of base stations is not limited to their placement but also includes the selection and deployment of base station antennas. The system planner may arbitrarily select omni-directional antennas as in traditional wireless systems, with no knowledge of the propagation characteristics of the environment [5]. This solution will likely be sub-optimal resulting in a loss of potential system performance/capacity [1]. Alternatively, the system planner may choose to acquire some information about the propagation characteristics of the environment and use that information to estimate the performance of the indoor wireless system to develop an improved deployment strategy. In the broadest sense, wireless communication refers to any type of communication without a physical connection between the participating parties [3]. Various parts of the electromagnetic spectrum can be employed for communications, which includes the spectra of radio waves, microwaves, visible light and infra-red [11]. The radio frequencies in the range 800MHz to 2.5GHz are generally used in mobile communications due to their excellent propagation properties. Though higher frequency bands at 5GHz, 20GHz, and 60GHz are being considered for indoor wireless local area networks (WLANs) or outdoor local multipoint communication systems (LMCS) [3, p. 54].Mobile users connect to the network of base stations and request services such as voice, data and multimedia communications[12]. High user capacity and high data rates are often required. Examples of such systems include third and fourth generation mobile communication systems and WLANs [12].

In the following sections we will discuss the following issues. Section 2 deals with the need for selection of antenna along with some important antenna parameters. Section 3 has classification of various types of antenna and it gives details of all the antennas in brief .Section 4 shows comparison of antennas followed by Section 5 which is the final conclusion.

2. KEY PARAMETERS FOR SELECTION OF ANTENNA

Propagation and generation of radio waves depends on the surrounding environment as outlined in the following section. For example, the magnitude of the multipath components of a received signal can be reduced if the propagating radio waves are focused in the LOS direction [30]. It is therefore essential to obtain an understanding of the device that generates propagating radio waves — **the antenna**. Stand alone antennas are not "smart". Careful selection of the antenna is "smart". An antenna is a physical structure that couples electromagnetic energy from a signal source to the propagation medium (such as free space) [11, pp. 85–86]. A transmit antenna bridges the signal source and the medium whereas a receive antenna intercepts electromagnetic energy incident on it and transfers the energy from the propagation medium to the receiver system. Some key antenna parameters that can influence system performance include **frequency range, radiation pattern, beam width, gain, directivity, efficiency, polarization and effective aperture**· [11, pp. 91–96].

- **Frequency Range** - The frequency range that the manufacturer specifies for the antenna is typically larger than the band you intend to operate in [35]. Make sure that the stated specifications are valid for the entire listed range.

- **Radiation pattern:** It is defined as the variation of the power radiated by an antenna as a function of the direction away from the antenna [39]. This power variation as a function of the arrival angle is observed in the antenna's field. For example, consider the 3-dimensional radiation pattern, shown in Figure 2.1.

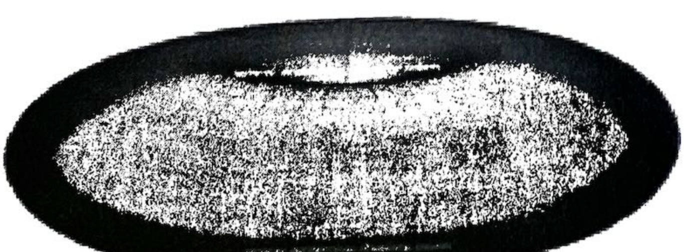

Fig. 2.1: Radiation pattern for an Antenna

These plots are useful for visualizing in which direction the antenna radiates.

- **Directivity:** It is a fundamental antenna parameter. It is a measure of how 'directional' an antenna's radiation pattern is [39]. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

- **Antenna Efficiency:** The **efficiency** of an antenna relates the power delivered to the antenna and the power radiated or dissipated within the antenna. A high efficiency antenna has most of the power present at the antenna's input radiated away. A low efficiency antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.

- **Antenna Gain:** The term Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. A gain of 3 dB means that the power received far from the antenna will be 3 dB (twice as much) higher than what would be received from a lossless isotropic antenna with the same input power. The polar (polar angle measured off of z-axis) plot is given by:

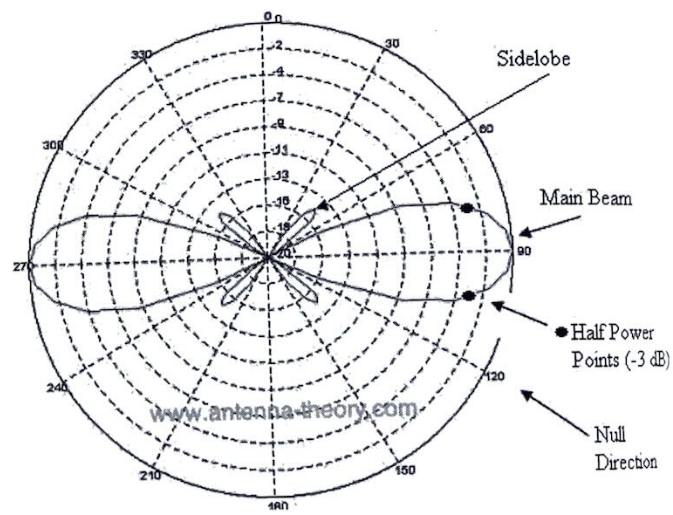

Fig. 2.2: Polar Radiation Pattern

The radiation pattern is a graphical representation of the received electric field (or as a function of magnetic field) at a constant radius from a transmitting antenna in any particular plane as shown in figure2.2 Radiation patterns are usually presented as polar plots

- **Polarization of Antenna:** The polarization of an antenna is the polarization of the radiated fields produced by an antenna, evaluated in the far field. Hence, antennas are often classified as "Linearly Polarized" or a "Right Hand Circularly Polarized Antenna". This simple concept is important fo antenna to antenna communication. First a horizontally polarized antenna will not communicate with a vertically polarized antenna. Due to the reciprocity theorem, antennas transmit and receive in exactly the same manner. Hence, a vertically polarized antenna transmits and receives vertically polarized fields. Consequently, if a horizontally polarized antenna is trying to communicate with a vertically polarized antenna, there will be no reception.

In the special case when the electric-field of the transmitted wave is normal to both the directional of propagation and the ground-plane (as illustrated in Figure 2.3(a)), the antenna is called vertically-polarized.

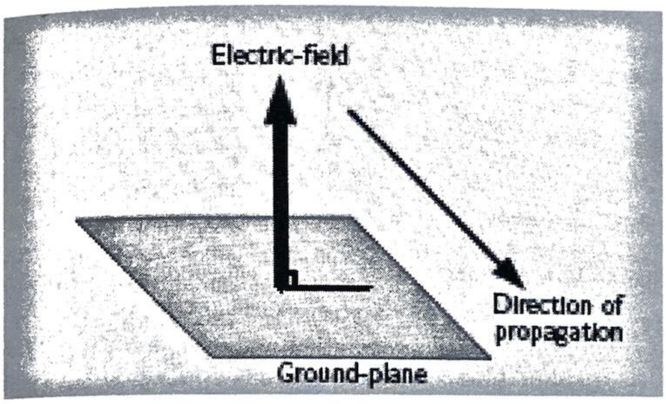

Fig. 2.3(a): Vertically polarized

Conversely, the antenna is horizontally-polarized if the electric-field is normal to the directional of propagation and parallel to the ground-plane, as shown in Figure 2.3(b).

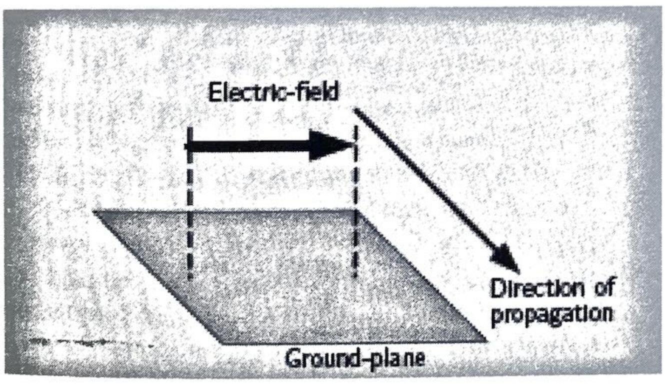

Fig. 2.3(b): Horizontally polarized

The electric-field of the transmitted wave from a circularly-polarized antenna rotates at a constant angular velocity as it propagates in space. The electric-field, therefore, traces out a spiral path in the direction of propagation as illustrated in Figure 2.3 (c).

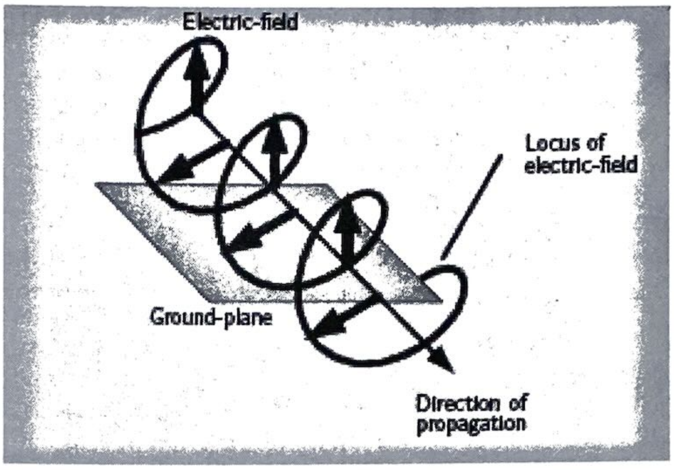

Figure 2.3(c): Circularly polarized

The choice of antenna polarization in a practical wireless system depends heavily on the environment that the system operates [5, pp. 332–335].Consequently, a receiving antenna with matching polarization to the transmitting antenna is usually preferred for minimizing signal losses due to cross-polarization. In contrast, the different propagation mechanisms in a multipath environment, such as reflection and diffraction, introduce different degrees of distortion to the polarization of the transmitted signal. In general, for two linearly polarized antennas that are rotated from each other by an angle ϕ, the power loss due to this polarization mismatch will be described by the Polarization Loss Factor (PLF):

$$PLF = \cos^2 \phi$$

Hence, if both antennas have the same polarization, the angle between their radiated E-fields is zero and there is no power loss due to polarization mismatch. If one antenna is vertically polarized and the other is horizontally polarized, the angle is 90 degrees and no power will be transferred.

- **Effective aperture:** A useful parameter calculating the receive power of an antenna is the effective area or effective aperture. Assume that a plane wave with the same polarization as the receive antenna is incident upon the antenna. Further assume that the wave is traveling towards the antenna in the antenna's direction of maximum radiation (the direction from which the most power would be received). Then the *effective aperture* parameter describes how much power is captured from a given plane wave. Let W be the power density of the plane wave. If P represents the power at the antennas terminals available to the antenna's receiver, then:

easy way to make a phased array of antennas with dynamic beam forming ability.[38]These antennas can be designed for any desired operating frequency of and their dimensions can be determined using the design procedure from [6, pp. 31–84]. The width of the rectangular patch W (in meters) is given by [6, p. 57].

$$W = c/2f_r\ [(\text{å}_r + 1)/2]^{-1/2}$$

Where c is the speed of light (3 x10^8 ms"¹), f_r is the resonant frequency (in Hz), and å_r is the relative dielectric constant of the substrate. The length of the microstrip patch L (in meters) is given by [6, pp. 46, 57].

$$L = c/2f_r\text{"}\text{å}_{eff}\text{ " }2\text{Äl}$$

Where

$$\text{å}_{eff} = (\text{å}_r + 1)/2 + (\text{å}_r \text{ " } 1)/2(1+12h/W)^{-1/2}$$

The variables å_{eff} and h are the effective dielectric constant and height of the substrate respectively, and Äl is the fringe factor due to the fringing field on the edges of the patch. A microstrip feed line is used to excite the patch at the centre of its edge. For an impedance of 50 ohms, the width of the feed line w (in meters) was determined using the design procedure from [8, pp. 11–12].

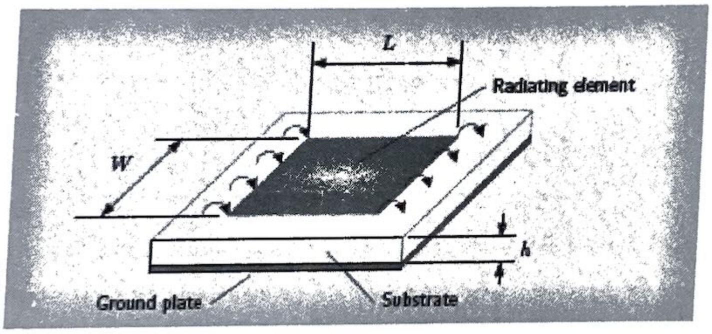

Fig. 3: Construction of a microstrip patch antenna showing fringing fields that account for radiation.

(iv) **Horn antenna:** A horn antenna or microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct the radio waves. Horns are widely used as antennas at UHF and microwave frequencies, above 300 MHz.[39] They are used as feeders (called feed horns) for larger antenna structures such as parabolic antennas, as standard calibration antennas to measure the gain of other antennas, and as directive antennas for such devices as radar guns, automatic door openers, and microwave radiometers.[24] Their advantages are moderate directivity (gain), low SWR, broad bandwidth, and simple construction and adjustment.[23]An advantage of horn antennas is that since they don't have any resonant elements, they can operate over a wide range of frequencies,(for example allowing it to operate from 1 GHz to 20 GHz).

(v) **Inverted vee antenna:** An inverted vee antenna is a modified dipole antenna supported in the center with the ends lower than the center. Viewed from the side, it looks like the English letter "V" turned upside down, hence the name. Inverted vee antennas are commonly used by many amateur radio stations, and aboard sailing vessels requiring better HF performance than available with a short antenna [34]. The gain of an inverted vee is similar to that of a dipole at the same elevation because most of the radiation is from the high-current portion of the antenna, which is near the center. Since the center of both antennas is the same height, there is little difference in performance. Maximum gain achieved 1.9 dBi.

(vi) **Loop antenna:** It is a radio antenna consisting of a loop (or loops) of wire, tubing, or other electrical conductor with its ends connected to a balanced transmission line[39]. Within this physical description there are two very distinct antenna designs: the small loop (or magnetic loop) with a size much smaller than a wavelength, and the resonant loop antenna with a circumference approximately equal to the wavelength. Small loops have a poor efficiency and are mainly used as receiving antennas at low frequencies. Except for car radios, almost every AM broadcast receiver sold has such an antenna built inside of it or directly attached to it. These antennas are also used for radio direction finding. They are typically used at higher frequencies, especially VHF and UHF, where their size is manageable.

vii) **Corner reflector:** They are frequently combined and commercially sold as residential TV antennas. Cellular repeaters often make use of external directional antennas to give a far greater signal than can be obtained on a standard cell phone. Satellite Television receivers usually use antennas. For long and medium wavelength frequencies, tower arrays are used in most cases as directional antennas.

3.3 SMART ANTENNA SYSTEMS

In radio, multiple-input and multiple-output, or MIMO [30] is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. Note that the terms input and output refer to the radio channel carrying the signal, not to the devices having antennas.MIMO technology [10] has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity [32] (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wifi), 4G, 3GPP Long Term Evolution, WiMAX [4].

A multiple-input multiple-output (MIMO) antenna system employs more than one transmitting and receiving signal branch as illustrated in Figure 4.1 [7]. The number of signal branches does not necessarily correspond to the number of antenna elements; instead, they represent the number of external input and output ports. MIMO systems require Multiple Element Arrays (MEA's[1]) [33] to transmit and receive on multiple signal branches. As these antenna elements are spatially separated, the propagation paths among the signal branches are different. Special signal processing and coding techniques can be used to exploit the spatial diversity of this channel and achieve a significant improvement in overall system performance [5, pp. 629–659].

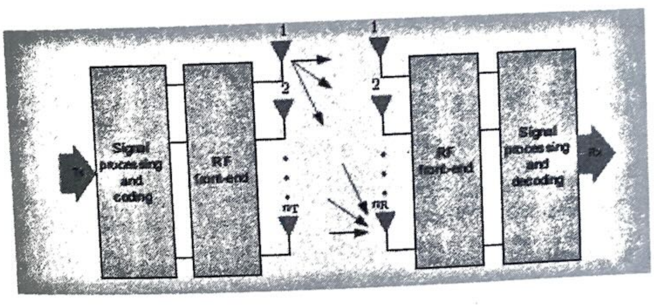

Fig. 4.1: A general MIMO antenna system.

In MIMO systems, signal processing is performed at both the transmitter and the receiver [34]. This type of MIMO system can, theoretically, provide the best performance at the expense of complex (and therefore costly) transceivers at the mobile devices [35].

4. COMPARISON OF ANTENNAS

On the basis of various parameters like radiation pattern, resonating frequency, cost implementation, advantages and disadvantages various comparisons are made between Omnidirectional, Directional and Smart antennas in the following paragraphs.

A. OMNI ANTENNA PROS AND CONS

Omni antennas are very easy to install. Due to the 360 degrees horizontal pattern, it can even be mounted upside down from a ceiling in the indoor environment [26]. Also, because of its shape it is very convenient to attach these antennas to the product. For example, you might see Rubber Duck antennas attached to the wireless APs (Access points). In order to obtain an omnidirectional gain from an isotropic antenna, energy lobes are pushed in from the top and the bottom, and forced out in a doughnut type pattern. This type of antenna design can deliver very long communications distances, but has drawback i.e. poor coverage below the antenna, as in Figure 4.2.

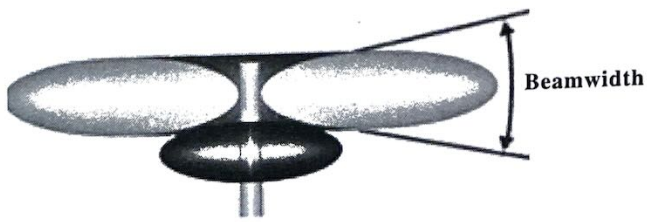

Fig. 4.2: Area of poor coverage directly under antenna

If we try to cover an area from a high point, we see a big hole below the antenna with no coverage. This problem can be partially solved with the design of something called down tilt. With downtilt, the beamwidths are manipulated to provide more coverage below the antenna than above the antenna. This solution of downtilt is not possible in an omni antenna because of the nature of its radiation pattern. The omni antenna is usually a vertically polarized antenna, so you cannot have advantages of using cross polarization here to fight interference [2]. A low gain omni antenna provides a perfect coverage for an indoor environment. It covers more area near the AP or a wireless device in order to increase the probability of receiving the signal in a multipath environment.

B DIRECTIONAL ANTENNA PROS AND CONS

With the directional antennas, you can divert the RF energy in a particular direction to farther distances. Therefore, you can cover long ranges, but the effective beamwidth decreases. This type of antenna is helpful in near LOS coverage, such as covering hallways, long corridors, isle structures with spaces in between, etc. However, as the angular coverage is less, you cannot cover large areas. This is a disadvantage for general indoor coverage because you would like to cover a wider angular area around the AP (Access points).Antenna arrays should face in the direction where the coverage is desired, which can sometimes make mounting a challenge. Directional antennas used for the indoors typically have a lower gain, and as a result, have a lower front-to-back and front-to-side lobe ratios [7]. This result in less ability to reject or reduce the interference signals received from directions outside the primary lobe area. While directional antennas can be of great value for certain indoor applications, the vast majority of indoor installations utilize omnidirectional antennas for the reasons cited in this document. The selections of an antenna, directional or omnidirectional, should be strictly determined by a correct and proper site survey.

C. SMART ANTENNAS PROS AND CONS

Multiple Input, Multiple Output or MIMO antenna technology [4] is the latest in communication systems. These include the WiWi or WiMAX-WiFi networks it's developing – which use WiMAX connections in the backhaul and affordable WiFi coverage of multiple local hotspots and provide wireless broadband coverage, especially in outlying areas not already served by existing networks. First it enables the increase of data rates by transmission of several independent multiplexed data streams on the different transmit antennas. Second, it can enable robust communications, especially in challenging environments for radio propagation, by sending instead redundant information over the multiple antennas. Multiple data streams enable higher data speeds, while with redundancy under less radio-friendly conditions, if one signal is disrupted by interference, the receiver can recover all data from the other, a benefit known as "diversity" [12]. It can be clubbed with OFDM (Orthogonal frequency division multiplexing).OFDM's main advantages is its greater scalability to support wider and wider bandwidths, more advanced services and higher data rates. "WiMAX now can operate with a 20MHz channel and next up to 100MHz channel and there is a direct correlation between channel bandwidth and the data rate. However the complexity involved in doubling the bandwidth with GSM-like physical layer increases exponentially with bandwidth, hence requires and exponential increase in processing power.

Few of the antennas have been compared on basis of characteristics and is summarized in the Table 4.1 given below.

Table 4.1: Comparison of antenna

S.No.	Parameters	Omni directional antenna	Yagi antenna (directiona)	Patch antenna (directional)	Parabolic antenna (directional)	Smart antenna
1	Location	Indoor/Outdoor	Outdoor	Indoor /Outdoor	Outdoor	Indoor/Outdoor
2	Radiation pattern	Omni-directional Antenna, 360 degree doughnut-shaped radiation pattern	Directional Antenna	Directional Antenna, Short-range; radiation pattern is in the shape of a hemisphere	Directional Antenna; very narrow, highly concentrated signal; requires accurate aiming	Highly directional. The higher the number of antenna elements making up the smart base station antenna array, the higher the available gain
3	Applications	Point-to-Multipoint applications; It is primarily used as a outdoor WLAN/ WISP access point antenna.	Point-to-Point applications; medium-range directional connections; Bridge antenna.	Work well as an indoor access point antenna, short-range bridge antenna, or a client antenna in any WLAN or WISP.	Long-range applications; Point-to-Point bridge antenna; long-distance access point client; works well where water is present	They are used notably in acoustic signal processing, track and scan RADAR, radio astronomy and radio telescopes, and mostly in cellular systems like W-CDMA and UMTS.
4	Poles/Masts	Mast	Mast or Wall	Any flat surface or Mast	Mast	Any flat surface or Mast

5. CONCLUSION

The various antenna options discussed above are theoretically applicable to wireless devices such as Mobile, WLan, WiFi, Wimax etc. The choice of antennas is, however, often restricted due to the relatively large number of mobile users and their dynamic nature; hence, low-cost omni-directional antennas are frequently used. In this paper, the investigation into antenna selection and deployment is therefore concentrated on base station antennas. It is also seen that instead of expensive active signal processing techniques (such as smart antennas and multiple-input multiple-output (MIMO) systems) [34] the deployment of directional antennas (Microstrip patch) [26] and MEAs has been considered as a low-cost option for improving the performance of wireless systems. Strategic antenna deployment can take advantage of this variation and maximize the performance of the antennas.

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