WHITEPAPER

Private networks

bai communications

Contents

At a glance

4G/5G cellular wireless technologies offer unparalleled capability and are backed by a huge commercial ecosystem.

Public networks often cannot meet extreme requirements for coverage, capacity, reliability, security, low latency, or low power devices. So, private networks make sense for organisations in sectors like transport, emergency and security services, factory automation, utilities, healthcare, and many others.

4G/5G cellular is an excellent technology to meet demanding private network needs. Organisations and businesses can utilise the public cellular network ecosystem to deploy private networks with extreme performance, security and IoT support. Public/private/hybrid cloud deployments are enabled. Common technology provides interworking with public cellular networks.

Wi-Fi complements, rather than replaces, 4G/5G cellular technology where extreme private networks requirements exist.

BAI Communications (BAI) designs, builds, and operates communications infrastructure around the world. Collaboration is at the heart of how BAI operates. BAI has the expertise and experience in understanding customer pain points to develop the right solutions to address these by working with leading global vendors. BAI has extensive experience in designing and deploying public private partnership projects; for example, the MTA in New York, TTC in Toronto and work is soon to begin with TfL on the London Underground.

1. The power of public cellular wireless networks

The now widely deployed 4G and the emerging 5G public cellular wireless networks offer unparalleled capabilities in services, scale, and reliability. Thanks to the international standardisation that has existed since 1982[1], there is now a huge commercial ecosystem backed by massive investments from network vendors, system-on-chip (SoC) silicon vendors, device vendors, mobile network operators (MNOs) and service providers. See Panel 2.

Mobile phones have changed our lives; it is estimated that there are now 3.8 billion smartphones in the world today[2].

4G LTE has become the first truly global cellular mobile standard. As at March 2021, 807 operators are running LTE networks in 240 countries/territories worldwide[3].

5G, a further evolution of LTE, with most 5G capable devices also supporting LTE to provide backwards capability. As at March 2021, 428 operators in 132 countries/territories are investing in 5G networks[3].

IoT – the ‘Internet of Things’ – will further densify device penetration as smart and connected ‘things’ become more prevalent. In day-to-day life people are using connected home appliances, smart speakers, wearables, and cars. For services and utilities, everything from dustbins to parking spaces are becoming networked. Connected machines and objects in factories offer the potential for a step forward in automation, sometimes called the Fourth Industrial Revolution[4]. Huge opportunities exist for healthcare wearable and embedded devices[5]. There are many potential applications in public safety[6]. Autonomous machines including self-driving cars are no longer science fiction. The collection and analysis of data from these ‘things’ – providing personal privacy is protected – offers potential for deep insights in people behaviours and optimisation of the services provided to them.

5G will also enable huge growth in B2B services in sectors including healthcare, manufacturing, energy and utilities, automotive, public safety, media and entertainment, financial services, public transport, retail, and agriculture[7].

2. Why deploy a private cellular network?

2.1 Shortcomings of relying on public mobile networks

Public cellular wireless networks cannot meet all the needs of all organisations. Reasons for deploying private cellular networks are shown in the table below.

DRIVERS DEPLOYING PRIVATE CELLULAR NETWORKS			PUBLIC MOBILE NETWORK LIMITATIONS
DRIVER	EXPLANATION	USE CASES	
Coverage	Provide ubiquitous coverage (expansive and/or deep with no dead spots)	• Large indoor spaces such as transport hubs, factories, and warehouses • Rural/remote outdoor locations • Tunnels and underground locations	In locations with no, or poor, public mobile network coverage
High capacity	Provide sufficient capacity at reasonable cost	• High bandwidth services (such as video) to many devices • Many mobile broadband users • Huge numbers of individually low-bandwidth sensors	Insufficient public mobile networks capacity, or high costs of capacity
Low latency	Ensure fast reaction times even across varying network loads	• Industrial control • Navigation and vehicle control • Augmented reality and gaming	Public mobile network latency is too high
Extreme high reliability	Ensure communications always available (even in adverse radio conditions)	• Safety and security critical applications • Business critical applications • Isolation from public mobile networks • Organisations who want complete control over their networks	Lack of trust in public mobile networks
High security	Protect data, device/user identities and locations, and the network		
Low power devices	Enable battery powered devices to operate for many years	• IoT • Reduced device costs	Lack of low power device support in public mobile networks

2.2 Private cellular network benefits for organisations

See Panel 1 for examples of how private cellular networks can benefit specific types of organisations.

Section 3 discusses how private cellular based on 4G/5G cellular technology can best provide these benefits and discusses deployment practicalities.

Note that businesses should strongly focus investments into 4G and 5G. As explained in Panel 2, 2G and 3G technologies are being phased out of active use.

3. Why use 4G/5G cellular technology to deploy a private network?

3.1 4G/5G cellular is a major industry and with a huge supplier ecosystem

Enterprises and industries can leverage the immensely capable, proven technology and huge supplier ecosystem of 4G/5G commercial cellular mobile for their own private network needs. See Panel 2.

Leveraging 4G/5G commercial cellular mobile is far more capable and economic than evolving existing legacy radio technologies such as VHF radio, P25, and TETRA.

The latest network vendor products support both 4G LTE and 5G standards, and most 5G devices are backwards compatible with 4G LTE. 5G is generally most sensible for new private network deployments since this maximises capability and it increases spectrum options.

	TECHNOLOGIES FOR PRIVATE NETWORKS (HIGH LEVEL COMPARISON)					KEY COMMENTS
	FEXIBILITY	BANDWIDTH	LATENCY	COST	DEVICES	
Fixed (ethernet)	✗ Network changes very costly	✓ 'Unlimited'	✓ < 1 ms	— Very costly to set up but locations already have one fixed network	— 'Unlimited' but costly to add new device	• Private wireless networks with significant benefits vs. fixed given higher flexibility and efficiency • Wi-Fi 6 as a more cost effective solution but can't provide reliability of 4G/5G • 4G would work today for the vast majority of use cases but is not future proof like 5G
Wi-Fi 6	✓ Easy to set up and change	✓ 9 Gbps	✗ < 50 ms Latency will vary based on backhaul solution	✓ Cheap solution	✗ Limited number of devices	
LTE	✓ Easy to set up and change	— 1 Gbps	— <25 ms	— Cheap solution	— Limited number of devices	
5G	✓ Easy to set up and change	✓ >10 Gbps	✓ <1 ms	More upfront capex however allows efficiency drives through AI etc	✓ Allows for high connection density	

3.2 Spectrum is available in most countries for 4G/5G private cellular networks

Unlicensed spectrum in the 5 and 6 GHz bands can meet some needs but is susceptible to conflicts created by other users of this spectrum.

Fortunately, in many countries around the world, regulatory bodies are allocating specific frequency ranges for private networks. Such spectrum is used by different organisations across a country or territory but is usually allocated to a single organisation in a specific local geographic footprint such as a port or factory.

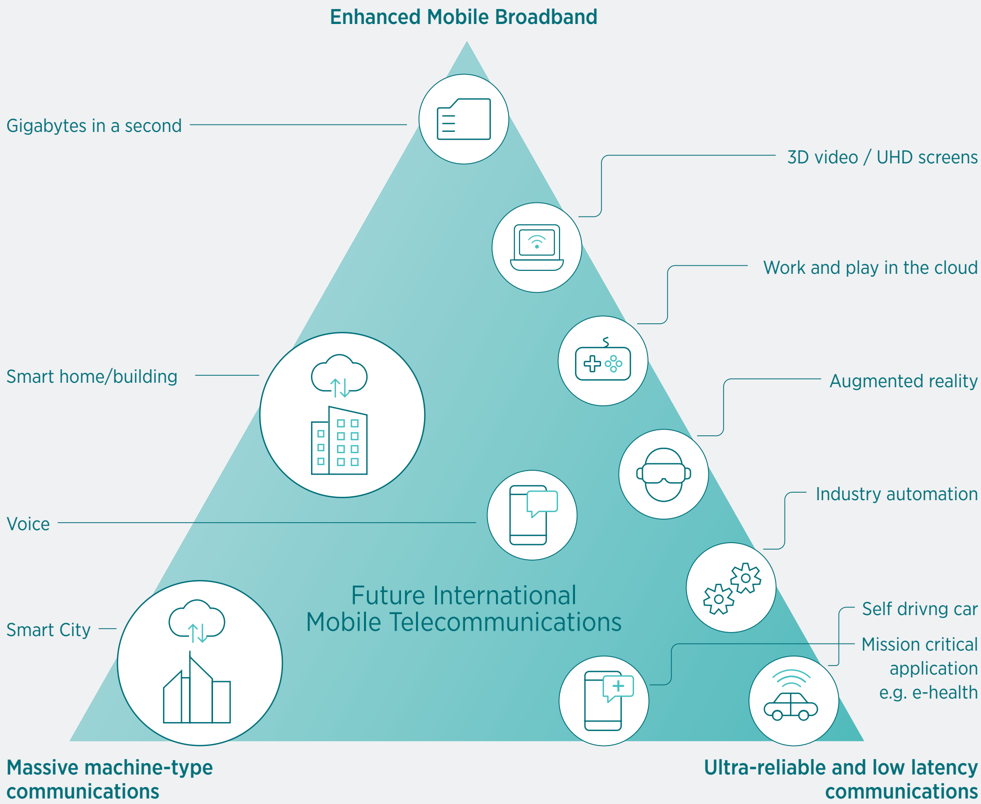
See Panel 3 for details of spectrum licensing models and suitable spectrum for private cellular networks.

3.3 5G cellular provides optimised private radio performance

The radios in 5G networks can also be optimised to simultaneously[8] support different uses:

- **eMBB** (enhanced mobile broadband): high data rates, user density and traffic capacity in wide areas, hotspots, and high mobility scenarios.
- **mMTC** (massive machine type communications): wide-area networking of huge numbers of low-power devices.
- **URLLC** (ultra-reliable and low latency communications): latency and reliability sensitive applications such as factory automation, autonomous driving, the industrial internet and smart grid or robotic surgeries.

Source: ITU's IMT-2020 framework https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf



3.4 4G/5G excels in dense multi-cell/multi-access-point environments

Cellular networks were created to handle multiple radio cells and ensure smooth handovers between cells. 4G/5G extends this to multiple radio layers with wide area radio cells providing coverage and small cells providing capacity in hotspots, including the ability to move traffic between layers depending on changing device connectivity and changing traffic flows.

Cell handovers are clearly critical for mobile devices. They also aid stationary devices in multi-access-point environments by providing resilience against access point failures, and adaption to reconfigurations and changing traffic patterns.

3.5 Cloud-based private mobile core network

4G/5G private cellular networks do need a 'mobile core network' to provide overall control and to provide the 'packet gateway' to link to private networks and/or the public internet. This mobile core network no longer involves major investment in bespoke equipment. The 5G software defined networking and virtualisation evolutions discussed in Panel 2 mean that the mobile core network can now sit in a cloud. This can either be dedicated to a company/organisation or provided as software-as-service, located either in the public cloud or within a dedicated private cloud data centre.

The IP multi-media subsystem (IMS)[9] is a standardised way of providing voice services in 4G LTE and 5G public cellular networks and extending calls over Wi-Fi networks. It can also be used for video and text messaging services. For private 4G/5G networks, this same IMS infrastructure together with applications loaded onto smart phones, can provide specialised services such as push-to-talk (PTT) group and point-to-point communications, person down capability (emergency button), and closed user group one-to-one and group messaging and video streaming.

3.6 Cloud native application enablement for 4G/5G private cellular networks

In 4G/5G private cellular networks, applications securely communicate with the private mobile core network to reach mobile devices. Subject to latency considerations, applications can be located anywhere. If low latency is needed, then it makes sense for applications to sit close to the private mobile core network, in the same cloud if (as discussed in section 3.5) the private mobile core network is cloud based. If extremely low latency is needed, 5G also allows applications to be located at the 'network edge' bringing them closer to the radio access network.

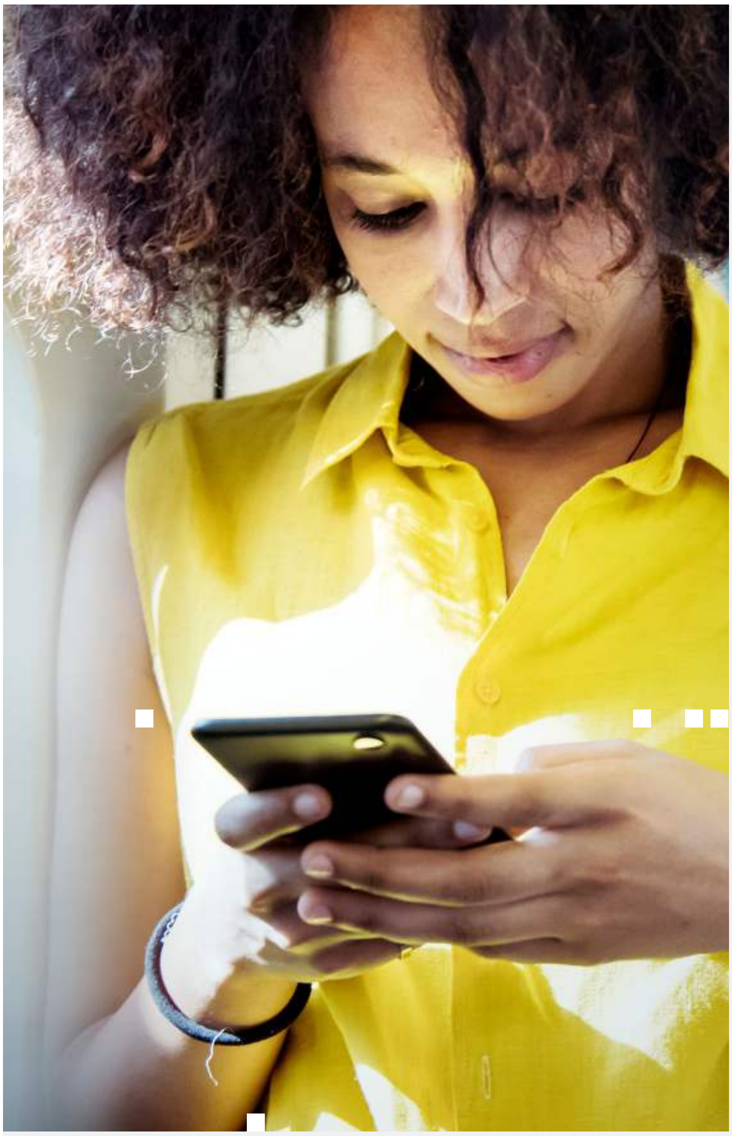
Public clouds, such as Amazon Web Services (AWS) and Microsoft Azure, are increasingly being utilised by organisations. Public cloud providers normally offer services from regional data centres. If there is need for low-latency and/or the reliability of continued operation in the event of wide area communications failures, then public cloud providers offer customers the ability to locate services in their own data centres, so called 'hybrid cloud', the Outposts [10] service from Amazon Web Services and the Stack [11] service from Microsoft Azure.

In the USA, marking the first time a 5G network will be run in the cloud, DISH networks has announced [12] that it will construct its 5G network in the AWS cloud. DISH and AWS foresee that this will transform how organisations and customers order and consume 5G services or create their own private 5G networks.

Many organisations have applications run from their own data centres and supported by their own dedicated networking equipment. Many will have implemented virtualisation to improve server management. A first step to using the public cloud is to rent virtual servers. This takes away the burden of running and maintaining server computers and their associated operating system software, as well as avoiding capex for initial procurement and replacing obsolete hardware.

The full benefits of public clouds are realised by deploying applications as 'cloud native'. This means that applications run in an on-demand software-as-a-service environment including supporting software such as database management and development and test tools. The public cloud provider takes the burden of sizing and (as necessary) expanding hardware and maintains all the supporting software including security and software updates.

Additionally, services traditionally provided by networking hardware, such as a full-featured Cisco IOS XE router [13], are now available as cloud-native services.



3.7 IoT support in 4G/5G private cellular networks

A huge focus in public 4G/5G is on IoT. Including LTE-M and NB-IoT for reliably communicating with huge numbers of low power IoT devices and 5G mMTC (massive machine type communications).

Public cloud providers, most significantly Amazon Web Services, have focussed on IoT. A huge set of software services are available for managing 5G IoT devices and building applications.[14]

Ericsson forecasts that the global IoT market will be worth $1.5 trillion by 2030.[15]

3.8 Security in 4G/5G private cellular networks

The SIM[16] card has played a fundamental role in mobile telecommunications since 1991. It provides a secure means for authenticating devices onto networks, all inside a removable 'secure element', which is easily transferrable between mobile devices. Cryptographic techniques are used for this security, making it much stronger than a simple user identity and password.

eSIMs, also known as eUICC, put the SIM security functions into the silicon inside devices to use less physical space and lower device costs[17]. Manageability is also improved since – instead of needing to change SIM cards – the SIM profile information can be securely rewritten remotely using the mobile network. eSIMs are especially useful in IoT devices.

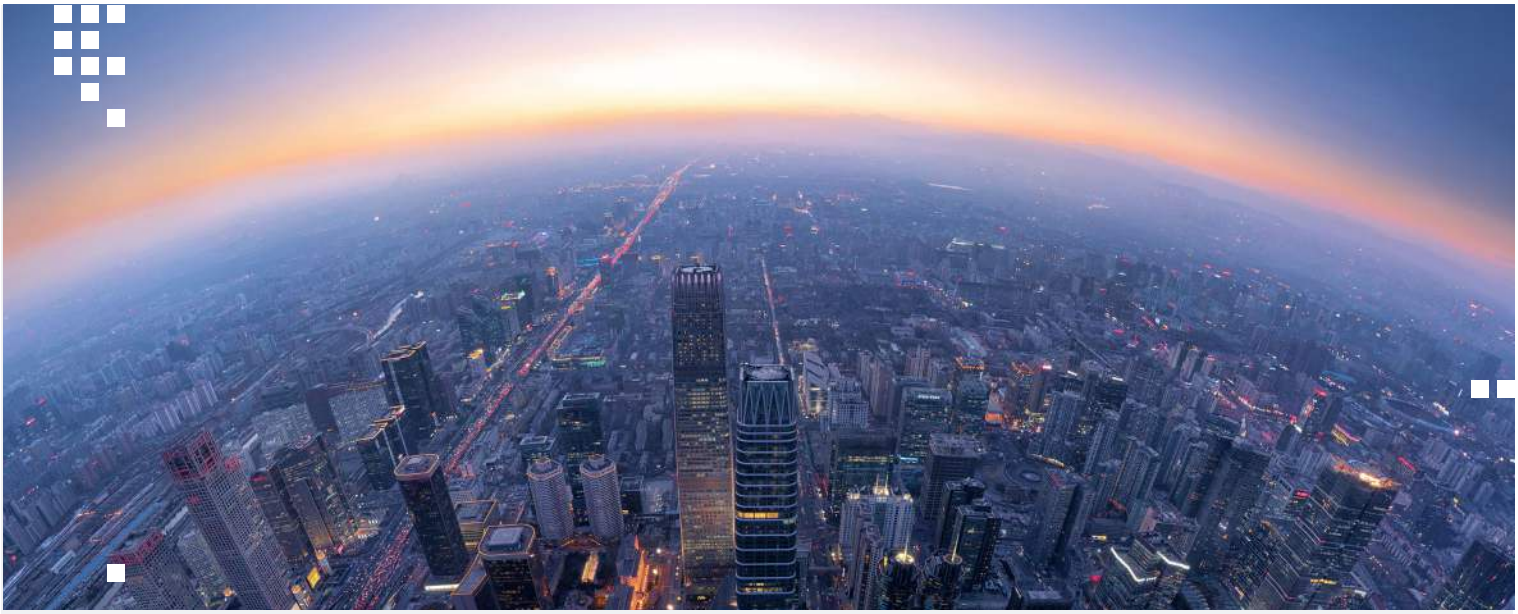
4G/5G Cellular Networks have evolved to be very secure in all other respects. For example, any data sent to or from any individual mobile device is independently 'tunnelled' through the mobile network. This prevents users of the mobile network having any visibility of each other or the network. So, data remains private and the network is protected from subversion.

3.9 Public mobile network inter-working with 4G/5G private cellular networks

Use of 5G cellular technology for private networks facilitates inter-working with public mobile networks. For example, to reach employees working at home or on remote sites, or vehicles out on public roads.

Technically, inter-working can be achieved through roaming agreements, or by using private devices containing dual SIM cards (one for the private 4G/5G cellular network and one for public mobile network).

4G/5G public mobile networks have good security (see section 3.8). Even higher security can be provided by encrypting communications between the private cellular network and the private network device (e.g. by using virtual private network software).



4. Wi-Fi complements private 4G/5G cellular networks

Widely deployed since the IEEE 802.11b standard was established in 1999, Wi-Fi is the normal way of wirelessly connecting devices to broadband networks in homes and offices. At small scale, Wi-Fi is easy to setup just requiring Wi-Fi enabled router or Wi-Fi access point. It generally works very well in small home and small office/workplace environments.

Wi-Fi will certainly continue to be widely used. However, for private networks with the types of extreme requirements discussed in section 2 and in Panel 1, Wi-Fi is often not as capable as 4G/5G cellular because:

- the Wi-Fi ecosystem is locked into the use of unlicensed spectrum (in the 2.4/5/6 GHz bands). This is a problem for many mission critical applications. Contrast 4G/5G cellular mobile being able to use unlicensed, shared licensed or dedicated licensed spectrum (see Panel 3).
- compared to 4G/5G Cellular, Wi-Fi is relatively poor in dense multi-access-point environments (see discussion in section 3.4).
- Wi-Fi does not natively support mobility and struggles in environments with high numbers of nomadic users. For instance, in many coffee shops the quality of service delivered by the local Wi-Fi is inferior to using the wide area 4G LTE cellular service.[18]
- Compared to 4G/5G cellular, Wi-Fi offers relatively poor security (see section 3.8).
- Wi-Fi can be deployed at large-scale in offices and public areas, but successful operation does require a management system such as Cisco's Catalyst and Meraki, HPE's Aruba, Juniper's Mist, and Extreme's Cloud IQ. Wi-Fi management systems are all proprietary, in contrast with the 3GPP internationally standardised 4G/5G cellular core network.

Wi-Fi has evolved through the 802.11a, 802.11b, 802.11g, 802.11n, 802.11ac ('Wi-Fi 5'), 802.11ax ('Wi-Fi 6') and emerging 802.11be ('Wi-Fi 7') standards. These have greatly improved the capacity and performance of Wi-Fi. In the meantime, the capacity and performance of 4G/5G cellular mobile has also advanced. Indeed, Wi-Fi and 4G/5G cellular have converged to use similar underlying radio technologies. Wi-Fi, through its long-range variant WiMax, greatly influenced 4G LTE to the extent that most WiMax deployments have been replaced by 4G LTE even for fixed wireless broadband applications.

5. Why BAI for 5G private cellular networks

BAI Communications (BAI) designs, builds, and operates communications infrastructure – cellular, Wi-Fi, broadcast, radio and IP networks – connecting communities around the world. This includes:

- Building complex networks in difficult environments. Including cellular and Wi-Fi systems to serve commuters using the New York and Toronto subways, and using the underground and light rail systems in Hong Kong (See Panel 4).
- We have a strong history of running mission critical communications networks. This includes Australia's broadcast transmission network serving 99% of the population and the New South Wales emergency services network. Transit Wireless provides a 4.9 GHz 802.11 mesh network which operates on 50MHz of licensed public safety spectrum (4940 to 4990MHz). This network is used by the Metropolitan Transit Authority (MTA) New York City Transit (NYCT) to provide Help Points (HP) in underground station platforms and mezzanines.
- Advanced data analytics to enhance travel experience for commuters and improved efficiencies and unlock new revenue streams for our transport operators.
- Collaboration is at the heart of how BAI operates with broadcasters, transit authorities, governments and municipalities, mobile network operators, enterprise, and vendors worldwide.

We have expertise and experience that covers the full lifecycle of projects by understanding the customer pain points and collaboration from definition and design, through implementation, into operation and support, and ongoing optimisation and evolution.

BAI has also been awarded the 20-year concession by Transport for London (TfL) to deliver full high-speed mobile coverage on the London Underground. As the largest infrastructure project of its kind in the world, passengers will be able to enjoy uninterrupted connected travel on the entire London Underground network once completed. BAI will also establish a backbone of connectivity across London, connecting buildings and street assets via a new fibre network to deliver city-wide improvements. Plus, we will help to create a safer, smarter London by building and operating critical communications infrastructure that will support police, fire, and ambulance services.

At BAI, we choose the right solutions and appropriate vendor(s) for our customers using an adopted methodology for vendor selection. We are vendor agnostic and work with leading vendors across the world. We do not sell specific products and do not have exclusive arrangements with suppliers.

BAI is majority owned by Canada Pension Plan Investment Board (CPP Investments) since 2009. CPP Investments is a trusted long-term investor with C$475.7 billion under management (as at 31 December 2020) and actively invests in infrastructure assets around the world.

Being majority owned by CPP Investments, BAI Communications has the financial backing to make infrastructure projects of any size work and the flexibility to participate in the financing of major infrastructure projects. We offer multi-faceted financing options between capex and opex that will allow our customers the flexibility they need to be able to make their projects work.

PANEL 1

EXAMPLES OF HOW PRIVATE CELLULAR NETWORKS CAN BENEFIT ORGANISATIONS

		TYPICAL NETWORK REQUIREMENTS							
ORGANISATION TYPE	BENEFITS OF USING A PRIVATE CELLULAR NETWORK	COVERAGE: EXPANSIVE	COVERAGE: DEEP INDOOR	CAPACITY: HIGH TRAFFIC	CAPACITY: ANY DEVICES	LOW LATENCY	EXTREME HIGH RELIABILITY	HIGH SECURITY	EXTREME LOW POWER DEVICES
Ports, airports and transport hubs	Expansive indoor and outdoor coverage, serving high numbers of densely packed users or connected things	✓	✓	✓	✓		✓	✓	
Emergency and security services	Adding data and video to legacy voice networks, while maintaining operation independent of public networks	✓					✓	✓	
Factories	Low-latency and reliable connection of high numbers and density of sensors/machines/robots, indoors and across campuses		✓		✓	✓	✓	✓	
Power generation facilities	Secure control of sensors and actuators, often in remote locations	✓			✓		✓	✓	
Mining and natural resources	Serving out-of-the-way or underground locations not served by public networks	✓	✓				✓	✓	
Warehouses	Tracking movements of huge numbers of items indoors		✓		✓				✓
Healthcare	Reliable connection of medical equipment in high density indoor environments, some massive transfer of analytic data, all secure		✓	✓	✓		✓	✓	✓
Campus and conference centres	High capacity and density communications to support large numbers or people and IT systems indoors and across campuses	✓	✓	✓	✓				
Sports stadia	Supporting a high density of users, including user generated videos and near real-time virtual and interactive services	✓		✓	✓	✓			
Smart towns/ cities	Connecting a huge number of devices, users, and applications	✓	✓		✓			✓	✓
Smart electric, gas and water grids	Providing secure national scale control systems and networks	✓			✓		✓	✓	✓
Railways	Providing secure large-scale control systems and networks for efficiency and safety	✓	✓			✓	✓	✓	
Shipping	On-board connectivity at sea for telematics, control, and cargo monitoring	✓	✓					✓	✓
Autonomous Road Vehicles	Near real-time information relay, control, and collision avoidance	✓			✓	✓	✓	✓	
Neutral hosts in special locations	Providing coverage for multiple public networks in locations not economically viable for single network operators		✓	✓	✓				

PANEL 2

4G/5G COMMERCIAL CELLULAR MOBILE NETWORK ECOSYSTEM AND CAPABILITIES

Commercial cellular mobile systems – through global collaboration (standardised by 3GPP) – have become hugely capable in services, in scale and in reliability. The 40-year history of commercial cellular mobile networks is summarised in the table overleaf.

With the now widely deployed 4G and emerging 5G we have:

- a huge commercial ecosystem backed by massive investments from:
  - network vendors: Ericsson, Nokia, Huawei, Samsung, NEC, etc
  - system-on-chip (SoC) silicon vendors: notably Qualcomm, MediaTek and Intel
  - device vendors: Apple, Samsung, Xiaomi, Lenovo Motorola, etc
  - mobile network operators: Verizon, AT&T, Vodafone, NTT Docomo, T-Mobile, Telefonica, etc
  - service providers: Google, Apple, Amazon, Microsoft, Netflix, etc.
- support for inter-working of multiple layers of large and small radio cells, using multiple spectrum bands, to optimise coverage and throughput.
- network radios that can adapt to, and support co-existence, of 'network slices' for multiple use cases: including, high-bandwidth mobile broadband, low-power and extended coverage for IoT, and ultra-low-latency and reliability for real-time applications.
- 4G/5G cellular mobile exceeds the capabilities of other wireless technologies such as Wi-Fi, LoRa, Sigfox and Zigbee:
  - 4G/5G excels in multi-cell/multi-access-point environments providing mobility, resilience against access-point failures, and adaption to reconfigurations and changing traffic patterns
  - 4G/5G excels in dense multi-user radio environments.
- standardised core network services for sophisticated user, device and service management and inter-networking with the Public Internet, Public Cloud, and corporate private networks and Private Cloud
- end-end quality-of-service and security
- an extensive application ecosystem providing domain specific apps that run on a plethora of devices.

PANEL 2 continued

40-YEAR EVOLUTION OF CELLULAR MOBILE NETWORKS

1G Analogue technology deployed in the 1980s. Introduced cell towers built around the country to provide wide coverage while reusing radio frequencies many times. Voice services only, poor security and frequent call drops. Various technologies were deployed, nationally or regionally. All 1G networks are now decommissioned.

2G First digital systems, deployed in the 1990s, introducing SMS and data services as well as voice. Higher security, capacity, and reliability. 2G technologies included GSM/GPRS & EDGE (many parts of the world), CDMAOne (North America) and PDC (Japan).

Real-world download data rates at 64 kbps. Real-world latency around 100 ms.

2G networks have been switched off in North America, Japan, Australia, Singapore, and South Korea. In other parts of the world, 2G will likely continue until the mid to late 2020s but with limited capacity as networks operators repurpose spectrum for 4G/5G.

3G Deployed from 2000 onwards, 3G shares the resources of wide-band radio channels across multiple users to deliver high-speed video/data services as well as voice and SMS. 3G technologies include UMTS-HSPA+ (many parts of the world), CDMA2000 1X/EVDO (North America),
TD-SCDMA (China) and WiMAX (a long-range version of Wi-Fi).

Data rates initially 384 kbps evolving to 1-5 Mbps (real-world downloads). Real-world latency around 60 ms.

Smartphones become viable because of 3G data services. Since the first iPhone in 2007, smartphones have evolved to become internet appliances and hubs of connectivity, not just devices for calling and texting.

3G networks are gradually being switched off around the world. Where 3G still exists, capacity is limited as networks operators repurpose spectrum for 4G/5G. In Europe, some network operators have announced 3G switch-off ahead of 2G.

4G LTE is the first true international mobile standard, deployed since 2010 and now available in most countries worldwide. A major change in technical architecture with underlying communications based on internet protocol packet data, with services such as voice and SMS layered on top. Very wide-band radio channels, advanced high spectral efficiency radio techniques and multi-user resource sharing. MIMO (multiple input multiple output) antennas to improve capacity and coverage. Evolved to LTE-advanced and LTE-advanced pro.

Real-world download data rates at 5-30 Mbps. Real-world latency around 30 ms.

4G brought multiple radio layers to reality where wide area radio cells provide coverage and small cells provide capacity in hotspots. Includes dual connectivity to wide area and small cells to ensure continuity of service.

In 2016, LTE-M and NB-IoT also emerged as standards to connect huge numbers of low-power ‘things’.

LTE networks are unlikely to be switched off in the foreseeable future. However, spectrum is increasingly being shared with 5G using a technique called ‘Dynamic Spectrum Sharing’ made possible because LTE and 5G use similar radio technologies.

5G Standardised in 2018, and now being widely deployed, 5G brings ‘new radio’ (NR). Supports new spectrum bands, notably C-Band
(3300–4200 MHz) and mmWave (including 26 GHz and 28 GHz). Evolution of MIMO to massive-MIMO antennas. Radio optimisations for eMBB (enhanced mobile broadband), mMTC (massive machine type communications), and URLLC (ultra-reliable and low latency communications). Dynamic spectrum sharing allows 5G NR and 4G LTE to operate in the same spectrum.

Real-world download data rates at 50-200 Mbps using C-Band spectrum, 500+ Mbps using mmWave spectrum. Real-world latency around 20 ms, with goal of less than 1 msec for mission-critical applications served from the network edge.

5G also brings re-architecting of the mobile core network, aften called 5G standalone mode. Control functions are separated from underlying data transport (the concept of ‘software defined networks’) and control functions are organised to become service-based (which facilitates virtualisation and cloud deployment). In practice, vendor implementations of 5G ‘standalone’ mobile cores support both 4G LTE and 5G NR radio access.

PANEL 3

SPECTRUM FOR PRIVATE CELLULAR NETWORKS

Different licensing regimes exist for cellular radio spectrum.

- Licensed spectrum is dedicated to a given organisation typically across a country, a territory, or (in the USA) a large metropolitan 'market' area. Such spectrum is typically allocated to public mobile network operators and utilities and emergency services.
- Shared spectrum is the most likely spectrum to be used in private networks. Such spectrum is used by different organisations across a country or territory but is usually allocated to a single organisation in a specific local geographic footprint such as a port or factory. In the UK, the regulator Ofcom is also proposing the innovation of allowing organisations to seek authority to locally use spectrum that is already licensed to a mobile operator, but which is not being used (or planned for use) in that particular local area.
- Unlicensed spectrum is freely available for public use, subject to limitations on maximum transmitted power. Of most significance is the 2.4 GHz band heavily used by Wi-Fi and Bluetooth, the 5 GHz band heavily used by Wi-Fi, and the new 6 GHz band which will likely soon be heavily used by Wi-Fi. The problem with unlicensed spectrum is that users are at the mercy of other users creating interference and therefore reduced coverage and throughput.

Some examples of spectrum that is, or is likely to become, available for private cellular networks is given on the following table.

COUNTRY/TERRITORY	BANDS	LICENSING TYPE
Australia	3700–4200 MHz 26 GHz and 28 GHz	• Consultations on spectrum sharing and private network use
Canada	3450–3650 MHz 3400–4200 MHz	• Shared local use, auction pending Consultations on spectrum sharing
France	2570–2620 MHz 3490–3800 MHz 26 GHz	• Shared, regional/local licensing • Shared, local 5G trial licenses
Germany	3700–3800 MHz 26 GHz	• Shared, regional/local licensing • Consultation on shared local use
Hong Kong	617–698 MHz Indoors 703–803 MHz Indoors 27.95–28.35 GHz	• Shared, local licensing
Ireland	3400–3800 MHz	• National licensing, with some private networks being deployed in collaboration with public mobile network operators
Italy	3600–3800 MHz	• National licensing, but with provisions for sub-licensing to private users
Japan	1880–1920 MHz 4600–4800 MHz 28 GHz	• Shared • Under consideration • Shared, local licensing
Netherlands	3500–3700 MHz 3400–3450 MHz 3750–3800 MHz	• Shared, local licensing planned from 2022 onwards
New Zealand	2575–2620 MHz	• Shared, local licensing
Spain	3400–3800 MHz 26 GHz	• National licensing, with some private networks being deployed in collaboration with public mobile network operators • Shared, local licensing under consideration
South Korea	3400–3800 MHz 28 GHz	• Government will start providing spectrum for private use during 2021
UK	3800–4200 MHz 1781.7–1785 MHz 1876.7–1880 MHz 2390–2400 MHz 24.25–26.5 GHz Indoors	• Shared, local licensing

PANEL 4

BAI SOLUTION USE CASE: **PRIVATE TRACKSIDE NETWORKS: TRAIN-TO-GROUND CONNECTIVITY IN ACTION**

SUMMARY

Transit authorities driving a better experience for their passengers

Staying connected across a transit journey is integral, not only to ensuring quality traveller experience, but also traveller safety. With reliable connectivity being the key enabler for critical safety features like higher resolution in-train CCTV, train status data offload, alarm reporting as well as train-borne infotainment and passenger Wi-Fi services.

We live in a connected world and the expectation to remain connected when travelling gets stronger with each passing year. Passengers want to be able to make the most of their journey in their own way. Whether that means working on the go, using social media, reading the news, or streaming their favourite video on their mobile devices.

While a focus on improving the travel experience for their passengers is important, transit authorities must also maintain the operation of this complex infrastructure without compromising quality and safety.

BAI Communications (BAI) engineers have the experience to deeply understand the relevant challenges and adopt a customer first approach in delivering customised solutions. So let's look at a transit connectivity use case and how BAI can provide train-to-ground solutions which address evolving connectivity needs.

The scenario: Service and security upgrade

Continuous improvement to service and security systems are a necessity for any transit authority. In this use case, the transit authority is looking to overhaul train-to-ground networks across the entire system, to provide higher data throughput between trains and the core network.

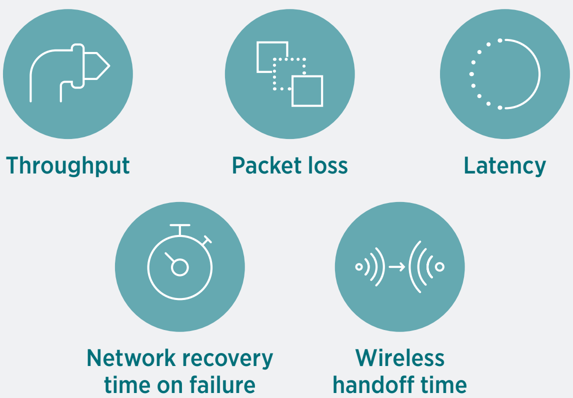
The transit authority wants to improve the train's closed-circuit TV (CCTV) capabilities, to support more cameras at higher resolutions as well as improve passenger safety and operational efficiency. In addition, they want to improve bandwidth and stability for other systems, such as on-train infotainment, train-status data offload, alarm reporting and possibly passenger Wi-Fi services.

In this example, BAI assumes the responsibility to design, install and test the upgraded train-to-ground network. They are also expected to maintain the initial operation, before handing over the maintenance to the transit authority. As a neutral host provider, BAI takes a vendor agnostic approach to address specific customer challenges, sourcing and implementing the best solution for each unique situation.

Example deployment for train-to-ground

a) Upgrade antennas, poles and access points

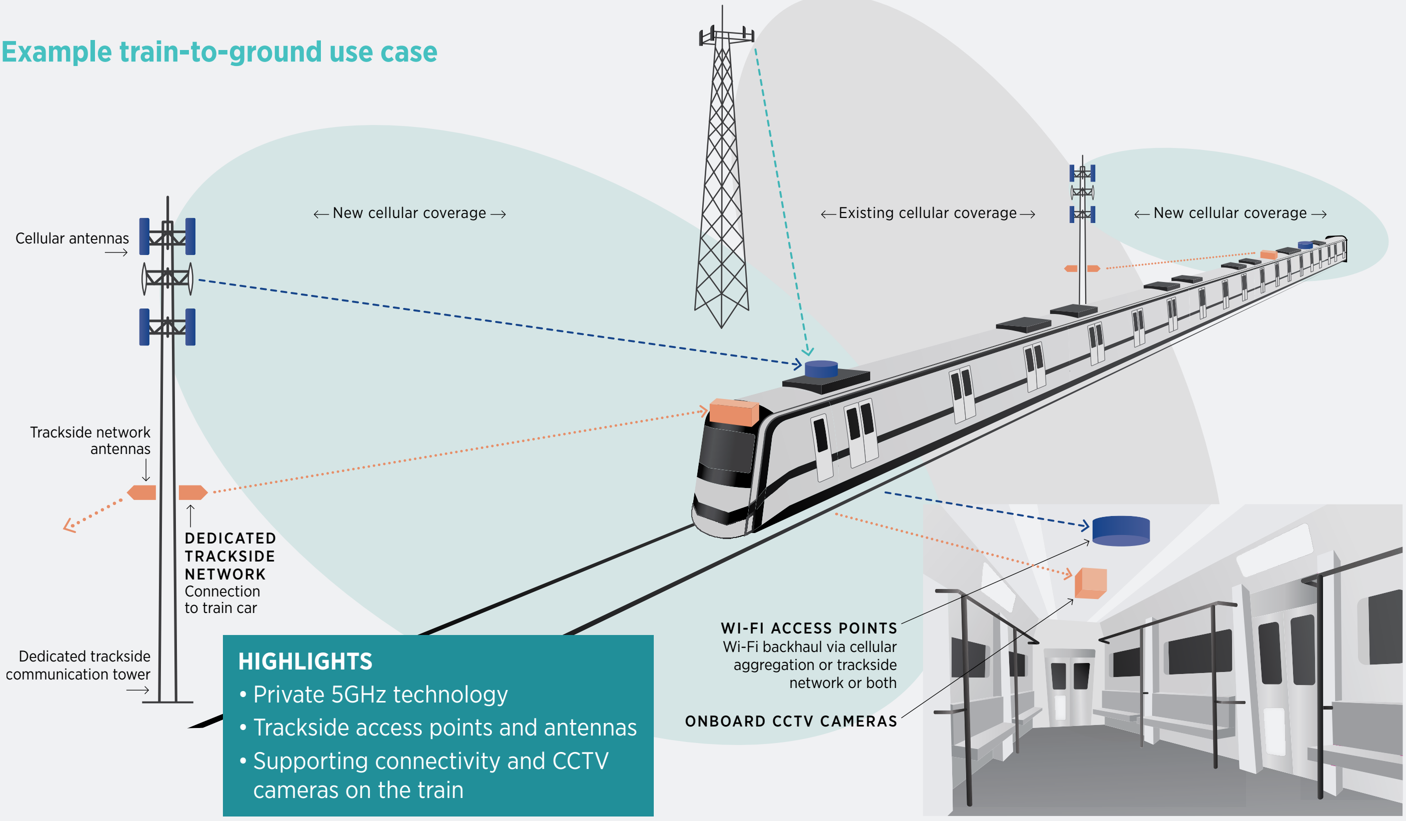
Upgrades and ongoing improvements are important for transit authorities to maintain and support alongside existing transit services. In this use case, key design specification and therefore potential challenges include:



BAI's methodology is to design and then prototype a system that addresses or exceeds customers requirements. In our approach to address the specific requirements of this use case we would deliver a solution with the following capabilities included:

- **Frequency and bandwidth:** A new train-to-ground network using the 5 GHz spectrum band, with a single 80 MHz bandwidth channel.
- **Trackside access points and antennas:** Access points positioned strategically along the track to accommodate obstacles (such as bridges) that block line of sight. Trackside space constraints necessitated a pragmatic solution for pole-mounted antennas.
- **On-train antenna placement:** Addressing unique customer requirements for deployment for antennas (the ideal solution), in a particular case having them to be mounted under the hood and above the driver window. This in turn required unidirectional antennas rather than omnidirectional / bidirectional units.
- **Fibre installation:** A single 24-core fibre connection along the line to link the trackside access points in a hybrid star / daisy chain configuration.

Example train-to-ground use case



b) Train antennas and trackside access points

The ideal location for a train-mounted antenna is on top of the car's roof (as seen in the graphic above). However, transit authorities may have specific requirements which prevent normal installation practices.

For the purpose of this use case, due to space constraints, the trackside access point poles now has to be installed with a minimal gap between two back-to-back directional antennas (the ideal gap is 200 mm). Upon initial deployment using unidirectional antennas on the trains, performance is reported as less than ideal. With trains experiencing a Radio Frequency (RF) shadow as they pass the trackside antenna poles and connections are handed over to the next access point.

To overcome the RF performance issues caused by the antenna placement in this instance, BAI would source and leverage a third-party patented technology from our list of ecosystem partners to ensure the train-borne access point handed the active link over to the second-best trackside access point as the leading cab approached the trackside pole. The third-party is expected to also provide a robust suite of commissioning tools for system parameter tuning. The BAI team then reviews the RF coverage and throughput performance and carefully tunes the system parameters to achieve optimal performance.

c) Antenna alignment

Antenna alignment and access point handover routine optimisation is a key function that BAI undertakes with any project. BAI's engineering and deployment teams have worked through some of the most challenging RF environments possible. As mentioned above, project has critical space limitations making antenna options and installation locations a key challenge.

Given that BAI has extensive experience working in tunnels, on trains and in stations, the deployment team in this case is able to rely on the lessons learned from other large-scale deployments like those undertaken in New York, Toronto, and Hong Kong. This comprehensive knowledge helps to reduce optimisation time and prepare for unforeseen obstacles. In ideal situations, the antenna placement and optimisation are simple, but BAI recognises that subway tunnels and low tolerance spacing on trains requires more effort and understanding.

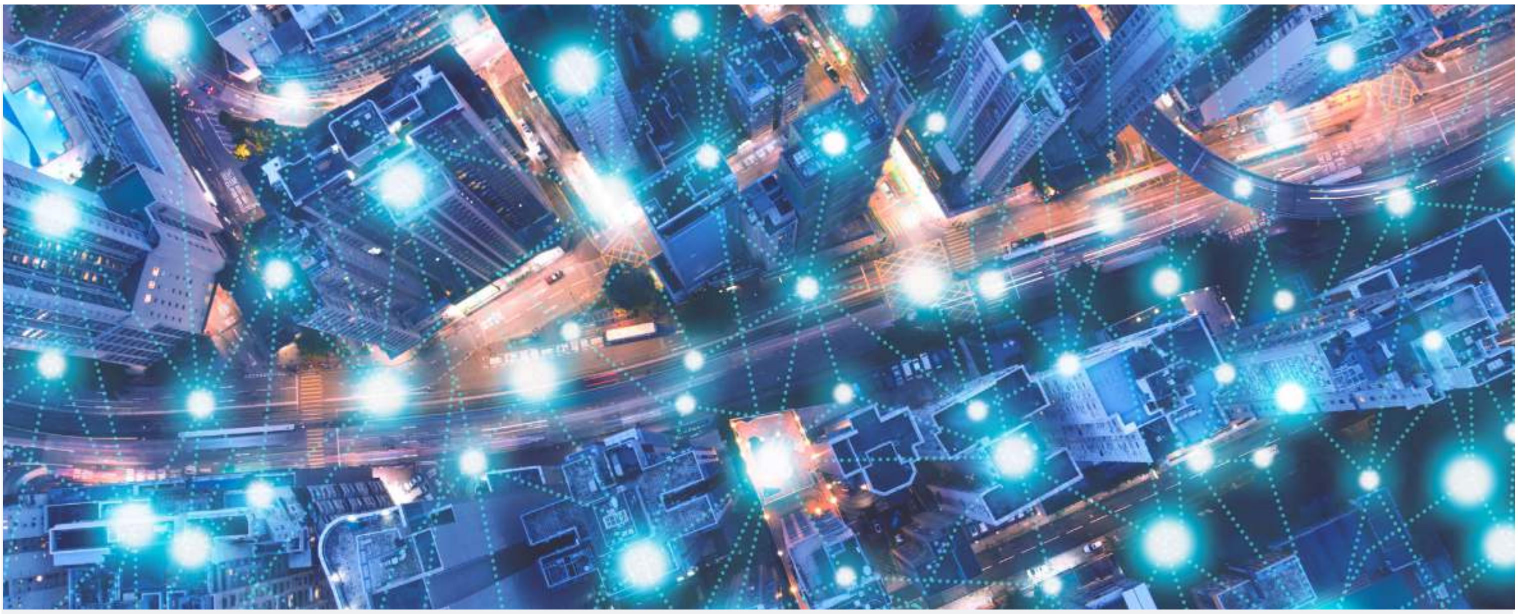
Key takeaway: Optimisation

In this use case the team learned that complex projects should include additional time for optimisation, including stages for testing, tweaking equipment, refining antenna alignment, and optimising access point handover parameters.

Just as we have with real-world transit customers, BAI would continue to identify further opportunities and functions for upgrading the network. These could include deploying communications-based train control systems and additional third-party services such as mobile network operator Wi-Fi offloading and installing small backhaul 5G cells on the train.

By combining tried-and-true technologies with a collaborative, team-based approach to design, deployment, testing and operations, BAI has demonstrated the capability top deliver a robust, high-quality connectivity to passengers across any transit network.

BAI supports transit authorities across New York, Toronto, Hong Kong and London in delivering a connected transit experience. BAI understands the customer challenges and through in-depth consultation provides, design, supply, installation, testing, commissioning, and maintenance of critical network infrastructure with a strong focus on project management – delivering a true end to end experience.



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14. AWS is extremely popular for hosting IoT services by virtue of AWS providing extensive pre-built IoT features and transparent charging, and AWS being a favourite destination for third party companies (Cisco, Juniper, Palo Alto, Fortinet etc) to offer virtualised services. See aws.amazon.com/iot/ and partners.amazonaws.com/
15. www.ericsson.com/en/internet-of-things
16. SIM is the abbreviation for Subscriber Identification Module.
17. eSIM is the abbreviation for embedded SIM, and the equivalent technical term eUICC is the abbreviation for Embedded Universal Integrated Circuit Card. For an introduction to eSIMs see www.gsma.com/esim/wp-content/uploads/2018/12/esim-whitepaper.pdf.
18. A basic Wi-Fi device takes no action if it can still see some downlink signal (from the access point) even if service quality has deteriorated because of interference from other Wi-Fi users or because the uplink signal (to the access point) has failed. Contrast 4G/5G cellular networks that continuously monitor service quality, are aware of alternative cells (alternative base stations and/or alternative frequencies), and proactively switch devices to these alternative cells as needed.

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