# Optical Network Services for Ultra High Definition Digital Media Distribution

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D. Simeonidou, D. K. Hunter, M. Ghandour and R. Nejabati
Photonic Networks Laboratory, Department of Computing and Electronic Systems, University of Essex,
Wivenhoe park, Colchester CO4 3SQ, UK
(dsimeo@essex.ac.uk)

**Motivation**

Recent technological developments in the fields of High Definition (HD) video capture and projection devices, high-speed data networks and storage hardware, and advanced digital image compression algorithms, are making HD digital broadcasting, HD on demand video streaming and "Digital Cinema" (D-Cinema or DC) feasible [1]. Large cinema chains worldwide have already opened theatres with digital projection systems, and a substantial growth in the number of digitally enabled screens is expected in the next few years. Much of the effort in deploying this new technology is driven by Digital Cinema Initiatives (DCI) [2], a joint venture of several studios, aiming to establish uniform specifications for digital cinema. The existing DCI framework does not specify the distribution strategies to be used for content delivery from production sites to theatres, which is left to technological development and to the market: the adopted transmission media could be high-speed transmission (fixed, wireless, satellite) or magnetic storage. In Europe, some research projects [3][4] are already are evaluating the use of satellite and WiMAX [5] as possible data distribution technologies. This paper will discuss the advantages and the technical challenges involved in deploying dynamic optical networks to support emerging super and ultra HD media applications.

The rapidly growing requirement for data-intensive digital media transport over large distances [6][7], including point-to-multipoint and multipoint-to-multipoint, has made it clear that this type of traffic cannot be supported by traditional data networking architectures and techniques. At best, these can provide only partial, low quality solutions that will not scale to meet the demands of new high resolution digital media formats (i.e. 4K and 8K DC formats). The data transport requirements for such data-intensive high quality digital media preclude the use of common L3 (layer 3 – i.e. IP or Internet Protocol) techniques for digital media. These requirements define a range of parameters including quality, data volume and scale. Consequently alternative techniques are being investigated.

These techniques require meeting the challenges of multiple issues such as the dynamic allocation of network resources, including light-paths, multicasting, dynamic integration of multiple L1, L2 and L3 operations, edge device addressing, and new mechanisms for network management and control. To address these and related challenges, we have created a new technology test-bed, the High Performance Networked Media Laboratory. The test-bed involves state-of-the-art optical and video technologies (including experimental prototypes) and high speed optical network connectivity to multiple content providers (entertainment, cultural and scientific) in the UK and Europe. The connectivity is provided in the UK through the UKLight network (part of SUPERJanet-5 infrastructure) can be used to interconnect sites at rates up to 10 Gb/s. In turn lightpaths are provisioned to sites in Europe via GEANT2. We are using this test-bed to investigate new methods for streaming digital media, particularly focusing on ultra high resolution media. The types of technologies under consideration include new integrated methods for discovering resources, transporting streams, multicasting and receiving streams using dynamically allocated optical bandwidth, signalling for services, and managing/controlling streams. The ultimate goal is to propose, create and demonstrate a stable version of a dynamic optical service for ultra high resolution media.

**Photonic Technologies for Ultra High Definition Media**

Next generation high-performance multimedia services will include super and ultra high resolution single and MultiView Video (MVV). These formats will be used for both on-demand delivery and live broadcast. MVV, coupled with the technological developments of SHD/UHD media (2K, 4K and 8K), will require data rates that are orders of magnitude higher than today's maximum HD rates. Numerous exciting applications in the fields of education, medicine, security, entertainment, etc. will benefit from these technologies. These applications can be categorized based on their media distribution requirements; i.e. depending on whether the video should be compressed or uncompressed, and whether it is single-view or multi-view. Table 1 below presents the data rates required in several possible cases. In this table, a compression ratio of 20:1 Motion JPEG2000 was assumed, and 16 cameras were used for the evaluation of data rates in MVV cases. However, this number is not fixed; the scene-modelling, real-time processing requirements and the available bandwidth for video transmission determine the variation in the number, type, and placement of cameras.

| | 2K | 4K | 8K |
|---|---|---|---|
| Frame Rate (Fps) | 48 | 24 | 60 |
| Resolution (H×V) | 2048×1080 | 4096×2160 | 7680×4320 |
| Chromatic subsampling | 12bits/colour | 12bits/colour | 12bits/pixel |
| Uncompressed Data rate (Gb/s) | 3.82 | 7.64 | 24 |
| Compressed Data rate (Gb/s) | 0.191 | 0.382 | 1.2 |
| Uncompressed MVV Data rate (Gb/s) | 61.12 | 122.24 | 384 |
| Compressed MVV Data rate (Gb/s) | 3.056 | 6.112 | 19.2 |

**Table 1: Data rates of SHD/UHD media**

From the table, the data rates of UHDM applications may vary from a few hundred Mb/s (in the case of a single compressed SHD video) to a few hundred Gb/s (uncompressed multi-view UHD video), which makes it difficult to use wireless or satellite communications for long distance transmissions while maintaining the QoS required by these applications, especially when more than a single compressed SHD video is transmitted.

The development of high-performance optical networks comprising photonic switching with Generalized Multi-Protocol Label Switching (GMPLS) capability has made ultra high definition digital media distribution possible over optical networks [8]. The optical transmission capacity used to carry the video traffic should be optimized to be as low as possible. Therefore, the optical transmission capacity should be configured dynamically depending on the widely fluctuating demands from such applications. The application capacity requirements may range from dynamic lambda services and optical burst switching to optical TDM and optical packet switching further into the future.

*Lambda-switched services:* These are most suitable for UHD media services that require long-lived high capacity connectivity between a limited number of well known users and data resources. For example, for post-production purposes, uncompressed 4K video streams (7.6 Gb/s) must be transmitted from the film production set to special effects departments at remote locations. Lambda switching will be therefore the technology of choice for this application, guaranteeing that digital streams are securely delivered – from source to destination – with the required QoS.

*Optical Burst Switching (OBS):* Other UHD media applications – such as SHD/UHD video clips – don't require resource reservation for a long period like the post-production case explained above. Instead, by reserving resources only for a specific period, it will be possible to achieve better capacity utilisation and a high degree of statistical multiplexing while also accommodating the bursty nature of such applications in an efficient manner. In order to provide higher utilization of wavelengths and more dynamic operation, OBS can be used on a pre-established optical path from each ingress edge node to each corresponding egress edge node. OBS, incorporating both multicast and restoration, could also be attractive and cost effective solutions for UHD video distribution in medium and long term metro environments.

*Optical Time Division Multiplexing (OTDM):* This may also be an appropriate multiplexing technique for SHD/UHD uncompressed MVV applications (122.24 Gb/s up to 384 Gb/s), because OTDM is intended to creating optical multiplexed streams at speeds significantly in excess of the maximum speed of electronics, typically in the order of >100 Gb/s per wavelength channel. In this application every view (7.6 Gb/s) will be an individual OTDM stream. All video streams must be synchronized. Videos captured from different cameras are used together with timing information in multi-view video. Using WDM to transmit each view on a different lambda will result in differential end-to-end delays and transmission quality between the separate views, so synchronization between the views will be lost and will need to be adjusted at the receiver. In contrast, when using OTDM, all the views are transmitted on the same lightpath, experiencing the same delay and transmission penalties, and therefore maintaining full synchronization between individual streams.

**Protocols and Architectures for Ultra High Definition Media**

Content Delivery Networks (CDNs) represent a potentially important technique for delivering SHD and UHD multimedia worldwide [9]. Presently, they rely on a set of geographically distributed proxies/gateways connected over the Internet. Streaming media is cached in the dedicated proxy servers, which are statically deployed beforehand. These proxies are currently connected in an overlay IP network. The closest proxy server is then used for streaming video, instead of the origin.

For multicast services, these servers presently use L3 multicasting to distribute media to their immediate group of users. This type of multicasting is highly scalable because an arbitrarily large number of users can efficiently share a single channel, however because it is implemented by IP, a L3 protocol, it cannot efficiently or easily support the needs of high-capacity users with stringent QoS requirements [10]. Therefore there will be a need for a more scalable solution that does not only rely on L3 multicast.

By extending multicasting into the optical domain, applications such as broadband video, high-definition TV and multimedia will be carried over high-capacity circuits. For content distribution, it is particularly important that this approach will offer reduced jitter and reduced delay while avoiding (or at least ameliorating) the problems inherent in L3 solutions which exhibit datagram loss. Indeed, a L1 solution implementing multicasting in the physical layer will reduce (or avoid altogether) the need for multimedia traffic to traverse multiple IP routers in datagram format, reducing the equipment cost required to achieve a given level of performance.

Multicasting in wavelength-routed networks has already been extensively studied [11], and these concepts may also be extended to Optical Burst Switching and Optical Time Division Multiplexing. Multicasting avoids the need for duplication of information transmission over any one link, which minimises transceiver usage in the network, and reduces the overall number of wavelengths or timeslots that are required. Employing optical multicasting implies that more receivers than transmitters are employed, due to optimisation of resource requirements.

A combination of L1 and L3 multicasting in a two-level hierarchy will facilitate distribution of compressed SHD/UHD video, with L3 (IP) multicasting only within domains, and L1 (optical) multicasting either within or between domains. As noted above, compressed SHD/UHD video typically requires capacities of hundreds of Mb/s, implying that pure L1 multicasting would not be appropriate because the channel granularity (typically 10 Gb/s or above) is too high. Where uncompressed video flows must be exchanged (i.e. in a post-production environment) data rates of tens of Gb/s are typically required, making pure L1 multicasting a potentially attractive and cost-effective solution. By using L1 multicasting in this way, existing and long-established assumptions about protocol design will be challenged and new protocols will have to be designed and evaluated in order to provide a scalable and cost-effective solution.

The point-to-multipoint nature of multimedia content delivery services require a specific traffic engineering mechanism to meet their QoS requirements, especially in case of SHD/UHD services. Point-to-Multipoint Traffic Engineering (P2MP-TE) based upon GMPLS will dynamically provision traffic engineered P2MP services, so that the required QoS can be guaranteed to:

- Efficiently map P2MP services onto network resources,
- Provide an efficient and scalable way of adding new, and removing existing, destinations to/from active P2MP services,
- Make it possible for P2MP services to recover from network failures within acceptable time limits, and
- Provide a way for P2MP service re-optimization if better paths become available after service setup.

Optical switching nodes with integrated multicast and gain control will be key devices in the implementation of dynamic, all-optical, multicast-capable networks. These will help solve one of the key design problems in optical multicast networks, namely managing the optical power budget. Because optical multicast inherently involves the distribution of the optical power among several client nodes, a power penalty is incurred. Flexible, dynamic power distribution keeps these losses to a minimum, while maximizing network efficiency.

The evolution of the optical switch into a multifunctional optical device will enable numerous novel networking solutions to be deployed that would not have been possible previously. These range from dynamic all-optical networks (WDM and/or OTDM) and optical burst switching to network self-diagnostics and perhaps, further into the future, optical packet switching. Next-generation infrastructures built on these technologies will provide new content distribution services at a significantly lower cost. Because the desired network will be based on optical multicasting, new optical switching architectures, compatible with the multicasting technique used, must be designed in order to achieve the required low levels of jitter and delay, and in order to ensure that the network and its applications are highly cost-effective and scalable.

**Conclusions**

Ultra high performance digital media applications are now creating the need for new network architectures instead of shared IP links to provide them with dedicated, on-demand high capacity. These demands will be more critical in the future, as applications employing a real time environment become more common. Dynamic optical services at lambda and sub-lambda granularities are proposed because they guarantee the appropriate QoS in terms of bandwidth, jitter and latency.

The technologies presented in this paper are merely initial considerations for use when providing the network services under investigation. Initial studies have shown that there is a lot of interest, and there are many advantages, in setting up network services to distribute high-performance media streams via optical networks to one or more locations.

Future research directions will concentrate on two main topics: data plane technologies and control/service plane software. The former will seek to provide optical transport and multicast services using the latest advances in L1 technologies while the latter will provide a higher level of service abstraction, as a basis for interaction with the user, and to allow services to be set up more intuitively.

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