The Future of Wireless Broadband in the Peak Smartphone Era: 6G, Wi-Fi 7, and Wi-Fi 8

Edward J. Oughton, Giovanni Geraci, Michele Polese, Monisha Ghosh, William Webb, and Dean Bubley

Abstract

The field of wireless communications has traditionally been defined by what seems like unending exponential traffic growth. History suggests this trend is unlikely to continue in perpetuity, at least with the current set of applications, with recent evidence pointing to moderating traffic growth. In this article, we evaluate the implications of the peak smartphone era for those designing wireless networks within the context of the next-generation of wireless broadband technologies. First, three potential future demand scenarios are identified, ranging from a return to exponential traffic growth (optimistic) to continued moderation in growth (realistic) and even a scenario of declining traffic (pessimistic). Second, we compare the emerging properties of the 6th generation of cellular technology ("6G") envisioned by IMT2030 and two new Wi-Fi standards, including IEEE 802.11be ("Wi-Fi 7") and IEEE 802.11bn ("Wi-Fi 8"). Finally, an alternative vision for the future of wireless broadband is proposed, focusing on enhanced coverage, reduced deployment costs, and improved energy efficiency. Four key recommendations include use of neutral hosts for superior indoor coverage, ensuring spectrum sharing and intelligent handover/roaming integration between cellular, Wi-Fi, and Non-Terrestrial Networks (NTNs), providing strong support for infrastructure sharing and national roaming in rural and remote areas, and efficient (re)organizing of existing spectrum allocations.

Introduction

Engineers require a thorough understanding of future demand trends to make effective decisions. Although forecasting beyond 2–3 years is challenging, traditional assumptions about unending exponential traffic growth have historically been sufficient for guiding engineers in designing wireless networks, primarily focusing on ever-higher peak data rates. However, this article builds on recent evidence [1] identifying moderating growth rates in mobile traffic to suggest that without new emerging demand drivers, the future of wireless broadband may look very different from what we have experienced in recent years, with significant implications for R&D and wireless network design [2].

The *peak smartphone* era is characterized by a weakening demand for smartphone upgrades, which traditionally occur in a 12–18-month cycle. This change correlates with plateauing screen time and video consumption, leading to a slowdown in traffic growth. Although this trend has been discussed by industry analysts, few considerations have been given to implications within the wireless engineering community, motivating this article. While some suggest this is a temporary slowdown driven by the pandemic, there are reasons to believe it may be part of a longer-term pattern. History suggests no previous general-purpose technology has sustained unending exponential growth; eventually, diseconomies of scale moderate demand, as seen in electricity. This topic deserves discussion, given the mixed commercial success of previous wireless technologies and the intense R&D and standardization activities underway for mobile networks and Wi-Fi.

Via the global deployment of 5G and Wi-Fi 6, consumers are gaining access to improved wireless broadband services, yet the path trodden to this point has been one of much debate [3]. From the mid-2010s, a 5G "hype cycle" built on inflated expectations has given way to realism in the 2020s. This is reflected in weaker equipment sales and millimeter wave licenses returned to spectrum regulators due to mobile network operator (MNO) inactivity (e.g., for all three South Korean operators, as well as T-Mobile in the USA). This offers valuable insights for 6G and Wi-Fi standardization.

Next, we will consider insights from the history of technology to define scenarios for future traffic demand. Then, we discuss R&D activities related to 6G, Wi-Fi 7, and 8 before presenting a technology comparison. Finally, we discuss the implications for engineers designing wireless networks and for standardization efforts, including a set of key recommendations.

Wireless Broadband Demand: Toward 2030 and Beyond

Since the third generation of cellular technology (3G), consumers have been able to access online services over mobile. However, it was not until the fourth generation of cellular technology (4G), in combination with Apple's iPhone, that users could

Edward J. Oughton (corresponding author) is with George Mason University, USA; Giovanni Geraci is with Telefónica and Universitat Pompeu Fabra, Spain; Michele Polese is with Northeastern University, USA; Monisha Ghosh is with University of Notre Dame, USA; William Webb is with Commcisive, UK; Dean Bubley is with Disruptive Analysis Ltd, UK.

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purchase mobile broadband contracts with smartphones. Thus, data consumption *exploded* over the next 15 years, driven by the ability to easily view mobile video on the go. However, there is no guarantee this trend will continue indefinitely, motivating the discussion within this section.

Insights from the History of Technology

General-purpose technologies define entire eras of societal progress, from the steam engine to smartphones. History illustrates the underlying statistical characteristics in the emergence and adoption of these technologies over recent centuries, following a classic S-shaped logistic curve. This begins with modest growth, where only innovators and early adopters take advantage of new technologies, followed by rapid adoption driven by the early and late majority. Finally, a period of plateauing growth occurs as the system reaches mature saturation, with laggards being the last group to adopt. Such a demand trend has been *universal* for general-purpose technologies. Here, electricity serves as a good analogy for mobile, given the various similarities exhibited, ranging from network properties to consumer usage patterns.

From the 1920s onwards, growth in electricity availability led to rapid adoption and use within homes and businesses, driven by consumer innovations such as the light bulb and electric oven. Eventually, demand moderated due to market saturation and diseconomies of scale, resulting in only incremental growth thereafter. Consumers and businesses had essentially adopted the technologies that could readily make use of this new resource, leading to headwinds on further growth (e.g., by the number of electrical appliances, hours of free time, etc.).

Given the proverbial adage that those who fail to learn history are doomed to repeat it, we believe wireless engineers should prepare for a full spectrum of eventualities. Thus, an important tool to help decision makers strategically understand different potential futures is the use of scenario analysis, as discussed later in this section with regard to traffic demand.

The Peak Smartphone Era

Mobile has brought revolutionary societal changes, from 2G voice/text to 4G broadband. However, the peak smartphone era is characterized by marginal developments in devices [1]. Moreover, clear revolutionary use cases for new wireless technologies have yet to emerge on the same scale as previous generations. Currently, the most successful 5G use case is fixed wireless access (FWA), primarily satisfying consumer demand in areas with few fixed fiber options.

The mass adoption of smartphones and the proliferation of on-demand video have led to capacity constraints on wireless networks. For indoor settings where Wi-Fi is readily available, such as homes and offices, users generally prefer this form of connectivity. In contrast, when outdoors or in indoor settings without free Wi-Fi connectivity, users rely on wide-area cellular networks as a second-best option (as demonstrated with data in Fig. 1). This behavior is driven by consumers optimizing their quality of experience (QoE), which relates to their satisfaction with various Internet applications.

Figure 1 illustrates a set of trends relevant to the future of wireless broadband. Globally, the rate of data traffic growth is declining, decreasing from > 90 percent in 2018 to 22 percent in 2022 [4], as per Fig. 1a. The Emerging Asia Pacific region saw one of the fastest growth rates in 2017 (> 180 percent) but slowed by 2022 to around 20 percent. A similar decreasing growth trend is found in Sub-Saharan Africa, with rates dropping from 97 percent in 2017 to < 60 percent by 2021. By 2022, this trend generally moderated across all regions to an annual growth rate of around 20–25 percent, significantly below the levels seen in past decades. This decline persists despite rapid growth in FWA adoption, which generates 10–20 times the average smartphone traffic, as supported by Ericsson Mobility Report statistics [5]. This change in traffic demand has substantial implications for wireless network design, commercial revenues, and wireless spectrum policy.

Figure 1b highlights the magnitude of monthly cellular traffic for 2017 [6], compounded forward with the growth rates reported in Fig. 1a. Regions with the highest data growth rates typically have the lowest monthly cellular consumption, and vice versa. For example, in North America, the growth rate was 16 percent in 2017, as the monthly cellular consumption was already nearly 6 GB. By 2022, most regions had increased their monthly cellular consumption to 10–30 GB. If mobile consumption continues to moderate in the coming years, it may reach only around 30–40 GB by the end of the decade unless new data-hungry mobile applications emerge. This is substantially below forecasts of > 250 GB/month, which the sector has been preparing for over the past decade [7].

Using recent crowdsourced data, Fig. 1c highlights that most US smartphone data consumption occurs over Wi-Fi, with the percentage of data usage being 71–78 percent for Wi-Fi downloads and 9–11 percent for Wi-Fi uploads. This contrasts with the percentage of data usage, which reached 10–17 percent for mobile downloads and 1–2 percent for mobile uploads. Opensignal reports that even when users are outside the home, they continue to rely heavily on Wi-Fi [8]. Indeed, the majority of screen time takes place when Wi-Fi is connected, either at home or away, suggesting users prefer Wi-Fi as their primary wireless broadband service. Although this data vignette is US-centric, similar patterns are seen in other countries, especially when there is strong fixed broadband availability.

Subsequently, another important factor for wireless traffic is the substantial deployment of fiber-to-the-premises (FTTP), as per Fig. 1d. In 2016, FTTP constituted 20 percent of fixed broadband connections in OECD countries, but by 2023, FTTP had risen to > 42 percent, with ongoing growth expected. Users will have readily available high-speed indoor Wi-Fi and private cellular connections for unlimited data access. This supports Fig. 1c, which illustrates that users generally prefer to connect to a Wi-Fi network, whether at home or beyond, most probably due to superior reliability. Importantly, while FWA has seen an increasing share of connections, this technology remains at a modest 4 percent of all connections in OECD countries and is likely to be an interim solution until full FTTP is deployed.

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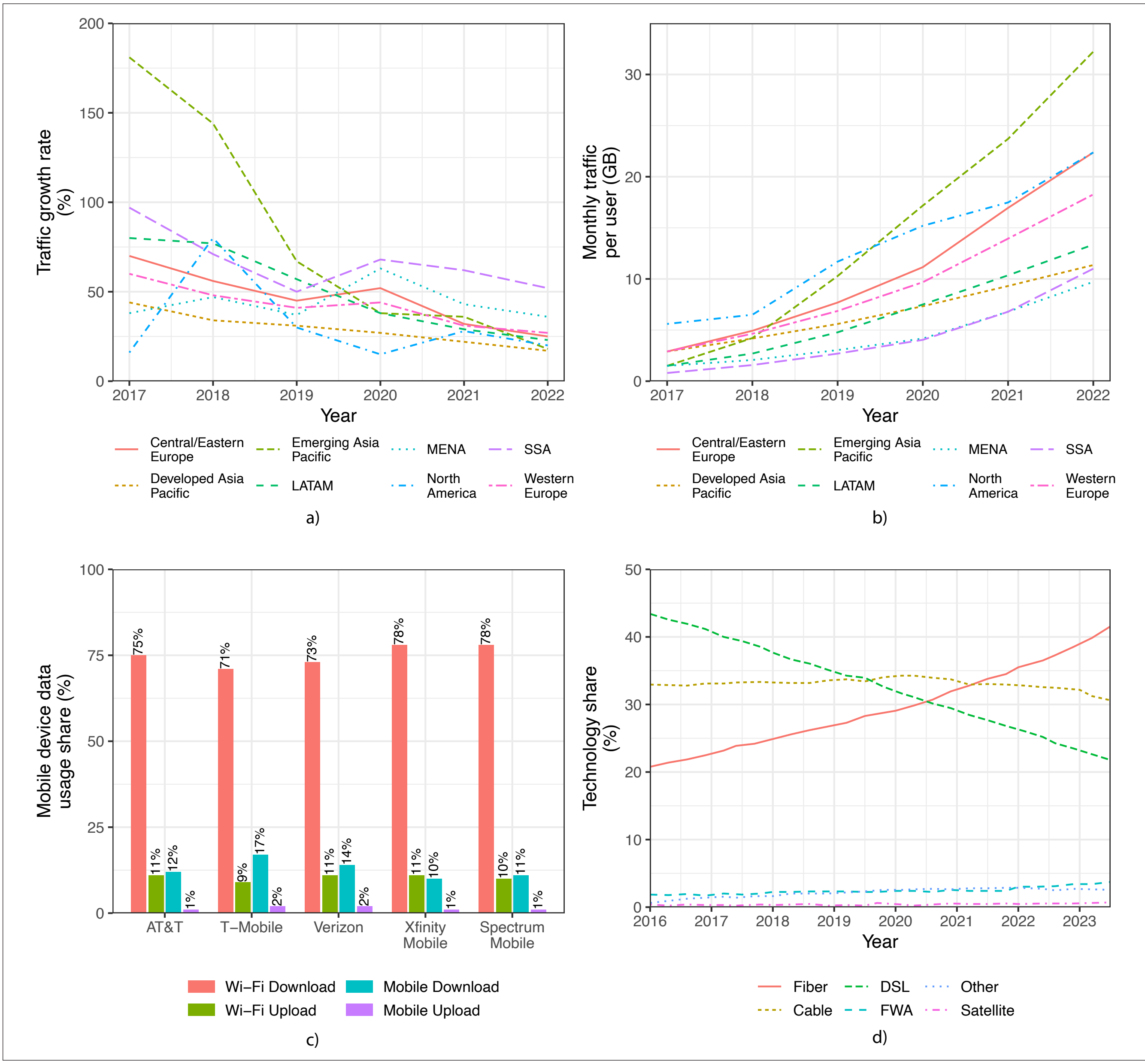

FIGURE 1. Important telecommunication trends relevant to understanding the future of wireless broadband: a) Global cellular traffic growth rates, based on [4]; b) Monthly cellular data traffic per user, based on [4, 6]; c) Share of smartphone data usage for Wi-Fi versus mobile, based on [8]; d) Fixed broadband technology shares in OECD countries, based on [9].

Possible Scenarios of Future Wireless Broadband Demand

With little possibility of predicting how traffic demand will unfold from here and the need for wireless engineers to be aware of possible futures, we posit three distinct demand scenarios. Wireless network designs should be stress tested against these three distinct futures so MNOs can strategize effective adaptation strategies, if necessary.

Returning to Exponential Traffic Growth: In this optimistic scenario, wireless engineers should prepare for a return to the growth rates experienced between 2010-2020. This is driven by consumer adoption of new futuristic 5G/6G use cases, such as AR/VR cellular-enabled headsets. If consumers are willing to pay more for this additional capacity, this is a best-case scenario for MNOs and equipment vendors. Yet, should consumers not be willing to pay more for this extra capacity, this would be highly challenging for MNOs who have progressed to unlimited data packages.

Continuing Moderation of Traffic Growth: In this realistic scenario, wireless engineers embrace the empirical data emerging on moderating traffic growth, preparing appropriately to re-organize network investments and management practices. Adding greater capacity may not be required for some areas, meaning MNOs can pivot resources to improving coverage. This situation may not be negative for MNOs, as undertaking generational network upgrades might be avoided, reducing capital expenditure. Reduced expenditure could bring a much-needed profitability boost for MNOs. Yet, equipment manufacturers would suffer falling sales.

Declining Traffic Demand: In this pessimistic scenario, wireless engineers should hypothesize a possible future where traffic demand declines,

Features	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6/6E	Wi-Fi 7	Wi-Fi 8 (speculative)
Peak data rate (Gb/s)	0.6	7	9.6	46	Potentially ≥ 100
Carrier frequency (GHz)	2.4, 5	5	2.4, 5, 6	2.4, 5, 6	2.4, 5, 6, potentially 45 and 60
Channel bandwidth (MHz)	20, 40	20, 40, 80, 160	20, 40, 80, 160	Up to 320	Potentially > 320
Frequency multiplexing	OFDM	OFDM	OFDM and OFDMA	OFDM and OFDMA	OFDM and OFDMA
OFDM symbol time (ms)	3.2	3.2	12.8	12.8	Similar to Wi-Fi 7
Guard interval (ms)	0.4, 0.8	0.4, 0.8	0.8, 1.6, 3.2	0.8, 1.6, 3.2	Similar to Wi-Fi 7
Total symbol time (ms)	3.6, 4.0	3.6, 4.0	13.6, 14.4, 16.0	13.6, 14.4, 16.0	Similar to Wi-Fi 7
Highest modulation	64 QAM	256 QAM	1024 QAM	4096 QAM	≥ 4096 QAM
MU-MIMO	No	DL only	DL and UL	DL and UL	DL and UL
Number of spatial streams	4	8	8	8	16

TABLE 1. Technical features and capabilities across current and upcoming Wi-Fi standards.

including how network design and management would adapt. While some may perceive this as unlikely, there are multiple potential causes. With a greater number of premises accessing FTTP, current FWA customers may prefer to opt for the reliability of fixed broadband. Equally, improved video compression may substantially reduce the data needed to be transferred, especially for video, reducing aggregate traffic. This may not be negative for MNOs, especially if revenue remains flat, boosting profitability. However, a situation of declining demand would be a worst-case outcome for equipment vendors.

Emerging Wireless Broadband Technologies

The three future demand scenarios outlined have significant implications for the development, standardization, deployment, and regulation of wireless networks. Thus, the following section examines three complementary wireless broadband technologies, including 6G, Wi-Fi 7, and 8. Importantly, we focus only on the future of wireless broadband and exclude current cellular and Wi-Fi technologies already evaluated in previous studies [3].

6G Mobile Network Features and Use Cases

The engineering community is currently making progress on candidate 6G technologies, although the final standard will not be determined until the late 2020s. Thus, the evaluation of 6G technologies includes a degree of speculation at this point. The current vision has been developed by ITU-R, with a consensus on future trends (e.g., use cases) for the standard emerging in 2023 [10]. 6G aims to provide connectivity to achieve the UN Sustainable Development Goals. However, this is challenging as the sector's relatively weak economics in many markets indicate that 6G must also be driven by commercial realities (weak revenue) and economic imperatives (reducing cost) [11].

Currently, the use cases defined for 6G include Immersive Communication, Hyper Reliable and Low-Latency Communication, Massive Communication, Ubiquitous Connectivity, Artificial Intelligence and Communication, and Integrated Sensing and Communication [10]. To achieve these goals, several technology areas have emerged, including:

- Virtualized, open networks with high flexibility and programmability
- Spectrum band carriers in the upper mid-band (7–24 GHz) and above 100 GHz
- Augmented network management via machine learning
- Multi-layered NTN connectivity integration
- Improved cellular network positioning and sensing
- Enhanced security and privacy [10].

Standardization will clarify key performance indicators but is likely to include peak rates of 1 Tb/s, latency of 0.1–1 ms, mobility of 500–1,000 km/h, and improved reliability [1].

Wi-Fi 7 and Wi-Fi 8 Features and Use Cases

Wi-Fi is crucial for providing low-cost connectivity. Users access this wireless technology through existing fixed broadband connections, increasingly via FTTP. While traditionally laptops and desktops were primary data producers, Wi-Fi now supports a wide variety of short-range devices, from surveillance cameras to smart TVs. Currently, there are estimated to be three times as many Wi-Fi-enabled devices as people worldwide, showcasing the technology's success. This boom in low-cost wireless devices has been driven by rapid improvements in new generations. From 1 Mb/s in the first standard to > 30 Gb/s theoretical peak in the latest, this is an increase of nearly four orders of magnitude over almost three decades, delivering affordable, high-speed wireless services in unlicensed spectrum bands.

The seventh Wi-Fi standard, IEEE 802.11be ("Wi-Fi 7"), was completed in 2024, with deployment in unlicensed spectrum bands. Compared to Wi-Fi 6E, initially utilizing the 6 GHz band, Wi-Fi 7 includes various technical improvements to provide extremely high throughput with lower latency. Key features, as highlighted in Table 1, include a maximum channel bandwidth of 320 MHz with aggressive modulation and coding schemes, more efficient use of noncontiguous spectrum through multiple resource unit allocation, multi-link operation (MLO), and stricter QoS management [1].

By 6G's release, the wireless industry will have progressed to the eighth generation of Wi-Fi technology, based on the IEEE 802.11bn Ultra High Reliability (UHR) amendment [12]. Features under consideration for Wi-Fi 8 include higher order MIMO, non-primary channel access (NPCA), multi-AP coordination (MAPC), and potentially higher spectrum bands (45 GHz and/or 60 GHz).

Technical features	**6G (speculative)**	**Wi-Fi 7**	**Wi-Fi 8 (speculative)**
Peak data rate	Target of 1 Tb/s	46 Gb/s	Potentially ≥ 100 Gb/s
Number of spatial streams	256	8	16
Coverage range	0.05–100,000 km^2	≤ 0.3 km^2	≤ 0.3 km^2
Carrier aggregation	Yes	Yes, via MLO	Yes, via distributed MLO
Inter-cell interference	Controlled	Mostly uncontrolled	Partially controlled, via MAPC
Spectrum	6G (speculative)	Wi-Fi 7	Wi-Fi 8 (speculative)
License type	**Mostly licensed**	**Unlicensed**	**Unlicensed**
Frequency bands	≤ 6, 7–15, 24–30, GHz	2.4, 5, 6 GHz	2.4, 5, 6, potentially 45 and 60 GHz
Maximum channel bandwidth	200/400 MHz at 7–15/24–30 GHz, resp.	320 MHz	Potentially > 320 MHz
Business and deployment	**6G (speculative)**	**Wi-Fi 7**	**Wi-Fi 8 (speculative)**
Business model	Traditionally mainly public	Traditionally mainly private	Traditionally mainly private
User equipment cost	Higher (≥ $500)	Lower (≤ $100)	Lower (≤ $100)
Chip/modem cost	Higher (≥ $100 at launch)	Lower ($10–20 at launch)	Lower ($10–20 at launch)
Data cost	Pre-/post-pay and temporary	Free, via fixed broadband	Free, via fixed broadband
Deployment	Controlled and managed	Mostly uncontrolled/ unmanaged	Mostly uncontrolled/ unmanaged

TABLE 2. Prospective comparison of 6G and Wi-Fi 7/8 engineering and economic features.

The usage of higher bands is being explored by the dedicated IEEE 802.11bq Task Group.

Wi-Fi 8 is set to prioritize UHR as its main feature, unlike previous standards that focused on boosting peak throughput, as per Table 1. Achieving deterministic low latency is a major challenge for next-generation Wi-Fi technologies. Wi-Fi 8 aims to complete its standardization cycle by 2028, with the UHR Study Group, established in July 2022, focusing on defining future protocol functionalities. Key areas include:

- Improving throughput at lower signal-to-interference-plus-noise ratios
- Reducing tail latency and jitter
- Enhancing spectral reuse
- Achieving greater power savings
- Improved peer-to-peer operations.

Comparing Engineering and Economic Characteristics of 6G, Wi-Fi 7, and Wi-Fi 8

As highlighted, users often have the option to exchange data over either cellular or Wi-Fi. While this technically makes these technologies competitors (e.g., for spectrum), they can also serve complementary roles (e.g., traffic offloading). Here, we examine the different engineering and economic characteristics of these two groups, referencing current and emerging wireless standards. Table 2 summarizes key features.

Peak Data Rates

As with previous generations of wireless technologies, an initial aim is to significantly increase the peak data rate. In 6G, the theoretical goal is to deliver wide-area capacity per site of 1 Tb/s (covering ≤ 100 km^2), whereas Wi-Fi 7 and Wi-Fi 8 target short-range throughput exceeding 46 Gb/s per AP (covering ≤ 50 m). Additionally, 6G aims to achieve global coverage via NTNs, including satellites and high-altitude platform stations (HAPS), expanding cell sizes to hundreds or thousands of kilometers.

Spectrum

While significant research is focused on integrating a higher frequency 6G spectrum, business incentives to do so remain uncertain. There is also no clear indication Wi-Fi will adopt the same approach. Using the upper midband could provide cellular systems with access to much larger bandwidths, but this approach also has notable drawbacks, such as weaker outdoor-to-indoor propagation, increased device costs, and higher energy consumption. MNOs are already facing challenges in utilizing 5G millimeter wave spectrum holdings, with some opting to focus fully on sub-6 GHz. Given the existing disappointing deployment of millimeter waves, MNOs may have mixed feelings about more high-frequency spectrum.

Business Model

The potential business models for deploying these technologies are also highly relevant. Mobile companies continue to utilize a traditional monthly subscription-based or pay-per-use service approach, although embedded SIMs have also made free or temporary usage possible. In contrast, Wi-Fi maintains its low-cost "plug-and-play" approach, leveraging fixed broadband as the key route to providing services. This is one of Wi-Fi's key advantages, as it avoids the large capital expenditure cycle historically involved in cellular generations. Other innovations are also occurring. For cellular networks, this focuses on infrastructure sharing [13], whereas for Wi-Fi, this centers on the Wireless Broadband Alliance's OpenRoaming initiative [1]. This roaming federation enables automatic and secure Wi-Fi connectivity for all participating providers, similar to the Eduroam system used by universities. The goal is to allow users to roam freely onto any network managed by a federation member, providing an agreement is in place, which will reduce the need for login credentials. This system enables seamless handoff from outdoor cellular connections to indoor WBA-certified Wi-Fi connections, ensuring uninterrupted connectivity.

Equipment Cost

In terms of access equipment, smartphones remain at the higher end of the consumer device price range, with premium models costing over $550, and new 6G handsets expected to start at well over $1,200. In contrast, Wi-Fi-enabled devices are more affordable, starting from around $100, provided there is already a fixed broadband connection. This affordability is evident in the array of smart home devices being adopted. Cost differences are due to advanced cellular chipsets offering greater functionality than more basic Wi-Fi chipsets [1]. Efforts to address this cost disparity include the development of 3GPP reduced capability (RedCap) devices, which aim to improve affordability and boost adoption, particularly in low-income countries.

Deployment Approach

Cellular networks are typically provided by MNOs offering public access, while Wi-Fi is traditionally installed by premises owners. This trend is expected to continue, with 6G remaining centrally controlled, using unlicensed spectrum infrequently. In contrast, Wi-Fi generations will maintain a decentralized, uncoordinated approach.

Wireless Network Standardization and Design in the Peak Smartphone Era

The common R&D perspective for new wireless broadband technologies is to provide ever-increasing peak data rates for users ("more is better"). For 6G, we see this being driven forward by the research community and equipment vendors. An alternative approach focuses on the need for improving coverage, lowering deployment costs, and enhancing energy efficiency. This vision is more commonly associated with policy circles aiming for reliable universal broadband. Yet, this concept is all the more compelling when considering empirical evidence suggesting that 5G improvements are predominantly due to wider mid-band bandwidths, denser deployments, and more beams rather than new, advanced technical radio capabilities [14]. Here, we identify four key themes pertinent to the standardization, design, deployment, and regulation of future wireless broadband technologies.

Neutral Host Approaches for Superior Indoor Coverage

A key issue facing wireless broadband is the provision of indoor connectivity. Here, we discuss the relevance of utilizing a neutral host architecture to overcome some of the issues of trying to take an outdoor-to-indoor approach. From an engineering viewpoint, indoor coverage is much better delivered from in-building transmitters. This results in higher signal levels as penetration of the building fabric is avoided. Further, that same fabric can help to contain signals within the building, reducing interference to other nearby networks. This has long been understood, but for mobile MNOs to deploy base stations in all buildings would be a huge task. However, the emergence of cheaper, private 5G options and the evolution of Wi-Fi systems can represent viable — yet advanced — connectivity options for building owners or tenants. This resource could be used directly by smartphones, as indeed it is in homes and offices. Wi-Fi could be supplemented by cellular solutions in buildings with high footfall, such as stadia, malls, high-rises, and transport hubs. Where cellular is deployed indoors, it is cheaper and more practical to have one solution for all consumers, regardless of MNO choice. This can be deployed by a "neutral host" operator as long as they can access shared spectrum and MNOs allow neutral host roaming [15]. This could be, for example, in the 3.8–4.2 GHz as enabled in some European countries or in the citizens' broadband radio service (CBRS) band in the US. Coupled with a simple model for Wi-Fi roaming, such that handsets automatically log onto any open Wi-Fi network, it would be possible to deliver excellent in-building coverage rapidly and at low cost (as discussed earlier in relation to federated Wi-Fi access). This could be developed through an evolution of concepts such as 5G NR-U or as part of a true multi-network solution in 6G.

Spectrum Sharing and Intelligent Mobility Integration with Wi-Fi and NTNs

Historically, MNOs have sought to deliver better coverage themselves by building even more towers. However, this has become uneconomic, and coverage expansion has stalled broadly. Ubiquitous coverage could be delivered instead through making use of multiple networks and radio access technologies. As discussed above, Wi-Fi could provide in-building coverage for most premises. NTNs, integrated into the 6G cellular architecture, could deliver coverage cost-effectively in rural and remote areas. Roaming between MNOs (often called national roaming) can also help by enabling any user to access the coverage of any MNO. Historically, this was seen as problematic as it disincentivizes MNOs to build more coverage, but since MNOs have largely ceased this activity, this objection has faded. In the most advanced approach, users at the end of coverage from a base station of their home MNO but close to the base station of another mobile MNO could be moved across temporarily. The higher signal level results in much more efficient communications, which hugely reduces network loading and improves user experience. Enabling inter-operator handoff in these situations could easily provide much greater capacity than concepts such as advanced antenna technology and at very little cost. Building in strong support for heterogeneous networks, the use of multiple networks and multiple technologies, including Wi-Fi, NTNs, and other mobile networks, could deliver much of what is needed for a user-centric 6G, with multiple radio access technologies (RATs) complementing each other.

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A traditional infrastructure model sees each MNO essentially deploy and manage their own exclusive network assets, coordinated independently to provide wireless broadband services. However, not only can infrastructure duplication be expensive, but often there are reasons why it is not ideal to build separate networks.

Strong Support for Infrastructure Sharing and National Roaming in Rural and Remote Areas

Going beyond indoor neutral host operations and multi-RAT mobility, an additional trend that can benefit a cost-effective 6G deployment is infrastructure sharing across MNOs. A traditional infrastructure model sees each MNO essentially deploy and manage their own exclusive network assets, coordinated independently to provide wireless broadband services. However, not only can infrastructure duplication be expensive, but often there are reasons why it is not ideal to build separate networks. Moreover, management of a single shared infrastructure is much easier than potentially three to four different companies needing to send crews to maintain their own assets, introducing efficiencies in coordination between real estate management companies and the government, among others. Increasingly, both the techno-economics of this traditional approach and the practicality of trying to maintain individual networks are being questioned, especially as we move toward a spectrum-sharing paradigm. From a technical point of view, virtualization and softwarization, part of the Open RAN architecture, can contribute to creating a shared infrastructure layer (i.e., the O-Cloud, using the terminology from the O-RAN ALLIANCE) that can onboard different RAN implementations from heterogeneous operators [15].

Efficient (Re)Organization of Spectrum Bands

Current 5G deployments focus on utilizing mid-band spectrum to provide capacity enhancement of wide-area cellular networks. While theoretically, novel features belonging to 5G could improve throughput (e.g., modulation, code rate, MIMO layers, etc.), when normalizing for bandwidth and beams, empirical evidence suggests 5G has not added a vast improvement in spectral efficiency at least with the 5G components currently deployed [14]. Indeed, some of 5G's advanced technology features (e.g., mmWave) have yet to see widespread deployment by MNOs, potentially explained by cost concerns. Given that FWA is the key 5G use case currently indicative of excess capacity, the question arises as to whether FWA should be considered an integral part of a "mobile network" (given that users are not explicitly mobile). Indeed, providing fixed point-to-multipoint access has fundamentally different spectrum requirements compared to a true mobile network, suggesting it may well be an inefficient use of precious mid-band spectrum to allocate these frequencies in such a way. Indeed, FWA might be better supported in the mmWave frequencies at 20 GHz and above. Importantly, 4G LAA and 5G NR-U make valuable contributions by allowing the aggregation of unlicensed bands in outdoor locations. Unfortunately, both technologies came late in their respective release cycles. Therefore, it is essential that support for unlicensed bands is integrated into the first official 6G release to ensure widespread deployment.

Conclusions

The history of technology tells us that new innovations have never been subject to unending demand growth. Indeed, exponential growth always moderates. Consequently, this article highlights three future traffic scenarios, each with substantial implications for the development, standardization, deployment, and regulation of wireless broadband. Emerging technologies were then evaluated, including the 6th generation of cellular technology ("6G") and two new Wi-Fi standards, including IEEE 802.11be ("Wi-Fi 7") and IEEE 802.11bn ("Wi-Fi 8"). Our conjecture is that the engineering community should actively *stress test* technologies, network designs, and management approaches against the demand scenarios posed here to strategize successful adaptation pathways over the next decade however the future unfolds. An alternative wireless broadband vision is then highlighted, which focuses on improving coverage, reducing deployment costs, and enhancing energy efficiency. Four key recommendations are identified, including:

- Utilizing neutral host approaches for superior indoor coverage
- Ensuring spectrum sharing and intelligent handover/roaming integration between cellular, Wi-Fi, and NTNs
- Strong support for infrastructure sharing and national roaming in rural and remote areas
- Efficient (re)organization of existing spectrum allocations.

This vision contrasts with the traditional dominant theme which targets ever higher throughput via expensive generational equipment upgrades. Such a reset could help MNOs provide improved wireless broadband services to consumers, while alleviating indebted balance sheets, returning MNOs to improved profitability.

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Biographies

Edward J. Oughton is an Assistant Professor at George Mason University and Guest Editor for the IEEE Commun. Mag. special issues on techno-economic assessment.

Giovanni Geraci is Principal Research Scientist at Telefónica, Associate Professor at Universitat Pompeu Fabra, and previously an IEEE ComSoc Distinguished Lecturer.

Michele Polese is a Research Assistant Professor at Northeastern University, with a Ph.D. from the University of Padova, Italy. His research focuses on wireless network architectures.

Monisha Ghosh is an electrical engineering Professor at the University of Notre Dame and Policy Outreach Director of the NSF Spectrum Innovation Center, SpectrumX.

William Webb is CEO of Commcisive, having been awarded three visiting Professorships and three honorary doctorates. He was the youngest IET President for a century.

Dean Bubley is founder of Disruptive Analysis Ltd, with over 25 years' experience in wireless, telecoms and policy fields. His commentaries have > 20k followers.