HOME NETWORKING ON COAX FOR VIDEO AND MULTIMEDIA

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Abstract

Home networking of multimedia, and particularly of video, is covered, including usage models, system requirements, installation and maintenance, security, and comparison of the various in-home mediums. Field characterization of the in-home coax plant is described, followed by home field testing data of the technology developed by Entropic and field tested by MoCA™.

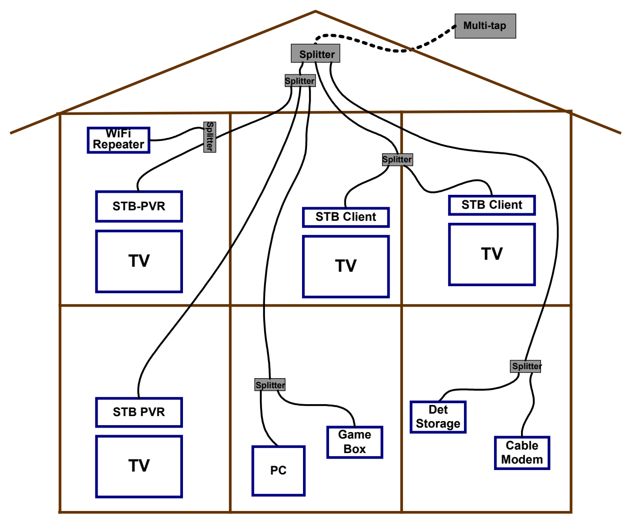
INTRODUCTION

The ability to home network digital entertainment, including multiple video, audio and data streams has received significant attention and effort in recent years. This effort is driven by the desire to have content from DVRs, audio devices, PCs, and broadband (including FTTH) available anytime and anywhere throughout the home. With the major new application being sharing video to all the home's displays, many product developers and service providers have realized that the "missing-link" to this capability is the availability of a ubiquitous, highly reliable and high throughput home network.

While consumers will accept lower quality or degraded video viewing on mobile and hand held devices, even occasional glitching, blocking or "buffering please wait" will not be tolerated for entertainment with standard home video devices such as TVs, flat panel displays, VCRs, DVRs, STBs, and media centers. This paper focuses on home networking of high quality video, defined as HDTV, SDTV and DVD without degradation, and is consistent with current operators' broadcast reliability.

USAGE MODEL

The following figure shows the home usage model with triple play services (voice, video, data). This home is using coax home networking, however the desired usage model is independent of home networking medium.



Usage Model Content

The home network must support multiple and simultaneous HDTV, SDTV, audio, data, VoIP, gaming, and other multimedia usages both from the broadcast network and from an in-home DVR or storage device. Video content will continue to be over MPEG2 as well as advanced coding (MPEG4, H.264, WM9, etc.).

Usage Model Data Flow

Each room and device may be either, or both, a source or sink of content both to and from multiple simultaneous devices. Consumers may add or move devices from room to room, changing where sources and sinks connect. Flow within a home may traverse the home network twice (double hop), such as when video is sent from a point of ingress to a DVR, and then from the DVR to a display.

Usage Model Installation

Devices may be provided from either retail or the service provider. While service providers may choose to professionally install these systems initially or perpetually, they do not want to choose a home networking technology that precludes a retail self-installation model.

REQUIREMENTS

The requirements on the home network are numerous. However, the key requirements are reliability and ubiquity, without which deployment is not feasible. There does not exist any reasonable home networking solution that provides 100% immediate penetration and ubiquity. Even 100 Mbps Ethernet over cat-5 has been shown not to be a 100% solution with issues including that rate negotiation problems can drop or bounce networks to 10 Mbps, many of the devices being deployed in homes can not in reality support more than 40 to 60 Mbps of real video, consumers can add hubs and collision domain devices to the network, and most devices lack QoS. The home networking solution that can and will be deployed is one that is:

- A >95% solution, with reasonable remediation for the remaining <5%.

This is the key criterion by which the home network must be judged .

With multiple HDTV and SDTV streams requiring the vast majority of data rate and the best packet error rate (PER), plus security, a home network that can support multiple HDTV streams meets the main requirements. The addition of low jitter and low delay for voice and gaming then covers it. Here, then, are the essential requirements:

- Coexist with existing services
- Medium collocated with target devices
- No changes to wiring or splitters or other medium specific devices
- Full mesh, peer-to-peer network
- Data rate net (MAC) > 60 Mbps
    - 100 Mbps preferred
- PER < 1e-6, BER 1e-9
- Delay < 20 msec
    - < 10 msec preferred
- Jitter < 1 msec
- Privacy from neighboring homes
- No degradation due to neighbor's home networking or general appliances
- No degradation due to other in-home networking products or general appliances
- No retransmissions above MAC layer
- Plug n' play on its medium
- Carry key protocols (Ethernet, 1394)
- Support various DRM
- Meet consumer price points
- Support multiple independent networks
- Service provider may open the home network to CE devices or keep it closed
- Futureproof to higher data rates

Key Requirement Drivers

Data Rate Requirements

An often overlooked but crucial point is that the home network must support the peak data rate per stream, and that streams can peak simultaneously. The vast majority of broadcast content in the USA today is MPEG2. Measurements of streams from the top 4 USA service providers showed that SDTV MPEG2 broadcasts are variable bit rate with average data rates between 2 and 3 Mbps, and peak rates around 9 Mbps. VOD SDTV streams tend to be constant bit rate between 4 and 5 Mbps.

HDTV MPEG2 streams can carry requirements from the content providers that a minimum of around 12 Mbps is allocated. Measurements of programs in San Diego showed that non-ATSC HDTV MPEG2 streams carry average data rates between 10 and 18 Mbps and peak rates between 13 and 19 Mbps.

Advanced coding schemes may reduce these average bit rates by around a factor of 2; however the peak rate does not reduce by as much as the average rate.

Fast forward and reverse, and other trick modes, can increase the peak data rate by a factor of 3 or more if continuous looking video is desired during the trick mode. If a decimated, fast slide show looking trick mode is acceptable, then data rates stay comparable.

Service providers will still need to make terrestrial or network ATSC content available to their subscribers. So even if an advanced codec brings the service provider's data rate down for HDTV, the subscriber may sometimes home network ATSC. Service providers must allocate the home networking data rate for ATSC streams at 19 Mbps regardless of their own HDTV data rates.

Table 1. Data Rates in Mbps

	Ave	Peak	Trick Modes
SDTV	1 – 3	3 – 9	3 – 20+
HDTV	6 – 18	9 – 19	9 – 40+
ATSC	19	19	19 – 40+
Double Hop	x2	x2	x2

Then, for example, a usage scenario with 1 HDTV stream, 1 ATSC stream, 2 SDTV double hops, and broadband at 10 Mbps requires allocation of 50 to 84 Mbps for play, and 50 to 148 Mbps if all streams did trick mode at the same time. A usage scenario with 3 ATSC streams and broadband at 3 Mbps requires allocation of 60 Mbps for play, and 60 to 123 Mbps for trick modes.

None of these numbers include another typically > 10% protocol and management overhead from the application. Additional data rate of 30% or more of a stream can also be needed to fill IPSTB buffers at channel changes in order to reduce channel change times.

Reliability Requirements

Digital cable programming is delivered with threshold PER of below 1e-6. The home network should have similar or better performance so as not to degrade viewing. When supporting UDP and 1394 protocols there is no request and retransmission of packets above the Link/MAC layer, so that this PER must be constantly maintained at the MAC layer by the home network. A home network with potential collision access will have a very difficult time achieving 1e-6 PER with any significant loading of its data rate. A fully coordinated MAC, collision free, is practically a necessity for currently reasonable home networks to achieve this PER for the desired data rates.

Reliability from Appliance and Neighbor Interference Requirements

The home network should not degrade due to other networking devices or typical electronic devices and appliances such as cordless phones, wireless laptops, wireless hot spots, vacuum cleaners, power drills, hair dryers and microwave ovens. This must be true for both the subscriber's other devices as well as the neighbor's devices. If reliability were subject to other devices and/or the neighbor, then not only would there be service interruptions but they would not be predictable or easily diagnosable.

Imagine a service provider's installer completing a successful installation of several home networked devices, rolling away in his truck, only to soon return when the subscriber experienced interruptions due to an appliance that when the installer returned, was no longer on, and there was no longer any interruption. Such a situation is not reliable, maintainable, or viable.

Quality of Service Requirements

In addition to a PER < 1e-6, the home network must deliver delay and jitter consistent with the services it carries. Gamers claim to be able to sense delays between 10 and 20 msec. Voice applications would like to see the delay budget allocated to home networking to be 10 msec or less. Jitter must be smoothed out in buffers at the transmitter and receiver. Such buffers must be a fraction of the total allowed delay.

Bandwidth Management Requirements

When the aggregate content's data rate exceeds, on a peak or average basis, the home networking data rate, then something must be delayed and/or dropped. Prioritization, for example using 802.1p, must be used to delay or drop lower priority traffic (typically data traffic). Video packets can not generally be delayed or dropped and must either have their data rate fully supported at PER 1e-6 or better, or else the video will be degraded... If there is not sufficient home networking aggregate data rate remaining to support a video stream or other traffic that can not accept dropped packets beyond a 1e-6 rate, then a bandwidth manager must inform the home owner that the traffic can not be supported and provide options for stopping other streams or services.

In practical usage then, where data rate is taken up by high speed videos, the important elements to ensure a quality experience are:

- very high aggregate data rate
- guaranteed packet delivery at PER < 1e-6
- a bandwidth manager and user interface

Installation Requirements

No new wires or changes of any sort to the in-home infrastructure should be the ≥ 95% rule.

A PC must not be required for self-installation. The target subscribers are TV viewers and not necessarily PC users. Even PC households do not expect to need a PC to install or operate their video systems.

MEDIUMS AND TECHNOLOGIES

The mediums in the home are wireless, phone line, powerline and coax. Each medium has innate characteristics, advantages and disadvantages. Each of these mediums has had one or more home networking technologies developed for it.

Selecting the Right Medium

For triple play, the medium selection is dominated by video, since all of the mediums can reasonably distribute the 1 Mbps received through broadband service today. The broadband service home networking will usually be wireless for mobility and laptop use. Video home networking, however, has very different requirements outlined above. Using these video requirements, the home mediums are evaluated below.

Wireless for Video Home Networking?

Numerous wireless solutions have been proposed and implemented. Despite its inherent attractiveness, and significant technology advances, no reasonable wireless solution has yet achieved the requirements for “whole-house” home networked video.

Furthermore, service providers can not subject their revenues to the potential of propagation and interference problems from existing and future other ever-expanding ISM unlicensed band wireless products and services. There can be no guarantee that services will be maintainable in an unlicensed band due to non-controllable and non-predictable interference. As a result, there exists no premium video service in an unlicensed wireless band.

Unfortunately, no technology can remove the “un” in unlicensed. Only the FCC can. With requirements of 100 Mbps, and a frequency band that should support going through walls, the economics do not make any sense for a licensed wireless home networking band to be created.

Real life tests of wireless “whole house” home networking shows that even in benign environment and optimistic scenarios, existing wireless solutions cannot come close to meeting the minimum data rates described above. Practical rates in homes are below 20% of the minimum required rates.

The wireless medium enables very easy pirating of a single subscription since it is very difficult to control wireless network reach. A neighbor’s living room is often much closer to an access point than the furthest bedroom. Installers have a much clearer understanding of existing wired networks and will require a learning curve to service wireless networks. The remedies for a whole wireless network can be fairly complex.

Thus, whole home wireless home networking of video does not provide close to a 95% solution and does not provide a reasonable remediation solution. At best, wireless home networking of video will some day be an in-room solution, with a wired backbone for whole house coverage.

Phone Line For Video Home Networking?

Real life experience and measurements of current phone line home networking devices is and has been available for years and shows that ubiquitous whole-house coverage is a fraction of the required data rates described above.

Furthermore, in many homes, there is no phone connection in the proximity of the television sets, especially in the primary family room location.

Powerline for Video Home Networking?

Powerline connectivity seems quite attractive since it provides a wide home coverage and is available at any location where a powered CE device is present. Powerline home networking has been used traditionally for various lighting and other low data rate control applications. For the past several years higher data rate solutions have been available. They have shown the limitations of the medium, since home testing showed that the 95% outlet can only be relied on to provide less than 2 Mbps, even though the particular technology was capable of much higher data rates.

Powerline has a similar situation as the unlicensed wireless band, but instead with effectively "unlicensed jammers". Appliances such as vacuum cleaners, drills, hair dryers, light switch dimmers, and power supplies in many devices output noise onto the powerline that overwhelms powerline communications. These appliances can be turned on and off at any time and in different locations in the home or in the neighbors' homes.

As with wireless, there can be no guarantee that services will be maintainable since powerline is subject to largely varying, non-controllable and non-predictable interference. This variation prevents a viable installation and service. Remediation of powerline would require a certified electrician, which cable operator installers are not.

Typically 6 to 8 homes in the USA share a transformer and therefore degrade each others performance. Powerline only has one frequency channel that all homes use. Isolating homes requires a certified electrician and expensive filter isolators.

Most all STB, PC and other device manuals recommend using a filtered power surge protector. A significant percentage of surge protectors greatly attenuate signals in the 4 to 30 Mhz band, and block or impair powerline communications.

Thus, powerline home networking of video does not provide close to a 95% solution and does not provide a reasonable remediation solution for the problematic percentage.

Structured Wiring For Video Home Networking?

An attractive medium for multimedia home networking is the Cat-5 structured wiring widely used for business local area networks. Cat-5 (or Cat-6) supports a reliable, repeatable, viable 100 Mbps or even 1000 Mbps. Many of the new homes built today, provide Cat-5 wiring with connectors which are mostly co-located with the phone connectors.

The main drawback of the structured wiring is its relatively low residential penetration. Critical mass penetration into the tens of percentage of US homes is not expected for many years to come due to the costs of outfitting existing residences.

Other drawbacks are that the Cat-5 locations are not always near the home's television locations, and that it is easy for the consumer to add data products, hubs and other devices that can degrade performance of the network.

Coaxial Wiring For Video Home Networking?

Coax and Cat-5 wiring stand alone as the reliable, repeatable, high bandwidth mediums in the home. However, coax is in around 100 times as many whole homes as Cat-5, and is located at over 250 million video devices in the USA, including, TVs, flat panel displays, DVRs, STBs, Media Centers, DVDs, VCRs and Cable Modems. Almost anywhere video is being watched today in USA homes it is via coax. Coax is already validated and used today to carry many gigabits per second of video, audio and data in the 5 to 860 Mhz band, as well as the 950-2150 Mhz band for satellite operators.

Coax is a shielded medium and is not subject to interference or changes due to appliances in the home or neighbors' homes, and does not have consumer adoption issues since all consumers expect to get their video over coax. Coax is a contained medium that can not be easily shared with the neighbor for piracy, and can be physically isolated from all neighbors with reasonable effort. Usually homes can not hear each others signals, and total physical isolation between homes can be accomplished simply by putting a small $1 filter at the POE or multitap. Coax has the bandwidth to support greater than 8 non-overlapping frequency channels so that homes do not degrade each other even without physical isolation.

Coax supports sufficient bandwidth above 860 Mhz to enable multiple 100 Mbps frequency channels to coexist, while phone line, powerline and the 2.4 Ghz ISM wireless band can only hope to support one such channel best case.

Coax is the only medium that simultaneously satisfies all of the following requirements:

- Exists at > 250M home video locations
- Ubiquitously supports whole home data rates > 100 Mbps
- Capacity of many gigabits per second for future higher bandwidth implementations
- Stable. Not a time-varying quality link
- No degradation due to neighbor's home networking or general appliances
- No degradation due to other in-home networking products or general appliances
- Supports multiple independent, non-overlapping networks
- Easily physically isolated from all other homes if desired
- Does not have a slew of legacy and data home networking products that can create reliability issues for service provider's video home networking

Shared Mediums

When a medium is a "shared medium," there are two concerns that must be dealt with:

- Preventing the neighbor from snooping content or pirating service
- Preventing neighbors from interfering with each other and degrading each others service

If neighbors' mediums are physically isolated from each other this solves all issues. Otherwise, encryption is relied upon to prevent snooping or pirating of service. However, interference is only reasonably solved by creating orthogonality between neighbors on different non-overlapping frequency channels.

Wireless, powerline and coax can all be shared mediums in that the neighbor can potentially demodulate another neighbor's signal.

Powerline in the USA is connected via the transformer to typically around 6 to 8 homes, whereas in Europe it can be to more than 100 homes. Powerline communication is restricted to low frequency operation (roughly 4 to 40 Mhz), due to attenuation, and can only support one high speed channel at best. Physically isolating homes on powerline requires a certified electrician to install expensive filters at the transformer.

Wireless can leak to many neighbors, or be purposely pointed to a neighbor with a directional antenna. The 2.4 Ghz ISM band only supports one whole home, high speed channel at best. Physically isolating home for wireless is not possible.

Coax between homes is isolated by drop cables and multitaps. Multitaps give varying amounts of isolation between tap ports that varies with frequency, and can be insufficient to fully isolate homes in the 860 – 2000 Mhz band. Multitaps come in 2, 4 and 8 tap versions. The majority are 2 and 4 tap multitaps. Coax can support reliable 100 Mbps in a 50 Mhz bandwidth or less, enabling more than 8 channels to exist above 860 Mhz.

Physically isolating homes on coax requires simple 860 Mhz low pass filters be installed between the multitap and the POE. However, since there are more channels supported than shared homes on a multitap, each home can be operated on its own frequency and eliminate the need for physical isolation filters until the neighborhood is heavily penetrated with multiple home networking channels per home and uses more channels than are available within the total bandwidth. Thus, in combination with encryption, coax supports private independent networks that are not degraded by neighboring homes.

Medium	Shared	Channels	Physical Isolation Method	Without Physical Isolation
Power Line	Typically 6 to 8 homes at a transformer	1	Certified electrician installs expensive filters	Without filters, homes will interfere with each other
Wireless 2.4 ISM	Practically unlimited	1	Not practical	Interference is practically unlimited
Coax	2, 4 or 8 homes share a multitap	> 12	Simple $1 passive filters between multitap and POE	Homes can coexist on separate frequency channels, without filters, preventing interference.

COAXIAL HOME PLANT CHARACTERIZATION

All communications on in-home coax today traverses between the POE and outlet, or from the headend to the room outlet (downstream) and from the room outlet back to the headend (upstream). There is no communication on in-home coax from room/outlet to room/outlet. In fact, the coax splitters used in homes are really directional couplers designed to isolate splitter outputs and prevent signals from flowing room/outlet to room/outlet. This isolation is for two reasons:

- Reduce interference from other devices' local oscillator (LO) leakage
- Maximize power transfer from POE to outlets

With tuner LO leakages around -35 dBmV, and isolation output to output in splitters at around 20 dB, then the LO leakage will arrive at other devices around -55 dBmV, which is sufficient to have minimal or no degradation.

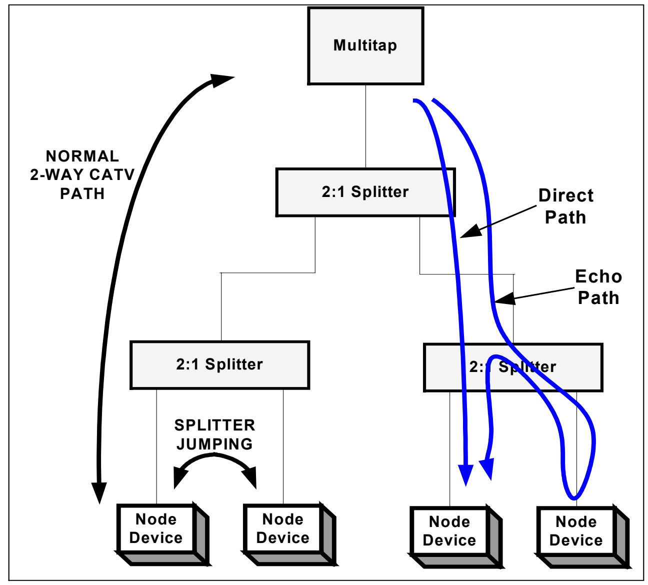
If true splitters were used instead of directional couplers, then the power loss through a 2-way splitter would be around 3dB higher in the normal direction.

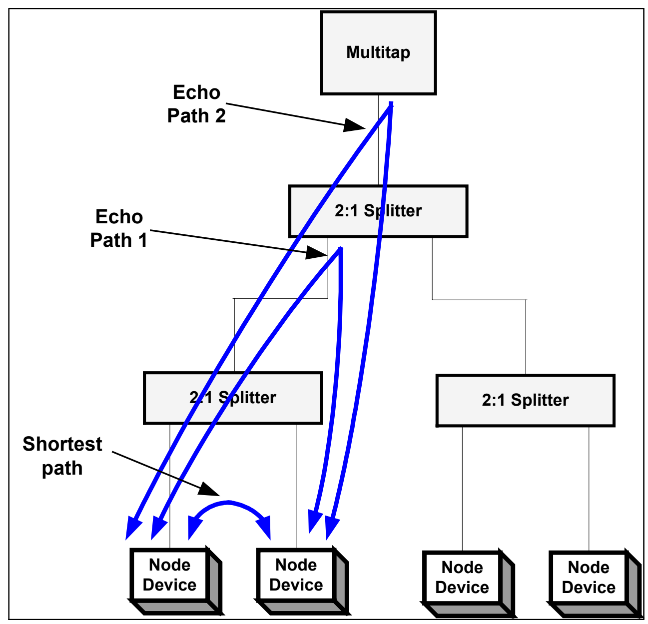
Coax Echo Characterization

The following diagram shows the direction of signal flow in the normal and device to device directions on in-home coax. Note that device to device flow requires "splitter jumping" output to output.

Measurements of homes and splitters have shown that splitter output to output isolation is frequency selective and varies between 8 and 35 dB. Echoes in the home vary between around 12 dB to > 35 dB and so cover the same attenuation range, and often have close to the same attenuation, as the splitter output to output signal path.

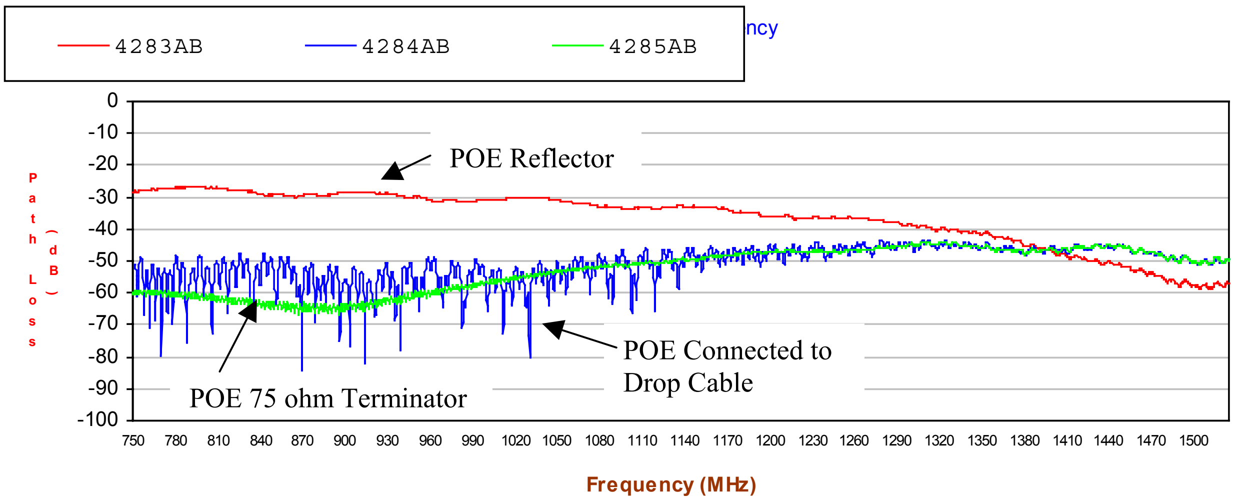
The normal direction signal flow in a home creates echoes that are always delayed and attenuated. The following diagram shows that device to device signal flow creates echoes that can be more, less or equal in attenuation to the shortest path. Systems designed for POE to outlet echoes, such as DOCSIS and other single carrier modulations with QAM and a decision feedback equalizer, can not operate reliably in an environment from outlet to outlet where there are regularly zero dB echoes and seemingly non-causal echoes.

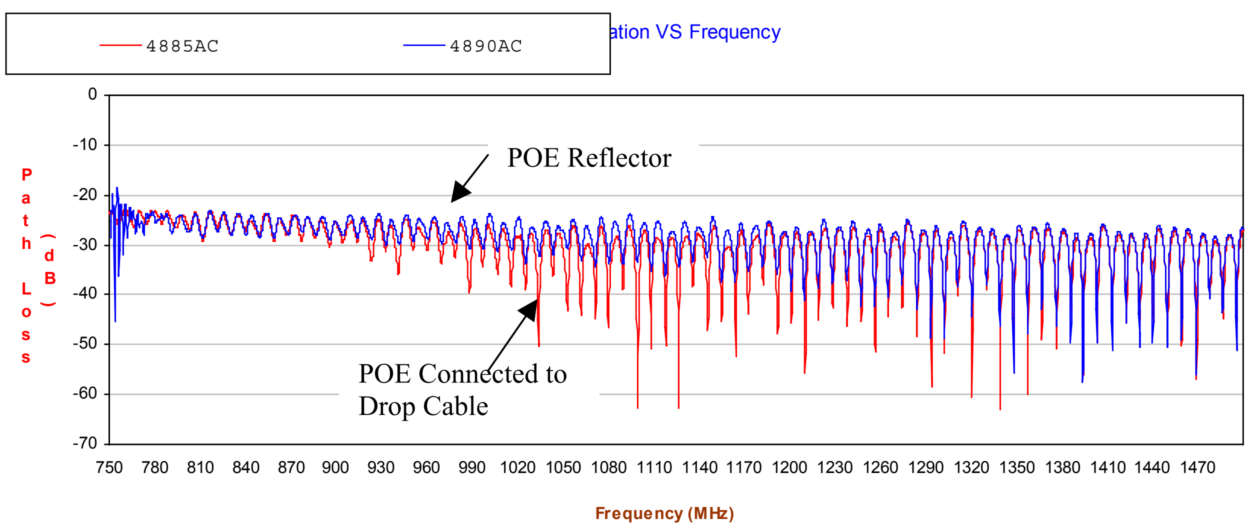




Two examples of characterized homes are shown in the following 2 figures. The first figure shows 3 scenarios: (i) POE connected to drop cable, (ii) POE terminated with 75 ohms, (iii) POE terminated with a reflector. Note that in the first figure the reflector case has less attenuation since the signal can go the normal path through the POE splitter and then perfectly reflect back instead of having to go output to output through the POE splitter and take the isolation attenuation. The 75 ohm termination is very similar to when connected to the drop cable, but does not have the heavy notches from an echo off of the multitap.

From the first figure it might seem that installing a reflector at the POE removes the need to operate in zero dB and non-causal echoes. However, the second figure shows that with or without a reflector at the POE, the home can have echoes generated from nested splitters, not the multitap, and thus still cause extreme echoes, which are manifested by the deep notches in the frequency response.



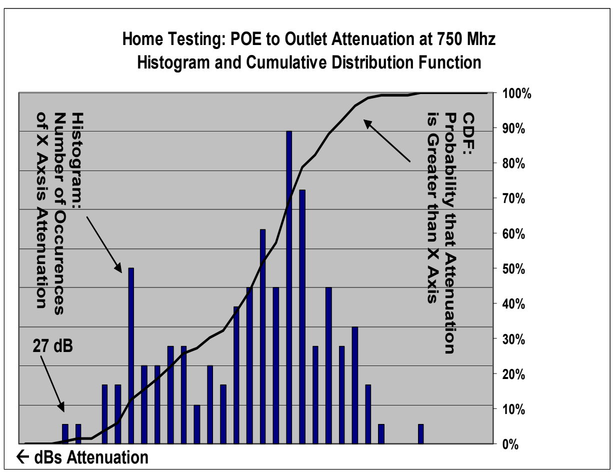


Coax Link Budget Characterization

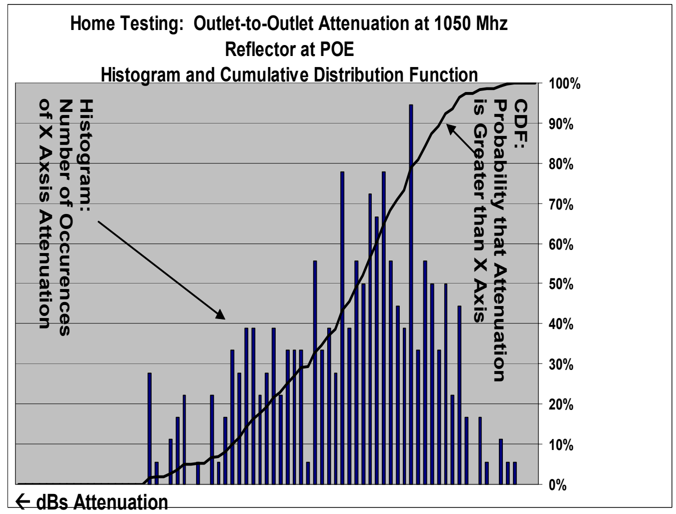
In addition to echoes that cause frequency selective attenuation, the overall average attenuation of an outlet to outlet link is substantial. Fortunately, the in-home cable plant must have a minimum quality in order for existing services to work.

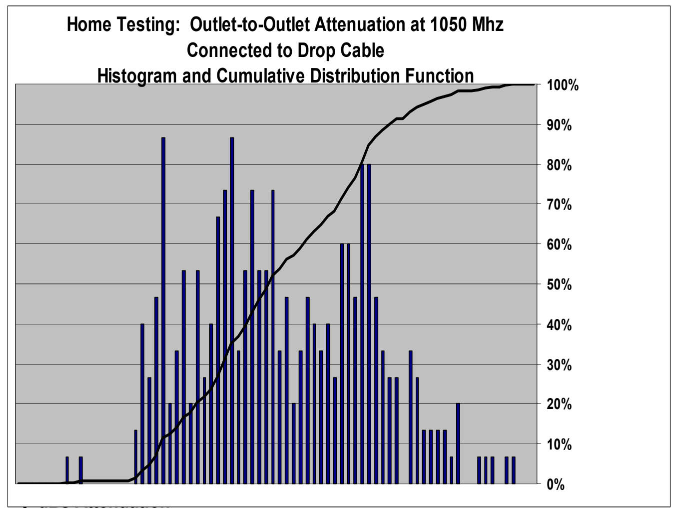
Existing digital and analog services tolerate a worst case attenuation of around 25 dB POE to outlet, at the highest frequency in the plant (750 Mhz, or 860 Mhz). Attenuation beyond this results in non-operation of the target devices, such as STBs, and therefore the home network is not required to work either. This was corroborated with home testing and is shown in the following figure.

	Max Power at POE dBmV	Min Power at Device	Worst Case POE to Outlet Attenuation
Analog Video	+15dBmV	-10dBmV	25 dB
Digital Video or DOCSIS	+10dBmV	-15dBmV	25 dB



With a POE reflector the signal traverses outlet to POE, gets reflected and traverses POE to another outlet. The attenuation is thus around 50 dB at 750 Mhz or 860 Mhz. Without POE reflector the signal must go through the splitter isolation instead of twice through the normal attenuator direction, increasing the attenuation 1 to 28 dB. This was corroborated with home testing and the following two figures show outlet to outlet attenuation with and without a POE reflector at 1050 Mhz.





Home measurements showed that attenuation typically gracefully increases with high frequency out to around 1500 Mhz, after which it can become very attenuative and frequency selective.

Home Coax Signal Environment

The cable operator uses 5-42 Mhz for upstream and approximately 54-864 Mhz for downstream. The 42-54 Mhz band is for diplexer roll off in TVs, cable modems, and STBs and can not be effectively used by the home network without an unacceptable probability of interfering with such devices. Thus 5-864 Mhz can not be used and the home networking must operate above 864 Mhz.

Coax Device Environment

The home coax plant has many existing devices in it including TVs, VCRs and STBs that are susceptible to interference from other signals on the coax. Even signals above 864 Mhz can degrade or overload existing devices so that there is a maximum power level that the home network signaling above 864 Mhz can be transmitted at. Characterization of over 130 existing devices showed that this non-interfering maximum power level is specifically frequency selective and varies in level from device to device. Double conversion tuners are in general less susceptible than single conversion tuners. A specific method of power control is required in order to meet the outlet to outlet link budget, yet not overload or degrade existing devices.

Home coax amplifiers are classified in two types: amplifiers in the drop side of the first splitter are termed “drop amps” and amplifiers in the home side of the first splitter are termed “inline amps.” Drop amps are outside of the home network signaling path and do not directly affect the home networking signal. Inline amps typically amplify in the direction of the devices from 50 to 864 Mhz and then roll off and can have significant attenuation above 1000 Mhz. Field tests and research indicate that around 2% of homes have inline amplifiers. Testing of inline amplifiers and homes indicated that in about half of the homes with inline amps the attenuation is not prohibitive and stays within the bounds of home attenuation described previously. This leaves half of the inline amp homes, or about 1% of homes, requiring remediation at the inline amplifier.

Remediation consists of either replacing the inline amp with one that supports signaling above 864 Mhz, or else putting a diplexer bypass around the existing inline amp. Such a bypass diplexer is low cost, and allows signals below 864 Mhz to operate as before, while signals above 864 Mhz are routed around the inline amp resulting in a passive network above 864 Mhz without high attenuation.

ENTROPIC’S c.LINK™ SOLUTION

Entropic has a production chipset and system solution for home networking triple play on coax. It includes a baseband controller doing MAC and Physical layers (BBIC), and an RF chip for conversion above 864 Mhz (RFIC).

The BBIC includes adaptive and modified multi-tone modulation over a 50 Mhz bandwidth, forward error correction, TDD burst generation and detection, mixed signal conversion, and an embedded processor that executes the TDMA MAC in software. Packet delivery across the link is guaranteed at 1e-9 BER without ever having a collision and thus not requiring retransmissions.

The RFIC includes LNA, PA, PLL for LO generation, quadrature up/down converter, and TDD controller to enable operation above 864 Mhz with up to 16 non-overlapping frequency channels.

Entropic’s overall system solution provides:

- Full mesh, peer to peer networking between all end points of a passive home coaxial cable plant
- Multiple, independent networks support via non-overlapping RF channels
- Physical layer data rate of 270 Mbps

- MAC layer (net) data rate of 135 Mbps
- 95% USA home MAC (net) data rate of >100 Mbps
- Co-existence with MSO cable services by operating above 864 Mhz
- Guaranteed/reserved bandwidth communications at 1e-9 BER
- Including isochronous traffic with jitter < 200 nsec
- Asynchronous communications at 1e-9 BER
- Including 802.1p 8 level prioritization
- Latency < 3 msec
- Link layer privacy encryption similar to DOCSIS privacy

Home Field Testing Entropic's Solution

Entropic has characterized and tested around 100 homes in southern California.

Entropic's testing showed that, for coax outlets that support existing digital and analog services, the 95% MAC (net) data rate is more than 100 Mbps from a physical layer rate of around 180 Mbps, and the 98 % MAC rate (excluding inline amplifiers) is more than 80 Mbps. This means that only 5% of outlets would not receive 100 Mbps or more MAC rate, and 2% of outlets would not receive 80 Mbps or more MAC rate.

The field testing experience indicated that this puts the home networking reliability comparable to the probability that an outlet will even support existing digital and analog services. In other words, the home networking solution is consistent with MSO operational parameters.

CONCLUSIONS

A home usage model, system requirements and comparison of home mediums led to the conclusion that MSOs must run their whole home networked premium services video over either Cat-5 or coax. The unique coax home environment when communicating from outlet/room to outlet/room was then described and field characterization was presented. This environment was shown to include zero dBC and pre-causal echoes that make single carrier solutions such as DOCSIS and other QAM with equalizer solutions non-reliable. Entropic's solution and production chipset were described. Field testing and characterization in around 100 homes showed the Entropic solution meets a 98% reliability for the MSO, with reasonable remediation for the remaining few percent of outlets.