Final Report

Document Name	Final Report
Author	Simon Rockman
Document Version	1.3
Publication Date	20/06/24
Review Date	n/a
Distribution	BoB/DSIT (under review by cellXica then expected to be ALL)

Version	Date	Amended By	Comments
1.0	08/05/24	SR	Initial Documentation
1.1	20/06/24	MM	Edits
1.2	25/06/24	SR	Edits, security additions
1.3	12/07/24	MM	cellXica edits

Contents

Executive Summary

Best of British emerged from the UK's efforts to diversify its telecom infrastructure after Huawei's removal. It aimed to create British-designed, efficient 5G cells for mobile networks. The project successfully deployed cells at events like Priddy Folk Festival and Glastonbury, facing challenges with network complexity and interference.

The name, Best of British, highlights an unusual characteristic of the project. While most complex high technology projects involve international co-operation, often spread over multiple continents, Bob was born from a desire to be home grown. All the consortium companies being British based. The cell was conceived as Cambridge project and software all the way down to the most basic levels was written in the UK. All design, engineering, production engineering and manufacture of both software and hardware was done within the UK. Inevitably some of the components and tools were sourced internationally. Perhaps the greatest supply chain threat comes in the form of the Zynq chip from Xilinx. While Xilinx is owned by AMD, an American company, the advanced fabrication is based in Taiwan. At this time no suitable alternative exists, but with a global understanding of the issues around the South China Seas fabrication is being moved to friendlier nations.

Cost comparisons highlighted nuances in government-sponsored infrastructure projects, showcasing varying costs and coverage effectiveness. Best of British aimed to provide a cost-efficient model for deploying small cells in rural areas compared to existing initiatives.

Lessons learned encompassed challenges faced during the project, from chip production constraints due to the global chip shortage to insights on radio planning, project management issues, and grant claim processes. Overcoming complexities in integrating intellectual property between collaborating entities proved difficult but highlighted the need for tighter cooperation and possibly joint ventures for smoother integration in the future.

Substantial challenges were encountered in running a project that would normally have taken three to four years within the timescales mandated by the FRANC projects. These were exacerbated by the overhead of the project management processes. The failure to secure an extension meant that the project was only able to deploy and conduct initial tests on five cells. This was not sufficient for meaningful data.

The project emphasized the importance of sustainable power consumption (measured as watts per UPRN) and the significance of understanding antenna design in optimizing cell efficiency. While the project aimed to bridge gaps in the UK's telecom infrastructure, it highlighted the need for better planning, collaboration, and efficient project management in such large-scale ventures.

Before the initiation of the project, cellXica was making specialist 2G and 4G cells which it sold at high prices and low volumes into tiny niche markets. It wasn’t seeing 5G demand from customers and did not have a product on its roadmap.

FRANC funding allowed the creation of a high quality, low power small cell suitable for mobile network operators, getting to the core objective of the Future Networks Programmes in improving supply chain resiliency while also opening doors for export and growing the UK’s reputation and markets overseas.

Aims and Scope

The Best of British, or BoB to its friends, project sits at the heart of the aspirations of the Future RAN Competition. Following the removal of Huawei from UK mobile networks and a number of reviews – the July 2018 Telecoms Infrastructure review, the 2019 UK Telecoms Supply Chain Review Report, and ultimately in the establishment of the Telecoms Diversification Taskforce under the leadership of Lord Livingston of Parkhead. It was the taskforce's recommendation that led to FRANC and Best of British is precisely the kind of project that the groundwork envisaged. A cell designed, engineered and manufactured in the UK which is built to a standard which means it can be deployed by the UK operators.

The project was envisaged deliver apparatus which would significantly reduce the cost of deploying a small network through advanced radio design, while expertise in engineering low power consumption cells would reduce the environmental impact and running costs. Some aspects of the power optimising technology failed to make the final product.

One of the benefits of the FRANC programme was co-operation between the different projects. In particular this saw the M5Q developed for the BoB project incorporated in the 5G Drive project where cellXica is working with Virgin Mobile O2. The validation of the equipment by a major UK mobile network operator cannot be overstated.

The Companies behind the consortium

About Telet

Andy Smith (left) and James Body with the award Telet won at the conclusion of the Testbeds and Trials

An important element of the project was that it was led by Telet Research, which as a full operator member of the GSMA bills itself as the fifth UK mobile network, working alongside specialist cell manufacturer cellXica and Southampton University spin-out AccelerComm.

Telet was established in 2016 to develop mobile telecommunications networks by James Body with a focus on cellular networks. He was formerly the head of research and development for the international mobile network Truphone, and before that a senior officer in the Royal Signals. This history gave him extensive experience in devising and implementing innovative solutions for specific problems. While living in the Chalke Valley in Wiltshire, England's largest mobile coverage not-spot, Body and his co-director and longtime collaborator Andy Smith looked at how to provide coverage in an area the major mobile network operators had neglected.

The success of a small network in James' village of Broad Chalke led to Telet winning funding from DCMS for the Rural Connected Communities programme and the start of a mission to rid the UK of rural not spots. The initial deployment was also the start of Telet's relationship with cellXica which provided the equipment for the Broad Chalke network.

Since the Rural Connected Communities programme required a 5G implementation, and cellXica had no plans to develop such apparatus the Mobile Operator Neutral Host, of MONeH project specified equipment from another British Manufacturer, Cable Free.

Through the Rural Connected Communities project Telet proved its ability to punch well above its weight. It pioneered use of Ofcom's new regulations with Local Access and Shared Access licences, and through these became a full operator member of the GSMA.

Telet's innovation and expertise in the acquisition of spectrum means that it is the holder of the most Local Access Licence spectrum, having significant more coverage than all other licence holders combined. Working with Ofcom and the major mobile network operators, Telet pioneered the use of point and radius to define coverage areas rather than the single cell approach anticipated when the spectrum was made available. This has made larger deployments quicker with less administrative overhead. Telet welcomes Ofcom's announcement of Sandboxes which are similar in nature to the Point and Radius local access licences but aimed at a wider number of networks.

Membership of the GSMA is something of a coup for Telet. It joins EE, Three, Virgin Mobile O2 and Vodafone as the only UK members. While the others have more staff than would fill a football stadium, Telet has fewer than would be on the pitch. GSMA membership gives Telet access to and influence on the future mobile standards, and an international relationship with all the major operators in the world.

About AccelerComm

Existing equipment uses generalised algorithms for some aspects of cell design. AccelerComm optimises these for 5G to deliver substantial performance gains. A network built using hardware designed with this technology would need 20 percent fewer cells. The relationship between the partners was as a direct result of UK5G organised events for FRANC.

This proved to be too ambitious within a timescale for the funded project, but it is expected that the work done in the early stages will bear fruit in later devices. It's worth understanding the principals as quite a bit of the work done for Best of British will benefit a pioneering British Technology

In many aspects of engineering there is a virtuous circle. If you make a car lighter it needs smaller brakes, a smaller engine and you improve performance and fuel economy. That in turn means it can be made lighter. The same is true of mobile phone networks. If you can improve the efficiency of the radio, both in the handsets and the base stations, you can have faster data transfer, fewer cell sites and better battery life.

Professor Rob Maunder has developed technology which will radically reduce the cost of deploying mobile

Technology developed by at the University of Southampton in 2016, has been spun out into AccelerComm which has established itself as a global leader in 5G New Radio physical layer IP, which increases spectral efficiency and reduces latency of the 5G Radio Access Network.

Rob is an industry authority on channel coding, having gained his PhD in Wireless Communications in 2007 from the University of Southampton. He has published over 100 IEEE papers and resources on the holistic design of signal processing algorithms and hardware implementations for error correction decoders, including Turbo, LDPC and Polar decoders.

Rob's research has reframed the industry debate around channel coding for 5G and significantly changed the direction of the 3GPP's RAN1 working group. In spite of long-standing myths to the contrary, this work has shown that both turbo and polar decoders can benefit from arbitrarily high degrees of parallel processing, without compromising hardware efficiency. This has enabled significantly improved throughput and latency, without requiring excessing chip area or power consumption. This breakthrough has formed the foundation upon which AccelerComm has been built. The physical layer is where hardware meets software. Improving the efficiency of this has a knock-on effect to the whole of the radio network.

AccelerComm's low density parity check code is a third of the size of its competition providing high performance low power 5G NR solutions in FPGA and ASIC.

High spectral efficiency is crucial in protecting cellular and other radio networks from insufficient capacity, low data rates, sparse coverage, and poor quality-of-service.

Despite the roll-out of early 5G networks these factors remain an issue that impact customer experience and risks stifling new service revenue opportunities for

operators. Improvements to spectral efficiency can also be used to significantly reduce infrastructure equipment and operational power consumption, with less equipment needed to provide the same network performance.

The company's IP is playing a significant role in helping to optimise the performance of Open RAN. While open systems offer significant benefits is to create a rich and broad ecosystem of vendors, with specialists in various components collaborating to drive technical breakthroughs and developments the extra standards and interfaces can impact performance.

Nowhere is this challenge more apparent than in the radio network itself. The spectral efficiency of a radio network (bits/sec/Hz) is a key indicator that defines how efficiently an operator is using the spectrum that in which they have invested. By relying on generic products, often derived from Wi-Fi or broadcast, Open RAN operators face significant impacts in the performance of their network in terms of spectral efficiency and performance, with more equipment required to serve the same number of customers.

AccelerComm's complete Open RAN 5G channel coder/decoder design can bring dramatic benefits: Recent research from the industry analyst firm Mobile Experts quantified the impact on a typical Open RAN US mobile operator as saving approximately 20% of base station equipment costs and operating power consumption.

The AccelerComm IP packages can be quickly integrated and flexibly delivered for use in custom silicon (ASIC), programmable hardware (FPGA), or as software solutions.

The company is already working with several major silicon manufacturers including Intel, Xilinx, Silicomm, and many others. Driven by a leadership team comprising executives and senior talent from ARM, Qualcomm and Ericsson, AccelerComm was recently named in the Electronic Engineering Times Silicon 100: Emerging Start-ups to Watch.

With both AccelerComm and cellXica having physical layer (PHY) software it was always going to be challenging to allocate tasks between the companies. It is heartening that there was no "not invented here" syndrome and both worked together with great respect.

One area of work that was undertaken by AccelerComm was to develop the physical uplink channel (PUSCH) that carries the user data. Initially when integrating the software between AccelerComm and cellXica proved challenging a decision was made for AccelerComm to prioritise the Uplink PUSCH Channel, and to pause the development of the Uplink PUCCH channel and Downlink Control channels in hardware. This led to longer timescales and increased cost as the project realised that the developments and acceptance could not be developed in parallel.

This massive overspend reflected the additional effort given to attempting to combine IP from cellXica and AccelerComm. The additional costs being reflected only in the work done by AccelerComm only. The integration of existing AccelerComm IP into the cellXica IP was completed but the effort required gave a clear warning of the difficulties that lay ahead without a change of course.

In the event the work of integrating the AccelerComm IP to the FRANC timescale proved too challenging. In addition to the technical challenges there were significant legal issues when providing evidence for grant claims. As the IP is the entire value of AccelerComm it was not willing to let the source code out of the company. While DCMS/DSIT asked to see it, this would be a bit like ordering a cake and then asking the baker for the recipe.

The telecoms world is small, and the number of people developing base station technology even smaller. While ultimately the work that AccelerComm is doing has not made it into the M5Q it is to be expected that the relationships built will find their way into future opportunities.

Since the ambition of the Future Network Programmes is supply chain security the development of fundamental cellular IP within the UK is a key component of the strategy. This not only protects the Uk from having to rely upon IP from possibly hostile nations – Huawei does a lot of research in this field – it has potential for export.

The solution that was adopted was to purchase the software components from Xilinx, the supplier of the FPGA at the heart of the M5Q. While it was appreciated that this is less power efficient than the AccelerComm software it was a necessary route to take give the fixed timescales of the FRANC project. In a commercial environment, where there may have been more flexibility on time and budget a different decision might have been made.

The need to keep to the timescales laid out in the Grant Funding Agreement led to AccelerComm leaving the project. Moving forward with two partners made it much easier to keep to the contracted timescales but as two thirds of AccelerComm's budget had been spent in the first year, and the Xilinx software had to be bought in, there was an increased cost to the project.

This extra funding was found from within the existing budget.

The costs for purchasing IP in general were significantly less compared with writing it, so the decision to purchase IP from Xilinx helped prevent a project overspend which would have been the case had cellXica written the IP themselves. There was, however, more labour required from cellXica to integrate this IP which duplicates work which had already been completed to integrate the AccelerComm IP.

One other aspect of the departure of AccelerComm from the project was that they were also to have been instrumental in the assessment of the effectiveness of the M5Q, in report writing and attending events associated with the project. Telet took over the responsibilities for these items from AccelerComm, which increases their labour costs.

About cellXica

There is a small British company in Cambridge that has been making mobile-phone base stations for ten years. Yet even people steeped in the industry have never heard of cellXica.

Niro Mahasinghe, director and CTO at cellXica with the 2G/4G M3Q cell which led to

Buried deep inside the base station is what cellXica most wants to improve; the hardest bit of mobile technology, known as the physical layer or layer 1. This is where the real radio engineering happens; where analogue meets digital and where the cleverest of clever people turn specifications and formulae into hardware. Wrapped around this is the software and hardware that make a mobile-phone base station.

There is something very Cambridge about cellXica. Products are 100% designed and engineered in the UK – the hardware, the stack, the physical layer, it's all British. It's a small company of just 22 people; and it doesn't seek world domination or a stock-market listing. The company doesn't even have a sales person. Instead, it concentrates on designs, which it licenses to other companies to manufacture in volume.

There is a common theme among Cambridge companies: they are most interested in fundamental, deep-technology challenges. This is what makes the science parks around the city so inspiring to visit.

The company started in 2011 by developing 4G software-defined radio, or SDR. It was enabled by the development of the Zynq chip by Xilinx Inc. This chip is a FPGA with hardened ARM cores, a class of device that bridges the gap between hardware and software. It's hardware, but the design of the hardware can be reprogrammed.

Director and CTO at cellXica, Niro Mahasinghe says: "That's the exciting thing; at that time RF technology was locked into the chip design process, so Zynq came in at the right time. Based on ARM cores, it made it quite possible for us to have a chip which was more like a system-on-a-chip, you can have high-speed digital design on it. So, we wrote all of the LTE base station physical layer and the protocol stack ourselves."

The work was prescient. SDR is a technology that has spent decades being the next big thing - by the time cellXica was formed, many had written it off as a pipe-dream. Today it's become the universal technology used for 5G.

As a niche product supplier, cellXica has some very special customers, with military or search and rescue comms being typical applications. This leads to interesting differences between cellXica and mobile network equipment vendors. When reliability is very much a matter of life and death, it concentrates the mind on the design priorities. When deployment means having a base station that can be flown, or carried by someone parachuting into harm's way and which needs to run reliably on batteries, a lot of thought must go into efficiency. And when command and control is within a fairly small area, it has to be a private network with no need for backhaul.

To meet the demands of these customers, cellXica has taken its physical layer, protocol stack and equally impressive SDR and wrapped them up into a range of base stations with different features and form factors. Out of this has come a couple of units that have mainstream appeal for industry and private networks. The eXsite-M3Q is a small cell capable of supporting up to 32 users including limited LTE-M, while the eXsite-SC6 is its bigger brother, which uses the Marvell OCTEON Fusion-M SoC as the modem and can link 512 devices. Both are currently 4G. It was the purpose of the Best of British project to accelerate cellXica's move into 5G. The M5Q being the 5G cell produced for BoB built on a new radio motherboard "SC7".

The M5Q is the first of a new generation of 5G small cells, there are four antenna ports, one socket for the GPS which provides timing information and power and data through a single cable.

The technology cellXica builds deviates a little from convention, which cellXica is not afraid to do in order to provide a practical solution to an otherwise unsolvable problem. For instance, the company has patented its GiLTE, pronounced "guilty", technology, which stands for GSM-in-LTE. That's GSM as in 2G and LTE as in 4G, which means that this radio can do both at the same time, with the GSM part embedded within the LTE carrier. That's especially exciting in the UK when a company wants to use the shared access licence part of band 3. This is available to any organisation that wants to use it on a first-come first-served basis by stipulating a postcode within which it will be used and applying to Ofcom. While the initial shipments of the M5Q for BoB are 5G only band 77, there are plans to evolve a 2G/5G version in other bands for wider UK and export markets.

Spectrum liberalisation is a driver for a number of British innovations. It means more demand for units such as the SC6, and that in turn means increased volumes and so reduced prices. In particular, having honed the design using Zynq, cellXica can commit to the volumes necessary to produce a system-on-a-chip design.

As cellXica devices are technology-driven and contain GiLTE, they are ideal for the community radio projects typified by the 5G Testbeds and Trials, Rural Connected Communities projects. In many rural locations, there will be a long-term need to support 2G as well as 4G, so the GiLTE

The company is working with partners to build OpenRAN systems by supplying hardware to vendors that integrate their own software.

Pop Up experiences

One of the applications Telet pioneered in the research work for the Best of British project was the deployment of 5G networks for events. The aim here was not to provide coverage for attendees but for services and event organisers. The two projects Telet undertook were for the organisers of the Priddy Folk Festival and for the Event Medical Services at Glastonbury.

For the Priddy Folk Festival the deployment was a single 5G N77 SA cell from Sunwave. We've seen speed of over a gigabit out of this equipment but for the Priddy deployment we were limited by a 200Mbs backhaul. Use of bandwidth was reduced, and flexibility improved by deploying an open 5GS core locally on a shuttle PC.

The installation at the Priddy Folk Festival delivered a reliable 150mbps across the village.

To allow the stall holders at the festival to use the Telet 5G network we provided them with low-cost CPE units using a Telet SIM. This gave the users access through Wi Fi, notably with their chip and pin point of sale terminals.

We deployed 12 CPE devices. While the network was built for the use of stall holders and the event organisers, we were aware that there was a likelihood of stall holders sharing the Wi-Fi passwords with attendees and that would rapidly outstrip our capacity to serve those for home the network was intended. To mitigate against this the traffic was shaped, giving limited throughputs for access from the point-of-sale machine, while the organisers enjoyed a much higher share of the connectivity. This worked very well and we saw no challenges to our ability to deliver a service.

One challenge we did encounter was poor management of the Wi-Fi frequencies from some of the older point of sale terminals. This was a key learning and in future deployments we will restrict the capabilities of the CPE to take this into account.

The Priddy Folk festival deployment worked exceptionally well. It raised a good amount of money for charity and provided essential connectivity in an area where there are next to no radio signals. Ofcom was very cooperative with a Trials and Innovation Licence.

The scenario was very different with Glastonbury. While Priddy Folk festival had very little to worry about in the way of other wireless users, Glastonbury had Vodafone as a major sponsor with 200,000 attendees, hot-spotting Wi-Fi, numerous blue light services, broadcasters, PMSE licensees. The radio environment was very much more complex, with the organisers strictly marshalling radio access. For this project Ofcom declined to issue a trials and innovation licence and asked us to apply for a Shared Access Licence which has a higher bar in terms of radio planning and interference avoidance.

Telet's pneumatic mast deployed at Glastonbury.

Telet has extensive experience with applying for Shared Access Licences and has seen the process take up to eight weeks. For this application we called those individuals within Ofcom who we have a good relationship with and talked them through the requirements and how we would mitigate interference. This included discussion on the different frequencies for the sites. We received the invoice for the licence in 12 days. While the licence then took another couple of days the invoice provides certainty that it will be granted and allows us to continue with deployment plans.


Festival Medical Services were delighted with the Telet deployment

The Glastonbury use case was tightly focused on supporting the event medical services, and in particular providing data access to, and tracking of, the six ambulances.

The network consisted of four sites using N77 5G SA radios from Cable Free and a local Open 5GS core. Access to backhaul represented a challenge both from an engineering perspective and politically.

Worthy Farm is a rural location that for a week a year or two turns into a place with the population of Swansea. Much of the core infrastructure is limited. Telet has a telescopic mast on a trailer which can be driven to a site and erected in minutes. This was used at Glastonbury but for the other three sites erection and testing was more involved.

The deployment proved very successful, and won plaudits from both the Event medical Services and the event organisers.

The plan is to extend the number of users in 2024 by adding Point of sale systems on the model we developed for Priddy Folk Festival.

Cost benefit Metrics

The comparison among various government-sponsored mobile infrastructure projects in the UK presents a nuanced analysis of deployment costs and coverage outcomes. The focus is primarily on the effectiveness and efficiency of these initiatives in providing mobile connectivity to specific premises, indicated by Unique Property Reference Numbers (UPRNs). Here's a condensed breakdown of the key points:

Mobile Infrastructure Projects Compared:

DCMS Mobile Infrastructure Project (MIP) [2016]: Costing £35.81 million, it established 97 mast sites, extending service to 7200 UPRNs, averaging just under £5k per UPRN.

Scottish Government 4G Infill Programme [2020]: Deployed 36 live sites and 29 sites in progress, averaging £440k per site, resulting in a cost over £5k per UPRN.

Shared Rural Network (SRN): Budgeted at £1.023 billion, aimed at providing coverage to 280,000 premises by 2026, with an estimated cost per UPRN of around £3.6k. However, concerns exist regarding fulfilling target population coverage and focusing mainly on rural areas where MNOs claim no coverage, neglecting urban 'not spots.' The programme is running much later than planned and although it claims it will still reach the final objective the interim milestones have been missed.

Challenges and Discrepancies:

Coverage Obligations: While MNOs committed to specific land mass coverage percentages, reports show discrepancies between declared coverage and actual service in areas supposedly covered.

Not Spot Discrepancies: Instances highlight areas with poor or no coverage despite MNOs claiming comprehensive network presence, such as within the M25 boundary.

Cost Model Demonstration:

The Best of British project established a costed model for deploying small cell-based infrastructure in rural environments, aiming to compare costs against conventional microcell networks like MIP and SRN.

Complexities in Comparison: Difficulty arises in aligning service profiles; MIP and SGRIP offered basic 2 Mbps 4G services, whereas the M5Q offer 5G services at up to 450 Mbps.

Methodology and Results:

Cost Calculation Method: Utilized coverage templates of 4G cell sites to generate UPRN listings.

In summary, while each initiative aimed to improve mobile connectivity across the UK, disparities exist in costs per UPRN and coverage effectiveness. Challenges in meeting declared coverage obligations by MNOs raise concerns about the actual service provided in various regions despite significant investments in infrastructure projects. The MONeH Project attempts to introduce a cost-effective model for rural connectivity, addressing the complexities of comparing different service profiles in mobile infrastructure deployment.

Improving Performance

Initial builds of the M5Q ran at around 7Mbps downloads and 0.6 Mbps up. That is clearly well below the speeds which is serviceable. Understanding the steps cellXica is taking to develop the technology gives a feel for how the equipment has been fundamentally engineered from the ground up.

This is important because it means that the technology and intellectual property for the M5Q is entirely British. A common way to develop products is to use a reference platform. A company which is good at manufacture will buy a mature design from its suppliers. Typically, Intel or Nvidia will supply its customers with plans for a product and the manufacturer will then be behoven to the suppliers, to use their components and methodologies. Given the exposure most chip manufacturers have to the Taiwanese semiconductor fabrication chain this represents a treat to the British supply chain. By engineering the M5Q from the ground up, albeit based on lessons learned from the M3Q, cellXica helps provide a more robust offering for British deployments.

Complete component choice control doesn't entirely ensure independence from the use of Taiwanese electronics but offers the flexibility to seek other options if the need arises. The Xilinx Zynq from Advanced Micro Devices used in the M5Q is fabricated in ROC but cellXica is not contractually bound to use it.

The development of a cell based on British IP has fantastic export potential, particularly with our FVEY partners sensitive to buying infrastructure from manufacturers in China or sharing borders with Russia. One thing which adds to the flexibility and IP security of the M5Q is that cellXica has its own real time operating system, written in house.

Low level control of the design also allows cellXica to optimise the radio performance and power efficiency of the cell, this is well illustrated by the process which is being undertaken to improve the speeds from 7mbps to 100mbps and beyond.

The power levels that are used to shape the radio signal to contain the data the cell is transmitting are at the low levels of digital electronics, but to transmit the signal over any distance they have to run through a component called a Power Amplifier. These, particularly in 5G applications, often eschew silicon for gallium nitride which is a British specialty through the Cardiff cluster around the Compound Semiconductor Catapult, and through other FRANC projects.

The problem with a power amplifier, particularly over high bandwidths such as the 100MHz the M5Q is capable of and at frequencies over 3GHz, is that the amplification is not linear across the frequencies. What comes out is not a clean, louder version, of what goes in. To address this requires digital pre-distortion, the creation of an algorithm that understand how the power amplifier will alter the signal and ensure that what comes out is not what goes in but what should have gone in.

It's where the maths hits the metal, a process of digital accounting for the non-linear nature of the amplifier. There's a feedback loop which looks at what should have been transmitted, what is transmitted and accounts for the discrepancy. At the output of the amplifier, there's a coupler where the amplified signal is fed back into the base band through another receive port and that constantly moves. This caps the ultimate power that you can push out. The M5Q will produce 30dBM (1 Watt) per channel. Across the four channels, with a high gain antenna this works well with the Shared Access Licence regulations.

The licencing rules allow for a bandwidth of up to 100MHz. The first step in improving the performance of the cell is to take it up to this limit which will produce initial download speeds of up to 120mbps, although uplink will still be extremely limited. For that more work needs doing in the scheduler side. Since cellXica has concentrated on the physical layer it has not had the resources to concentrate on the cell software. When there is the opportunity to optimise the higher levels there will be a significant improvement in the uplink speeds, the end result will be symmetric. This reflects the changing requirements of consumers, who are increasingly content creators. One application cellXica cites is use of CCTV. For this the symmetric 400mbps speed which the M5Q will ultimately be capable of is more than adequate.

Ideally a cell would dynamically change its uplink and downlink according to need, and the 5G standard allows for this but there's a problem because all cells in that entire geographical area need to be coordinated. They're all same frequency and at the same time. So, if one is transmitting, all the other cell is receiving then nearby cell then they'll inhibit each other. So, what you do is you synchronize all the cells in your network to typically GPS or IEEE 1588 Precision Time Protocol. For this you have the PTP grandmaster in your ethernet network and you have to have an ethernet switch passing the PTP traffic. This is important to critical infrastructure security as since the UK left the European Union, we no longer have input into the Galileo GNSS system. The M5Q supports GPS and will add IEEE 1588 PTP.

While the M5Q is based on the 4G M3Q there are some significant challenges moving to 5G, with a 2G, 3G or 4G signal, because it's narrower when it fades, everything fades in the same way. With 5G and a signal 100 MHz wide, some parts of the signals, some frequencies, fade more than the others. The processing needed to mitigate this is one of the things that makes higher speeds a challenge.

The project started with the M3Q. That is a 4G radio developed for a few low volume customers in areas such as mountain rescue. Funding through FRANC has allowed cellXica to develop a 5G radio capable of being sold to MNOs. This goes to the core of the aims of the Future Networks Programmes.

While the physical layer was mostly re-written for the M5Q having the M3Q as a starting point was a huge help. As was having a full software stack and a working cell. Some elements of the M5Q physical layer had been developed for a customer prior to the starting of FRANC, but this was specialist and didn’t support MIMO. One of the enabling technologists is bigger and better Xilinx chips. This is a more flexible approach than that taken by Nokia and Ericsson which uses multiple discrete components.

The move from a 28-nanometre processor to the 16 nanometre Xilinx is one of the things that has given the M5Q exceptional power saving benefits. This in turn has allowed the cell to be powered through the ethernet cable, albeit at 90W. That allows for a 5W loss in the cable to give headroom to 85W over an expected consumption of 60W to 75W. A draw akin to a tungsten lightbulb.

The end result is a British designed and built 5G small cell. Developed to the most fundamental level in Cambridge. This is not a product where a kit of parts has been assembled from a number of manufacturers and as a result it’s a design which can be licenced to drive exports, and it’s flexible enough to be adapted for any custom requirements a mobile operator might have. At the end of the project, it is at Technology Readiness Level 6. Beta units are on site and being tested, with the extension that testing and development will take it to Technology Readiness Level 8.

Building on Best of British

The Best of British project has succeeded in developing a highly efficient new small cell. This is crucial in the aims set out by the Telecoms Diversification Taskforce to provide UK mobile operators with more choice in who they purchase equipment from.

The next stage is to convince the operators that the M5Q is suitable for their needs. One route would be through SONIC which has been established for just this purpose, unfortunately the M5Q falls outside the SONIC remit as the testing service is looking to ensure compatibility between Open RAN devices and to this end is looking for equipment which comprises of separate Radio Units and Distributed Units, and to test compatibility between vendors. While the M5Q conforms to OpenRAN guidelines it combines the RU and DU in a single box so SONIC is not a viable option for testing.

A better solution is happy customers using the equipment, and Telet is well on the way to developing this. Outside of its work on government funded projects, Telet installs small networks to fill in the telecommunications potholes in the information superhighway for communities, campuses and companies. Deployment of M5Qs through Telet and similar companies such as Freshwave, Wavemobile and AQL is a potential route to operator acceptance. Another is through cellXica's relationship with Virgin Mobile O2, in the 5G drive FRANC project.

The use of Best of British M5Q cells will provide public service to UK PLC, that doesn't necessarily have to be through the four, soon to be three UK MNOs. One of the big outputs is that there is very much a place for neutral host players based on the commercial model. Big MNOs can't do it, therefore we've got to find another way.

A key technology developed by Telet for the project understands that the new generation of mobile operator which fills in the not spots left by the major mobile network operators needs a different core architecture. Telet has split the core into a front end, multiple instances running separately at each deployment, and a back-end running centrally. The front end controls the radio side of the network, registering handsets, and the like while the back end provides interconnect. It becomes both a local and a national network.

The architecture provides a single logical entity to interconnect with the rest of the world. If you had many hundreds of privately owned radio networks it would be unwieldly for the big MNOs to interconnect with them. By separating the front and back ends you eliminate this problem. It also reduces the vectors for attack from a security perspective. Telet has built the system using software from a number of vendors and integrated them. Using this technology Telet expects to be the first network in the world to achieve a 5G SA bilateral interconnect.

The acid test is meeting the hundred percent objective, which was in the DSIT wireless infrastructure strategy published on April 11th 2023. It set out a more ambitious goal than that proposed by the shared rural network and is something that will become essential when the analogue fixed phone system is switched off.

One of the most important things to do to ensure universal coverage is to identify where the not spots are and what spectrum is being used where. Telet has started work in both of these areas. The use of an app within the Telet SIM which monitors coverage provides valuable, anonymised data on when the phone falls out of coverage. Other technologies map where there is coverage, it's more valuable to map where there is not. Spectrum has become too valuable and useful to be awarded on a blanket basis and needs to be optimised location by location. By equipping the M5Q to sniff out what spectrum is being used locally it is able to report to Ofcom where licences that have been

granted are and are not being use. This paves the way to dynamic spectrum access, akin to the US CBRS model but more elegant. This will allow rapid deployment of coverage in not spots, and then backing away when a preferred licence holder takes over. With the merger of Three and Vodafone more spectrum should be liberated to shared access licence holders, and band 3, 1800MHz, which is little used by Vodafone, is a prime candidate.

One of the key learnings from Best of British has been the importance of SIMs within the 5G ecosystem. It is largely misunderstood or not understood at all and is absolutely an essential component within any 5G deployment. It's important to develop this further, working on both physical and eSIMs, and again to have British development capability.

Power Efficiency- understanding watts per UPRN

A key metric for the sustainability of the M5Q is the power consumption of the unit. The mobile industry has long had a drive to reduce the cost of operation but as environmental concerns grow there is added impetus to reduce the consumption of all elements of the power consumption of the network. The metric of watts per UPRN has a number of influencing factors not least the height and design of the antennas used, and these are reflected in the Telet Planning tool. But the power consumption of the M5Q is an important element and is worth measuring in isolation.

The M5Q has been designed to be especially power efficient. It runs on a Power over Ethernet connection which limits the input power to 90W so making the best use of this is crucial to the economics of deployment. The more locations, defined by Unique Property Reference Numbers, that can be covered within that 90W budget the more sustainable the M5Q.

One metric the Best of British Project can use to define the efficiency of a cell is the physical mass. This is the reflection that the components, especially cavity filters, used within traditional cell design are both large and heavy. The mass, the size and weight of the cell, isn't an absolute metric but has an impact on sustainability.

It is worth remembering that the M5Q is based on the M3Q and that in turn on cellXica's previous applications that are designed to run on battery power. The complete engineering of the cell being under cellXica's control, very little of the engineering is bought-in components, allows for very much greater optimisation.

Conversely their nature of the design must be considered, using a software defined radio and Xilinx System on Chip is inherently more power hungry than discreet components. There is a trade-off between efficiency and flexibility.

The main metric needs to be emitted Watts against Watts consumed. The specification calls for 90W in and 30dBm (one Watt) per port. This needs to be measured when we have production units with stable firmware.

The metrics can be measured internally within the cell and give a break-down for the efficiency of the power amplifier. There is a trade-off between the power used to compute the optimum pre-distortion for the power amplifier and using less compute but having the power amplifier be less efficient.

Security

While the Best of British Project was in train the head of the National Cyber Security Service was Ian Levy, in an informal discussion he described Open RAN security as “A bag of spanners”, and side that he didn’t want nigh on a decade’s work on protecting mobile networks to be blown apart by introducing Open RAN, but neither did he want the UK to be vulnerable by having such a narrow choice of vendors. Both are security risks and the solution was to make Open RAN systems as secure as the proprietary ones.

The NCSC’s Ian Levy NCSC “We are here to make the UK the safest place to live and work online.”

As Levy explained in an interview “With DCMS we are trying to diversify some of the product supply, because at the moment we’re overly reliant on a very small number of suppliers, to the point that we are nationally dependent on them. And from a national security point of view, that’s a terrible place to be. We need to better understand how we can shape the markets so there’s more supply. That helps both private networks and public networks, big and small, increased diversity, increased robustness. That’s a key part of our mobile work with DCMS.”

1. Confidentiality
2. Integrity
3. Availability
4. Risk Management
5. Compliance
6. Continuous Improvement
7. Management Commitment
8. Security Policies
9. Asset Management
10. Access Control
11. Incident Management
12. Business Continuity Management
13. Human Resources Security
14. Physical and Environmental Security
15. Supplier Relationships

ISO 270001 Security Principels

The aspect of security which Open RAN exposes is the increased number of vectors of attack which come from having publicly documented links between crucial parts of the system. Links like the S1 interface between the Radio Unit and the Distributed Unit. In the case of the M5Q this was not as issue as both parts of the cell are housed in the single unit but the principal of increased vecors remains. To counter this the Best of British project closely guarded access and only SIMs with a listed IMSI were allowed access to the cell and the network. A further level of security was added in that the IMSIs were allocated on a cell-by-cell basis and not across the whole network. This may prove impractical for a commercial deployment but was quite a manageable at the scale with which we ran Best of British.

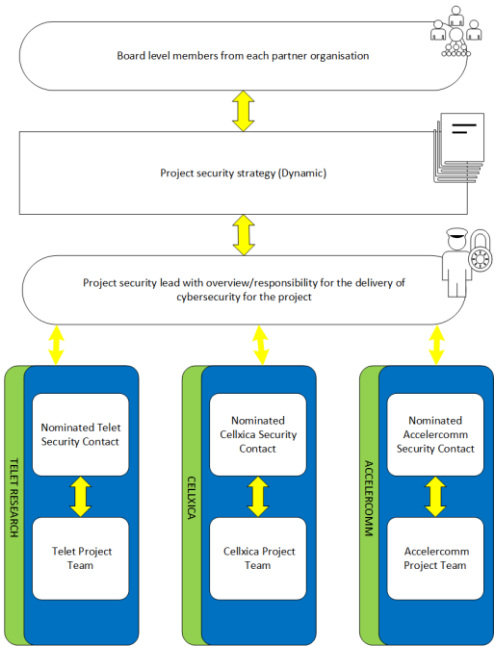
The threats to attack that most concerned Levy were those around network security so the consortium partners employed ISO 270001

At the heart of the "Secure by Design" principles, developed for DCMS by Copperhorse, is the goal of making cybersecurity a fundamental aspect of product design. By embedding robust security measures from the design phase, eliminating default passwords, ensuring secure software updates, protecting user data, and promoting transparency, these guidelines aim to create a safer digital environment for consumers and reduce the risk of cyber threats.

The guidelines advocate for manufacturers and developers to prioritise security features during the conceptualization and development phases, ensuring that devices are resilient to attacks throughout their lifecycle. This involves implementing robust security measures, such as secure storage of sensitive data, encryption, and regular software updates, to protect against vulnerabilities.

One of the key tenets of the guidelines is the management of passwords. In a consortium with multiple partners and subcontractors this presented a challenge which was solved by having good governance.

The Secure by Design guidelines also highlight the importance of secure software updates. It was ensured that the M5Q was capable of receiving updates in a secure manner to address newly discovered vulnerabilities. This included implementing mechanisms for verifying the authenticity and integrity of updates before they are applied. By ensuring that devices can be kept up-to-date with the latest security patches, the risk of exploitation by cybercriminals is significantly reduced.



Board leadership ensured security was always top of mind.

This was an approach that went to the heart of BoB which worked to take a secure-by-design approach throughout and a secure-by-default approach wherever possible. This is often difficult when working in collaboration, working with emerging technology and ideas, and dealing with a set of, as yet, unknown issues. An ethos of security is baked into all of the work that cellXica does as this is a requirement for the majority of its existing customers. Within Telet the leadership comes from the top, the CEO having been an officer in the Royal Signals and many of the staff and subcontractors having worked on projects involving national security.

It is from this perspective that an appropriate security governance framework was developed that protected and secured the network without stifling innovation. In an ideal environment all cells would be connected through dark fibre and not over the public internet, this unfortunately is not economic so it was necessary to ensure that VPNs and firewalls were in place to ensure the security of the network. The serial number of the cell is part of the security mechanism. Ensuring that each cell only logs into the network once, to look for fake cells as bad actors.

One aspect which greatly enhanced the security of the project was the use of in-house software. It is remarkably unusual for small vendors to have control of the full software stack. While some elements did come from Xilinx the need for integration meant that cellXica had a full visibility of the code. With the wide bandwidth of the cell, up to 100 MHz, the radio performance differs significantly between the top and bottom of the frequency range. This puts an onus on timing and the efficiency of the code meaning that it has to be understood in detail.

While focusing on security and design during the project but also prioritising security in relation to configuration, management and monitoring.

A major security concern with the project was the protection of Intellectual Property from compromise. It was necessary to ensure that some of the PHY software developed by AccelerComm was kept to a tight internal distribution within the company. Requests from DSIT to compromise this security were rebutted.

One aspect of security which is often neglected is physical security. At a network level this was addressed initially by running the core at the home of the CTO of cellXica. Had the project been extended, with more devices the core would have been moved to Telehouse North which houses all the other UK Mobile Network Operators and has ISO 27001 accreditation, with the highest standards of physical and network security. The lack of a project extension also meant that there were only limited deployments and the project did not encounter any issues with site security.

Telet is a full operator member of the GSMA, and take part in the Security Working Group. The GSMA is looking to establish guidelines for smaller operators to ensure that they don't become a vector for attack into the major operators. In future Telet will look to use key learnings from Brest of British and its other projects to inform the GSMA's world standards for security.

Security is traditionally though of as wanting to prevent unauthorised access, but an additional aspect we considered was theft. Any equipment which might be perceived to have high value and which is essentially left bolted to a lamppost is vulnerable. The solution for this was local education. We had to ensure that any street thieves where aware that our cells were highly specialist with no value in parts or for resale.

As much as we wanted to discourage theft however the use of Power over Ethernet, rather than running a 204V or 400V power supply to the cell meant that anyone who did climb a lamppost to steal a cell was not electrocuted.

Overall, the best demonstration of the project security is perhaps, that there were no incidents throughout the running of Best of British.

In summary the project's security strategy:

1. Demonstrated that British development of hardware and software, in particular the physical layer can lead to improved visibility of the technology and reduced the opportunity for bad actors to insert code.
2. The availability of British built technology improves supply chain security
3. Having an understanding of the security models requested by the National Cyber Security centre and Government was important to the project.
4. A "Security mindset" helped reduce the friction between the teams developing the systems. The need for VPNs and passwords can otherwise be seen as a hinderance.
5. Feeding back through the GSMA to help define future standards for the Small Independent Mobile Operator Networks. This is an important "what next?" step.
6. It was important to understand that security is more than just VPNS and passwords but a holistic approach to protection.

Lesson Learned

Trying to do a five-year project in two years proved challenging. Best of British is more than a research project, it developed a new British mobile phone cell. In the balance between research and development the programme was heavily biased towards development. The path to that inevitably led to a lot of discovery, and it is useful to look at what has been learned from the project.

Chip Production

Best of British kicked off in the shadow of the Covid-19 pandemic. While working from home is an option for knowledge workers it's not the same in a manufacturing environment. And this led to the global chip shortage. In particular the packaging stage of the process.

The photolithographic part of the production of silicon chips is not that labour intensive, and so was not particularly impacted by the need for social distancing. The packaging stage, where the silicon wafer is sliced into individual chips and each is parcelled into a ceramic or plastic case, is much more labour intensive. This led to a bottleneck in all chip supply. In particular it affected the lower value chips, such as those used in automotive.

The Xilinx Zinq processor used by the M5Q is a low volume, high value processor. Understanding the whole chip manufacture process was a valuable lesson for the BoB project, it meant that even in a chip shortage we could negotiate supplies. For the more seriously affected low value support chips it proved useful to have second sources. This was not possible with the Zynq so maintain a good relationship with AMD, the manufacturer proved essential. Xilinx did however allow orders of prototype quantities which didn't have the same lead times as production volumes. Each customer is allowed to buy 50 units. The initial target was to build 150 cells for the project. A workaround that cellXica implemented was to order both of the two different versions of the Zynq chip – the one that was specified and the higher duty version which worked to higher and lower temperatures. This allowed cellXica to play an order for 100 chips and the project requirement was lowered to accommodate the smaller volume than initially anticipated.

Radio Planning

Key to the programme was the need to deploy cells to establish their abilities and reliability. Essential to this was the need to plan the deployments. To facilitate this Telet developed its own radio planning software working in conjunction with CloudRF. The software has been developed to calculate the most efficient deployment of a small network to fill a not spot. The radio planner can define a polygon to take in as many premises as possible – UPRNs – and the software will show the optimum location for locating cell sites. This considers the nature of the radios, the frequency used and the model of antenna. The software estimates the construction of buildings – a stone kirk will block radio in a way a wooden barn will not. To establish the fabric of the structures, the software references the land registry database.

A crucial element to this software is knowing land and building heights. Not having this to a detailed enough resolution initially cause problems with the planning. Telet was only able to optimise the software once it was able to licence 1m accuracy data from the Ordnance Survey.

Project Management

The M5Q project breaks new ground in both hardware and software. Understanding the work done proved exceptionally difficult for the non-technical elements of the staff at DSIT working on the project and this led to unreasonable requests and severe blockages to the progress of the project.

In a VC funded business the investors would not put the project at risk in such a way. Asking to see source code for AccelerComm's technology is an outrageous request, and that it was made shows significant flaws in the procurement of the Future Networks Programmes. The aim of the programme was to reduces the vulnerability of the UK supply chain to imported hardware. Not to educate DSIT on new algorithms within the physical layer. An analogy would be that if this process was used to buy a birthday cake it would ask the baker for the recipe and all the suppliers of the ingredients. It would then require the baker to enter a six week change request process if the sugar supplier was changed from Tate and Lyle to British Sugar, but to still expect the cake to be made in time for the birthday.

Grant Claim Process

The restrictive grant claim and change request process is not compatible with a research project, this is compounded by a bid application process which requires a significant amount of work to being done at risk. Bids are made with no certainty of winning. This leads to the submission being made on an expectation of how a project might work without the resources to fully investigate how partners in a consortium might divide work and collaborate.

This lays the seeds of inefficiency. If a submission wins it then forms the basis of the grant funding agreement which lays down rigid targets and milestones. Over-zealous adherence to those milestones and unreasonable linkages between milestones and grant claims leads to the process running the project and not the ultimate success of the project. The cost to the public purse of all the process far exceeds any wastage that might result from the project being allowed to run at full speed and perhaps make some mistakes.

Telet has several on improvements to this process.

1. The problem of the initial bid not being fully worked through is partly as a result of it being conducted at risk. If bids were paid for there would be the resources to develop them properly.
2. On the DSIT side it needs fewer people in the decision-making process. There should be a single owner able to sign off and to have enough technical understanding of the nature of the project to do so. The reliance on external TAs is a significant weakness. The involvement in the minutiae of the programme is not helpful.
3. It would be worth looking at how organisations like the Wellcome Trust and The Gates Foundation monitor spending from their donations.

The allocation of funds, and the competition process means that the formation of the consortium leads to an entry with no certainty and this means that the makeup of roles withing a consortium are not nailed down, so when the bid is won there is a half-formed consortium with some parameters set without due attention. A solution to this would be if bids were paid for. This would allow more attention to be given to working through problems that may never need to be addressed, before they became a problem.

Product Integration

An issue that the project failed to resolve around IP was that it required both AccelerComm and cellXica to contribute to the Physical Layer. This proved too difficult from both a technical and business model perspective. With more time both could have been solve with tighter co-operation and the establishment of a joint venture company to licence the resulting reference platform. Such code typically takes around three to four years, which goes beyond the lifetime of a DSIT project. Benefits should be captured beyond the project (i.e. 10-15 years later), specifically around new licensing opportunities, and should be revisited every quarter to make any changes to ongoing work Impact on the market takes longer when dealing with IP and we need to consider the project's impact on the market after its closure.

Sim Development

Telet learned a lot about SIM development through the project, in proved necessary to educate the suppliers , Card Centric and Giesecke+Deevrient, who were new to 5G SIMs. The work included a SIM management web-platform from which supported physical UICC and eSim formats with Over the Air configuration and Management to support a modular range of pre-qualified profiles supporting different use scenarios and the ability to run independent 'private' slice operation within local RAN and wide area operation on public networks

As part of the dissemination of the understanding the project gained from development of the SIM cards and platforms the project ran an event, SIMposium to disseminate much of what had been learned. The event in conjunction with Nick Hunn from the Cambridge Wireless Connected Devices Special Interest Group looked at how the new breed of small networks might conquer the barriers to deployment such as minimum order quantities of 10,000 units and the high costs and long lead times inherent in a component which has traditionally been bought by multi-national MNOs. Michael Moorfield, from Mindszi talked about how to Build your own SIM factory at home for creating your own SIMs.

Telet has pioneered 5G SIM development and in some cases taught the SIM manufacturers what is necessary for Release 17 SA.

Reduced Deployment cost

Recent UK infrastructure projects for mobile infill have costs around £5,000 per Unique Property Reference Number (UPRN) (DCMS Mobile Infrastructure Project - MIP- and Scottish Government Rural 4G Infill Project, the Bob Project, with its efficient small cells that can be deployed without dedicated power feeds, look to come in at around £1,000 per UPRN. With the limited timescale for the project and the small number of deployments the project was able to achieve it was not possible to confirm the supposition. The aim is however to Enable privately owned 5G RAN to generate sufficient revenue/benefit in order to support continuous operation without additional Government funding

Open Source

There are two approaches to security. Either full lockdown on code or making it public, Open Source, to allow the development community to assert its robustness. Each is appropriate for different aspects of development. While cellXica led on the principal of iron clad security, Telet looked to an Open-Source approach and worked on the development of Open 5GS, the leading 5G platform.

Project Sustainability

The major benefit of the project is the creation of a new 5G cell, designed and manufactured in the UK. This now gives both the existing mobile operators and the new generation such as Freshwave, Quickline, Telet, AQL and others an option to buy domestic equipment.

Early work is underway with O2. In the late stages of the project there was significant demand for early cells for testing.

There is significant export potential for the M5Q, not just as hardware but as intellectual property which can be sold as a reference design to volume manufacturers with the possibility of larger scale availability of this British technology. This has the potential to add new vendors to the challenged supply chain: one of the core ambitions of the Future Networks Programmes.

There is now an on-going business for cellXica with the M5Q.

Work done on developing the core network will yield future benefits for Telet. It is envisioned that this will lead to coverage of more of the nation's not-spots.

SIM card development has produced a saleable product for Telet. Early sales have started and there are some projects which are being tendered for which are only possible through the work done on SIM cards.

While the majority of the work done by AccelerComm did not make it into the M5Q the company is now in negotiations with major manufacturers. This has the immediate benefit of export revenue for the UK allied with the soft power of overseas manufacturers realising the ground breaking potential of software developed with British universities. There is also a commercial benefit for Telco customers in the reduced power necessary for cells with the AccelerComm physical layer and the consequential lower carbon footprint of such deployments.

Contact details

James Body Telet 14 Great College Street London SW1P 3RX www.tel.et	Niro Mahasinghe cellXica Building 7200 Cambridge Research Park Cambridge CB25 9TL https://www.cellxica.net/	Rob Maunder AccelerComm 5 Benham Rd, Chilworth, Southampton SO16 7QJ https://www.accelercomm.com/