Wi-Fi and 5G redefine wireless

Convergence creates a pervasive connectivity fabric

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SENZA FILI

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1. Introduction

Do you remember back when you had to get online to check your email? Or when you could claim you could not be reached because you could not get connected? Connectivity used to be a deliberate choice, and often one that entailed an effort and a cost. Today, most of us (56% according to ITU) have a wireless broadband connection and are almost always effortlessly connected to a Wi-Fi or cellular network. Wireless connectivity has become the default access channel to communicate with each other. Yet, there is more to come. We are entering a world of pervasive connectivity in which the reach of wireless networks keeps expanding beyond our phones and laptops. New types of devices, terminals and sensors connect us to our environment, and change the way we interact with each other and the environment. Why hail a cab on a busy street when you can book it through your phone in less time and at a lower cost?

To complete the transition to pervasive connectivity that is already under way, all wireless networks have to continue to evolve to provide the coverage, capacity, latency, reliability, security, and cost efficiency that we need for new wireless use cases, and to meet the demand for massive connectivity to people and things, and to reach the remaining 46% of the world population that is not yet connected. From a technology perspective, it is a demanding task. But because of the increasing reliance of our society and economy on wireless connectivity, it is also a great responsibility. No single wireless access technology can support this transition on its own. Multiple technologies, each with its different strengths, have to work together to realize the IMT-2020 vision for pervasive connectivity.

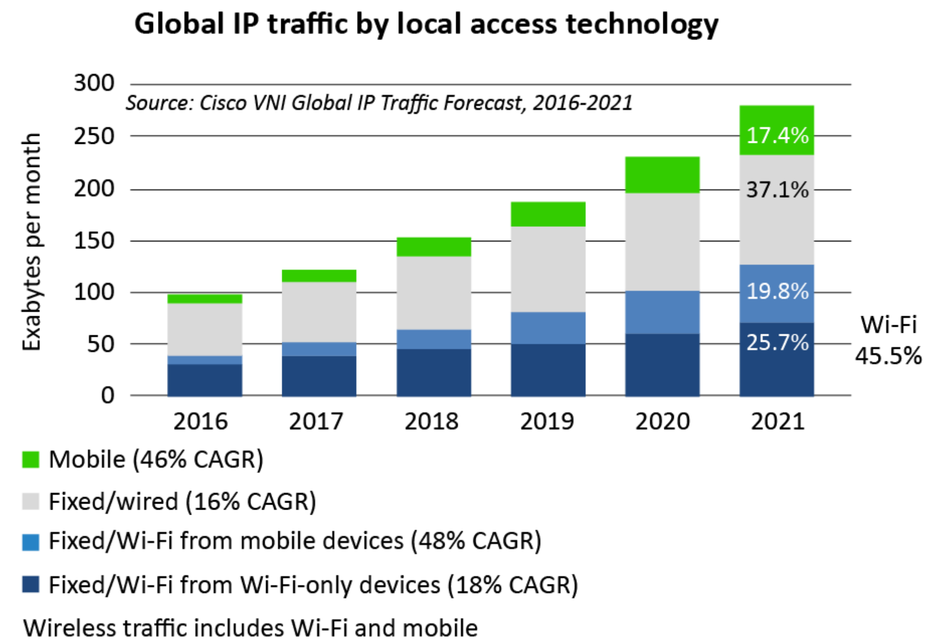
Wi-Fi and 5G are by no means the only wireless technologies we need, but they are the most powerful ones in redefining wireless connectivity, because of their expected share of wireless traffic, their technological evolution, and their ability to support many of the existing and new use cases. Wi-Fi and cellular have jointly created the wireless fabric that supports broadband connectivity. Wi-Fi carries most of the traffic – cellular covers most of the land. Wi-Fi is best indoors – cellular is best outdoors. Wi-Fi started as a data technology – cellular was initially only about voice. With 5G and Wi-Fi 6 (IEEE 802.11ax), this relationship between cellular and Wi-Fi will remain largely unchanged, but they will get closer to each other, as they expand their capabilities. Cellular and Wi-Fi will remain complementary in addressing different traffic demands and application requirements, and become more integrated to share the traffic between them more efficiently.

This paper overviews the evolution of Wi-Fi and how it addresses the new connectivity requirements driven by increased data volumes, latency-sensitive traffic, and IoT applications – and how it will meet the IMT-2020 vision together with 5G. With the introduction of new functionality and improved performance, Wi-Fi evolution continues unabated since the ratification of the IEEE 802.11 standard in 1997. The upcoming Wi-Fi 6 captures most of today's attention with its increase in throughput, spectrum efficiency and device battery life, but the evolution of Wi-Fi covers more ground – including traffic management, security, new spectrum bands, and integration with cellular – to accommodate new use cases, especially for IoT applications, smart-city deployments, and latency-sensitive traffic.

See also our interview with Carlos Cordeiro, Senior Principal Engineer and Senior Director in the Next Generation and Standards Group at Intel, "Next-generation Wi-Fi goes hand in hand with 5G."

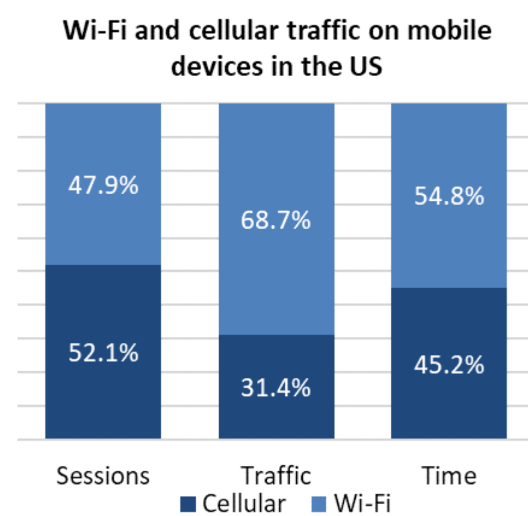
2. Wi-Fi, the powerhouse feeding our data connectivity

It is easy to take Wi-Fi for granted, in the same way most of us take electricity or water for granted. And just like electricity and water, we know Wi-Fi is not available everywhere, but we expect to have Wi-Fi at home, at work and in many public places – the places where we generate most of the traffic. However, even within the wireless industry, we often need to remind ourselves that Wi-Fi carries most of the wireless traffic, and that wireless networks carry more traffic than wireline networks. According to Cisco VNI, Wi-Fi will account for 45.5% of traffic by 2021, and cellular for 17.4%.



Going back in time, it was Wi-Fi that convinced subscribers that wireless broadband was possible. When Apple launched the first iPhone, Wi-Fi stole the show – data experience over cellular was limited and networks got quickly congested. Even as capacity and throughput increased with 4G, Wi-Fi retained its dominant position as a data access technology. This is a remarkable achievement if we consider that all this traffic relies only on the 2.4 GHz and the 5 GHz unlicensed bands; it shows how Wi-Fi enables an intensive and efficient use of spectrum resources.

Of course, cellular networks are essential to our overall wireless experience. They keep us connected throughout a much wider footprint, and to do so, service providers have to face a steeper per-bit cost for cellular than for Wi-Fi, without Wi-Fi's level of spectrum reuse.



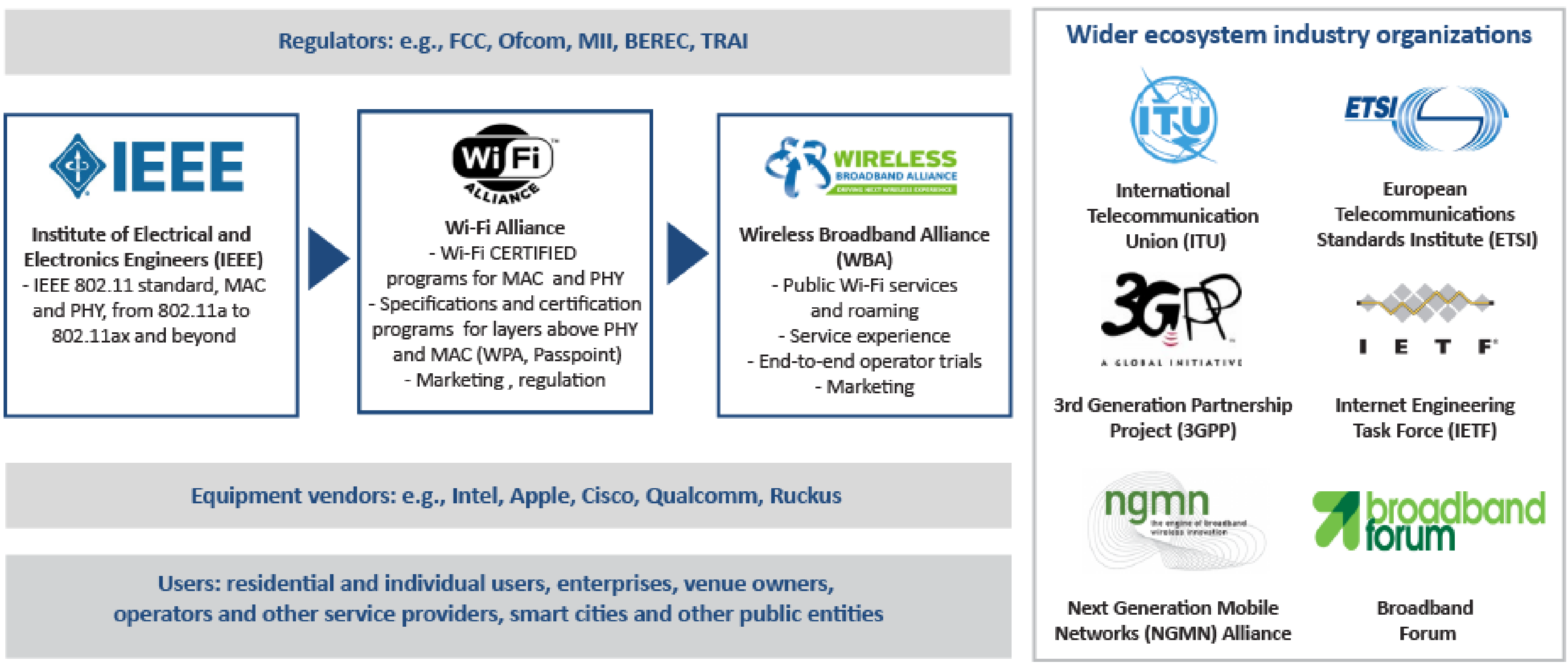
Source: P3, Telecom Advisory Services

The two access technologies address different and complementary connectivity needs, and use patterns demonstrate this. In the US, for instance, Wi-Fi carries almost 70% of traffic to phones and SIM-based mobile devices, but accounts for slightly less than 50% of sessions and about 55% of time. For activities that require more bandwidth and longer times and are not perceived as urgent, subscribers prefer Wi-Fi. If they have more urgent and time-sensitive things to do, subscribers are more likely to use the cellular network. Across geographies, the ratio may change, but the pattern is consistent. And, as we will see in the rest of the paper, 5G is unlikely to reverse this trend, because it is rooted in a close and mutually supportive relationship between Wi-Fi and cellular.

The Wi-Fi ecosystem: from standardization, to deployment and access

The success of Wi-Fi rests on a large and mature ecosystem that spans from regulators across the world allocating unlicensed spectrum, to vendors, service providers, enterprises and many types of users. Wi-Fi has an enduring commitment to interoperability, backward compatibility, coexistence, and ease of access. The development of standards, specifications, certification programs and best-practice recommendations has been and continues to be essential to the evolution and expanding adoption of Wi-Fi. Three industry organizations – IEEE, Wi-Fi Alliance, and Wireless Broadband Alliance (WBA) – have central roles in the continued evolution of Wi-Fi. IEEE created the 802.11 standard for the MAC and PHY layers for Wi-Fi, and continues to expand it, currently with 802.11ax (now branded as Wi-Fi 6) and 802.11ay. The Wi-Fi Alliance develops Wi-Fi CERTIFIED programs which define test specifications and ensure interoperability through optional certification programs covering not only MAC and PHY layers, but also upper layers, to offer consistent user experience and security. The WBA has worked with operators, service providers and neutral hosts to develop a roaming platform and to give subscribers easy and seamless connectivity. Other industry organizations – ITU, 3GPP, NGMN, ETSI, IETF, and the Broadband Forum – do not have a direct role in defining Wi-Fi, but act as liaisons to the rest of the wireless ecosystem – for instance, to support coexistence of Wi-Fi with cellular and other wireless technologies.

The Wi-Fi ecosystem: The role of IEEE, Wi-Fi Alliance and Wireless Broadband Alliance



Source: Intel, Senza Fili

4. A successful balance of continuity and innovation

Wi-Fi is the most widely adopted wireless technology, with an installed base of 9.5 billion devices and over 3 billion new device shipments in 2018, according to ABI Research and Wi-Fi Alliance. There are more Wi-Fi devices than people in the world (7.6 billion), or unique cellular subscribers (5.2 million; GSMA), and about the same as number of mobile connections (9.2 billion, including M2M; 60% are broadband, GSMA). The number of Wi-Fi devices will continue to rise, along with the number of connected devices per person. Cisco VNI predicts that by 2021, the number of devices and connections per capita will be 12.3 in the US and 3.5 worldwide. Wi-Fi's ubiquity, flexibility and affordability have been instrumental in the growth of connectivity in emerging markets, where it has been a powerful tool for bridging the digital divide, as well as the driver for many IoT and machine-to-machine applications.

The success of Wi-Fi caught the industry by surprise. It was developed initially as a fixed wireless technology, and then as a wire-replacement solution. Wi-Fi rapidly moved to become the dominant wireless broadband access technology – and in fact created that market – as IEEE and the Wi-Fi Alliance expanded its functionality and worked to ensure interoperability and backward compatibility. Following Intel's introduction of the Centrino platform, in which Wi-Fi was built into every laptop, Wi-Fi became a mass market technology and vendors started adding Wi-Fi to other types of devices beyond laptops.

Wi-Fi has continued to evolve since the standard's ratification in 1997. Standard updates have improved the air interface (802.11n, 802.11ac, and eventually 802.11ax), added new spectrum bands (WiGig in the 60 GHz band with 802.11ad and 802.11ay) and kept up with security needs (WPA, WPA2, WPA3). In addition, the Wi-Fi Alliance and the WBA have introduced new functionality to improve traffic management, ease of user access and authentication, roaming, voice calls, and, more generally, support for new use cases.

After decades, Wi-Fi is still at the forefront of innovation and performance in wireless networks. Crucial to its success are backwards compatibility and interoperability, which provide a continuity that has set the foundation for market growth and that benefits vendors, service providers and users alike. Wi-Fi networks can gradually evolve to include new functionality and improved performance, while supporting legacy devices. For instance, there will be no need to replace devices in order to connect to a Wi-Fi 6 AP, and a new Wi-Fi 6 device will still be able to connect to legacy APs. In the future, as the number of connected devices per user or per household and the number and variety of IoT devices grow, the ability to support a greater number and range of devices per network will become even more valuable. For instance, a residential user can install a Wi-Fi 6 and still use the Wi-Fi legacy devices already installed without making any change, and can add new Wi-Fi 6 devices gradually, as desired.

The evolution of Wi-Fi

1971	ALOHAnet in Hawaii: fixed wireless access
1985	ISM band released for unlicensed use by FCC
1997	IEEE 802.11 standard ratified
1999	WECA founded, becomes Wi-Fi Alliance in 2000
2000	Wi-Fi branding introduced, 11 Mbps 2.4 GHz
2002	54 Mbps in 5 GHz
2004	WPA2 (security)
2007	802.11n, iPhone released
2012	Wi-Fi in 25% of homes, Wi-Fi Passpoint
2013	5 million hotspots, 802.11ac
2014	Over 20,000 certified products
2016	WiGig (60 GHz)
2018	WPA3 (security)
2019	802.11ax, 802.11ay

Source: Wi-Fi Alliance, Wikipedia, Senza Fili

5. The new Wi-Fi radio interface: Wi-Fi 6, aka IEEE 802.11ax

Wi-Fi evolution proceeds in multiple directions, but the air interface is the one that attracts most attention, because it has a direct impact on the user experience. The evolution from 802.11b to 802.11ac has profoundly changed the performance of Wi-Fi in terms of increased capacity, ability to manage devices and infrastructure resources, and efficiency of spectrum use.

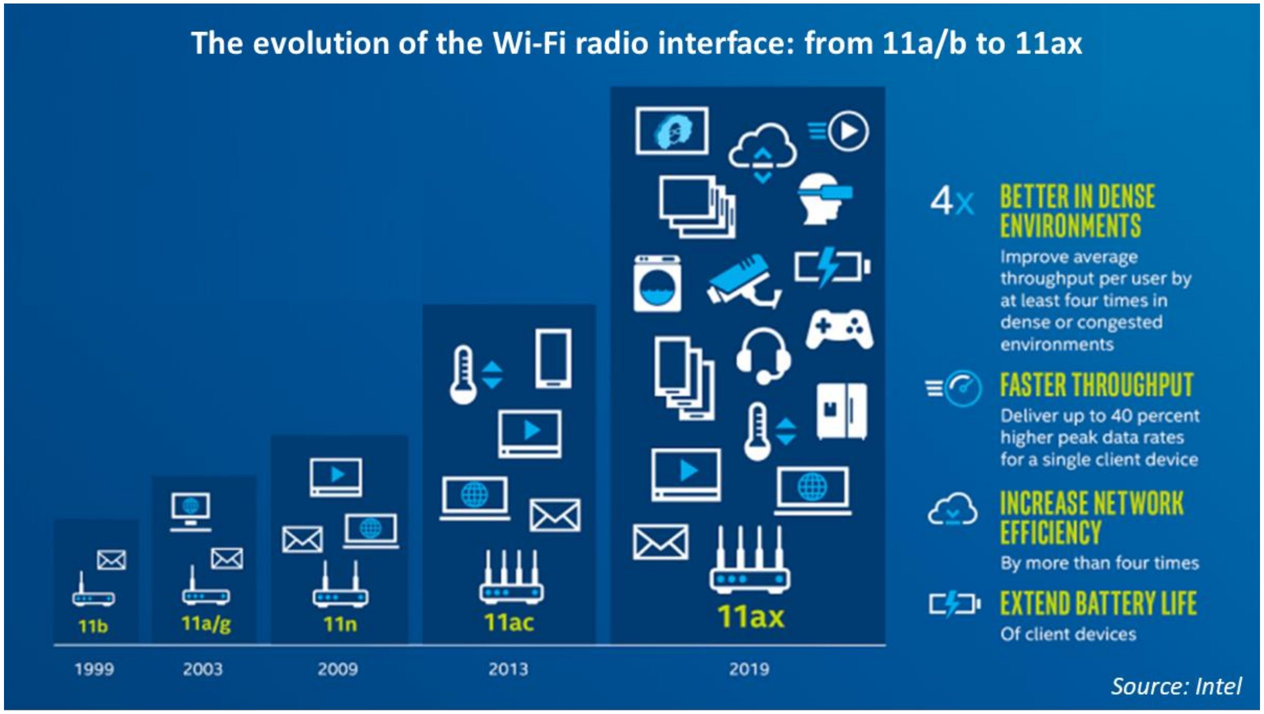
With Wi-Fi 6, devices may see a 40% increase in peak rates that come from an enhanced air interface. Overall network capacity will grow as well, due to an increase in network efficiency. The new Wi-Fi 6 air interface strengthens the Wi-Fi's ability to meet new traffic requirements, connect a wider range and number of devices, and serve new use cases. The table on the next page lists the major changes in the interface and their impact on performance and use cases.

Dense, high-traffic environments. Here Wi-Fi 6 shines the brightest – stadiums, airports and transportation hubs, retail locations, college campuses. The combination of higher capacity in both the downlink and the uplink transmission, a more efficient use of network resources and a better frequency reuse further increases Wi-Fi's capacity density – the amount of traffic it can transport within an area (e.g., Gbps/km^2). The lower latency of Wi-Fi 6 also benefits high-traffic environments where it improves the experience for real-time traffic (e.g., video and VR/AR), which is sensitive to latency.

Outdoor environments. More capacity and higher throughput for devices at the edge of the AP coverage area make Wi-Fi more attractive for outdoor deployments by service providers, real-estate managers and smart cities.

Connected homes. As traffic and the number of devices increase within households, better resource and device management, lower power consumption, and lower latency improve the overall performance and coexistence across multiple device types with different traffic profiles (e.g., IoT dev and laptops).

Enterprise, IoT and IIoT. More capacity, lower latency and more flexible and efficient use of network resources appeal to enterprises as they increasingly rely on wireless connectivity for their voice and data connectivity and enterprise-based services and applications. In particular, IoT and IIoT applications benefit from 802.11ax's support for a high density of devices with different requirements (e.g., surveillance cameras and sensors) and variable power availability.



Real-time, latency-sensitive traffic. Lower latency and more granular management of devices and network resources improve the ability to support real-time content and applications, such as voice, conversational video, and gaming.

Transportation. Higher capacity and improved traffic management strengthen Wi-Fi's role to provide in-vehicle connectivity (e.g., in cars or in trains where often Wi-Fi is used for access, and cellular for backhaul), automated vehicle services in the enterprise, and applications for parking, toll payments and other transportation activities.

WISPs and fixed broadband. The increased capacity and edge peak rates will make Wi-Fi a better-suited candidate for fixed broadband connectivity. The expected availability of the 6 GHz band for unlicensed access will further promote the use of Wi-Fi among WISPs. With fixed broadband, Wi-Fi can help bridge the digital divide in rural and low-density areas as a cost-effective and easy-to-deploy solution that brings broadband to underserved households.

What's new in 802.11ax: impact on performance
OFDMA DL/UL. Lower latency; more supported devices per AP; more capacity; and more efficient use of spectrum and network resources in dense environments.
8x8 MU-MIMO DL/UL. Serving up to 8 simultaneous users, doubling capacity over 4x4 MIMO, both in the downlink and in the uplink.
1024 QAM. Higher per-device peak speed, higher capacity (25% increase over 256 QAM). More efficient use of network resources.
Uplink resource scheduling. Better management of network resources, lower latency. Better support and performance in dense environments, increased battery life.
Long OFDM symbol. Higher efficiency and capacity. Improved outdoor performance, 4x increase in data speed at the cell boundaries.
BSS color. Better spatial frequency reuse by coordination among neighboring APs. Increased capacity in high-traffic environments with a high density of APs.
Target wake time. Device-specific, more flexible management of wake/sleep cycles. Longer battery life, leading to improved support for IoT applications.
6 GHz band support. More spectrum available to Wi-Fi. More capacity and ability to serve more diverse use cases.
Sources: Intel, Qualcomm, Wikipedia, Senza Fili

6. The evolution of Wi-Fi

The air interface (802.11ax), security (WPA3, see table on the right) and manageability (Passpoint, multi-band operation) are some of the prominent directions the evolution of Wi-Fi is taking as its ecosystem adapts to a heavier and more diverse use of Wi-Fi networks. But there are many additional evolutionary paths that extend the functionality, flexibility and efficiency of Wi-Fi and improve its performance in specific use cases.

A major development is the expansion of Wi-Fi in two directions:

- Multi-gigabit connectivity in the 60 GHz band (WiGig, 802.11ad, 802.11ay), to provide even higher capacity density in the highest-traffic environments, in wireless backhaul and fixed wireless access (e.g., Facebook's Terragraph), or in home or other indoor environments where some applications, or
- devices require very high throughput over short distances (e.g., AR/VR, 360-degree video, a home video projector). 802.11ay enhances that initial WiGig standard by supporting peak data rates in excess of 100 Gbps through the use of channel bonding and 8x8 MIMO.
- Long-range, low-power, low-bandwidth connections to devices (HaLow, 802.11ah) that will set the stage for some IoT or IIoT deployments. While connections may be in the kbps range, devices may have challenging battery life requirements in the order of months or years. HaLow operates in the unlicensed 900 MHz band.

Together, WiGig and Wi-Fi HaLow expand the reach of Wi-Fi to new spectrum bands (60 GHz and 900 MHz) while retaining backward compatibility to Wi-Fi networks in the 2.4 GHz or 5 GHz bands. As is typically the case in Wi-Fi, devices using WiGig can seamlessly associate to any Wi-Fi network operating in the 60 GHz band, and any Wi-Fi HaLow device will be able to associate with any HaLow network, when HaLow will be commercially available.

Traffic management and efficient use of network resources are other areas of innovation. Wi-Fi is evolving to a more active approach to connect devices to the best band, channel or AP, depending on the device requirements and network conditions. Roaming functionality is also expanding to enable devices to stay connected as they move from one network to another, and to make it easier to choose and connect to roaming networks, and to improve Voice over Wi-Fi handoffs with cellular networks.

Because of the extensive use of Wi-Fi for cellular offload, Wi-Fi keeps expanding the support for service providers (e.g., SIM-based authentication, encryption, roaming) and simplifying subscriber access in service provider networks (e.g., authentication, network selection, security).

Finally, Wi-Fi has been developing standard-based, interoperable meshing capabilities. Vendors have been offering mesh Wi-Fi networks for some time, but as proprietary solutions that put restrictions on the hardware that can be used. In early 2018, the Wi-Fi Alliance introduced EasyMesh to enable the deployment of self-organizing Wi-Fi networks that use APs from different vendors to expand the reach and performance of multi-AP networks. Households with many high-traffic devices or a challenging RF environment may need more than

Wi-Fi Protected Access 3 (WPA3): Raising the bar on security

Security is a top priority for Wi-Fi. Not only is Wi-Fi ubiquitous, but mobile Wi-Fi devices typically connect to multiple networks, and it can be difficult for users to independently verify which networks should be trusted or are secure. Wi-Fi provides robust technology that does not require a significant direct intervention by the user, yet protects traffic and allows devices to connect to secure networks and to verify that the devices do not present a security threat. Security requirements and threats change through time – and changes in use cases may require different approaches and solutions. For instance, headless IoT devices create multiple security challenges that access technologies like Wi-Fi have to address forcefully.

WPA3 was introduced in June 2018 to address the security needs created by new use cases and the increased reliance on wireless connectivity. WPA3 will ultimately replace WPA2, which was introduced in 2004, but for the next few years the two will coexist, until both APs and devices have all transitioned to WPA3. WPA3 comes in two flavors:

- **WPA3-Personal** for residential and small business networks. Simultaneous Authentication of Equals (SAE) improves protection when users use weak passwords, and it strengthens the initial key exchange. WPA3 makes it easier for users to select passwords that are easy to remember and improves ease of use for security features.
- **WPA3-Enterprise** to protect enterprise, government and defense networks. It introduces 192-bit encryption to protect networks with the tightest security requirements.

The Wi-Fi Alliance has released two complementary certification programs to strengthen Wi-Fi security:

- **Easy Connect** simplifies the security configurations for IoT devices and other devices with limited display capabilities.
- **Enhanced Open** supports individualized data encryption in open networks.

one AP to have uniform coverage and sufficient capacity. With EasyMesh, users can add a new AP and create a mesh network with the other AP(s) at the same location. With a mesh architecture, APs autonomously coordinate transmission and manage device connectivity, taking into account the overall network conditions and device requirements. Mesh networks facilitate the introduction of new home entertainment and IoT devices, especially ones with demanding traffic requirements (e.g., video distribution) or requiring uniform coverage throughout the house (e.g., sensors).

Wi-Fi and 5G integration

There is much standardization and developments work to integrate Wi-Fi with 5G and other cellular networks, because integration between these access technologies will increase the efficiency of both technologies and will improve the user experience.

When Wi-Fi and cellular coexist in the same location but are not integrated, devices typically connect to one or the other, regardless of applications or services used and network conditions. Devices often do not connect to the best available network at a given time and location, and this results in poor performance and experience.

Multiple tools and approaches are available to integrate Wi-Fi and 5G at different levels:

- **Devices.** With Dual Connectivity, devices can simultaneously connect to both a Wi-Fi AP and a 5G (or 4G) cell, and use the channel that is most efficient and that gives the best user experience. With IETF-driven Multipath TCP, a mobile device connected to both Wi-Fi and cellular can retain the TCP connection as transmission shifts from one access interface to the other, so that the transition at the application level is seamless to the user. ANDSF allows mobile devices to scan the environment to see what networks are available, and to decide which one to associate with. Mobile operators can then use policy rules to manage device access with ANDSF.
- **RAN.** The cellular link manages the control plane to allocate traffic to Wi-Fi and cellular, and Wi-Fi carries only data traffic. This arrangement makes it possible for mobile operators to optimize offload – for instance, they can preferentially use Wi-Fi for specific application types, e.g., those that require streamed video. There are also parallel ongoing development efforts to use Wi-Fi as the anchor for cellular (instead of using cellular as the anchor for Wi-Fi) and they will further expand the integration options of Wi-Fi and cellular and enable new use cases.
- **Core.** Wi-Fi can also use the 5G core for a deeper integration, in which Wi-Fi is one of the access technologies that the 5G core manages. This approach enables mobile operators to include Wi-Fi traffic in edge computing and network slicing, thus increasing their impact and efficiency gain. At the same time, Wi-Fi and 5G integration does not require all Wi-Fi traffic to go through the core, hence helping to avoid core overload, added costs and increased latency. With local breakout, traffic from the RAN can be routed to the internet without having to traverse the core network, but the 5G core still manages both cellular and Wi-Fi traffic.
- **Roaming.** SIM-based authentication with Passpoint enables cellular devices to roam onto trusted Wi-Fi networks that have a roaming partnership with the user’s mobile operator.

The work on standards and specifications for Wi-Fi and cellular integration is shared across multiple organizations – including 3GPP, Wi-Fi Alliance, WBA and IETF – and has wide participation from the Wi-Fi ecosystem, including mobile operators.

7. Wi-Fi and 5G convergence

Wi-Fi has to continue to innovate and improve performance to meet our connectivity needs, to expand its reach to more users and devices, and to satisfy new use cases. Not surprisingly, the evolution of Wi-Fi is well-aligned with the IMT-2020 vision of next-generation connectivity, which is grounded on ambitious and demanding requirements for capacity, latency, density, coverage, efficiency, reliability, spectrum, and number of devices.

To meet the IMT-2020 goals, multiple technologies have to converge and contribute. Wi-Fi 6 and 5G are the two main players in terms of market and traffic share and their ability to support a majority of use cases. Wi-Fi 6 and 5G are complementary because each brings a different contribution to creating a pervasive connectivity fabric. At the same time, the transformation of Wi-Fi and cellular expands the capabilities and performance of both technologies in ways that bring them closer to each other in some respects as they aim to meet the same performance targets. But unlike what happened in the past with the harsh competition between GSM and CDMA, or between LTE and WiMAX, not only will Wi-Fi and 5G coexist, but, as discussed in the previous section, the industry has developed the tools to integrate them to increase overall wireless efficiency and create a better user experience.

The current equilibrium between Wi-Fi and cellular will be fundamentally preserved as we move to 5G. The main strength of Wi-Fi is to provide in-building connectivity to users who may be either stationary or nomadic. According to most estimates, this accounts for over 70% of overall wireless traffic. The use of unlicensed spectrum, the ability to deploy Wi-Fi quickly and cost effectively in stand-alone networks that do not require a centralized core are attractive to residential users, enterprises and cities that want to deploy a network in a confined environment that they largely control. With Wi-Fi, everybody can afford to take control of their own wireless infrastructure. Wi-Fi will retain this advantage because of its massive installed base, its ability to gradually evolve without the need to replace the existing infrastructure, and its performance improvements.

At the same time, small stand-alone Wi-Fi networks provide valuable islands of connectivity, but they do not have the citywide or countrywide coverage, or the support for vehicular mobility that cellular networks have. 5G brings together multiple generations of cellular networks that have the extensive outdoor coverage and mobility support that Wi-Fi will never match. Wi-Fi is cost effective in high-traffic environments, but it can be expensive when used for wide-area coverage, even with its improved range and edge peak rates. Because wide-area networks are expensive to deploy and complex to operate, and have to serve a large set of subscribers, mobile operators or other service providers will still be the primary entities deploying 5G.

Another distinction between Wi-Fi and cellular that will remain is that because it uses unlicensed bands, Wi-Fi has better spectrum reuse, even though in licensed bands 5G – or LTE – is more spectrally efficient. The unlicensed regime encourages users to share spectrum and this naturally leads to contention among users. To ensure fair coexistence among users, Wi-Fi uses listen-before-talk (LBT) mechanisms that impose an overhead in performance that is absent in licensed bands. However, network utilization is typically lower in cellular networks because the operator has exclusive use of the channel. Where there is contention among Wi-Fi networks, Wi-Fi can pack more bits than 5G in licensed bands because the throughput benefits of spectrum reuse outweigh those from the higher spectrum efficiency.

While Wi-Fi and 5G/legacy cellular will retain their relative strengths and continue to complement each other, there are also several areas where technological evolution is converging:

New spectrum bands. Both Wi-Fi and 5G have moved into new spectrum bands to accommodate new use cases (especially for IoT) and hyper-dense traffic locations. Wi-Fi targets more spectrum in low frequency bands (e.g., 900 MHz for Wi-Fi) and in mmW frequencies (e.g., 60 GHz for WiGig).

Differentiation: What each technology does best	
Wi-Fi	**5G and legacy cellular**
Unlicensed spectrum sharing	Licensed spectrum
In-building coverage	Wide-area coverage
Stationary or nomadic access	Mobile access
Higher frequency reuse	Higher spectral efficiency
Lower per-bit cost	Lower cost for wide-area coverage
Residential and enterprise networks	Mobile public networks
Shared evolution: What Wi-Fi and 5G increasingly have in common	
New spectrum bands	
Unlicensed access	
Distributed architectures, edge computing	
IoT, private networks	
Mutual offload	
Real-time traffic management, automation, AI	

Unlicensed access. Historically, cellular has relied exclusively on licensed access, and Wi-Fi has been the main access technology in unlicensed bands. While the commitment of Wi-Fi to unlicensed spectrum has not changed, there is a growing interest in using 4G and, eventually, 5G in unlicensed bands, either to support local, private networks, or to offload traffic from licensed bands.

Distributed architecture, edge computing. 5G is moving toward a distributed architecture, in which edge computing plays a prominent role in keeping latency low. This creates the opportunity for Wi-Fi and 5G to share the edge infrastructure, which in turn increases the benefits of Wi-Fi and 5G integration. In smaller Wi-Fi networks, a distributed architecture, with most content and processing kept on-premises and using local breakout, has been the default all along.

IoT, IIoT and private networks. 5G will be able to support a wide range of IoT and IIoT applications and will fuel growth in private networks in the enterprise. We should keep in mind however that Wi-Fi has been supporting IoT applications for a long time, although in most cases – e.g., surveillance – they were not labeled as such. Similarly, nearly all Wi-Fi networks are private networks, paid for and operated by the enterprise, and used to support enterprise services and applications. Both Wi-Fi and 5G will be crucial technologies to support the enterprises' needs to own, control and operate their own networks and use them to optimize and automate their process.

Mutual offload. Initially, it was cellular networks that offloaded traffic onto Wi-Fi networks – often treated as an inferior alternative to be used opportunistically, that was cheaper, but not as secure and reliable. Even with the improved performance of 5G, there will still be a need to offload, but it will be a bidirectional process, with 5G networks sending traffic to Wi-Fi and Wi-Fi networks sending traffic to 5G, depending on network conditions or any other criteria (e.g., cost, roaming relationships, policy or availability) that the service provider chooses.

Real-time traffic management, automation, AI. Today's wireless networks – regardless of the technology – could be more efficient in their use of network and spectrum resources. The growth in traffic is so strong that new air interfaces and new spectrum allocations cannot keep up with it. IoT will further exacerbate the need to increase capacity and to support a massive number of connections. Increasing efficiency is both imperative and cost effective. Both Wi-Fi and 5G are making major strides toward improving efficiency with real-time management, automation, and AI. These are all evolutionary trends that are new to both technologies, and a ground where there is much they can learn from each other.

8. Implications

We are entering a world of pervasive connectivity, in which wireless technologies will not only reach more users and devices, but will redefine the way we deploy and use wireless. No single technology can achieve this transformation: Wi-Fi and 5G are both needed to meet the IMT-2020 requirements.

Wi-Fi carries most wireless data traffic and it will continue to do so, by combining continuity – i.e., backward compatibility and interoperability – and innovation – i.e., new air interface, improved performance, and support for new use cases.

The most anticipated innovation in Wi-Fi is Wi-Fi 6, based on IEEE 802.11ax, a new air interface expected to bring a 4x increase in capacity in high-traffic environments, a more efficient use of network resources, and better support for IoT applications.

Wi-Fi evolution goes beyond Wi-Fi 6. It includes a new security certification program (WPA3), expansion to 60 GHz (WiGig), better support for IoT (HaLow), improved traffic management and roaming, and mesh capabilities (EasyMesh).

As Wi-Fi and 5G/cellular continue to develop, they will retain their role in the wireless fabric. Wi-Fi will mostly serve indoor traffic in residential and enterprise locations. 5G/cellular will continue to dominate carrier wide-area networks and to support mobile access.

Wi-Fi and 5G convergence spans multiple domains and reflects the potential that both technologies have to jointly redefine wireless connectivity as they both carve their own role within the wireless infrastructure.

Glossary

3GPP	3rd Generation Partnership Project
AI	Artificial intelligence
ANDSF	Access network discovery and selection function
AP	Access point
AR	Augmented reality
BEREC	Body of European Regulators for Electronic Communications
BSS	Business support system
CAGR	Compound annual growth rate
CDMA	Code division multiple access
DL	Downlink
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GSM	Global System for Mobile Communications
GSMA	Global System for Mobile Communications Association
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IIoT	Industrial IoT
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
LBT	Listen-before-talk
MAC	Media Access Control [layer]
MIMO	Multiple-input multiple-output
mmW	Millimeter wave
MU-MIMO	Multi-user MIMO
NGMN	Next Generation Mobile Networks [Alliance]
OFDMA	Orthogonal frequency-division multiple access
PHY	Physical [layer]
QAM	Quadrature amplitude modulation
RAN	Radio access network
RF	Radio frequency
SAE	Simultaneous Authentication of Equals
SIM	Subscriber Identity Module
TCP	Transmission Control Protocol
TRAI	Telecom Regulatory Authority of India
UL	Uplink
VNI	Cisco Visual Networking Index
VR	Virtual reality
WBA	Wireless Broadband Alliance
WECA	Wireless Ethernet Compatibility Alliance
WPA	Wi-Fi Protected Access

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Senza Fili provides advisory support on wireless technologies and services. At Senza Fili we have in-depth expertise in financial modeling, market forecasts and research, strategy, business plan support, and due diligence. Our client base is international and spans the entire value chain: clients include wireline, fixed wireless, and mobile operators, enterprises and other vertical players, vendors, system integrators, investors, regulators, and industry associations. We provide a bridge between technologies and services, helping our clients assess established and emerging technologies, use these technologies to support new or existing services, and build solid, profitable business models. Independent advice, a strong quantitative orientation, and an international perspective are the hallmarks of our work. For additional information, visit www.senzafiliconsulting.com.

About Monica Paolini

Monica Paolini, PhD, founded Senza Fili in 2003. She is an expert in wireless technologies, and has helped clients worldwide to understand technology and customer requirements, evaluate business plan opportunities, market their services and products, and estimate the market size and revenue opportunity of new and established wireless technologies. She frequently gives presentations at conferences, and she has written many reports and articles on wireless technologies and services. She has a PhD in cognitive science from the University of California, San Diego (US), an MBA from the University of Oxford (UK), and a BA/MA in philosophy from the University of Bologna (Italy).