THE IEEE-1394 HIGH SPEED SERIAL BUS

by R.H.J. BLOKS

Philips Research Laboratories, Prof. Holstlaan 4, 5656 AA Eindhoven, The Netherlands

Abstract

The IEEE-1394 is a new standard for a digital high-speed serial interconnect bus. It allows real-time data to be mixed with other data transfers at transmission rates of 100, 200 and 400 Mbit/s. This makes it flexible enough for applications in multimedia environments where multiple video and audio streams have to be transported between several devices simultaneously. One of the most important applications in the consumer electronics world is MPEG-2 data transport between set-top box and digital video recorder. The extremely time-critical nature of MPEG-2 requires some additional processing before it can be sent on an IEEE-1394 bus. This has led to the standardization of the audio/video layer described in this article.

Keywords: multimedia, digital television, bus, MPEG, real-time, protocol.

1. Introduction

One of the most important reasons for Philips Research to investigate digital interfaces is digital television. Today most stations broadcast analogue signals, but in the very near future this will start to change as more and more broadcasters are going to provide digitally encoded data streams containing multiple TV programmes. Perhaps even more interesting is the possibility of including not just TV programmes but all kinds of data services in the stream, such as interactive games, teleshopping, telebanking, video-on-demand, various data services, etc. Broadcasters and cable networks will make sure that these new services are delivered to many homes. Therefore it is important that we can handle these services in consumer electronics (CE) equipment/home systems.

The first device to connect to the digital TV in the wall is the set-top box (STB) which contains a decoder (amongst others) that converts the received
digital signal into analogue video to be viewed using an ordinary TV set. A nice application of such a system would be to record the digital stream on tape and replay it later. To do this it is necessary to transport the stream from the STB to a digital video recorder and back, by means of a digital interconnection.

2. Global requirements for a digital interface

Of course the digital interface (DIF) should be much more versatile than just be able to handle MPEG transport streams. There are other formats being standardized today, and we would also like to participate in the multimedia world (connect disc players and computers to CE equipment, for example). The digital interface must be able to handle all these formats, provide means for transporting both real-time and non real-time data streams (data and commands), and be inexpensive and fast.

Currently there is only one candidate for a digital interconnect network that appears to meet these demands and that is also mature enough for immediate application. This is IEEE-1394, also called FireWire™ by Apple, its inventor.

3. Properties of IEEE-1394

An IEEE-1394 high speed serial bus [1] can connect up to 63 devices in a tree-shaped network using point-to-point cables. Signals on the cable always travel from one device to one other device. The reason why 1394 is nevertheless called a bus is that each device acts as an active repeater so that logically a signal emitted by a transmitting device will propagate to all other devices on the bus. The maximum number of ‘hops’ (repeaters) that a signal may pass in a single bus is 16. The maximum cable length of a single hop is 4.5 metres. Currently defined cable bit rates are 100, 200 and 400 MBit/s, and a recently-started workgroup is looking into 1 GBit/s transmission rate. Figure 1 shows a possible configuration of a home system interconnected by 1394. Note that IEEE-1394 is also being adopted by computer and peripheral manufacturers, which means that 1394 will enable us to interface the consumer electronics world to the (multimedia) computer world.

A distributed arbitration algorithm ensures that only one device has permission to transmit anything on the bus at any time, and also that all other devices have their repeater function switched in the right direction, away from the transmitting device.

IEEE-1394 supports two kinds of traffic: asynchronous and isochronous. The former is used for non real-time data (data without strict bandwidth or
IEEE-1394 high speed serial bus

timing requirements). Examples are data services, device commands, or data storage on a hard disk. Isochronous traffic is used for real-time data and has a guaranteed maximum delay time and guaranteed bandwidth. Examples are digital audio and video.

To support real-time traffic, IEEE-1394 nodes must maintain a local timer which increments at every clock tick of the node's local clock. Once every 125 μs the root node will arbitrate for and transmit an asynchronous packet containing the value of its timer which all other nodes receive and use to update (read: synchronize) their own timer value. In Fig. 2 this is indicated by the CS (Cycle Start) packets. Given the clock tolerance and cycle time this guarantees that all nodes have the same time value (there can be small differences because of the signal propagation delays from the root to each node, but these are constant for any node in a given topology).

The isochronous cycles can vary to some degree in duration and position, but on average a new cycle will start every 125 μs. Before a transmitter may use isochronous transfers for data, it must first reserve a portion of this cycle

Fig. 2. Isochronous cycle timing and traffic on the 1394 bus.
R.H.J. Bloks

at the isochronous resource manager node which keeps track of the number of bit cells per isochronous cycle that is still available. To distinguish isochronous data streams from one another, each one is labelled with a unique identifier, called a channel number. A free channel number can also be obtained from the isochronous resource manager. In Fig. 2 the packets labelled ‘I’ are isochronous packets. The bandwidth allocation procedure ensures that the total time for all isochronous packets including overhead will never exceed a safe maximum (currently 100 μs).

The basic procedure to transfer real-time data on IEEE-1394 therefore consists of the following steps: First compute the required number of bit cells per cycle, including all overhead (for arbitration, etc.), then allocate this amount and a free channel number at the isochronous resource manager node. If this is successful the transmitter is permitted to arbitrate for isochronous access in each cycle and may hold the bus for not more than the allocated amount of time per cycle. This will guarantee that all isochronous transmitters will get access for all allocated transmissions during each cycle without overloading the bus. The only thing not guaranteed is the exact point in time within a cycle where a node will get access. Hence the end-to-end transmission delay is not constant but can vary between certain limits. The peak-to-peak amplitude of this jitter interval is approximately 310 μs for the worst case topology situation. Because a node does not have continuous or immediate access to the bus when an application delivers data to be transmitted some buffering is required in each node. The fact that the operation of the bus protocol guarantees that the next access to the bus is always granted within a known time interval allows an exact computation of the required buffer sizes at receiver and transmitter nodes for any application. This is very important for CE applications.

The time that remains after the last isochronous transmitter has sent its data in a cycle until the start of the next cycle is available for asynchronous traffic (labelled ‘A’ in Fig. 2). An asynchronous packet that starts to appear on the bus just before a new isochronous cycle should start can delay the transmission of the cycle start packet and therefore the isochronous cycle. This is a major contributing factor to the size of the previously mentioned jitter interval.

4. MPEG-2 transport on an IEEE-1394 bus

An MPEG-2 transport stream consists of a continuous stream of transport packets which are 188 bytes each. The specification states that these packets may experience only a very small transport delay variation (jitter) between encoder and decoder. Without some additional work such a stream cannot be sent over IEEE-1394 without violating this constraint. Another problem
is the fact that in each of the 8000 cycles per second only one transmission may take place on a given channel. If we could simply map an MPEG-2 stream onto one channel and each transport packet onto one isochronous packet this would limit the maximum bit rate of an MPEG stream on IEEE-1394 to about 12.2 Mbit/s. What we want is the capability to transport at least one entire transport stream (for example, 40 Mbit/s) plus a few other real-time streams (for example, single video or audio channels). To overcome these problems several companies, including Philips, participated in the definition of a new protocol layer, called the AV layer (Audio/Video) which is located on top of the layers of the IEEE-1394 protocol. This AV layer is now being prepared for standardization in IEC.

The AV layer consists of 3 parts:

- A function control protocol (FCP) which will enable CE devices to issue commands, request status information, etc. This is necessary for new applications and because functionality will probably become more distributed over devices (i.e. devices will have to cooperate more). FCP definition is finished. Command sets are being discussed.

- A connection management protocol (CMP) that allows real-time connections to be created, maintained and broken by any device. CMP contains resources (control and status registers), access rules for these resources and management algorithms. CMP definitions are complete.

- An isochronous data packing and processing mechanism, explained below.

The application delivers its real-time data in packetized form (packets with fixed length). For MPEG these application packets are 188 byte long transport packets. For data that require a transport jitter less than what IEEE-1394 can guarantee, a 32 bit header ('quadlet' in IEEE-1394 terminology) can be inserted before the application packet. This header contains timing information which can be used by the receiver to compensate the transport delay jitter. In the case of MPEG this header contains a time stamp indicating the intended time of delivery of the packet to the application at the receiving node. The value of the stamp refers to the timer register whose value is kept synchronized between all nodes. The transmitter computes the stamp value by sampling its own timer when the transmitting application writes a packet in the transmit buffer, and adding a constant (large enough) value to it. When the packet arrives at the receiver it will remain in a delivery buffer until its stamp value matches the local timer value.

Another problem that is solved by the AV layer is that of bandwidth efficiency. If isochronous packets on IEEE-1394 could only contain entire MPEG packets (now 192 bytes, with the extra header) then it would be necessary to allocate
the bandwidths in chunks of $192 \times 8 \times 8000 = 12.3\text{ Mbit/s}$. This is because space for an entire packet is available in every isochronous cycle on the bus, even if only one out of $n$ cycles is actually used. Especially for lower bit rates (which will be common) this is too inefficient. The AV layer solves this by chopping the packets into 1, 2, 4 or 8 equal parts (called data blocks), and then uses these data blocks to construct isochronous bus packets. For MPEG the size of an application packet with time stamp is 48 quadlets which divides perfectly by 1, 2, 4 and 8. For other data types this is not necessarily true, so the AV packing protocol allows up to $K-1$ dummy quadlets (with value 0) to be appended to an application packet before dividing it into $K$ data blocks of equal size ($K = 1, 2, 4$ or 8). This process is called quadlet padding.

Isochronous bus packet construction proceeds by concatenating the first $N$ data blocks in the transmit buffer and inserting a special 2 quadlet header before the first data block. The value of $N$ is restricted to certain values depending on the data type and bit rate of the data stream. The special header is called CIP (Common Isochronous Protocol) header and contains information about the method used by the transmitter to pack the data, as well as a data type identifier and data type dependent flags. These values allow a generic receiver to unpack the data without specific knowledge about the data type itself and deliver it with proper timing to the receiver application, i.e. a receiver can unpack a packed MPEG stream without knowing that the data make up an MPEG stream. The CIP header information also allows packet loss

---

Fig. 3. Bus packet construction for MPEG (example: 3 Mbit/s < bit rate < 6 Mbit/s, $K=2$).
detection and identification of the transmitter node from which the stream originates.

The case for MPEG is illustrated in Fig. 3 for a low bit rate situation. The original MPEG transport packets generated by some application are first stamped to record the precise packet arrival timing. The actual stamp values represent the intended delivery time to the receiving application rather than the arrival time in the transmitter, but these values differ only by a constant. The resulting packets are divided into data blocks (2 in this example). Each data block then gets a CIP header \( h_i \) inserted, yielding an isochronous bus packet payload. This payload is converted into a bus packet in the link layer by adding a 1394 header and CRC error codes for both this header and the entire payload. If not enough data are available to send a whole data block in any particular cycle, then an isochronous packet is sent with a payload consisting only of the 2 CIP header quadlets (shown as \( h_e \) in Fig. 3).

5. Conclusions

IEEE-1394 is a suitable digital interface for application in consumer electronics. It can carry both real-time data and commands. Applications in the computer world are also being developed, for example, as a successor to SCSI. Connections between CE equipment and multimedia PCs are a possibility.

IEEE-1394 is also a mature interface. Not only is it currently in the final IEEE standardization phase, but implementations in silicon are already available for 100 Mbit/s and soon there will be 200 Mbit/s versions as well. Furthermore a new Audio/Video layer (not IEEE standard) is being defined by CE manufacturers and submitted for standardization to IEC. This layer allows time-critical data streams, such as MPEG-2, to be transported on IEEE-1394 in an interchangeable way with efficient use of available bandwidth.

At this moment CE manufacturers are working on applications for digital interfaces in the area of digital video recorders.

For a more detailed description of IEEE-1394 and the Audio/Video layer, see Refs. [2,3].

Acknowledgements

The above results have been reached by the contributions of several people. I would especially like to mention Ronald Saeijs, for taking the lead in many discussions during the standardization meetings, preparing proposals and coming up with new concepts, and Jörgen Rosengren, for his work on MPEG related issues for the AV layer.
REFERENCES


Author