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A LAWO AND ARISTA NETWORKS WHITEPAPER

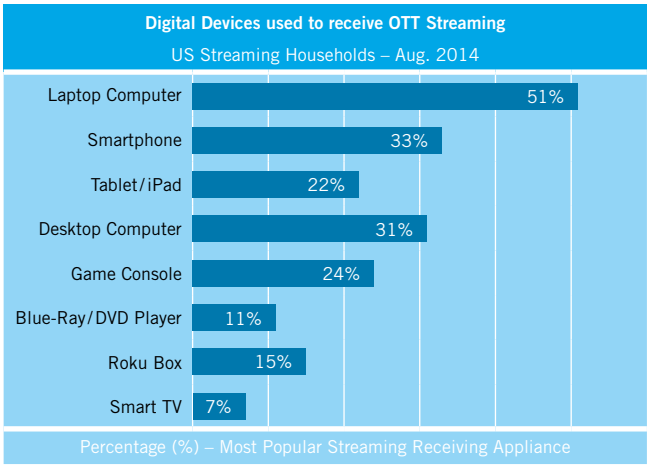
From SDI Baseband to IP Routing: An Essential & Timely Migration

Television is no longer served well by the SDI Baseband Router, coaxial cable and BNC connectors. New IP-based video/audio infrastructure and work-flows are far more flexible and cost-effective. This Lawo / Arista Networks White Paper explores a practical technology solution: A Software Defined Video IP Network using Lawo's Encapsulators, Gateways and Edge Processors, integrated with Enterprise-level high performance IP switching from Arista. The combination promises to advance and automate Television work-flows to meet near and long term demands of production, contribution, distribution and content delivery… and do it cost effectively.

For the longest time, outside of movie theaters, the TV set at home was the only way to watch moving pictures. The audience expects high quality TV programming including live sports entertainment televised with a large complement of TV cameras attempting to cover every detail of each player on and off the field. The beginning of TV delivery was over-the-air, moving to cable and satellite, and now increasingly turning to Internet delivery. Internet streaming gives the audience the opportunity to consume TV content while on the go using Smartphones and Tablets, rather than only at home in front of the TV.

This TV Everywhere delivery has been driving the demand dramatically higher for new and additional content over the past several years. In the beginning of that process, we saw new well-funded OTT VOD delivery services like Netflix, Amazon and Hulu spring up and become highly successful almost overnight, first by delivering movie and TV show reruns, and more recently by also successfully producing and delivering their own TV shows.

Over-The-Top (OTT) television program delivery (over the Internet) has seen tremendous growth over the past several years, and in the US alone this is a multi-billion dollar business. It is interesting to examine which are the most popular digital devices used by the viewers. The Chart below shows, in percentage terms, the popularity of each device. The total exceed 100% as many survey respondents reported viewing on more than one device.



The most popular is the laptop computer followed by Smartphone and Desktop. But if one adds up the viewing likely to occur on a flat screen home TV (Game Console, Blu-Ray/DVD player with built-in OTT Internet receiver, Roku Box, Smart TV), that adds up 57%. So OTT viewing at home on a larger flat screen TV is the most popular.

Over the past several years, the second tier TV programming companies are ramping up new content production, particularly in the areas of reality shows. The industry needs to respond intelligently to the increased demand for production services and sophisticated facilities. **New technologies and workflows need to be developed and made commercially available to support the new demands of content production!**

IP technology has become common place in business and in private life for transporting, delivering and presenting all kinds of data as files, or more recently, as real-time streaming of video and audio. Our lives have been digitized over the years, from the CD appearing in the 1980s to the rapid growth of the public Internet and the continuous expansion of IP technologies in the 1990s. The last decade from 2000 to 2009 produced a large number of advanced IP-based devices for business and personal use including the I-Pod, I-Phone, I-Pad, Smartphone, Tablet and more. We saw the development of personal and business “apps” running on these new devices, making it possible for the everyday consumer to access and use remote email, SMS and media streaming, and remotely control home appliances and security systems. These fast-paced developments continue in all areas of IP technology.

Business and industry at large rapidly embraced IP including real-time video/audio conferencing, VoIP and WiFi. This IP technology is continuously evolving and improving. New software designs often require faster processors, and the faster digital hardware yields the opportunity to further improve software including IP-centric applications.

The professional television industry has embraced IP-technology in many areas including video point-to-point transport and wireless HD-ENG backhaul. But, because the TV-specific professional “coaxial-based” streaming formats (SDI, HD-SDI, 3G-SDI) require TV-specific

digital routing systems, commercial IP-based data center networks were not implemented in the broadcast plant. **Until now.** The television industry is currently facing the need for tremendous amounts of content distribution as well as supporting new 4K-UHD formats that require switching of uncompressed video at bitrates of 12Gbps and above. It is simply impractical, or even impossible, to accomplish this with traditional broadcast SDI router design, "forcing" broadcasters to embrace commercial off the shelf (COTS) Enterprise-level IP networking that delivers per-port wire-rate performance of 10GbE, 40GbE and even 100GbE. The table below shows that a single 40GbE IP network connection can carry 3 concurrent uncompressed 4K-UHDp60 streams.

IP Router/Network Port Datarate

Capacity – Video Streams per Port

Serial Video Format	1GbE	10GbE	40GbE	100GbE
SDI 270Mbps	3	30	120	300
HD-SDI 1.5Gbps	None	6	26	66
3G-SDI 3Gbps	None	3	13	33
4K-UHD p30 6Gbps	None	1	6	16
4K-UHD p60 12Gbps	None	None	3	8
4K-DCI p24 4:4:4 12-bit 8Gbps	None	1	5	12

Up until now, local facility-based TV broadcast signal routing has been accomplished using baseband (first analog, then digital) switching matrices which connect a specific input to a specific output through manual operator selections or via automation. The router was originally analog, switching NTSC signals using – believe it or not - matrix relay contacts! Analog migrated to digital when NTSC was encoded using SDI (Serial Digital Interface) at 270Mbps. At that time, a router matrix of 256x256 was regarded as large. Then, starting around the year 2000, the need for 1.5Gbps HD-SDI routing surfaced to support digital television ATSC HD OTA (over-the-air) transmission in North America. This included a need for router matrices to scale up to 1152x1152 to serve the considerably larger new HD-capable network facilities being built around the world, many devoted to major league sports. And not that many years ago, the television industry agreed that 1080p50/60 should replace 1080 interlaced in some acquisition, production and contribution environments, requiring 1.5Gbps HD-SDI to be doubled to the 3Gbps standard of 3G-SDI. So, we now require the old 75-ohm coaxial cable to carry 3Gbps, or 10x more bits than original SDI at 270Mbps, making the internal switching matrix designs very expensive to manufacture. The television industry needs new advanced technology, but where will it come from?

The IP "Data Center" Network

While the TV broadcast industry was busy going from 270Mbps coax to 3Gbps coax, the enterprise IT industry was busy creating ever faster, cost effective IP networks and related appliances. Although the television community over the past 10 years has recognized video-over-IP as cost-effective and reliable point-to-point transport of SDI and HD-SDI (usually compressed JPEG2000 – J2K), intra-facility video-over- IP and routing has just caught their attention. Broadcast applications using modern Enterprise-level IP switching fabrics such as the Arista 7500E, with a "foot-print" of only 11RU, can take advantage of the 30 Tbps fabric to provide new levels of performance for TV broadcasters. Look at the illustration below.

Arista 7500 Series "COTS" Data Center IP Router

- 30 Tbps Fabric – 23 Tbps Active Switching Capacity
- 14.4 Billion PPS (Packets/sec) Forwarding L2/L3
- 1152 x 10GbE or 288 x 40GbE or 96 x 100GbE
- 1152 x 1152 4K-UHD Uncompressed (25/30p), or
- 7000 x 7000 HD Uncompressed, or
- Many thousands x Many thousands Compressed

Compare the 11RU foot-print of the Arista 7500E COTS Ethernet switch with a traditional 3G-SDI router requiring a foot-print of 40RU to provide a switching capacity of 1024 x 1024, with NO 4K-UHD capability. The 11RU IP data center switch can handle many thousands of uncompressed HD signals or 1152 x 1152 uncompressed 4K-UHD, or any mixture.

TV Broadcasters can greatly benefit from video-over-IP routing and networking, taking full advantage of attractive Enterprise COTS (Commercially Off-The-Shelf) economics to deal with the needs of 4K-UHD and 1000+ switched ports.

IP: Real-time Streaming or File Transfer?

In the television business, the IP Network must deal with both real-time streaming and file transfer, just as we do at home and at the office using the Internet. Watching a Netflix program at home OTT is a real-time stream of IP packets that includes buffering of data "faster-than-real-time": data transfer speed is faster than the actual media stream so that buffering can be used to achieve smooth playout. The Netflix program is NOT LIVE but recorded on a server so that it can play out faster and use buffering at the destination to handle an unreliable transmission medium like the Internet. It is still considered real-time streaming (it's not a file transfer), but not LIVE. However, LIVE television coverage is different; TV camera LIVE video output is streamed in real-time through the contribution and delivery network to the home where the audience is viewing the LIVE video on their flat screen TV. There is no way to accelerate the source video because it is LIVE. So real-time streaming is either playing back from a video server OR it is a LIVE televised transmission, glass to glass.

In addition to real-time streaming, there are LAN (Local Area Network) applications that mostly involve file-transfers, such as email, document collaboration and web surfing. The growing exception is video conferencing such as Skype, Face-time, Go-to- Meeting etc., where data transfer is LIVE as the participants can see each other at the same instant, with little latency.

File transfer is relatively easy as it rarely involves a real-time transfer. Transmission can be considerably slower than real-time in order to preserve network and port bandwidth for other critical real-time communication. There may also be a requirement to transfer the file much faster than real-time. Imagine we have a one-hour HD video file recorded on a server and partly edited at a remote venue with a compressed bit-rate of 50Mbps (x 60sec x 60min / 8 bits = 22.5 GB file size). The TV program is scheduled to air very soon from a different Network Operations Center (NOC) and some work is still required to be done on the content at that NOC prior to going on air, so the 22.5 GB file needs to get to the NOC very quickly. Assuming an IP Network with 10GbE bandwidth, we could easily transfer the 22.5 GB file ten times faster than real- time or in about 6 minutes, as a 500Mbps data-train will only consume 5% of the 10GbE pipe. File transfers are generally very tolerant to routing and data-rate, which of course must be considered when programming the SDN (Software Defined Network).

So in summary, LIVE transmissions must have highest priority in any IP Network, closely followed by real-time on-the-air program streams, followed by file transfers. In practical terms, as far as network affiliated TV stations are concerned, the network feed will always have the highest priority whether the feed is LIVE evening national news or a prime time TV program playing out real-time from a server at the NOC.

IP: Seeking 100% Reliability & On-time Delivery

TV Broadcasters require 100% reliability in the delivery of LIVE/OTA signals. Are they getting 100% in the real-world? Very close, as their long distance contribution and distribution facilities currently operate over mostly dedicated links of various kinds (satellite, optical, ATM, VPN). If moving to shared transmission facilities, there is really no network platform that can guarantee 100% delivery of content and control data in a shared environment. The problem generally occurs when the load increases towards the upper limit of pipe capacity. Traditional IT storage and networking technology was architected for shared environments and therefore default to best efforts as the load increases. These technologies are designed around many data transactions where each takes a small portion of infrastructure capacity, while a single video flow can take a majority if not all of a single link's capacity.

Therefore, television companies put a lot of effort into making their network operation centers, master control and transmission facilities optimized for LIVE. Sophisticated mechanisms are developed to transmit signals in real-time without buffering, with redundancy schemes including hitless protection switching (without losing frame sync), and establishing full management software control over routers and infrastructure

equipment. This allows the television engineer to maintain and operate IT- specific components in addition to the broadcast-specific equipment.

Lawo is meeting the challenge to greatly expand the use of IT infrastructure in Broadcast TV as we are very familiar with traditional broadcasters' needs and we understand the future requirements of the Broadcast world, and how to best utilize modern, cost effective COTS IP Switches in the broadcast plant.

Increasing production demands can no longer be served by traditional switching and distribution, instead requiring a new approach based on the world of Enterprise IT. But IP Networking technology gives rise to new challenges while delivering clear benefits:

- The television industry will greatly benefit from recent and ongoing advances in the very large Enterprise IT industry, without paying directly for the cost of such developments.

- Implementing an IP "Data Center" in the broadcast plant will instantly increase switching capacity and reduce facility space requirements, and capacity will continue to grow as the IT industry advances Networking technology.

- The various digital broadcast standards such as SDI, HD-SDI, 3G-SDI, 4K/UHD, 24/32bit Audio in stereo, 5.1, 9.1, 22.2 can coexist in IP formats and be switched within the same IP routed network.

What does this mean for professional television facilities?
The classic HD/3G/SDI Router will almost disappear, being replaced by IP infrastructure. IP Network switches with copper and optical wiring will be the infrastructure for video and audio, including intra- and inter- facility video/audio connectivity. Edge Devices with IP network ports will ensure that video and audio are injected into and extracted from the broadcast network in the appropriate production format and quality.

How is complexity behind the new IP Infrastructure managed?
The key is Software Defined Networking and Network Management Software to configure the underlying network to give the broadcast professionals the opportunity to (a) define the network's operational parameters, and (b) to easily configure any special processing and temporary routing with a "push of a button or click of the mouse". This includes the challenge of performing seamless frame accurate switching over IP, just as any classic SDI router has done for years.

The Challenge of Seamless Frame Accurate Switching

As we'll discuss in detail below, the IP Video Router implementation in television broadcast facilities has one major challenge. Broadcasters need seamless "LIVE" switching between two sources, as classic SDI Routers have been doing for years. However the classic SDI Router approach of switching synchronous streams in a very small real-time window at the RP-168 switch point, known as "network-timed switching", is not easily duplicated in an IP Network as each port is carrying multiple signals (i.e. a 10GbE port may carry six (6) uncompressed HD 1.5Gbps signals) and COTS Ethernet switching gear is not designed to enact real-time control-plane decisions with such precision. The industry has discussed two possible solutions to this challenge:

Destination timed switching and Source timed switching

Destination Timed Switching is the easiest to implement, whereby a receiver subscribes to a new stream, handles switching to the new stream at the correct point in the video raster, and then drops the original stream. This is a make-before-break approach that has ONE major disadvantage: because the switching occurs at the Destination Edge Device, both Video IP streams must be sent to the Destination, consuming double bandwidth.

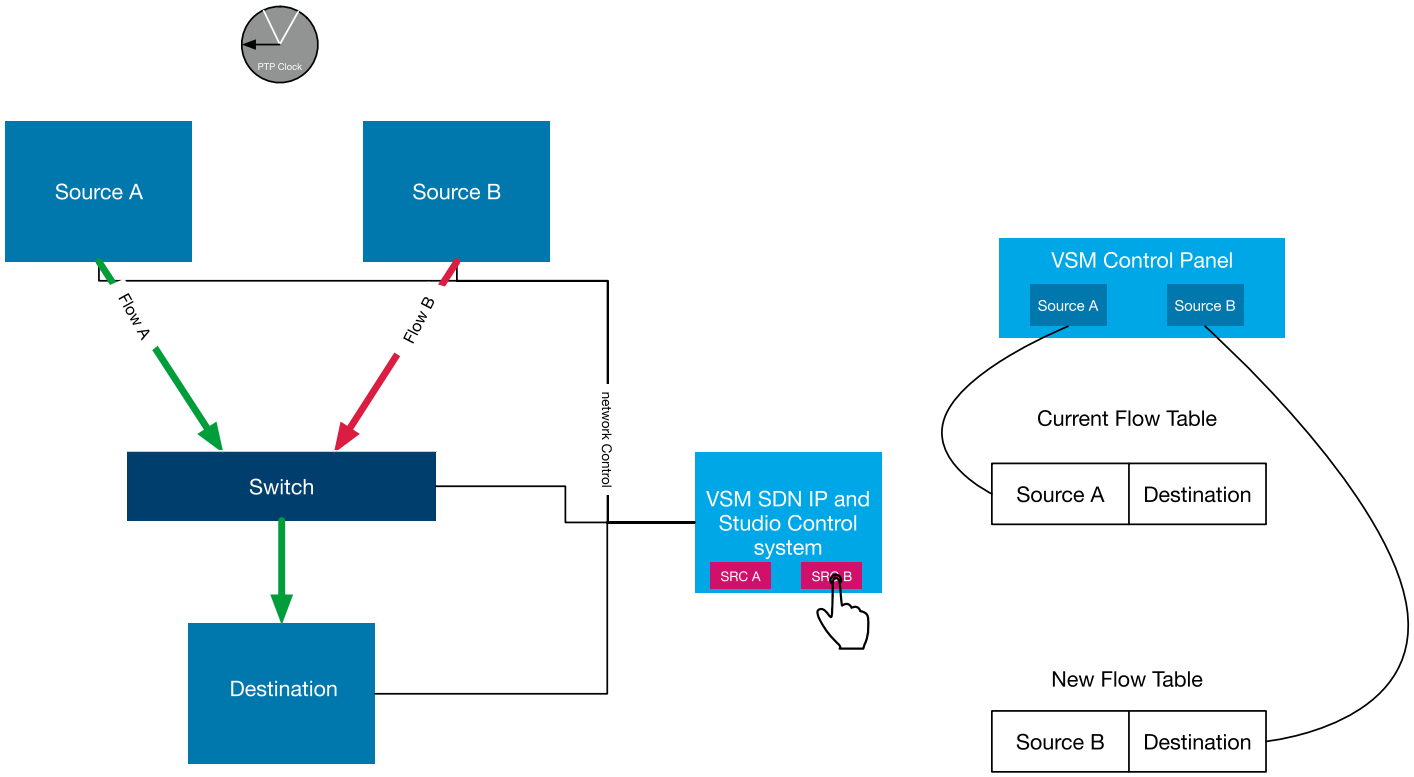
Source Timed Switching can be done precisely with frame accuracy using COTS IP network switches, without consuming double bandwidth and without affecting future scalability. And Source Timed Switching is independent of any IP video bitrate from SDI to 4K-UHD/DCI. Lawo and Arista joined forces to find an ideal solution for performing seamless frame-accurate switching through the IP Network. (See illustrations below)

Each source edge device "Source A" and "Source B" is capable of sending UDP multicast media streams. The COTS switch is configured with L4 UDP-port-specific flow rules via OpenFlow. The interactive VSM/SDN IP and Studio Control system is setting up the internal IP flow tables in the Ethernet switch so that multicast stream A is delivered to the destination edge device. For this multicast stream, UDP Port "X" is used.

All edge devices and the control system are PTP synchronized. When a clean switch from source A to source B is triggered via button or command sequence, the control system first prepares a new flow table with a flow rule to steer Stream B to the destination device. This multicast stream will utilize another UDP port "Y".

The control system then informs the destination edge device about the upcoming video switch. Subsequently, the edge devices handling Source A and Source B are told to switch at the next video frame boundary following a specific PTP value (Precision Time Protocol); 12:00 in the example below.

The Source edge devices then change the source UDP port address coming from both sources at the same synchronized time. As both flow rules in the switch have



VSM prepares to switch at PTP time 12:00
VSM prepares Flow Table for Switch

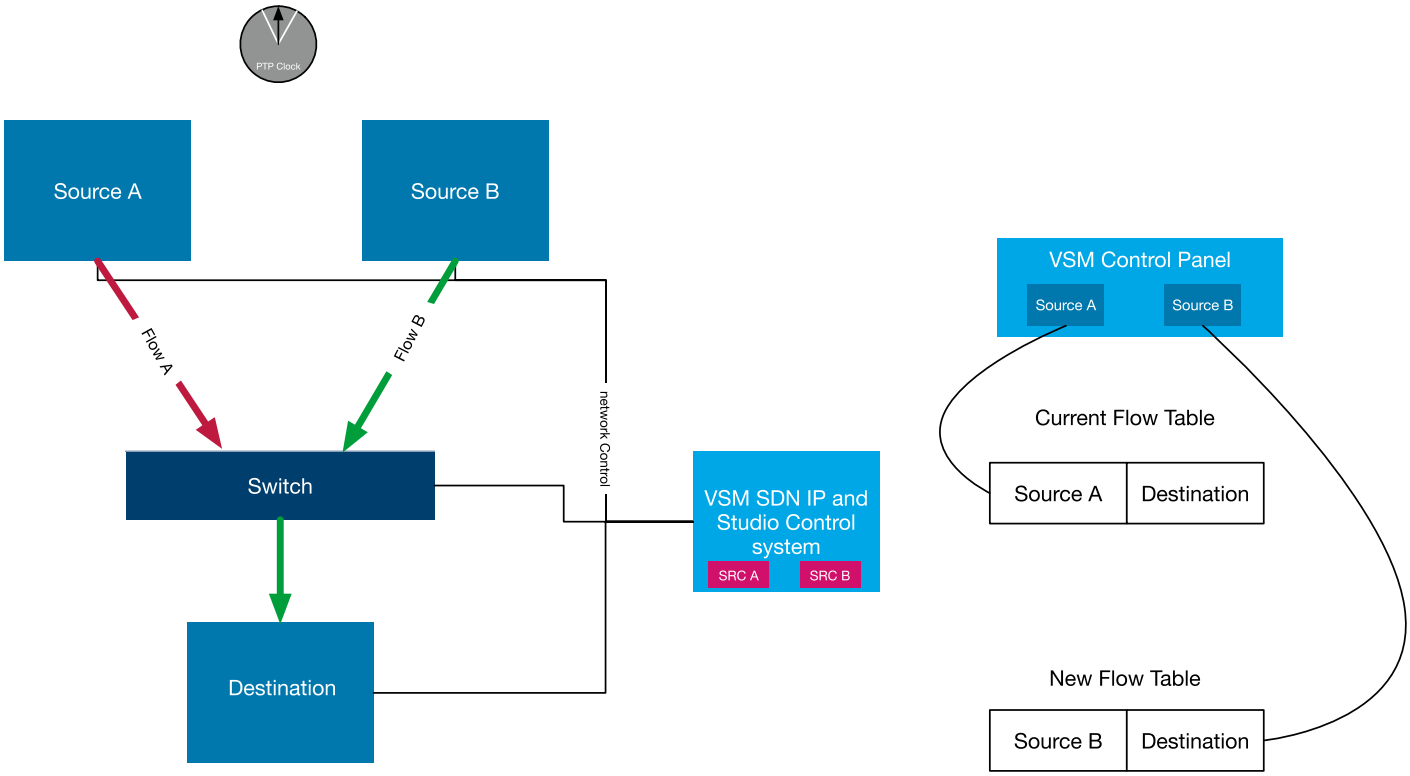
Illustration 1 – Source Timed Switching: Source A Active

already been set up before this time, the destination edge device continues to seamlessly receive a single RTP multicast stream, but now coming from Source B instead of Source A. Thus, this clean IP-based video switch is essentially identical to an SDI Router clean switch.

The use of PTP, complete programmatic control of both edge devices, and a high-performance / low-latency, non-blocking SDN controlled COTS Ethernet switch are the tools that allow IT equipment to be used effectively in the broadcast environment.

The major advantage is obvious: Source Timed Switching does not consume double bandwidth.

To guarantee 100% reliability, the IP switching network needs to be fully orchestrated by a broadcast control system to avoid any oversubscription that could result in packet loss for real-time streams. If the same IP Network is also used for Office-LAN purposes, then the controller must clearly separate ports and flows used for Office- LAN purposes from those used for Broadcast purposes. This prevents any unintended consequences such as an administrators' Windows laptop interfering with a Broadcast flow. However, most major television IP Network/Router installations are likely to dedicate the infrastructure exclusively for Broadcast use initially, perhaps having one or more interconnections to the Office-LAN environment with limited, secured access.



All devices change by themselves automatically at 12:00

Illustration 2 – Source Timed Switching: Source B Active

Does that mean we lose the benefits of sharing all-IP Infrastructure between Broadcast and other applications?
No, the flexibility of scaling with SDN orchestration and sharing one IP Packet switching network is still completely viable.

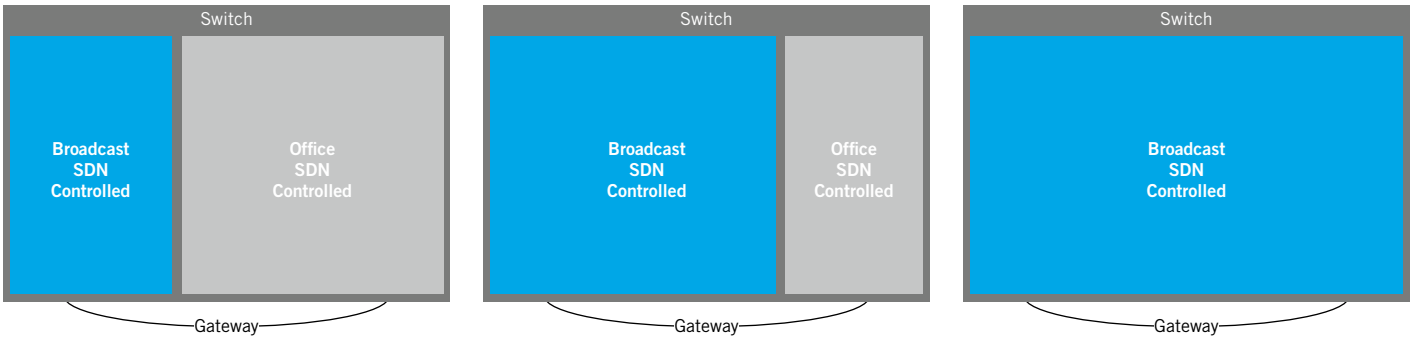


Illustration 3 – Switch Configuration with Gateway

Fully orchestrated control means the network can be configured to separate ports and capacity between broadcast SDN and office SDN. As stated above, it's likely that infrastructure will initially be dedicated to Broadcast SDN to simplify migration and operations.

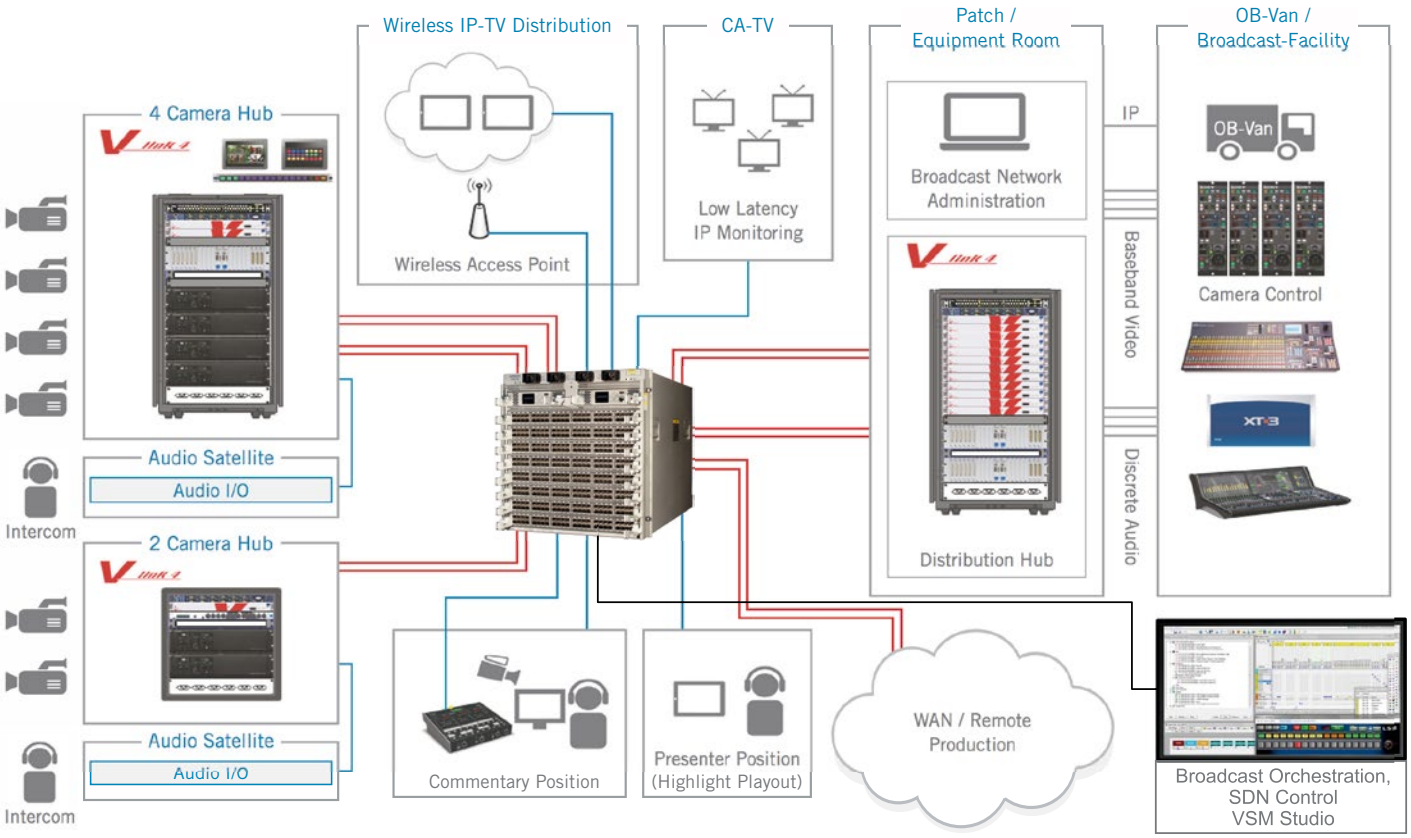
But it is of paramount importance that any TV Broadcast implementation of a COTS IP "Data Center" network needs to deliver the same robustness and stability as decades of legacy SDI and MADI router operations.

The transition from SDI routing to IP infrastructure in professional television will take several years, but it is anticipated that all major television facilities requiring new and larger switching capabilities will select the COTS IP "Data Center" networking approach. However, legacy SDI Routers and new IP infrastructure will live side by side for a number of years during a coordinated migration to full IP Video Routing with Software Defined Networking. Tally Management, Scheduling, Tie-line Management are some of the topics to be addressed early on in this important migration.

During this transition, a smooth operational integration between the old and the new must be accomplished in a way to avoid burdening the production teams. The production staff should not see any material difference in operations whether a particular project's signals are SDI-based or IP-centric, assuring the ability to efficiently process and seamlessly route old SDI video streams as well as new IP-based signals, including shuffling audio, time-code, adding Metadata etc.

The illustration on the right shows a typical but simplified Video-over-IP Network at a TV Network Studio Facility utilizing an Arista IP "Data Center" network. The "Foot Print" of a single chassis switch in just 11RU can provide up to 1152 ports at 10GbE each (1152x1152 port router, with each port able to carry multiple streams). Lawo Encapsulators, Edge Processors and Gateways, compliant with all requirements of SMPTE 2022, VST, AES67, provide the interfaces between the IP world and the Edge "hands-on" video and audio facilities, controlled by the Lawo SDN module in concert with the Studio Orchestrator VSM Studio.

Various types of productions are built on Software Controlled environments. Once everything is "virtualized" and orchestrated by a Studio Control system, the TV Studio/ Facility can be operated very efficiently. To reconfigure the studio (the IP Network and Edge Devices) from delivering sporting content to an Entertainment show, the Studio Control System simply loads a new SDN configuration to support the desired workflow and video



routing. With the inherent flexibility of Ethernet cabling, the re-configuration can be done within minutes.

Remote Production to save cost is also enhanced. The IP connection from the facility infrastructure to a remote studio, with intelligent integration of Control & orchestration, makes it possible to save time, personnel and travel costs, and can ultimately deliver a higher quality program through the use of tools available from a broadcaster's primary larger-scale facility.

The Reasons why IP Routing is essential

- **Future Proof** – Enterprise-level IP Networking is much more scalable in terms of ports, bandwidth and geographical reach, vastly exceeding any traditional SDI router architectures.

- **Flexible and Responsive** – Software Defined Networking (SDN) orchestration and control provides exceptional flexibility and speed to (re) configuring the IP infrastructure for any special workflow and delivery requirements, whether temporary or longer term.

- **Legacy SDI Routers are not compatible with new formats such as 4K.** New television facilities and network operations centers, requiring full 4K-UHD/ DCI capabilities, greatly benefit from a Video-over-IP architecture that can support new and emerging formats without any hardware changes.

- **CAPEX and OPEX Savings** – IP networks and appliances with 10GbE and 40GbE capabilities cost significantly less than comparable SDI router designs, due to the capacity of high-speed Ethernet and the very large market demand for these products… offering COTS (Commercially Off-The-Shelf) pricing. This delivers a much higher level of performance, more capabilities, and much more flexibility than traditional SDI routers for a given investment in a medium-to-large sized television or broadcast facility. Today's Enterprise-level IP infrastructure also delivers the benefit of advanced telemetry, monitoring and maintenance working in concert with Lawo's SDN performance monitoring, contributing to high reliability and significant operational cost savings.

- **Large Savings in equipment footprint** – a traditional 1152x1152 HD-SDI router needs around 40RU while a Lawo/Arista 1152x1152 (10GbE) IP "Data Center" Router only requires 11RU.

- **The Single "Port/Cable" Advantage** – A single port on an IP network can carry multiple media streams. A 10GbE port has the capacity to concurrently carry six (6) 1.5Gbps HD-SDI channels (6x 1.5 = 9Gbps) and is bi-directional, while a single port on a traditional HD-SDI router can only carry ONE, either as Input OR Output. A 40GbE port could carry multiple uncompressed 4K-UHD channels.

- **Future Cloud-based services** – Use of Cloud computing, now or in the future, requires IP connectivity, enabling adding or removing resources and capacity through Lawo's Software Defined Network controller.

Conclusion: An Essential and Timely Migration

The migration of the Broadcast world to IP infrastructure is definitely under way as evidenced by early adoption in some very large and influential television facilities already using IP Network architectures.

The establishment of IP Video Routers and IP Networks in television over the next several years requires substantial efforts by Broadcasters and broadcast equipment suppliers, similar to the efforts we saw in the transformation from analog to digital television which took over a decade to be fully realized. This new paradigm shift merges the disciplines of Broadcast and IT, which requires cross-functional skills and knowledge that is sure to keep the industry busy for years to come.

The move away from proprietary and bespoke broadcast technology will eventually change the approach for many types of productions, creating new workflows which are difficult to envision today. But the migration from SDI Baseband to IP Video Routing/Networking is ESSENTIAL and TIMELY.

About Lawo

Lawo designs and manufactures pioneering audio and video technology for TV and radio broadcast production, post-production, as well as live performance and theatrical applications. Products include digital audio mixing consoles, routers, video processing tools as well as IP-based video and audio transport solutions. All products are developed and manufactured according to highest quality standards at the company's headquarters in the Rhine valley town of Rastatt, Germany. For additional information, please visit the company online at www.lawo.com.

About Arista Networks

Arista Networks was founded to deliver software-driven cloud networking solutions for large data center and computing environments. Arista's award-winning 10/40/100GbE switches redefine scalability, robustness, and price-performance, with over 3,000 customers and more than three million cloud networking ports deployed worldwide. At the core of Arista's platform is EOS, an advanced network operating system. Arista Networks products are available worldwide through distribution partners, systems integrators and resellers. Additional information and resources can be found at www.arista.com.

About L-S-B

L-S-B Broadcast Technologies GmbH, Wiesbaden (Germany), is the leading manufacturer of control systems for radio and television production. The company's core product is the IP-based Virtual Studio Manager (VSM), a universal control system. As a single-source solution, VSM works independently of any single manufacturer and thus represents a flexible and powerful answer to technical challenges in the fields of production and broadcasting. Founded in 2003, L-S-B Broadcast Technologies can draw on an excellent worldwide sales network. A staff of 35 at Head Office in Wiesbaden is responsible for management, project implementation, services and software and hardware development. Further information can be found at www.l-s-b.de .

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