Off-the-shelf IP Routing Switchers in the Hybrid IP/SDI Television Broadcast Environment

White Paper

Introduction
The most disruptive technology to hit the broadcast industry, possibly even more so than the transition from analog to digital production, has been the introduction of Information Technology (IT) into the broadcast plant. As IT has become increasingly commonplace in the broadcast facility, the computerization and automation of numerous devices and operations have occurred, changing the roles of the engineering staff and the fundamental way that broadcast works.

This started in the latter 20th century with, as an example, the introduction of computer-based systems for linear editing. In short order, the need for the flexibility of non-linear manipulation of video and audio elements led to nonlinear editing systems wholly computerized to take advantage of hard-disk storage, eliminating videotape and its linear access. In similar manner, disk-based video servers began to replace videotape-based players and cart machines to provide more flexible playback of programs and commercials for on-air distribution.

Until recently, the media files stored on computerized devices would be converted to SDI for real-time streaming, as required for live production. Now, however, a new methodology of streaming video over Internet Protocol has emerged as an alternative. There are various advantages for this new approach but a key demand is the increasingly large bandwidth requirements for 4K and 8K UHDTV. UHD-1 at 4K today requires four 3G SDI coax interconnections—a lot of copper cabling. A single 10Gb Ethernet connection easily allows a UHD-1 interconnection (with light, lossless 2:1 compression), which is a perfect application for video over IP.

IP Routing
Why is it that we are talking about using IP routing infrastructure in broadcast facilities at this point in time? There are several reasons. As we have seen, IT technologies are already finding themselves in “islands” of the broadcast landscape. Second, commodity off the shelf (COTS) equipment is becoming increasingly powerful and flexible, capable of replacing purpose-built broadcast equipment. Third and not least are the cost advantages of COTS equipment.

There has been a drive to COTS purchases as a means to improving cost efficiency as revenue per service declines (illustrated in table 1). The positive news here is the opportunities afforded by offering additional services such as sub-channels, Video on Demand (VOD), mobile, and Over-the-Top (OTT).

The enterprise market for IP routers is magnitudes larger than that of broadcast specific routing and infrastructure; estimates of the broadcast routing switcher market run to about $300M or more; the IP switch market exceeds $12B. With this size of market, there are the economies of scale that leverage cost savings and enable a high velocity of technological advancement in the products offered by major vendors such as Cisco, Brocade, and Juniper.

There is of course another aspect of the IT technological landscape and its effect on the broadcaster and viewer: the emergence of alternative video distribution models such as Over the Top (OTT). These new means of video distribution may well fit into a broader mission for the broadcaster to support Over the Air as well as OTT; the flexibility of video over IP fits well with this expanded requirement.

SAM has been actively researching how to deliver media-centric IP routing, processing and control solutions for several years. As a result of this research, rather than develop a video-centric IP switch, SAM has partnered with Cisco to deliver the next generation of IP routing switching fabric and control solutions.
There are several compelling reasons for our customers that have influenced SAM’s decision:

- Cisco leads the world in IP networking technologies, cloud based infrastructure, data centre virtualization solutions and broadcast distribution infrastructure
- Such a solution offers the most cost effective and extensible solution for IP distribution and processing
- The enterprise market for IP routers is magnitudes larger than that of broadcast specific routing, allowing our customers to leverage the economies of scale and high velocity of change of the larger marketplace
- Taking advantage of proven network technologies for the efficient distribution of IP video streams; for example: IGMPv3 (Internet Group Management Protocol, RFC-3376) Source Specific Multicast
- In our view, building an IP switch that effectively replicates the functions of a traditional SDI based router limits potential for new distribution and processing models
- There is a need to make a transition from today’s SDI based infrastructures, through a migration path of a hybrid SDI / IP environment to complete IP based processing & distribution

**Traditional Routing Switchers**

Traditional routing switchers are sized and defined by the number of physical ports, which bears a direct relationship to their cost. Ports may be either sources or destinations; signals flow in a specific direction, in or out. Routers can be symmetrically configured such as the example of the SAM Sirius 830 with 288 x 288 ports, or asymmetrical such as the SAM Vega, the 4U version of which sports 192 ports, each port assignable as input or output.

The traditional router sits at the heart of a broadcast plant’s infrastructure and acts as the central point of control for the selection and distribution of signals. In fact the router is often the first block drawn in the blueprint design of the plant, surrounded by the remainder of the system’s infrastructure. The router needs to be large enough to manage all of the video, audio and ancillary signals in the facility. Signals may be embedded audio with video, the router may provide hybrid processing, signal synchronizing, and other enhanced features; inputs and outputs can be coax or fiber; signal redundancy and monitoring can be provided. A standard practice is to time all signals to the router, with the router timed to house reference black and burst. Synchronized signals may be clean switched, so that the output can be directly used either on air or with broadcast devices that would be otherwise disturbed by crash switching.

One of the benefits of IP routing is that it allows a move away from the traditional SDI router approach of a single large frame that provides all routing requirements. Using an aggregate of multiple, smaller IP routers can bring added redundancy, cost-savings, and flexibility of deployment. It may well be more appropriate to use a hierarchical tiered deployment of switches, e.g. a Cisco Nexus 9K at the core, with satellite Nexus 3548s providing localized access.

**IP Routing**

Specifying a router’s size works differently in the IP world as compared to the SDI world; 1152 sources does not necessarily mean 1152 interface ports on the switch. With an IP network switch, the size of the router is defined by its total bandwidth. The physical ports are less relevant to size as they may carry multiple signal paths and are inherently bi-directional. The switch routes packets based on IP addresses embedded in the packet header. Control of routing is achieved by instructing destinations to join IGMP groups. A SDN (Software Defined Networking) approach allows for efficiency, elasticity, scalability, controllability and the logical segregation of the network as required. In fact, if devices are simultaneously source and destination then a single interface port can operate bi-directionally. The signals flowing through the IP switch can be video (i.e., real-time video over IP), audio, or files; video streams do not need to be media aware, are not necessarily the same frame rate, and timing reference can be applied on a case by case (signal by signal) basis. Timing is used for clean switching, a topic that we will need to come back to.

If we were to build an IP switch that effectively replicates the functions of a traditional SDI based router, we would limit the potential for new distribution and processing models. Instead, we need to move away from today’s SDI-based infrastructures, by providing a future-proof migration path for a hybrid SDI / IP environment, ultimately to achieve completely IP-based processing and distribution.

Can an off-the-shelf IT switch do the job for broadcast switching? Absolutely. A non-blocking, carrier-grade IT switch—for example the Cisco Nexus series—can be deployed in unmodified form to achieve the functionality and reliability of an enterprise class broadcast router. While SAM has partnered with Cisco, our approach is vendor agnostic as the underlying IP fabric does not need to be media aware.
For the video signal flows through the router, we will use IP Multicast IGMPv3 (Source Specific Multicast). The advantage of the v3 protocol is that it is software driven, allowing for greater flexibility than previous, hardware determined models. To manage the integration of SDI-based equipment we utilize edge devices that are broadcast-aware to provide synchronization and clean switching at the destination. Across the infrastructure we provide broadcast-aware control intelligence, which allows broadcasters to continue to use the routing control systems that they are familiar with. System timing is maintained with IEEE1588-2008 Precision Time Protocol (PTP) v2. To reiterate, the core technology is an unmodified standard IT network switch, to exploit economies of scale from IT industry.

Timed Switching
The underlying IP fabric does not need to be media aware. To allow the IP infrastructure to be content agnostic, we propose a destination-oriented switching model, placing the intelligence of how to handle media at the edge devices and treating the IP core as a high speed and low latency data mover.

Placing the clean switching requirements inside the router is no longer necessary or even desirable as we consider these distributed IP video models. Performing the clean switching at the destination edge devices reduces system complexity and cost of the central IP core.

Clean switching with IP routing switches can be achieved in one of several ways: source-determined; switch-determined, or destination-determined. While each approach has its advantages and disadvantages, SAM has taken the approach of destination-timed switching as the method that provides the greatest flexibility. Simply put, a destination-determined clean switch is “make before break”, i.e., join the new stream before dropping the old one. With this approach, there is an additional burden on the edge device at the output in handling two streams simultaneously for the moment of the switch’s timing alignment. It should be reiterated that the additional bandwidth is only required for the brief moment of the switching process.

The key advantage of destination-timed switching is that the entire IP switch fabric remains completely asynchronous. The system is not tied to any specific raster sizes, formats, codec types, streaming models etc.

In SAM’s opinion this is a highly desirable design characteristic, given the rapid and constant state of change in our marketplace, as it allows for the adoption of new transports as we transition through 4K, 8K, high dynamic range, high frame rate, object based audio and other developments in the professional media space.

In contrast, we believe there are significant limitations associated with source-timed and switch-timed models, especially as the system grows beyond the capabilities of a single Ethernet switch that have yet to be addressed at the technology level:

- Switch-timed requires video-specific switch fabric, which means the cost benefit of adopting standard COTS data network equipment cannot be realized. As such, existing switch-timed solutions do not scale across wider routed IP infrastructures.
- Source-timed solutions have challenges scaling for large systems, for example: where a single source is feeding multiple destinations across a routed switch fabric and accurate switching of the source is required to all of those destinations. This requirement can be met by using a destination-timed switch and IGMP v3 Multicast.

Our opinion of destination-determined switching is that it:

- Can accommodate switching to different formats and codecs, with non-co-timed streams.
- Can provide switching at any of the layers as appropriate (RTP, 2022, baseband).
- Allows for clean switching where needed with PTPv2 timing and management of broadcast aware edge devices.
- Incurs some extra bandwidth if clean switching is required, for the period of timing alignment.
- Only requires extra decoding resource when switching between non-similar codecs.
- Exploits proven technologies such as IGMPv3 (Source Specific Multicast) to achieve efficient and optimal distribution of video data across the IP switch fabric from sources to destinations.
- Allows any transport streams and codec types, providing longevity of investment with changing standards, formats, metadata requirements.
- Permits end-to-end bespoke security if required.
- Allows for complex architectural models with distributed, hierarchical, spine & leaf etc.
- While the IP environment is itself asynchronous, accurate timing can be distributed using IEEE 1588-2008 Precision Time Protocol (PTPv2). Signals are time stamped upon entry to the IP world, so that separate essence streams can be recombined with the correct synchronization in decoder edge devices.
With a traditional SDI router, of course, clean switching was effectively available on all destinations for free, and hence it became the norm. But in reality, SAM believes that as customers move more to IP streams and file-based workflows, there will be fewer places where clean switching is really required.

Traditionally, the house router has been the center of a facility with all switching requirements handled within it, primarily because the cost of video memory made it prohibitive to consider performing the switching elsewhere and the control interface was traditionally hard wired using RS422 or similar, requiring a centralized device.

These restrictions no longer apply and the implementation models for IP fabric and distributed control can be much more flexible when an IP routing solution is considered. Placing the clean switching requirements inside the router is no longer required or necessarily desirable as we consider these distributed IP video models.

Furthermore, SAM’s view (based on actual usage logging from SAM SDI routers in customer installations) is that very few destinations actually require clean switching. Many routes are effectively static once the router has been installed and configured, and routes that do change are generally set up ahead of time. So the number of destinations which are routed ‘live’ and really need clean switching is typically quite small.

The asynchronous environment may work for some users. Others will depend on some amount of clean switching in one of two scenarios:

- Clean switch as soon as possible, e.g., in response to user control
- Clean switch at a precise time, e.g., under automation control

That said, with the low cost of video memory today the cost of performing clean switching on the edge is low and will be supported in all SAM products.

**IP Routing Cost Characteristics**

This table compares the cost of traditional routing using SDI with IP routing based on use of three different codecs throughout the plant. What becomes apparent is the cost of processing in edge devices is the most significant factor with system size, not the cost of the IP router bandwidth.

<table>
<thead>
<tr>
<th>Costs for Traditional SDI Routing</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vega 96-port router with 3G, HD-SDI ports</td>
<td>28,000 USD</td>
</tr>
<tr>
<td>Total signal bandwidth = 96 ports *3Gbps</td>
<td>288 Gbps</td>
</tr>
<tr>
<td>Cost per Gbps</td>
<td>97 USD/Gbps</td>
</tr>
<tr>
<td>Total cost per signal</td>
<td>292 USD</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs for IP SDI Routing Solution</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cisco 3548 switch (48 ports +10G SFPS)</td>
<td>40,000 USD</td>
</tr>
<tr>
<td>Total signal bandwidth = 48 ports *10Gbps</td>
<td>480 Gbps</td>
</tr>
<tr>
<td>Ports are bi-directional</td>
<td>960 Gbps</td>
</tr>
<tr>
<td>Derate to 75% utilization</td>
<td>720 Gbps</td>
</tr>
<tr>
<td>Cost per Gbps</td>
<td>56 USD/Gbps</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compression Comparisons</th>
<th>VC-2</th>
<th>AVC-I/ JPEG2K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitrate for high quality HD</td>
<td>1.5Gbps</td>
<td>500 Mbps</td>
</tr>
<tr>
<td>Number of signals per derated 48-port Cisco 3548</td>
<td>83</td>
<td>28</td>
</tr>
<tr>
<td>Cost of routing fabric per signal (USD)</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Cost of edge processing (USD)</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Total cost per signal</td>
<td>158</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 1: CODEC Cost Characteristics.

- Edge device costs dominate.

**Codec Requirements**

When looking at an IP model, the total cost of ownership of the IP Router(s), the Edge devices for converting between IP and SDI and media processing need to be considered in terms of rack space requirements, power consumption and control, as well as the performance factors of video quality, latency and IP bandwidth required.

The following table highlights considerations for codec selection. We can see a direct correlation between bitrates required and codec complexity. This matters as increased codec complexity requires more resource in FPGA gates or computational power, which potentially impacts the number of streams an edge device can present to an Ethernet connection in a high density solution, or increases the cost & power requirements of the edge device.
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<table>
<thead>
<tr>
<th>Codec</th>
<th>H264/AVC</th>
<th>H264/AVC1</th>
<th>JPEG 2K</th>
<th>VC-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video quality</td>
<td>medium</td>
<td>high</td>
<td>v high</td>
<td>Lossless</td>
</tr>
<tr>
<td>Edge device complexity</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>Recode times</td>
<td>4</td>
<td>6-8</td>
<td>6-8</td>
<td>5-many</td>
</tr>
<tr>
<td>Delay</td>
<td>high</td>
<td>lines-frame</td>
<td>lines-frame</td>
<td>lines-frame</td>
</tr>
<tr>
<td>Mbps - HD</td>
<td>50 Mbps</td>
<td>200 Mbps</td>
<td>200 Mbps</td>
<td>500 Mbps</td>
</tr>
</tbody>
</table>

Table 2: CODEC Requirements

Unicast Vs. Multicast
Multicast expands on the capability of the router in its most basic function as a patch panel, by providing the flexibility similar to that of built-in distribution amplifiers, allowing a single source to be distributed as multiple outputs. A standard such as IGMP-V3 (RFC-3376) allows for source-specific Multicast with fast access across a distributed network of routers. It’s possible to use different Multicast groups to segment sources, so that different compression algorithms are easily handled simultaneously. SAM is developing an enhanced control protocol to simplify source selection and destination so that operation is perfectly analogous with today’s broadcast SDI router controls.

System Architecture
In keeping with past migrations from analog to digital and HD, the interim systems have always developed as hybrid environments in an evolutionary manner. This is likely to be the case again during the conversion from a fully SDI environment through a mixed SDI and IP environment to a fully enabled IP environment with SDI I/O only as required by legacy and video based systems. To support this evolution, I/P enabled edge and program production devices will allow best of breed hybrid systems to function in a unified and integrated manner.

Possibly the most important aspect of the solution from a business operations perspective is the control layer. A system that abstracts the underlying switching fabrics to an operator is desired, enabling staff to concentrate on the business needs rather than having to understand and separately control the technology needs.

Fundamentally, the operator will see no difference in controlling IP routes compared with SDI based routing. The control surfaces are the same and the additional configuration information used to control the IP devices is abstracted from user operation. We are investigating a control framework for IP routing to provide improved scalability, persistence, redundancy, replication and security and automatic discovery of devices.

Processing Example: Cross-Conversion
Let’s look at a case study of cross-conversion in a hybrid IP/SDI environment. The initial signal is an IP feed that is providing a 720p 59 signal over IP encoded JPEG2000 in SMPTE 2022-2. The target application requires 1080i 59 while the edge device feeding the SDI-based mixer is capable of decoding SMPTE2022-6 uncompressed video only. A level of complexity has been introduced in the system. First, we have to manage the cross-conversion process, which today requires decoding to SDI to feed a legacy device, then re-encoding to support the format supported by the destination edge device. Separate control steps are required for routing and the conversion process.

Example 1: Incoming live feed is providing a 720p 59 signal as MPEG2 in ASI stream. Master Control Switcher requires 1080i 59 HDSDI.

With an SDI router, we would typically use an ASI decoder to SDI followed by a 720p to 1080i cross conversion. To set the routes through the required device chain accordingly and configure the cross-converter to do the correct job, we rely on a cross-converter being available and operator intelligence to know that the converted output is what is required by the source on the Master Control Mixer.

In the next example we utilize an extended control protocol and replace the SDI bound converter with a software media processing engine which uses CPU / GPU virtualization technologies to spin up the required media transformation functions and scale these on demand. With the router control system being aware of the formats supplied at the source and required at the destination, along with real-time software media transformation, the entire path can be delivered using a simple X-Y router command, with the control system initiating the media processing requirements to ensure the delivered content is formatted and encoded to match need.

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In this scenario we are using an IP router in conjunction with legacy SDI processing equipment: incoming live feed is providing 720p 59 signals over IP encoded JPEG2000 in SMPTE 2022-2. Target application requires 1080i 59 HDSDI and the edge device feeding the SDI based mixer is capable of decoding SMPTE2022-6 uncompressed video only. We can see an additional level of complexity has been introduced in the system. First we have to deal with the cross-conversion process, which today requires decoding to SDI to feed a legacy device, then re-encoding to support the format supported by the destination edge device. Separate control steps are still required for routing and cross-conversion.

In the next scenario we leverage an extended control protocol and replace the SDI bound cross-converter with SAM’s xStream software media processing engine in a data center which is able to utilize CPU/GPU virtualization technologies to bring up a wide range of media processing functions and scale them on demand. With the router control system being aware of the formats supplied at the source and required at the destination, along with SAM’s xStream realtime software media processing engine, no operator intervention is required. The entire path can be delivered from a simple X-Y router command, with the control system initiating the media processing requirements to ensure the delivered content is formatted and encoded to match need.

A final scenario removes the SDI based master control switcher and replaces it with an on-demand Channel-in-a-Box engine, ICE OD, which is SAM’s CiaB engine with IP-based I/O, designed to be deployed and scaled within a virtual machine IT infrastructure. Multicast based IP is used for I/O and final distribution.

Example 2: Incoming live feed is providing 720p 59 signal as SMPTE 2022-2 IP stream. Master Control Switcher requires 1080i 59 HDSDI.

Example 3: Media processing is managed in the IP domain

Example 4: Master control is managed in the IP domain

Example 4: Master control is managed in the IP domain

In this example edge devices are no longer needed. All signal distribution is handled in the IP domain and all media processing including transmission presentation is carried out using generic CPU/GPU resources.

Extended Protocol for Routing of IP Streams

As indicated in the above example, an extended routing protocol can be the basis of intelligent switching that manages stream formats as a function of signal distribution. SAM plans to use an enhanced communication protocol for communication between the control system and IP Edge Devices. This protocol is a data-centric open standard (Data Distribution Service) defined by the Object Management Group (OMG) for the real-time distribution of data and is designed to cater for large volumes of data and many clients. This will provide the system with automation abilities that current generation platforms are not able to offer such as:

- Auto discovery of edge devices in local and remote locations
- Interrogation of available services on the devices
- Ability to intelligently switch and incorporate media processing services based on the needs of the destination device

Adoption of DDS for this control interface will be a major step towards ensuring vendor interoperability, as DDS is an open standard with proven interoperability between various commercial software vendors and open source solutions.
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**Future IP Media Production**
The larger picture is that IP operations will impact the entire media creation and distribution process. Trucks in the field could be simply camera trucks, delivering IP streams to a facility-based production process consisting of edge enabled video switchers, audio mixers and image processors. Virtual and automated IP based playout systems will provide server and graphics operations delivering synchronized IP streams to distribution and consumer systems in real-time.

**Conclusion**
Our journey towards IP-based infrastructures for streaming broadcast production and playout has just started. In many ways it feels like we’re back at SDI all over again, where interoperability was crucial to realizing its benefits. The same is true many times over as we build the IP infrastructures our industry will rely on in the future. Standardization is key to allowing vendors to concentrate on core value add, rather than interfacing. Critically, this standardization must be in line with commodity IT if we are to benefit from the massive investments IT manufacturers are making.