IEEE1394: versatility, performance, security, flexibility

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The advent of digital representations of all media types has fundamentally changed the way consumers use electronic products and blurred the distinction between computers and consumer electronics. Today, consumers demand products that interoperate whether a device lives in the office or the living room. Interoperability mandates a versatile interconnect. Too often, consumers must rely on multiple links – a situation that's inconvenient, often offers sub-par performance, and hampers the user experience. IEEE 1394 (also known as FireWire™ (and the terms are used interchangeably throughout this document) remains the single best interconnect across the range of computer, data storage, consumer electronic, and service-provider-supplied products in terms of performance and versatility. Simply put, 1394 moves more data faster and with lower latency that any other option including USB, Ethernet, and HDMI, and compares favorably with eSATA. Moreover, the 1394 Trade Association has defined a 3.2-Gbps extension called S3200 that will make 1394 the best choice for years to come for moving the rich data streams required by digital video, audio, and photos.

FireWire is elegant, simple, and fast. The architecture connects as many as 63 devices in a flexible topology. Most 1394 devices include multiple ports and allow simple daisy chaining of additional devices. Computers and other 1394-enabled devices can host more than two ports and effectively act as hubs. Hubs are not required, but some manufacturers do offer them for convenience.

Regardless of the physical topology of a FireWire installation, it operates logically in a peer-to-peer manner. Unlike master/slave interconnects such as USB, 1394 installations don't require a computer on the link. For instance, a device such as a digital camcorder can communicate directly with a 1394-enabled DVD recorder -- without a PC. On the other hand, 1394 is prevalent in PCs and proves to be the best way to move video from a camcorder to a PC for video editing.

Consumers have become increasingly comfortable with 1394 as a way to link all sorts of consumer and computer products. 1394 provides a superior user experience because of its performance and the plug-and-play capability. Product designers working on digital-media-centric products who want to maximize the utility of their

The 1394 Trade Association is a worldwide organization dedicated to the advancement of the IEEE 1394 (FireWire) standard. The 1394 TA recently celebrated its 13th year of promoting 1394 and its one billionth 1394 port shipped. FireWire is used today in mass-market computer, entertainment, and professional products, and in a wide range of specialty applications such as music, defense, aerospace, industrial, and robotics products. For more information, visit www.1394ta.org designs must include 1394 support on the feature list.

1394 succeeds across markets and platforms

To understand the ubiquity and versatility of 1394, consider the broad range of products with 1394 ports shipping today in volume. Examples span the spectrum from computer products to off-the-shelf consumer products to products such as set-top boxes distributed by leading telecom and cable service providers.

The 1394 link essentially enabled the digital camcorder revolution. There was no other standard capable of moving the dense audio/video stream the devices captured to a computer for editing. Until recently, virtually all tape-based and most memory-based digital camcorders shipped with 1394.

The success of 1394 in camcorders led directly to 1394 becoming a ubiquitous feature in desktop and notebook PCs. Almost all Apple PCs introduced since the birth of 1394 have included it. Subsequently, most PCs from leading vendors such as HP, Toshiba, and Sony include 1394, and it is simple to add 1394 ports to any desktop or notebook system.

Other advanced digital-media products for the living room have followed with 1394 support included. Dozens of living room DVD recorders from all major manufacturers include 1394 support to allow recording and playback of content. A number of A/V receivers, digital audio components, and still cameras include 1394.

The High-Definition Audio-Video Network Alliance (HANA) has also endorsed 1394 for living room usage. HANA's mission centers on enhancing the consumer experience with digital media products that connect seamlessly with maximum fidelity. HANA has focused on 1394 in part because 1394 is the only interconnect that the FCC mandates be included in HD set-top boxes. Moreover, 1394 ports are included in dozens of HDTV sets from every major manufacturer.

In today's home, however, end-users will surely mix and match computing- and consumer-centric peripherals. The 1394 interconnect is offered by a broad group of vendors making computer products such as external disk drives and arrays. You will also find it on external optical drives and even scanners and printers.

In fact, 1394 has even found use in a variety of industrial applications ranging from motion controls to vision systems. And 1394 has begun to find success in infotainment, navigation, and telematic applications within automobiles.

1394b compared with USB 2.0

The range of 1394 use in real products certainly indicates its value. But how does 1394 compare with the competition, and why is 1394 often the superior choice? A detailed look at 1394 relative to other choices in specific applications shows why engineers should integrate 1394 in any product that handles digital media streams and the benefits that consumers realize from 1394.

Anyone using a PC is familiar with USB a perfect low-cost, PC-centric, low-performance interconnect for devices such as keyboards, mice, printers, and even relatively low-capacity storage devices such as USB Flash drives. 1394 rarely competes with USB in these applications. Conversely, 1394 is a far better choice for high-capacity external hard drives and video devices such as camcorders.

The advantage 1394 affords comes in terms of maximum bandwidth, low latency, and PC independence. To fully understand the performance issues, consider the difference in the two interfaces both at the physical layer and beyond. Let's start with the media-access scheme and logical architecture.

Low costs drove the development of USB. Back in the mid-1990's when both the1394 and USB specs were matriculating through development committees, silicon prices were much higher than today. The USB group wanted to make their interface chips as simple as possible and rely on the CPU in the PC to handle as much of the protocol as possible. That philosophy inherently resulted in an unintelligent interface in which host polling of devices on the USB link would always gate performance. Even though host CPUs have continued to escalate in terms of performance, so have the demands placed on the CPU for other processing tasks. Therefore, the master/slave architecture still limits USB both in data rate and latency.

Conversely, the philosophy behind 1394 centered on high-performance from day one with the goal to equal parallel SCSI performance. Moreover, the engineers behind 1394 foresaw early on the need to support rich data streams from devices such as cameras and to do so without requiring a PC on the link. The 1394 group developed a scheme allowing peer-to-peer connections where devices could stream data directly to one another with or without a PC present.

So how do 1394b and USB 2.0, presently the fastest version of each spec, compare in an application such as an external hard drive? In terms of maximum bandwidth, 1394b has an almost a 2:1 advantage with an 800-Mbps rate compared with the 480-Mbps rate of USB 2.0.

External Hard Drive Read and Write Speeds in Mbytes/sec[1]

Connection / drive	Read	Write
FireWire800		
Iomega	72.7	67.2
LaCie	75.0	66.3
FireWire400		
LaCie	39.2	30.5
USB 2.0		
Iomega	19.5	22.6
LaCie	19.0	22.8
eSATA 1.5 Gbps		
LaCie	79.4	60.6

The physical numbers, however, don't tell the full story. The physical speed of a network has little to do with the actual data throughput provided to an application. In reality, 1394b's throughput is far greater than USB 2.0. In fact, even S400 1394 devices are faster than USB 2.0 devices. Lab test show that S800 1394b delivers more than 97% of its physical layer bit rate as payload. USB doesn't fare nearly so well. Overhead often accounts for 50% of the maximum USB data rate.

For a quantitative example of the advantages of 1394 over USB, consider some tests recently conducted by TechInsights editors and posted on the Digital Home DesignLine website. Editors ran multiple tests on USB, and S400 and S800 links using widely available disk drives. The respected h2benchw storage-benchmarking software revealed that S800 FireWire links offered an almost four fold advantage over USB. The program revealed S800 read rates around 75 Mbytes/sec compared with USB rates less than 20 Mbytes/sec. Indeed the performance of the fastest FireWire drive and host adapter rivaled the performance offered by an internal SATA drive used as a reference. Even drives connected via a S400 link offered essentially double the USB performance. Check the Digital Home web site for a look at the full results of three different types of benchmarks.

The performance advantage directly impacts the user's experience. Clearly even simple tasks such as copying files happen much more rapidly with a 1394 disk. But the fact that FireWire disks rival the performance of directly connected SATA disks mean that users and efficiently use FireWire drives in a primary storage role, for example, as a real-time storage resource in a video-editing application. USB drives are not generally effective in primary storage applications.

The advantages of 1394 also go beyond maximum data rates. Remember that 1394 supports direct transfer of data between devices while USB needs a PC as an

[1] Using h2benchw v3.12 software on an AMD Phenom 9500, 2.2-GHz, quad-core processor running Windows XP with Service Pack 3. Full test procedures and results are available at the Design Home link on page 4.

intermediary, further halving realized performance in some cases.

Moreover, the performance differential perceived by an end user can be even greater because of network architecture and topology. Look at the typical PC today and note than many carry 6 or 8 USB ports. You might wonder why so many ports when presumably low-cost hubs could offer all of the expansion you need for USB conveniently located on the user's desk. There are some relatively well-designed USB hubs on the market but there are many poorly designed ones as well. And any hub degrades performance relative to devices connected directly to the root hub. In the flexible 1394 topology, adding more devices has a minimal effect on the transfer rate. All nodes operate as fast as the slower of the two devices connected in a peer-to-peer transfer.

The advantage afforded by 1394 extends to end-user convenience. The 1394 standard specifies that the link cable can supply 45W of power at voltages to 30V. The power delivery feature means that even high-end, power-hungry, external disk drives can run from cable power without a power brick in some applications. By contrast, USB can at best power a Flash drive or low-end notebook drive.

1394 compared with eSATA

The external hard drive is a good vehicle for comparison of interconnects because hard drives by nature create fast data streams. And if performance is important to the end user experience, then the fastest interface is always the best choice right? Well not always. Today, most mainstream disk drives use the SATA interface standard as a native interface. And the eSATA (External SATA) interface has emerged for connecting external drives. Initially SATA was launched with 1.5-Gbps rates and the second revision along with eSATA support 3-Gbps data rates. But an interface can never operate faster than drives can read or write data. Most of the mainstream drives used in consumer PCs and consumer electronic devices such as DVR-equipped set-top boxes use drives with a maximum data rate of about 100-Mbytes/sec or about the same speed as S800 1394. Drive performance will continue to escalate as will the speeds, with products built using S1600 and S3200.

Meanwhile, eSATA does not offer the convenience or versatility to end users to match what 1394 offers. The eSATA cables are limited to 2m – less than half the maximum length of 1394 cables. The eSATA cables can't power a disk drive. Inherently, eSATA is specifically a disk interface – it can't connect other peripherals such as cameras. Finally, eSATA is a one-port to one-disk-drive link. There will surely be applications where eSATA performance is needed, but those application won't likely include the digital home where a robust interconnect will serve many products and peripherals.

1394 compared with HDMI

Moving from external disk drives that these days might find use in the office or the living room toward the dedicated task of connecting set-top boxes and TVs, we'll look at where 1394 plays. As noted earlier, the FCC mandates the inclusion of 1394 on HD set-top boxes that service providers deploy in the US. Moreover, there are many dozens of TVs with 1394 plugs. And despite what some HDMI advocates might have you believe, there are no content security issues that prevent 1394 from carrying protected content between a set-top box and a TV or across a broader A/V-centric network. The 1394 Trade Association has adopted the DTCP (Digital Transmission Content Protection) scheme and all of the major content owners and service providers recognize the solid protection that DTCP affords. What's more, unlike many other security technologies, DTCP has never been broken.

HDMI has become the primary connection for DTVs for two reasons. Content providers like it because, as an uncompressed connection, it is nearly impossible to network or record using commonly available technology making it inherently secure, even without HDCP copy protection. Service providers like it because it ensures consumers will continue to need a cable

STB to get enhanced services like an interactive program guide. The program guide is generated within the cable STB in an uncompressed format. This is no problem for analog TV receivers, but is a problem for digital HDTV receivers since only DVI or HDMI connections can handle un-compressed digital HDTV signals.

The real weakness in the capabilities of HDMI is evident in the focus that the HDMI Working Group places on it as a video patch cable that carries audio as well. Indeed the HDMI group admits that the point-to-point cable will play no role in distributing video around a home.

As mentioned earlier, HANA's mission is focused on interoperable full-fidelity A/V networks in a home. The 1394 protocol is perfect for carrying such data around a home. Existing 1394 cables and physical-layer technology can link many different types of full-fidelity gear within a room. Going forward in the HANA vision, 1394 protocols carried over Cat5 and/or coaxial media will provide the room-to-room link as well.

1394 compared with Ethernet

Today, you will also find 1394 and Ethernet mentioned as competitors. Engineers working on digital media products need to clearly understand both 1394 and Ethernet and leverage technology that delivers the best user experience for the application at hand.

But Ethernet and 1394 are different. You could use 1394 cables and ports to link a few PCs into a workgroup and share files. But 1394 doesn't excel in that role. In the home today, a combination of wired Ethernet and more often wireless Wi-Fi serve to link PCs around the home. That data-networking technology is very effective for file and printer sharing. Indeed Ethernet even does well in moving batches of audio or video data on a non-real-time basis. For instance, users might transfer their audio collection across Ethernet for playback on a different computer. With relatively low-rate audio, Ethernet can even stream the data.

Whole-home high-definition video distribution, however, demands a real-time protocol like 1394 with inherent isochronous support. Consumers don't want to copy a video program from the DVR in the living room to a second DVR in the bedroom before watching the program. Consumers simply want the full-fidelity program to play anywhere in the home. It is more than simply the cost and inconvenience of having a second DVR. If the content must be replicated to view it, it is taking up twice the hard drive space.

Ethernet proponents believe that speed solves all, including the real-time video distribution problem. Without doubt, a 1-Gbps Ethernet network would fair better than a 100-Mbps Ethernet network in serving video. But neither is the answer, especially with other traffic such as multiplayer gaming happening simul-taneously on the Ethernet or Wi-Fi IP-based network.

The answer is almost assuredly the separation of IP traffic like multiplayer gaming, Internet downloads, and even VoIP services from real-time video distribution. The video distribution network will require a network with video friendly protocols such as 1394 affords.

Perhaps the ultimate compliment has been paid by Ethernet proponents by their work to improve its handling of real-time content. For many years they have been working to add features such as prioritization based on the type of data (voice, video, etc.) and parameterization (higher priority given to data based on certain defined parameters accompanying the data). Such features are an attempt to approach the quality of service built into 1394. However, all such attempts fall short of the guaranteed QoS, synchronization, low latency, and throughput of 1394. Additionally, they require new Ethernet routers and new protocol stacks in connecting devices stranding the millions of legacy Ethernet devices already deployed.

The ultimate solution may or may not require separate physical networks. The 1394TA and HANA are working on running 1394 protocols over Cat5 cable plants simul-taneously with Ethernet IP traffic. The same mix can also run over existing coaxial cable plants already present in many North American homes.

What the future holds – S3200 and USB 3.0

Looking forward, it's clear that 1394 will continue to serve in the myriad roles that if finds use in today. Both USB and 1394 will continue to evolve in terms of data rate and feature set.

Intel has stated that it intends to push USB data rates toward the 5-Gbps range. A preliminary spec may be forthcoming later in 2008, although products won't likely emerge before 2010. Without knowing details of the USB 3.0 plans, it's tough to project how USB 3.0 and present and future versions of 1394 will compare.

Intel has acknowledged that the PC-CPU-centric polling of USB simply won't work with the bandwidth that's envisioned for USB 3.0. Intel presumably will design the next-generation spec planning on controller ICs that can handle some level of data inspection and packet routing and transmission capabilities. Indeed, inter-connect intelligence is an outstanding idea. That's why 1394 included intelligence in the nodes from day one.

It's not clear how Intel can change the protocol significantly and maintain backwards compatibility with all of the peripherals that require that the CPU be in control. Intel has also promised backwards compatibility in the connectors and cabling. (However, preliminary indications are that the 3.0 cable will actually incorporate a separate 2.0 cable within the 3.0 cable.)

Presumably the move to the 5-Gbps speed range may require Intel to limit cable lengths to 2m from 5m. And certainly with a move to 3.0, USB will no longer have a silicon cost advantage over 1394.

With 1394, the evolutionary path is far clearer. Each evolution of 1394 has been true to its origins. The later revisions do offer options such as running the protocols over alternative media such as Cat5 cable, but such an option can connect islands of traditional 1394 nodes. Moreover, even the transition to the 9-pin cable for 1394b has been a non-issue for consumers, as most S800 devices carry legacy 6-pin ports as well. 1394 is clearly positioned to remain the most versatile and capable interconnect. Product designers clearly realize the value that 1394 brings to consumers and a broad array of applications.

1394 history, present, and future

Like most all technology industry standards, 1394 has been through an evolutionary process with steady improvements in performance and versatility. The engineers behind 1394 have made the evolutionary moves in a way that minimally impacts the end user and always provides a clear path to support any 1394 device ever designed.

The original standard, often called 1394-1995 (1995 being the year of ratification), defined a half-duplex interconnect that could operate at 100-, 200-, or 400-Mbps data rates using a 6-conductor cable. The modes are generally referred to as S100, S200, and S400 respectively. The 1394a standard ratified in 2000 didn't offer data rate improvements in terms of maximum bit rate but did add data transfer efficiencies and implement power-saving features. The 1394a revision also standardized the miniature 4-pin connector used on most small devices such as cameras omitting the power signals but remaining compatible with 6-pin devices.

The 1394b standard ratified in 2002 provided a significant performance boost both in terms of maximum data rate and a move to full-duplex operation. The 1394b devices can operate at 800-Mbps (S800) rates. The faster spec does mandate a new cable and connector type but the effect on consumers is minimal. Most 1394b devices carry both the new 9-pin connector and the older 6-pin connector.

The 1394b standard also defined modes whereby 1394 traffic could traverse network style cable plants. The revision supports S100 traffic over standard Cat5 network cables and faster rates over optical or other specialty cable. The 1394c standard ratified in 2007 added S800 rates over Cat5 cables and the ability to mix Ethernet and 1394 traffic on a single physical network. New PHYs operating at 1.6 Gigabits/second are now ready for designs.   And the 1394 Trade Association has also announced plans for a 3.2-Gbps version of the standard and a mode called S3200.

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