Enhancing Tourist Experiences through 5G –
The 5G Smart Tourism Case Study

Konstantinos Katsaros*, Dimitrios Gkounis*, Dritan Kaleshi*, Ben Thomas†, John Harris†,
Hamid Falaki†, Dimitra Simeonidou†

*Digital Catapult, London, UK
†Department of Electrical & Electronic Engineering
Smart Internet Lab, University of Bristol, Bristol, UK

{ben.thomas, jw.harris, hamid.falaki, dimitra.simeonidou}@bristol.ac.uk
{kostas.katsaros, dimitrios.gkounis, dritan.kaleshi}@digicatapult.org.uk

Abstract—The pioneering 5G Smart Tourism (5GST) project demonstrates how the cultural, heritage and tourism sectors can create interactive immersive experiences in a way never seen before; from an augmented reality tour of the 2000 year old Roman Baths, to 360 degree immersive experiences, and an entirely new way of looking at art, all enabled by 5G. This paper presents the key technical findings from the public trials of several 5GST use cases. These findings explain how Multi-Access Edge Computing (MEC) infrastructure is utilized to run compute workloads closer to the end user, therefore reducing end-to-end latency and thus improving quality of user experience. Finally, this paper discusses how 5G will transform the business models for delivering such 5G-enabled services.

Index Terms—5G, Smart Tourism, AR, VR

I. INTRODUCTION

The advent of 5G will drive new business models, products, services, applications and experiences to market faster. 5G goes further than its predecessors, as not merely a mobile communication technology platform, but a support mechanism for digitisation across the economy and as an innovation enabler. Rather than being simply the next generation of mobile technology, it will transform infrastructure and increase productivity.

The 5G ecosystem is gaining momentum, with first movers deploying commercial services across the world. Particularly in the UK, all four national mobile operators have announced plans for commercial offerings by the end of 2019 in selected locations. Meanwhile, the UK Government through initiatives such as the 5G Testbeds and Trials Programme [1], is aiming to stimulate market development and deployment of 5G technology and infrastructure in the UK and create new opportunities for businesses, developing capability and skills and encouraging inward investment. This has led to the development of several testbeds and trials across the country. In 2018, Digital Catapult identified more than 200 5G-related activities [2], in a highly interconnected ecosystem comprising of academic institutions, private enterprises (big and small) and public sector bodies.

By 2025, there will be 100 billion connections worldwide, between people, things, and organisations; this dense level of connectivity creates new requirements for communication networks. The main transformational powers of 5G are in providing higher capacity, increased reliability, low latency, and security to larger number of connected devices over a common infrastructure. These new possibilities have the potential to greatly improve immersive experiences for media, entertainment, training and other uses. For instance, higher bandwidth will improve display quality and 3D visual experience by increasing data transfers to larger audiences, while lower latency will further enable fully immersive mobile experiences, decreasing dizziness and disorientation.

The pioneering 5G Smart Tourism (5GST) project aims to change how the cultural, heritage and tourism sectors create interactive immersive experiences in a way never seen before by launching a virtual and augmented reality tour of 2000 year old Roman Baths, 360 degree immersive experiences, and an entirely new way of looking at art enabled by 5G. By bringing together small and medium-sized enterprises, universities and local authorities, 5G Smart Tourism represents one of the best examples of UK innovation, resources and expertise. 5G deployment will improve the tourism sector, which is valued at £1.75 billion for West of England region. For the consumer, 5G will give the perception of almost unlimited communications, data and computation services in real time and strengthen the level of immersion. For the tourism sector itself, it will give much better insights of their customers, their characteristics and preferences, creating more engaging visitor experiences.

This paper describes the 5G Smart Tourism use cases which were trialled in the areas of Bristol and Bath using a 5G testbed. In particular, Section II presents the high level network architecture and capabilities of the 5G testbed, Section III describes five use cases developed, deployed and trialled in public during the project, while Section IV discusses the potential business opportunities unlocked by 5G for the tourism sector.

II. TESTBED ARCHITECTURE

The 5G Smart Tourism testbed infrastructure, Figure 1, is an urban testbed covering multiple locations in Bristol and Bath, including the Roman Baths. It is deployed and operated by
the University of Bristol’s Smart Internet Lab\textsuperscript{1}. Furthermore, the testbed has a node in London, which is deployed and operated by Digital Catapult and is inter-connected to the rest infrastructure through the 5G UK Exchange \cite{3}.

The testbed consists of hardware and software components capable to support the needs of the use-cases, with a focus on automating the installation and deployment of these components. The components are integrated under a common orchestration platform which is managing and controlling the access, transport, core and cloud networks by rapidly deploying network resources to support specific use-case’s requirements. One of the many challenges of optimising this platform for the given used cases was the integration of the Graphics Processing Units along with the Compute Resources for the Multi-access Edge Computing (MEC) that enabled remote rendering of high resolution video media.

The use cases of the 5GST project have several cross-cutting requirements from the network. Typically, each use-case in the 5GST project demands a network slice, Internet access, compute and network resources. The 5GST network has a wide deployment of radio access network covering Millennium Square, M-Shed, High Performance Network Lab and The Pump Rooms.

The Smart Internet Lab has also deployed a private cloud system for the use of Smart Tourism use-cases. This cloud offered tenants the ability to slice infrastructure, such as compute and network resources, provide edge computing resources as close to the end-user as possible and automate the manual system deployment and tear-down of tenants. The delivered private cloud solution consists of a split-location data centre of generic white-box compute resources between Bristol and Bath, where tenant use-cases are deployed according to network proximity and suitability.

There remains a requirement for significant hand optimisation of the cloud infrastructure before these solutions are truly cloud-ready. A 5G orchestration platform must realise and understand these intricacies before it can reliably assume control of a wider network. Current solutions fall short of what will be required for such rich, next-generation use-cases.

As a step closer to achieve the aspiration of being able to replicate use cases in different environments, the London node of the 5GST tested at Digital Catapult has been built using software automation principles to replicate the testbed and the deployed use cases in Bristol and Bath.

\section{5GST Use Cases}

This section provides an overview of each use case and its technical aspects, including how the public perceived these experiences. The majority of them focus on delivering novel immersive visitor experiences and one targets at the safety of visitors by delivering an on-demand network slice for emergency services.

\subsection*{A. Mobile AR/VR content}

BBC and Aardman Animations collaborated to create a 5G-enabled experience at Roman Bath’s\textsuperscript{2} utilizing AR/VR content for mobile devices. The collaboration aimed to bring the history of Roman Baths to life, by delivering rich and engaging video-based experiences to users exploring an area of Roman Baths in different ages. This enables visitors to understand the different uses of the baths in different time frames in history, a narrative which the cultural institution had previously lacked. The location is complex and covers several floors, including indoor and outdoor areas. The most iconic area is probably the Great Bath, which can be seen from two different levels and is open air. This use case is split into two distinct phases:

- \textit{Phase 1:} is focused on looking at the Baths through a different lens by showing visitors to the Roman Baths an experience that could only ever be provided by handheld devices. Visitors see the Great Bath at three different points in history and are able to compare the real world in front of them with the virtual view provided by the device. Although the rendered scene is entirely virtual (VR), the image is aligned with the position and orientation of the user in the real environment, providing what is essentially an Augmented Reality (AR) experience as the mobile device provides an overlay on the real world, showing a ‘window’ into the past. This is achieved using pre-rendered 360 video, designed for viewing at a few pre-selected locations within the Great Bath area. The high bandwidth of the 5G network allowed the video to be activated with minimal delay and streamed without stuttering. In the first trial, high-quality 360 video coded at 10Mbit/s was streamed over the network to up to 20 concurrent users, requiring in total about 200Mbit/s. This was delivered by local “edge” deployment of video streaming software application at edge compute nodes of the 5GST network in Bath.

- \textit{Phase 2:} is built on the concept of Phase 1, but a more advanced technological solution is used enabled by mobile edge computing and low latency. The streamed experience included 3D modelled scenes that were rendered in real time on a GPU-equipped edge compute node, using position and orientation data streamed from the handset. NVIDIA's CAPTURE API was used and it was set to encode the video at a rate of 5MBit/s per user. This allowed the users to walk around, with the scene being rendered from their current viewpoint, rather than having to consume the experience from one of the pre-selected fixed locations within the Great Bath as in Phase 1. They could also use a ‘zoom’ function to enlarge a part of the scene whilst retaining full resolution, rather than having the resolution limited by the resolution of a pre-rendered 360 video stream as in Phase 1.

The use case was based on hand-held mobile devices, rather than being a fully immersive headset based experience due to restrictions in the location, hence a round-trip latency of the

\textsuperscript{1}http://www.bristol.ac.uk/engineering/research/smart/

\textsuperscript{2}https://www.bbc.co.uk/rd/blog/2019-04-5g-latency-bandwidth-augmented-reality

478
order of 100ms as perceived by the user (from moving the device to seeing the image move) is acceptable. This delay budget includes the capture pose, network uplink, rendering, video encoding, network delay and decoding. For the network part, a 20ms latency is acceptable. The overall latency achieved in the tests was in the order of 100ms, and no issues were raised by users about any delay or latency.

User experience data was gathered from users of the application (Fig. 2), with 85% positive response rate on the feedback time (delay and latency) on the 5G network. Further, 90% of respondents said they were more likely to visit a museum which had these kinds of augmented reality and virtual reality features. Consequently, this suggests low latency as a capability of 5G to be an important feature for the future of tourism.

B. Streaming synchronous 4K 360 degree video

Synchronised VR-content delivery to groups of users has been developed and field-tested by Mativision using proprietary technology. This allows users to share the same experience at the same time in the same environment, while each one maintains individual interactivity control, i.e. point of view of the 360 video. Mativision’s platform was also used to deliver in-app 360 videos for LandMrk tourist guide of Bristol.

Using existing network infrastructures, Mativision has faced limitations in fully exploiting the technology’s functionality and performance.

The video playback used by Mativision’s interactive player is HTTP Live Streaming (HLS), which allows dynamic adaptation of resolution and bitrate during playback. For streaming 4K 360 degree video, there is an expected 50Mbps user data rate requirement, without lowering the quality of the stream. However, the minimum sustained data rate for 360 degree video shall be at least 15Mbps per user for minimum accepted by users 360 video quality. Such sustained data rates are not consistently achievable with the currently in use technologies such as WiFi and LTE.

To overcome these challenges, the use case has utilized two solutions. First, similarly to the rest 5GST use cases, it utilized edge compute facilities, where a back-end service and content was served by. Then, the “FLAME” platform [4], which was deployed on top of the 5GST testbed, was used for delivering the content, allowing for use of multicast content delivery and thus lowering the backhaul capacity needs.

While running 10 devices the most achievable bitrate was 20mbps (15% of the time) and 30mbps (13% of the time) while 52,5% of the time maintaining a bit-rate of over 15mbps. The network latency when synchronising users should be below 500ms and the user perceived synchronization latency on the application level must be less than 2000ms. Our metrics showed an average sync delay of 138ms for the Mativision application / sync server over 5GST infrastructure accessed via a single 5Ghz WiFi AP. Nearly 94% of times was the application-level latency well below 500ms and maximum latency recorded during testing was 575ms (well below the
2000ms threshold). For the LandMrk Tourist Guide application, when using edge facilities, latency was dropped to less than 60ms, while it was more than 400ms when using public cloud to deliver the content. Finally, and in order to measure user-perceived quality and latency of the experience, Mean Opinion Score (MOS) is used and MOS score of at least 4 is targeted (on a scale of 1 to 5). Our metrics showed that ~94% of users rated the Mativision’s experience at MOS score of 4 or higher and ~75% of users rated the Mativision’s video quality at MOS score of 4 or higher.

C. 5G-enabled 3D motion tracking

Mo-Sys have developed a wireless handheld AR application that was deployed at We The Curious, a science museum in Bristol, utilising edge computing infrastructure to render an environment containing a 3D model of an Airbus A330 on top of real life landing gear within the museum. Mo-sys’ proposal aims to give tourists the ability to experience and walk around a high-quality representation of a plane in a virtual environment, while physically walking around a real indoor space, without the burden of wearing uncomfortably heavy hardware. The Mo-sys Virtual Window product consists of an iPad tablet with a tracking system attached, retro-reflective stickers stuck to the ceiling of the physical space for the system to track, and a wireless module to communicate between the Virtual Window and a remote server running the experience. This use case was mostly focused on latency reduction and MEC applications of 5G network infrastructure from a technical point of view.

To track the tourists as they walk around freely in the physical world while exploring the virtual world, the product incorporates a 6-degree of freedom positioning device (capturing position and angle data) using MoSys StarTracker technology. By detecting the reflections from the stickers as the camera moves, it is possible to perform rotational and positional tracking accurate to 2mm over a large area (20m²), without the need for powered sensor systems associated with other room-scale VR devices. This enables robust, industrial grade and absolute tracking in very large spaces, meaning that the tourists can get a high-quality experience with minimal jitter and tracking loss, while being able to truly explore the virtual tourism site for maximal immersion and experience value. To ensure consistency between the real world and virtual world, the StarTracker is absolute so will not drift, unlike “natural tracking” systems such as the Apple AR kit. This is because it tracks small, randomly placed low-cost retroreflective stickers stuck to the ceiling of the real space.

Mo-Sys has identified that the maximum acceptable end-to-end solution delay must be consistently less than 39ms for a 50fps experience, from the start of Mo-Sys StarTracker gathering tracking data. At this latency most end users will not notice the delay and therefore get a smooth and immersive experience. Previously, this could only be achieved by having a local render engine (a VR backpack) with all components connected through cables. In the current setup using WiFi and a compute node for local “edge” rendering, the E2E solution latency was approximately 73-75ms which accounts for time to track, transmit data, render the video transmit back and display it (Table I). This is unacceptable from a user immersion standpoint, as users have an exceptionally noticeable delay in their experience. Utilizing GPU-powered edge compute resources to run the rendering process, similar to the BBC Phase-2 use case, it was possible to cut the delay down to more than half of the previous setup, with a delay of approximately 35ms. This was below the delay budget of 39ms for acceptable immersive experience, and close to the expected 5G solution which assumes ultra low uplink and downlink latencies.

<table>
<thead>
<tr>
<th>Solution Timing Step</th>
<th>Existing Latency (ms)</th>
<th>Expected 5G Latency (ms)</th>
<th>5GST Attained Latency (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gather and process tracking</td>
<td>11</td>
<td>No improvement expected</td>
<td>11</td>
</tr>
<tr>
<td>Tx tracking data</td>
<td>20</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Remote Render video frame</td>
<td>20</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Rx video frame</td>
<td>20</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Display video frame</td>
<td>2</td>
<td>No improvement expected</td>
<td>2</td>
</tr>
<tr>
<td>E2E Latency</td>
<td>73</td>
<td>25</td>
<td>35</td>
</tr>
</tbody>
</table>

D. 5G-enhanced gallery experience

The fourth use case was delivered by Smartify⁵ and involves an image recognition application that uses a phone’s camera to identify artwork, and then display related facts and audio commentary. It is effectively able to replace traditional audio guides associated with galleries and museums by using the device most people have in their pockets. The application can also display contextual information via AR and presents an opportunity to understand customers preferences and habits, a relatively untapped resource in the GLAM (galleries, libraries, archives, museums) sector. Smartify works with some of the world’s most prestigious institutions and have found that high-speed, reliable and user friendly internet service is still a luxury offering that has yet to be ubiquitous. Even institutions such as the National Gallery and National Portrait Gallery, located in the heart of London display their collections within large areas over multiple floors and rooms separated by walls, where 3G and 4G do not always offer the required quality of service and resilience to the Smartify app to operate at its optimum capabilities. This has led these institutions to invest in WiFi and expensive network infrastructure that offer sufficient coverage across the entire collection. Although, WiFi does offer a high-speed and reliable experience in some cases, it is not the most user-friendly, as visitors have to accept

⁵https://smartify.org/
separate terms and conditions and landing pages for each individual institution.

This is where the Smart Tourism 5G testbed, in this case connected to M Shed in Bristol, comes in to explore four possible benefits:

- More pervasive and resilient than public WiFi, including high density connections, offering the app in more alternative or outdoor venues e.g. public sculpture; heritage properties and other sites without WiFi.
- Better user experience quicker scanning and download, particularly of videos and initial app download. Smartify can offer access to video and AR through the app with more immediacy.
- More economical solution for GLAM institutions compared to WiFi. A combination of 5G and Smartify offers a more profitable alternative to traditional audio-guides and WiFi offering a complete over the air model with value added services.
- Predict and manage visitors numbers and congestion in museums and galleries, offering advanced analytics of user interests.

E. Network Slicing for emergency services

The last use case was developed by Zeetta Networks in collaboration with Bristol is Open, Bristol City Council and IBI Group. This use case was focused around automated provision of a network slice for an Incident Area Network (IAN) across a heterogeneous network, using a pop-up network (Fig. 3) and managed from a central SDN controller (NetOS).

The IAN relies on two core technologies: network slicing and splicing of virtual networks to establish a priority communication channel to an operations centre. It is essentially a "pop-up" network to be delivered at short notice in response to an incident and which supersedes the demands placed on other slices. IAN has three segments: wireless access segments, metro segment and application/services segment. It is designed to be an ephemeral network extension designed to support a set of priority services using a slice of the existing network infrastructure.

For the IAN, the end-user’s requirement is to minimise the time to create a working prioritised slice on the network from the point at which the mobile link is activated. During the testing in the 5GST project, it was possible to achieve a time of 210 seconds from “power on” at the IAN equipment to the creation of a working link and/or new local WiFi SSID (Table II). This time is dominated by the hardware boot time (around 100 seconds) followed by the backhaul link, i.e., in this case an additional mmWAVE node joining the local “mesh” (around 60 seconds), and the provision of the predefined slice by the network’s NetOS controller (around 50 seconds).

E. Business Models

All the use cases were trialled with the public and received feedback on the experiences. As discussed earlier, most of the results received a positive response from the end users and a recent report from Ericsson [5] suggests that consumers would pay more for such 5G immersive services. Some companies have incorporated the results and learnings from the project into a future business model which has created an opportunity to offer a different service. It is worth noting that such services can be applied on experiences that merge virtual and real worlds, a common practice in the TV/broadcast industry, and other entertainment industries, including museums and amusement parks.

As seen with most 5GST use cases, 5G will allow delivery of immersive content via more generic hardware which is easier to set up remotely, more widely available and more capable of flexibly adapting to meet evolving requirements. The business models for who pays for the edge servers are not defined yet. For example, will this be something provided by mobile network operators (MNOs)? It may become common for MNOs to be public “mobile cloud” providers or new entrants could spin out to fill the gap. Edge computing aggregators could act as middle-men, handling where and how the application is deployed on the edge, on demand. This means developers do not need to know where the application needs to be. Such aggregators could potentially increase trust for both sides, they could closely work with MNOs to increase the revenue the network generates and also handle more intricate aspects of deploying, particularly if they work across multiple operators and countries.

The 5G specific capacities of network function virtualisation (NFV) and software defined networking (SDN) will allow
companies to save on operational expenditure: support and maintenance costs, ability to manage networks and much faster troubleshooting. The centralised nature of SDN allows for the network to be reconfigured on the fly; creating and managing new slices in a time critical manner. Further, given the bandwidth and enhanced mobile broadband (eMBB) of 5G there is a large business opportunity in helping clients to improve revenue.

V. CONCLUSIONS

We are still in the very early stages of exploring the benefits derived from combining immersive technologies with 5G and the UK is set to establish itself as a global leader alongside China, South Korea, the US and Japan. 5G Testbeds and Trials have enabled the de-risking of experimentation around 5G by prompting consortia of academia, industry and innovators to come together and assess this infrastructure’s commercial viability. The sheer number of immersive companies involved across all regional testbeds demonstrates the transformative nature of 5G for content making across multiple sectors.

At its simplest, 5G will reduce latency and increase bandwidth allowing for the better exploitation of VR, AR and MR’s functionality and performance. However, it also has the potential to go much further than the current network landscape allows. For the everyday consumer, SMEs involved in the testbeds have demonstrated the possibilities of democratising immersive experiences when 5G is rolled out to the wider public. On the industry side, 5G slicing can enable industry to select the very elements of 5G network they wish to capitalise on. In the tourism sector, this can enable cultural heritage sites to manage visitors, create hotspots and even analyse insights from visitors in a way that has not previously been possible. Reduction of costs and time can be derived for immersive companies when they will be able to reduce network delays, increase data transfer capabilities, reliability, security and speed.

ACKNOWLEDGMENT

The authors would like to acknowledge the support of all the partners of 5G Smart Tourism project and DCMS for the funding provided.

REFERENCES