Prospects for Software Defined Networking and Network Function Virtualization in Media and Broadcast

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Written for presentation at the
SMPTE 2015 Annual Technical Conference & Exhibition

Abstract Software Defined Networking (SDN) and Network Function Virtualization (NFV) provide an alluring vision of how to transform broadcast, contribution and content distribution networks. In our laboratory we assembled a multi-vendor, multi-layer media network environment that used SDN controllers and NFV-based applications to schedule, coordinate, and control media flows across broadcast and contribution network infrastructure.

This paper will share our experiences of investigating, designing and experimenting in order to build the next generation broadcast and contribution network. We will describe our experience of dynamic workflow automation of high-bandwidth broadcast and media services across multi-layered optical network environment using SDN-based technologies for programmatic forwarding plane control and orchestration of key network functions hosted on virtual machines. Finally, we will outline the prospects for the future of how packet and optical technologies might continue to scale to support the transport of increasingly growing broadcast media.

Keywords Software Defined Networks, Network Function Virtualization, Ethernet, Broadcast, Contribution, Optical Switching.

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1. Introduction

The broadcast industry is in a time of significant change which is impacting the way we design, deploy and operate broadcast and contribution network infrastructure.

As the number of consumer media consumption devices continues to increase exponentially, whether to watch live television or on-demand content, the pressure on the broadcast network operator to deliver fast, secure, and reliable connective capacity across the contribution and distribution infrastructure increases.

Although the contribution and distribution network share common technology requirements, distinct objectives must still be defined. Contribution networks need to support seamless, resilient, uncompressed and real-time transmission of multi-format production content. Distribution networks must also scale, but to support a wide variety of low bit-rate streams, as consumer electronics manufacturers push 4K Smart TVs into the home, and sell High Dynamic Range-equipped TVs, creating consumer demand for Ultra High Definition (UHD) content to view on Internet connected TVs.

![Graph showing UHD TV shipments from 2013 to 2017](image)

**Figure 1: UHD Shipments from DIGITIMES Research 2014**

“The primary problem we have is that our customer traffic continues to grow exponentially and the revenue we receive to carry the traffic is not growing at the same rate” (*Principal Member of the Technical Staff, Verizon*).

This paper provides a view into the British Telecom’s media and broadcast, contribution and distribution laboratory efforts. We outline how the technology and economics of “Software Defined Networking” and “Network Functions Virtualization”, both buzzwords of broadcast shows and conferences, are already impacting the way we consider requirements, design and deploy network infrastructure. We conclude with our future research objectives for continued development of media and broadcast network infrastructure.
2. Media & Broadcast Goals, Stakeholders and Infrastructure

The reader of this paper is no doubt familiar with broadcast, contribution and distribution network types. This paper may interchange the terms occasionally as key infrastructure components are shared across multiple network types.

As British Telecom operates multiple network types, we are subject to a variety of market forces that we must balance. These may be categorized into the stakeholders (i.e., producers, broadcasters, content and distribution operators, and consumers). These perspectives and requirements are sometimes shared, where unique to a specific stakeholder we will endeavor to underline the fact.

This paper will refer to network and infrastructure, i.e., the hardware and software resources enabling network connectivity, communication, operations and management of broadcast services. Deployment scenarios include in-facility (studios, production sites and broadcast plants) and Wide-Area Networks interconnecting media locations.

2.1 Leveraging an Economy of (Network) Scale

Broadcasters are challenged with increasing capacity demand, reducing service setup times and competitive pressures. The need for innovation is focused on finding more cost efficient ways of moving high volumes of data, and in particular the need to address the current dependence on expensive, dedicated hardware and processors.

“The biggest problem is that we’re so used to using legacy equipment, where you’ve got dedicated equipment that do very specific functions” (Senior R&D Engineer at BBC Research & Development).

A leading organization in this search for solutions based on cheaper, generic Ethernet and IT hardware has been British Telecom, working independently initially but then with a growing group of other operators from around the world.

“I had various discussions with colleagues going back over many years about the potential for generic processors to shift packets and got into various discussions as to what sort of packets; you know packet performance was obviously the main parameter of interest. We then got into more detailed discussion with Intel [about five] years ago and initiated a study for them which they grew into a wider set of partners” (Chief Data Networks Strategist, British Telecom).

The development of these exploratory collaborations between operators and vendors was a significant precursor to the current move towards commodity-based Ethernet switching. In these early stages the main focus was on finding innovative ways to use cheaper, generic Ethernet hardware using a centralized controller as an alternative to the more costly dedicated network hardware, running proprietary chips and proprietary software. These current provisions were costly in part because the vendors could lock-in operators through the lack of interoperability of their hardware and software solutions with others on the market.

“It’s about reducing, well, the direct hour costs, if you are buying normal standard switches and servers it’s much cheaper than buying expensive dedicated boxes. One of the things that organizations like mine really hate is; you’re always talking about vendor lock-in, you don’t want to be caught by a single vendor” (Head of Technology Exploration, Telefonica).
This lock-in effect is a legacy of the layering that evolved since privatizations took place and the vendors took an increasingly important role in R&D. The rapid improvements in generic switching and processors and their proven, cost effective use in large data centers makes them an attractive alternative, provided that their performance is satisfactory.

“Thanks to Moore’s Law with respect to processor speed, and power and storage costs coming down, being able to take advantage of that, which you can do much more in a data centre environment.” (Principal Member of the Technical Staff, Verizon).

If infrastructure begin to look more like data centers, with commodity hardware managing the networks in place of distributed, specialist hardware, the costs of operating such networks will tumble as they have done with Cloud platforms.

Although the focus appears to be on commissioning of new hardware, the rapid obsolescence of existing specialist hardware is another important issue:

“[It’s] as much about decommissioning as commissioning savings. We [currently] simply leave equipment at customer sites, it’s cheaper than collecting and disposing” (Chief Network Services Architect, British Telecom).

With commodity-based Ethernet and virtualized functions the full-life cost of hardware drops significantly, and costs savings may be passed onto the content consumer.

### 2.2 Ensuring Infrastructure Flexibility

In addition to hardware cost considerations, there are long term broadcast service implications that the new approaches must allow. As well as shifting the primary technological core of network infrastructures, there must be a shift towards the use of software-based network functions, in place of hardware reliant functions.

“Since it is software only, the composition or decomposition of functions allows us to be more flexible in responding to the market place” (Distinguished Network Architect, AT&T).

The importance of deployment speed is emphasized within BT, an important internal driver for change by providing a clear indication of just how much faster and more responsive they want services to be:

“One of the tag lines we’ve used was ‘from 90 days to 90 seconds’ that our lead time to deploy a box to wherever in the world the customer premises happens to be” (Chief Data Networks Strategist, British Telecom).

In addition to this aspect of flexibility, we also see real benefits to both operators and customers of being able to delay purchasing decisions.

“There’s a real option which is being able to defer a decision on what you deployed because the hardware is exactly as you say, generic, so you’ve not committed to the particular functionality at the time you deployed the hardware” (Chief Data Networks Strategist, British Telecom).

We will have the ability to select and install “applications” (software-based network functions) at the time and place they are most needed, without having to try and predict what might be needed ahead of time. In addition functionality can be scaled up, scaled down or repurposed in
the event of changing demand without the need to redeploy engineers into the field, or incur both the economic and environmental cost of hardware removal.

The long term flexibility goals stated include a desire to create a true software infrastructure for broadcast networks, both wide-area and in-facility. The separation of hardware and software supply chains eliminates the de-facto lock-in associated with proprietary hardware, and at the same time it creates a potentially much more capable and competitive software-based broadcast network. It will encourage new entrants and start-ups to enter the marketplace with innovative products tailored to the needs of broadcasters but with their roots firmly in the IT and data services industries.

“[SDN], is a disruptive technology, and it requires new switches and a new way of working, and there are issues around bringing all the different application interfaces, software and hardware vendors together, to have a completely functioning system that replaces the original network.” (Senior R&D Engineer at BBC Research & Development)

Therefore we anticipate a shift in the skillsets required to design, develop, operate broadcast networks away from highly skilled broadcast specialists to more broadly skilled personnel with background in software engineering and information technology disciplines. This will include a greater emphasis on automation and a shift to the development and operations (DevOps) model.
3. Media and Broadcast Network Requirements

Multiple use cases exist depending on the type and scale of media and broadcast application, each with a specific set of requirements and capabilities depending on the type of media network. We may summarize core requirements across most use cases:

- Aggregation of multiple flows and formats across studio infrastructure
- Broadcast industry native interface support
- High-bandwidth connections

Each broadcast or contribution flows have their own formats, underpinned with the use of Serial Digital Interfaces (SDI). There is Standard Definition (SD), High Definition (HD), and Ultra High Definition (UltraHD, also known as 4K). Each of these formats is typically based on a well-defined protocol based on published standards. HD-SDI can be multiple format streams, i.e., 1080p, 1080i or 720p. The format type specifies vertical and horizontal resolution, aspect ratio, pixel aspect ratio, scanning and frame rate of the content.

The increasing use of 4K as UltraHD translates into a considerable increase in bandwidth consumption. As the trend to continue with yet further growth in frame rates, color depth, and number and quality of sound channels, only compounds the need to provide scalable high-capacity bit-rate services.

Additional application requirements are outlined in the following sub-sections.

3.1 Content Capture and Encoding

In some situations SDI must be encoded to a broad spectrum of formats for live or production content. One of the primary considerations with respect to selecting a format is its intended use or delivery platform. Once content is captured it may be encoded and forwarded across the network via a router, production switcher, or directly to a production server. Typically, this decision is handled by a Media Manager. In some cases the higher resolution content may use multiple outputs at the camera and need to be recompiled and synchronized at the router, production switcher, and encoder.

3.2 Content Transport

In addition to encoding, media will be ingested directly from other sources as files or flows and as mentioned may require encoding to traverse IP infrastructure. There are a number of well-defined standards and protocols allow media to be encapsulated and transported across network infrastructure, including:

- SD-SDI – SMPTE 259M
- HD-SDI – SMPTE 292M
- ETSI – ASI- TR 101 891
- MPEG2 – ISO/IEC 13818
- MPEGTS – ISO/IEC 13818-1
- MPEG4 – ISO/IEC 14496
- MPEG4 H.264 – ISO/IEC 14496-10
• JPEG2000 – ISO/IEC 15444-12

3.3 Bandwidth, Compute & Storage

Studio environments typical contain nodes with HD-SDI interfaces and 10Gb/s network cards, allowing for receive, transmit, encode and decode services, with centralized management.

Multicast may be used to distribute UHD (4K) compressed video at 2160p 59.94fps, using H.264 encoding this would require between 800Mb/s to 1.2Gb/s per service.

Demands by content consumers for increased video resolution, frame rate, color depth & sound channels, all add to bandwidth consumption for services. As indicated by the British Broadcasting Corporation (BBC), contribution network uses are requesting a move to near lossless or uncompressed video streams, these equate to:

- HD 1080p 8bit 4:2:2 50fps uncompressed bit rate @ 3Gb/s
- 4K UHD 2160p 12bit 4:2:2 50fps uncompressed bit rate @ 10Gb/s
- 8K SHV 4320p 12bit 4:2:2 50fps uncompressed bit rate @ 48Gb/s

3.4 Studio Media IP Evolution

Our ultimate objective is to facilitate end-to-end IP media production. This would require a mass migration from dedicated synchronous interfaces to generic IP networks. The rationale for migration to an all IP network, running over a high-capacity optical infrastructure, is compelling:

- Leverage the flexibility and operational experience of IP networks
- Deliver video, audio and data from a variety of sources and formats over IP infrastructure, low latency, and minimal jitter
- Efficiently utilize network resources, resource sharing where applicable
- Elastic control of the network, setting up and tearing down occasional-use services, links for optimal cost-effectiveness

If the studio production is live or recorded, it may have a slightly varying set of requirements. Typically content encoding and format decisions have already been made. When media is delivered from the field as SDI, it arrives in the facility and is encoded to a file in the house format and bitrate. If it’s an IP stream it will be encoded in the field, streamed to the broadcast centre, and captured to a file as it’s received.

During production workflow, media files may need to be accessible to various production applications and processes and possibly need to move between storage locations. Normally the applications (hardware or software) for production workflow are dedicated and/or fixed, and may only be used part-time. If functions were entirely software based and could be efficiently deployed in a “just in time” manner and scaled accordingly, it would provide significant cost savings and flexibility. However, different layers of automation to manage these applications and processes, with the capability to handle the file movement would also be required.

3.4.1 Linear Contribution and Content Transport

Our initial use cases for the lab were based on a linear contribution service, a typical requirement for broadcast networks. This type of service has the following key requirements:

- Automation: request, setup, teardown of the end-to-end service
• Initial support for HD and 4K contributions, but capable of scaling up to 8K
• Integrate encoding functions, scale-out storage, durability, adaptive performance, self-healing capabilities
• Supports high frame rates and other developing formats that exceed client expectations and requirements

The media flows are expected to be IP-based and support both live, linear TV programs and transport of media content files for production.

Today’s commercially available broadcast video contribution links are typically based on data connections via Ethernet or SDH, with variable data rates up to 200Mb/s compressed, or 3Gb/s uncompressed. We therefore designed our infrastructure to support anything from a few 100Mb/s to 10Gb/s, based on a control architecture capable of evolving beyond 100Gb/s.
4. Applied SDN and NFV for Converged Architecture

Current networks consist of switches and routers using traditional distributed control planes and a data plane technologies. Ensuring network efficiency is limited in such networks as intelligence is distributed across many switches or routers and often involves complex protocols and procedures. By contrast, in an SDN network, with or without OpenFlow, we tend to use a centralized control plane (or Controller). This entity is directly responsible for establishing the paths or flows directly, and the data planes perform simple packet matches, forwarding, replication or dropping actions.

A Controller, per domain (administrative or technology) discovers, organizes and layers multiple services across infrastructure. Programmable control facilitates network behavior to be implemented and modified quickly and cohesively: automation techniques may be used to set up end-to-end services, with flexibility beyond the initial deployment, and with the capability to modify paths and network function nodes to be modified (torn down, resized, relocated) at any time particularly in response to rapid changes in the operational environment. This includes revised network conditions, fluctuations in the resource location or availability, and in the event of partial or catastrophic failure.

The advent of NFV is used to leverage Information Technology (IT) virtualization techniques to migrate entire classes of network functions typically hosted on proprietary hardware onto virtual platforms based on general compute and storage servers. Each virtual function node is known as a Virtualized Network Function (VNF), which may run on a single or set of Virtual Machines (VMs), instead of having custom hardware appliances for the proposed network function.

Furthermore, this virtualization allows multiple isolated VNFs or unused resources to be allocated to other VNF-based applications during weekdays and business hours, facilitating overall IT capacity to be shared by all content delivery components, or even other network function appliances. Industry, via the European Telecommunications Standards Institute (ETSI), has defined a suitable architectural framework, and has also documented a number resiliency requirements and specific objectives for virtualized media infrastructures.

Utilizing the benefits of enabling technologies, i.e. SDN control principles and NFV-based infrastructure, we have the potential to fundamentally change the way we build, deploy and control broadcast services built on top of flexible optical networks allowing dynamic and elastic delivery and high-bandwidth broadcast and media resources.
5. British Telecom Media and Broadcast Laboratory

BT has built a research laboratory to explore the potential impact of SDN & NFV on networks required to carry high bandwidth broadcast video traffic. The lay-out is depicted in the figure below which shows our intentions to do research on the various aspects of building end-to-end video contribution networks. Video creation at HD and UHD rates produces multi-Gb/s SDI formats that require (optional) compression and conversion into Ethernet before progressing into the network. From here we have the options of using labelled or white-box switches, both effectively setting up high bandwidth Ethernet circuits across a core network. There is also an option to include IP routers in the network – used to handle compressed video flows with lower bandwidths.

Traditional Network Management System (NMS) platforms lack the flexibility to fully enable our test infrastructure so we needed to look towards the architecture and principles defined by the Software Defined Networking (SDN) architecture developed and ratified by the Open Networking Foundation (ONF). These core SDN architectural principles offer a variety of possibilities when looking to plan, control, and manage flexible network resources both centrally and dynamically. Solutions exist that encompass direct control of switching resources from a central orchestrator, distributed control through a set of controllers, or devolved control through a hybrid with an active control plane.

The advent of Network Functions Virtualization (NFV) has also provided the ability to deploy network functions on virtualized infrastructure hosted on commodity hardware, decoupling dedicated network function from proprietary hardware infrastructure. Consequently this allows network function to be instantiated from a common resource pool and to exploit performance predictability where dimensioning remains stable whatever the use of virtualized hardware resources. Emboldened with the suitable control and orchestration tools, these virtual and on-demand capabilities could have a significant impact on how broadcast infrastructure is managed.

The optical cloud comprises a combination of optical switches, amplifiers and fiber. The switches here are Reconfigurable Optical Add-Drop Multiplexers (ROADM) which have at their heart Wavelength Selective Switch (WSS) technology. These route wavelength channels from any input to any output fibre and can be switched in just a few seconds.

Sitting above the hardware are a range of controllers, able to control each of the network elements – for example there is a controller whose job is to interface to the optical cloud. These controllers provide inputs to an orchestrator which has now a centralised view of all the network resources. Applications can take advantage of this SDN-based network orchestration and we have demonstrated a Scheduler application that can request on-demand large bandwidth pipes set up at specific times and durations.

The figure below presents our initial view of this idealised architecture.
One key purpose of the laboratory is to compare proprietary and more open methods to control networks like this. In the extreme case, assuming all the equipment provides OpenFlow means of control, open source software such as Open Daylight may be used to create complex behaviours, interlinking optical and electrical switches from multiple vendors.

The laboratory has had a great deal of use assessing the potential of the various SDN approaches available. It is absolutely essential to try out these concepts in a laboratory, as this is the only way to discover the potential issues involved when trying to do complex network coordination.

5.1 BT M&B Lab Architecture

Typically the purpose of a functional architecture is to decompose a problem space and separate distinct and discrete functions into capabilities so we could identify the components required and the functional interactions between components. We must consider the core requirements that are shared across contribution and distribution networks, as well as the specific capabilities of each environment.

It should be noted:

- An architecture is not a blue-print for implementation
- Each component is an abstract functional unit
- Functions can be realized as separate software blobs on different processors
- Depending on resiliency requirements, functions may be replicated and distributed, or centralized
- A protocol provides a realization of the interaction between two functional components

There have been a few useful attempts to document SDN and NFV network architecture, but very limited research has been published on said technologies for broadcast and media infrastructure.
Therefore:

- Our work has tried to present a blueprint for combining emerging technologies to solve commercial and technology requirements, we embrace SDN and NFV without becoming focused or obsessed with them
- We address a range of broadcast and media network operation and management scenarios
- We encompass (without changing) existing broadcast and media services
- We highlight available existing protocols and components that may be uses for solution development

Our architecture is designed and built around core SDN & NFV capabilities and their subsequent applicability to the broadcast contribution network and media distribution network. An idealized view of this model is presented below:

![Figure 3: BT M&B Layered View](image)

5.1.1 Design Considerations

**Merchant silicon**

A key principle for the lab network was to avoid complex IP switches and routers targeting small-volume, large feature sets, and high reliability. We identified general-purpose commodity off-the-shelf Ethernet platforms with merchant silicon switching ASICs.

**Centralised Control**

Control and management becomes substantially complex and expensive with distributed control planes. Existing routing and management protocols were not well-suited to our initial designs.

**Reduce Network Complexity**

Overall, our software architecture more closely resembles control in large-scale storage and compute platforms than traditional networking protocols. Network protocols typically use distributed soft state message exchange, emphasizing local autonomy. We were looking to use the distinguishing characteristics of distributed control planes via a centralized controller.
Optical Transport

The optical transport layer provides the high capacity underlay fabric. The flexible optical network concept is attracting a lot of attention from network infrastructure providers, with the purpose of offering their Infrastructure as a Service (IaaS) to variety of broadcast and contribution consumers.

In the future optical network virtualization technologies might allow the partitioning/aggregation of the network infrastructure into independent virtual resources, where each virtual resource has the same functionality as the physical resource, but it can be apportioned by the broadcast media user. Facilitating users to dynamically request, on a per need basis, a dedicated packet slice for each media interface when required.

Open Application Program Interfaces

An Open Application Program Interfaces (APIs) are important architectural components of our design goal. We need the capability to push or pull configuration or information directly to each layer of the network. This will facilitate applications being capable of interacting directly with the infrastructure itself.

5.2 Functional Components

A short description of each component, its function and the vendor or open source platform tested.

Applications

• Video Service Scheduler

Controller

The Controller is implemented strictly in software and is contained within its own Java Virtual Machine (JVM). As such, it can be deployed on any hardware and operating system platform that supports Java.

• Packet Controller (Open Daylight)

This Open Daylight project is a collaborative open source project hosted by The Linux Foundation. The goal of the project is to accelerate the adoption of SDN and create a solid foundation for NFV-based applications. The platform is an open source project with a modular, pluggable, and flexible SDN controller platform at its core.

Optical Controller

Optical Network Hypervisor is a multi-tenant capable application that creates and exposes abstract representations of the underlying transport network and exports that abstracted network to client SDN controllers. An abstracted network can be exposed as a single node or multiple nodes with abstract links.

From the perspective of the exposed SDN interface the Network Hypervisor acts as one or more (virtual) nodes.

Gateways

• Media Gateways
The media gateway must be capable of encoding and decoding a variety of broadcast formats.

Optical Switching

- Optical ROADM

5.3 Deployment Phases & Capabilities

5.3.1 Phase 1

Design and build out of the Phase 1 architecture started prior to 2013. Testing began in 2014 and by October 2014 we were able to demonstrate automated scheduling, setup and teardown of broadcast services across multi-layer (IP, over Open Flow, over optical)

The initial architecture used Open Daylight 1.0 (Hydrogen) and Open Flow 1.0 interacting with a limited number of whitebox switches.

Major issues were identified at this early stage of development, issues included:

1. Whitebox Software
   Equipment was plagued with incompatibility problems, requiring numerous software upgrades and working around bugs.

2. Resource discovery and inventory management
   The controller of nodes and elements in its domain needs to know about the devices, their capabilities, reachability, etc. Automated discovery of Open Flow switches was limited, and each switch would need to be configured with Controller location. Capability exchange and negotiation was also non-existent.

Limited Open Flow functions (using version 1.0)
We would have preferred to use Open Flow 1.3 but were limited to a version that was supported by the widest number of switches.

**Hardware-based video encoding**

General hardware-based video encoding provide cost and performance benefits but it also meant we needed to select specific sites to place the encoders and add new sites or moving locations meant the equipment also had to move.

**Optical transport layer abstraction**

Due to a limited API, we had minimal control automation between packet and service layers, to the optical transport domain. It then required manual intervention to setup or tear down new optical connections. Abstraction of the optical layer was nothing more representative than a switch.

### 5.3.2 Phase 2

![Figure 5: Phase 2 Architecture](image)

Phase 2 saw a number of upgrades and enhancements to the network, these included:

**Open Daylight Upgrade**

Migration to the “Hydrogen” release of Open Daylight. Hydrogen Virtualization Edition for data centers includes all the components of Base plus functionality for creating and managing Virtual Tenant Networks (VTN) and virtual overlays, key goals for separating different types of broadcast and media content and users. The second release of Open Daylight also provided OpenFlow1.3 protocol library support, and Open vSwitch Database (OVSDB) configuration and management protocol support, a key requirement for commodity switching platforms.

**‘Media Functions Virtualization’**

We also added the product of another vendor: Aperi to our network. Aperi provided reprogrammable FPGA based cards capable of being dynamically transformed to perform different functions. Those included: JPEG 2K encode/decode, uncompressed to IP encapsulation, hitless switching and packet generation and analysis.
Consideration of Service and Network Resiliency
The testing program on the Phase 2 network underlined the need for hitless switching, again a key requirement for media and broadcast services. A large number (but not majority) of critical functional components could either be failed over/switched without interrupting existing services. However, the setup or teardown of services was impacted in the event of single failures of key components (either internal or external to the Controller). Therefore, resiliency continues to be an area of research and challenges for us.

Improvement of Maintenance and Stability of Whitebox Switches
A notably issue we saw was the time it took to load new firmware onto line interface cards. This could vary from a few seconds to several minutes.

5.3.3 Phase 3
A number of capability requirements have been identified as we move into the third phase, these include:

Optical Domain Flexibility
As our investigations and experiments continue we want to ensure the same flexibility that exists in the IP and Ethernet layer is available in the optical transport domain. This is non-trivial problem, if we pursue an open Controller architecture. Paths through an optical network are tricky as we consider non-linearity effects wavelength continuity, paths are often blocked and end-to-end optical connections be optimized in many different ways.

Increased Bandwidth
Bandwidth must continue to increase, but provide the flexibility requirement described previously. We have identified that Elastic Optical Networks (EON) may provide significant bandwidth flexibility by utilizing recent ITU-T flexi-grid (flexible bit rates to beyond 100Gb/s).

Virtual Network Function (VNF) Infrastructure Management (VIM)
Open Stack provides the tools required for managing application, compute and storage. In our lab this will equate to virtual media encoders, caching nodes and file storage. Initial testing has found that Open Stack does not currently meet important SDN & NFV requirements, such as distribution, networking, operational optimization, and data plane optimization. However, OpenStack is still under heavy development in many areas. As the platform matures, we anticipate that more stable and richer in functionality, allowing it to better meet SDN & NFV requirements.

Architecture, Interfaces (API’s) and Models
The following figure utilizes the ETSI NFV Reference Architectural Framework, and demonstrates a proposed converged SDN and NFV candidate architecture for Phase 3 testing. It identifies the functional components and interfaces that were established for both SDN and NFV vendors to develop solutions and ensure interoperability:

1. Os-Ma: an interface to OSS and handles network service lifecycle management and other functions
2. Vn-Nf: represents the execution environment provided by the Vim to a VNF (e.g. a single VNF could have multiple VMs)
3. Nf-Vi: interface to the Vim and used for VM lifecycle management
4. Ve-Vnfm: interface between VNF and Vnfm and handles VNF set-up and tear-down
5. Vi-Ha: an interface between the virtualization layer (e.g. hypervisor for hardware compute servers) and hardware resources

Figure 5: Candidate SDN & NFV Framework based on ETSI NFV ISG Model

5.4 Wider Challenges and Open Questions

5.4.1 Viability of OpenFlow for Optical Networks

We have found OpenFlow to be very efficient for our Ethernet layer but concerns remain for its optical technology viability. A new set of port properties add support for Optical ports was introduced in OpenFlow version 1.4, they include fields to configure and monitor the transmit and receive frequency of a laser, as well as its power. Those new properties can be used to configure and monitor either Ethernet optical ports or optical ports on circuit switches.

There is also motivation to provide additional optical transport extensions to future versions of OpenFlow: “Optical Transport Protocol Extensions”.

5.4.2 Underlay Network Abstraction

Abstracted representation of each server (optical and Ethernet) layer and client layer (IP), is an important goal. We would like to leave each vendor to control their equipment and balance the decades of knowledge about how to manage complex optical parameters, engineering rules and non-linearity effects, whilst providing an open interface for a high-layer application to request a new service, resize an existing service or perform a network wide optimization.

Generating a well-defined and understood information model for multiple forwarding technologies remains an elusive goal. We recognize that different organizations are working toward a solution but we wonder if these models will be consistent with each other.
5.4.3 Role of Standards and Open Source

Our engagement and participation of Standards Development Organizations is limited. It is often a complex and costly affair. Open Source communities are much easier for us to engage with, we have immediate access to software platforms and an active and willing support community. Unfortunately, we also have to build interoperable networks so well defined interfaces, via formal standards, is sometimes a safer option over “de facto standards”.

The larger SDO’s should provide greater opportunities for their standard proposals to be implemented in Open Source and tested by a willing community of users, creating a feedback loop back into the SDO to improve the developing standard.

5.4.4 Integration of Whitebox Switching into Legacy OSS/BSS

Initial excitement for whitebox switching was motivated by a desire for significant capex reductions, thus forcing the consideration of SDN. In a large complex environment like ours, and especially with the interworking of our OSS/BSS layers, we have yet to see viable management platforms for very large number of whitebox switches that would also allow integration with existing OSS and BSS platforms.
6. Findings and Conclusions

Our efforts to design and build broadcast and contribution infrastructure based on the principles on SDN, NFV and related technologies are yielding exciting results. These benefits are manifesting as new service capabilities and flexibility, while reducing costs across multiple layers for the transport of media and broadcast services.

We are able to setup and tear down end-to-end connections, via a centralized controller, significantly faster and with less protocol complexity compared to existing IP/MPLS broadcast and contribution networks. Furthermore, using OpenFlow and commodity Ethernet switches, we have demonstrated rapid video path switching, and ‘clean’ switching by utilizing make-before-break mechanisms.

Emerging optical technologies are providing a compelling answer for exponential bandwidth consumption, but this must not come at any economic cost. Furthermore, current optical networks lack elasticity and operational complexity and costs increase as they scale. We have identified that Elastic Optical Networks (EON) and the flexi-grid (flexible bit rate) technology offers important benefits and capabilities, including wavelength slicing from 100Mb/s up to 200Gb/s, and beyond. Thus our Phase 3 testing will include components of the ITU-T and IETF Flexi-grid forwarding technology and Application-Based Network Operations (ABNO) controller framework and functional components.

Other challenges still remain, as highlighted in section 5.4 “Wider Challenges and Open Questions”. However, we are confident that by close cooperation with industry partners, Open Source communities, and Standards development organizations, solutions will be found.
Acknowledgements

We thank our hardware and software partners for their ongoing support, including: ScheduALL, Nevion, Aperi, ADVA Optical Networking, and Intel Labs.

Special thanks to Telefonica, Verizon, Orange and the BBC who were willing to share their thoughts and ideas with us.

Finally, we would like to acknowledge and thank our University partners and the EPSRC-funded project “Towards Ultimate Convergence of All Networks” (TOUCAN).
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