SDI over IP

— seamless signal switching in SMPTE 2022-6 and a novel multicast routing concept

Matthias Laabs
IRT

As bitrates increase and equipment prices drop, IP-based communication technologies – both fixed and wireless alike – are pushing more and more dedicated communication systems into retirement. The sheer amount of connectors currently found on professional video cameras make some of the advantages obvious that an IP/Ethernet-based solution brings. Also, the number of HD SDI signals that you can squeeze into a 10GigE or even 100GigE line is a convincing argument for medium-term migration to IP. With SMPTE 2022-6, the wrapping of all SDI formats within IP will be defined, but previous wrappings were never used to actually do anything in the IP-layer – they were just used as a transparent channel.

This article outlines the steps and required mechanisms to go "all-IP" and leverage the possibilities that come with it. The first step to take is to achieve seamless switching between signals in the IP layer, which was implemented at the IRT as a software-based Proof of Concept, followed by a novel approach regarding multicast signal distribution within a network. The applications made possible by these features are only limited by your imagination.

SDI, IP, SDI-over-IP

The Serial Digital Interface (SDI) is a family of video interfaces standardized by SMPTE including:

- **SD** (@270 Mbit/s, formally defined in SMPTE 259M);
- **HD** (@1.485 Gbit/s, formally defined in SMPTE 292M) and;
- **3G** (@2.970 Gbit/s, formally defined in SMPTE 424M).

As the name indicates, (video) data is transported serially line-by-line, frame-by-frame. Each frame has vertical ancillary data (VANC) where no video is transmitted and each line also contains horizontal ancillary data (HANC). These usually contain audio, time code and other packetized data, accompanying the video, which for most cases is transmitted as uncompressed YC_bC_r 4:2:2 with 10-bit colour depth. Traditionally, SDI is carried over an electrical interface with 75Ω BNC connectors but, today, there are optical fibre connectors as well.

In the case of IP-over-Ethernet, the BNC-based 10BASE2 cable has long been superseded by Twisted Pair, also an electrical connection which is still sufficient for 10GigE speeds. However, and especially in backbones and for higher speeds, fibre is more common. In contrast to SDI, where the data is transmitted serially bit-by-bit at a constant rate, IP – the Internet Protocol – is packet-based: all data is chunked into small packets (usually no more than 1500 bytes) and contains multiple protocol layers stacked on top of each other. Each layer consists of a header part and usually the layer on top of it is the payload. Thus an IP packet starts with several different protocol headers and finally the innermost layer will contain the actual payload. The entire IP packet is then put inside an Ethernet frame. The outermost layers (Ethernet, IP) contain address information, for the network to know where to deliver the packet to, followed by UDP (or TCP) that define which networking socket within the destination machine should receive the packet. Finally there are application-specific protocols that contain metadata, timing information, etc. about the actual payload itself.

SMPTE 2022 is a group of standards that specifies the wrappings of professional video into IP. There is always an even part for the actual wrapping accompanied by an odd part defining forward error correction (FEC).

SMPTE 2022-2 and SMPTE 2022-4 define the wrapping of the MPEG-2 Transport Stream with constant and variable bitrate, respectively. SMPTE 2022-6, still a draft at the time of writing, will define the wrapping for SDI (and possibly also compressed and wrapped media formats). It is based on the Real-time Transport Protocol (RTP) and adds another protocol layer for a high-precision clock and extra metadata: the ***High-Bitrate Media Transport Protocol*** (HBRMT). The layer model of an IP packet containing SDI according to SMPTE 2022-6 is depicted in *Table 1*. Each packet contains 1376 Bytes of SDI payload with the last packet of a frame being zero-padded to have each frame packet-aligned.

Table 1 – SMPTE 2022-6 layer model

Layer	Abbreviation	Full name	Standard	Length
Application	SDI (payload)	Serial Digital Interface	SMPTE 259M, 292M, 424M	1376
	HBRMT	High Bitrate Media Transport	SMPTE 2022-6	8-16 [a]
	RTP	Real-Time Transport Protocol	RFC 3550	12 [a]
Transport	UDP	User Datagram Protocol	RFC 768	8
Internet	IP	Internet Protocol (v4/v6)	RFC 791 / RFC 2460	20/40 [a]
Link	MAC	Media Access Control (e.g. Ethernet)	IEEE 802.3	42

a. Plus optional fields

The layers (from outermost to innermost) are: Ethernet, IP, UDP, RTP, HBRMT and finally the SDI payload. *Table 2* summarizes the resulting figures for the three common SDI speeds.

Table 2 –Statistics for different SDI formats wrapped in SMPTE 2022-6

SDI format	Speed	Packets/frame	Packets/second	Streams		
				1GigE	10GigE	100GigE
SD@25i	270 Mbit/s	982	24’550	3	33	335
HD@50p	1.485 Gbit/s	2’699	134’950	-	6	60
3G@50p	2.970 Gbit/s	5’397	269’850	-	3	30

Deploying a new technology for the aging SD standard is economically not feasible and the high bitrates for HD and 3G SDI demand 10GigE equipment, which has not yet entered the consumer market (and price point) ... but prices for it have dropped to levels that are roughly comparable to dedicated SDI hardware. Looking at the historical development of Ethernet in *Table 3*, a shift to 10GigE in consumer commodities would be due, but the limited speeds of consumer broadband and hard disks make it questionable whether this will happen anytime soon. Nevertheless with the rise of 100GigE technology, prices are expected to drop further.

Table 3 – Historical development of Ethernet standards

Name	Standard	Speed	Published in	Consumer commodities
Ethernet	802.3a	10 Mbit/s	1985	1990s
Fast Ethernet	802.3u	100 Mbit/s	1995	Late 1990s till early 2000s
Gigabit Ethernet	802.3ab	1 Gbit/s	1999	Since mid-2000s
10 Gigabit Ethernet	802.3ae	10 Gbit/s	2003	Not foreseeable
100 Gigabit Ethernet	802.3ba	40, 100 Gbit/s	2010	Probably never

Seamless switching between signals

Switching between two SDI sources must be executed according to RP168-2009 for the down-stream devices to handle the change seamlessly. Both signals must be synchronized and the actual switch-over must occur within line 6 (for PAL), 10 (for NTSC) or 7 (for HD). As the SDI frame in IP is packet-aligned, one can count down from the start of the frame (which is conveniently detectable by the *marker bit* in the RTP header) to the switching position. To know the correct switching position, one needs to know the exact SDI format (which is referenced as *Video Source Format* in the HBRMT header) to calculate the packet in which to switch over. This calculation can be done once for all existing SDI formats and then be stored in a lookup table in the device. Even the shortest SDI line (NTSC with 2145 Bytes) is much longer than an HBRMT packet's payload, thus there is at least one possible switching position per line without the need to cross over the signal within a packet. This has advantages for hardware and software implementations as only the headers need to be manipulated; no copy operation from one packet's payload to another is ever required.

If the SDI-over-IP signals are not received frame-synchronized, buffering of at least one frame is required to synchronize the sources. In order to have not only the SDI layer switched seamlessly, but to provide integrity for *all* layers during and after the switch-over, the system needs to calculate and add proper offsets for all sequence counters and timestamps in both the RTP and HBRMT layers.

Abbreviations

10GigE	10 Gigabit Ethernet
100GigE	100 Gigabit Ethernet
DMA	Direct Memory Access
FEC	Forward Error Correction
HANC	Horizontal ANCillary data
HBRMT	High Bit-Rate Media Transport
HD SDI	High-Definition SDI
ICMP	Internet Control Message Protocol
IEEE	Institute of Electrical and Electronics Engineers http://www.ieee.org
IETF	Internet Engineering Task Force http://www.ietf.org/
IGMP	Internet Group Management Protocol
IP	Internet Protocol
MAC	Media Access Control
NTSC	National Television System Committee (USA)
PAL	Phase Alternation Line
PoC	Proof of Concept
PTP	Precision Time Protocol
RAM	Random-Access Memory
RFC	Request For Comments (IETF standard)
RTP	Real-time Transport Protocol
SDI	Serial Digital Interface
SFP	Small Form-factor Pluggable transceiver
SMPTE	Society of Motion Picture and Television Engineers
SNMP	Simple Network Management Protocol
SOAP	Originally stood for Simple Object Access Protocol, now doesn't stand for anything – see http://www.w3.org/TR/soap12-part1/#intro
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
VANC	Vertical ANCillary data

Regular vs. SDI-over-IP-aware Multicast-IP routing

Multicast-IP is a standard way of carrying out one-to-many communication in IP. The multicast group to receive a packet is defined by its destination IP address. For both IPv4 and IPv6, there are specific IP ranges reserved for multicast: `Ex.xx.xx.xx` for IPv4 and `ff00::/8` for IPv6.

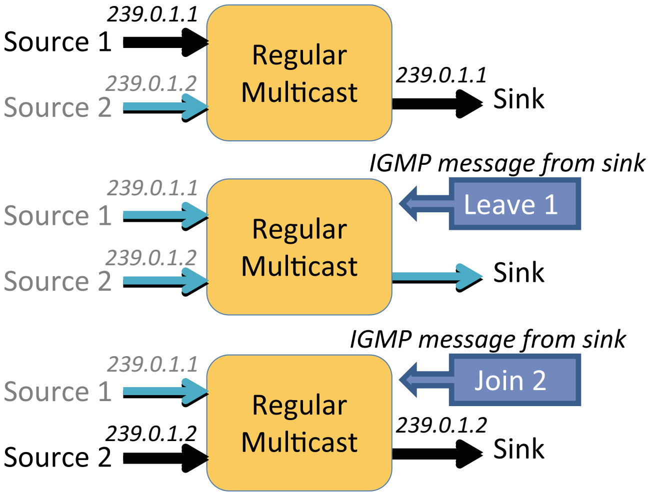

Figure 1
Regular multicast

Joining or leaving multicast groups is handled by dedicated protocols, namely the Internet Group Management Protocol (IGMP) for IPv4 and the Internet Control Message Protocol (ICMPv6) for IPv6. These protocols do not have guaranteed answering times and thus do not suffice for exactly synchronized actions such as switching of SDI-over-IP signals. Furthermore the control messages must originate from the device that receives the multicast stream. Hence, controlling the flow of videos across a big network would be difficult to manage for classic multicast routing.

Fig. 1 shows how source switching could be realized with regular multicast IP. At the top, the sink receives data from Source 1 with the IP Address 239.0.1.1. To change to Source 2, the sink first sends an IGMP Leave message to stop receiving data from Source 1 and in a second step sends an IGMP Join (Membership Report) message to start receiving data from Source 2 at the IP address 239.0.1.2. This results in a discontinuous data flow with changing IP address and random gaps between timestamps and sequence numbers throughout all protocol layers.

The suggested approach defines two classes of multicast addresses: *source addresses* and *sink addresses*.

Any device that generates a video stream, e.g. a video camera, has a (configurable but) static source address attached, while a device that receives a video stream, e.g. a monitor, statically joins one sink address (or more, depending on the device class). According to our proposal, the multicast router will contain not only the traditional multicast-routing tables (to know on which port which multicast groups are requested) but, additionally, a table to map the sources to sinks. It terminates the incoming stream with a source address and generates a new stream with a sink address. The execution of stream forwarding according to this mapping must (especially upon changes) take into account the above-stated requirements for seamless switching to achieve a continuous valid signal across all protocol layers up to the SDI payload. Obviously before the switch-over can happen, both multicast sources must be received at the switch. Thus (if not yet joined), the switch must first join the multicast stream to which it will switch over to, and wait for the arrival of packets from the said source.

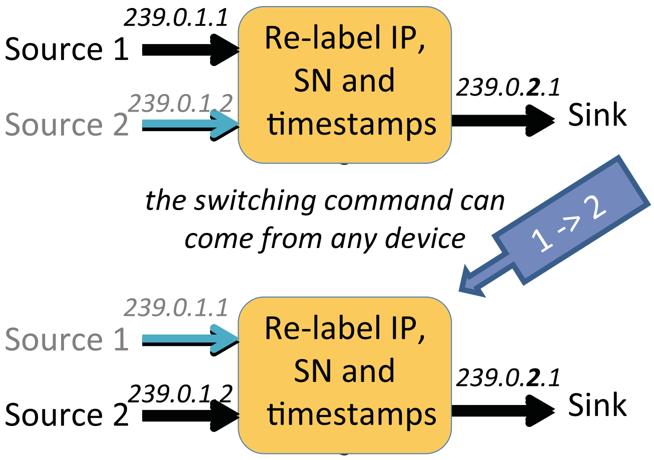

Figure 2
Suggested approach

Fig. 2 depicts the process of source switching, where the control message to alter the source can originate from any device and the resulting data stream is continuous and error-free throughout all protocol layers including the SDI payload.

As the proposed source-to-sink mapping can be controlled by any protocol, e.g., SNMP or SOAP, it is easy to integrate it into any existing or new management system. The resulting multicast streams comply 100% with the standard and therefore not every switch in the network needs to be SDI-over-IP-aware. Theoretically, one central switch would be sufficient but, for a large network, a distributed approach will be advantageous.

Building SDI-over-IP-aware devices could happen at different levels. Preferably the logic would be deeply integrated into the devices firmware, but programmable switches could be used to add this new technology to existing devices. Alternatively, in a totally decentralized manner, the logic might be shifted into the Small form-factor pluggable transceiver (SFP), this would allow for upgrading the existing infrastructure, especially if there would also be SFPs that connect to electrical or optical SDI and do the SMPTE 2022-6 conversion as well.

Proof of Concept

To demonstrate the general soundness and applicability of the idea, a software-based Proof of Concept (PoC) with two Dektec SD-SDI capture and playout interface cards was realized at the Institut für Rundfunktechnik (IRT) in Munich. The PoC consists of three different software modules: an SDI-to-IP converter and an IP-to-SDI converter, both implementing SMPTE 2022-6 on the IP side and using the Dektec API on the SDI interface side, and thirdly an A-B-switch for SDI-in-IP.

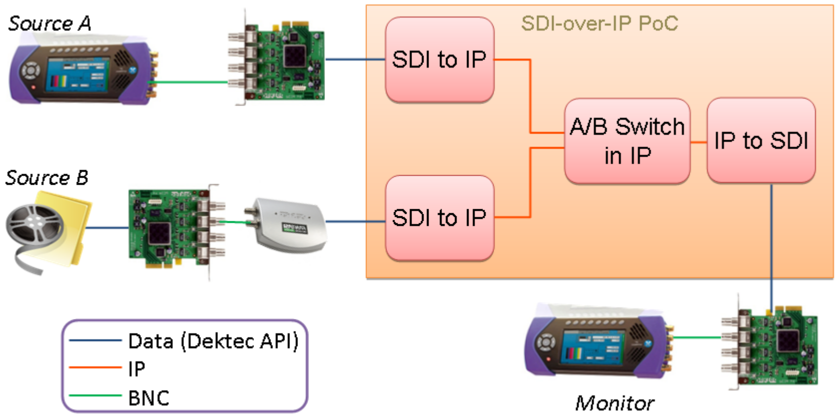

Figure 3
Proof of Concept

The PoC, as depicted in *Fig. 3*, consists of two physical SDI input ports, to each of which an SDI-to-IP converter is attached. The A-B-switch receives the multicast streams generated from the said converters and its output is sent to an IP-to-SDI converter attached to a physical SDI output port. The setup was successfully tested using a Phabrix SX for long-term robustness and correct switch-over behaviour over several thousand switching operations. A more advanced setup is planned using newer HD-SDI capture/playout cards.

The computational power needed for the PC-based PoC is very low; mostly the data is moved around using DMA transfers and only a few header bytes per packet need to be read and modified. With a static ring buffer, no recurring memory allocations are required, and therefore only the system load induced by the network stack and the Dektec driver is noticeable. A hardware implementation within a switch should be possible without upgrading the computational power, as every packet can be inspected and modified in several layers by professional switches. The memory required for buffering at least one frame per stream (~4 MB for HD) may require RAM upgrades.

Reliability, FEC and error concealment

The UDP/IP protocol on which SMPTE 2022-6 is built is not a reliable protocol. There is no built-in mechanism to guarantee arrival in the correct order, or even arrival of the packet at all. The order of packets can be restored through sequence numbering in the RTP layer, but packet loss remains a problem. Manufacturers claim to be able to build managed networks where packet loss does not occur as long as the available bandwidth is not exceeded. For lossy networks, SMPTE 2022-5 offers an XOR-based one- or two-dimensional forward error correction (FEC) scheme. This of course adds network overhead and, for every step, additional delay and computation power.

A trivial form of error concealment for video can be implemented by using a one-frame buffer (which is required anyway), that can be utilized to regenerate lost packets using the content of the corresponding packet of the previous frame. For audio or generic metadata, other concealment techniques may apply.

Applications, synchronization and timecode

Developing IP-based solutions can be much faster and cheaper than developing traditional SDI equipment. Splicing in any kind of extra data, such as subtitles, to an IP stream will no longer require any dedicated hardware, and even adding visual overlays could be done right in the IP layer. Also, conversion from SDI to compressed video, e.g. JPEG2000 or H.264, and back again to uncompressed video can be implemented anywhere to tunnel through the lower-bandwidth networks.

Matthias Laabs studied applied computer science at RWTH Aachen University and the Czech Technical University (Prague), receiving his Dipl.-Ing. degree in 2007. While preparing his thesis at Fraunhofer Institute for Applied Information Technology, he worked on parallelisation of image processing algorithms and developed a control system for semi-automatic cell cultivation.

Since joining the Institut für Rundfunktechnik (IRT) in 2007, Mr Laabs has participated in various past and present EU research projects on topics such as mobile interactive TV, 3D TV and hybrid broadcast-broadband distribution. He is heavily involved in several IRT software products for MXF, network-quality monitoring and user-friendly switching of DTM networks. Currently he is also carrying out research on SDI-over-IP and adaptive multicast streaming technologies.

With the rise of the Precision Time Protocol (PTP/IEEE1588), a UDP/IP-based clock synchronization protocol with up-to-a-nanosecond precision, a possible solution is offered to synchronize SDI-over-IP sources without the need of additional cables and equipment, such as for the currently used Black Burst or Tri Level Sync. PTP can run on the same physical cable as the video stream, therefore reducing the infrastructure complexity, costs and setup-time and, if studio-wide synchronization can be facilitated, the delays caused through buffering in the SDI-over-IP-aware switches can also be minimized.

This version: 28 November 2012

Published by the European Broadcasting Union, Geneva, Switzerland

ISSN: 1609-1469

Editeur Responsable: Lieven Vermaele

Editor: Mike Meyer

E-mail: tech@ebu.ch