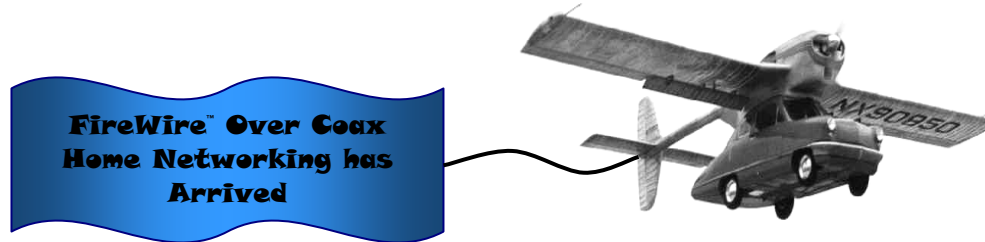


# Home Entertainment Networks and Flying Cars



## A White Paper on the IEEE 1394-Coax Bridging Standard “Networking IEEE 1394 Clusters via UWB over Coaxial Cable”

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### Introduction

Today’s entertainment networks are reminiscent of the flying cars we have been promised for years but only see in magazines or demonstrations. They are typically cobbled together from parts that require professionals to assemble and maintain, are expensive, and both have a tendency to crash when operated by someone with inadequate training.

They also solve a similar problem. Highways, like most of today’s networks, do not guarantee when you, or your data, will arrive at the destination. The problem is traffic. Even cars traveling on the Autobahn will grind to a halt in too much traffic. We want to know that a 60 mile trip will take an hour every time, GUARANTEED.

It is the same with an entertainment network. We absolutely need to know that when we start a movie that it will play to the end uninterrupted, guaranteed; no blue screens while buffers fill or blocky images from lost bits, and no finicky hardware or drivers that need constant maintenance. It also shouldn’t cost more than the devices we want to connect.

### Background

Let’s start with the requirements. First, moving entertainment content around the home requires a robust networking technology with end-to-end Quality of Service (QoS),

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ensuring that a movie or program will play without interruption. It must also be easy to use – plug in your new networked DVR and it works every time, all the time, without requiring a degree in IT to download new drivers, ‘configure’ the network or enter a long string of security codes.

Next, it must be secure. Not because you are worried that your neighbor might steal that new movie you rented, but because if it is not secure, the content owners will not allow the movie to be placed onto your home network. As we have seen time and again, software-based security is typically hacked within days or weeks of its release. To be truly secure, security needs to be processed in hardware.

Of course, the solution shouldn’t cost more than the devices you are trying to network. Ethernet and WiFi, the primary networks in homes today are inexpensive but the cost is not just the equipment. WiFi doesn’t provide the throughput necessary to carry multiple HD movies to the far reaches of the home or support the QoS needed to do it reliably. Therefore, wires must be run between the rooms you want to connect. Someone has to drill the holes and pull the wires unless it is possible to use existing wires – the same wires that already carry cable and satellite TV – coax. That brings us to the subject of this paper.

### **Networking IEEE 1394 Over Pre-Existing Coax Cable**

The 1394 Trade Association has just completed a new standard, “Networking IEEE 1394 Clusters via UWB over Coaxial Cable”, that meets all of the above requirements. The specification defines a bridge from IEEE 1394 (aka FireWire™) to the coax cable wiring that exists in many homes in North America and elsewhere. FireWire has long been recognized as the best network for entertainment and in particular video entertainment. It was designed from the beginning to stream video with guaranteed QoS. And it is fast.

The standard is divided into four parts, each of which specifies a different aspect of the standard. The remainder of this paper describes each section in detail.

#### **Part 1: “Continuous Wave Ultra-Wideband (CWave-UWB) PHY”**

Part 1 specifies the physical layer (PHY) and Medium Access Layer (MAC) designed to provide signaling suitable for operation over the standard coaxial cabling found in many homes today. Pulse~LINK, a pioneer in the development of wireless and wired UWB solutions, has implemented Part 1 of the standard in a 2-chip set that delivers 400 Mbps of application layer throughput over hundreds of feet of coax cable through several CATV RF splitters. That’s fast enough to carry 10 or more HD movies with bandwidth to spare. In fact, even when carrying 10 HD movies, it has enough spare bandwidth left over to support a full 100baseT Ethernet network. The standard also provides for 800 Mbps connections over coax, which falls within Pulse~LINK’s UWB-over-coax performance roadmap.

Continuous Wave (CWave®) UWB works by spreading each of the data bits it carries across 1.35 GHz of spectrum. Spreading each bit across such a large bandwidth makes

each bit much less susceptible to loss due to noise and reflections in the cable than is possible using a narrower signal. This is important for several reasons.

Coax cable carries existing cable television (5-860 MHz) and satellite (900-2150 MHz) services, and will continue to do so. In fact, next generation cable systems are extending their service up to 1000 MHz. Therefore, any new use of existing coax cabling in homes must operate above 2150 MHz to ensure it will coexist with those signals. CWave UWB accomplishes this by operating at the unused frequencies above 2.5GHz. This sounds simple enough, but the frequencies above 2.5GHz are not already being used for other services because, on coax cabling, this “empty real estate” has been un-usable using traditional radio frequency techniques.

Think of it like a football game where one team’s offense plays with one football (narrow band solutions) while the other team (UWB) gets to play with ten balls spread across the field. Assuming both teams face the same defense (i.e. the conditions on the coax wiring are identical for both), and any player crossing the goal line with a ball in hand results in a score (successful transmission), obviously the odds favor the team with 10 footballs.

Thus, not only does the UWB signal coexist with all of the signals that currently operate over your coax cable due to its operating at higher frequencies, it will more efficiently deliver its payload bits through the harsh operating environment characteristic of the existing home coax network at these high frequencies.

Finally, CWave UWB allows for a very low complexity implementation which translates to low cost ICs. CWave’s architecture is designed to place most of the complexity in the digital domain allowing it to scale easily with shrinking CMOS process technologies thereby leveraging the well known Moore’s Law of digital chip development.

Part 1 also specifies the use of the IEEE 802.15.3b Media Access Control (MAC) layer. The IEEE 802.15.3b standard was designed from the ground up to guarantee QoS in multimedia networks. Like FireWire, IEEE 802.15.3b uses a TDMA (Time Division, Multiple Access) MAC to provide real-time isochronous QoS, making it ideal for streaming HD content. Similar to IEEE 1394, 802.15.3b supports both isochronous and asynchronous channels<sup>2</sup>. This is critical to provide the low latency and highly deterministic delivery requirements of HD video.

Both Ethernet and WiFi were designed as “Best Effort”, asynchronous networks. Asynchronous MAC architectures are similar to a highway system. Cars looking to get on the highway have to wait until there is a large enough gap between cars before they can enter. Further, just as the average speed of traffic on a highway drops as the number of cars on the highway increases, the average throughput on these networks will decrease with increasing traffic. When the number of packets being sent exceeds a critical number, the network becomes unstable and you get the equivalent of a traffic jam.

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<sup>2</sup>

IEEE 802.15.3b and FireWire are reservation based isochronous networks. Isochronous networks are more like a railroad than a highway. You reserve as much space as you need on the train and that space is guaranteed, along with the departure and arrival times. Similarly, isochronous networks allow an application to reserve the bandwidth they require, and that bandwidth is theirs until they release it (after the movie ends). Rather than becoming unstable with increases in traffic, these networks will continue to assign bandwidth until there is none left at which point they simply inform new devices or applications that there is inadequate bandwidth. Of course due to the large amount of bandwidth available to the network this should rarely if ever happen. This approach makes for a highly deterministic network with negligible latency and jitter.

Latency is the delay from when the source, a DVD player for example, reads the data off of the disk, to when the display receives it. A TV displays one picture frame of data at a time – 30 to 60 times per second. Each frame must arrive exactly when it is needed. Without guaranteed time of arrival, buffering must be added, which increases the complexity and cost of the system dramatically.

It might seem that, as long as the latency is consistent, a delay of tens or even hundreds of milliseconds is of no concern. However, if the audio is sent to a different destination than the video, those delays can result in lip syncing problems. A consistent delay lets the designer accommodate it by measuring the delay and adding an equivalent amount between the audio and video. However, if there is a variation in the delay an even more complex solution is required. A deterministic network that can guarantee “just in time” delivery of frames avoids the cost and complexity to buffer and resynchronize A/V content.

Admittedly, there are ongoing efforts to improve Ethernet and WiFi’s ability to reliably support multimedia applications. Those attempts, such as providing higher priority to video data and establishing parameterization, have certainly yielded improvements. But there is only so much that “HOV” lanes, flashing lights and sirens can do to speed a handful of high priority vehicles on a highway (at the expense of all other traffic). No matter how you manage the data going into a “Best Effort” asynchronous network such networks are fundamentally “Contention-Based” networks and therefore can never be comparatively optimized for achieving the efficiencies and QoS guarantees that isochronous reservation based networks provide.

## **Part 2: L3 IP Bridges**

A common misperception is that Ethernet and WiFi are Internet Protocol (IP) networks and FireWire is not. Actually, IP is a collection of protocols defining how messages find their way from one device to another across a network or the entire Internet. The “L3” part of the name comes from the fact that they operate at the networking layer, also called Layer 3. Interfaces such as Ethernet, WiFi, 1394 and 802.15.3b operate at Layers 1 and 2 below the layer 3 IP protocols. Layer 3 protocols such as IP are designed to be independent of the lower layers.

<i>Layer</i>	<i>Protocol</i>
Application	FCP, CMP
Transport	TCP, UDP
Network	DHCP, Link-Local Addressing
MAC (Medium Access Control)	CWave: IEEE 802.15.3a, 1394b (Guaranteed QoS) Ethernet: IEEE 802.3 (Contention Based QoS)
PHY (Physical)	CWave: Continuous Wave UWB Ethernet: 100BaseT, 1000BaseT

Figure 1: ISO Stack Layer Diagram

IP version 4 (IPv4) is a universally accepted networking layer that provides addresses for devices as well as other features necessary to route messages between devices, even if they are located on different network segments. Within the context of this standard, it enables a cluster of FireWire devices in one room to be connected over the home coax cable to clusters in other rooms. It does this using a number of standards such as DHCP, Link-Local Addressing, ARP and others that are part of the IP family of protocols.

The specific details of operation are too complex and technical for this paper. Suffice it to say that once IP discovery is complete, every device on the 1394 network will have an IP address that uniquely identifies it. Further, the Layer 3 bridge defined in Part 2 knows if the device is located within the local FireWire cluster, or on a cluster in another room.

However, additional things must be done to maintain the QoS, latency and deterministic nature of FireWire across the coax. A typical representation of a home network operating on a UWB over coax network might look like the following diagram:

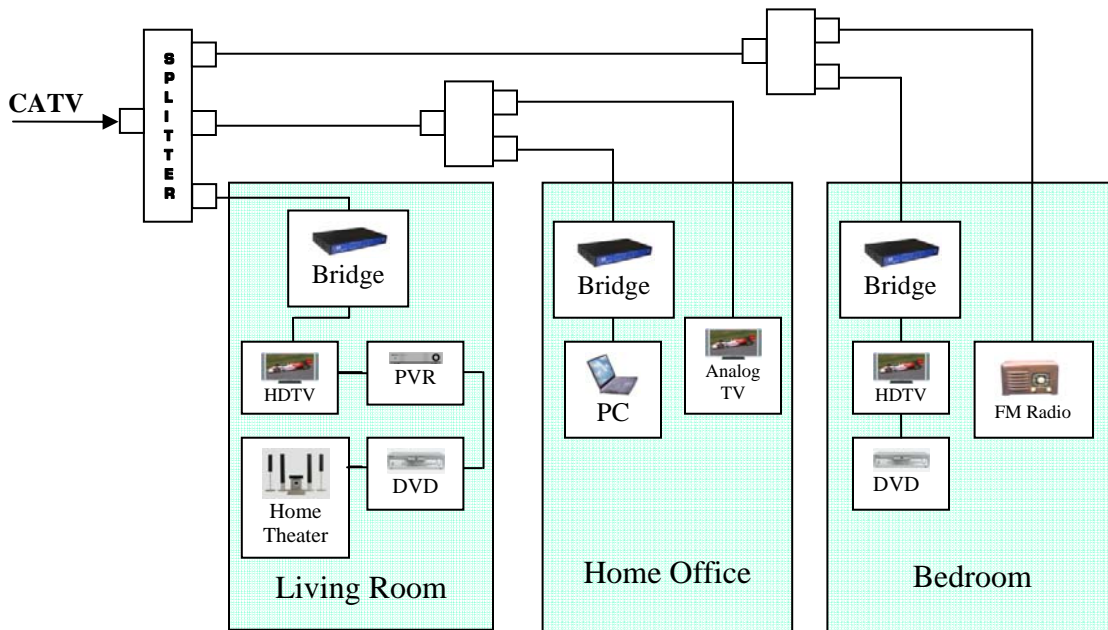


Figure 2: Typical Home Entertainment Coax Network

Ordinarily each of the FireWire clusters in the living room, office and bedroom would maintain their own timing to keep their clocks, and hence the cluster of devices synchronized to each other. However, to maintain synchronization across the entire network, it is necessary to synchronize each segment to a single common clock. Part 2 of the standard defines how this is done. This is accomplished by selection of a “cycle master” for the entire network to which all devices will synchronize.

Another task that must be performed to enable movies to traverse the network is securing the content, also called content protection. The use of content protection ensures the content owners (movie studios, etc.) that their content will not be illegally copied or distributed across the Internet for free. FireWire uses DTCP, which has been approved by the major film studios for FireWire networks. DTCP works by encrypting the data in a manner that only authorized devices can decrypt. Protected content is never allowed to be sent over the network unencrypted. The details of how this is accomplished are unimportant. What is important is that to ensure the content is not distributed to a remote device across the Internet, DTCP requires that a message be sent from one device to another and back again within 7 milliseconds. This ensures that the consumer can enjoy content anywhere in their home, while the content owner can rest assured that the content is not being sent over the Internet inadvertently or illegally.

All of this is invisible to the user, of course. The important thing is that the connection is guaranteed, synchronized and secure.

### **Part 3: FCP and CMP over IPv4**

Now that we have a method to allow safe, secure and robust IP connections between rooms across the coax cable, what else is needed? Well, key to any network is the ability to send commands between the devices. A lot happens when you select a movie to watch from a DVR located in another room: the two devices must set up a connection between them, reserve bandwidth from the network, request actions to be taken such as play or pause, etc. FireWire historically used a command language called AV/C to do this. However, AV/C is not an IP language or protocol. As its title implies, Part 3 uses FCP (Function Control Protocol) over IPv4 to convey AV/C commands between, and TCP/IP to encapsulate one or more FCP messages. The use of TCP/IP is universally accepted for IP networks, making it compatible with IP software stacks from many companies.

Part 3 further specifies the use of CMP, or Connection Management Procedures. CMP provides the “path management” required to make connections between the devices. Making, maintaining and breaking connections from anywhere is crucial to making a home network simple and reliable. For example, you may want to set up a recording between an STB in one room and a DVR in another from your DTV located in a third room. CMP provides the IP compatible mechanism to accomplish this.

With Part 3, developers have all of the mechanisms in place to develop their products and applications in an IP world with the assurance that they will operate between and among the FireWire clusters in a home entertainment network. However, we are not done yet.

#### **Part 4: AV/C Relay Agents**

While the first 3 parts of the standard are concerned with bridging IP enabled FireWire devices, the final part of the standard deals with how non-IP FireWire devices can be relayed across the Layer 3 bridge. While it is strongly recommended that all FireWire devices support legacy AV/C (non-IP) communications so that they can communicate with devices such as FireWire camcorders, digital cameras and hard drives that may not support IP networking, it is not possible to do so across the Layer 3 bridge. To communicate with legacy devices across a bridge, there must be a “helper” device on the network that can represent them as if they are IP-enabled. Remember the bridge is a Layer 3 (IP) bridge and requires that all communications use IP. These helper devices are called “AV/C Relay Agents” or simply “Relay Agents.”

Part 4 of this standard defines how these “helper” devices operate. The Relay Agents act as surrogates for the legacy devices. They are essentially translators. They relay messages between legacy devices and either legacy or IP enabled devices that reside on the other side of the bridge. Naturally, the Relay Agent must speak both “languages.” It therefore must not only support all four parts of this specification, it must support the legacy AV/C language as well.

The process begins by the Relay Agent performing standard IEEE 1394 discovery to locate any legacy devices on its local cluster. It then advertises these devices to the network. In effect, it becomes the legacy device from the perspective of the rest of the network, and it represents all other devices to the legacy device. All communications between the legacy device and devices residing on other clusters are sent via the Relay Agent.

As noted above, the Relay Agent can set up connections between two legacy devices or a legacy device and an IP enabled device. The process is different but the result is the same. Each device communicates in its own native language (AV/C or IP) to the Relay Agent, as if the Relay Agent is the end device.

One limitation is that a Relay Agent can only represent one AV/C target (e.g. camcorder, camera, AV/C HDD) to a given controller (e.g. STB, DTV – note that a DTV or STB may be both a Target and a Controller) at a time. It can, however, represent more than one AV/C target at a time, as long as it is to different controllers.

#### **Conclusion**

The 1394 over coax standard provides the most reliable and efficient IP network available today for moving entertainment data around the home. The first three parts solve the problem of building a 400 Mbps, deterministic, simple-to-use network over hundreds of feet of the same coax cable already installed in many of today’s homes. The IEEE 1394-Coax Bridging Standard can simultaneously carry numerous HD video streams over its isochronous channel along with the equivalent of an entire 100baseT Ethernet network over its asynchronous channel without complex and expensive buffering. This also eliminates the need to install new CAT-5 wiring in the home and

upgrade the switches, routers, and other Ethernet and WiFi devices you already own that were not originally designed to stream video.

Part 4 of the standard adds support for existing non-IP FireWire devices. With more than 1 billion legacy FireWire ports in the world, this is obviously important. The 1394/FireWire to coax bridges, as defined here, will implement Part 4, thus ensuring that all clusters connected to the coax will have the necessary Relay Agent to support those devices.

Finally, the entertainment networking equivalent of the flying car is here. No longer do we need construction crews to pave CAT5 wiring throughout our homes. With 1394 over coax, we can speed past the commuters stuck on traditional home networking highways and avoid the slow and unpredictable back roads of WiFi. No pilot's license required.