BT SPORT ULTRA HD – EUROPE'S FIRST ULTRA HIGH DEFINITION TELEVISION SPORTS CHANNEL

Andy Beale[1], Simon Jones[2] and Ian Wallace[3]

[1]BT Sport, London, UK. [2]BT TSO, London, UK

ABSTRACT

The increasing availability of Ultra HD displays in the consumer market combined with the acquisition of exclusive European football television rights created the ideal opportunity for BT to launch Europe's first live sports Ultra HD channel; BT Sport Ultra HD.

This ground breaking new channel went live on the 2nd August 2015 and since then has broadcast a wide range of sports, including Premier League and Champions League football, European and domestic rugby, PSA squash, NBA basketball and the world's largest UHD OB to date, the British Moto GP from Silverstone.

The technology for live UHD production was in its infancy when BT started the project. The first productions used separate UHD and HD production units, but as the season developed increasing numbers of cameras have been shared. This paper will describe how new technical approaches and production values have enabled several broadcasts to be delivered using a single Outside Broadcast (OB) truck delivering all the UHD, HD and SD requirements.

This paper also describes the many innovations introduced in the end-to-end ecosystem for the capture and delivery of Ultra HD including contribution networking, playout technology, HEVC encoding, broadband distribution and Set Top Box.

INTRODUCTION

BT launched its IPTV service in 2006 offering a combination of On-Demand video and Digital Terrestrial Television. In 2012 BT TV added multicast delivered channels to the service providing High Definition (HD) Linear TV, over a Fibre-To-The-Cabinet (FTTC) access network, to BT Broadband customers. In June 2012 BT acquired broadcast rights to UK Premier League football and in less than 14 months, on the 1st August 2013, BT Sport went on-air.

On August 2nd 2015 BT launched Europe's first live sports Ultra HD channel, BT Sport Ultra HD. The UHD channel was one of a set of, innovative and award winning, service enhancements that BT developed following the acquisition of the exclusive live broadcast rights to Union of European Football Associations (UEFA) Champions League, and UEFA Europa League football. Since its launch BT Sport Ultra HD has broadcast a wide range of sports, including Premier League and Champions League football, European and domestic

rugby, PSA squash, NBA basketball and the world's largest UHD outside broadcast to date, the British Moto GP from Silverstone.

The combination of the acquisition of exclusive European football television rights, the increasing availability of UHD displays in the consumer market, and the maturity of BT's Fibre-To-The-Cabinet broadband service created the ideal opportunity to develop a UHD channel. BT Sport Ultra HD is only available over BT's FTTC network to BT Customers. This paper will describe the end to end solution with a particular focus on the production of the channel.

BT SPORT UHD END TO END

BT Sport Ultra HD is a next generation television service delivering 3840 x 2160 resolution pictures progressively at 50 frames a second. All live content is produced with 5.1 surround sound. The channel showcases premium sporting events and runs promotional content.

TV Production starts with the OB Unit at the Stadium where the program is produced. The OB Unit creates the 2160p50 UHD video feed that has to be compressed and sent as IP packets, over BT's Media and Broadcast's UK Media Network, to BT Sport production hub at the Queen Elizabeth Olympic Park in London. The encoding takes place in the BT links vehicle and the compressed stream is decoded at BT Sport and converted back into 3G-SDI Quadrants. A local recording of the program and clean feed is made and the live feed presented to the playout centre in White City via Ultra HD facility lines. Playout provides for the integration of the live production with branding, advertising and off-line material, and also plays-out promotional content when no live event is underway. The BT Sport Monitoring Centre (SMC) at the BT Tower was upgraded to include monitoring and control of the UHD channel. The channel is then passed to the BT TV Headend where it is encoded for distribution over BT's FTTC Broadband network to the customers' homes. The channel is decoded in the new BT Youview STB and viewed on a UHD TV.

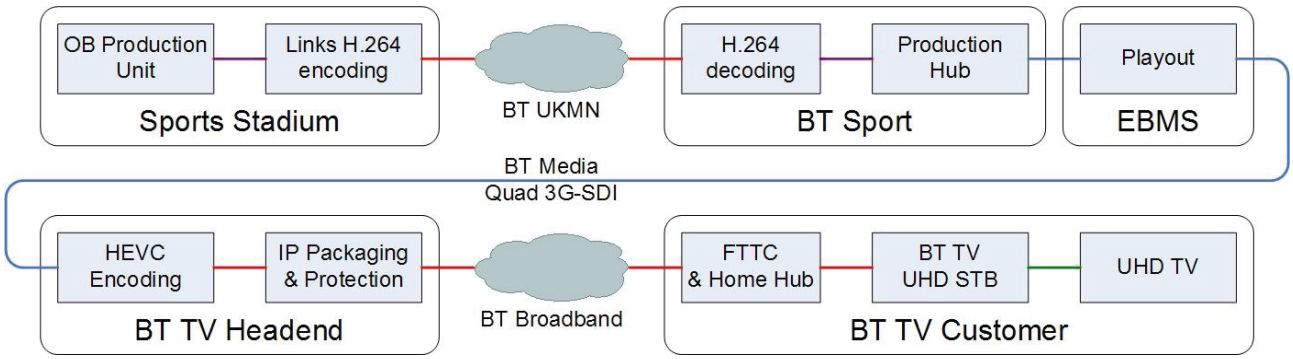


Figure 1 - BT Sport UHD End to End

ULTRA HD INTERFACES AND STANDARDS

Ultra HD equipment was in in infancy when BT began the UHD project and different manufacturers had adopted different techniques for interfacing the 12Gb signal required by 2160p50. A small amount of equipment was using the emerging 12G-SDI standard, which potentially offered cabling and synchronisation benefits, but this was mainly limited to

broadcast peripherals, not key equipment like large switchers, routers and cameras so was ruled out very quickly.

Most were using quadrant based 3G-SDI interconnects. “2 Sample Interleave” (as described in SMPTE-425-5) was not widely implemented at the time the service launched and even now not all 3G-SDI equipment understands the SMPTE-352m payload IDs used with it.

Square Division (SQD) is used to split the UHD image into 4 x 1080p50 signals each carried in its own 3G-SDI (SMPTE 424M) signal. Some manufacturers had implemented support for Level A, others Level B-Dual-Link and a few supported both. BT settled on level A as this was gaining wider support and was the “correct” application of SMPTE 424M.

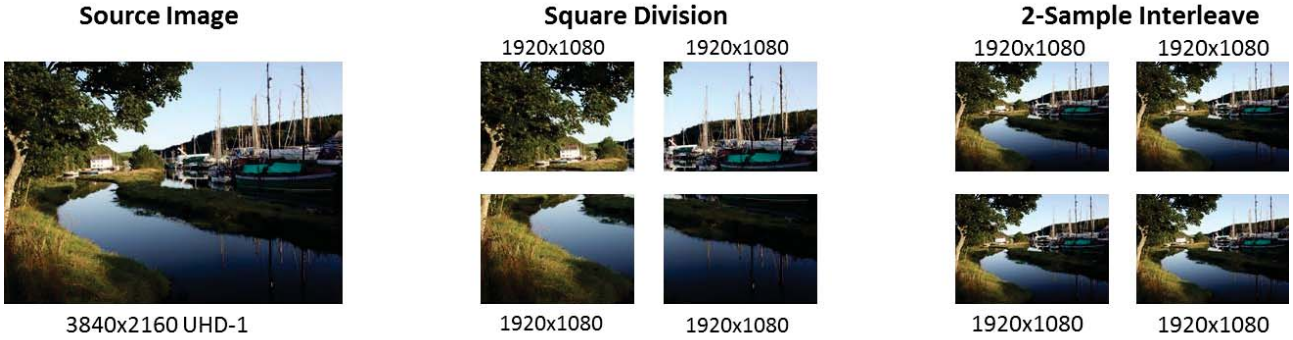


Figure 2 - UHD carriage over Quad 3G-SDI

OUTSIDE BROADCAST

Although some television outside broadcast trucks were already capable of basic Ultra HD operations, none were suited to the high demands of regular sport production and had many short comings.

BT Sport worked with Timeline Television to design and construct the first purpose built Ultra HD truck in the world. It would take advantage of the very latest UHD solutions in the market place and accommodate the specific requirements of UHD production.

Production OB Unit

One of the operating constraints that required consideration was the amount of physical space available within sports venue OB “compounds”. Existing HD productions consume a considerable amount of real estate and securing space for additional vehicles was a challenge. Therefore BT decided to limit the Ultra HD truck footprint to a rigid vehicle.

The production specification simply called for the vehicle to provide the same editorial capability as existing HD trucks. This meant it needed to be capable of adding all the production elements that make up a show including keying graphics sources, multi-camera replays, picture-in-picture resizing and replay wipes. It also needed to be able to handle a number of 3rd party HD sources and create HD feeds.

In the small vehicle footprint, space for equipment to deliver the production specification was limited. A key decision was the vision switcher. The quadrant based demands of Ultra

HD put significant pressure on traditional switcher architecture; powerful multi Mix Effect (ME) mixers being reduced to single ME power with only a couple of keyers being left available.

After careful consideration BT selected the Snell Kahuna switcher; it's unique "Make-ME" concept divorcing the ME tools from routing buses and therefore allowing all of its processing power to be deployed where required. The second major benefit was "format fusion; technology which allows up and down conversion between HD & UHD to be done on the fly. This offered a number of benefits: vastly reducing the amount of external up and down conversion hardware required, saving the number of inputs (4 being required for every UHD source) and preserving the integrity of signals on their respective destinations. This meant that Ultra HD sources that are routed on the UHD output are switched natively and all HD sources unconverted as required. Similarly Ultra HD sources are down-converted on the HD output, but crucially HD sources are passed through in native resolution, not requiring an unnecessary up/down conversion cycle and therefore preserving their quality.

Audio embedding was necessary for contribution through to playout, but traditional embedders are limited to either a single or pair of HD signals. Maintaining the line synchronous timing of all four quadrants through the chain was essential, and introducing multiple parallel embedders to try and achieve this was deemed very risky due the tolerances specified by manufacturers. To solve this Axon developed the U4T140. The U4T140 is a quad input device that line synchronises the four inputs and embeds PCM and Dolby E audio into quadrant 1 whilst adding appropriate delay to quadrants 2, 3 & 4.

Cameras & Lenses

All pre-launch research and testing had been undertaken using the Sony F55 35mm single sensor camera. Whilst this provides a very clean and sharp image the shallower depth of field suited for cinematography was a huge challenge for sports camera operators; tracking fast moving sports players on a field of play whilst retaining focus proving a near impossibility. Sony developed the HDC-4300 in response to this problem, the first 2/3" three sensor Ultra HD camera with B4 lens adapter.

HD lenses with PL / B4 adapters had been deployed with the F55 in testing with a reasonable degree of success. However, the outer 50% of the picture was noticeably softer than the centre, the HD lenses not delivering full UHD resolution across the raster. Cinema lenses offered the superior image quality desired but lacked the operational interfaces and control required for sport production. Fuji developed the UA80x9 and UA22x8 to solve this problem. These 80:1 and 22:1 lenses offer near 95% UHD resolution. The HDC-4300 and Fuji lens combination "feels" like a traditional HD setup to camera operators, smoothing the transition.

Both the cameras and lenses were so new that they were only delivered to BT a matter of days before the first transmission.

Production Values & Development

The OB truck is equipped with 12 HDC-4300 2/3" cameras and 2 35mm F55's. The F55's are used for "camera 1" (the wide angle main camera in football) as well as the stadium beauty shot. This is because the F55 large sensor offers superior noise performance whilst

the shallow depth of field is much less of a problem for wide angle coverage. This not only looks better subjectively (particularly when used with pin sharp UHD graphics) but also improves the performance and picture quality of the compression systems used in contribution and distribution.

One of the biggest operational challenges was camera operators maintaining focus (despite the 2/3" sensor cameras) due to the fact that operators only have 7" HD viewfinders. Tools such as "focus assist" help but extra support is offered in the form of quadrant 1 (top left) being routed back down reverse 3 to the camera operator.

The production monitor stack is equipped with a 55" domestic television for the Program monitor. This is crucial so the director can experience the Ultra HD program in full resolution like the viewer at home and also check focus on the UHD cameras. Testing proved that a slightly defocused UHD picture was not obviously perceptible on a 30" professional UHD screen at >1 meter nor on a 1080p50 down convert.

A pair of UHD graphics engines were supplied to provide all on screen graphics and branding.

Scale of Production

BT Sport Ultra HD launched on the 2nd August at the FA Community Shield. In the 2015/16 season BT broadcast 75 UHD events. During the season new developments have been deployed.

Initial UHD productions were completely separate from HD with side by side camera positions. This is not ideal for a number of reasons. There are limited positions in most stadiums for cameras, HD always occupied the premium locations and it is onerous commercially to double up equipment and human resources. Testing revealed that 18 yard camera positions were scarce so early on the decision was taken to share these camera's; UHD camera's installed but directed by the HD production who had a down-converted feed. This worked well as 18 yard cameras are almost only used for replay.

On lower league football the UHD truck was deployed solo from the start of the season, providing both the UHD and HD coverage with great success, proving that single truck production was viable.

In December, at a Stoke Premier League fixture BT shared camera one with the HD production for the first time. Directed by HD, the predictability of the camera one coverage gave no problems to the UHD production team and ensured the very best position was enjoyed by all BT Sport viewers. The beauty camera was also upgraded and shared.

The British Moto GP at Silverstone on the 30th August was the largest Ultra HD OB in the world to date. Nineteen UHD camera's covered the 4.5 mile circuit including 2 UHD radio cameras. These used Vislink h.265 encoders to pass the UHD video signal over the existing HD RF infrastructure, occupying the same 18Mhz slot as the H.264 HD cameras. The UHD OB also had eight HD external sources in the form of six on-board camera's, host beauty and hele tele. A second UHD gallery was built in a porta cabin to provide presentation switching downstream of the race production.

Shared UHD mini cameras where introduced in autumn, deployed behind the goal in football coverage, in dressing rooms in rugby union and over the nets in the NBA London game at the O2.

UHD graphics analysis was developed for the European rugby clash at bath in December, and live UHD hele tele made its worldwide debut at the champion's league clash between Arsenal and Barcelona in February.

UHD CONTRIBUTION

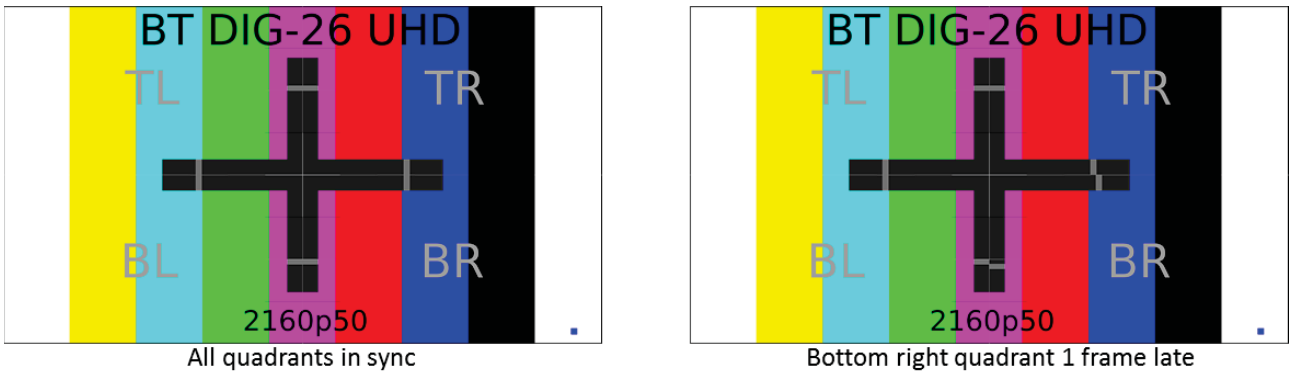
The challenge of moving 12Gbit/s UHD signals between OB venues, Studio, playout and the distribution headend was given to BT's Media and Broadcast division.

Uncompressed 3G-SDI links are utilised in blocks of 4 to get UHD content between BT Sport's studios at Stratford, the playout centre and the BT TV encoding platform at BT Tower.

At OB venues the UHD feed had to fit within the bandwidth of the existing OB contribution network which also had to continue to carry the HD feeds for BT Sport and other broadcasters; as a result compression had to be used. The contribution feed carries video and audio (2 x stereo and 2 x Dolby-E streams).

The compressed delivery is based on synchronised quad h.264 encoding and decoding.

Early demonstrations and trials showed that quadrant synchronisation could be problematic; all of the potential manufacturer solutions exhibited this issue to some extent. Following vendor selection a significant amount of time was spent working with the vendor to ensure quadrant synchronisation was correctly acquired and then maintained. During the early stages of trials a moving test pattern was developed to allow synchronisation of links to be visually checked even when monitored as a small tile on a multi-viewer (Figure 3). Although it was never intended to become a formal line up pattern it is still used as part of the line-up process today.



All quadrants in sync

Bottom right quadrant 1 frame late

Figure 3 - UHD carriage over Quad 3G-SDI

All four quadrants are carried in the same DVB-ASI Multiple Program Transport Stream to ensure that all quadrants are subjected to the same delay over the contribution network. The encoded stream is carried over BT Media & Broadcast's UK Media network as IP multicast flows using SMPTE-2022-1/2.

Another side effect of using separate encoders and decoders for each quadrant of the signal is the risk of different picture quality in each quadrant; in extreme cases the difference in quality can cause the quadrant boundaries to become very easy to see. This is highly dependent on the complexity of the picture content in each quadrant.

A lot of the issues encountered during testing and development were actually 3G-SDI related; UHD was one of the first real use cases for 3G-SDI. Manufacturers understanding and implementations of 3G-SDI interfacing varied; some manufacturers were not even aware of the differences between 3G Level A and 3G Level B dual link and many didn't support both.

Initially, two outside broadcast links vehicles were upgraded to support the delivery of UHD from event locations back to BT Sport's studios. A decision to use Optical interconnect between the production unit and links vehicle was taken very early on in the design process; based on experiences of early field tests. Although Coax can be utilised there was concern that in some scenarios this would end up very close to its distance limits. Using Fibre removed this worry and using a Quad fibre connector means that each UHD vision is still a single connector. The lack of optical interface on the h.264 encoders and decoders creates some interesting disaster recovery scenarios that need to be thought through (you can't just patch out a faulty matrix if its input is optical and the encoder can only take electrical).

BT worked with the manufacturer of the SDI matrix in the links truck to allow UHD feeds to be switched as virtual sources and destinations (*i.e. switch all 4 x 3G-SDI links that make the UHD signal in one operation*), but also allow the individual SDI signals to be switched on their own on when the links vehicle is doing an HD outside broadcast.

Figure 4 - Inside a BT UHD links vehicle

In order to ensure that the field teams could deliver UHD links day in day out as business as usual a lot of effort was put into training and developing of checklists. BT developed and ran its own internal training course. This was a mixture of theoretical and practical. The course was run by a mixture of experts from BT's design team and by the field engineers who had been involved with the testing and development of the solution.

BT SPORT PRODUCTION HUB

Studio

The BT Sport Production Hub was upgraded to cater for the UHD signals that would be passing through on the way to playout. One of the four engineering positions in the Master Control Room (MCR) was equipped with UHD monitoring including a UHD waveform monitor, professional 30" UHD monitor and a 55" UHD television to monitor the off air accurately. A 4 channel XAVC server was installed for line recordings and fast turnaround edits or reruns. Content recorded on the server is streamed to nearline storage for access by edit suites.

Two UHD edit suites were built to cater for the requirement to edit live programs into highlights shows. Based around Adobe Premier these suites were equipped with 30" UHD professional monitors, waveform monitoring and 5.1 sound monitoring.

BT Sport's asset management tools were designed to cater for HD 1080i25 workflows and not suited to supporting UHD media. A new web based asset management tool was

provided to administer the new UHD assets and control ingest, transcode and file delivery workflows. The system was integrated into the existing Hierarchical Storage Management (HSM) system, allowing BT to make use of existing archive infrastructure. New transcode hardware were deployed to support the processing and throughput the of 500Mb XAVC UHD files.

Playout

Broadcast manufacturers had given very little thought to or investment in UHD playout systems. So the choices of equipment available to BT Sports' playout provider were very limited. Consequently the UHD playout infrastructure was designed around production tools. Switching was also done using a live production vision mixer and playback achieved using the same XAVC production server deployed in the OB truck and studios. The automation system required the development of new control protocols and the adoption of new API's.

BT Sport developed a file delivery specification based around the XAVC codec with a side car xml based on the DPP program master specification.

SECONDARY DISTRIBUTION

The produced channel needs to flow from the output of Playout in the BT Sport facility to the BT TV Headend for onward distribution. To ensure the maximum efficiency and quality for the distribution encoding the connection is made uncompressed as four 3G-SDI feeds over a single fire. Two fibre routes are used for resilient operation.

The existing BT TV headend was upgraded by the addition of Elemental Technologies HEVC encoders. The encoder receives the incoming video as quadrants over 3G-SDI, composes this to a full frame, and encodes the video using 3840x2160p50 10-bit HEVC. The use of 10-bit encoding was chosen as, with HEVC, it can achieve better compression ratios than 8-bit encoding and it also reduces the occurrence of colour banding in images. The audio is received over the SDI links using Dolby E and is encoded to provide a Dolby Digital Plus 5.1 stream. The audio and video stream is then multicast using the RTP protocol.

The content protection, stream protection and monitoring of the existing BT TV HD service were re-used for the UHD channel, though extensive validation at the higher bit-rates was carried out.

Once the channel leaves the headend it is carried over the BT Broadband FTTC network to the customers' homes. Reliable delivery is ensured by carrying the multicast traffic in a separate VLAN that is capacity managed to ensure no congestion. Protection against pack-loss, at any point between the Headend and the STB, is provided by the stream protection that implements the DVB Application Layer packet Retransmission DVB (1). The retransmission requests from the STB are monitored and used to provide information on the Quality of Experience of the service.

Customer Equipment

The Customer Premises Equipment for a BT TV UHD customer includes the BT Home Hub and the BT UHD STB. The UHD service uses the existing BT Hub 5 which was validated for correct operation at the UHD Channel's bit rate.

Figure 5: BT TV UHD Customer Equipment

A new UHD STB was developed to decode and securely output the channel to suitable Ultra HD TV set. The STB uses the same form factor and software of the BT TV Youview HD Personal Video Recorder (PVR). It supports UHD content received over IP multicast for Linear TV channels and IP unicast for On-Demand.

The STB is based on a Broadcom UHD System-On-a Chip which provides a multi-core processor, 3D graphics processor and 10-bit HEVC decoder. The STB includes a 1 TB Hard Disk to support the PVR features and a DVB-T2 Terrestrial tuner for access to the UK Freeview SD and HD channels. Connection to the network is via a 1 Gbps Ethernet connection and to the TV via an HDMI 2.0 interface that supports HDCP 2.2 copy protection. The STB supports the Youview [2] interface and the UHD channel appears in the Electronic Programme Guide (EPG) where upcoming event can be seen and recordings scheduled.

END TO END

The successful launch of BT Sport Ultra HD would not have been possible without extensive testing. Multiple test events were carried out to determine impact the on production and outside broadcast. Full end-to-end rehearsals from contribution, via Playout and distribution to STBs were used to ensure that a consistent, high-quality, customer experience could be sustained.

Significant work was needed to ensure all components in the end-to-end production and delivery chain were truly 10-bit, not just on interfaces but 10-bit for internal processing.

CONCLUSION

BT Sport Ultra HD launched on time and has received very positive feedback from customers. In production the technical approaches and values have evolved, from launch where separate UHD and HD production units were used, to the level where several broadcasts have used a single OB truck to deliver all the UHD, HD and SD requirements.

The challenge of moving 12Gbit/s UHD signals between locations was addressed. Square Division was used to split the UHD image into 4 x 1080p50 signals, each carried in its own 3G-SDI signal. These signals were carried as baseband between the Studio and the

Headend and using h.264 compression between the OB Production and the studio. An issue of synchronisation between the quadrants was successfully resolved, assisted by the development of a synchronisation test pattern.

The BT TV Headend with enhanced by the addition of HEVC encoders, all other distribution components are common with the HD service, but were extensively validated at the UHD bit-rate. A new UHD STB was developed to decode and securely output the channel to suitable Ultra HD TV set.

REFERENCES

1. DVB, Digital Video Broadcasting (DVB); Transport of MPEG-2 TS Based DVB Service over IP Based Networks, ETSI, 2016-04.

2. Youview, Youview, [Online]. Available: www.youview.com. [Accessed 10 05 2016].

AUTHOR AND COMPANY INFORMATION

Andy is Chief Engineer for BT Sport, joining the innovative and disruptive British broadcaster at the beginning of its journey in 2012 to oversee the technology and construction of the landmark BT Sport Production Hub in the Queen Elizabeth Olympic Park.

Simon is Chief IPTV Architect for BT, which includes architectural responsibility for BT's Consumer TV service, BT TV, and Wholesale TV services. Simon is actively involved in TV standardisation and represents BT at the DTG (Digital TV Group) and at the DVB (Digital Video Broadcasting)

Ian is the technology architect for BT's Media and Broadcast products.

BT is one of the world's leading communications services companies, serving the needs of customers in the UK and in more than 170 countries worldwide. BT's main activities are the provision of fixed-line services, broadband, mobile and TV products and services as well as networked IT services.

BT Media and Broadcast provides real time video, audio and data transmission solutions for content owners, producers, channel service providers, DTH providers.

BT Sport is a group of sports television channels provided by BT Consumer; a division of BT.