REF2021

Institution: University of Hertfordshire
Unit of Assessment: 12 – Engineering
Title of case study: Broadcast Wi-Fi: Commercialisation of a disruptive video streaming technology that improves audience experience and benefits national broadcasters.
Period when the underpinning research was undertaken: 2008 – 2020
Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Pandelis Kourtessis	Professor of Cognitive Networks	2003 – present
John Senior	Professor of Communication Networks	1998 – present
Matthew Robinson	Postgraduate Research Assistant	2014 – present

Period when the claimed impact occurred: 2015 – 31 December 2020
Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Despite significant advances in mobile and broadband technologies, the broadcasting of uninterrupted, high-quality video content to thousands of smartphone or tablet devices simultaneously is constrained by limited bandwidth, capped data allowances and poor coverage. A decade of research by the Optical Networks Research Group at the University of Hertfordshire (UH) resulted in the commercialisation of a patented video streaming technology, co-developed with world-leading satellite communications provider Global Invacom and the BBC. The Broadcast Wi-Fi service, marketed as Bx-WiFi, has delivered new commercial opportunities to Global Invacom, enabling the company to access more than half a million pounds of R&D funding, sign a licensing agreement with Italy's national broadcaster Rai Radiotelevisione Italiana and pursue a '*significant shift*' in its strategic business direction. Both the BBC and Rai have used Bx-WiFi to offer people an enhanced visitor experience at major arts and culture events that had not previously been possible, and the technology informed the development of new global standards for wireless broadcast services.

2. Underpinning research (indicative maximum 500 words)

The UK Government's Future Telecoms Infrastructure Review in 2018 highlighted the need to 'deliver faster and better mobile broadband services to consumers and businesses, and to enable innovative new services for industry'. Research since 2003 by the Optical Networks Research Group has focused on the design and implementation of novel network architectures capable of processing very high volumes of data with minimal latency in order to unlock the potential of new broadband and 5G services. Led by Kourtessis, the work's overarching aim was to develop new ways to transfer video data more efficiently and dynamically to improve the user experience.

In initial studies, researchers developed novel medium access control (MAC) protocols and algorithms for optical access networks, which allow users to access a common optical fibre communications channel. These MAC protocols delivered a significant increase in transmission bandwidth, providing users with dynamic access to very high data rates and quality of service [**3.1**]. As a key partner of the EU FP7 ACCORDANCE project [**G1**], UH researchers developed new protocols and dynamic bandwidth allocation algorithms to support the successful integration of wireless mobile technologies within a fixed optical communications network, again expanding bandwidth [**3.2**]. Within **G1**, the Group worked with leading universities and telecommunications providers, including Deutsche Telecom and Telefonica, to develop protocols for orthogonal frequency division multiple access passive optical networks (OFDMA-PONs), delivering the highest data rates recorded at the time to optical and fixed and mobile wireless users [**3.3**].

In 2013, responding to industry demand for network technologies that could unlock opportunities afforded by 5G, the Group expanded its laboratory infrastructure to place emphasis on the application of, and further research into, their existing data transfer protocols and algorithms within a software defined networking (SDN) architecture. SDN is a system that moves the intelligence from the underlying network (e.g. routers, switches), into a central system (the

cloud), allowing network-wide decisions to be applied to the infrastructure dynamically, based on a global topology. Using OpenFlow, a protocol that facilitates communication between the SDN controller and the network hardware, the group initially integrated the SDN principles of centralised control into a millimetre-wave radio-over-fibre topology, enabling virtualised 5G service providers to lease and manage network capacity from 5G hardware owners [**3.4, 3.5**], and subsequently flexible cell association within multiple-input and multiple-output (MIMO) Heterogeneous Cooperative Networks [**3.6**].

Kourtessis began collaborating with Global Invacom, a leading satellite communications equipment provider, in 2013. This led to a sponsored PhD and a Knowledge Transfer Partnership (KTP) in 2015 through which the Group explored, for the first time, whether their SDN solutions could facilitate the integration of a satellite TV-based video platform and a terrestrial video broadcast system (mobile broadband or Wi-Fi) [**G2**]. They demonstrated how Wi-Fi, long-term evolution (LTE) and optical networks could be integrated and controlled using an SDN framework, and described how intelligent orchestration can allow multiple competing network services to coexist while sharing the same physical hardware.

A grant from the European Space Agency (ESA) followed, for UH to collaborate with Global Invacom and the BBC to develop a commercial technology that delivers live, high-quality video over a Wi-Fi network to thousands of people simultaneously [**G3**]. This would allow providers to offer a virtual 'big screen' experience at large-scale events (e.g. music or arts festivals) to phones and tablets, without buffering or service charges. The UH group developed the Sat>IP Wi-Fi Hotspot, a device that can transcode video content and add Forward Error Correction (FEC) to video streams before multicasting it out over a wireless network to thousands of mobile devices via a dedicated app. The FEC is added so that any data lost during transmission over the multicast wireless network can be recovered for a high-quality user experience. This resulted in two patents, one for Europe published in 2019 and one for the US published in 2020 [**3.7**].

UH, GIL and the BBC secured ESA follow-on funding [**G4**] to further develop the technology, now called Broadcast Wi-Fi, or Bx-WiFi. Based on the SDN framework, they developed novel SDN applications and algorithms, and integrated SDN functionality into the Wi-Fi access points themselves. This allowed the Bx-WiFi system to self-optimise in real time for any given installation, environment and usage level, based on live feedback.

3. References to the research (indicative maximum of six references)

3.1 Chang C-H, Alvarez NM, Kourtessis P, Lorenzo RM, Senior JM. Full-Service MAC Protocol for Metro-Reach GPONs. Journal of Lightwave Technology. 2010;28(7):1016-1022. https://doi.org/10.1109/JLT.2009.2037342
3.2 Milosavljevic M, Kourtessis P, Senior JM. Multi-wavelength WiMAX-PONs with overlapping cells. Journal of Optical Communications and Networking. 2011;3(2):172-177. https://doi.org/10.1364/JOCN.3.000172
3.3 Lim W, Kourtessis P, Milosavljevic M, Senior JM. Dynamic Subcarrier Allocation for 100 Gbps, 40 km OFDMA-PONs with SLA and CoS. Journal of Lightwave Technology. 2013 Apr 1;31(7):1055-1062. https://doi.org/10.1109/JLT.2013.2242046
3.4 Amate A, Milosavljevic M, Kourtessis P, Robinson M, Senior JM. SDN based millimetre wave radio over fiber (RoF) network. In Broadband Access Communication Tehnologies IX. SPIE. 2015. 938706. (Procs SPIE). https://doi.org/10.1117/12.2077547
3.5 Kourtessis P, Milosavljevic M, Robinson M. Chapter 17: Low Latency, Optical Back-and-Front-hauling for 5G Networks. In Access, Fronthaul and Backhaul Networks for 5G & Beyond. The Institution of Engineering and Technology. 2017. p. 419
3.6 Papazafeiropoulos A, Kourtessis P, Renzo MD, Senior JM, Chatzinotas S. SDN-enabled MIMO Heterogeneous Cooperative Networks with Flexible Cell Association. IEEE Transactions on Wireless Communications. 2019 Apr 1;18(4):2037-2050. 8637958. https://doi.org/10.1109/TWC.2019.2896154
3.7 'Apparatus and method relating to data distribution system for video and/or audio data with a software defined networking (SDN) enabled orchestration function', European Patent (EN

3520326) publication date 07 August 2019 and US Patent (Pub No US2020/0044930 A1), publication date 06 February 2020.

Key underpinning grants
G1 EU FP7: ACCORDANCE (Grant ID 248654); €3,499,148; 2010-13.
G2 Innovate UK Knowledge Transfer Partnership: Digital Distributed Antenna System; University of Hertfordshire and Global Invacom Ltd; £180,000; 2015-18.
G3 European Space Agency ARTES Competitiveness and Growth Programme: SAT>IP WiFi Hotspot; UH, Global Invacom and BBC R&D; £50,000; 2017-18.
G4 European Space Agency ARTES Competitiveness and Growth Programme: SAT>IP WiFi Mobile TV; UH, Global Invacom and BBC R&D; £200,000; 2018-21.

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4. Details of the impact (indicative maximum 750 words)

People can watch live audio-visual content on their mobile devices in public spaces using internet-streaming applications, either over a mobile data connection or via a free Wi-Fi access point. However, there are several drawbacks that Bx-WiFi is designed to address. Users risk exceeding their monthly mobile data allowance, potentially incurring costly bills, and the user experience is typically poor due to limited available bandwidth. Video streaming of content in areas with a high density of users, such as a sporting event or music festival, is often impossible; 43% of mobile users globally have connectivity issues in crowded areas, according to a 2019 report by Ericsson.

Through KTP and ESA funding [**G2**-**G4**], UH researchers worked closely with Global Invacom and the BBC to translate the patented technology from a hardware device into a PC-based software platform, so its functionality could be tailored to each service provider's specific requirements. The Forward Error Correction and multicast streaming technology allows multiple users to receive broadcast quality TV and radio simultaneously, via satellite, without buffering or loss of signal. A key advantage is its ability to enhance the audience experience at large-scale live events. In a sports stadium scenario, close-ups or replays can be delivered to the personal handheld devices of those in the crowd. At music and arts festivals, audiences can access exclusive 'backstage' content via their smartphones or tablets to complement the live experience. Event operators can use the technology to sell new services and develop alternative revenue streams.

Delivering commercial benefits to the satellite communications and broadcasting industries

Global Invacom, which is listed on the Stock Exchange of Singapore and the London Stock Exchange's Alternative Investment Market, has long been known as a satellite equipment provider; it has six manufacturing plants around the world, generates annual revenues of $30m (£22.3m) and has around 2,500 employees. In recent years the company has increasingly turned its attention to the delivery of live audio-visual content to mobile devices in recognition that the size of the global video streaming market is expected to reach $184bn (£136bn) by 2025, according to a 2020 report by US consultancy Grand View Research. Kourtessis introduced GIL to the concept of Software Defined Networking and how, through further research, it could be applied to the development of a video streaming platform by creating a SAT>IP WiFi hotspot and adapting an existing GIL wireless transmitter product. The subsequent development of the Bx-WiFi technology represents a '*significant shift in the strategic direction of Global Invacom's busines*s', according to Global Invacom's business development director [**5.1**]

Through the research collaboration with UH since 2015, Global Invacom has been able to access £556,000 in combined funding from Innovate UK and ESA to bring the technology to market [**5.2**]. This allowed the company to pursue a new R&D direction, drawing on the research expertise of the Optical Networks Research Group. The company said: '*It would have been very difficult to justify the R&D spend internally as fundamental research was required, which we knew wouldn't yield a commercial product for several years. The external funding allowed us to*

keep the R&D investment separate from the company's core resources [**5.1**].' The initial developmental work gave Global Invacom confidence to invest £843,000 of its own budget in progressing the technology [**5.1**]. The development of Bx-WiFi has also enabled the company to form a strong relationship with the BBC.

On August 23, 2017 Global Invacom announced to investors the successful launch of Bx-Wifi at the Edinburgh Festival [**5.2**]; the company's share price rose to a near 18-month high [**5.3**]. Global Invacom described it as a '*breakthrough in streaming technology that is set to redefine video broadcast for large-scale events*', also saying that '*its scalability and flexibility ensure it can be deployed in diverse venues, including coffee shops, stadiums and even aboard aircraft*' [**5.2**]. The BBC saw it as an opportunity '*to offer a virtual big screen experience at an event to people on their existing phones and tablets*'. ESA said the Bx-WiFi project was '*an excellent example of … collaboration between industry and university communities in developing innovative technology and products for satellite communications*' [**5.2**].

After further development and optimisation of the technology, in June 2019 Rai Radiotelevisione italiana (Rai), the Italian national public broadcasting company, commissioned Global Invacom to provide the Bx-WiFi service at the Feast of St John celebrations in Turin [**5.1**]. This resulted in Rai purchasing a perpetual R&D licence for the technology [**5.1**]. In July 2019 the BBC used Bx-WiFi to offer visitors to the SummerTyne Americana Festival in Gateshead access to two streams of exclusive content on their mobile devices [**5.1**, **5.5**]. At this point, Global Invacom prioritised entering the conference, exhibitions and events sector, where dedicated venue content and advertising can be streamed to the mobile devices of visitors/delegates [**5.1**, **5.6**]. The company was in advanced talks with the World Retail Congress in Rome (originally scheduled for April 2020) and had been invited by world-leading production company NEP Group (the Olympics, the Oscars) to showcase Bx-WiFi to its customers in London at the end of March 2020 [**5.1**]. However, the Covid-19 pandemic decimated the events sector and plans were postponed [**5.1**].

Another industry beneficiary is Canada-based Edgewater Wireless Systems, an industry leader in Wi-Fi hardware technology that can support high-density applications. The UH-GIL-BBC research collaboration led to Edgewater being selected in 2019 as a partner in the development of Bx-WiFi. The company said the partnership allowed it '*to push the boundaries of our hardware*', enhancing the capabilities of their technology to '*further drive market demand*' [**5.7**]. The company referenced this agreement as a '*third quarter financial highlight*' in 2019 [**5.7**].

Enabling the BBC and Italy's national broadcaster to enhance the live audience experience

The BBC has benefitted directly from ESA funding, through the UH-GIL collaboration, to co-develop Bx-WiFi; it has received funding as one of the three partners in the ESA-funded projects [**G3**, **G4**], which includes the BBC making its own matching financial contribution [**5.8**]. The BBC believes Bx-WiFi offers new ways of improving the live audience experience, offering a more flexible and personalised alternative to the 'big screen' format and helping set the national broadcaster apart from competitors like Netflix and Amazon [**5.8**].

At the 2017 Edinburgh Festival, the BBC offered Bx-WiFi to the public for the first time. For three evenings, visitors to the Big Blue Tent, the BBC's broadcasting hub for the festival duration, were given access, through a dedicated app, to two content streams, including a special Edinburgh comedy highlights package. They watched the content via the Bx-WiFi network, without encroaching upon their mobile data allowances or experiencing buffering. The BBC said, '*the system worked well across the wide range and number of different devices we saw* [**5.8**].' Several thousand people visited the tent each day [**5.8**]. The Bx-WiFi offering was scaled up in July 2019 for the three-day SummerTyne Americana Festival, a popular annual music festival organised by Sage Gateshead (a music and cultural centre). The Bx-WiFi app, accessed through the dedicated Wi-Fi network 'nomorebufferface', offered two content streams: exclusive footage from SummerTyne Secret Garden Sessions and backstage podcasts [**5.5**]. A BBC

development producer said they were '*really excited to bring Broadcast Wi-Fi to the public*' as it gave them the opportunity to '*enhance live events with extra content*' via '*a virtual screen*' [**5.8**].

The Bx-WiFi development process has prompted the BBC to consider new programming and event ideas [**5.8**]. BBC R&D's lead research engineer said: '*Working on developing the technology has given us the opportunity to propose completely new entertainment ideas that would otherwise be unfeasible, from virtual drive-in movies at festivals, to screenings of premieres in disused cinemas, to pop-up film events on village greens* [**5.8**].' He said the BBC is exploring the use of the technology to provide pre-show mobile content to keep live audiences entertained. The BBC was in advanced talks with an artistic director to use Bx-WiFi at a number of unique live events; the streaming of performances directly to multiple mobile devices would overcome potential licensing and noise pollution barriers. Covid-19 postponed these plans; under the terms of the ESA grant, the BBC was due to use Bx-WiFi at two further large-scale events in Q2 of 2020 [**5.8**].

In June 2019, Rai, working with the Ministry of Economic Development and city authorities, offered the public access to the Bx-WiFi platform during the Feast of St John celebrations, an annual public holiday in Turin [**5.4**]. Live content of the festivities, using 360° cameras in the central city square and on drones, was captured and transmitted through HD 5G technology from the main television transmitter towards the city of Turin. The received signal was then fed through the Bx-WiFi system at the Rai Museum of Radio and Television in order to stream exclusive live content to multiple mobile devices belonging to members of the public attending the festivities. This marked Italy's first mobile TV broadcast over 5G in Italy [**5.1**, **5.4**].

Influencing industry standards for new wireless broadcast technologies

The Institute of Electrical and Electronics Engineers (IEEE) is a leading developer of industry standards for a broad range of technologies. Its Broadcast Services Study Group was set up in 2018 to initiate a new amendment to IEEE 802.11, the global standard that sets the rules for wireless local area networks, in order to improve the user experience through enhanced broadcasting services. The Group requested a presentation from the BBC on Bx-WiFi as part of its goal to significantly reduce the number of access points required to stream audio-visual content (something that Bx-WiFi has succeeded in doing). As a consequence, the capabilities of the Bx-WiFi technology have influenced the ongoing development of the new standards [**5.8**].

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 Corroborating statement from the Chief Technology Officer, Global Invacom Group.
5.2 Groundbreaking New Video Streaming Technology Launched (Global Invacom release): https://globalinvacom.listedcompany.com/newsroom/20170823_072227_QS9_GO510QPVVO4 URAZF.1.pdf
5.3 Graph showing changes to Global Invacom share price over time, demonstrating rise in line with the launch of Bx-WiFi at Edinburgh Festival (via screenshot).
5.4 RAI television news segment (in Italian) demonstrating use of Bx-WiFi at the Feast of Saint John, Turin in June 2019 (available as mp4 file on request). http://www.crit.rai.it/CritPortal/wp-content/uploads/2019/06/SGiov5G_ServizioTG1.mp4
5.5 BBC R&D's BBC SummerTyne App showing use of Bx-WiFi at the SummerTyne Americana Festival, Gateshead, July 2019. https://sagegateshead.com/bbc-summertyne-app
5.6 Bx-WiFi Overview – a client presentation on Global Invacom's Bx-WiFi website: http://www.bx-wifi.com/pdf/Bx-WiFi_Overview_Presentation.pdf
5.7 Investor announcements by Edgewater Wireless Systems, 2019: https://www.businesswire.com/news/home/20190314005246/en/Global-Invacom-Selects-Edgewater-Wireless-for-Bx-WiFi-Partnership; https://financialpost.com/pmn/press-releases-pmn/business-wire-news-releases-pmn/edgewater-wireless-reports-third-quarter-fiscal-2019-financial-results
5.8 Corroborating statement from the Lead Engineer, BBC Research & Development team.