WIRELESS DOCSIS™ CABLE EXTENSION

PRACTICAL CONSIDERATIONS

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ABSTRACT

In recent years, cable Multi-System Operators (MSOs) have begun deploying wireless technology to quickly and economically extend their existing RF cable plants. Specifically, wireless DOCSIS^{TM} compatible equipment is now available that extends the reach of the cable plant to address the rapidly expanding Small and Medium Business (SMB) and Small Office Home Office (SOHO) markets' need for high speed internet service. Adding wireless technology to existing cable plants provides unique applications tempered by technical constraints that are not encountered in wired- only systems. This paper describes the opportunities and challenges and provides guidance in implementing DOCSIS wireless technology resulting in reliable, transparent compatibility with MSOs' existing infrastructure.

INTRODUCTION

MSOs have in the past few years begun to embrace wireless technology as a quick and economical means of expanding the reach of their existing cable plants and thereby increasing their subscriber base. As new fixed wireless technologies have arisen, some have proven very applicable for use in cable networks. Specifically, there are wireless products expressly designed to be DOCSIS compatible that expand the reach of cable modem access to SMB and SOHO markets. However, incorporating wireless technology to existing cable plants presents constraints and challenges not encountered in wired-only systems. This paper describes these challenges and provides guidance in implementing wireless technology resulting in reliable, transparent compatibility with MSOs existing infrastructure.

There are two fundamental ways in which wireless technology can be implemented to extend the reach of DOCSIS cable systems. One method is to access the downstream DOCSIS signal, demodulate it to baseband (i.e. digital bits), input these bits to a non-DOCSIS radio, transmit it over the air to a compatible radio located at the client side, and then demodulate the signal to baseband (e.g. Ethernet) for use by the client. The upstream path is handled in the same fashion. A benefit of this technique is in allowing the use of any over-the-air transmission protocol. The limitations of this architecture include: (1) no point-to-multi-point capability, (2) non-scalable (i.e. 2 radios are required to service each customer), (3) existing MSO monitoring, provisioning, and back office systems cannot be leveraged, (4) having the radio create the DOCSIS uplink signal to be injected into the cable plant is very difficult, and (5) non-DOCSIS radios are not designed to interface to the DOCSIS cable plant (power, signal levels, etc.).

The second method, which has gained favor in recent few years, does not demodulate/re-modulate the DOCSIS signals to baseband. Rather the DOCSIS signal is directly up-converted and transmitted over the air at higher frequencies (typically 2.4 GHz, 3.5GHz, or 5.8GHz) than used on the wired plant, then down-converted and fed into a standard cable modem. This simplified architecture can be conceptualized as a "point to multipoint wireless bridge" that replaces the last mile of cable yet still terminates at a cable modem. This method does not suffer the drawbacks of the previous method, is a less expensive overall solution, and requires simpler electronics.

Though the second method described has tremendous potential for MSOs, understanding the constraints and implementation issues of this type of wireless DOCSIS solution is the topic of this paper. The objective is to present applications and key considerations as MSOs look to leverage wireless capabilities into their networks.

For existing 2-way cable networks, wireless DOCSIS technology can be used as an overlay to fill in the gaps within the network where the cable does not reach. Alternatively, at the boundary of the network, wireless can be used to extend the overall network footprint. Wireless DOCSIS is also worth considering wherever cable is planned to be deployed, but in advance of laying cable, thereby providing immediate access and revenue.

APPLICATIONS

Point to Multipoint

DOCSIS is a point-to-multipoint architecture allowing one cable modem termination system (CMTS) to communicate with many cable modems. A DOCSIS wireless system must offer this same capability. One CMTS should have the ability to be connected, via coax cable, to one or many wireless access point hubs. Each wireless hub should then be able to communicate to multiple CPEs, with each CPE connected to a cable modem.

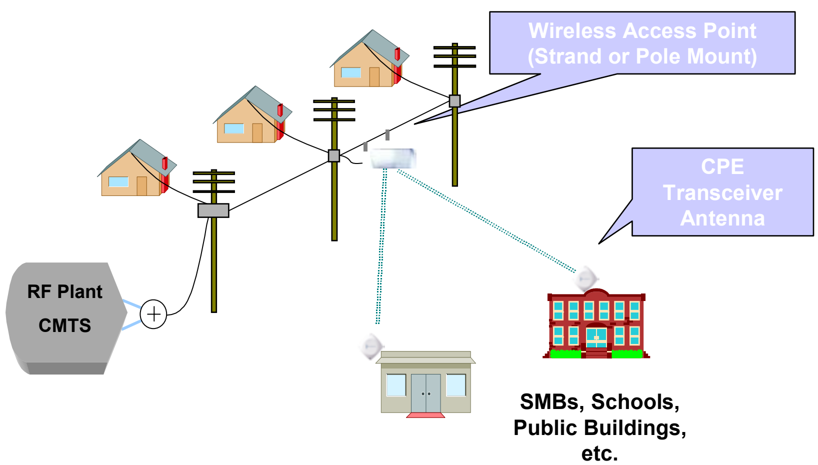

Figure 1 - Point to Multi-point to extend cable plants

A slightly modified architecture than that shown above is to have one CPE connected to multiple cable modems. This requires only that a splitter and possibly amplifiers be inserted between the CPE and the cable modems. An example of where this topology could be applicable is in a Multi-Dwelling Unit (MDU). For this case, care must be taken to maintain the proper DOCSIS signal levels between the CPE and each cable modem being serviced.

Upstream Only

For cable networks that have one-way plants and have yet to upgrade the plant to two-way, a wireless link is a very quick way to provide an upstream path. Wireless can be used to enable multiple cable modems, via one or more CPEs, to send an upstream signal to a wireless access point hub that is connected to the cable plant. The only part of the cable plant that then requires 2-way capability is that between the hub and the CMTS.

Downstream Video

As wireless DOCSIS equipment is designed to support a 6MHz wide 64 or 256 QAM signal, compressed digital video can also be transmitted just as easily as a DOCSIS signal. Using statistical rate multiplexing to perform grooming, MSOs and local cable operators can multiplex MPEG-2 streams for output to a 64 or 256QAM modulator providing either 27Mbps or 38.4Mbps data streams respectively. This data stream, containing multiple video channels, can be transmitted over the air and demodulated by a set top box at the other end of the link.

WIRELESS PROPAGATION

Range

Most wireless texts begin wireless path discussions using the Friis free space propagation equation to calculate range (1). This equation is derived from electromagnetic first principals. It states the power received in a wireless link is dependent on transmit power, transmit and receive antenna gains, air frequency, and distance. The Friis free space equation expressed in dB is:

$$P_R\,(\text{dBm}) = P_T\,(\text{dBm}) + G_T\,(\text{dB}) + G_R\,(\text{dB}) - 32.44 - 20\log f\,(\text{MHz}) - 20\log d\,(\text{km}) \qquad (1)$$

Where P_R = Power Received, P_T = Power Transmitted
G_T = Transmit Antenna Gain, G_R = Receive Antenna Gain
f = Over-the-Air Frequency, d = Distance

Unfortunately, the Friis equation is often misused in practice, which can produce highly inaccurate results. Friis requires free space, which is not a common occurrence. The distances achievable in a wireless link, especially in urban or dense urban environments, tend to be much less than predicted by the Friis equation. This is due to common real world impairments.

Looking closely at equation (1), "20log d" is termed the path loss. The path loss exponent, which is 20 in Friis formula, equates to 20dB attenuation for a 10 times increase in distance, or alternatively 6dB of attenuation for each doubling of distance. Empirical test data shows this does not hold true for many environments. Table 1 below lists empirical measurements of the path loss exponent, n, for different environments. Note that as the path loss exponent n increases, the greater the path loss attenuation and the shorter the distance.

ENVIRONMENT	PATH LOSS EXPONENT, n
Free space	2
Urban area	2.7 to 3.5
Shadowed urban	3 to 5
In building line of site	4 to 6

Table 1 - Path loss exponent for various environments

The key question to be answered is what exponent should be used to calculate path loss. Assuming that one or both sides of the link are relatively close to the ground, the 2-Ray Ground Reflection model has been shown to be a fairly accurate predictor of path loss versus distance. The 2-Ray model is valid under the condition where the path length d is much greater than the square root of the height above ground of the transmit antenna (H_T) multiplied by the height above ground (H_R) of the receive antenna. This case is shown in Figure 2.

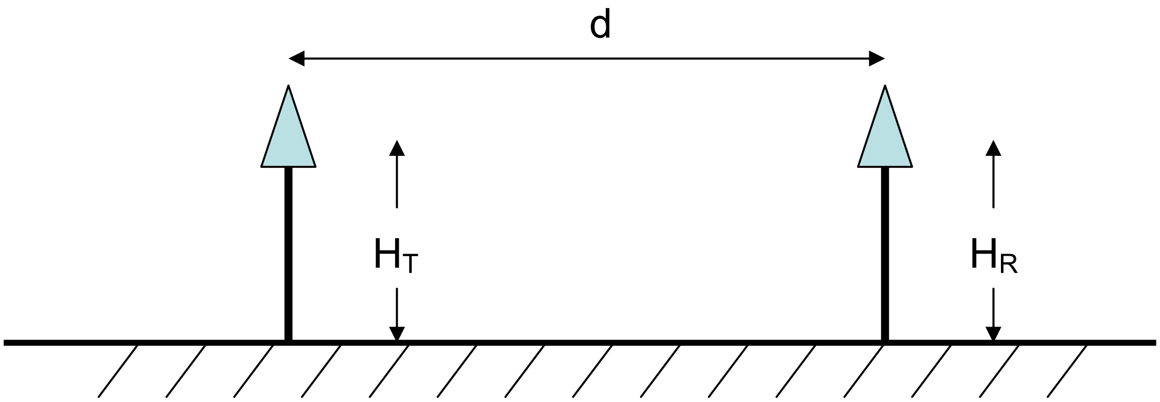

Figure 2 - 2-Ray Ground Model case when d >> $\sqrt{HT * HR}$

For the 2-Ray model, instead of using 20log d (km) as in the Friis model, path loss is expressed in dB as:

$$PL\ (dB) = 40\log d\ (km) - 20\log H_T + 20\log H_R \qquad (3)$$

Note in equation (3) the path loss exponent, n is 4 which equates to a 40dB increase in path loss for a 10 times increase in distance, or alternatively 12db path loss for each doubling of distance. As a first approximation the affects of H_T and H_R can be neglected.

Sample Range Calculation

The key parameters in calculating the range of a wireless link are the transmit power, antenna gains, path loss attenuation, receiver sensitivity, required carrier to noise and margin to account for real world impairments. Rearranging (3) to calculate path loss results in:

$$20\log d\ (km) = P_T\ (dBm) + G_T\ (dB) + G_R\ (dB) - 32.44 - 20\log f\ (MHz) - P_R\ (dBm) \qquad (4)$$

Assuming a 2-Ray ground model with path loss exponent of 4 and assuming antenna height attenuation is negligible, path loss is calculated using:

$$40\log d\ (km) = P_T\ (dBm) + G_T\ (dB) + G_R\ (dB) - 32.44 - 20\log f\ (MHz) - P_R\ (dBm) \qquad (5)$$

Table 2 below shows common values for a DOCSIS downstream using the unlicensed 5.8 GHz band. In no way are these values meant to be representative of all deployments as vendor equipment and each wireless link are unique.

DESCRIPTION	VALUE	COMMENTS
Effective Isotropic Radiated Power (EIRP) – Sum of transmit Power Amp output (P_T)+ transmitter antenna gain (G_T)	+33 dBm	FCC part 15.247 quasi-peak limit at 5.8 GHz is +36 dBm for point to multi-point applications. +33 dBm based on RMS power level plus margin for manufacturing variability
Receive antenna gain (G_R)	22 dBi	Dependent on antenna gain chosen
Carrier to noise minimum requirement	31.5 dB	Based on 256 QAM modulation
Received noise floor	-103 dBm	Theoretical noise floor in 6 MHz bandwidth plus 3dB receiver Noise Figure
Fade Margin + miscellaneous losses	7 dB	Inclusive of fast and slow fade environments and losses between antenna and radio

Table 2 Example of Wireless DOCSIS link budget

Assuming all else being equal, with the downstream modulation at 256 QAM and the highest upstream modulation at 64 QAM, the downstream will determine the shortest link. Using equation (5) and the values in Table 2, it is left to the reader to verify the link distance is 2.4 kilometers or 1.5 miles.

Line of Sight

To ensure a reliable wireless link, DOCSIS requires line of sight (LOS) conditions. In a wireless link, LOS ensures that a dominant signal with minimum distortion due to multipath fading, reflections and diffractions is received at the receive antenna.

A key question is what constitutes true line of sight. An accepted rule of thumb is that LOS conditions exist when there are no physical obstructions within 60% of the first Fresnel (pronounced "Frennel") zone. As shown in Figure 3, Fresnel zones are a series of ellipsoids between the transmitter and the receiver. The cross section of the first Fresnel zone is circular in geometry. For any Fresnel zone, the necessary keep-out area to maintain LOS is greatest at the center point of the link.

Table 3 lists the keep-out radius as a function of the distance from the end points of 2 mile link. Note that the higher the frequency, the smaller the keep-out area between the link end points to ensure LOS.

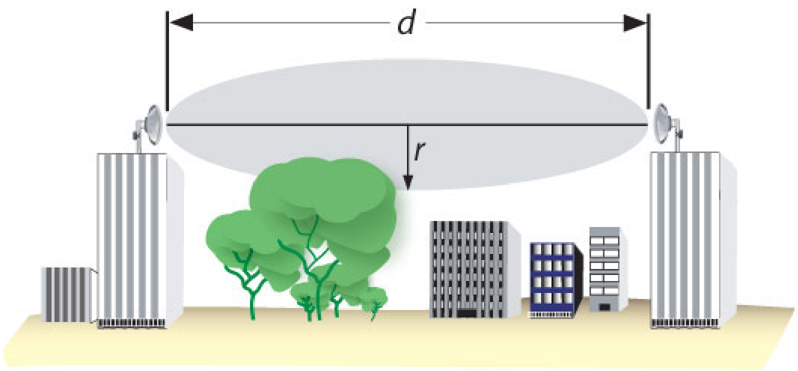

Figure 3 - Keep-out area to ensure Line of Sight

	Cross sectional keep out radius (ft) to ensure LOS for a 2 mile link		
Distance (miles)	**900MHz**	**2400MHz**	**5800MHz**
0.25	**20.5**	**12.6**	**8.1**
0.50	**26.8**	**16.4**	**10.6**
0.75	**30.0**	**18.4**	**11.8**
1.0	**31.2**	**19.0**	**12.2**
1.25	**30.0**	**18.4**	**11.8**
1.5	**26.8**	**16.4**	**10.6**
1.75	**20.5**	**12.6**	**8.1**

Table 3 - Radius of 0.6 Fresnel Zone (feet) as function of frequency for a 2 mile link to maintain LOS

UNLICENSED FREQUENCY BANDS

Wireless spectrum in the United States and Canada is allocated as either licensed or unlicensed. Licensed bands are awarded or auctioned by the FCC and purchased by any number of operators for mobile, point-to-point and point-to-multipoint applications. As a group, cable operators have not traditionally purchased national frequency spectrum licenses in the United States. This may change in the future as wireless becomes more significant in the battle for ownership of broadband subscribers. The relevant unlicensed frequency bands in the U.S. are listed below.

Compared to the lower unlicensed frequencies, the Unlicensed National Information Band in the 5GHz band typically has less congestion due to fewer devices operating in this band and the amount of spectrum available. The lower frequency unlicensed bands are popular bands for consumer applications such as 802.11b/g due to lower cost for components at these frequencies.

Industrial, Scientific and Medical	902MHz to 928MHz
Personal Communication Services	1.91 – 1.93GHz
Industrial, Scientific and Medical	2.4 – 2.48GHz
Unlicensed National Information Infrastructure Band	5.15 – 5.35GHz, 5.725 - 5.85GHz
FCC NPRM 03-110 Part 15 – New Spectrum	5.470 – 5.725GHz

Table 4 - Unlicensed frequency spectrum

PRACTICAL WIRELESS DOCSIS CONSIDERATIONS

Plug and Play

A major benefit of utilizing the DOCSIS protocol between the RF plant, wireless system, and cable modem is in maximizing the use of the existing HFC architecture, including:

1. Using the Baseline Privacy Interface (BPI) or BPI+ for over-the-air security
2. Remote telemetry for control and monitoring of the wireless link, which also follows the hybrid fiber management system (HMS) guidelines
3. Easily interfacing with the MSOs' existing Network Management Systems (NMS)
4. Back office systems such as billing and customer service are already in place

Interface to Coaxial Plant

To meet the needs of MSOs, wireless products must offer more than DOCSIS compatibility. The wireless system has to fit seamlessly into their huge installed physical plants. This puts further demands on the wireless equipment including:

1. Meeting stringent environmental outdoor specifications
2. Passing FCC certification
3. Adhering to the DOCSIS interface specifications to both the cable plant and the cable modem
4. Easily deployable by cable technicians with little or no specific wireless training
5. Be field serviceable with standard hardware and available cable test equipment

In addition, the wireless hub that interfaces directly to the cable plant must also meet the following:

1. Connect easily to the cable plant using standard taps
2. Draw low power directly from the cable plant's AC line
3. Mount on a cable strand, utility pole, or mast mount
4. Provide a high level of upstream ingress noise suppression (see next section)

Upstream Considerations

Plant engineers are understandably very concerned with potential upstream ingress noise in the cable plant. While DOCSIS requires 25dB carrier to noise ratio, most plants are designed to exceed this with significant margin. With the wireless hub receiver path passing over-the-air signals into the upstream cable plant, the risk of noise and interference is even greater. Each wireless vendor implements various techniques to ensure that non-DOCSIS over-the-air interference and noise that are received into the hub do not degrade the upstream cable plant performance

Per DOCSIS, the CMTS measures and commands each cable modem's upstream power level, ensuring the proper level is received at the CMTS. The output level of the cable modem is often set between 8 and 58dBmV . When a wireless link is added between the CMTS and cable modem there should be no impact to setting. This requires the wireless link's upstream path to (1) be fixed gain (i.e. no Automatic Gain Control) and (2) to the ability to set it's internal upstream gain to compensate for the differences in path loss depending on how far the CPEs are from the hub.

SUMMARY

Wireless technologies continue grow in use as a key enabling technology for the cable industry. Specifically, new wireless DOCSIS compatible equipments that utilize the unlicensed frequency spectrum easily extend the cable network, allowing MSOs to offer highspeed internet service to a greater number of customers. Implementing DOCSIS compatible wireless technology will result in reliable, transparent compatibility with the existing infrastructure. With a proper understanding of the wireless issues, DOCSIS wireless equipment can be a valuable addition to the MSOs tool kit to grow their SMB and SOHO markets.

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