5G Connected Forest

CLOSURE REPORT
August 2022

Department for Digital, Culture, Media & Sport

Nottinghamshire County Council

Prepared by
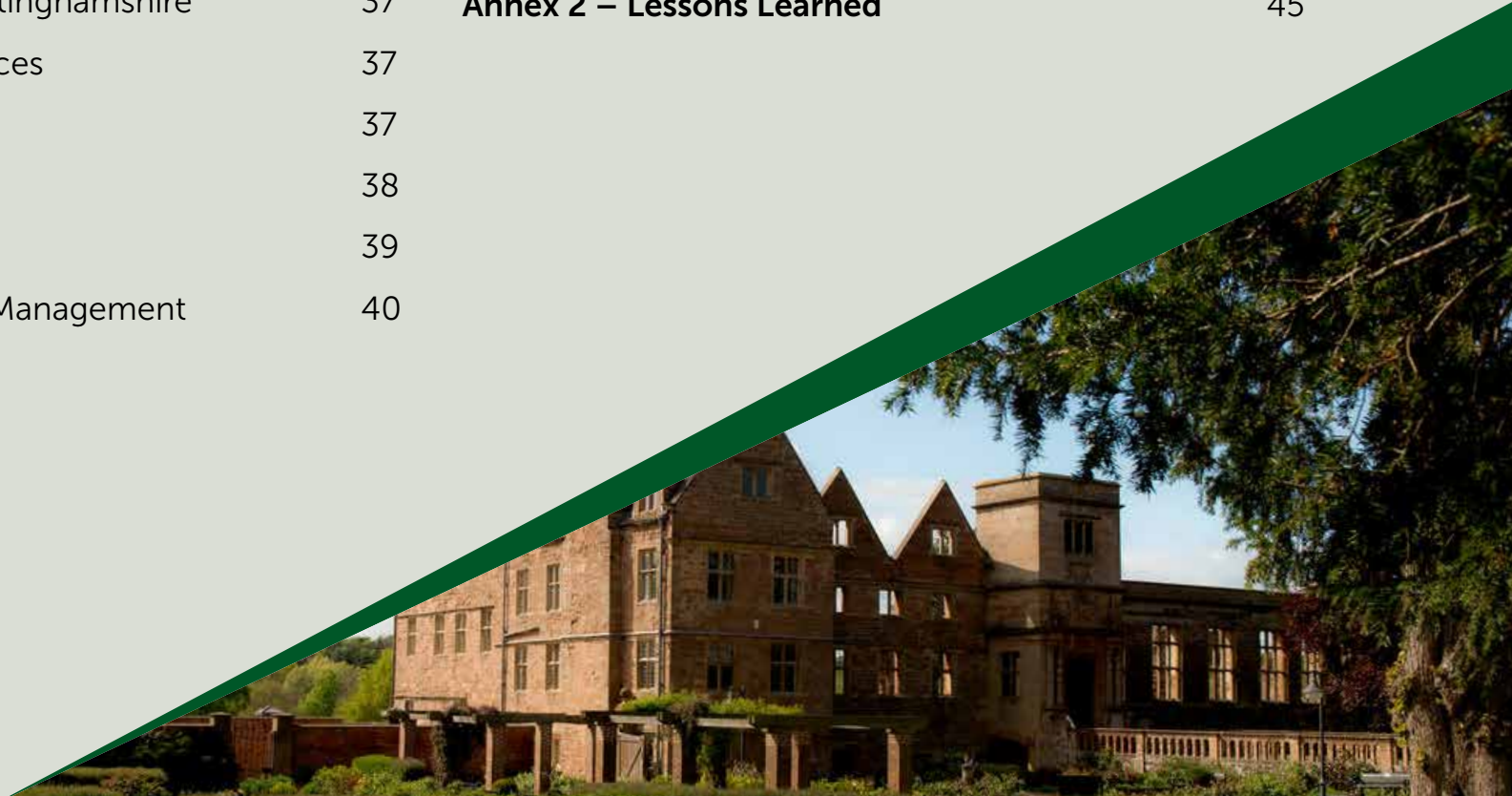
iN Innovation Nottinghamshire

ISPB

In partnership with

netmore

Gooii

BIRMINGHAM CITY University

NTU NOTTINGHAM TRENT UNIVERSITY

Parkwood LEISURE

rspb

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Executive Summary

Nottinghamshire's 5G Connected Forest project was established to identify ways in which 5G could be used to protect and promote areas of natural and cultural heritage, such as the area in and around the legendary Sherwood Forest.

The 5G Connected Forest project successfully delivered the world's first 5G network in a non-commercial forest setting. It also delivered three separate 5G enabled visitor attractions as well as delivering a programme of environmental science research to monitor and manage the health of this treasured woodland area.

As with all projects in the 5G Testbed and Trials programme the project faced significant challenges, not least the restrictions caused by the Covid pandemic (preventing some original partners from continuing with the project and also severely restricting the ability for partners to meet together and work on-site at key times) and global supply chain issues for newly emerging technologies (including disruptions caused by Covid & especially Far East lockdowns, European supply changes, Suez Canal closure, 5G standards developing during the life of the programme, global 'chip' shortages).

Despite these uncertainties the final project partnership of:

- Nottinghamshire County Council – local authority, lead partner
- Netmore UK – network operator
- Birmingham City University
- Gooii Ltd – augmented reality developers
- Nottingham Trent University
- Parkwood Leisure - managing agents for the Rufford Abbey setting
- ISPB Ltd – business consultancy
- Royal Society for the Protection of Birds (RSPB) – managing agents for the Sherwood Forest Visitor Centre and National Nature Reserve

successfully achieved their objectives to:

- Deploy two 5G Testbeds in rural/forest settings, in three locations
- Deliver three different 5G-based visitor experiences ('An Arrow Through Time' based at Sherwood Forest Visitor Centre and 'Rufford Ghost Walk' & 'Tag in the Park' at Rufford Abbey)
- Deploy 5G-powered Robot Forest Ranger and Robot Forest Manager drones and robots - to gather real-time data on the health of the forest, using artificial intelligence and machine learning to provide new insights into the protection of the forest and its visitors, and to develop the concept of a '5G Forest Emergency System' for visitor safety.

Additionally, the project also acted as the inspiration for activities outwith the project's remit including the creation of:

- The Turbine Innovation Centre, a new digital innovation centre in north Nottinghamshire hosting Private 5G, LoRaWAN and Bluetooth Mesh test networks,
- The UK's first 5G Careers programme raising students' awareness of the impact 5G and the technologies it powers are having on every business sector, and the opportunities for their future careers across all sectors from care to construction and from education to hospitality
- A new range of public engagement events using Gizmo and Eric (Birmingham City University's 5G-powered robotic dogs) to inspire future generations in the wonders of science and technology
- The development of proximity-based applications to support patient health and wellbeing.

In parallel with the project; Nottingham Trent University also worked in partnership with the Digital Catapult, Midlands Engine and the D2N2 Local Enterprise Partnership to create the SWIFt Lab (https://www.swiftlabs.co.uk/) , a brand new state-of-the-art indoor and outdoor Private 5G and IOT commercial testbed. Although unconnected with the project, the teams at SWIFt and the Turbine Innovation Centre are already collaborating with project partners to share and develop the four 5G Testbeds now available in Nottinghamshire.

These achievements recognise both the commitment and resourcefulness of staff across all the project partners,   as well as the patience and flexibility of colleagues in DCMS.

Introduction

Nottinghamshire's 5G Connected Forest project set out to address the core question *"how might the power of 5G be used to protect and promote areas of natural and cultural heritage like the area in and around the legendary Sherwood Forest"*.

In leading the project, Nottinghamshire County Council also recognised the potential for Nottinghamshire to become a leading showcase for 5G and related technologies.

The project commenced in early March 2020 with a large consortium of 10 organisations including local authority, academic, and large & SME private sector partners. However, the arrival of Covid restrictions within a few days of project kick-off – with partner staff being furloughed, travel and meetings banned, and significant economic uncertainty – resulted in major changes to the project structure which continued to impact the project through 2020 and the majority of 2021, including a further partner needing to step away from the project during 2021.

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- Deploy 5G-powered Robot Forest Ranger and Robot Forest Manager drones and robots - to gather real-time data on the health of the forest, using artificial intelligence and machine learning to provide new insights into the protection of the forest.

This report highlights the activities, results and future potential for the 5G trials and use cases.

What is Nottinghamshire's 5G Connected Forest?

Delivering 5G in a rural woodland setting

As the project's initial application stated, "the deployment of mobile connectivity in rural forested areas is inherently difficult, limiting the ability of residents and businesses in these areas to benefit from technologies more easily found in other areas. By developing a mobile 5G network in one of the most highly designated forest areas in the country, the project will aim to identify business models and applications suitable for commercial development, boosting the skills and employment opportunities for residents and encouraging the creation of new tourism business opportunities across the region".

The 5G Connected Forest project therefore set out to understand 'the art of the possible' in the deployment of the latest 5G technology in a rural and forest area, to enable 5G powered applications which could be used to protect and promote such areas of natural and cultural heritage.

Netmore UK led the 5G technology workstreams, as a new entrant to the UK's 5G eco-system with a strong track record in the deployment of mobile networks in forested areas in Scandinavia.

Using a new type of local private 5G network

As the main public mobile network operators are rolling out 5G across the country the risk is that areas of low population density – like Sherwood Forest – will not have coverage for some time. To address this, part of the project was about testing a new way of addressing the challenge using a private 5G network. A private 5G network also allows the local operator to design and configure the network as best suits the specific business application (in this case for the visitor economy). We can focus on very high peak speeds for AR in a tightly defined area for example whereas a public network shares resources across thousands of users in an area and, typically, cannot support extreme speeds.

The telecom regulator Ofcom had made available some new "Shared Access" spectrum for just this type of use shortly before the project began so we opted to use that new spectrum rather than try and rent a small part of a major operator's spectrum (which would have taken much time - as operators were still developing their own processes and commercial models at the time - and not allowed the network to continue in use for some years which was another important objective as we were developing a prototype commercial solution, not just experimenting). [Note however that Shared Access licences do not allow for drone use (or any type of aeronautical application) and are designed for building type or ultra-local use, not to cover a whole forest, village or a town. The licences are quite limited in those respects, and we believe Ofcom should look into some further liberalisation of the 4GHz band to see if further innovation in private or community 5G results].

One factor which was also not fully understood before the project started was the added complexity of working in a protected environment such as special scientific interest or AONB. Sherwood Forest, rightly, has many environmental limits designed to protect the forest, birds and wildlife. Similarly, at Rufford Abbey the site has special archaeological protections and listed building status which understandably impose numerous restrictions on telecom networks in order to preserve the site and grounds.

Overall, the project managed to develop sensible and discrete deployments on these special sites by working closely with site owners and relevant authorities plus a degree of lateral thinking; for example, using existing cable routes and precedents wherever possible.

It was a struggle to house the numerous servers that 5G needs at present, all of which generate a fair amount of heat, so the project ran fibre over longer than ideal distances in order to allow servers to be placed into historic buildings or areas where some form of housing was permitted in terms of planning permission and aesthetic impact.

Project challenges were numerous but generally overcome

In developing and delivering 5G connectivity in the area Netmore addressed multiple challenges, not least:

- The restrictions caused by the Covid pandemic (preventing some original partners from continuing with the project and also severely restricting the ability for partners to meet together and work on-site at key times)

- Significant project and deployment scope changes resulting from early partners having to leave the project as a result of pandemic restrictions

- Early adopter challenges defining and applying for Shared Access 5G Spectrum licencing through OfCom

- Restrictions on the deployment of 5G infrastructure on sites of protected natural heritage

- Global supply chain issues for newly emerging technologies (including disruptions caused by Covid & especially Far East lockdowns, European supply changes, Suez Canal closure, 5G standards developing during the life of the programme, global 'chip' shortages)

- Specifically, supply chain issues for small cell technology resulting in the use of pre-production and trial equipment provided by suppliers (whilst the project welcomed the opportunity to provide the world's first test sites for some of this technology, the inherent novelty of the systems added time and complexity to the deployment and testing).

- Complex site ownership and governance arrangements arising from the special protected nature of the area impacting design and deployment decisions.

By their nature, all of these challenges resulted in multiple iterations of the network architecture design and deployment throughout the life of the project – **however the end result was two local 5G testbed networks deployed across three sites of special natural and cultural heritage**.

High Level Network overview

To deliver the wide range of 5G-powered visitor experiences and environmental management use cases required by the project, Netmore rolled out two 5G networks across three sites partnering with several hardware and software suppliers to provide connectivity for AR, drone and robotic devices.

Sherwood Forest Visitor Center
Edwinstowe

Abbey and Mill
Rufford

Amito Data-Center
Reading
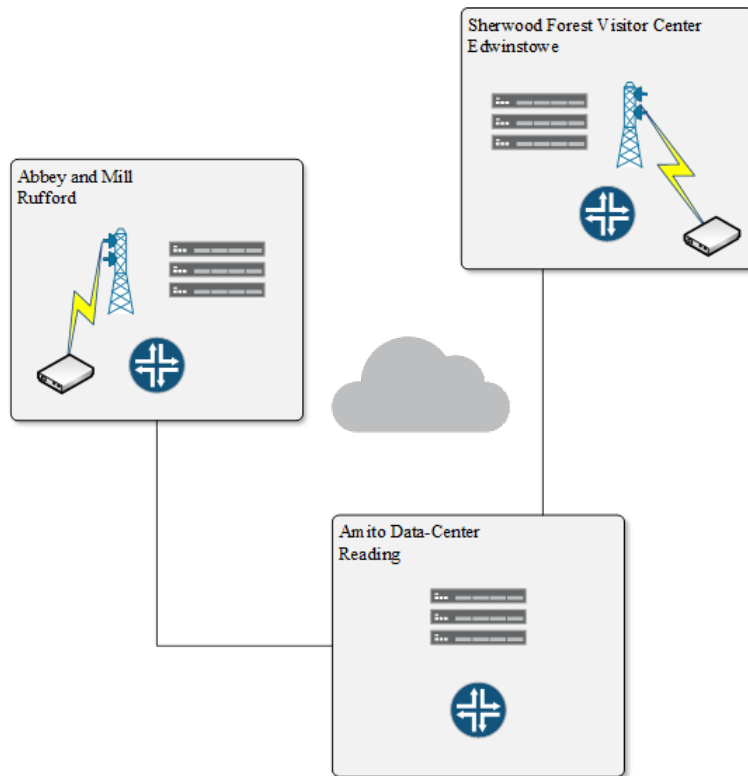
Sherwood Forest – outdoor network
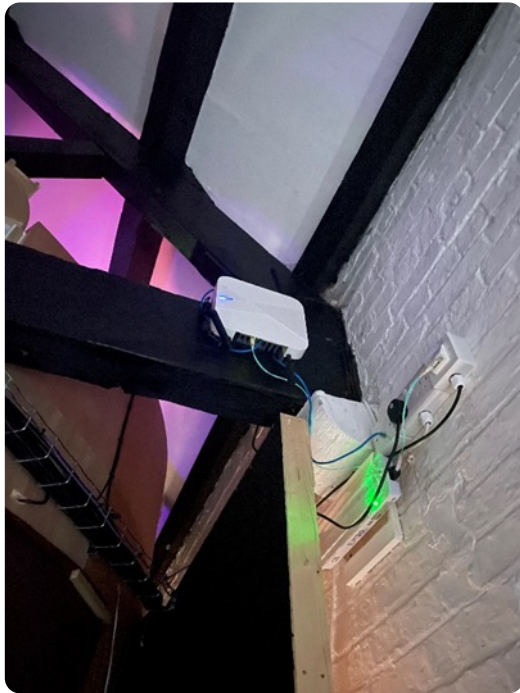
Rufford Mill – indoor network

In order to test solutions which can be used at any tourist location, Netmore opted to use the then new Shared Access radio spectrum made available by the telecom regulator, Ofcom. These frequencies are relatively new for mobile services but have now been licenced in several countries so mobile phones and other devices are starting to support their use. However, early on in the project the lack of equipment in these bands posed a significant challenge.

The main Shared Access band is at around 4GHz which is quite a high frequency but between the two bands used in normal WiFi (2.4GHz and 5GHz). As with WiFi, power is limited by regulation to ensure the band may be shared by many users. In the case of rural use, Ofcom allows slightly higher power in Shared Access and this was useful to boost outdoor range a little. Range is important as, at a tourist location, it may not be practicable to put radio equipment exactly where one would prefer for performance because of listed building, protected environment or aesthetic limitations. In the case of 5GCF the team tested various outdoor antennas and set-ups in the forest. The final configuration provided a good and high-speed private network over the 20-30m range required in that location despite a fair bit of tree and bush cover detracting from the signal.

5G-Powered Visitor Experiences

Pre-pandemic, the visitor economy in Nottinghamshire was worth £1.75 bn, supporting around 15,000 jobs. Day visits dominated, accounting for 90% of all trips. Over the previous decade the volume and value of tourism in Nottinghamshire grew much more slowly than the national average and the visitor economy was severely affected by the recession. In the five years to 2014, visitor numbers dropped by nearly 10% in Nottinghamshire.

Nottinghamshire County Council's Visitor Economy states, *"There is work to be done to re-energise the visitor economy, boost performance and realise potential. Nottinghamshire needs a much clearer identity and a higher profile in the marketplace, more bookable product, more joined up experiences, more things to see and do, and more accommodation to enable the County to grow the short break market. This means capitalising on new digital opportunities, including virtual and augmented reality, and the sharing economy, and focusing on quality experiences to ensure Nottinghamshire is competitive in the marketplace. Nottinghamshire has great natural capital, inspiring stories and heritage with wide appeal."*
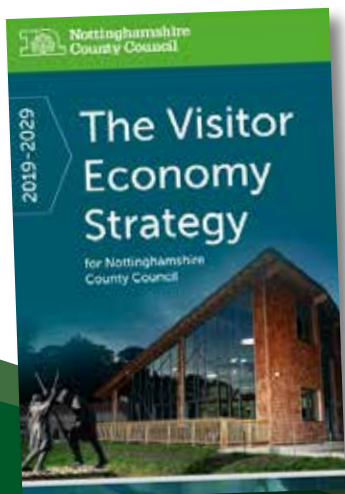
Within their portfolio of responsibilities, Nottinghamshire County Council own two natural and cultural heritage destinations in the centre of the county – Sherwood Forest National Nature Reserve (NNR) and Visitor Centre, and the nearby Rufford Abbey (a Grade 1 listed Jacobean abbey and country park). Against this economic and strategic background, the 5G Connected Forest project set out to identify how 5G might be used to power a new generation of high-quality digital visitor attractions at these iconic visitor settings.

In partnership with Parkwood Leisure who manage Rufford Abbey on behalf of the council, the Royal Society for the Protection of Birds (RSPB) who manage the NNR and visitor centre in the heart of the forest, and the Sherwood Forest Trust (a local community group dedicated to preserving and promoting the nature and history of the area); Netmore, Gooii and Nottingham Trent University partners developed three separate 5G enhanced digital visitor attractions:

- '**An Arrow through Time**' – an outdoor based AR experience
- **Rufford Ghost Walk** – an indoor based AR experience
- '**Tag in the Park**' – a mobile proximity-based outdoor treasure hunt

The attractions were selected for their:

- Potential to demonstrate different types of digital visitor attraction,
- Potential to demonstrate 5G in a range of applications,
- Future commercialisation potential.

Arrow Through Time

Project partners Gooii led the workstream, with support from RSPB and historical/editorial input from the Sherwood Forest Trust community group, NCC's Senior Practitioner in Heritage Tourism and local community historians.

Sherwood Forest is one of the UK's most iconic forest areas. World famous for the legend of Robin Hood, as a royal forest and hunting ground the forest once covered about 100,000 acres - a fifth of the entire county of Nottinghamshire, stretching from the River Trent in the south to the Yorkshire borders in the north. Today the forest is home to around 1,000 trees that are over 400 years old, including the iconic Major Oak which is over 1,000 years old.

Based outdoors near the Sherwood Forest Visitor Centre the project delivered what is believed to be **the world's first ever interactive holographic movie, 'Robin Hood: Arrow Through Time'**. The experience mixes video, CGI and interaction to tell a new story of Nottingham's legendary outlaw. Featuring a strong and well-known cast, co-written Bafta winning BBC writer Nick Hutchings and Gooii's Phil Hasted, with video produced by Immersion VR.

The project worked with RSPB colleagues identifying and trialling a range of different potential settings to identify a suitable location with sufficient shade for the AR experience to work effectively, a suitable forest 'backdrop' for the AR characters to appear against, a safe location for visitors that did not impact other forest users and, most relevantly given the sensitive nature of the forest, a location whose use would not have a negative impact on the natural beauty and heritage of the setting. Linked with this selection, colleagues at Netmore explored multiple potential approaches to delivering a 5G service in such a sensitive and protected setting.

The characters were filmed as live action characters, with AR displaying them as holograms supplemented with interactive features including the ability to 'fire arrows' at the characters and make group choices on the flow of the story line (an interactive movie experience in the style of a 'choose your story based video game').

For the experience, users wore Hololens 2 AR headsets linked with Subpac haptic backpacks (the project were able to get advance pre-production backpacks as development delays meant final versions were not available in time for the trials). In light of the suitability of the headset and backpack for smaller children, an advisory 7+ age limit was suggested for visitors.

5G Specific Functionality

'Arrow Through Time' was an ambitious project that aimed to use 5G to:

- Network Hololens headsets outdoors
- Stream high quality video content to the headsets
- Manage the experience remotely, so that the experience can be started and reset for via a mobile app
- Use location anchors to place content
- Enable an online voting system for story options.

Rufford Ghost Walk

Project partners Gooii and Parkwood Leisure led the workstream, with editorial input from NCC's Senior Practitioner in Heritage Tourism.

Rufford Abbey was founded in 1146 and has a long, and sometimes gory, history; the Rufford Ghost Walk was conceived to entertain and educate visitors on some of the characters from the history of the abbey and surrounding areas. In parallel with the project Parkwood Leisure also commissioned a new digital visitor experience, 'Abbey Tales', where visitors move around a series of spaces with audio visual content taking visitors through the history of the abbey from its foundation to the present day; it was envisaged that the Rufford Ghost Walk would offer a supplementary visitor offering.

The design objective was to create unique but shared experiences for groups of users (so if you go round with a friends/family you all experience the same things at the same time, but each group may get a different experience), with the potential for a different experience if you repeat the visit. The aim was to bring back the ghosts of Rufford as holograms and:

- Deliver a large pool of content stored online, with up to 30 clips available
- Within a 12-15 minute experience, 1/3 of the content is pulled in at random from the pool of content and shown to each group
- Headsets networked, so each group of users sees the same content at the same time
- Use anchors to place content, all users to see the content in the same place
- A web app developed to manage the experience.

Originally it was hoped to set the experience in the Undercroft of the original abbey; however, visitor safety concerns would have required further restoration to the area, as well as significant levels of authorisation for the work necessary to install a private 5G network in the historic setting. For the project trials the ghost walk was therefore staged in the Rufford Mill building (which did not have the same listed building constraints), with the added benefit that this building is already used as a wedding and event venue providing better opportunities to operate the visitor trials.

The Undercroft (prior to closure to the public)
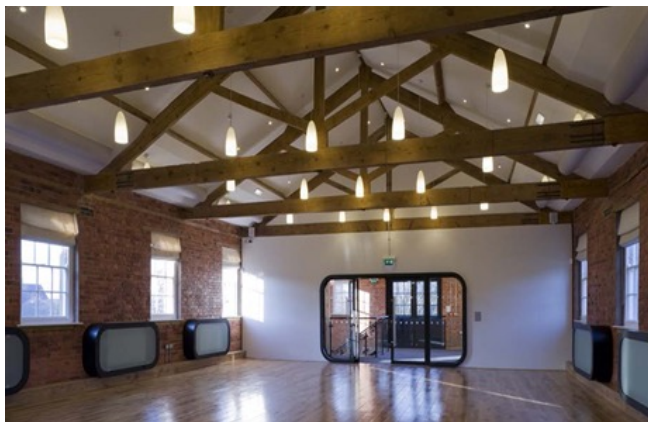
Rufford Mill

The ghosts were filmed as live action characters, with AR displaying them as holograms supplemented with CGI in some cases (for example the seance scene below where items fly out at the viewer).
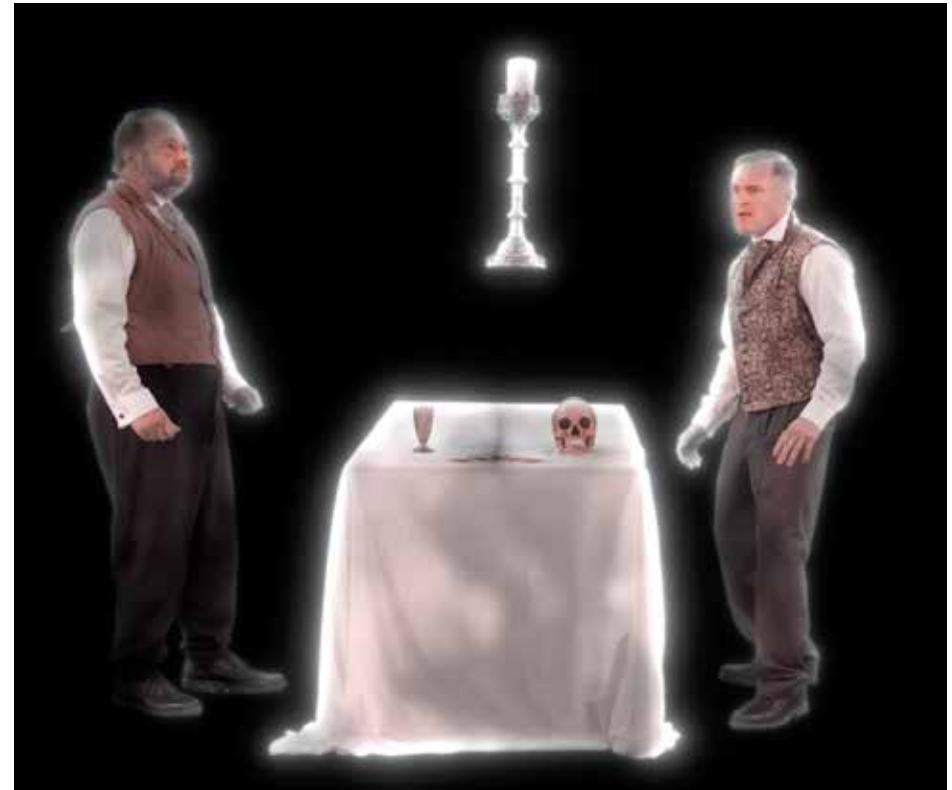
For the experience, users wore Hololens 2 AR headsets linked with Subpac haptic backpacks (the project were able to get advance pre-production backpacks as development delays meant final versions were not available in time for the trials). In light of the subject matter and presentation, an advisory 14+ age limit was suggested for visitors.

Public visitor trials were held during February and March 2022 with 137 participants providing feedback on their experience. During the trials some changes were made to the operation, including using stage setting 'stone walls' to break up the space which had a positive impact in the visitor's experience. Some of the 'milder' holograms were also 'upgraded' during the trials in the light of user feedback to make them 'gorier'.

> **5G Specific Functionality**
>
> The experience was specifically developed to operate in a 5G environment, providing the capacity to handle the large amounts of data needed to be delivered in real-time to multiple linked mobile devices.

Tag in the Park

Nottingham Trent University (NTU) research partners explored the potential for proximity-based applications to be used to create new visitor experiences which would entertain and educate visitors, encourage exercise and mobility, and extend visitor stay times at the venue; enhanced by the power of 5G.

The app encourages players to explore Rufford Abbey Country Park through an interactive treasure hunt where players are challenged to find 16 hidden locations around the park. The app is designed to utilise advances in IoT and 5G connectivity to detect the proximity of players to each of the locations where once the player successfully visits a location they partake in an interactive activity. Three main activities have been embedded within the app including an object recognition challenge taking advantage of advances in artificial intelligence including deep transfer learning where players aim to scan a nearby sculpture using their smartphone camera. The second challenge involves finding and scanning a nearby tag, encouraging visitors to explore the surrounding area and finally an educational quiz allows visitors to learn about the history and culture of Rufford providing an educational aspect to the experience. Many other interactive elements were also explored such as robotics and Augmented Reality (AR) to add new dimensions to the platform and continue its evolution.

Multiple users including visitors and researchers tested the app using a variety of different smartphones using both the Android and iOS operating system to ensure compatibility with all devices. During testing differences between the operating systems were discovered resulting in the proximity detection algorithm being adapted for each operating system. As a result, the app is able to correctly identify locations as players walk near them and then automatically activate the location-relevant challenge within a short range (typically 1-3 metres).

On successful completion of all levels of the app, users are rewarded with free refreshments at the visitor café.

5G Specific Functionality

An additional feature has been developed for Tag in the Park to take advantage of the low-latency and high-speed of 5G connectivity is a shared collaborative augmented reality environment. When connected to a compatible 5G network, players are able to download a range of 3D computer generated models and place them in a fixed position within an augmented environment using a real-time camera view. After placing a model, players can dynamically upload these to the cloud allowing other players to view their models, creating a shared experience between all players.

The ability for players to view models placed by other players in addition to placing their own models for others to view creates a shared experience within the app that has not traditionally been possible. As 3D computer generated models can be large in size, the ability to store them on a server and allow users to dynamically download them using 5G connectivity enables the models to be frequently changed allowing for new experiences to be developed. Furthermore, the low latency of 5G means players can upload new models and view previously placed models in real-time with no delay. Utilising these advances in 5G, AI for positioning the models in the real-world and AR; enables this new form of multiplayer universe to be created combining the virtual gaming world with the natural environment of the park, providing visitors with a new immersive way to engage with the park.

5G-Powered Environmental Management

All the 5G-powered environmental management use cases were led and delivered by partners at Birmingham City University (BCU).

Forest degradation is becoming more of a threat as a result of their important impact to climate change. The process of biodiversity loss, greenhouse gas emissions, and decline of ecosystem products have all contributed towards forest degradation.

Many forest health indicators (FHI) are monitored by forest management and forest ecological research to help maintain the forest health; including climatic conditions, insect infestations, animal signals, tree species, and deadwood. Field surveying by people has a variety of limitations, including time consumption and high labour-intensive expenses. As a result, viewing and obtaining accurate data is difficult, necessitating constant attention and focus throughout the phase of analyses and surveying.

The project recognised that sensors, Internet of Things (IoT) devices, and cameras could gather and transmit forest data; with the integration of 5G and artificial intelligence (AI) improving its effectiveness in terms of a faster and more reliable detection of the target objects. The project also recognised that these technologies might also be applied to protecting visitors to the area by exploring the potential for a '5G Forest Emergency System'.

The project therefore developed a series of trials around the concepts of a Robot Forest Ranger and a Robot Forest Manager.

Robot Forest Ranger

The Robot Forest Ranger use case was developed and delivered using data collected via robotic quadrupeds – two 'robot dogs' named Gizmo and Eric in a competition to build engagement with local schoolchildren.

Gizmo and Eric were used as mobile sensor platforms, allowing a range of different devices to be used to gather a wide range of different data types for analysis.

The aim was to collect various information from specified objects and to process this through AI and machine learning techniques, as the robot moves around the forest. The set-up incorporates a single- board computer (SBC) - RaspberryPi (RPi), connected to the GoPro9 camera via the MediaMod interfacing unit. A 73Wh portable battery was used to deliver long-lasting power to the SBC as it collected the relevant information from the forest.

To ensure that the health of the forest is monitored accordingly, the data to be collected must be coupled with its location. As the battery life of the robot is limited, a low-cost, lightweight single-board computer was used as an interface device between the data collected from the camera and the GPS location. An Antenna was also used to improve the location accuracy of the robot, which supports rapid detection of the unhealthy factors specified by the forest rangers.
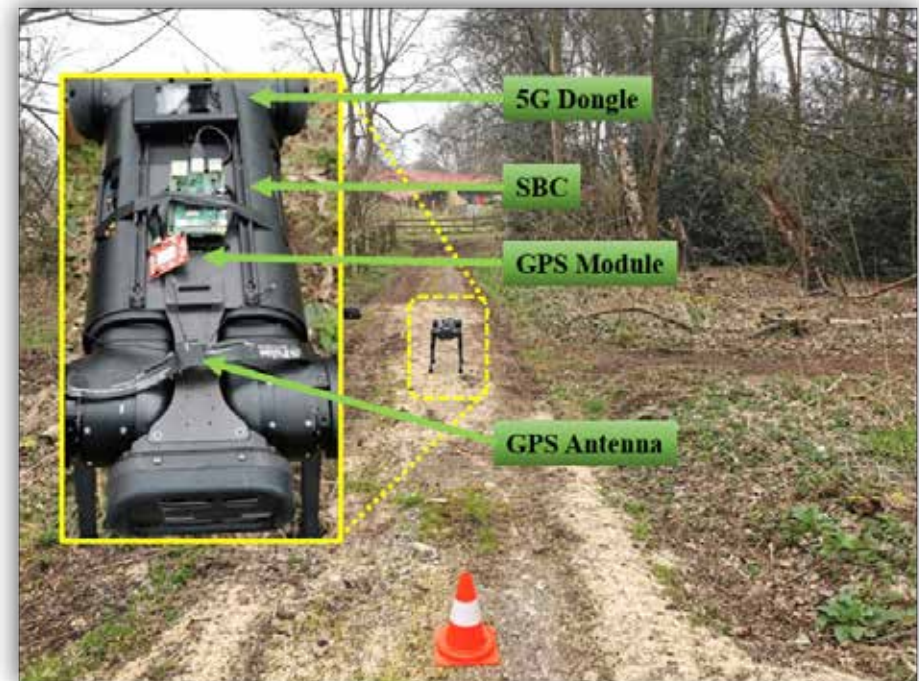
Initially the robot was set to stand at a location in the trial site at Sherwood Forest. Control logics were implemented by commanding the robot to move in the positive direction, then turning by 90 degrees counter clockwise before moving approximately 6m forward. Following that, the vehicle was commanded to rotate by 180 degrees counter clockwise followed by a 3m forward motion. Rotation of 90 degree clockwise were implemented again, followed by a 3m forward displacement. Lasty, the robot turned hard left before moving 3m; then 90 degree counter clockwise rotation before reaching the start point. The robotic dogs also dealt successfully with different ground conditions, with a mixture of soil and gravel, as well as different sloping conditions.

5G Specific Functionality

Surveying the forest includes the use of visual perception sensors; however, the images captured are of high-quality and require strong internet connectivity to successfully transfer large files of datasets. Although 4G has been used before in this type of work, the increased development of new technologies including 4K cameras has resulted in the frames consuming more memory, which results in the 4G connectivity becoming a bottleneck for such technologies.

The project therefore carried out a comparison between 4G and 5G with experiments focused on utilising the robot to move in a certain direction within an open spaced area, while maintaining connectivity for 5 minutes. Following that, the same experiment was repeated in the same area, but with 5G connectivity.

Robot Forest Manager

The Robot Forest Manager use case was developed to explore the use of 5G powered Unmanned Aerial Vehicles (UAVs - drones) and robotics to support the traditional forest manager to preserve, protect and maintain the forest, its inhabitants and users Specifically the use case looked to deploy a Forest Manager System for discharging the tasks of Forest Emergency and Forest Search and Rescue (SAR) in the forest by using digital technologies to accelerate the process of data collection, transmission and analysing to facilitate a smoother and quicker action by the forest management.

In the Sherwood Forest, forestry personnel are spread out in the area to notify the managers of any emergency. They use 2-way radios to communicate with each other. Local people in the community give their hand in notifying of any unexpected event. The time required for responding to these situations varies with the longest procedure of response and recovery being when there is a need for an ambulance or the fire brigade. The longest time of recovery was around 4 hours based on the previous experience.

They also employ lone workers for remote areas of the forest where there is limited phone coverage. In the current management system, the manager has different approaches for different forest management activities, which vary according to the number of people involved, the amount of time taken, and the number of visits required to the site.

5G Specific Functionality

The project therefore explored the potential for a '5G Forest Emergency System' featuring:

- 5G network
- Data collection at edges, i.e., at UAVs and robots
- Data analysis for detection at Cloud and edge of the network.

Using UAVs, robots and cameras; the danger in the forest can potentially be detected more rapidly aided by the speed, capacity and low latency of 5G communications and machine learning intelligence implemented at the Cloud server or at the edges of the network where data is collected from the forest - where possible, performing these operations at the edges would result in a faster detection of dangers than at the Cloud.
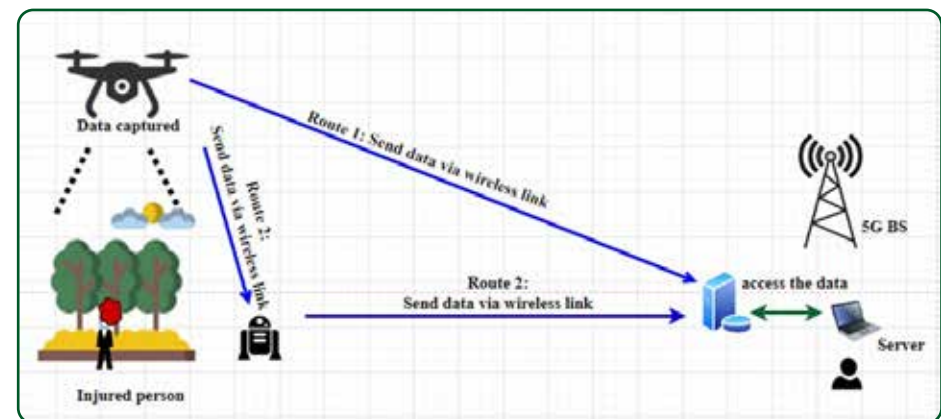
5G Connected Forest – The Results

5G Connected Forest – The Results

5G Network Deployment in a rural woodland setting

Despite the significant challenges caused by Covid restrictions and resultant project scope changes, restrictions deploying infrastructure in highly protected areas of natural and cultural heritage (in reality the experience of the project suggests that many highly protected natural and heritage sites are unlikely to be able to support the installation of even the smallest pieces of 5G infrastructure without extensive local and inter-agency consultation and agreement; and to overturn these protections would be wholly unacceptable), industry-wide shortages of 5G equipment, plus the normal challenges developing and deploying new technological solutions within time and cost constraints; Netmore UK successfully deployed two Private 5G networks across three rural and forest settings at Sherwood Forest Visitor Centre and the Rufford Abbey Country Park.

Sherwood Forest Visitor Centre: 5G Non-Standalone (NSA)

Network elements

- UPF cluster (2 * Dell R740 servers) running Affirmed MCC (SGW/PGW) for local breakout
- gNodeB (Dell R740 server) running Amarisoft software
- 5G RRH by AW2S handling 100MHz carrier in 5G shared spectrum (n77 3800-4200MHz)
- 4G RRH by AW2S handling 3.3MHz carrier in 4G shared spectrum (B3 1800MHz)
- IP infrastructure nodes (Cisco router and switch)

- Fiber optical link to ISP and leased e-line to data centre
- Edge compute node (Dell XR2 rugged server) for AR/VR content and throughput testing.

Test Results

	Sherwood Forest Visitor Centre
Downlink UDP/iPerf throughput test (Mbps)	230
Uplink UDP/iPerf throughput test (Mbps)	30
ICMP/Ping latency test (ms, min/avg/max)	11/26/44

Rufford Abbey & Mill: 5G Standalone (SA)

Network elements

- Mavenir NPN solution (3 * Dell R740 servers) handling 5G Core and OpenRAN based gNodeB functions
- Fronthaul switches (by Fibrolan) aggregating RRH connections and supplying PTP sync reference signal from GPS/GLONASS
- 5 * Mavenir 5G indoor small cell RRH handling 100MHz carrier in shared spectrum (n77 3800-4200MHz)
- IP infrastructure (Cisco switches and routers)
- Edge compute node (Dell XR2 rugged server) for AR/VR content and throughput testing.

Test Results

	Rufford Abbey	Rufford Mill
Downlink UDP/iPerf throughput test (Mbps)	230	950
Uplink UDP/iPerf throughput test (Mbps)	30	50
ICMP/Ping latency test (ms, min/avg/max)	11/26/44	23/28/43

Learnings for future similar deployments

Future operators of such locations though should be aware of the understandably long and complex processes and sheer manpower cost of creating a new network in such protected sites.

It can be done but is extremely costly compared to a typical suburban area. Key to success is to form a good relationship with all stakeholders early on and to put effort into understanding who the extended network of stakeholders are (there can be many different bodies and organisations) and where their remit will overlap with the planned project. This stage takes a good deal of time.

While it is difficult to be sure, we believe planning, project and similar costs are well over 50% of the total project in such locations. Even though private 5G technology costs are significant but reducing over time, the major issues are in labour and process when working in such locations.

5G-Powered Visitor Experience

Overall, all three 5G-powered visitor experiences worked successfully. Given the experimental nature of the project and the cutting-edge nature of the applications, it was expected that there would be challenges in developing and delivering the visitor applications. However, despite these challenges all the applications received high levels of user support and satisfaction.

The trials provided valuable insights into the operational requirements to deliver this type of visitor attraction on a commercial basis, as well as valuable track record and development expertise to enable the developers and venues to use the experience for future commercial applications.

Arrow Through Time

The Arrow Through Time application itself worked successfully during the trials, however the outdoor setting and network connectivity did provide challenges for the operation of the user trials.

When conducting the trials, issues primarily centred around the speed and stability of the network. The speeds were greatly below expectations and technical tests; technically speeds of 90Mbps were achievable but, when using fast.com, speeds were significantly below this. As a result the team were unable to stream the hi-res version of the content to the headsets during the trials.

The Xiomi 11T Android device was used to manage the experience, running the Android app and subsequently the web app. The HoloLenses then connected to the 5G network via wifi using a Zyxel NR2101 NR Mobile wifi dongle/router, containing a Netmore 5G sim. The Xiomi 11T also had a 5G sim, which enabled as pure a 5G experience as possible. However, throughout the user trials, whether connecting to the network via the Zyxel routers or using the Xiomi 11T Android device, speeds were often far below 90Mbps' additionally, the connection would frequently drop or not be found.

This made delivering the experience very challenging. In response, new versions of the 'Arrow Through Time' HoloLens app were coded that could help deal with the network issues, along with switching to the lower quality video content.

Also, early pre-trials identified challenges with hologram visibility being greatly impaired when viewed outside. The area selected in the forest was by far the best within range of the 5G antenna, however March proved to be a challenging time of year, with both bright sunlight and little to no coverage on the trees. To help improve visibility - in addition to the lighting techniques used (in-app shaders) and the carefully designed costumes worn by the actors - a white outline was added to the video during the R&D stage of development. During the trials, the team found the outline was no longer required with the high-quality video when viewed in the shaded forest area. However, due to the lighting conditions in the forest, the outline needed to be re-introduced. This was added to the online version of the app, so that at the start of the experience, the option was made available to select 'Outline' or 'No Outline' around the content. This provided an option when the light was too bright - during the trials all updates were only applied to an online version of the app.

Despite these challenges the trails produced good levels of positive visitor feedback – from 132 responses total (97 adults, 35 aged 13 or younger):

- 91% were satisfied or very satisfied with the experience
- 77% felt the length of the experience was about right (21% wanted more)
- 82% said the experience would make them likely or very likely to re-visit Rufford.

NB not all questions were answered by all trialists, therefore the percentages reflect the percentage of responses per question

Thinking about the location, would this experience make you more likely to return? • Very likely **32** • Likely **39** • Don't know **19** • Not likely **5** • Very unlikely **2**	Length of experience: • About right **101** • Too short **28** • Too long **1** • No response recorded **2**
How satisfied/dissatisfied were you: • No recorded answer **1** • Very satisfied **32** (First time/new experience, fun, good story, interactive/engaging) • Satisfied **56** (Offers an alternative experience at the site, novel experience, new tech) • Neither satisfied nor dissatisfied **7** (Inaccurate arrows, field of vision, sunlight issues) • Dissatisfied **1**	

Rufford Ghost Walk

The Rufford Ghost Walk worked successfully throughout the trials; apart from one occasion when the network router was inadvertently unplugged between sessions which halted the entire experience as all content was online and a network is required to provide the shared experiences, as well as to run/manage the experience.

Due to the network being stable, the Ghost Walk app was incredibly light weight at around 50Mb and all content was stored online. This meant that updating the app and installing on the 10 devices was fast and could be done in the morning ahead of the first trial of the day. There were some minor issues with bandwidth and speed for some of the longer or higher detail video clips which sometimes struggled with 4 or more users/headsets on the network.

The trials produced consistently high levels of positive visitor feedback - from 137 trialists:

- 86% were satisfied or very satisfied with the experience
- 71% felt the length of the experience was about right (26% wanted more)
- 83% said the experience would make them likely or very likely to re-visit Rufford
- 96% would recommend the Rufford Ghost Walk to others.

How satisfied/dissatisfied were you:	Length of experience:
- **6** no answer recorded - **52** very satisfied (great technology, very unique, good content, great holograms, wasn't expecting to enjoy it this much as not done anything like it before) - **66** satisfied - **13** neither satisfied nor dissatisfied (location not up to scratch/technical difficulties)	- **1** no answer recorded - **4** too long - **35** too short - **97** about right
Thinking about the location, would this experience make you more likely to return? - **55** very likely - **59** likely - **11** don't know - **8** not likely - **4** no answer recorded	**Recommend to others:** - **131** would recommend the experience to others - **2** would not recommend (too limited/needs further development) - **2** N/A - **2** maybe

5G Specific Functionality

Unfortunately, due to the significant issues and delays creating the first 5G network at Sherwood Forest (above) it was not possible to create a 5G network at Rufford in time for the trials. The Rufford Ghost Walk therefore used a fibre connection to generate a high speed wifi network for the trials, this gave a stable connection for which to conduct the trials with speeds around 90Mbps up/down but these were constant and reliable, so there were very few of the issues experienced in Sherwood Forest. Bandwidth and speed were still an issue in some specific cases and some of the longer or higher detail video clips would struggle with 4 or more users/headsets on the network.

Following the AR trial, a live 5G network was established using prototype Mavenair small cells was established in both the mill and abbey buildings. Live 5G connectivity was established with a specially tuned laptop with special 5G router however, at the time of project closure, it was not possible to connect the 5G network to the prototype network – further research and development continues outwith the project with Netmore, Mavenair and Parkwood Leisure, with the intention of delivering the Rufford Ghost Walk through the 5G wireless network in the future.

Tag in the Park

The Tag in the Park app is available for free through the Android and iOS phones through the Google Play and Apple app stores and has had over 600 downloads. Before and after user surveys were conducted on a sample of users.

Before testing, a survey of 50 potential users indicated:

- the majority of participants were extremely interested (55%) or very interested (32.5%) in location-based games and similarly

- were extremely (57%) or very (35%) interested in the concept of Tag in the Park.

- participants believed a mobile app would help encourage visitors to attractions and parks and would encourage them to spend more time visiting the location demonstrating the potential benefits of gamifying the visitor experience.

- the majority of participants believed a treasure hunt game would greatly encourage families and children to visit the location potentially helping to promote physical activity with children and encourage them to explore more green spaces.

Overall, this feedback shows the high demand for such an application to encourage visitors to attractions and parks.

Following the development of the app, 35 participants were recruited to use Tag in the Park and complete a feedback survey.

- 29 **(83%) found the app to be very easy or easy to use** - demonstrating the simplicity of the game making it accessible to all
- 31 **(89%) participants enjoyed using the app a great deal or a lot** - showing how the vast majority of users reported a positive experience after playing the game
- 32 **(91%) were likely to recommend the app to a friend**
- 29 **(83%) said they would use the app again**.

Visitors reported they spent longer at Rufford Abbey due to using the app and were more likely to return to find the remaining locations within the treasure hunt. Furthermore, visitors who have visited Rufford Abbey Country Park in the past stated the app helped them explore areas of the park they didn't previously know existed.

5G Specific Functionality

It was not possible to demonstrate the 5G functionality of the app in the live setting of Rufford Abbey as the Private 5G Network was not accessible for the non-Netmore SIM cards available in phones carrying other network operators. However, NTU researchers were able to demonstrate the 5G functionality in their own 5G campus laboratory.

The 5G powered cloud AR functionality is a very recent development and while it has been implemented there are still limitations such as the 3D models appearing different for users on iOS and Android operating systems. However, participants who have tested the feature all enjoyed the unique experience and believed it was an innovative feature that would benefit natural environments and encourage visitors in particular families to visit the park.

An initial wearable version of the application has also been developed to allow groups of people, or those without a smartphone such as children, to take part in the experience. The wearable experience utilises the same advances in IoT but due to wearable technology only recently advancing there are limited opportunities currently to embed 5G connectivity within the wearable. Additionally, wearables do not contain cameras meaning they cannot activate the AI object recognition challenge. Finally, the limited storage, screen size and resolution of wearable devices make it a challenging proposition to embed the full Tag in the Park experience within such a small device.

In addition to the exploration of wearable technologies, the use of robotics was also investigated. Robots using LiDAR were developed to navigate around a maze. In the future robotics may be used to provide a unique experience for players such as needing to find and tap the robot to complete an activity. However, current limitations with battery life and the inability for most small-scale robots to navigate the rough terrain of the park environment means it is not yet feasible

Overall, the research demonstrated the future potential for 5G to enhance proximity-based applications as the technology develops and assuming open access to the 5G network. The future of 5G enabled wearable devices for this type of app would need further research and development of enhanced devices/robotics.

5G-Powered Visitor Experience

The project successfully connected the robot dogs and drones to the local Private 5G Network and demonstrated improved performance with 5G connectivity compared with 4G connectivity.

In creating the environmental management use cases, the team at Birmingham City University conducted a significant amount of new academic research to both create models for a 'healthy forest' and to develop Artificial Intelligence / Machine Learning models to 'train' the robot dogs & drones.

The detail of this cutting-edge research and development work has now been published in the academic paper - Evaluating the Forest Ecosystem through a Semi-Autonomous Quadruped Robot and a Hexacopter UAV by Moad Idrissi, Ambreen Hussain, Bidushi Barua, Ahmed Osman, Raouf Abozariba, Adel Aneiba and Taufiq Asyhari.

In summary the paper identifies that "accurate and timely monitoring is imperative to the resilience of forests for economic growth and climate regulation. In the UK, forest management depends on citizen science to perform tedious and time-consuming data collection tasks. In this study, an unmanned aerial vehicle (UAV) equipped with a light sensor and positioning capabilities is deployed to perform aerial surveying and to observe a series of forest health indicators (FHIs) which are inaccessible from the ground. However, many FHIs such as burrows and deadwood can only be observed from under the tree canopy. Hence, we take the initiative of employing a quadruped robot with an integrated camera as well as an external sensing platform (ESP) equipped with light and infrared cameras, computing, communication and power modules to observe these FHIs from the ground. The forest-monitoring time can be extended by reducing computation and conserving energy. Therefore, we analysed different versions of the YOLO object-detection algorithm in terms of accuracy, deployment and usability by the EXP to accomplish an extensive low-latency detection. In addition, we constructed a series of new datasets to train the YOLOv5x and YOLOv5s for recognising FHIs. Our results reveal that YOLOv5s is lightweight and easy to train for FHI detection while performing close to real-time, cost-effective and autonomous forest monitoring." The full paper is publicly available at - https://www.mdpi.com/1424-8220/22/15/5497

Robot Forest Ranger

BCU researchers trained the Robot Forest Ranger for:

- Person detection (the robot dogs have been trained to identify human presence)

- Depth camera exploration during night (in relation to finding lost persons)

- Plants explorations (the robot dogs have been trained to identify specific plant types).

This functionality was tested in laboratory conditions. However, as the robotic dogs are not water proof, one of the major challenges faced during the trials was conducting the field tests during adverse weather condition.

This could have been resolved by using the newly released version (March 2022) of the Unitree robots as the B1 robot is known to carry larger payloads and is fully waterproof, making it align perfectly with 5GCF use case; unfortunately, these were not available in time for set up for the project's trials.

For the purposes of the project's trials this did negatively impact on the trial timescales as several test days had to be cancelled due to weather conditions. A further round of trials has therefore been planned to be carried after project closure to continue BCU's work.

5G Specific Functionality

The 4G/5G comparison assessed the 'jitter rate' (the variation in the time between data packets [e.g. video data] arriving, caused by network/routing delays) – the longer data packets take to transmit, the more jitter affects audio quality - the standard jitter measurement is in milliseconds (ms).
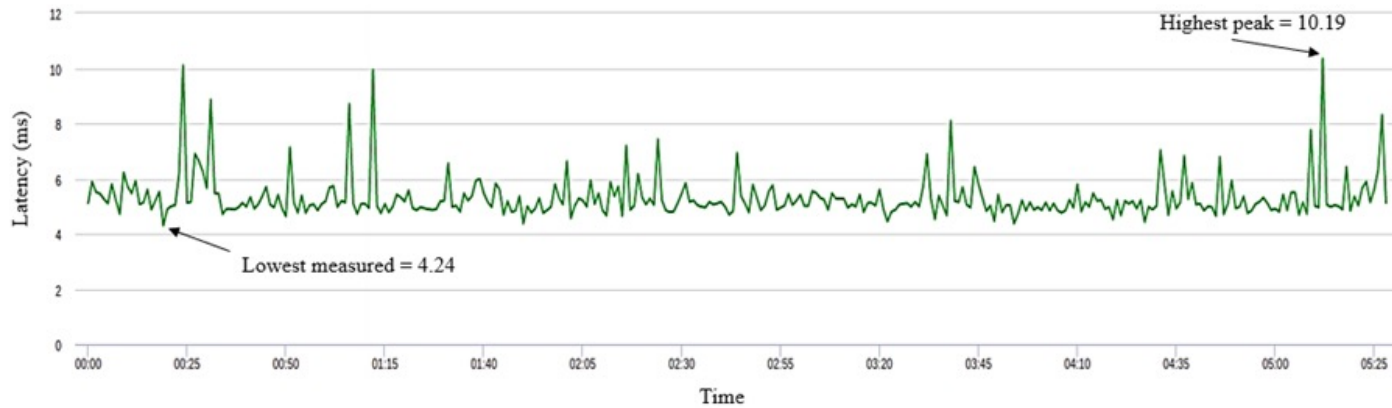
a) Measuring the Jitter latency through RFR video streaming via 5G
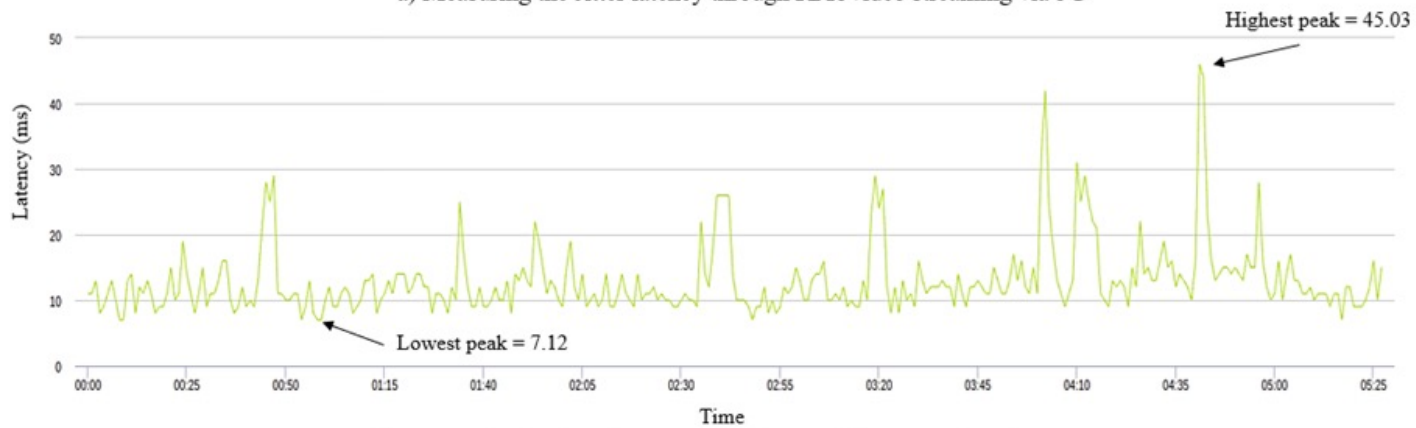
b) Measuring the Jitter latency through RFR video streaming via 4G

Using like for like comparisons, the jitter for 5G ranged between 4.24 to 8 with some ripples going up to 10.19; with 4G achieving ranges between 7.12 and 30 with some ripples reaching 45.03 (nearly 3-4 times 'poorer' than 5G. In other words, the video streamed from the depth camera on the robot dog reached the ground station at an efficient rate with minor delays in comparison to 4G which is approximately 3-4 times slower. Also, the average latency for 5G was approximately 4ms with a download speed between 600-700Mbps, whilst it was 13ms for 4G) with a download speed between 20-40Mbps. This clearly demonstrates that the data transferred between the smart system deployed in the forest can perform much faster with 5G connectivity, which as a result, can enable wider surveys in more settings in the time available for survey work.

Robot Forest Manager

Experiments were carried out to determine the effectiveness of the proposed system in detecting fire. Since BCU researchers could not create an actual fire in the forest, they tested their system on videos showing forest fire. Among these 30 videos, their system correctly identified every frame that contained a fire. However, when there was something that looked like fire (in one case a model dressed as a punk rocker with flame coloured hair!), the system was faulty detecting it as fire. To overcome this, they trained their fire-detection model with more pictures that included fire and those that included features that resemble fire. This improved the accuracy of the model to detect fire and decreased the false alarms.

Field Trials for SAR

For the search and rescue, BCU researchers first used open-source model for person detection (YOLOv5s). This model worked fine to detect a person when the footage is ground view, however, it couldn't detect a person when the footage was aerial view. The team therefore decided to train their own model from scratch. They collected a lot of video and image data from different sources and created their own dataset augmented with different background images and different people images. In outdoor, drone based, trials the BCU developed system worked well for the aerial identification of people.

Field Trials for Streaming

The objective of the streaming field tests was to see how the height of the drone affected the video quality and latency. The team discovered that when the drone was lower to the ground and closer to the server, the video was higher quality and lower latency. For example, the jitter rate was at its lowest when the drone was on the ground (0 meters). The latency of the video was also lower on the ground compared to the other altitudes. In terms of latency, streaming from the drone at 10 meters above the server was better than streaming from 3 meters. This is likely because the wifi signal was better at that time and there was less interference.

0 Meters
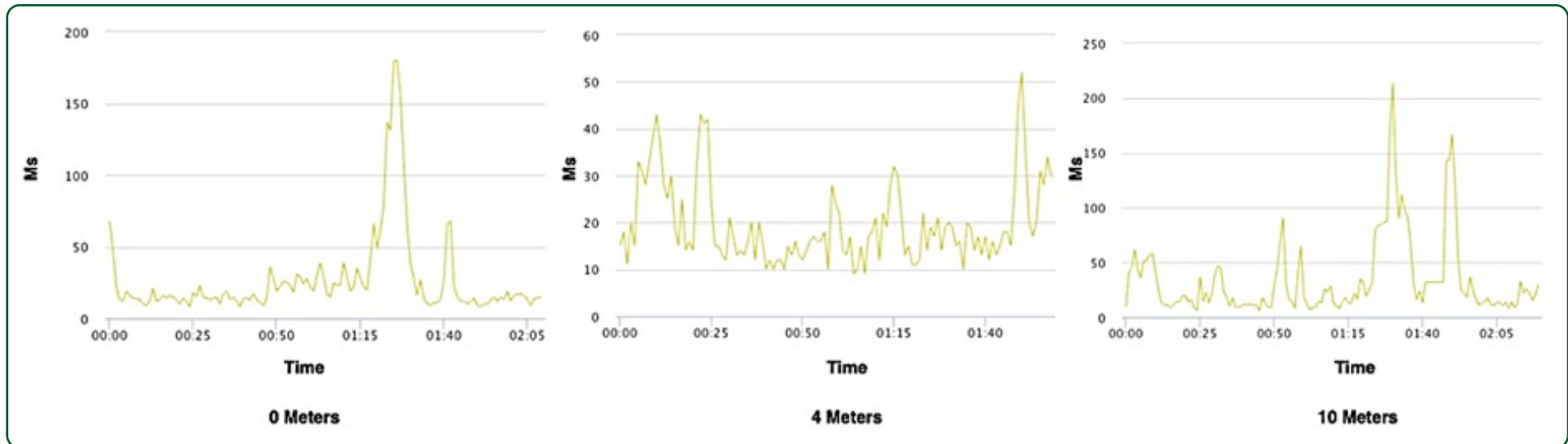
4 Meters

10 Meters

Overall, we found that streaming video from a drone is best at lower altitudes (0 to 10 meters). This is likely because the Wi-Fi signal is stronger and there is less interference.

Further research is being undertaken by BCU beyond the closure of the 5G Connected Forest project to further identify the potential for 5G to significantly improve this performance.

Additional Spin-off Benefits & Achievements

In creating the 5G Connected Forest project it was hoped that the project would not be a standalone one-off activity but rather contribute to Nottinghamshire's growing commitment to Digital Connectivity and the development of new business and skills opportunities in the county and surrounding area.

Nottinghamshire's new 5G-enabled Digital Innovation Centre

Inspired by the 5G Connected Forest project, Nottinghamshire County Council and ISPB/Innovation Nottinghamshire were successful in obtaining funding for the upgrade of the data and telecoms facility of the Worksop Turbine Centre (a serviced office facility for SMEs run by NCC) and the creation of a digital innovation centre in the building to act as a catalyst to support and inspire local businesses and careers.

To May 2022, the Turbine Innovation Centre had:

- Created 8 new jobs using digital/5G skills
- Assisted 89 businesses
- Supported over 1000 learners (see 5G Careers below)
- Upgraded 2,270m2 serviced office accommodation
- Installed Private 5G, LoraWAN and Bluetooth Mesh networks for businesses to showcase/trial innovations.

5G Careers

In discussion with local schools and colleges, and with the broader 5G community through the DCMS 5G Skills Working Group; it was recognised that, without a major telecoms sector in the area, there was a significant challenge for young people in understanding the opportunities presented by 5G and the digital technologies it powers.

In collaboration with NUAST (a secondary academy school in Nottingham city) and Vision West Notts College (an FE college based in north west Nottinghamshire), the UK's first 5G Careers Programme was developed in the digital innovation centre to showcase how the power of 5G is already changing every business sector and career.

The 5G Careers Programme is a flexible modular programme designed to introduce students to the new technologies that are already shaping the world of work that they will enter; and to inspire them to think about how this will impact them and their future careers.

The programme is relevant for students in every topic area and learning level (not only computing or other STEM topics) and can be tailored to focus on any business sector or study area - from construction to care & beauty, from engineering to teaching. It consists of three elements which can be combined or used standalone:

- A presentation (virtual or in class) "5G Will Change Every Career You're Thing About … and a load more besides"
- A self-study Resource Pack
- A team Challenge Project.

The programme was also shared with 5G Skills Working group partners and at national and international workshops.
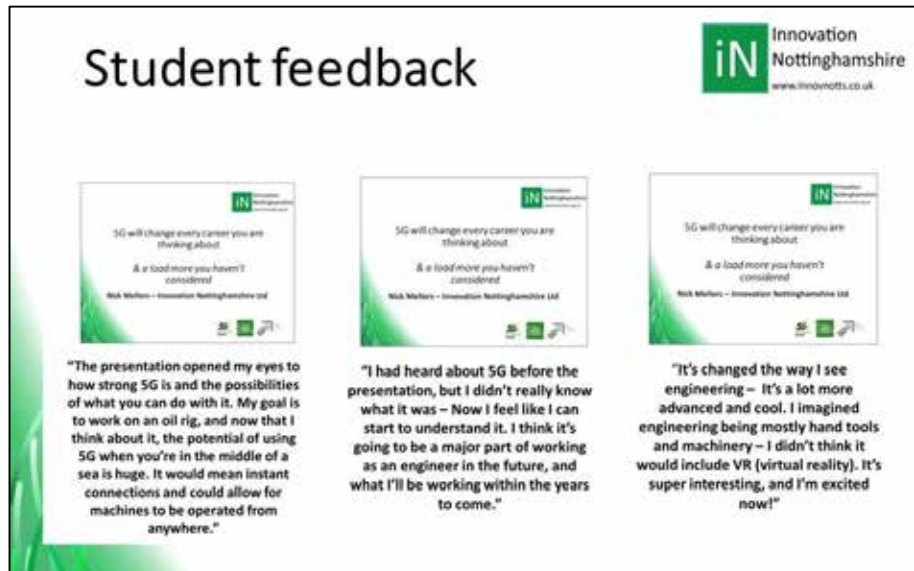
To May 2022, the 5G Careers Programme had worked with over 1,000 students across Nottinghamshire – with all four of the county's FE Colleges signed up to the programme in addition to three of the county's non-FE youth education services.

5G Business Research

In discussions with project partners, DCMS, other 5G testbed projects and the local business community; a sense of 'disconnect' was identified between the interest, knowledge and commitment of those involved with 5G and the telecoms sector in general and those outside this 'technology bubble' – this was almost certainly exacerbated by the overwhelming impact of the pandemic underway at the same time.

In order to establish some form of evidence base to understand the position of the broader business community, Habit5 were appointed to conduct primary research with businesses in the Greater Sherwood Forest area and across the county of Nottinghamshire, to provide insights and evidence to inform the continued implementation of the 5G Connected Forest project and any comparable or follow-on projects that may arise in the future.

The objectives for the primary market research conducted by Habit5, were:

- Gathering a strong evidence base to inform the Programme's work in both cascading and promoting the current use cases of 5G.

- Encouraging and inspiring local businesses to start looking at potential opportunities for using digital technologies to enhance the Visitor Economy.

- Benchmarking levels of awareness/interest/perceived benefit for both the Visitor Economy and wider industry sectors, in 5G and the technologies it enables.

Phase 1 of the research consisted of six 90-minute Focus Groups conducted via Zoom between Tuesday 10th August 2021 and Thursday 29th August 2021 with participation from 24 relevant business decision maker contacts. Phase 2 consisted of a bespoke Online Survey entitled the '5G and Your Business Survey' conducted between 8/12/2021 and 23/01/2022 with a total of 175 responses, from senior business decision makers, working in enterprises across Nottinghamshire.
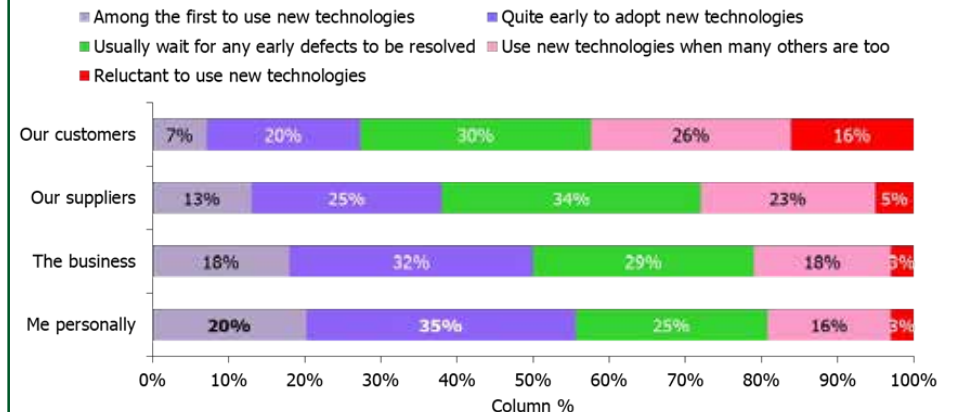
Population	Businesses					
All participants	Senior decision makers (e.g. Owner, Director, Senior Manager) in a business of whatever size, based in Nottinghamshire.					
Segment	Target Sectors Operating in the Visitor Economy sector or serving it				All Other sectors potentially capable of commercially harnessing 5G	
Phase 1 | Qualitative Research 6 x Zoom Focus Groups • 90 minutes duration • Up to 6 participants per group • NB 6 participants were recruited for each group but dropouts on the day did occur.	FG1 Attractions Potential AR/VR Experiences led x2 participants	FG2 Transport Potential transport use cases led x4 participants	FG3 Hotels + Potential smart accom. & property led x5 participants	FG4 Venues Potential catering & hospitality led use cases x4 participants	FG5 Other - Small Micro businesses <10 employees or fte equivalent x4 participants	FG6 Other – Large SME businesses 10 – 249 employees or fte equivalent x5 participants
Phase 2 | Quantitative Research Bespoke Online Survey • <10 minutes to complete • Device responsive design	175 survey responses received 58% of the survey sample were working in a business based in the Greater Sherwood Forest area 29% of the survey sample were employed in businesses that fell into the Target Sectors being prioritised within the 5G Connected Forest project.					

Thinking now about general attitudes towards innovation in digital technologies. Please select the description that best fits how you yourself, your company, your suppliers and your customers think about digital technologies.

Legend:
- Among the first to use new technologies
- Quite early to adopt new technologies
- Usually wait for any early defects to be resolved
- Use new technologies when many others are too
- Reluctant to use new technologies

	Among the first	Quite early	Usually wait	Use when many others	Reluctant
Our customers	7%	20%	30%	26%	16%
Our suppliers	13%	25%	34%	23%	5%
The business	18%	32%	29%	18%	3%
Me personally	20%	35%	25%	16%	3%

Base: Me personally (n=122), The business (n=122), Our suppliers (n=122), Our customers (n=122), Sample Size = 122

The researchers were able to confirm that the size/sector demographics of focus group and survey participants were in line with general size/sector demographics of the Nottinghamshire business community as a whole. However, it is recognised that as participation was voluntary it is likely that, by the nature of respondents being interested enough in the topic to spend time participating, there is likely to be some pro-5G/digital bias inherent in the results.

Key findings from the research include:

- Survey participants see themselves personally as more open to innovation in digital technologies than is the case for their business, their suppliers or customers. Exactly a fifth of the sample categorise themselves as 'Innovators' (20%), with over a third regarding themselves as 'Early Adopters' (35%) – this could affect the speed and degree of corporate adoption of future 5G projects

- Just over a third of businesses (35%) believe they 'know quite a lot about 5G' or have an excellent understanding of it. Conversely, just over a quarter (26%) self-effacingly admit they know very little or nothing about 5G. The most common position is to 'know a few things about 5G' (38%). 45% of those in the Core Target segment (Digital leads working in the target sectors) believe that they have good knowledge or an excellent understanding of 5G - a slightly higher proportion than is true for the other target segments.

Which statement below best reflects your current understanding or knowledge of 5G - the next generation of mobile technology?

Chart axis (Column %): 40%, 35%, 30%, 25%, 20%, 15%, 10%, 5%, 0%

Bar values:
- I am totally unaware of 5G: 4%
- I know very little about 5G: 22%
- I know a few things about 5G: 38%
- I know quite a lot about 5G: 30%
- I have an excellent understanding of 5G: 5%
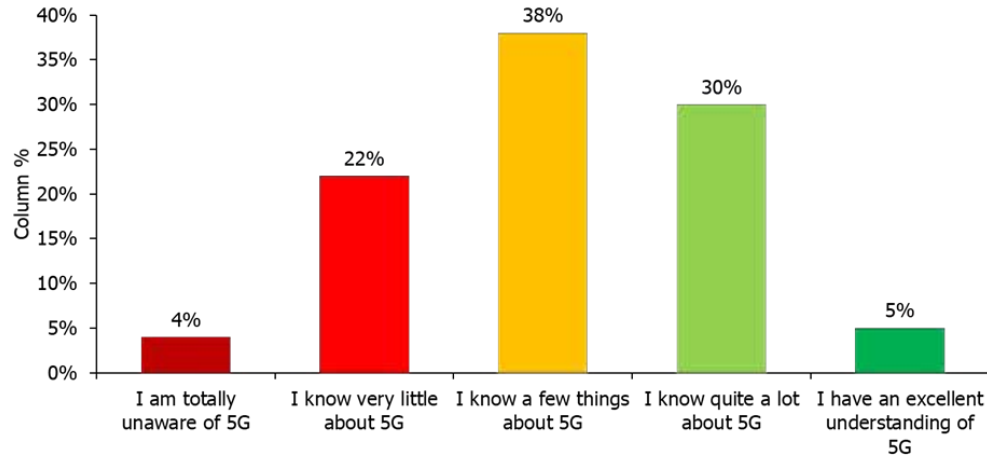
Base: I am totally unaware of 5G (n=5), I know very little about 5G (n=26), I know a few things about 5G (n=45), I know quite a lot about 5G (n=35), I have an excellent understanding of 5G (n=6), Sample Size = 117

- 12% of businesses are starting to use 5G in some way, with 20% having identified some way 5G could be used and 7% considering 5G could transform their business.

Thinking about using 5G, which of the statements below apply to your business? (Please tick all that apply)

■ % Valid Cases (Mentions / Valid Cases)

- We are not currently using 5G in any way: 77%
- We are starting to use 5G: 12%
- We have identified ways in which 5G could change how we do things: 11%
- We have identified ways to use 5G: 9%
- 5G enabled technologies could transform our business: 7%
- We are using 5G throughout our business: 1%
- 5G enable technologies have already transformed our business: 0%
- We are using 5G extensively in our business: 0%

Base: We are using 5G extensively in our business (n=0), 5G enable technologies have already transformed our business (n=0), We are using 5G throughout our business (n=1), 5G enabled technologies could transform our business (n=8), We have identified ways to use 5G (n=10), We have identified ways in which 5G could change how we do things (n=13), We are starting to use 5G (n=14), We are not currently using 5G in any way (n=89), Sample Size = 116

- Businesses most widely ('Extremely Relevant' 50%) regard 'Greater consistency and reliability of service' as very relevant to them, followed by 'Vastly enhanced mobile broadband' (45%) and then 'Instant connectivity' (41%). Removing current frustrations or at least significantly improving provision, is very much the first criteria that needs to be met by 5G. If it fails to meet this expectation, it is likely to severely impact receptiveness to all of the other capabilities of the technology.

Please rate the overall relevance to your enterprise (e.g. you, the business, your customers, etc) of each of the capabilities of 5G listed below, where a rating of '1' = No Relevance and a rating of '5' = Extremely Relevant.

■ 1   ■ 2   ■ 3   ■ 4   ■ 5

Capability	1	2	3	4	5
Greater consistency and reliability of service	9%	7%	14%	20%	50%
Vastly enhanced mobile broadband	12%	8%	13%	22%	45%
Instant connectivity (e.g. Dramatically reduced load times)	13%	10%	10%	26%	41%
Much faster download speeds (Average 100-200 megabytes per second. 2-4 times faster than 4G)	15%	8%	14%	25%	39%
Internet of Things (e.g. IoT, multiple devices communicating as required with each other)	17%	10%	16%	22%	35%
Greater capacity (e.g. Around 500 times more connected devices supported per square mile versus 4G)	20%	13%	15%	17%	35%
Much improved latency or responsiveness (e.g. Speed of response to a request, halved versus 4G)	16%	5%	16%	28%	34%
Much faster upload speeds (e.g. Less than 60 seconds for full HD film)	15%	11%	17%	24%	33%

Column %

Base: Much faster download speeds (Average 100-200 megabytes per second. 2-4 times faster than 4G) (n=110), Much faster upload speeds (e.g. Less than 60 seconds for full HD film) (n=110), Much improved latency or responsiveness (e.g. Speed of response to a request, halved versus 4G) (n=110), Greater capacity (e.g. Around 500 times more connected devices supported per square mile versus 4G) (n=110), Instant connectivity (e.g. Dramatically reduced load times) (n=110), Vastly enhanced mobile broadband (n=110), Greater consistency and reliability of service (n=110), Internet of Things (e.g. IoT, multiple devices communicating as required with each other) (n=110), Sample Size = 110

- Businesses more readily and more widely see the relevance of how 5G can solve or at least mitigate, current problems, challenges or frustrations; than the role 5G could play in helping them seize or realise new opportunities. The problems are very much being felt now, the absence of a missed or deferred opportunity is much harder to sense and relate to.

Which, if any, of the potential applications of 5G listed below, do you see as relevant to your enterprise in the future? (Please tick all that apply) – All Other Sectors

Application	% Valid Cases
Reduced load on wi-fi networks (Improving running speeds for devices)	65%
Improved and more consistent access to cloud-based services	59%
Improved ability for employees to work on the move	49%
Remote monitoring of land, buildings, premises, factories or plant	34%
Provision of real time data on efficiency (e.g. of production line or supply chain)	28%
Increased automation (e.g. of machinery or processes)	23%
Ultra High Definition (UHD) and 3D video applications and content	21%
Impending fault detection and alerts for machinery, vehicles, etc	20%
Enhancing service delivery by using Virtual Reality (VR) or Augmented Reality (AR)	14%
None of the above	12%
Self-driving vehicles	12%

Base: Self-driving vehicles (n=10), None of the above (n=10), Enhancing service delivery by using Virtual Reality (VR) or Augmented Reality (AR) (n=12), Impending fault detection and alerts for machinery, vehicles, etc (n=17), Ultra High Definition (UHD) and 3D video applications and content (n=18), Increased automation (e.g. of machinery or processes) (n=20), Provision of real time data on efficiency (e.g. of production line or supply chain) (n=24), Remote monitoring of land, buildings, premises, factories or plant (n=29), Improved ability for employees to work on the move (n=42), Improved and more consistent access to cloud-based services (n=51), Reduced load on wi-fi networks (Improving running speeds for devices) (n=56), Sample Size = 86

- businesses who do not see relevance in any of the potential applications of 5G presented, explain their attitude on this by referencing:

  - A desire to prioritise the full rollout of 4G over 5G

  - Health concerns and a perceived lack of independent trials

  - Fears surrounding the increased ability to track people in greater detail and with more precision

  - Minimal perceived relevance to the day-to-day operation of their business, which can be contextualised around the small size of their business as well.

As expected, the research paints a mixed picture of a business community focused on short term problems but with some positive recognition of the changes and opportunities presented by 5G. The research is being used to shape business engagement events '5G will change every Business Sector' and to support proposals for further projects to support and grow 5G adoption across the business community in Nottinghamshire.

Building on the Successes of the 5G Connected Forest

5G Network Deployment in a rural woodland setting

As new entrants to the UK 5G market, Netmore UK were ideal for the 5G Connected Forest to demonstrate the potential for DCMS's 5G Testbed & Trials to grow and develop the UK's 5G eco-system.

By successfully deploying two Private 5G networks in three rural and forest settings at Sherwood Forest Visitor Centre and the Rufford Abbey Country Park, Netmore have been able to establish excellent track record to support the development of future commercial opportunities in the UK.

5G Commercialisation in Nottinghamshire

Right from the initial planning of the project, Netmore and Nottinghamshire County Council were determined to find commercial applications for the 5G and related assets resulting from the R&D project. Specific commercialisation opportunities for each of the Nottinghamshire 5G enabled visitor attractions trialled within the project are shown below.

By working together throughout the project, the commercial approach has evolved between Netmore and Gooii in particular; particularly around augmented reality and the visitor economy.

The business model is to provide AR attractions to tourist locations with pricing being a case-by-case mix of upfront and rental. During the project a market size estimate was developed by the project for DCMS which showed at least 700 sites for potential installations in the UK. The specifics for each location of content and technical issues will be highly variable but we believe there will be market demand, some of the early sales leads already include:

- An attraction at a theme park and
- A historical and entertainment attraction similar to that at Rufford Abbey in Sherwood Forest for a district council that wants to make much better use of its under visited local castle.

5G-Powered Visitor Experiences

The successful delivery of all three of the visitor experience use cases were well received by users and have related commercialisation opportunities for the venues and developers.

Arrow Through Time

Despite the initial technological challenges of delivering the AR experience trials outdoors and in a sensitive environment; 'Arrow through Time' achieved very high levels of user satisfaction across all age demographics. RSPB, as hosts for the trials and managers of the Sherwood Forest Visitor Centre, are currently exploring the operational and commercial potential for including the experience as an additional 'paid for' visitor attraction (triallist feedback indicated an expected fee for the experience would be around £10 for adults & £5 for children).

Sherwood Forest once covered over a fifth of the entire county of Nottinghamshire, with the legend of Robin Hood and the foresters forming a core part of the county's 'DNA'. As such there are large number of other potential locations that would be suitable to stage this experience (indoors or outdoors) such as Nottingham Castle, Newstead Abbey, Newark Castle, the Thoresby/ Clumber/ Welbeck estates (all once part of the original royal forest), as well as many local history and commercial visitor attractions. The 'location-agnostic' nature of 'Arrow Through Time' would allow it to be deployed in multiple visitor destinations across the county, or elsewhere. Gooii are currently exploring the additional commercial potential of the application with NCC/RSPB as well as other potential organisations/sites.

Additionally, the creation of the world's first interactive holographic movie, as well as the development of track record and internal skills on the development and deployment of 5G enabled Hololens AR experiences has provided Gooii with the opportunity to develop and implement these ground-breaking technologies with other clients (whilst future discussions are commercial-in-confidence the company believe the potential for 5G-powered AR visitor experiences is significant).

Rufford Ghost Walk

With significantly high levels of visitor satisfaction, and a close strategic fit with the aspirations of both NCC and Parkwood Leisure for the Rufford Abbey site, a decision has already been taken to deliver the 5G enabled Rufford Ghost Walk as an ongoing attraction linked to the venue's newly developed Abbey Tales visitor experience.

A commercial business case has been developed by Parkwood Leisure which indicates an operational surplus will be generated in year 1, increasing in future years. It is currently expected that the surplus could be applied to fund the restoration work required to restore public access to the ancient Undercroft, which in turn could be used as an authentic setting for the Rufford Ghost Walk to continue in the future.

Additional related benefits

As a result of the installation of highspeed fibre connectivity to the abbey and mill buildings for the 5G networks, a by-product of the development of the visitor experience at Rufford Mill has been to significantly enhance the wireless communications available in and around the buildings. Public wifi access has therefore been enabled to provide free access for visitors, both adding value to visitors and also extending the highspeed coverage available to users of the Tag in the Park visitor app.

Future opportunities envisaged as a result of the availability of 5G and enhanced mobile connectivity include:

- Enhanced ticket sales when the experience is re-set in the more authentic Undercroft setting
- Adding additional AR packages for schools and other group visits.

- Creating children's virtual gaming parties & themed parties

- Robot dog litter picking/customer locations - walk round the site to show high footfall areas and update cleanliness before deploying staff in areas

- Virtual Bins, real time monitoring of rubbish levels to enable focussed collection & cleaning.

Tag in the Park

The project has demonstrated good levels of user interest and satisfaction in wireless proximity-based applications in a visitor setting such as Rufford Abbey and its surrounding country park.

Parkwood Leisure, as managing operators of the venue, are continuing to operate the Tag in the Park reward scheme; which is seen as a cost-effective method of enhancing the visitor experience and increasing visitor stay times and re-visit potential. There are no current plans to apply download charges for the app as it is seen as an enhancement to the current visitor experience, rather than an additional chargeable experience.

As a result of the 5G Connected Forest partnership; Parkwood Leisure will also be supporting NTU researchers in future trials and adaptations of the app and related research.

Additionally, NTU researchers have adapted the 'Tag with Me' concept for other settings. For example,

- To help increase physical activity for hospital service users. 'Tag 4 Active Lives' at the Highbury Hospital in Nottingham offers a fresh and innovative way for service users to explore the hospital grounds. Previously service users walked the "Highbury Mile" as part of their exercise regime but this became repetitive and mundane for patients. Tag 4 Active Lives now provides a unique treasure hunt experience to keep service users engaged while completing the "Highbury Mile". Users scan co-created objects using AI, tap tags around the route and answer educational and supportive information questions while completing the walk

- Nottingham Industrial Museum are interested in adopting the platform to encourage new visitors by providing an interactive mobile experience. Here the platform will be used to automatically provide informative interactive content when visitors are viewing an exhibit as well as provide quizzes about the exhibits to engage players.

Potential Future Research

Public 5G Networks – further research could be undertaken to explore how to make the benefits of 5G's low latency and high capacity could be applied through public, rather than a private closed, 5G network. This would appear to have the potential to open up the enhanced capability to any phone user, irrespective of their network SIM card.

Enhanced wearables and robotic devices – further research could be undertaken to explore the potential to integrate the platform with enhanced wearable devices or robotics.

5G-Powered Environmental Management

As the UK's first ever 5G connected forest using 5G-powered devices to capture Forest Health Indicator data in this way for the first time anywhere; the successful deployment of these technologies has significantly added to the understanding of the 'art of the possible' in this area.

The information from these use cases has already been disseminated through a series of papers and presentations for the benefit of both environmental and technology audiences. This work will continue beyond the life of the project.

In addition to the benefits and future potential for the Robot Forest Ranger and Manager concepts set out below; there has been one (less expected but extremely powerful) over-arching benefit which has flowed from the work.

The use of drones, and especially the robotic dogs, has really captured the imagination of everyone who has had an opportunity to see the project in action – especially young people. In addition to being showcased at major national events such as the UK 5G Showcase and The Cloud & 5G Live, the project has received national mainstream press coverage (eg 'Robots of Sherwood will guard the forest' – The Times, June 2022).

The team at BCU have been able to build on this to develop a new programme of public engagement activities, aimed at inspiring future generations to explore science and technology, including:

- Birmingham's "Inspired Family Festival"
- The forthcoming Nottinghamshire Day celebrations at Newark castle and Sherwood Forest.

BCU, NCC and ISPB/Innovation Nottinghamshire are now exploring the potential for funding future public environmental and 5G science awareness activities to build on this success (eg it is hoped to be able to create activities to support Nottinghamshire's Festival of Science & Curiosity in 2023).

Gizmo & Eric inspiring the next generation of 5G & environmental scientists at Birmingham's Inspired Family Festival

Robot Forest Ranger

In the live trials which were possible on days with fine weather; the vehicles were equipped with visionary sensors to carry out various object detections while feeding this data through the 5G connected WebRTC platform. As for the quadruped robots, multiple ground experiments were carried out in the rural area of Sherwood Forest including analysing the robot's motions and capabilities with the uneven terrain. It was observed through the GPS module operated on the onboard computer that the robot was able to successfully manoeuvre the forest on grass, footpaths and dense plantations.

The experimental deployment of the Unitree ground robots with the incorporation of AI and 5G connectivity have demonstrated its ability to gather an excellent range of Forest Health Indicator data in the bottom layer of the forest. Also, the comparator tests between 4G and 5G connectivity, demonstrated significant benefits for 5G deployments.

Having proven the technology, BCU researchers will continue their research beyond the life of the project for:

- Person detection (the robot dogs have been trained to identify human presence)

- Depth camera exploration at night (in relation to finding lost persons)

- Plants explorations (the robot dogs have been trained to identify specific plant types).

Robot Forest Manager

The Robot Forest Manager trials have proven that the concepts around 5G powered fire detection, search and rescue and streaming of data from airborne sensors and cameras in a forest setting are sound.

Whilst it wasn't possible to demonstrate all the proposed benefits within the time constraints of the project, the Birmingham City University research team are continuing their work beyond the life of the 5G Connected Forest in order to further develop the UK body of knowledge on the use and capability of these technologies to support forest managers across all these scenarios.

The team will continue to share their findings for the benefit of the wider technology and environmental management communities in the UK and internationally, with further research around:

- The additional benefits of 5G connectivity, including drone to robot communication
- Cost/benefit analysis of traditional versus 5G-powered use cases
- Improving machine learning models and algorithms

expected for publication in the second half of 2022.

Additional 5G Skills & Development

5G Careers

The 5G Careers Programme will continue to be delivered for the remainder of the 21/22 academic year and through the 22/23 academic year.

Additionally, work is underway in collaboration with Nottingham College to develop a pilot online version of the programme to increase accessibility and reduce the dependency on an individual presenter. Linked with this there are aspirations to develop some form of '5G Student Ambassadors' programme to support and inspire college students; as well as to build cross-college networks to embed 5G-related knowledge in course content and learning.

In collaboration the with D2N2 Local Enterprise Partnership, a 5G 'module' is being developed to integrate with the existing 'START' careers portal, providing career insights for school pupils and their families on the opportunities available through the power of 5G. It expected that this will be completed ahead of the 22/23 academic year.

Turbine Innovation Centre

Created outwith the 5G Connected Forest project, the Turbine Innovation Centre in Worksop in north Nottinghamshire hosts a Private 5G test network which is available to local businesses to test ideas and act as a showcase site for 5G and other digital innovations. Specific 5G based trials already have included:

- Testing 5G compatibility for a device to provide internet connectivity to remote areas
- Trailing IoT building management sensors
- Testing 5G compatibility for VR devices.

Building business/academic collaboration

The project identified very early on that there was more value in building on the collaboration opportunities with existing business and academic communities across the county; than in attempting to create a new ecosystem of 5G-specific business support and engagement schemes. As a result, through project partners and the Turbine Innovation Centre:

- A collaboration network has been established between the hosts of the 5G networks for the three project 5G sites, Innovation Nottinghamshire and the Turbine Innovation Centre, and Nottingham Trent University's SWIFt Lab with the Digital Catapult. Opportunities to share resources and signpost potential partners to the most appropriate trial setting are continuing, along with the development of future bid opportunities

- Integrating 5G information into existing business support programmes, for example the East Midlands Chamber of Commerce's Digital Upscaler programme (which provides business support & funding for local businesses looking to invest in new technologies, such as 5G) and the work of local business groups such as the North Notts Business Improvement District (BID).

These business and academic collaborations will continue to grow inspired by, but beyond the closure of, Nottinghamshire's 5G Connected Forest project.

Annex 1 – Additional External Links

5G Connected Forest Website

https://5gconnectedforest.org.uk

UK5G – 5G Connected Forest

https://uk5g.org/discover/5G-projects/testbeds-and-trials/5g-connected-forest

UK5G - Innovation Briefing Issue 9 | Project Roundup: 5G Connected Forest (May 2022)

https:// innovation-briefing-issue-9-project-roundup-5g-connected-forest (uk5g.org)

Mobile Magazine – 5G Connected Forest Digital Report 2022

https://mobile-magazine.com/brochure/ncc-cultivating-the-worlds-first-5g-connected-forest

'An Arrow Through Time' – example event booking site

https://uk5g.org/attend/an-arrow-through-time-ar-experience-sherwood-forest

Smart Sensing Lab (Tag in the Park)

https://smartsensinglab.com

Rufford Abbey

https://www.parkwoodoutdoors.co.uk/centre/rufford-abbey

Sherwood Forest Visitor Centre

https://www.visitsherwood.co.uk/at-the-visitor-centre

Evaluating the Forest Ecosystem through a Semi-Autonomous Quadruped Robot and a Hexacopter UAV by Moad Idrissi, Ambreen Hussain, Bidushi Barua, Ahmed Osman, Raouf Abozariba, Adel Aneiba and Taufiq Asyhari

https://www.mdpi.com/1424-8220/22/15/5497

Annex 2 – Lessons Learned

Throughout the life of the project, the 5G Connected Forest team worked closely with DCMS colleagues and colleagues across to 5G Testbed & Trials programme to share experiences and learnings. A summary of the Lessons Learned is shown below.

Lessons Summary	Using a phone device to connect the HoloLens to the network is a workable but flawed solution	Automate as much as possible when using the HoloLens	Accounting for video perspective when viewing in the HoloLens 2	Clothing can cause issues with hand tracking
Challenge (where appropriate)	To use a phone device tethered to the HoloLens device to connect to the 5G network	User placement of holograms on the floor was error prone and tricky, especially in poor lighting. Getting the distance correct was also inaccurate	When viewing a single video file in the HoloLens 2 - and the same would apply to any AR/MR headset - we film on a key colour eg. Green screen and drop out the background. When a single person is on screen they can walk forward in the video and it will look like they're walking towards you. However if there are two people in the video and one is further back than the other we found that there is no concept of depth, similar to being blind in one eye. The result would be that the person in the background wouldn't look like they are behind the person standing in front of them but they would look like they are standing level but are smaller and floating in the air	Tracking issues started to occur when the user is wearing dark clothing. Much as black cannot be projected as a hologram it seems the device cameras can also struggle to pick up jet black colours. What is interesting to note, is that the tracking becomes a lot more difficult when the clothing has lighter patches blended into dark clothing, which may hint that it relies on clothing options with a solid colour. A follow up text could be considered that experiments with clothing that contains patterns
Resolution (where appropriate)	This works but with caveats. Speeds are reduced to around 50%, you can only wirelessly tether - wired tethering to a RealMe X50 Android device drew power from the HoloLens and didn't provide a network connection. The connection was also lost after disconnection and would need to be reconnected each time its used. The results would be sinilar using any such connection eg. an iPhone 12	Our code now autoscans the floor and automatically places the content the correct distance from the audience with no interaction from the user.	One solution would be to use multiple video files but this would prove tricky to sync and would also place additional stress on the hardware. The simplest solution was to ensure that when filming, as much as practicable, the actors always kept on the same line. This was a challenge when filming Robin Hood, as we sometimes had as many as four actors on stage for some comple scenes.	Not to wear clothing that can interfere with hand tracking

Further Detail	We do not believe this method provides a reliable long term solution		This wouldn't be a problem using full CGI. However, the performances and engagement from using live actors creates a far more believable solution that is easier for audiences to connect with. Note this was discovered in the September quarter, not June though investigations into this did start in the June quarter	This is an important consideration when commercialising, to ensure that operatives are aware of this issue
Date lesson recorded	22/06/2021	22/06/2021	08/09/2021	08/09/2021

Lessons Summary	What AR/VR headsets currently offer the best potential for adoption with 5G?	Numerous technical lessons learnt have been reported in the HLD deliverable which has been reviewed and accepted by DCMS	Underestimating labour related costs and delays	Viewing Hololens holograms outside is a challenge
Challenge *(where appropriate)*	Rapidly changing marketplace with no existing guidance	1) The 3.8 - 4.2GHz and 26GHz bands are relatively new and so finding vendors that support them is difficult 2) It is anticipated that an AR headset will be connected to the 5G network by means of a dongle to start with. This is because we do not expect headset devices to include support for 5G in band n77 within the life of the project 3)We face major issue providing such coverage using Shared Access because there are existing indoor users of the 1800 Shared Access spectrum a few miles away which Ofcom deems too risky in terms of our technology interfering with them. The 1800 band also has an antenna height limit of 10m which is below the level of the treetops	Time and effort involved organising the design, procurement and construction of a new small 5G network as expected but additional time and effort involved in organising the practical aspects - as opposed to the technological aspects - of the network has been higher than expected. Linked to partners Due to supply chain issues delays with infrastructure installation affecting 5G (Brexit, post-COVID and Ukraine war). As a simple example, the ground beneath and around the Rufford Abbey area used for family recreation is subject to special archaeological measures. This means that it is virtually impossible to do anything there and certainly not to deploy fibre across the grassy area so that we can create a cell on the other side of the area a couple of hundred metres away. Also delays with products arriving from Europe caused a knock on effect on completion	The ampitheatre has no shade, which makes it difficult to see the holograms in bright light. The Hololens cameras also have difficulty finding the floor to place the holograms.

Resolution (where appropriate)	Develop a set of evaluation criteria & assess a range of current models	After checking what is possible in the Shared Access bands, in the end we took a strategic decision to deploy an OpenRAN. This meant that the consortium had to procure such dongles which proved difficult to find. In the end we found Zyxel devices which worked, but the product is now discontinued. We also have working phones but the HoloLens insists on charging from them so this is not a practical for production solution In the end we could demonstrate a working solution with the dongles but the issue revealed was the capacity of Internet access required – 100Mbps we contracted was not enough as proven by monitoring. The future solution agreed by all was to rely on an Edge computing system. Air interface speeds seemed sufficient, but in the absence of edge computing of the AR experience, we cannot be completely sure	Overall, it seems to us that the time and effort involved in the non0technical aspecs of setting up a network is significantly not greater than the cost of the equipment itself Important to insurance contingencies built in with current market issues for any short/medium term projects	To change location is possible or add shade. Brighten the holograms, film with bright light, and use only light coloured costumers where possible. Also added a white CGI outline to the video in our code to help actors stand out
Further Detail	This is a known requirement for the project within existing milestones, without it the project would be delayed, or risk unecessary costs. Microsoft HoloLens 2 were selected as the headsets			We've mitigated this as much as possible however in the future we would not recommend using the HoloLens outdoors, though we are pushing the technology as far as possible in this respect. We also expect future iterations and other hardware manufacturers to migigate some of this via the use of better screens and lidar cameras
Date Lesson Recorded	10/01/2021	12/11/2020	24/04/2022	22/06/2021

Lessons Summary	Difficult tracking the floor due to dirt or grease on the HoloLens cameras	Focussing on the technological aspects of 5G can reduce business/workforce and interest/engagement in exploring and developing 5G based business solutions	n77 network code locks in 5G devices for 5G standalone mode	OpenRAN configuration complexity takes more time than anticipated initially
Challenge (where appropriate)	We had issues with tracking the floor and placing content that we found was caused by dirt OpenRAN configuration complexity takes more time than anticipated initiallyor grease on the HoloLens camera from it being handled during everyday use	Outside the 5G/telecomms sector there was little interest/awareness of the relevance/importance of 5G	Many of the devices that were tested within the project have shown that firmware has a white-list which allows only specific network codes (PLM Nid) to work in 5G standalone mode	OpenRAN software maturity (Mavenir in the case of 5G Connected Forest) is not yet that flexible and many simple configuration changes that we used to do in traditional networks requires complete deployment of network function stack. This significantly increased time needed for rollout and optimisation of the 5G network
Resolution (where appropriate)	As simple as wiping the camera lens and cleaning them. The solution sounds obvious but identifying the cause was not, as the first port of call is traditionally to check the code, not the hardware.	When developing 5G careers, skills and business awareness information - focus on the use cases that other technologies (AR/VR, IoT, Avs, robotics, AI/machine learning, haptics) can make in delivering their potential through 5G. In the same way that 'the internet' is simply the thing that powers/enables real life applications	Consult and request device suppliers to lift restrictions for 5G standalone if possible	Consult OpenRAN software suppliers for more friendly interfaces and documentation to be included into software roadmaps
Further Detail	This is an important consideration when commercialising, to ensure that operatives are aware of this	Nottinghamshire's 5G Careers programme was created as a spin-off from the work of the 5G Connected Forest project and has now worked with over 1000 students across the county	All devices that were tested work pretty well in 5G NSA mode or in N78 band, which confirms issues are specific to N77 band only	
Date Lesson Recorded	08/09/2021	29/04/2022	04/05/2022	04/05/2022

Lessons Summary	GPS/PTP timing sync reference is critical for 5G network enabling	Outdoor sites security and protection	Advantage of edge computing for augmented reality applications	
Challenge (where appropriate)	Time sync reference (GPS/PTP) in 5G networks should be carefully planned in as much detail as possible at the very early stages of the network planning. Small differences in profiles, or protocols, supported by hardware or software, might block 5G network enabling	Outdoor rural sites require proper, secure installations in order to accommodate expensive hardware which includes vandal/damage/theft protection coupled with CCTV operation	Throughout the project there was a debate concerning whether edge computing (ie. A local server) would be needed, or whether the internet connection provided would suffice. After field testing with real users it was found that when refreshing certain scenes, or at key points such as the start-up, the AR application was flooding the 100Mbps link. Whilst providing a giabit or faster link may have solved this technical issue, commercially of course it would be unviable.	
Resolution (where appropriate)	Network planning phase should include more detail analysis of timing sync references	Carrier grade telecom shelters with proper fencing and damage/theft protection should be used for rural, outdoor sites	Tourist attractions using 5G AR are technically possible but also must be profitable for the site owner and providing a very high speed connection in many tourist locations outside major cities would require professional DIA based on Openreach's EAD as was used in this project. This would generally be too expensive for most tourist use cases. IT was generally agreed in the project that commercial use of AR would be much better enabled by edge computing although this creates its own set of challenges. In particular, if able to rely on temperature sensitive enterprise grade servers at a particular location (as opposed to the availity of space on site requiring a cabinet which is a more expensive option coupled with being difficult to obtain currently from telecom rugged servers)	
Further Detail	Transport and Radio network hardware and software that has minor differences in supported GPS/PTP profiles may result in 5G radio units not receiving a proper timing reference, and this will be a blocker for 5G network enabling	Local IoT/CCTV solution developed and deployed at testbed		
Date Lesson Recorded	04/05/2022	04/05/2022	21/05/2022	

Nottinghamshire's 5G Connected Forest project was established to identify ways in which 5G could be used to protect and promote areas of natural and cultural heritage, such as the area in and around the legendary Sherwood Forest.

5G Connected Forest

Department for Digital, Culture, Media & Sport

Nottinghamshire County Council

Prepared by
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