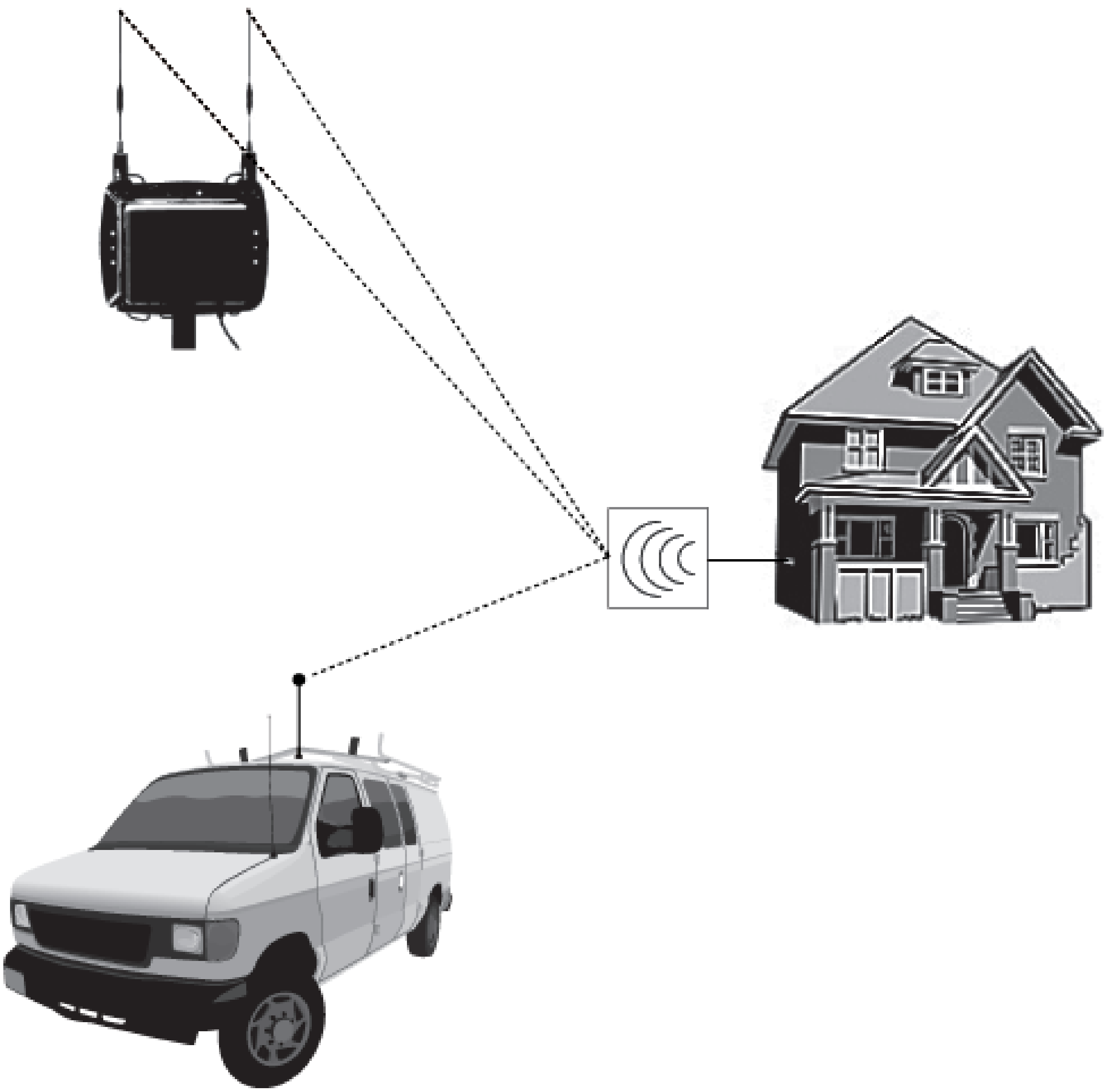
Understanding RF Propagation of AMR/AMI Systems



MRT-WP-1 (6-11)

White Paper

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Introduction

Most Automatic Meter Reading (AMR) systems installed in utilities use radio frequency (RF) communication. RF communication is also used for two-way radios, wireless supervisory control, data acquisition (SCADA) systems, office wireless networks, routers and cell phones.

In an AMR system, the AMR endpoint (transmitter), located on or near the utility meter, transmits meter reading information via RF. If the endpoint is a two-way design, it can also receive information and instructions from the utility. If the utility uses a mobile data collection system, the receiver collects and stores meter information to transfer to the utility billing system.

Alternately, a utility might use a fixed network referred to as an Advanced Metering Infrastructure (AMI) system. In AMI systems, permanently mounted gateways receive the transmitted endpoint data, which forwards to a central utility computer.

Users and installers of AMR and AMI systems should be familiar with RF technology to understand the conditions that affect proper data transmission.

Radio Propagation – Sending Signals Through the Air

Radio signals are electromagnetic waves caused by vibrating electrons at a transmitting antenna. Waves leaving the antenna are called RF propagation (RFP). The signals have a unique frequency set by the endpoint and are based on Federal Communications Commission (FCC) frequency allocation and regulation. AMR/AMI applications operate in frequencies that are measured in megahertz (MHz) or millions of cycles per second.

Frequencies above 30 MHz are often referred to as line-of-sight (LOS) communications, as the radio signal travels in a straight line. The endpoint and the receiver are ideally positioned to “see” each other, with the radio waves traveling unimpeded between the two antennas. LOS frequencies are typically used with utility AMR systems (450 MHz licensed band or 902-928 MHz non-licensed band).

Ideal conditions for line-of-sight signals include an unobstructed path between the endpoint and receiver.

Factors Affecting an LOS RF Signal

Environmental and equipment factors affect RF propagation. Some of these factors include:

Environmental and physical factors

- Free-space attenuation
- Absorption
- Reflection
- Diffraction
- Scattering

Equipment factors

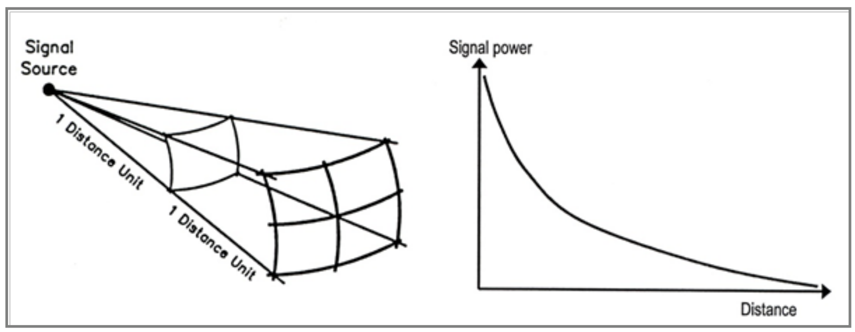
- Receiver sensitivity
- Transmitter power
- Antenna height
- Antenna design

Environmental and physical factors can negatively affect propagation and limit the maximum range of the signal. In mobile data collection systems (AMR), the RF path changes as the receiver in the vehicle is moving relative to the meter endpoint. Fixed network systems (AMI) have the meter endpoint and gateway (or data concentrator) mounted in fixed locations, possibly resulting in RF path blockage. Good planning for gateway locations minimizes the factor effects.

Free-Space Attenuation

A radio signal behaves like light in free space. As the radio energy expands outward from its source, the energy is dispersed over an increasingly greater area. However, this dispersion causes the radio waves to weaken as they travel away from the endpoint. This weakening, or attenuation, grows rapidly with distance; the signal weakens with the square of the distance traveled. For example, if the distance between the endpoint and the receiver is increased from 100 feet to 1000 feet (10 times), the signal will only be 1/100th as strong. Free-space attenuation or path loss is a significant factor governing the strength of an AMR endpoint signal, even if no other hindrances exist in the signal path.

Radio energy is dispersed over larger areas as the distance from the source increases. The disbursement causes a weakened or attenuated signal. The change of one distance unit causes the signal to be one-quarter as strong.



Absorption

RF energy is also lost to absorption when radio waves travel through substances. Any non-metallic (non-conducting) objects in the path between the endpoint and receiver will absorb some of the signal, reducing the signal strength and signal range.

Permanent obstructions, such as buildings, trees and other foliage, along with large dense objects, such as thick concrete walls (especially with no windows) absorb RF signals. In pit/vault applications, non-metal lids can absorb some of the signal if endpoints are mounted below the pit lid. Flooded pits and even the soil surrounding the pit vault can hamper RF signal strength.

Terrain can also act as an obstruction. Hills and other landscape features located between the endpoint and receiver may absorb significant amounts of the RF signal.

Depending on the day and the season, signal paths may have different absorption characteristics. During the summer, trees will have more absorption due to foliage. Conversely, less absorption occurs during the winter months. Wet trees absorb more than dry trees. Pine trees absorb more than leafy trees. Rain, snow, fog and air pollution absorb RF signals. Snow buildup around a gas meter endpoint results in signal absorption. Debris on pit/vault lids, such as grass, dirt and bark, will also absorb the signal.

Absorption characteristics for a specific signal path can change permanently due to additions and removal of various objects, such as new or renovated buildings, landscaping changes, etc.

RF energy is absorbed by non-metal objects between the endpoint and receiver, reducing the effective range.

Reflection

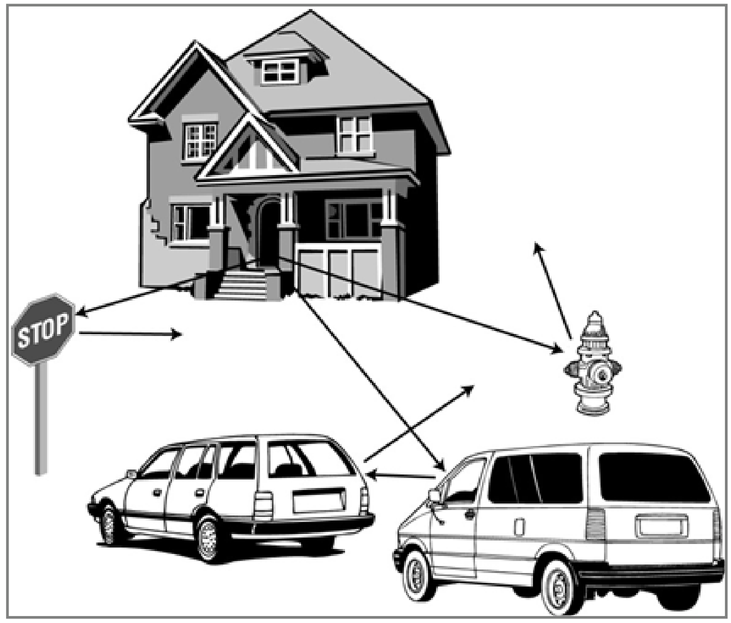
Metal and other conducting objects reflect RF signals. Metal structures and materials like aluminum siding and flashing, walls with metal lathe or rebar, chain link fences, vehicles, water towers, and metal meter vault and pit lids all cause RF reflections. Endpoints located in basements might have to contend with metal furnaces, boilers, water heaters, metal ducts and pipes. Other objects such as a large truck parked over or near a pit or vault endpoint will cause temporary signal degradation due to reflections back into the surrounding soil.

Radio signals traveling over relatively smooth ground or bodies of water can also experience "ground reflections." Frozen lakes and crusted snow cover can also cause ground reflections.

Reflected signals create multiple paths of the same signal that might be out-of-phase with each other, which can cause signals to cancel each other out. The result is an undetectable signal at the receiver.

Reflected signals might also result in reception of signals at unanticipated locations.

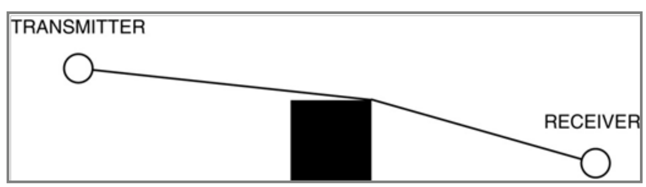
RF signal reflection can occur with a variety of metal objects. Multiple reflections can make it difficult to predict signal strength.



Diffraction

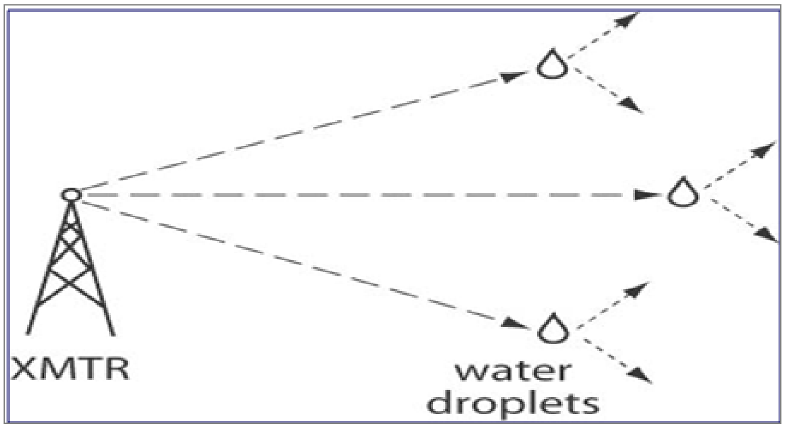
Diffraction is a common natural phenomenon that affects light, sound, radio and other coherent waves. Abrupt changes and sharp edges of path obstructions can lead to signal diffraction, which changes the signal direction. Diffraction normally causes signal distortion; however, communications might occur even though the line of sight is entirely obstructed and the signal is distorted.

Diffraction occurs when a radio signal encounters a surface with sharp edges, which bends the radio wave.



Scattering

The direction of radio waves can also be altered through scattering. An example of scattering is the effect on a beam of light in fog. Radio waves are similarly scattered when they encounter randomly arranged objects of wavelength size or smaller, such as water droplets or vegetation. For reference, the wavelength of a 900 MHz signal is about 13 inches. Recall that both water and vegetation also absorb some of the signal.



Radio waves are scattered when encountering particles, such as rain or fog, that are equal to or smaller than the signal wavelength.

Receiver Sensitivity

Receiver sensitivity is the minimum signal strength that must be delivered to the receiver before the signal can be detected and amplified. Receivers that are more sensitive can detect lower strength signals. Receiver antennas may also differ and affect the signal strengths delivered to the receiver.

Transmitter Power

Transmitter power level is influenced by modern design concepts and regulated by the FCC. In water and gas applications, the endpoint is typically battery powered, so the design trade-offs of transmitter power, time interval between transmissions and battery life are major considerations. Mobile systems typically have lower power endpoints transmitting at short intervals compared to a fixed network endpoint, which typically transmits less often but at a higher power.

Antenna Height

When a fixed network is used, the height of the gateway will limit the absolute maximum range of the signal paths between the gateway and the endpoints it serves. This is due to the curvature of the earth, limiting the line-of-sight path between the two radios. In the simplest form, an approximation of the distance (D) in miles between a gateway at a height (H) in feet and an endpoint at ground level is:

$$D = 1.23 \cdot \sqrt{H}$$

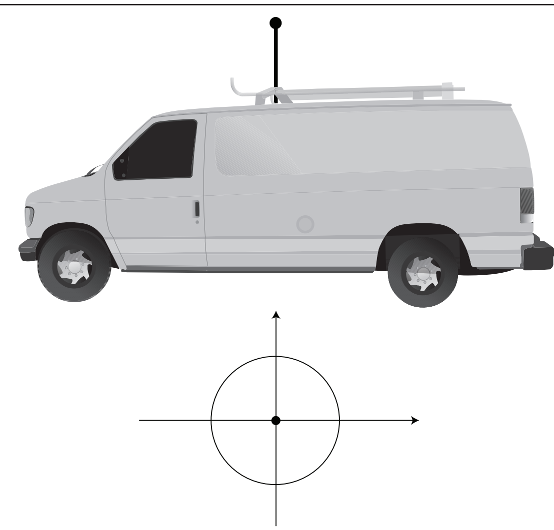
This simplified formula sets the maximum limit for line-of-sight range due to the curvature of the earth. It assumes no terrain irregularities within the range of a specific gateway, nor does it account for any other RF propagation factors previously described that may limit the RF range.

While taller gateway mounting locations are generally preferable, there is a practical limitation to how many endpoints a gateway can manage. Theoretically, a gateway mounted very high in a densely populated area might encounter too many endpoint signals to properly receive and manage. However, pre-planning for a fixed network layout will improve signal management.

Antenna Design

Most AMR transmitters utilize omni-directional antennas. Assuming no other influences, the RF energy is radiated and received equally in all directions around the antenna.

Omni-directional antennas, often used in AMR applications, transmit and receive equally in all directions.



Radiation pattern of a vertical antenna; top-down view

Omni-directional antennas may also have different levels of efficiency. A small flexible antenna on a handheld data collector will not be as effective as a larger antenna mounted on the roof of a vehicle.

Directional antennas are used in SCADA applications to maximize antenna efficiency in a single signal path direction, as the endpoint and receiver are fixed relative to each other. However, since AMR has multiple endpoints in potentially unlimited directions, directional antennas are not used.

The Real World – Various Scenarios

Radio signals are often obstructed in AMR applications and in most other LOS communication applications. Sometimes, the path between the two radios is obstructed due to permanent environmental factors, such as trees in the line of sight. In other cases, the issues may be temporary with no long-term limitations to communications. However, in most cases communication is routinely successful since the obstructions are not enough to be an issue, or there are alternatives available to minimize the obstruction. The following are illustrations of a number of AMR scenarios.

Basement Endpoint

Meters and endpoints are rarely located in optimum locations for RF propagation. Gas and water meters are often located in basements. Absorption from the building foundation, building materials and soil outside the basement wall can significantly limit range. Reflections from metal objects such as furnaces, water heaters, metal ducts, etc. may hinder RF signals. Sub-basement locations present more obstacles.

To improve communications, a remote endpoint (separated from the meter by a wire) can be mounted in the floor joists of the floor above, near an outside wall. Another alternative is to run the wire through the wall to the outside and mount the endpoint on the outside wall. Both alternatives potentially result in fewer obstacles for the signal path.

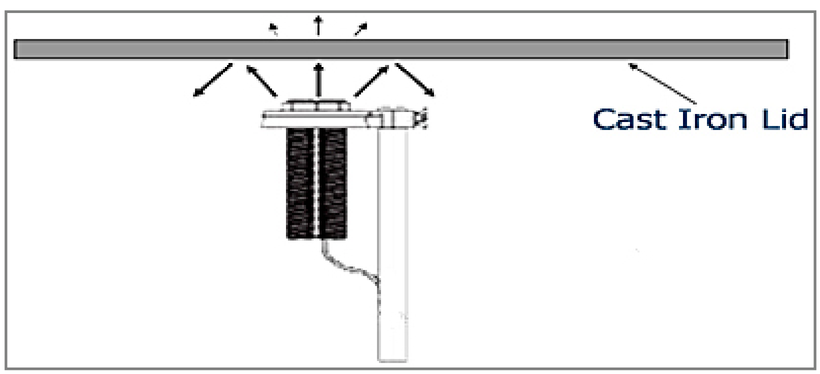
Meter Vault and Pit Lids

Metal lids present two challenges to successful RF communications. First, if the endpoint is mounted under the metal lid, most of the RF signal is reflected off the lid, back into the vault/pit, and most likely absorbed by the soil. The small amount of RF that does escape the vault/pit is through holes in the lid or the air gap around the edge of the lid. This may be adequate for a mobile collector that is in proximity to the endpoint. In a fixed network, where maximum range is desired, metal lids severely limit effective communications.

Second, antennas are designed to be electronically matched to the endpoint circuit so that maximum energy transfer occurs. Since antennas are conductive (made of metal), any large masses of metal close by will interfere with the antenna/circuit matching and could easily decrease the antenna performance. An example is a metal lid used for vaults or pits. The mass of the lid and proximity to the antenna causes severe degradation of energy transfer from the transmitter circuit, thereby compromising the RF signal.

To maximize RF performance, the antenna should be mounted through a non-metal (composite) lid. Or locate the endpoint outside the pit or vault and away from the metal lid.

Metal pit and vault lids reflect RF signals from an "under the lid" endpoint; the signal is then absorbed by the soil. A small amount of RF may escape through holes in the lid or through the air gap around the edge of the lid.



Dead Zones and Sweet Spots

In mobile data collection, the path between the endpoint and the collector is constantly changing as a vehicle travels down the street. A detected signal in one location with an unobstructed RF path between endpoint and receiver is called a "sweet spot." However, the same signal may not be received a short distance away due to various obstacles, thereby creating a "dead zone" or a "null" reading. Physically moving the receiver may create a "sweet spot."

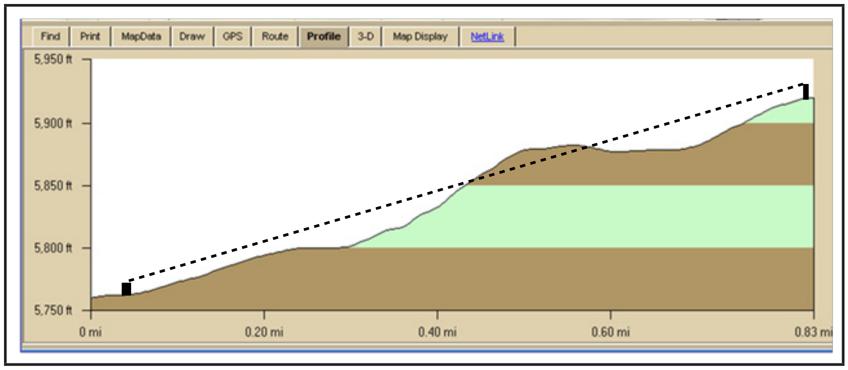
Weather-Related Challenges

Rain, snow and fog particles in the air absorb RF energy. Signal range might decrease during those types of weather. Rainstorms can also cause a meter pit or vault to fill with water. If the endpoint becomes submerged, signal range would be severely diminished. Wet leaves and other vegetation absorb more RF energy than leaves and vegetation that are dry. Snow cover on a gas meter endpoint might diminish RF range.

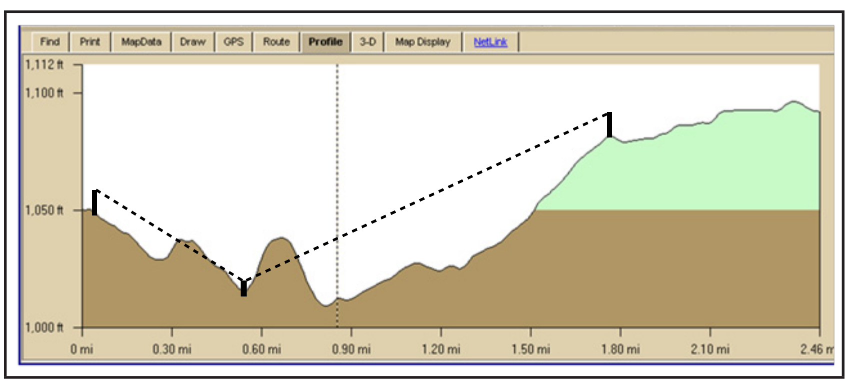
Topography

While topography is typically not an issue for mobile data collection, it can be an issue in fixed networks. Hills and other terrain features that lie in the RF path between an endpoint and gateway may be significant enough to absorb the entire RF signal. Since the RF signal travels in a straight line, the radio signal will not likely "fill in" behind major obstacles. The two dimensional topography drawings on the next page illustrate terrain absorption between an endpoint and a gateway.

A meter endpoint located at the bottom of a hill may not communicate with the gateway at the top. Signal improvement may be created by increasing the height of the gateway or moving it to another location. However, signal reflections might allow the signal to be received intact, even though the primary line-of-sight signal is obstructed.



A meter endpoint located in a deep valley is likely restricted from communicating with both gateways. Possible solutions might be to increase the left gateway height or add a repeater (gateway) to the system.



Wire Mesh Cages Around Meters

To minimize tampering with meters, especially those located in public-access areas, chain link fences or cages are occasionally installed around the meter. While beneficial for anti-tampering, the chain link mesh cage acts as an RF shield, therefore reflecting most, if not all signal transmission inside the cage.

Using a non-metal cage or fence would have minimal impact on the signal. Alternatively, a remotely mounted endpoint could be used outside of the cage.

Locating Gateways

Planning for fixed networks (AMI) involves a complex location analysis of all the endpoints, potential locations and heights for gateways, communication integrity based on topography, and other possible obstructions. This planning analysis is not absolute since many current planning tools cannot include all potential obstacles, plus meter and endpoint locations may not be exactly identified.

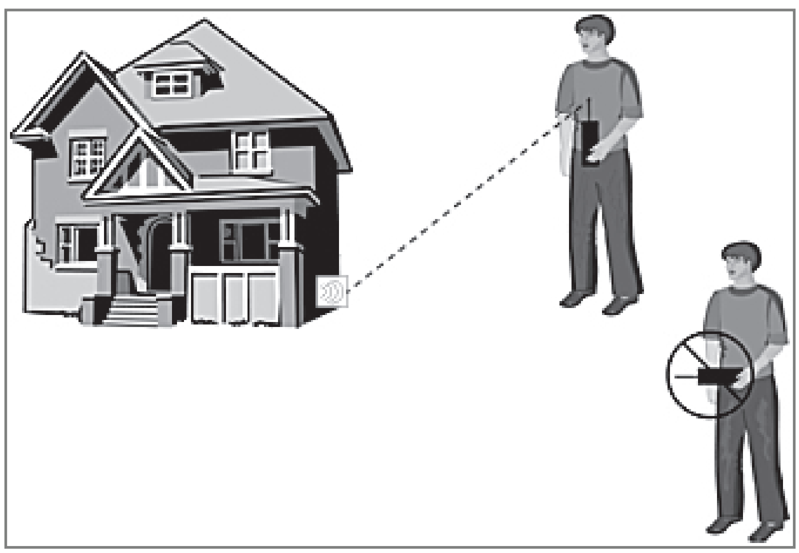
When mounted on a pole, a gateway has a full 360-degree "view" of endpoints located around the pole. However, if the gateway is mounted on the side of a water tower, the view of the opposite side of the tower might be restricted by the water tank itself. One solution is to mount the gateway on tower legs, if available, to improve the "view." However, mounting at a lower height potentially limits communications with endpoints on the outer fringe. Conversely, a gateway mounted on the top center of the water tower will have a clear 360-degree view, but endpoints located close to the tower base might be blocked from communications by the sides of the water tank.

Some gateways employ two separate antennas for one gateway, thereby enabling multiple line-of-sight paths for a single endpoint. If one antenna is experiencing poor signal reception, it is possible the other antenna has a sufficient signal. Collectively, systems with two antennas provide a robust solution.

Antenna Orientation

An AMR endpoint has an integrated antenna that emits radio waves while the receiver has another antenna that collects waves. Maximum signal strength between endpoint and receiver occurs when both antennas are using identical orientation (polarization). Antenna designs are optimized by the manufacturer to specific equipment. The manufacturer's installation instructions indicate proper installation guidelines for both the endpoint and receiver antenna to achieve optimum performance.

Significant signal degradation can occur if antenna misalignment occurs. For example, a handheld receiver is typically designed to have the antenna pointed perpendicular to the ground. Pointing the antenna/receiver toward the endpoint can negatively affect its performance, since the two antennas are not in alignment. Alternately, a pit or vault endpoint that is only placed in the bottom of a pit, rather than properly mounted, will likely perform poorly due to a misaligned antenna.



The manufacturer defines proper orientation of the transmitter antenna and receiver antenna (to achieve maximum signal strength). Pointing the handheld receiver antenna at the transmitter negatively affects reception.

Additional Considerations

Interference and Licensed Versus Unlicensed Frequencies

Some AMR systems utilize FCC-licensed frequencies. These frequencies are licensed for a fee and a specific period of time, with the assumption that the license holder is the sole user in a given geographical area. Generally this arrangement works well, however, users from adjacent frequencies or licensed users from geographically distant areas may inadvertently cause interference. Interference investigations and resolutions may take some time and effort. Certainly, "licensed" does not guarantee "interference free."

Other AMR frequencies are within the unlicensed Industrial, Scientific and Medical (ISM) band. While the FCC tests and approves all devices operating in the ISM band, communications equipment operating in these bands must accept any interference generated by other ISM approved devices. Designers of ISM systems often include methods of eliminating or minimizing interference from other users. "Unlicensed" does not mean "unregulated."

Frequency Hopping Spread Spectrum

Frequency Hopping Spread Spectrum (FHSS), a method of transmitting radio signals, minimizes interference in the ISM band. Originally utilized by the military for protection against eavesdropping and jamming, FHSS is highly resistant to interference. FHSS rapidly switches radio signal transmission among many frequency channels using a unique sequence known only to endpoint and receiver. As a result, many users can utilize the license-free ISM band simultaneously.

Conclusion

Millions of utility AMR and AMI endpoints are installed and successfully communicating with mobile reading equipment and fixed networks. These systems operate with a high degree of reliability under many different conditions. Understanding the basics of RF propagation and paying careful attention to proper installation, along with good data collection practices are important to optimizing the overall performance of an AMR or AMI system.

Installations that include significant obstructions may require testing signal reception at potential reading locations. Relocating the endpoint and/or the receiving location may be necessary. The maximum distance between an endpoint and a receiver will vary for each individual meter and is dependent on the environment between the two devices. It is important to note that this environment continually changes due to weather, season, vegetation growth, movement of vehicles, new buildings, modifications to existing buildings, etc. A list of both installation and data collection tips follows as a guide to ensuring optimum RF signal transmission and collection.

Installation Tips

- Carefully follow the manufacturer's installation guidelines, especially those regarding the mounting and orientation of the endpoint.
- Attempt to achieve a clear line of sight between endpoint and receiver.
- Mount remote endpoints as high as possible.
- Locate endpoints to minimize obstructions – especially metal and large, dense objects – in the line-of-sight path.
- Consider a remote endpoint mounted in basement joists or outside the building as alternative to an integral meter transmitter.

- Mount endpoints for pit/vault applications *through* a composite lid or *just below* the composite lid per the manufacturer's instructions. An endpoint only placed in the bottom of a pit will likely exhibit poor performance.
- Avoid metal pit/vault lids which would likely compromise signal performance.

Data Collection Tips

- Attempt to achieve a clear line of sight between receiver and endpoint.
- Walking/driving at a slower speed might improve results of a hard-to-read endpoint.
- Being closer to the endpoint is not always better due to reflections causing signal cancellation.
- Try different angles of approach if the endpoint is hard to read.
- Keep the handheld antenna pointed vertically. Pointing the antenna at the endpoint is not recommended.
- Note the best spots to receive endpoints that are particularly challenging.
- Seasonal change, increased vegetation, building construction and remodeling will all contribute to changes in signal strength over time.
- Keep pit/vault lids free of dirt, grass and other debris to minimize signal absorption.

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