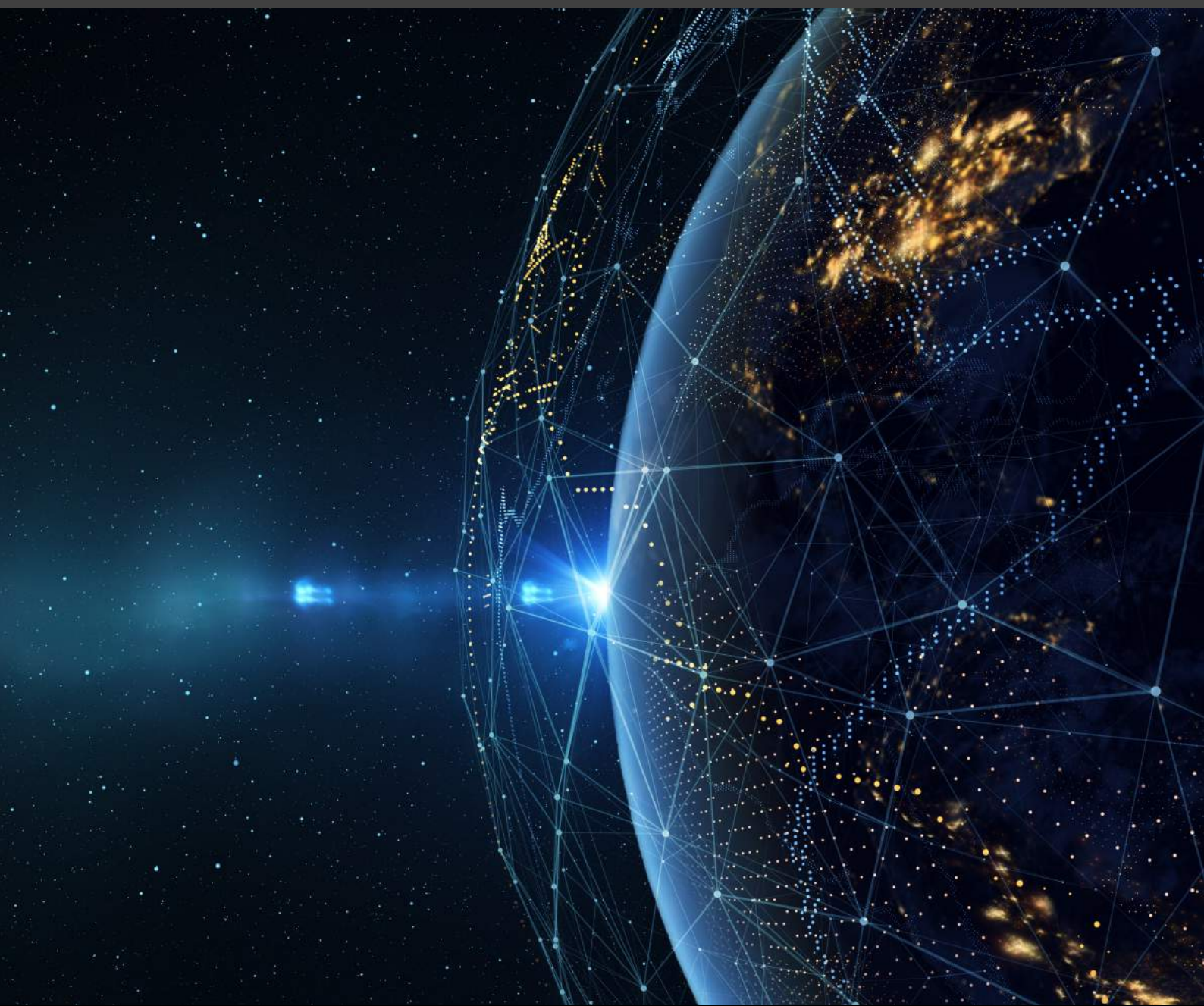
UNIVERSITY OF SURREY

TOWARDS CONVERGED 5G NETWORKS

Accelerating the UK transformation to a digital economy



EXECUTIVE SUMMARY

During the first half of 2018, a study led by the University of Surrey explored future directions of 5G mobile networks. The aim of the study was to look at the opportunities and challenges of *converged* satellite and terrestrial 5G services, with a focus on the commercial implications for business (rather than consumer) applications.

Excitement around the technology improvements delivered by 5G is growing. In parallel, the focus on greater speed and lower latency promised by the application of 5G is often described in terms of improvements to existing business-to-consumer (B2C) activities. Whilst standards and technologies are still in development, 5G will offer huge potential for businesses, and multiple critical industry sectors.

Satellite technology has been important in 3G and 4G communications delivery. Recently, alongside rapid advances in terrestrial communications technologies, **space-based communication is undergoing its own phase of improvement** due to advances in satellite technology. The potential for harnessing enhanced satellite bandwidth in the context of future communications has been under-researched.

In this report, we explore the use cases that will drive future mobile communications in the context of the UK digital economy. **Here we look at the *convergence* of satellite and terrestrial 5G technologies in a business and societal context**. We offer insight into whether such an approach might deliver new opportunities – or help to overcome challenges in the development and deployment of 5G.

The study has resulted in several important outcomes of significance to the future of a converged 5G solution. Notably, through discussions with major industry experts, we explored and confirmed at *least six sectors where converged 5G could respond to current gaps*, and help foster a genuine transformation in business impact. These sectors were characterised by business concerns involving wide geographic distribution, constant mobility of goods and service consumption, unpredictable and unmet communications needs, and wide-scale connectivity across dispersed communities.

We describe an initial set of scenarios that can be used to characterise the demand for a converged 5G solution, and to explore new revenue-generating opportunities for key players in the value chain. In validating these needs with organisations supplying communications infrastructure and those guiding communications standards, we add our voice to existing calls to strengthen the dialogue between all those involved in determining the future of 5G.

Our study recommends several important next steps to explore the value of converged satellite and terrestrial 5G services.

The most urgent is a call to mobilise the community to deepen our initial sector scenarios through a series of test beds and trials with key players from each sector.

The way to achieve this with potential customers is through a phased approach requiring awareness, engagement, experimentation, and reflection. In particular, these activities require involvement from a broad set of stakeholders bringing a balanced view of technology 'push' and industry 'pull'.

Further work is needed to develop the future of 5G as a converged satellite and terrestrial proposition. Its potential, according to our study, is significant. With this report we invite the broad community of stakeholders across the 5G domain to engage in conversation to deepen our understanding of this potential, and work together to maximise opportunities.

THE REPORT

INTRODUCTION

In the UK government's recent update to its 5G strategy in December 2017, it was emphasised that world-class digital infrastructure is a critical building block to achieve the country's ambitions for delivering a modern Industrial Strategy. And with that in mind, it promised to accelerate the deployment of 5G networks to ensure that the UK can take early advantage of the application of those networks.

The application of 5G to key business scenarios is fundamental to the nation's future.

Activities aimed at development of 5G mobile networks are in full swing. Investments around the world have moved the concepts and research ideas from the academic world into functioning technology test beds, field-based trials, and limited upgrades to commercial solutions aimed at proof of concept (as exemplified by the work taking place at the University of Surrey's 5G Innovation Centre[1]).

The continued focus on driving technological advances in all aspects of 5G is resulting in a stream of new announcements as the technical characteristics are defined and matured. Wide-scale rollout of 5G infrastructure is expected from 2020 onwards.

Alongside these technical breakthroughs, the standardisation activities concerning 5G are similarly well advanced.

This is progressing through a series of activities supported by the Institute for Electronic and Electrical Engineers (IEEE), the 3rd Generation Partnership Project (3GPP), the Internet Engineering Task Force (IETF), ITU Radiocommunication Sector (ITU-R), and ITU Telecommunication Standardization Sector. These organisations are engaged with a diverse community across many projects to create the standards needed to deploy the complex communications infrastructures and associated services to support the 5G vision.

However, despite the enthusiasm for technological advances inherent in 5G, many expect a gradual rollout of 5G services. There is a certain tentativeness: from a business perspective, the telecommunications providers are still deeply vested in commercial activities around current (3 and 4G) generations of mobile network services. However, commitment to 5G is gathering momentum. The UK government and industry players are centring their efforts around the 5GIC based at the University of Surrey and further sites in Europe, and promise rapid evolution. At the Mobile World Congress this year, many near-production 5G solutions were showcased.

5G is not yet a reality, but its development is rapidly gathering pace.

The projected timeline for 5G infrastructure rollout is shown in figures 1a and 1b below.

Fig 1a. A projected timeline for 5G rollout.[2]
Northstream view on the expected 5G roadmap: Mass adoption after 2023.

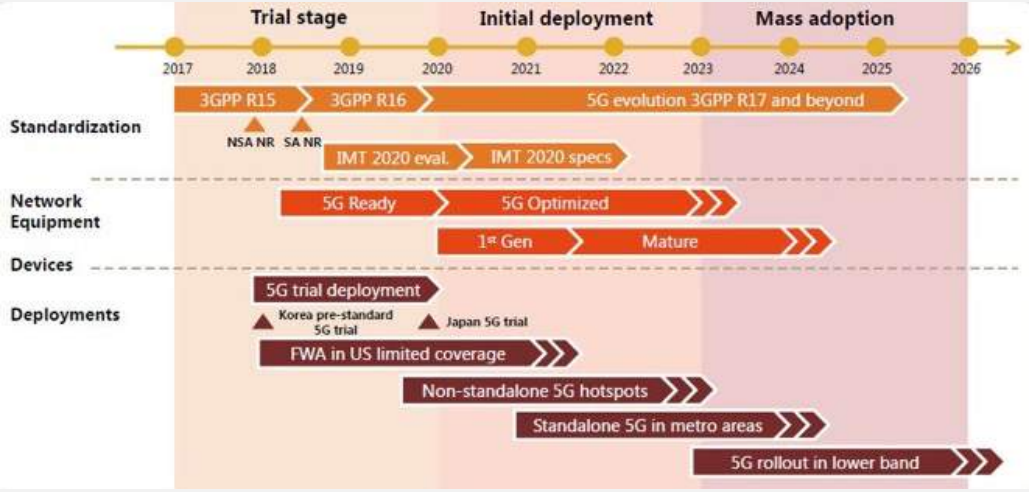
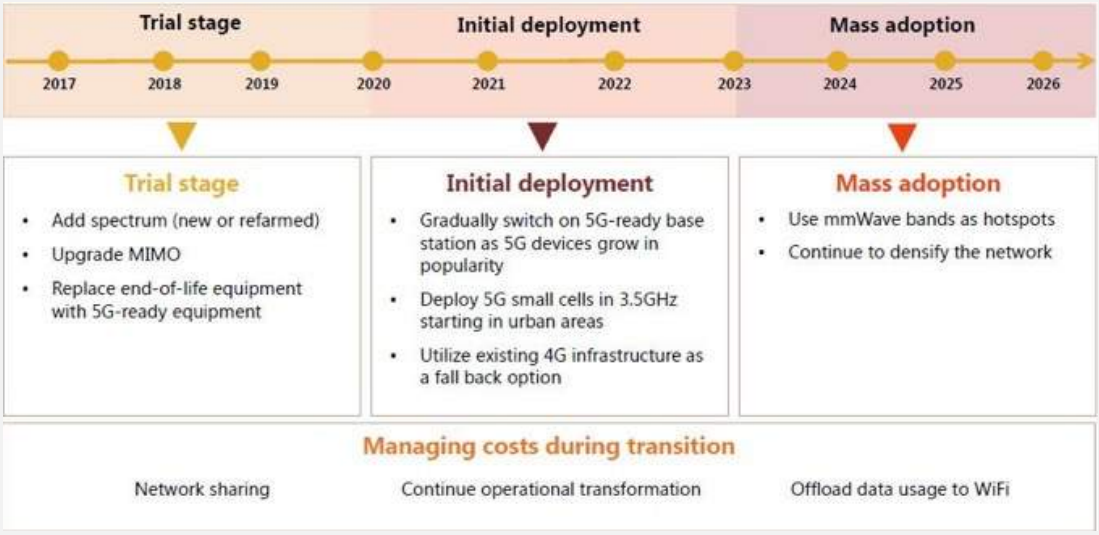


Fig 1b. A projected timeline for 5G rollout.[3]
How operators will roll out 5G: A gradual process.



ECONOMIC AND SOCIETAL ISSUES SURROUNDING 5G

As 5G takes shape, two main challenges dominate discussions on its use: meeting the high demands of a wide set of application domains, and deploying across diverse social and geographic environments.

The disruptive impact of 5G on businesses relies not only on the increased speed and lower latency promised by a terrestrially-based 5G, but also on availability of demanding scenarios where mobility, wide-scale distribution, and broad geographic coverage are essential.

In domains such as utilities management, construction, agriculture, logistics, travel, and emergency services, the requirement is that communication coverage is not just consistently fast and predictably performant, but also scalable and widely available across disparate communities.

With respect to digital inclusion and fairness, the social impacts of **current terrestrial approaches emphasise the deployment of terrestrial networks driven by the coverage of population centres rather than by the coverage of diverse geographical areas.**

This can lead to the creation of locations where access to 5G services through radio coverage of a terrestrial network will not be possible.

The limitations of this approach may have severe implications for rural areas, disadvantaged communities, and cross-border communities with a range of urban, rural, and maritime characteristics.

Such constraints are not new. However, the difficulty for terrestrial networks to achieve minimum thresholds for profitability or resilience across diverse geographies remains a cause for concern, and it is expected that 3GPP will highlight the use of satellite technology in future standards.

The most effective way to address these concerns is to look to the convergence of satellite and 5G as a basis for overcoming the shortcoming of a terrestrial-only 5G solution.

In fact, **the 3GPP standards body now accepts that the 5G system needs to provide services using satellite access for the next generation of new services and markets**. They also specify that the 5G system must support service continuity between land-based 5G access and satellite-based access networks owned by the same operator, or by agreement between operators.

PROSPECTS FOR 5G AND SATELLITE CONVERGENCE

The capabilities, cost, and viability of satellite communications have evolved significantly in recent years.

In fact, the economics of satellite deployment and use are changing frequently because of trends toward miniaturisation that lower cost. Additionally, new players such as Space X, Blue Origin, OneWeb, Virgin Galactic, and PlanetLabs are investing in delivering and deploying large constellations of satellites into orbit.

It is estimated that in 2017 there were 329 small satellites[4] launched into orbit. Several thousands of new satellite deployments are planned for the next few years as further manufacturing facilities become available.

These advances in satellite technology will have major impact on the two key drawbacks affecting convergence of satellite and 5G: cost and latency.

With the advent of high throughput satellites capable of up to 1 terabit-per-second performance and deployment of large satellite constellations, the cost per megabit of data delivery via satellite has dropped by up to 90% in the past five years, and many expect the costs to drop by an additional order of magnitude in the next five years. Similarly, because of deploying Low Earth Orbit (LEO) satellites[5], latency of round-trip time to/from satellites is now in the order of 10 milliseconds.

Both improvements open up satellite use for many kinds of applications previously considered infeasible.

As the concept of a converged satellite and 5G solution has evolved, debate has focused on technical issues. Fast-moving application domain considerations have received less attention, and the priorities of those companies driving such applications have often been underserved.

The use-case requirements from businesses have largely been left out or underplayed.

Input from industry is essential to understanding the *applications* of 5G as they relate to the requirements and feasibility for a converged satellite and 5G solution. **Companies with a commercial interest in next-generation communications must help establish the priority and pace of 5G investments.**

In response, The University of Surrey brought together a wide variety of industry business leaders, communications technology practitioners, industry commentators, academics and representatives of relevant standards bodies to explore the opportunities and challenges of converged satellite and 5G solutions[6]. In this report we call for terrestrial mobile operators and satellite operators to engage with business leaders to identify differentiated use cases where commercial and societal value can be derived.

The cost of data delivery via satellite has dropped by **up to 90%** in the past five years.

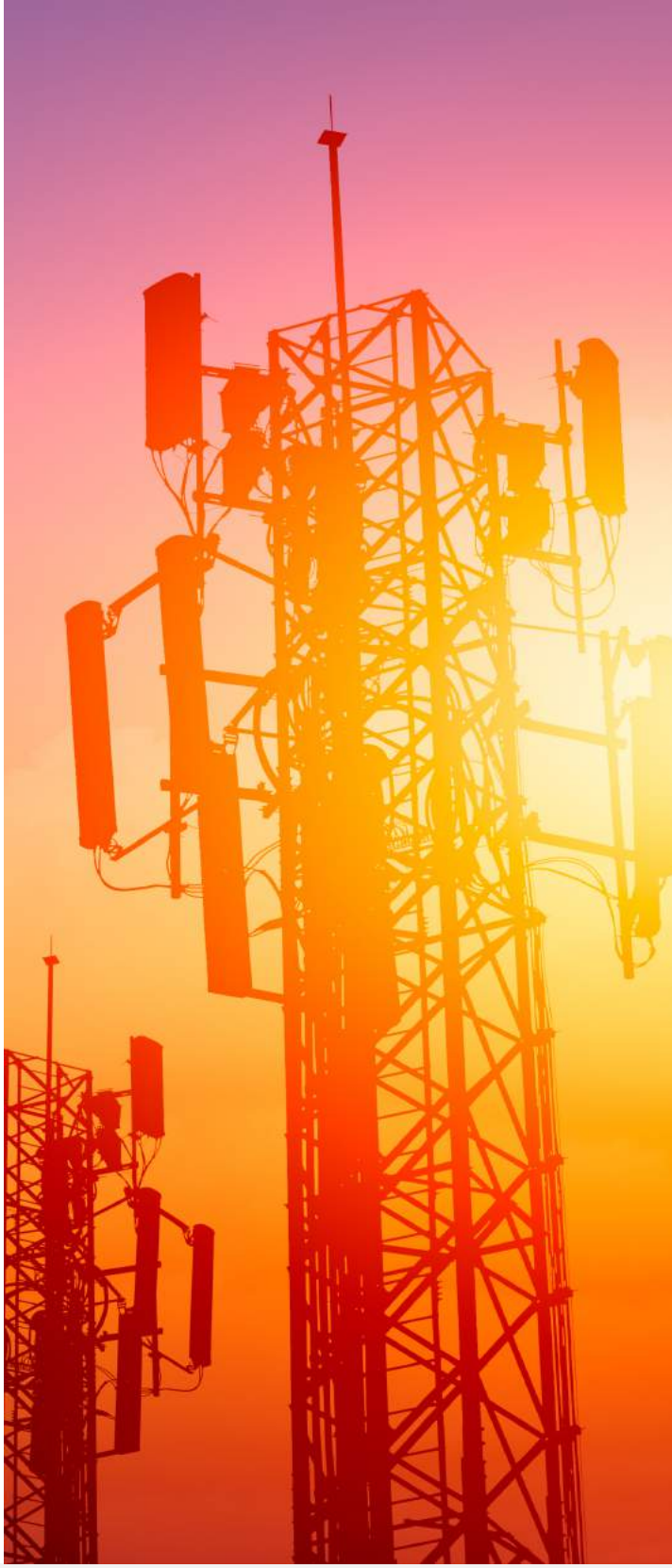
WHAT ARE THE QUESTIONS WE SOUGHT TO ANSWER?

Organised around key use cases, and initiated by provocative position statements, the study we initiated addresses several important questions:

- What are the individual capabilities of converged satellite and 5G technologies, and how might they complement or enrich each other to overcome limitations of 5G?
- What are the incentives and accelerators that affect the supply model for a converged satellite and 5G solution?
- How might the extended reach of satellite communications (land, air, and sea) open up new categories of opportunity beyond traditional mobile networks (often centred on dense urban communities)?
- Where are the connectivity gaps today in key sectors, and how might a converged satellite and 5G solution respond with attractive propositions?
- How could converged services impact the consumer agenda in areas such as entertainment, healthcare, education, financial services?
- What might be the timescales for adoption, and which potential barriers might impede development (e.g. device technologies, regulations)?

This report captures stakeholder feedback.

We wish to use this report to open up a broader dialogue with communities interested in the future of a converged satellite and 5G solution. And we invite them to join us in expanding the conversation on the future of the digital economy, and how the UK can drive business and societal impact through a converged satellite and 5G approach.



THE IMPORTANCE OF A CONVERGED SATELLITE 5G SOLUTION TO THE UK DIGITAL ECONOMY

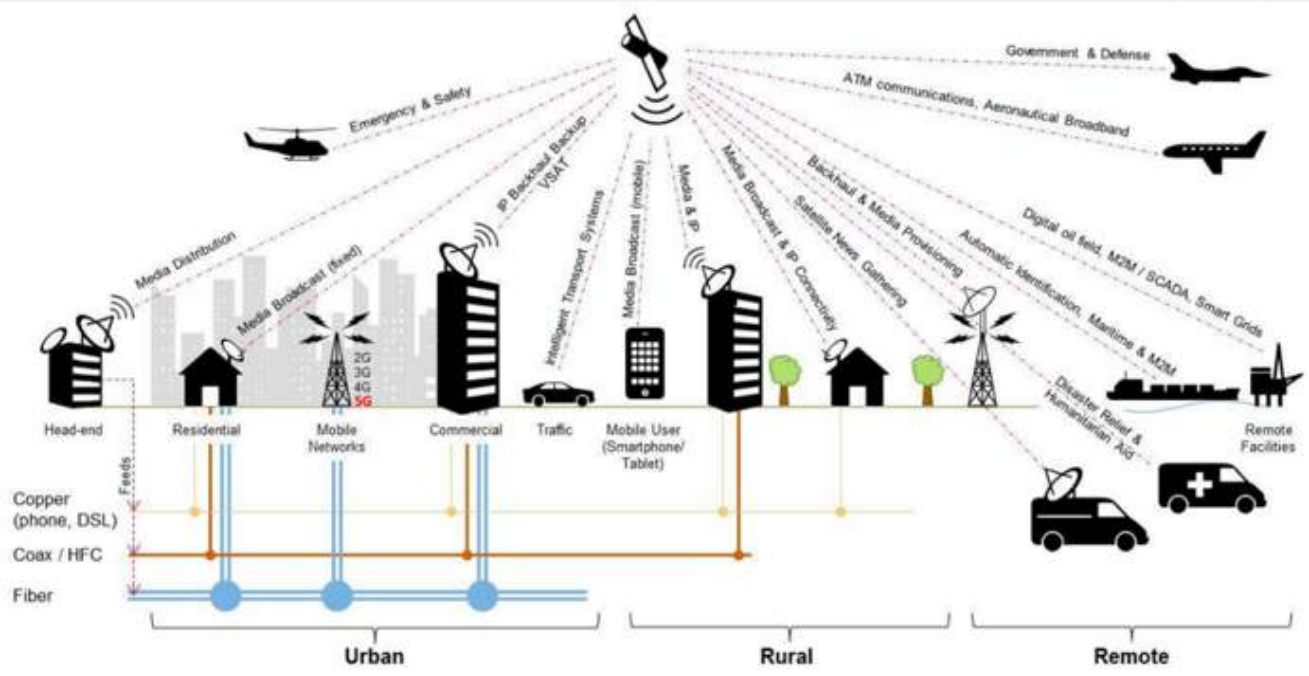
Demand for communications services in the UK continues to increase. In August 2017 Ofcom reported that 94% of UK adults personally own or use a mobile phone, and there were 92 million mobile subscriptions (including M2M).[7]

Similarly, a 2017 report from Cisco states that video accounts for 63% of all mobile traffic in the UK and predicts that it will grow seven-fold by 2021[8]. Worldwide, the number of connected devices could well exceed 20 billion by the year 2020.

Consequently, communications infrastructures are being driven by a broad, diverse set of needs where connectivity is an essential element in providing the capabilities and service capacity necessary for success. Usage forecasts for these scenarios are dependent on multiple technologies delivering the quality of service required.

In Figure 2, the fixed terrestrial technologies that support existing land-based communications are shown alongside satellite capabilities that can augment service levels. The complementary capabilities offer much wider coverage than either can achieve alone.

Fig 2. A View of the Converged Opportunities Landscape for Future 5G.[9]



Supplementing terrestrial capabilities with satellite-provided mechanisms adds the following features critical to deployment and commercial success of 5G:

- **Wide coverage to complement and extend dense urban cells**. Terrestrial solutions excel in urban areas where the density of coverage can be matched to the high demand and continuous local intensity of the application needs. Business models and commercial terms can be optimised within these circumstances to drive investment. Outside of these areas in rural and remote regions, coverage via terrestrial means is often lagging or economically infeasible. Wide deployment of fibre infrastructure is often expensive. In such cases, the addition of space-based solutions may be a good fit to address technical and commercial challenges.
- **Connectivity to mobile nodes (e.g. aircraft, ships, trains and other vehicles)**. Increasingly, there are higher expectations for connectivity for mobile nodes as they navigate between urban and rural areas. These scenarios challenge current terrestrial systems when they transverse coverage boundaries, or place high demands for quality and speed over extended periods of time. Such scenarios may be better served in combination with a variety of satellite-based approaches.
- **Offloading a temporarily congested mobile network**. Certain events, whether planned or unplanned, can place intense demands on communications systems with severe implications for the quality of service delivered. A great deal of planning often precedes activities such as festivals, sporting events, and public gatherings. In other situations, such as emergency events and weather-related unplanned outages, terrestrial communications systems must be rapidly reconfigured to provide services to meet local, high-demand needs. In all such cases, the addition of satellite-based systems can have significant benefit, extending the range of options open to the various agencies involved.
- **Offering 'backhaul' services to fixed and mobile base stations.** A critical part of any mobile network is known as the backhaul. It consists of the connection from base stations to the core network, taking the traffic from the base station and backhauling it to the network to ensure speed and capacity as it relates to the transport of data and voice from distributed network sites to the network core. Increasingly, network operators are turning to satellites to provide this function to reduce congestion and increase capacity in a cost-effective way.
- **Emergency response and disaster recovery communications**. Satellite communications have long been essential components of communications systems in emergency response and disaster recovery. In such circumstances, when cost and value issues are not the highest priority, there are well-understood scenarios where terrestrial systems can be supplemented with satellite-based solutions as the most effective way to offer high-throughput, targeted communications. Often this occurs as a temporary solution while terrestrial systems are repaired or replaced. But increasingly combinations of satellite and terrestrial approaches are used to ensure diversity and reduce risk.

In summary, the high demands and expected growth for communications services in the UK highlights the breadth of capabilities necessary to ensure the future of 5G.

Satellites will play an important role in the rollout, deployment, and on-going success of 5G in an increasingly communication-intensive digital economy.

PLACING CONVERGED 5G WITHIN A FUTURE CONTEXT

5G and associated developments in satellite technologies promise to offer a leap forward in communications functionality. And they come at a time when a confluence of social, economic, and technological developments will require dramatic improvements to existing levels of connectivity. Such trends include:

- Rapid growth in global populations from seven to ten billion by 2050, with emphasis on developing regions such as India and China. Such populations will need to be educated, fed, and cared for in new ways. At the same time, up to 25% of populations in developed countries will enter retirement, with associated healthcare and occupational needs. Advances in communications could play a key role in meeting such challenges on a global scale.
- Autonomous machines will populate our homes, cities, and factories. The Internet of Things (IoT) could be the next 'killer app' for mobile networks as some 50 billion devices come into usage by 2030. Ubiquitous networking will be required to connect such a 'massification' of devices.
- New supply patterns are displacing traditional manufacturing practices with the widespread adoption of 3D printing in areas as disparate as home construction and body part replacement. This could lead to 50% of manufacturing becoming localised, as compared to current global sourcing practices. The compute power necessary to enable flexible manufacture and associated robotics will be cloud-based. Improved connectivity between local facilities and remote computer centres will be a critical success factor.
- The nature of work will continue to change and evolve, with typical employment patterns compressing in time from years to months or even days. Most people in the developed world will be employed in units of ten or less staff. Connectivity will be the essential glue that binds together such disparate work groups and enables hyper-scaling of winning products and services.

These macro trends offer a useful context within which to envisage possible converged 5G scenarios. We anticipate at least four new scenarios giving rise to new opportunities for future mobile communications as techniques such as artificial intelligence, augmented reality and IoT become mainstream in both business and consumer markets. Such scenarios may include:

- **'Everything as an experience'** that exploits advances in virtual and augmented reality to bring new forms of entertainment, education, healthcare, and other services to the rapidly growing global population.
- **'Pop-up enterprises'** that align with current trends in design thinking and agile delivery. In such a scenario, small teams of people from multiple geographies connect in a temporary fashion to test new business ideas in days or weeks. Successful ideas can be hyper-scaled using universal digital platforms.
- **'Flexible manufacturing'** that combines advances such as 3D printing with robotics to transform factories and the workplace. Such flexible production units may be small enough to operate in or close to the home, with new possibilities for high street retailers – designing and building items on demand.
- **'Digital twinning'** that enables integration between physical (e.g. white goods) and digital (e.g. data) assets. Value shifts towards understanding 'products in use' rather than 'products in exchange' (e.g. at the point of sale). Consequently, the ability to monitor products through the full lifecycle is a critical success factor for suppliers.

Illustrative of the dynamic, always-connected environment we are now entering, these trends stretch current thinking about where and how 5G will succeed. And while none of these scenarios are properly proven and will depend on a confluence of factors such as technology maturity and economic stability, they nevertheless emphasise the central role that advanced connectivity such as converged 5G will play in enabling such radical possibilities. This is explored further in the use cases that are described below.

EXAMPLE USE CASES

Inspired by these trends in mobile communications, discussions with selected industry partners during our study have helped to identify six practical applications that can be used to explore the potential of converged 5G.

Unlike previous generations of mobility (3G and 4G) that focused largely on the end consumer (e.g. in mobile banking, media streaming and e-commerce), these application areas relate primarily to the business-to-business domain, and represent critical pathways to organisational and sector-wide transformation in a digital economy.

In this respect, converged 5G could have a powerful impact on productivity and industrial performance within the UK and elsewhere.

In all such use cases improved network infrastructures, as exemplified by converged 5G, enable transformational improvements in business efficiency across individual sectors. These could deliver measurable improvements in the consumer experience, including quality and timeliness of service at lower costs. Such infrastructural enhancements could lead to wholesale transformation of entire sectors, as illustrated by these use cases.

This initial exploration of application domains for future 5G solutions provides helpful insights to drive new thinking. Further work is now required to validate these six use cases and to broaden our investigation into other sectors such as education, healthcare, media, financial and professional services where similar possibilities exist for transformation of internal structures, and the customer experience.

1. Digital construction

With increasing digitization across the construction industry and a complex supply chain of organisation, demands on mobile communications systems continue to grow and diversify.

Productivity challenges in construction

The sector has faced productivity challenges for many decades, with manual activities and a fragmented supply chain consisting of thousands of parties – from the very large contractors (Kier and Lang O'Rourke) and material suppliers (Aggregate Industries) to SMEs. Its ability to undertake large projects such as HS2 has been hampered by these factors – with timescales and budgets often overrunning. Terminal 5 was a turning point in project management, adopting a just-in-time approach to supply. Cross Rail has also performed well against targets due in part to advanced computing techniques.

With the recent introduction of BIM5 (Building Information Management), the sector is transforming itself away from physical towards data assets. The innovative combination of these two asset classes is being termed as the 'digital twin' and promises transformational changes in project outcomes (time and cost) and improved supply-side margins (from 1-2% to 10%+).

Transforming the build and operate process

The critical tasks in the construction sector are: design; build; maintain. The latter being a 30 year plus obligation on behalf of contractors. By establishing a comprehensive BIM5 model in design, participants at all three stages can work from a common knowledge base (including hard and soft building elements). Sensible exploitation of the data can reduce time to build and improve overall life cycle costings. The digital thread across the supply chain also provides provenance to the finished build and its component parts (as per cladding on tower blocks).

In addition to a shared data model of a building, other developments can help to transform the construction process. Robots will shortly be used on site for assembly. Augmented reality will tackle health and safety issues as well as improving quality control during builds. In the 2020-2025 period it will be possible to partially substitute on-site assembly with 3D printing, as is being piloted by Lang O'Rourke.

Buildings themselves will take on 'smart' capabilities that could transform running costs and environmental impact. Sensors can monitor and adjust heating and air conditioning as well as identifying potential health threats such as Legionnaires disease. Just in time allocation of space can improve space utilisation, often by a factor of two. Improved access control and security will benefit from advanced

Adopting share platforms

To help streamline and unify the production process, multiple parties need to work closely to deliver complex projects. BIM5 provides the necessary information architecture on which such platforms can be established – encouraging universal sharing of data. Such platforms could help synchronise the delivery of parts and materials to site in a just-in-time fashion. Ultimately, they could schedule large scale, flexible 3D printing factories to meet different construction jobs.

Blockchain may also become a key component of sector transformation, providing a means of transferring cash and managing complex contracts between multiple parties. This could streamline the role of the prime contractor who currently coordinates such activities, with possible economic benefits (speeding up payments and reducing physical inventories). The challenge will be to convince a few lead players to adopt such methods – especially prime contractors, thus creating a positive environment for shared platform developments.

Role of the converged network

Construction by its nature is a highly distributed activity, with materials and components sourced widely across the UK and elsewhere. Aggregate Industries alone operates 300 geographic locations. Connectivity for the shared BIM5 database and associated production documents will require large data transfers between parties during the design and build phases. The operation of robots will also require reliable and secure communication.

Once operational, sensors will need to communicate data frequently within and between buildings for remote maintenance and capacity balancing. Hospitals will need to communicate with ambulances and field personnel on a constant basis. Logistics hubs will need to connect with their vehicle fleets. One interesting application is the maintenance of road surfaces – enabled by embedded sensors connected via 5G to central data hubs that can detect degradations and plan maintenance accordingly (with potential for lifetime cost reduction).

Summary

5G will support the transfer of mass data and the development of intelligent buildings. However, given the highly disparate construction activities at design and build, satellite coverage could help fill the geographic coverage gaps. In this sense, converged 5G could be a powerful enabler to the entire sector.

2. Connected utilities

Wide deployment of sensors delivering real-time data is opening up new business opportunities for utility companies able to connect, analyse, and predict in intelligent ways.

Sector transformation opportunities

The sector is heavily verticalised due to historic conditions – characterised by regional assets and customers. This has led to some 20 different water companies offering localised products, supported in many cases by differing service providers, telemetry and IT systems, and processes. Some efforts are now in place to share water resources during droughts, such as the South East Water Resources group.

As reform of the sector progresses – enabling customers to have more choice, and pressure on cost increases, the sector is facing some tough decisions. At the core will be the need to adopt best standard practices – both processes and systems, to improve operational efficiencies across the value chain, and enable a more competitive market dynamic. Sharing of customer data will also be necessary to open the competitive environment.

Technology, especially IoT sensors and data analytics, opens the door to substantial improvements in areas such as leakage detection, asset health and monitoring maintenance, intelligent pumping systems. However, connectivity across rural areas continues to limit progress here. Converged satellite and 5G offers a potential breakthrough for the entire sector.

Taking the first step forward

A key issue today affecting cost efficiency and supply reliability is leakage – often as high as 20-30% of all water production. This amounts to a bill of £130M over five years. The current industry target is to cut leakage by a further 15%. All water companies are looking for ways to tackle this problem and are currently consulting with vendors.

A combination of low power acoustic sensors embedded within the piping (IoT) and 5G would enable water companies to monitor their assets more closely and detect early signs of leakage. Plans for 5G are likely to be restricted to urban areas, at least in the initial years (2020-2025). Given the dispersed proximity of such assets, the inclusion of satellite coverage would extend the reach of such operations across rural areas, thus creating a more practical solution. As the cost of geostationary satellites decreases, new low earth orbit (LEO) satellites are also being deployed to broaden satellite options by providing additional coverage and service levels.

Transformational opportunities are now emerging

In line with the 2020-2025 regulatory planning horizon, the water companies are considering more radical solutions to achieve cost savings and open the industry to full competition – helping to reduce customer bills and deliver improved service.

One approach could be to aggregate water assets at the physical level into regional platforms. Overlaid on such physical platforms would be asset health and monitoring maintenance services that could follow standard procedures and offer larger savings across the end-to-end life cycle of plant. Independent wholesalers and retailers would build their own CRM systems at the customer interface that reflect local needs of businesses and consumers.

Future horizons

This radical 'layered' approach to the sector also positions the industry to deliver "water trading" by providing the demand and movement data of water across company boundaries. DEFRA is currently exploring the feasibility of incorporating natural capital evaluation into abstraction licensing as a more dynamic way than it is done currently. This could lead to monthly or even weekly trading of abstraction rights meaning that the environment can be protected in a way that brings further resilience to water supply.

This approach supports the Regulator's strategic direction to move the sector to a "Totex" model rewarding greater innovation to extract more out of existing assets and infrastructure and reduce traditional capital expenditure, e.g. creating reservoirs, building desalination plants.

Summary

By adopting a layered approach, asset management becomes more economical and open data enables greater competition, and product innovation. This has happened already in most utilities such as electricity, gas and telecommunications. Converged 5G and satellite would help enable such a horizontal structure to emerge by improving connectivity at each level of the stack. This would satisfy the regulator and deliver more value to the customer.

3. Responsive disruption

New pressures to increase responsiveness for logistics and delivery service providers require diverse mobility services with wide coverage and easy access to all stakeholders.

Changes in retailing and distribution patterns

High street retailers are challenged by direct routes to the consumer such as online companies (Amazon) and door-to-door delivery services (Ocado and Uber). Speed of fulfilment is also becoming a critical factor in the eye of the consumer. To remain attractive, and to maintain margins, retail organisations need to improve availability of items in store. This requires the rapid transfer of data across the entire supply chain to identify item location and time to shelf.

With the prospect of integrated supply chains within the next five years, organisations such as Wincanton are transforming themselves from third party logistics (3PL) players to full service integrators (4PL) – coordinating a growing range of partners involved in supply and distribution and offering complete 'supply chain' solutions.

The road to digital transformation

The imminent transformation of end-to-end distribution systems requires semi or full automation in the warehouses, with extensive use of robotics, as well as connected vehicles. It needs to sense and locate every item within the supply chain (warehouses and trucks), using RFID tagging and optical sensors. Goods are being fitted with Bluetooth devices to further increase visibility.

With such innovations in place, retailers, working with distribution companies, can identify the exact location of any item required by a customer, and select an optimal delivery route either to store or to the home. To further improve speed and efficiency, intelligent route planning of trucks can help to avoid inner city congestion and improve the accuracy of the delivery time.

Given the vast amount of data that will be generated and captured from goods, warehouses and transport vehicles, machine learning and AI will be applied to make rapid decisions about availability and optimal routing. Acting as integrators, distribution companies can optimise inventory levels across the end to end supply chain and choose the most efficient means of transport.

In the case of Wincanton, this means equipping some 200 warehouses and 4,500 vehicles with robots, RFID sensors and tracking devices. As an integrator (4PL player) it also requires intimate connectivity with its supply partners as is the case in the construction sector where Wincanton works closely with materials suppliers such as Aggregate Industries to deliver goods to site.

In a digital future, 4PL integrators will be able to predict and respond to real-time demand patterns, even down to an individual home for day-to-day supplies of food and milk. Already Amazon is trialling its 'treasure truck' where favourite items are hand-picked and transported to local communities to offer surprises and treats.

Summary

The explosion of data within 4PL distribution companies and between their partners, combined with the need for real-time responses, requires a quantum-leap improvement in connectivity, within the warehouse, on route, and ultimately at the point of arrival (to supervise the delivery experience).

5G will be a boost to capture and share data from RFID tags and robots within the warehouse environment. However, different means of connection could be needed on route, linking trucks to central control stations (visual as well as data). This will require optical connections in the future to assess road conditions (especially in the case of traffic accidents or criminal activity) as well as truck loadings. The combination of 5G and satellite appears to cover all these needs well into the 2020 period and beyond. For example, companies such as Wincanton are interested to work with the Consortium to experiment with such techniques on a local basis.

4. Smart farming

New forms of intelligence in food production, animal husbandry, and farm management are revolutionising the industry to connect diverse, widely-distributed agencies to improve business efficiency and drive opportunities.

Improving agricultural productivity

Farming productivity in the UK lags many other sectors and is in genuine need of innovation with respect to crop yield, environmental impact, live-stock wellbeing, and supply chain efficiency (farm to fork). Many of the large supermarkets have a stranglehold over supply, and farmers are seeking alternative channels to the consumer to increase their margins (which can be reinvested).

Farming is prone to livestock epidemics that can cause national crises. Such epidemics need to be anticipated and mitigated to save lives.

Overseas there are some 20 million subsistence farms that have not benefited yet from any level of automation. With rapid growth of the global population especially in the developing world (8.6 Billion by 2025), dramatic improvements are needed on a global scale.

Data is the new infrastructure

The Internet of Things (IoT) can provide valuable information on every aspect of farming as well as the subsequent supply chain (the digital thread from farm to fork). Sensors can gather data on weather, soil, live-stock. Such data can be processed to separate out crops into different grades, as well as offering customised solutions to transportation and logistics. Wearables on animals can help to anticipate epidemics as well as improving overall health and wellbeing.

Farmers are naturally cautious about sharing such data, but the prospect of national platforms to monitor crop yields, animal wellbeing and other farming related activities may be near at hand. Government is keen to encourage such developments, as are suppliers.

Given the growing availability of such information, suppliers such as Syngenta who serve the farming community can enhance the relevance and impact of their services to help optimise farm production and distribution. Many partners are involved along the food chain, so the sharing of data can be helpful in streamlining production and distribution.

Working together with farmers, Syngenta believes that more information around provenance can flow through the system, building more transparency, and responding to the increasing information demands of consumers.

In addition to IoT, farmers anticipate the more extensive use of automation and robotics in the coming 5-10 years. Machines will replace many manual tasks. In turn, machines will need to be monitored and controlled through wireless data networks.

Networking grows in importance

Many of the tools to analyse farm data are available today, including predictive analytics, machine learning and AI. However, the sensors that capture this information need to be connected to local and remote (cloud) compute resources to harvest such data. Equally farms need to access remote data from weather forecasters, distribution companies and many other relevant sources.

Summary

5G holds the answer to connecting IoT low power sensors but is unlikely to be available in rural areas where farming takes place. Satellites may help extend 5G coverage to local farms as well as distribution vehicles. The combination of 5G and satellite could help yield a revolution in the agricultural sector by streamlining both production and distribution. Ultimately, such advances in network could help create direct linkage between the farmer and the consumer, helping to mediate supply and demand on a dynamic basis.

5. Distributed IT Platforms

The vast infrastructure required to support cloud services continues to expand. Ever-greater demands for speed, coverage and diversity will drive new investment.

Changes in the digital landscape

Over the last decade public cloud computing has grown rapidly in preference to on-premise facilities due to its flexibility and economic price points. Today, public cloud-based services account for over 35% of all IT storage and compute power, and this is likely to exceed 60% by 2025. Equinix is one of the world's leading utility companies hosting many such cloud services in its 175 global data centres.

Several factors are placing increasing demands on these public cloud utilities such as the explosion in quantities of data (structured and unstructured), the emergence of machine to machine traffic (Internet of Things or IoT); adoption of digital platforms; and sophisticated software algorithms such as machine learning. All these developments will reach maturity in the 2020-2025 timeframe.

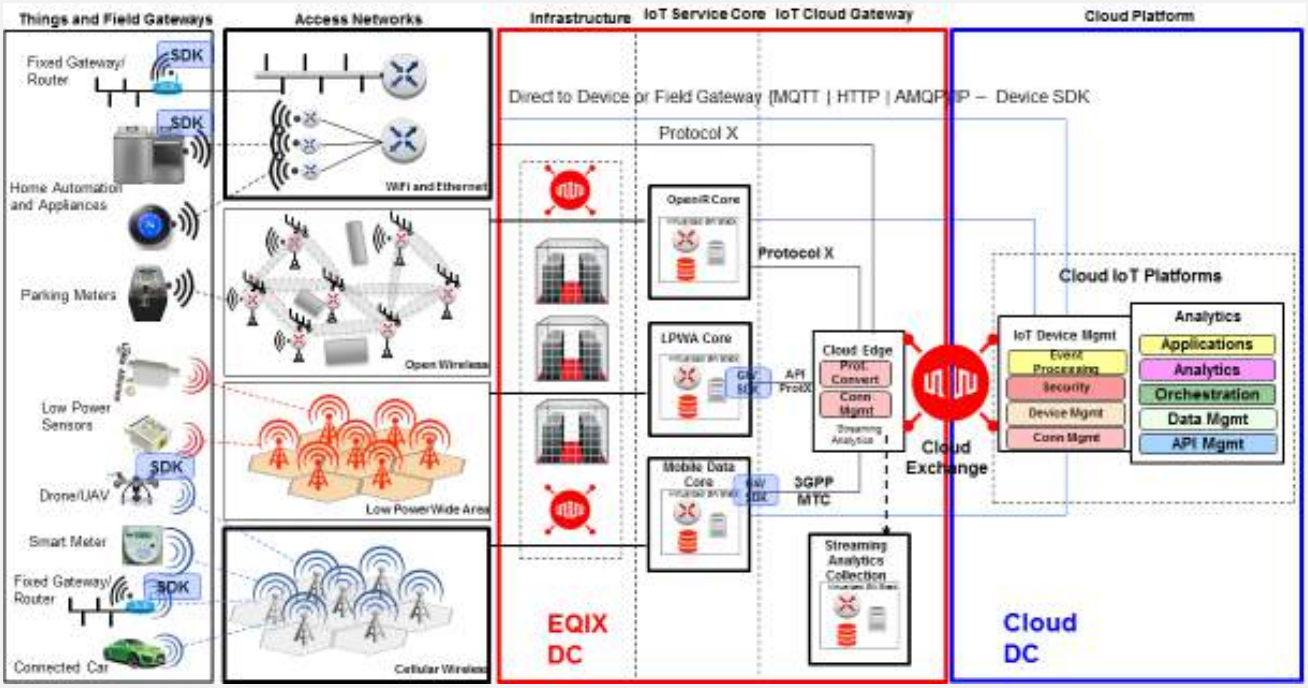
At the same time, network complexity is increasing, with low power connections to IoT sensors; 2, 3, and 4G mobile networks operating often in parallel; Wi-Fi covering urban areas; and extensive fibre to the home. This requires numerous gateways and access points that are hard to control within the local context. Figure 3 is an example of a modern IoT infrastructure linking up four different access networks.

What will be the next phase of utility computing?

These developments are fuelling the growth in demand for additional data centre capacity and related connectivity. They are also challenging current utility compute models, placing more emphasis on distributed computing techniques – compared to further centralisation of resources into mega-data centres. Equinix has pioneered an 'Interconnection Orientated Architecture' (IOA) to accommodate the move to decentralised IT infrastructures.

With the central importance of data as an asset in many sectors such as finance, media, health, retail, the need to exchange information between organisations on a vast scale has also become a key opportunity for global compute utilities. Through its lead position in this area, Equinix becomes an attractive hub for such data exchange. It is working on a new 'digital data exchange' model that enables transformational opportunities within sectors, and between them, especially with respect to emerging digital platforms. These aspects suggest the growing importance of interconnectivity within and between organisations involving a multiplicity of channels and devices (with IoT beginning to occupy a central position).

Fig 3. Interconnection Architecture at Equinix.[11]



Defining new infrastructures for 2020 and beyond

The 'digital data exchange' assumes that as infrastructural complexity increases, data aggregation from a growing number of device and network sources can best be handled within the data centre itself. The likely structure for the digital exchange will include:

- Devices of all kinds acting as data sources (people, vehicles, homes, sensors).
- Telecommunication networks providing point connections to these data sources (through mobile, Wi-Fi, wireline, satellite channels).
- Aggregation of data sources and network access points in some 2-3,000 data centres across the globe where intelligent network control can be located.

The implication here is that utilities such as Equinix will offer intelligent routing that combines networking and compute functions within its data centres, reducing complexity of the overall infrastructure, and offering a wider range of services to end users such as data aggregation (including storage and security) and data augmentation (access to multiple cloud platforms).

Summary

Connectivity becomes an ever more central aspect of the next phase of computing, especially with the prospect of 5Billion connected individuals and 50Billion interconnected machines by 2025. 5G will be an essential conduit to support mass data transfers given expanded capacities of 100 Gbps. It will also be a critical conduit to connect low power sensors that are emerging rapidly on the digital landscape. However, 5G coverage is likely to be concentrated on highly populated urban areas (some 500 cities worldwide).

Satellites will bring greater ubiquity to such 5G connections, especially where applications involving IoT are widely dispersed in rural and underdeveloped areas of the world, as is the case in farming, water, and distribution. It will also be able to support 5G services on moving vehicles such as planes and ships. Overall, converged 5G is considered by companies such as Equinix as key enablers for the next phase of computing.

6. Engaged mobility

As transportation systems evolve, demands for always-on interconnectivity and continuously high quality-of-service will be a necessary foundation for the travel and transportation industry.

A new travel context

Few sectors are changing as fast as automotive. Most governments are now legislating mandatory electrification of all vehicles by 2040. For millennials, the idea of owning a car, especially within cities, is rapidly receding. Instead, they prefer to depend on Uber or car sharing services such as Zip Car or Drive Now. The growing social trend is towards 'access' rather than 'ownership'.

At the same time, cars are becoming mobile computers, with software representing over 50% of product value. Lead vendors such as Ford and VW are focused on developing a new generation of intelligent vehicle that will constantly receive software updates and generate data relating to performance, road conditions and passengers. The emphasis today is on the traveller's experience, encompassing efficiency factors such as avoidance of traffic congestion, and in-car information and entertainment. With fully autonomous vehicles on the horizon, the car becomes an extension of office and social space.

Ecosystem developments

Transport of the future will depend on collaboration between different agencies and vendors. Companies such as Amazon, Microsoft and Google are entering this sector with new approaches towards navigation and in-car entertainment, especially in autonomous vehicles. However, they are unlikely to manufacture the physical vehicle. Vehicles will connect with other

Two factors need to combine to create intelligent vehicles capable of transforming the traveller's experience. The first being an agreement on open standards that will enable a multiplicity of providers to serve the traveller with a relevant mix of applications – as per iTunes in the music business. The debate is likely to centre around iOS and Android operating systems.

The second will be the digital platforms themselves on which such applications can be developed and delivered to a variety of vehicle brands. Open platforms will encourage software developers to develop and test innovative solutions such as road tariffs and vehicle insurance, route optimisation and emergency cover as they have in other areas such as social media.

Connectivity will be a key enabler

Updating in-car applications, optimising vehicle performance, and providing a constant stream of information and entertainment services will require ubiquitous and volume connectivity between vehicles, highway agencies, manufacturers, and service providers. The identification of individual travellers will ensure a fully customised experience.

Summary

New demands for in-car services and the move toward increasingly autonomous, connected vehicles will mean that a converged 5G infrastructure could become an exchange platform for services to the vehicle, acting as a hub for the growing multiplicity of service providers.

COMMENTARY AND CONCLUSIONS

Analysis and review of inputs to this study have led to six key principles emerging as central to the future of 5G and the role of a converged satellite and terrestrial solution.

1. **Use of satellite technologies MUST be part of the conversation on the future of 5G. Currently, they are receiving little attention.**

   Many of the most critical use cases for the future of 5G will require support from satellite-based communication systems. The high availability and broad-based connectivity offered by satellites add significant value to use cases that require ubiquitous coverage. Traditional space industry experts and new entrants to the industry bring relevant new perspectives to the discussions.

   Hence, the satellite industry needs to participate actively in conversations about the future of 5G taking place in various committees such as 3GPP, EC and ITU-T, and must be a key consideration in government 5G strategy.

2. **Business applications will help drive the economic case for 5G. Business leaders in critical application domains deserve higher profile and influence in guiding the pace and priorities for the future of 5G.**

   To ensure a robust economic case for 5G development and deployment, closer attention must be paid to the potential B2B use cases of future 5G-enabled services. Leading organisations in several business domains are exploring a wide variety of potential new demands on mobile communications. The significant technical advances to be delivered by 5G can only be evaluated and understood by considering the value derived by those using and paying for such services.

3. **New investment has driven advances in space technology that make it wholly relevant for 5G convergence. With increasing demand for connectivity and data distribution, these are becoming ever more relevant to the future of communications delivery.**

   Demand for digital technology is evolving rapidly in several directions, driven by transformative advances in big data, internet of things, artificial intelligence and machine leaning. Many of these rely on a resilient, reliable, and ubiquitous communications backbone. While terrestrial telecommunications have been the engine for digital connectivity over the last two decades, additional considerations need to be addressed to support future needs, particularly as they relate to envisaged B2B scenarios. Massive investment in space communication technologies (primarily from private wealth sources) is bringing new capabilities and enabling new business models that provide an opportunity for the telecommunications and space industry to work collaboratively to generate a future ecosystem to drive the next wave of digital growth.

4. **Many important 5G usage models, essential to the business case for 5G, will not be viable without aligning satellite and terrestrial infrastructure. Optimising different infrastructures will be essential to the near-term and long-term success of 5G.**

   In recent years, the expectations for 5G have been growing. Meeting the key performance indicators being defined for 5G will be difficult with a terrestrial-only 5G approach. A combination of infrastructure approaches appears to be essential. By elaborating several use cases in application domains of vital importance to the future of 5G, the impact of satellite communications has been shown to be a critical consideration.

5. **5G will be progressively rolled out over several years to offer a fully converged inclusive and ubiquitous ecosystem: satellites can help support, focus, and accelerate the rollout of 5G.**

   Current approaches to 5G face challenges to implement the physical infrastructure in densely populated areas due to the disruption and cost involved and may find deployment in sparsely populated areas to be infeasible or too costly. Deployment may be impossible for mobile platforms (such as aircraft, ships, and trains). Satellite-based solutions may provide the opportunity to overcome all these challenges.

6. **Investment in 5G and its implications for the UK requires a broader and deeper study. Further conversations, tests, trials and experiments must be initiated to properly understand converged satellite and 5G solutions as they impact near and longer-range strategy for 5G.**

   The UK government is placing much emphasis on the success of 5G to drive economic growth and productivity. Innovate solutions are required to overcome the risks and unknowns must be addressed to successfully deliver 5G. Much of the investment will inevitably be slow, expensive, and inflexible. Despite these challenges, as in other domains facing massive uncertainties, new approaches to encourage greater experimentation are required that allow converged satellite and terrestrial solutions to be defined and tested in a variety of situations.

CALL TO ACTION

Much further work is needed to develop the future of 5G as a converged satellite and terrestrial proposition. With this report we invite the broad community of stakeholders across the 5G ecosystem to engage

1. **Enhance industry-based use cases to deepen understanding of future needs for connectivity and data services.**

   This report has begun the task of exploring use cases for 5G in several industry domains. These must now be validated and enhanced with the knowledge and experiences of key players in those industries.

2. **Join or create a community across your ecosystem to share ideas on future 5G mobile communication needs.**

   Add to the understanding and collaboration across your industry ecosystem by taking part in discussions on future business needs. Identify and work with those who wish to explore those use cases more deeply to validate their client desirability, technical feasibility, and commercial viability.

3. **Expand your knowledge and understanding of future 5G solutions.**

   Build your organisational capability by creating a shared knowledge base of satellite and terrestrial technology developments, new digital business models, and market trends with respect to 5G adoption. Challenge your organisation's strategy in the context of this trend.

4. **Experiment by creating and testing new business models and revenue possibilities for converged 5G.**

   By designing short, low-impact experiments, knowledge can be gained about the future opportunities for your business that will be opened through the capabilities of a converged 5G solution. Engage in these experiments to improve your perspectives on the opportunities and challenges that a converged 5G solution will bring. Define, debate, and share those experiences within and outside your organisation.

5. **Take part in the conversation on the future of 5G.**

   Join one of the emerging communities, such as the 5GIC at Surrey, exploring the future of 5G to help examine issues such as the role and impact of standards bodies, the relationship between the business and technology issues in 5G, and the research directions for future 5G solutions in the digital economy.

Take the first step to join the conversation and engage in the discussion of the future of 5G by going to **www.horizons5G.com**.

THE APPENDIX

FOOTNOTES

1. https://www.surrey.ac.uk/5gic
2. Source: Northstream
3. Source: Northstream
4. A small satellite is defined as weighing between 1 and 500 kg.
5. LEO is defined as less than 2,000 km above the earth's surface.
6. See Appendix A for details of these workshops and their attendees.
7. https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf
8. https://www.sciencedirect.com/science/article/pii/S0040162517313525#bb0110
9. Source: Booz&co.
10. Source: ETRI graphic, from ITU-R IMT 2020 requirements.
11. Equinix Inc. 2017.

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APPENDIX A – CONTRIBUTORS

We are indebted to a large team of people who provided their time, views, and experiences in producing this report. We are pleased to acknowledge their support and help.

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Equinix

Giff Gaff

Kier Highways

McLaren Applied Technologies

Ofcom

Portsmouth University

Roke Manor

Shell

Syngenta

Vodafone

VW Financial Services

Wincanton

APPENDIX B – THE UK DIGITAL ECONOMY CONTEXT

Driving the UK Digital Economy

In the UK government's recent update to its 5G strategy in December 2017, it was emphasised that world-class digital infrastructure is a critical building block to achieve the country's ambitions for delivering a modern Industrial Strategy. And with that in mind, it promised to accelerate the deployment of 5G networks to ensure that the UK can take early advantage of the application of those networks.

The application of 5G to key business scenarios is fundamental to the nation's future.

Fuelled by the drive for job growth and increased UK productivity, the impact and influence of the digital economy is viewed as critical to future prosperity in a time of growing uncertainty. Whether it is encouraging new digital businesses to grow or helping traditional businesses to transform in a digitally-enabled world, creating the conditions for the UK to be at the forefront of digital economy activities is now at the top of the government's agenda. And it is seen by businesses as essential to their future survival.

Broadly, the digital economy is concerned with the adoption of new digital technologies, particularly Information and Communication Technologies (ICT), and the subsequent reengineering of the digitally-delivered products, services, and business practices that are enabled by these new capabilities. This breadth underlies much of the evolution of current business activity and investment in a digital age. In fact, the European Commission goes as far as to call the digital economy "the single most important driver of innovation, competitiveness and growth".

Consequently, it is essential that the UK government understands and participates in the digital economy in support of all its citizens, and in the broader national interest. The positive view of the UK as a digitally-connected place to live and carry out business must be balanced with the risks that, as William Gibson stated, "the future is already here – it's just not very evenly distributed". The accelerated pace of change is already stretching us as individuals and redefining many aspects of our society. New technology advances bring to the forefront questions concerning job insecurity due to adoption of digital solutions for increasing efficiency and flexibility, inequalities due to lack of consistent availability and fair access to basic social services through digital channels, out-of-date approaches to overseeing ethical and legal standards enforcement for digitised services, ineffective governance for protecting the most vulnerable in our communities from malicious or unforeseen dangers online, etc.

In fact, these concerns are exacerbated by the most recent trends and directions, pulling at the core of established business and cultural norms. Three areas are illustrative:

1. **Automation, artificial intelligence (AI) and machine learning (ML).**
   The immense computing power that is being brought online through ever more reliable high-speed internet infrastructure is now being utilised to analyse large amounts of data being generated by all sorts of digitally-enabled devices. The sophisticated algorithms being developed are "trained" by this data to look for regularly occurring patterns that could be replaced with simplified automated approaches, and for anomalies that may identify deviant or divergent activities requiring further investigation. Such systems are compelling in their speed of analysis and their ability to predict actions with increasing accuracy. Hence they begin to augment, and often to replace, human interpretation when applied to domains such as financial management, healthcare, legal services, and many more.

2. **Industrial strategy, manufacturing output, and productivity.**
   The UK government has turned its attention toward the broader concerns that surround the competitiveness of UK industry, and announced that it will produce an industrial strategy to galvanise action in this area. Currently emerging, the focus areas are seen in the selection of a number of key domains in which the UK must invest to gain or retain a leadership position, a reshaping of the relationship between research investigations and industrial practice, and the development of the skills necessary to retune the workforce to be more effective, productive, and engaged in driving the UK forwards. However, even the very notion of "productivity" in a digital era must now be redefined, to say nothing of

the reforming job markets due to increased automation, and the re-skilling of the workforce.

3. **Brexit and ongoing macro-level uncertainty.** Today, any strategic activity must be positioned within the reshaping of UK society and a world that is undergoing widespread political change. As the UK comes to terms with the implications of Brexit, the only certainty appears to be that we must prepare for uncertainty and ambiguity for some time. We must expect changes will occur in our working and living conditions and become more accustomed to dealing with that change. That means that we will need faster ways to carry out analysis of emerging situations and their potential impact, to implement changes in complex, ambiguous circumstances, to measure the impact of change and offer a balanced assessment of the status of alternatives, and to apply the lessons learned from sub-optimal actions to improve our on-going execution.

Highlighting these three areas reinforces the view that flexibility and speed of action will be essential future attributes. The importance of ICT and other technological advances will drive the UK government and businesses to embed digital technologies within their operational model to speed up existing practices, and at the same time force us toward reimagining the kinds of products and services that will be necessary in a digitally-connected world. So this raises the importance of digital economy concerns as a foundation for future industrial competitiveness. For the UK this will be particularly important as it seeks to address the economic and societal risks that emerge, and as it exploits the digital technologies that underscore the essential alignment between the UK government, businesses, and individuals.

APPENDIX C – A PERSPECTIVE ON CONVERGED SATELLITE AND TERRESTRIAL 5G SOLUTION

Technological change is now occurring at a such a pace that we are in danger of no longer being able to adapt to it quickly enough to take advantage of the benefits it brings. At an individual, organisational, and societal level we see evidence that multiple streams of development are coming together to challenge our ability not only to address today's needs, but also to predict future opportunities. For more than a decade, Thomas Friedman, the New York Times author and futurist, has been exploring the implications of "convergence" in an increasingly digital society. Rather than a single specific advance, he maintains that it is the convergence of significant changes in multiple areas that define our digital age. He emphasises that the combination of these advances provides something much more powerful and disruptive than anything that could be created individually. His observations are particularly appropriate to the world of communication technologies and infrastructures as we anticipate needs for the coming years.

Context

Although expectations for 5G technology vary, the targets widely discussed include: increasing download speeds to more than 20 gigabits per second; reducing response latency toward 1 millisecond, and; supporting high densities of devices typical in urban areas where there may be as many as 1 million devices per square kilometre. With such characteristics, the impact of 5G will be more than simply an incremental push for existing mobile technology and internet use. We can foresee many new applications being re-hosted on such an infrastructure and anticipate significant disruption to existing data-hungry or connection-intense scenarios.

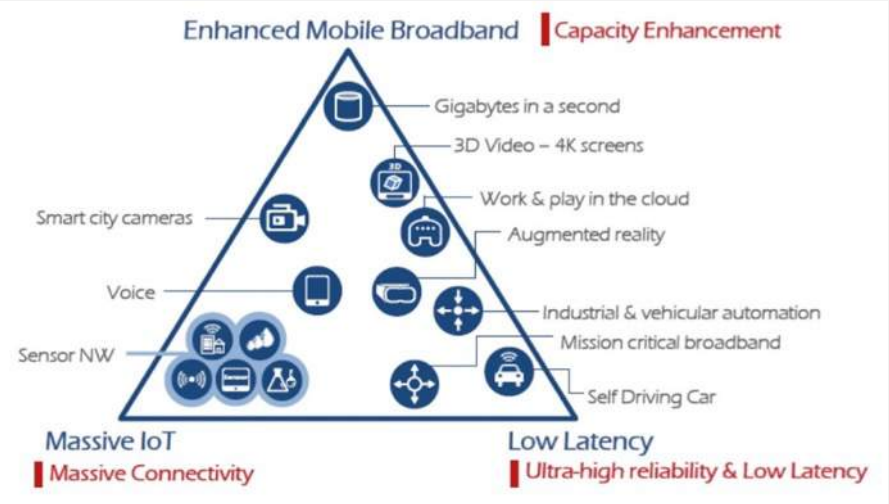
The technological aspects of 5G have been widely discussed and described. While there are many important aspects to be explored, we focus here on three core elements of 5G that define the range of applications that are enabled, as illustrated in Figure 4. These are:

- **Capacity enhancement.** The rapid growth of bandwidth use on mobile networks has far exceeded many people's expectations. As a result, a key focus of 5G is to increase network capacity through intelligent architectural approaches such as use of software defined networks and network function virtualisation, techniques, network slicing, high-density cells, and other approaches.

- **Massive connectivity.** With the deployment of large numbers of IoT devices, a key role of 5G-enabled networks is to support the communication needs of billions of sensors deployed in high densities in the home, workplace, vehicles, and throughout the environment.

- **Ultra-high reliability and low latency**. Domains such as industrial control, healthcare and automated vehicles place high demands on communications infrastructures. Essential to deployment of 5G in these areas will be high-speed predictably reliable network performance suitable to meet the demands of dependable systems domains.

Fig 4. The Three Key 5G Characteristics Driving Applications.[10]



What satellites bring to 5G

Delivering the benefits of 5G requires differentiated solutions across a range of key application domains delivering high value services. Currently, business leaders and investors are struggling to elaborate the business cases necessary for 5G to fit their contexts. And, despite the many technology and standardisation issues, the biggest challenges are economic ones. Investment in a new generation of communications infrastructure will only be possible if the economic benefits of that investment are explicit, the risks involved can be managed, and necessary alignments between the various players in the value network can be forged. Several studies have highlighted the importance of the currently perceived lack of a clear business case for 5G. For example, in a 2017 study by GSMA of over 750 telecom leaders, over half of them placed lack of a clear business case as a critical factor hampering progress.

The convergence of satellite and terrestrial approaches to 5G offer enormous potential benefits in key usage scenarios essential to the success of 5G. The strengths of satellite-based communications infrastructures form an important complement to terrestrial-based systems. In fact, the satellite industry can now be seen in a new light as it moves from wholesale provider of bandwidth to value-added partner for 5G. Four key characteristics of satellite communications are particularly relevant with respect to 5G. They provide enhanced coverage and help to ensure 5G meets user expectations for functionality and cost effectiveness:

- **Ubiquity.** Broad access to services is an essential characteristic required for many applications of 5G. One of the critical scenarios for 5G is to support the use of billions of sensors and actuators packed densely into urban areas and widely distributed over remote regions. Such IoT use cases require support for devices that frequently transmit small amounts of data, interact in dynamic networks, and change behaviour based on local context. These scenarios are ideal for data collection and control via satellite.

- **Mobility.** Many uses of communication infrastructure exist in mobile devices moving predictably in small fixed areas, or unpredictably across larger domains. These scenarios require persistence of access across wide geographical regions with varied physical characteristics, and while crossing different geographical features (built-up cityscapes, mountainous regions, maritime situations, etc.). Offering both regional (via a Geostationary satellite) and broad geographic (via constellations of geostationary or non-geostationary satellites) coverage, satellite-based solutions can provide wide access to enable 5G capabilities continuously. This includes urban and rural areas, locations where no fixed-line terrestrial services are available or possible, on board vessels, in aircraft and trains, and so on.

- **Broadcast.** The ability for satellites to broadcast over wide areas, particularly when deployed in broad constellations, provides coverage in scenarios involving delivery of similar content in predictable loads to an unlimited number of terminals or network nodes consuming high bandwidth services. For example, satellite-based approaches are often the most cost effective for many kinds of media distribution applications such as video streaming, and so on.

- **Security and resilience.** Sudden increases in communications load are challenging for network service providers to handle. Yet these situations are a critical element of the 5G value proposition. They require a combination of resilience to disruption, and dependability in the face of significant demand. For example, in emergency and public safety scenarios, use of a satellite-based solution can play an important role in helping to monitor and control critical infrastructures and provide alternative channels for information flow.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