



WHITEPAPER

5G's future is hybrid – the non-terrestrial opportunity

The technology and antenna innovations that are enabling
hybrid terrestrial/non-terrestrial 5G networks

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Executive summary

5G is widely touted as a game-changer in mobile broadband services in terms of data speeds, low latencies and massive connectivity features. And it is. But there's far more to the disruptive power of 5G than fast speeds – it's also about the resulting network architecture that brings new levels of flexibility and service innovations the mobile industry has never seen before. In fact, the architecture itself will be like nothing seen before in the mobile sector because it will be the first architecture to combine terrestrial and non-terrestrial networks (NTNs) – including high-altitude platforms (HAPs) such as unmanned aerial vehicles (UAVs) and low earth orbit (LEO) satellites constellations – into a hybrid network providing true ubiquitous mobile broadband to every corner of the globe.

Hybrid terrestrial/NTN 5G networks unlock new revenue and service opportunities for operators, not least the rural consumer market that operators have found too expensive to serve. Other possibilities range from rural business applications such as agriculture, forestry and mining to automotive apps, industrial IoT services, logistics and asset tracking and remote healthcare, to name a few.

However, just as 5G needs to evolve from its current incarnation to the full promise of gigabit speeds and millisecond latencies, NTNs have their own evolutionary path to pursue before full integration can be achieved. Challenges abound, from link budgets and terminal costs to mitigating RF interference and high Doppler shifts. Even keeping the electronics cool at high altitudes is a key challenge to overcome.

All of the challenges ultimately come down to the antenna technology. Advanced intelligent antenna solutions – including key breakthroughs such as multibeam and lighter, more scalable digitally phased array antennas – are essential to ensuring that NTNs are not only economically viable, but also able to integrate seamlessly into terrestrial 5G networks. And it will require involvement of the entire telecoms ecosystem – from the operators to the various vendors and systems integrators – to make that work and unlock the true value of 5G.

The future of 5G is hybrid

The 5G era is underway. According to GSMA Intelligence, operators globally had 234 million 5G connections by the end of 2020. Meanwhile, 135 operators had commercially launched 5G networks in 52 markets worldwide by the end of 2020.

And that is just the start. It is well understood that the 5G technologies being rolled out today are just the first step in a new evolutionary path towards the headline capabilities of 10-Gbps data speeds, 1-millisecond latencies and massive connectivity. No 5G network supports those capabilities today – but they will.

What is perhaps less understood is that 5G evolution will not be limited to terrestrial networks. The rise of 5G will be accompanied by the rise of non-terrestrial networks (NTNs), which includes high-altitude platforms (HAPs) such as unmanned aerial vehicles (UAVs) and low earth orbit (LEO) satellites. These NTNs will be integrated with terrestrial networks to create a hybrid terrestrial/ non-terrestrial 5G mobile infrastructure serving consumers and enterprises.

NTNs, explained

LEO satellites are nothing new, of course – Iridium Communications launched the first such network in the late 1990s, and has recently completed a \$3 billion satellite constellation upgrade to provide global coverage of its latest services. A number of new LEO projects have also emerged in the last couple of years, including Blue Origin, StarLink, Telesat and OneWeb with the goal of providing further connectivity to every point on the planet.

LEO constellations are gaining traction thanks to a number of factors, from innovative satellite designs and cheaper launch costs to advanced electronics and antenna capabilities.

HAPs – in combination with larger scalable antennas – are a more recent development, and such platforms come in various forms, including balloons and aerostats. The most promising platform for HAPs connectivity is UAVs, which fly at a higher altitude (around 60,000 to

80,000 feet, which has the benefit of stable weather and no commercial air traffic to contend with). UAV platforms benefit from advances in automation, intelligence and energy, enabling them to fly almost autonomously for weeks at a time. HAP-based networks are designed to provide connectivity services that can be integrated into terrestrial cellular services in areas with no ground infrastructure.

For both HAPs and LEO systems, the key ingredient to the hybrid terrestrial/NTN architecture is the development of advanced 4G and 5G antenna systems that have pushed the area of beamforming and phased arrays significantly forward. A commercial 4G or 5G antenna today features 64 antenna elements. However, new antenna technology has been developed that can transmit hundreds of beams simultaneously that can be narrowed so finely and accurately that it's the equivalent of one user having their own personal cell site. We will discuss antennas in more detail in Section 5, but suffice to say that advanced antenna technologies make it possible to turn a UAV or a LEO satellite into a 5G base station or backhaul provider that can be integrated into terrestrial 5G networks.

This is why LEOs and HAPs will both have their place in the future 5G ecosystem, determined by the economics and the expectations of the users and the service to be provided. For example, HAPs will typically provide connectivity over a specific rural area with a population density that is too low by terrestrial standards to economically provide cellular services, but large enough to justify deploying a HAP to serve that area. HAPs can also communicate with standard devices and allow seamless roaming between networks.

Meanwhile, LEOs will be able to serve areas with much lower density populations because the constellation coverage is global by default. Even though LEO bandwidth will be somewhat lower than terrestrial connectivity due to power, distance and signal constraints, such systems will still enable previously unreachable populations to get online with sufficiently fast connections.



Game-changer

It's hard to overstate how much of a game-changer this hybrid infrastructure could be for mobile broadband communications. Cellular network evolution to date has mainly been an upgrade of the existing infrastructure with new radios, expanded antenna capabilities and the integration of IP and software-based networks. 5G offers a different paradigm from the radio to the core network, creating revenue opportunities that previous generations couldn't deliver, whilst NTN-based platforms offer a viable solution to increase coverage to all. The importance of complete country-wide cellular coverage is marked by the many national governments stepping in to fund rural broadband initiatives, ten years after the initial 4G deployments began.

Integrating non-terrestrial infrastructure will result in a mobile network infrastructure unlike anything we have seen in previous generations. This hybrid 5G network will offer growth opportunities for both carriers and the supply chain, whilst providing a range of valuable new services for consumers and enterprise alike and finally enabling truly ubiquitous mobile broadband services. In the long run, end users would not be aware whether they are communicating with a terrestrial tower or an NTN-based platform. They will simply be connected, which is all that is really important to them.

This new hybrid architecture could give rise to more converged operators, alongside those which are focused on one platform or the other. But the converged operators will have the advantages of better economics, flexibility and service quality. We will explore the promise of NTNs and the revenue opportunities they will enable in the next section.



NTN revenue opportunities

At its heart, 5G is not just another speed upgrade for mobile broadband, but a paradigm shift that enables operators to innovate and create new revenue opportunities that previous generations weren't capable of supporting. The obvious example is the enterprise sector – 5G's IoT capabilities and ultra-low latencies can be combined to enable smart factories, smart campuses and smart cities, all of which represents an unprecedented opportunity for mobile operators to expand outside of their typical consumer-oriented service portfolios.

That opportunity expands further when you look outside of the urban centers and suburbs. Plenty of vendors have touted the capability of 5G to enable telemedicine in remote areas, as well as IoT-powered services for agriculture, forestry and mining. However, the perennial challenge is in enabling the actual connectivity in those remote areas where setting up base stations is expensive (due in large part to lack of a reliable power grid and sufficient backhaul) and therefore economically unviable.

In other words, the revenue potential is well understood, but the capex and opex can't justify the business model.

Revenue opportunities

The integration of NTNs into carrier network architectures will change that, both in terms of the cost of deployment and operation of broadband connectivity, and the rich suite of high-performance services that connectivity will enable. Here are just a few examples:

- Rural consumer broadband that bridges the digital divide and expands the reach of new services such as mobile banking and payments
- Rural business applications such as forestry, mining, and agriculture, from predictive maintenance and logistics to crop monitoring and autonomous treatment
- Automotive apps such as semi-autonomous control of long-range vehicles
- Industrial IoT services (sensing, monitoring of remote assets, etc)
- End-to-end logistics and asset tracking
- Remote health, from managing health via 'direct to cloud' health monitoring to treating illness more effectively via greater collaboration between healthcare practitioners
- The LEO component can also expand services such as container tracking, advanced drone operations (including beyond visual line of sight) and maritime insurance to have a global reach

All of these add up to revenue potential that will drive investment and development of NTNs themselves and hybrid terrestrial/NTN architectures.

Benefits for incumbent operators

The appeal of this proposition to operators is not hard to understand, although the benefits of a hybrid terrestrial/NTN architecture extend well beyond the potential to gain new customers and revenue.

For a start, operators stand to gain far superior coverage. This is a crucial competitive differentiator for 5G – improved coverage enables more innovative service models necessary to provide additional competitive advantage.

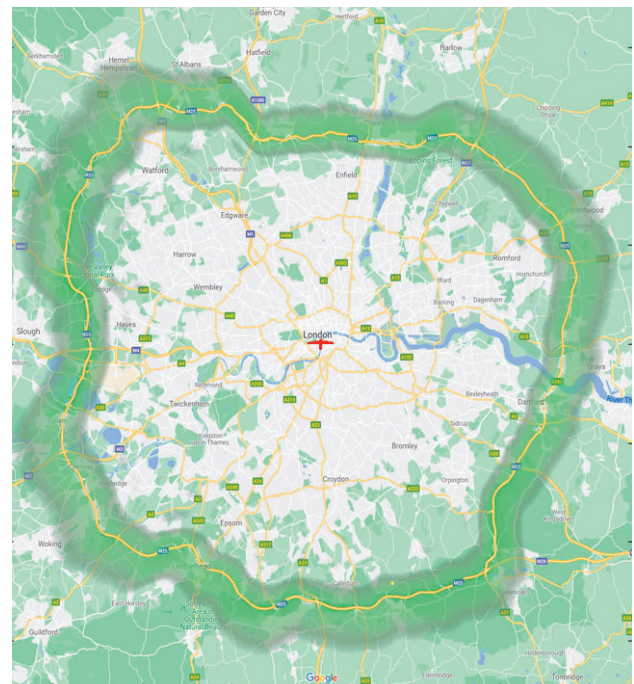
Poor coverage is also a potential barrier for service uptake. Peter Liu, VP analyst at Gartner, noted in a recent webinar that uptake of 5G in South Korea during its first year of commercial service has actually been slower than 4G's first year of service, and while data usage is higher, ARPUs are generally flat. Liu cites limited 5G coverage as the main reason for slower uptake – in April 2020, 4G base stations outnumbered 5G base stations 8 to 1, which meant users were far more likely to get the 4G connection they already had rather than the 5G connection the operators were selling.¹

NTN integration also enables operators to exploit new technologies. Digitally phased array antennas are in the pipeline that enable simultaneous beams packed with enormous amounts of extra capacity. For example, the case study on the next page from Stratospheric Platforms Limited (SPL) and Cambridge Consultants demonstrates that 200 beams can support 28 Gbps of downlink data with 64QAM and 2x2 MIMO (that amount could be even higher with 256QAM).

HAPs have the additional benefit of high flexibility. Put simply, unlike a terrestrial base station, they are not nailed down in one geographical location – they can be deployed wherever extra capacity is required.

By adopting a hybrid network, NTNs can offer significant capex and opex reductions compared to deploying only terrestrial base stations to achieve the same amount of coverage. According to the same case study, providing full 5G coverage across the UK would require tens of thousands of additional terrestrial sites, while the same coverage could be achieved with a fleet of around 60 HAPs.²

NTNs also offer operators the ability to get the most out of their cellular-based IoT offerings, whether they are based on 3GPP standards such as NB-IoT or LTE CAT-M. Cellular IoT solutions typically connect devices such as sensors with relatively low QoS requirements. The key requirement for such solutions is a low-cost infrastructure that enables massive connectivity over a wide coverage area to field large amounts of incoming data from these devices. While terrestrial 4G networks can support such services via NB-IoT and LTE CAT-M, HAPs and LEO platforms enable them to extend the reach of those services significantly at a much lower cost compared to deploying extra base stations.



Steerable beamforming gives massive flexibility, enabling coverage to be 'painted' on transportation routes and reconfigured in flight to track individual vehicles. Image courtesy of Cambridge Consultants. Map data © 2020 Google United Kingdom

¹ Peter Liu, VP analyst, Gartner: "Rethink the Scale and Pace of 5G Investments in the New Normal", October 2020

² Cambridge Consultants, "The World's Largest Commercial Airborne Antenna: Beaming 5G from the stratosphere"



Image courtesy of Stratospheric Platforms Limited (SPL)

Case study: Beaming 5G from the stratosphere

Stratospheric Platforms Limited (SPL), in partnership with Deutsche Telekom – its largest shareholder, technology partner and launch customer – plan to launch a fleet of unmanned, zero-emission aircraft into the stratosphere to deliver 5G at a fraction of the cost of terrestrial infrastructure.

The aircraft will be airborne at an altitude of 20,000 meters for more than a week, and will deliver 5G into existing networks and directly to standard phones.

The project includes what is believed to be the world's largest commercial airborne antenna, developed by Cambridge Consultants. The full-scale antenna will be over three metres square, create 480 individual beams and provide even coverage of high performance 5G to areas up to 140km in diameter, or create precision patterns to cover specific areas such as remote villages, roads and railways.

This single 'mega cell tower in the stratosphere' will deliver mobile speeds in excess of 100Gbps in aggregate and provide coverage equal to the combined efforts of hundreds of terrestrial cellular masts.

Benefits for new operators

A hybrid terrestrial/NTN architecture not only creates the potential to develop new innovative services, but also could herald the rise of all new operators in the ecosystem, while enabling incumbents to expand into new service areas.

For example, we could see "mini-MNOs" running LEO satellite constellations or HAPs to provide independent broadband services to underserved and unconnected areas. In addition, we could also see incumbent operators starting up their own private 5G NTN to expand coverage, launch specialized near-real-time IoT services for things like agricultural monitoring, asset monitoring for insurance, or medical device monitoring, and even create new MVNO platforms.



Reality check: early days for NTN

That's the promise of hybrid terrestrial/NTN infrastructure for 5G. Now for the reality check.

As mentioned earlier, 5G's promise makes great headlines, but the technology has a considerable evolutionary path to travel before it can make good on its headline-grabbing promises.

The same is true when it comes to integrating NTNs. While integration is part of the plan in terms of 5G development, current 5G deployments won't support that required level of integration. That's not to say the technology is several years away – as we will see in the next section, most of it is already here. The point is that terrestrial 5G itself is still in the early stages of deployment, and it will take time for them to evolve to the point where integration makes sense.

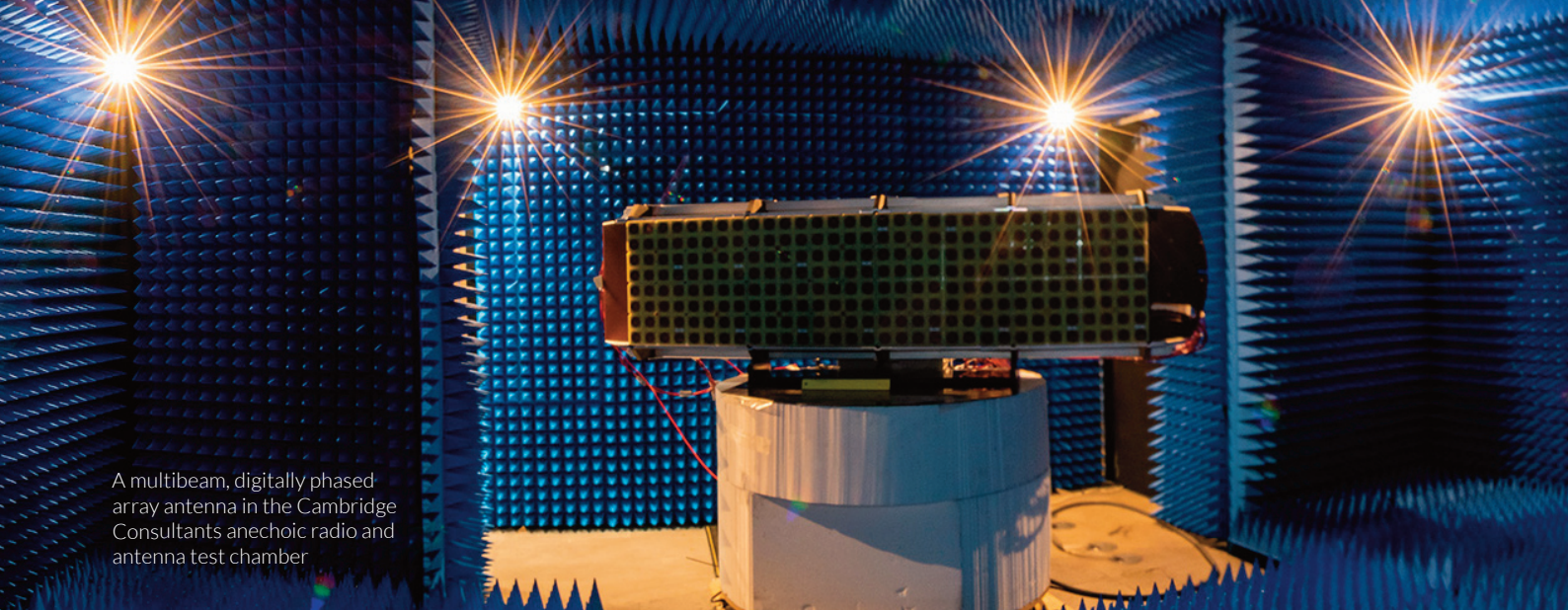
This is also the case for NTNs themselves. To be sure, there is clearly momentum behind the development of HAPs and LEO satellite systems, and several networks are set for commercial launch in the near future, such as AST SpaceMobile and Blue Origin. This is in addition to the new Starlink system that has already launched. Initially, they will mainly support relatively lower bandwidth services such as enhanced consumer broadband and IoT. In fact, initial interest is centered more around the economic advantages of NTNs over purely terrestrial networks (via reduced infrastructure costs in providing connectivity) rather than integration of both infrastructures.

Even so, the point is that NTNs are already being planned to launch with standalone business models to justify their investment in the first place. Those business models will evolve over time as the technology matures and new use cases emerge – to include integration with terrestrial 5G, which will not only maximize the value proposition of NTNs, but also expand 5G's reach to achieve truly global coverage.

However, for that to happen, NTNs (both HAPs and LEOs) face a number of challenges that have to be overcome before they can deliver the promised benefits described above. Key challenges include:

- Link budget – getting enough signal strength on the ground to provide the service (this is true of both HAPs and LEOs, but it's particularly more challenging for LEOs, as we'll see in the next section)
- Reducing terminal costs and form factors
- Mitigating RF interference
- For HAPS, keeping the payload cool, especially over the long periods of time they're expected to be airborne
- Doppler shifts (especially for LEOs, as these move from horizon to horizon in five to 10 minutes)
- Integration with terrestrial networks

We will address these challenges in detail in the next section.



A multibeam, digitally phased array antenna in the Cambridge Consultants anechoic radio and antenna test chamber

It's all in the antennas

The vast potential of NTN will be unlocked via a combination of factors, from innovations in radio and antenna technology to HAP aircraft and control systems, and the reduction of launch costs for LEO satellites.

But the crucial innovation lies in advanced intelligent antennas, which will serve as the fundamental breakthrough that will help overcome the challenges listed in the previous section and enable mainstream adoption by operators.

Link budget and terminal costs/form factor

Arguably the biggest hurdle for NTN serving as 5G platforms is the link budget, for the simple reason that the radio signal has a much longer distance to travel. LEO satellites orbit around 800 km above the surface of the Earth. HAP systems fly as high as 24 km and need to support standard form-factor terminals up to a range of 100 km for 4G and 300 km for 5G.

There are two related and key challenges to be addressed here:

- High signal quality is required to maintain high service quality on the ground
- Terminal costs need to be minimized in order to maximize adoption – ideally, this means the NTN must operate seamlessly with standardized terminals

To understand the challenge involved here, it is useful to look at current LEO terminals. Satellite phones are comparatively larger than the average smartphone, with a larger battery and antenna. That's because LEO

satellite phones must transmit at ten times the power of a smartphone (around 10 Watts vs 1 Watt) to reach the network.

This will change over time – work is ongoing that will allow LEOs to support the next generation of handsets and terminals with reduced size, weight, power (SWaP) and costs compared to the devices we see today, which will increase accessibility.

In the short to medium term, new antenna technology has the potential to overcome current link budget challenges to enable LEO systems to increase support for NB-IoT devices. In the longer term, we could see dual-mode smartphones that allow operators to offer a 5G service that leverages terrestrial networks and NTN seamlessly – from the consumer's point of view, the actual network being accessed won't matter (although consumers connected to LEOs will inevitably have a slightly different level of service, as we'll see below).

A key aspect of solving the link budget challenge for LEOs is to use larger antennas on both the satellites and terminals, transmit at a higher power and make protocol adjustments to overcome the timing delay. For HAPs, this there is an opportunity to use large aperture phased array antennas, which create highly focused beams which direct RF energy to where it's needed for the highest service levels. This is now possible thanks to the recent innovation of multibeam, digitally phased array antennas.

Multibeam, digitally phased array antennas use thousands of elements for both transmit and receive. This can enable UAV manufacturers to install a

9 sq-meter antenna that can supply hundreds of beams. These antennas are also capable of being built inside the weight and power consumption envelope of NTN platforms. Put simply, they enable high signal quality over hundreds of beams at a much lower transmit power.

In the case of HAPs, this technology will enable NTN platforms to operate with existing cellular terminals and smartphones. This means the low-cost terminals can be used in emerging markets, while at the same time enabling new networks without reliance on specialized and expensive next-generation devices. It also means operators need not deploy all-new IoT devices to connect to HAPs – they can keep their existing IoT devices.

Avoiding RF interference (both self-induced and malicious)

RF interference is an issue for any wireless network, as it directly impacts service quality. However, interference mitigation is particularly challenging for NTN platforms that are not stationary but constantly on the move. NTNs have to avoid not only interfering with terrestrial signals, but also with each other.

There are two key categories of RF interference to manage:

Inter-cell self-interference: this is a problem with any single frequency cellular network. Because adjacent cells use the same frequency, unwanted energy from one cell can bleed into another.

Inter-cell interference can be kept to a minimum by using antennas that have low sidelobes, typically referred to as ‘good sidelobe control’. Low sidelobes reject the interference coming from other cells. To achieve this, the arrays must have an accurate calibration system. It is necessary to continuously keep the array in calibration in the changing temperature conditions whilst the system is operating.

Malicious and deliberate interference: A hostile third party with intent to deny service may intentionally try to jam NTN signals. This can be mitigated by using null beamforming to reject unwanted signals.

Another up-and-coming aspect to RF interference mitigation is artificial intelligence (AI), which could be used to adapt coverage capacity in real time by learning patterns. AI also has potential applications in terms of assessing user experience and tuning network configuration accordingly.

Minimizing power consumption and managing heat dissipation of the payload

Power consumption is a crucial issue for NTNs on a couple of levels. For a start, the energy available and the power consumption of the payload determines the flight duration. For HAPs, the flight duration is a significant component of the economics – taking a UAV out of service to land and refuel costs time and money.

Then there’s the matter of heat dissipation, especially for HAPs. High levels of signal quality imply high DC energy requirements. This also means the electronics will create more heat to achieve the necessary link budget across a great many beams. This requires a bigger heat sink, which adds size and weight, and thus reduces flight times.

An additional challenge is that cooling the electronics is actually harder at HAPs altitudes. While the atmosphere is much colder at 80,000 feet, it’s also one-tenth the air density compared to sea level. Heat transfer essentially involves shifting that heat from one mass to another – consequently, lower air density means less mass to transfer the heat. (For LEOs, the challenge with heat dissipation, of course, is that there’s no air density at all.)

In other words, heat generation has to be reduced as much as possible so there is less iron to carry and less heat to dissipate.



Solving this problem starts with putting an appropriate power source on the HAP dimensioned to provide sufficient power to the payload for the duration of the flight. The HAP also needs to be dimensioned to carry the weight of the power supply and the payload for the duration of the flight. For LEOs, the power supply is limited by the size of the solar panel, the fuel cell capacity or the ability to carry any other power source.

Advanced digital electronics within the phased array antenna can be used to reduce power consumption and heat dissipation. There are solutions in the form of new chipsets that help with this. The corollary is that efficient cooling keeps weight down and reduces energy requirements, which means smaller UAVs and longer flight times. For UAVs, antennas designed with passive cooling systems make use of the air flowing through the UAV in flight to cool down the electronics.

Overcoming Doppler shifts to maintain signal integrity

As mentioned earlier, HAPs and LEO satellites do not stay in one fixed place – they are constantly in motion at high speeds. Radio signals from fast moving objectives incur a Doppler effect, which the receiver needs to overcome for the system to be able to function. Synchronization must overcome time delays from long ranges.

This challenge is especially demanding for LEO satellites, as these move from horizon to horizon in about five to 10 minutes at speeds of around 27,000 kilometers per hour. By comparison, UAVs experience reduced Doppler effects due to lower velocity, reduced range and an easier link budget and greater coverage area per HAP. (For HAPs such as airships and aerostats, Doppler is naturally not a concern.)

For LEOs, system access must accommodate long round-trip delays, and system synchronization must be possible on low-cost hardware across a broad temperature range with high Doppler. Solving these problems on existing cellular systems, from 2G to 5G, requires combining sophisticated RF and digital signal processing techniques, which has the potential to enable far greater range than we see today.

Ensuring terrestrial network integration

The Integrating of NTN with terrestrial 4G/5G networks poses a number of challenges to overcome:

- Fitting the NTN-based frequency plan into the terrestrial cellular frequency plan
- Paging issues: Which cell and which network do you page on? How are Location Areas managed?
- Integrate the NTN base stations with the terrestrial core and transport networks
- Logically ensuring seamless handover between the NTN cell and the next terrestrial cell

Frequency planning can be managed via geographic separation between terrestrial and non-terrestrial coverage, or using different dedicated frequencies for NTN and terrestrial networks and enabling handover between the two coverage areas.

The handover can be done using the same protocols and algorithms that terrestrial networks use, but adapted for the hybrid architecture. The reason: if the network is going to hand off a signal from the base station five miles away on the ground to an airborne base station 30 km above the user, this means shifting from one form of signal strength, time delay and latency etc, to another one. The protocols need to be modified to handle that level of difference. This also requires implementation of different routing strategies – for example, instead of routing from the core to the base station to the user, the network must route from the core to the gateway to the satellite to the user. Operators will need to design appropriate protocols and parameters in the network – for example more HARQs, larger RLC buffers, RACH modifications, RS distribution and so on.

Backhaul must also be provided from the NTN to the terrestrial network. There are various options for doing this, such as mmWave and self-backhaul with the same antenna doing fronthaul, for example. These cover bent-pipe techniques as well as more advanced signal regeneration methods.

Strategies for the new 5G hybrid ecosystem

The rise of hybrid 5G infrastructure will provide a range of valuable new services for consumers and enterprise alike, and create new opportunities for just about everyone in the ecosystem.

This is a matter of 'when', not 'if' – the 3GPP is incorporating support for NTN elements into Release 17, including UAVs. Under the current timeline, the 3GPP expects to complete work on Release 17 around the middle of 2022.

The combination of advanced radio technology, together with the inherent economic advantages of NTNs over terrestrial networks, will see a growing number of carriers exploring hybrid terrestrial/NTNs and building these into their future strategies. Meanwhile, this opportunity will stretch to cover the whole telecoms ecosystem, with the potential for many vendors to diversify their portfolios, particularly in areas such as antennas, electronics (to reduce SWaP), new network protocols and AI (for beam steering).

Here are some of the future strategies that different ecosystem players should consider to leverage this opportunity:

Service providers: The economic advantages of NTNs over terrestrial networks (reduced infrastructure costs,

etc) provide a huge opportunity to be part of a full integrated carrier network. Service providers, both traditional cellular carriers and satellite companies, should take this opportunity seriously for both the cost reduction and new service revenues.

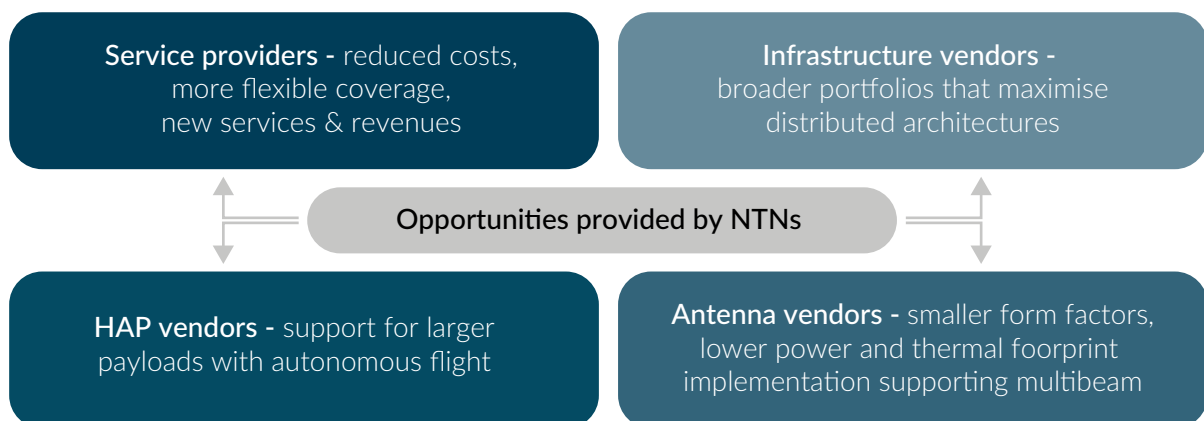
Infrastructure vendors: Vendors and systems integrators should optimize their portfolios for these applications to allow seamless integration of NTNs into their network solutions. They should also look at new ways of splitting the stack to maximize the benefit of distributed architectures using NTN for low-PHY and radio heads.

Antenna vendors: These vendors should look into smaller form factors, lower power and thermal footprint implementations supporting multibeam.

HAP vendors: HAP players need to provide platforms that can support large payloads with autonomous flight.

Meanwhile, the eventual commoditization of enabling technologies, combined with low costs, will make it viable to have wholesale network provision for enterprises and verticals – and even introduce personalized network quality.

Figure 1. Strategies for new 5G hybrid ecosystem



Let's talk about latency

The future of 5G networks is a hybrid infrastructure combining terrestrial cellular networks with NTN networks such as HAPs and LEO satellite constellations. However, this proposition raises a fairly obvious question: what about the latency?

One of the key selling points of 5G is ultra-low latencies of less than a millisecond, which promises the advent of applications from real-time mobile gaming to remote surgery and connected autonomous cars, among other things. However, this presents a well-known challenge for satellite networks, whose latency capabilities are limited by simple physics – satellite data signals must travel much further distances without the assistance of repeaters. Indeed, a key feature of LEO and MEO (medium earth orbit) systems is bringing the hardware closer to the Earth to minimize the distance that data must travel. But while LEO altitudes of 800 km reduce latency significantly compared to geostationary satellites, the 1 millisecond ambition remains out of reach. (HAPs platforms such as UAVs can reduce latency further, but still not quite enough to achieve 5G latency levels.)

This raises the question of whether a hybrid terrestrial/NTN architecture runs the risk of inconsistent 5G service quality. Handing over from a terrestrial base station to an NTN would be technically seamless, but the user would notice if the performance of a highly latency-sensitive application they're using suddenly drops.

However, the disparity may not be all that drastic – at least not for a long time. One thing to keep in mind is that currently, no 5G network in commercial service delivers 1 millisecond latency, and this is going to be the case for a number of years (outside of application-specific deployments, such as smart factories).

We're in the early stages of 5G, and most commercial 5G networks currently use the non-

standalone (NSA) version of the 3GPP's 5G New Radio (NR) standard. That means 5G radios are being overlayed on 4G LTE core networks – which in turn limits latencies to LTE levels. Put another way, operators with limited 5G coverage already face the same consistency challenge with their terrestrial networks every time a 5G user is handed off to 4G.

That said, 5G and 4G were always meant to coexist for a long time (just as 3G and 4G have). Operators already have network planning and optimization tools to help them manage that coexistence with minimal service quality disruption for the user.

This will also be the case with NTNs. With the right protocol adjustments to account for things like scheduling delay, NTNs such as HAPs being deployed today should be able to keep up with the latency performance of 4G terrestrial mobile broadband networks, which is on the level of 10s of milliseconds.

As for LEOs, while they're simply too far away to support latencies lower than around 80ms, there are plenty of applications that can run just fine on those latencies.

In other words, each layer of a hybrid terrestrial/NTN architecture will have different latency capabilities. Service providers can deploy the appropriate layer based on the requirements and business case of a given application or location. Services can then be segmented into different QoS levels – for example, terrestrial and private 5G networks can support applications with ultra-low latency services, whilst HAPs and LEO can support mainstream latency applications over wide areas. This will enable the strengths of the different technologies to be fully utilized whilst enabling investment in a focused manner.

Conclusion

The future of 5G networks isn't the usual terrestrial networks, but a hybrid architecture of terrestrial and non-terrestrial networks providing ubiquitous coverage, extending the reach (and the benefits) of ultrafast mobile broadband to underserved and unserved communities. This is a matter of when, not if. NTN's are coming; they provide clear economic advantages for network providers and value for consumers; and they have a clear role to play in this future.

The enabling trends and technologies for this hybrid 5G architecture are all coming together now – smart antennas, low launch costs for LEOs, long duration of flights for HAPs with appropriate control and distance, and enhancements to protocols to enable seamless integration and provide dramatic improvements to the provision of cellular connectivity. Central to all of this is the development and deployment of advanced, intelligent antennas, and the key to their success is making them small and power efficient enough to be viable on a HAP/LEO platform – which is now possible.

It's early days for NTN's, but it's also early days for 5G rollouts. Operators need to rethink their rollout strategies to incorporate an NTN component and take advantage of the new opportunities and growth potential this will create.

At the same time, all technology vendors in the ecosystem also need to get in the game and consider how their portfolios can grow to support this emerging use case.



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We know and understand the requirements of diverse industries and have direct experience of working on the next generation of terrestrial networks, satellite connectivity and high-altitude platforms.

We can be your guide when it comes to planning your path for the next five to ten years of success and helping you develop the technology to realize it.

Please get in touch to continue the conversation.

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