WIRELESS BROADBAND ALLIANCE

DRIVING NEXT WIRELESS EXPERIENCE

WBA Annual Industry Report 2021

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Author(s):
Adlane Fellah & Caroline Gabriel

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ABOUT THE WIRELESS BROADBAND ALLIANCE

Founded in 2003, the vision of the Wireless Broadband Alliance (WBA) is to drive seamless, interoperable service experiences via Wi-Fi within the global wireless ecosystem. WBA's mission is to enable collaboration between service providers, technology companies and organizations to achieve that vision. WBA undertakes programs and activities to address business and technical issues, as well as opportunities, for member companies.

WBA work areas include advocacy, industry guidelines, trials and certification. Its key programs include NextGen Wi-Fi, 5G, IoT, Testing & Interoperability, Roaming and Policy & Regulatory Affairs, with member-led Work Groups dedicated to resolving standards and technical issues to promote end-to-end services and accelerate business opportunities. WBA's membership is comprised of major operators, identity providers and leading technology companies, including BAI Communications, Commscope. Facebook, HPE Aruba, Nokia, Orange, Qualcomm, Rogers, Samsung, Shaw, Swisscom, Softbank, Telstra, Telus and T-Mobile US.

Find out more about WBA **Board** and the complete list of current WBA members, **click here**.

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Maravedis is a premier wireless infrastructure analyst firm since 2002. Maravedis focuses on broadband wireless technologies (including 5G, LTE, Wi-Fi, Small Cells) as well as industry spectrum regulations and operator trends. More information at **www.maravedis-bwa.com**.

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1. Executive Summary

In last year's report we predicted that 2020 would be a landmark year for Wi-Fi. This has proved true, though not quite as we anticipated. Wi-Fi took center stage in the new reality imposed by COVID-19, which has seen millions of people working from home or studying online for the first time.

That has made high quality Wi-Fi connectivity not just a convenience but an essential enabler of the new way of living. The new levels of speed, security and reliability this demands are possible because of years of innovations, from multi-access point mesh to Wi-Fi 6, from very high throughput to ultra-low latency.

Working from home has taken center stage this year, but the pandemic will force users everywhere, including many enterprises, industries and cities, to turn to enhanced Wi-Fi to help respond to crisis. At the heart of the platform that will enable their transformation are the latest Wi-Fi standards, Wi-Fi 6 and 6E, based on IEEE 802.11ax standards, which deliver a step change in Wi-Fi capabilities and performance on 1200 MHz of additional spectrum.

Wi-Fi 6 has true 5G capabilities, including support for multi-gigabit speeds, massive device density and very low latency. Not only does it boost performance, but it is readily deployable for a huge array of use cases.

The Wi-Fi community has worked to turn an impressive core standard into a fully deployable, monetizable platform. With publications like the new **Wi-Fi 6 Deployment Guidelines and Scenarios**, the WBA eases the path for service providers to deploy networks that are optimized for many different markets and applications, and so have far greater commercial potential than previous platforms.

Networks based on Wi-Fi 6 can be sliced; they can support service level agreements (SLAs) in terms of throughput, latency, traffic prioritization and other requirements; and they remain backwards compatible with previous Wi-Fi generations, which protects investments and ensures a huge installed user base from day one.

The similarity of commercial purpose could put the Wi-Fi and cellular communities into competition with one another, but in fact there is broad recognition – strongly encouraged by the WBA, NGMN, Broadband Forum and other influential partners – that the new use cases are so demanding that they will often be optimally supported by a combination of technologies with different key strengths.

In this 2021 Industry Report, we once again look back and highlight the important milestones which have been crossed during the past year, as we move into the 5G era. From Wi-Fi 6 and 6E, to deep cooperation with other bodies, including Wi-Fi Alliance, IEEE and others, the WBA is playing a key role in shaping next generation wireless.

The report also looks ahead to the opportunities that the new era of wireless platforms will open up for the Wi-Fi community with the advent of Wi-Fi 6 and 6E as well as other enhancements and the challenges which must still be addressed by the WBA working groups and the wider industry.

Key Aspects of the 2021 Report:

- Interview with WBA chairman JR Wilson of AT&T who shares his assessment of the WBA's work in the past twelve months and his vision for the role of Wi-Fi
- Impact of COVID-19 on the telecom industry and the Wi-Fi's role in the new green recovery
- Case studies for next generation Wi-Fi enabled services and their impact on key Industries from aerospace to healthcare, and how Wi-Fi can work with complementary technologies in unlicensed spectrum.
- Detailed analysis of the Wi-Fi 6 and 6E roadmap, and how it relates to service provider business models, and to the wider next generation wireless platform, including details of the WBA's ground-breaking Wi-Fi and 6E trials.
- Overview of WBA OpenRoaming™, a service, a product and a standard which will realize the full promise of a unified global Wi-Fi network.
- Analysis of the latest developments in home Wi-Fi deployment best practices including multi-access points, mesh Wi-Fi and emerging applications and standards such as Wi-Fi sensing.
- The latest development in security and privacy issues and especially the impact of the fast-evolving MAC randomization for all stakeholders.
- A review of the current and future spectrum position for Wi-Fi and unlicensed technologies, including the potential impact of emerging spectrum sharing mechanisms.
- The latest developments in convergence of Wi-Fi and 5G NR from chips to RAN to core.

Notable Survey Results

This year's WBA Annual Industry survey highlighted some interesting trends in the changing patterns of technology and business case evolution. As in previous studies, some trends are continuations of previous years' developments, such as the rising diversity of monetization strategies for Wi-Fi; while others have clearly shifted the goalposts compared to a year ago, such as Wi-Fi 6E.

- This year's WBA Industry Survey gained inputs from across the ecosystem, including many kinds of service providers, as well as equipment and device vendors. The results showed that confidence in investing in license-exempt spectrum technologies has risen sharply since last year's survey despite the ongoing pandemic, with 55% of survey respondents saying they had more confidence than a year ago.
- 43% said they were more confident about investing than in the previous year. That implies that investing in the latest Wi-Fi capabilities is seen as a way to help the business to remain resilient under pressure.
- 43% of respondents said they have already deployed a Passpoint-compliant network, such as OpenRoaming, or plan to do so within a year, while 22% would do so in 2022. This was in line with stakeholders' plans in 2019, though it is notable that, a year ago, more than one-third still

did not have a date in mind to implement Passpoint, whereas in 2020, plans and timelines were far more concrete.

- 52% said convergence was critical or very important to their business strategy, and that figure rose to over 67% with regard to future strategy.
- 57% coexistence said it was critical or very important now, while 72% said the same for the future, with 40% deeming it critical and a key enabler of improved customer experience.
- By far the most deployed technology will be Wi-Fi 6/6E, with over 65% having already implemented the latest Wi-Fi standard, or planning to do so before the end of 2021.
- Streaming video services were cited as a top three network driver by 54% of the stakeholders, followed by IoT and new vertical chains (46%) and new roaming services, such as OpenRoaming (33%).
- Edge computing is a hot topic, and 57% believe multi-access edge computing (MEC) will lead to new use cases for Wi-Fi.
- The top three industry verticals targeted by the 2020 survey respondents to monetize Wi-Fi are government with smart cities (56% placed it in their top three) followed by retail and education or campus networks (39% apiece).
- In this 2020 survey, 45% placed roaming in their top three monetization strategies for the coming year, up from 43% a year ago. That was followed by offload (Wi-Fi SP) on 38% and marketing and analytics on 32%.

To conclude, Wi-Fi is important to different businesses in many different ways, and the richness and diversity of services it enables are growing in line with new spectrum, standards and business models.

These final results highlight how the Wi-Fi platform is constantly evolving and so enabling additional services and business cases. Despite the challenges of 2020, the clear roadmap to next generation standards - with enriched spectrum, roaming and convergence – is clearly instilling high levels of confidence in Wi-Fi to support a very wide range of applications and revenue streams in the coming year.

All these topics and more are covered in this year's Report. We hope it provides a valuable guide to the varied and influential work the WBA carries out in the world of Wi-Fi and unlicensed spectrum technology; and inspires you to take part in the rich and business-critical agenda that lies ahead in 2021.

2. Wi-Fi at the center stage of life under COVID-19

A large number of the world population are still facing great social restrictions with some still confined at home due to COVID-19. As businesses and consumers around the world adjust their routines amid this new reality, the Internet is being used at a scale that the world has never experienced before. Fast and reliable broadband at home has become the lifeline to millions for work, education, socialization, and entertainment. Various sources such as Cisco have reported average growth of internet traffic at 40% and a decrease in download speeds of more than 13% in various countries as a result of school closures and shelter-at-home orders.

Some notable statistics reported include:

- Comcast reported a 32% surge in peak traffic; a 24% increase in mobile data use over Wi-Fi on Xfinity Mobile; VoIP and video conferencing is up 212%; and VPN traffic is up 40%.
- Network-monitoring company Sandvine reported that YouTube traffic is up by more than 10% worldwide.
- British Telecom reported that daytime usage on the network rose to 7.5 Tbits/s from the normal 5 Tbits/s.
- Bell Canada reported that traffic was up 60% during the day, with video, Netflix and video conferencing accounting for most of the surge, and with peak time still occurring in the evening.
- Orange in France reported that WhatsApp audio usage was multiplied by 5, video conferencing usage doubled, while transatlantic traffic surged because of streaming demand, in turn putting a lot of stress on Wi-Fi network.

Fastly, a cloud computing services provider reported some interesting numbers for different countries which were hit hard by the spread of the pandemic:

Country or State	Traffic Change	DL Speed Change
France	↑ 38.4%	↓ 13.9%
Italy	↑ 109.3%	↓ 35.4%
Japan	↑ 31.5%	↑ 9.7%
Spain	↑ 39.4%	↓ 8%
United Kingdom	↑ 78.6%	↓ 30.3%
USA - California	↑ 46.5%	↑ 1.2%
USA - Michigan	↑ 37.9%	↓ 16.1%
USA - New York & New Jersey	↑ 44.6%	↓ 5.5%

Source: Fastly, www.fastly.com, Blog - How COVID-19 is affecting internet performance, April 8, 2020

Millions of people are now working from home after previously working in offices and other workplaces, while students around the world are continuing their studies online. Governments are increasingly leveraging the Internet to communicate with their citizens while vast amounts of commerce have moved online. Houses of worship are streaming their services to keep their communities connected and entertainers are engaging with their audiences online to provide an escape from the isolation that so

many people and families are feeling. In other words, home Wi-Fi has never been so important to our daily lives.

As remote working is here to stay for the foreseeable future, ISPs are under pressure to deal with increased Wi-Fi traffic coming from all sides—from online video collaboration to gaming to wireless virtual reality to smart home applications. Managed Wi-Fi is the best way to ensure quality of service, security, and proper coverage in the home.

Well before COVID-19, the home was already becoming a highly Wi-Fi-dense environment with many connected devices. While the average number of connected devices in the home is estimated to range from seven to ten, depending on the region, the trend is clear toward an increase of twenty, thirty, or more in the next few years due to the proliferation of devices and IoT. Not only is the number of connected devices in the home growing, but the proportion of high capacity devices—such as virtual reality (VR) and 4K gaming—is also increasing, requiring high bandwidth and driving multi-AP growth. Those devices and related applications also require lower levels of latency, an increasingly important measure of quality of experience for home Wi-Fi.

Managing the quality of broadband experience in the home is more than ever a priority for service providers, and Wi-Fi is at center stage of that effort. As a result, service providers are now increasingly taking ownership of the Wi-Fi experience, while OTTs (such as Netflix and Zoom) are innovating with video techniques to guarantee a better quality of experience. Just as the diversity of wireless use cases and the demands they make on networks are exploding, so is the radical expansion of Wi-Fi capabilities underway to meet those demands. The center piece of this transformation is Wi-Fi 6 and Wi-Fi 6E, based on IEEE 802.11ax standards, which delivers a step change in Wi-Fi capabilities and performance.

Unfortunately, many home Wi-Fi users are still using legacy Wi-Fi equipment such as 802.11n and are having a poor experience, especially with upload time which has increased as much as 80% among many service providers. Some equipment vendors have reported congestion on home Wi-Fi networks in both the 2.4 and 5 GHz bands, thus reminding us of the importance of the new 1.2 GHz of spectrum in the 6 GHz band. The WBA[1] recently outlined the recommended industry guidelines and best practices for operators to achieve high-quality In-Home Wi-Fi.

The past few months are the beginning of a permanent change in working practices, to the benefit of connectivity providers, as more people and organizations change their habits. Start-ups across the US are letting leases expire and preparing for an extended period of remote work. The heads of major companies are touting the viability of their employees working from home for the long term — raising questions about the future of a post-coronavirus office market. More offices may move from higher density downtowns to the suburbs, as jobs move closer to where employees live.

[1] https://wballiance.com/resources/wba-white-papers/

With this new opportunity comes new responsibility as service providers will have to ensure new levels of reliability, security, and trust with their customers. In the future, the need for quality and reliable Internet shall become even more pronounced, and it is our aim to continue to support progress toward this target by providing instant solutions for each and every Internet user, as well as for companies.

Wi-Fi as a sustainable technology

The science is clear: to limit the catastrophic impacts of climate change, we must ensure warming does not exceed 1.5°C. The ambition is high but it's achievable — and science-based targets give companies a roadmap for getting there. The telecom and ICT Industries have an unprecedented opportunity to be at the very forefront of the transition to a net-zero economy — and it makes business sense.

Perhaps more than ever before, the world is witnessing tremendous innovation in wireless technologies, leading to significant changes in how humans and machines interact with one another. These new wireless and ICT technologies and the changes they support are generating exciting opportunities to address environmental impacts in a range of fields—from agriculture to utilities, to forest conservation, and beyond.

The telecom industry consumes between 2-3% of the world's energy and energy consumption for mobile network operators accounts for 20-40% of network opex. This bill is set to increase as operators roll out 5G technology. The promise of gigabit speeds has a price: cell sites need more power to run 5G services. The amount of power 5G requires is significant and has many operators thinking carefully about related trade-offs. For their part, vendors are rapidly evolving their 5G equipment to incorporate the latest technologies and introduce new techniques to improve the efficiency of wireless infrastructure.

Wi-Fi and 5G serve of course different purposes with Wi-Fi the ideal solution for indoor coverage and both technologies will be improving their energy efficiency with features such as sleep mode. When deploying technologies, operators will have to include the climate impact of their network into their calculations for total cost of ownership and from that perspective, Wi-Fi may be a better choice.

3. A Year in Wi-Fi… Interview with JR Wilson, Chairman of the WBA

In this interview, JR Wilson, the Chairman of the WBA, talks about this year's achievements at the WBA, and about what we should expect from the WBA and the Wi-Fi ecosystem in the next year.

1. **Looking back over the past year, what do you consider to be the biggest achievements of the WBA?**

   Several accomplishments come to mind:

   - Launch of **WBA OpenRoaming** in May – a globally available Wi-Fi federation that creates the framework for automatic and secure connection of billions of devices to millions of Wi-Fi networks.
   - Release of the **next phase of the WBA's guidelines on In-Home Wi-Fi** released in June, detailing best practices in deploying multiple AP solutions. The topic of In-Home Wi-Fi has never been more important with people around the world suddenly working and being educated from home.
   - **Wi-Fi 6 & early 6E trials** - The WBA has been leading a series of successful Wi-Fi 6 trials across different verticals including residential, education, transportation hubs, sports stadiums etc. and these are now extending to Wi-Fi 6E and additional verticals. The WBA confirmed that its early trials of Wi-Fi 6E achieved speeds of 2Gbps as well as consistent two-millisecond low latency connections, and a major step-up from current Wi-Fi technology. Carried out in San Jose, California, by WBA member companies Broadcom and Intel Corp.
   - Lastly the **WBA's Wireless Global Congress Summer Webinar Series in June and July**. The WBA had to quickly pivot to a virtual conference and did so with great success in terms of attendees and speakers which included FCC Chairman Ajit Pai.
   - We also welcomed dozens of new members and the WBA continues to grow at a healthy pace.

2. **What will be the biggest challenges for the WBA to address in the year ahead, and how will these be best met?**

   I think our biggest challenges in 2021 will be to build on the accomplishments of 2020. By that I mean:

   - **OpenRoaming** – Now that WBA OpenRoaming has launched, our challenge in the year ahead will be to scale and grow participation quickly which includes developing support for several business models and monetization strategies. To do that we need to raise awareness about OpenRoaming among a great variety of small and medium businesses across the globe.
   - **Wi-Fi 6E** – Wi-Fi 6E is a tremendous opportunity across the industry. The WBA will work with our members to identify deployment best practices, drive areas of convergence with 5G and share new business models Wi-Fi 6E can support. Trials are also an essential work by the WBA to generate best practices and move the industry forward.

- **In-Home Wi-Fi** – The WBA will need to continue to build on our work in identifying how to get the most out of in-home Wi-Fi. The reality is that while many homes now have access to fiber broadband, they are still not having a good experience throughout their homes.
- **Events** – I think it is inevitable that how any organization holds conferences will be different in a post-COVID world. This of course includes the WBA and we will need to continue to evolve our event strategy to align with the new reality.

3. What are the most important evolutions in the Wi-Fi technology, which will expand business opportunities in the next decade?

I do not think it is an overstatement to say that Wi-Fi 6 in 6GHz – so called 6E – will rewrite the rules of what is possible in terms of the capability and capacity of networks. Making available 1200 MHz of spectrum to unlicensed services will have a substantial impact to Wi-Fi performance and its ability to offer both higher speeds and better reliability/latency performance. This is where Wi-Fi and 5G really start to converge under a next generation core network that is access layer agnostic. This represent a big shift that builds on previous work including Passpoint/NGH where Wi-Fi becomes part of the 5G experience.

4. The WBA has had a strong position on driving Wi-Fi services like NGH-Passpoint technology over the last years. Can you update us on its progress and key objectives for 2020?

Connecting to a Wi-Fi network via NGH/Passpoint is an integral part of OpenRoaming – so as OpenRoaming grows so does the adoption of Passpoint. The point of developing a roaming federation such as OpenRoaming is make it easier for identity providers and network providers to get the scale more quickly than would have otherwise been possible.

5. How is WBA helping AT&T to support and develop its mobility business, including Wi-Fi Offload and Wi-Fi Roaming especially considering the launch of OpenRoaming?

One of the main drivers behind AT&T's participation in the WBA was the resources available to support and drive a standard set of guidelines for Wi-Fi roaming. This work has given us the leverage to significantly expand our Wi-Fi roaming relationships both domestically and abroad. Those standardized approaches are also helping the overall ecosystem. OpenRoaming is simply leveraging many standards-based components that were already in place – Passpoint and WRIX (Wireless Roaming Intermediary eXchange) - for example.

At AT&T we only use NGH/Passpoint as our authentication method and our customers enjoy a seamless and secure connection whether they are in an airport or a military base.
In the US we use Passpoint Wi-Fi roaming to add capacity (as needed/ on demand) in high density venues like airports, convention centers and stadiums. This is automatically available to all AT&T Mobility customers with a Passpoint-capable smartphone. Internationally for customers with an AT&T International Day Pass, in addition to their cellular allowance we make Passpoint Wi-Fi

roaming available in the UK, France, Thailand, Chile and Brazil to name a few places. As a result, NGH is giving our customers more coverage in more places to fill critical gaps. We believe OpenRoaming will enable us to expand in many more venues and locations.

This will also change the in-building wireless dynamic as sometimes it is difficult to provide proper coverage to a building from a macro base station. We can instead use a properly designed Wi-Fi network that is already in the building, thus fundamentally improving the in-building experience.

6. **With Wi-Fi 6 and 5G being deployed this year, how do you envision them working together in the '5G era'? In which scenarios will they be complementary to one another, for service providers?**

   I think you will continue to see convergence in the areas we experience it today – for example Wi-Fi Calling and Cellular offloading to Wi-Fi. However, 6E really brings these 2 two technologies together. We continue to believe that the two technologies complement each other even as 5G enters the market, billions of mobile and IoT devices do not have SIM cards and will continue to rely on Wi-Fi to connect.

   What is interesting is that 5G and Wi-Fi 6 have made enhancements to each technology that actually bring them much closer together in terms of the services each technology can support and 5G network cores are expected to support multiple access technologies and apply similar policy and security regimes.

   What the customer cares about is being connected to the best performing network at any given time on whatever device they are using. This becomes more of a reality with 5G and Wi-Fi 6E.

7. **How significant will the extension of unlicensed spectrum into the 6 GHz band be to the Wi-Fi industry, and will it enable new use cases?**

   I've heard people in the industry refer to Wi-Fi 6E as a game changer and I do not think that is an overstatement because this is the most significant release of spectrum in the past twenty years. With Wi-Fi 6E, performance will be even better than with 5 GHz due to the availability of the additional seven 160 MHz channels, clean spectrum, no legacy devices, and scheduled access. Wi-Fi 6E will provide unique opportunities to build networks for more targeted, latency stringent, bandwidth demanding applications. In terms of new use cases, the ongoing trials indicate that low latencies at 2ms or less combined with very high speeds enable new use cases such as telehealth and many more to emerge.

8. **What are the other significant developments in unlicensed spectrum, for Wi-Fi or other technologies? Do you believe global harmonization of these bands is essential, and is it improving?**

   - There is shared spectrum – CBRS band (3550-3700 MHz) – of course. The PAL license auctions continue, and it will be interesting to watch what new use cases, particularly for the enterprise space, manufacturing and so called "Private LTE", emerge. There are still

few mobile devices with CBRS chipsets so the market will take time to materialize. In the meantime, IoT modules will be the most deployed CBRS devices.

- There is so called Wi-Fi 7 – 802.11be which is still in the early stages of development and scheduled to be available to consumers sometime in 2024 that we are keeping an eye on.
- And finally, the C-band auction set to kick off in the US in December, with 280 MHz of licensed mid-band spectrum to be auctioned.

I am not sure harmonization with all the different regulatory regimes in each country/region is feasible, but it was promising to see Ofcom in the UK open up 500MHz of new spectrum for unlicensed in the 6GHz in July of this year. The WBA is fortunately represented by companies from around the globe which have relationships with their local regulators, and they may help harmonize some of the regulatory regimes. The WBA engages with many regulators across the world not to lobby but to provide latest findings from WBA programs on how Wi-Fi is becoming better technology

9. **How do you see Wi-Fi working with other radio and wireline technologies in IoT, and what will be WBA's role to facilitate that?**

Wi-Fi will remain a key access technology for IoT due to Wi-Fi's cost effectiveness and almost ubiquitous presence. The focus of the WBA is to make Wi-Fi better, faster, more efficient, and more focused on the customer experience. Not only for the phone or tablet users, but also for IoT applications. At the WBA, we continue work towards a solid framework for IoT and this work will continue in 2021. We are working on streamlining authentication and interoperability, on improving security, and offering a seamless experience.

Another thing that comes to mind is the impact that Wi-Fi 6/6E will have on IoT. It is estimated that by 2021, machine to machine (M2M) IoT connections will account for more than half of all wireless connections. IoT devices already outnumber smartphones. Wi-Fi 6/6E will improve signal strength to support IoT deployments, support always-on devices and reduce overcrowding of resources with high-capacity networks. IoT devices will be able to send more information and use less power.

10. **Finally, when we come to write the 2022 industry report, what do you most hope will have been achieved by the WBA, and in the wider Wi-Fi community?**

As always, my vision is that we have robust, growing and active organization that continues to add value to our membership by delivering projects that equip them to drive real business results.

From an industry perspective, that the WBA leverages OpenRoaming to scale adoption of Passpoint Wi-Fi and has an active role in adoption and advancement of Wi-Fi 6/6E and convergence with 5G. That the WBA is playing an instrumental role in improving the performance of In-Home Wi-Fi networks and continues to work with other trade associations to reach our ultimate common outcome of a better user experience for millions and millions of users.

4. Wi-Fi key market segments – emerging trends and business models

Wi-Fi has become the most popular indoor wireless technology in homes, offices, businesses, and increasingly public spaces. Wi-Fi serves all market segments, and service providers have been keen to find ways to monetize it. According to Cisco annual internet report[2] published in February 2020, 45% of all networked devices will be mobile-connected (3G and below, 4G, 5G or Low Power Wide Area and 55% will be wired or connected over Wi-Fi.

4.1 How COVID-19 impacted behaviors and risk to investment

Overall, the telecom, media and technology sectors have been able to absorb the first shockwaves of COVID-19 with relative resilience. However, medium-term (2020–2021) implications are unclear as macroeconomics threaten industries highly dependent on consumers' confidence and government decisions.

According to a variety of analysts, worsening macroeconomic conditions will impact consumers' spending power and sentiment. Analysis Mason expects the impact of COVID-19 to correspond with a year-on-year decline in telecoms revenue of 3.4% in 2020 across developed markets but projects the industry will return to growth in 2021, with a year-on-year revenue increase of 0.8% driven by pent-up demand in consumer broadband. Operators will be able to manage their costs by deferring some capex and scaling down opex where possible.

Telecom operators have been dealing with increased operational complexity and some losses in B2B revenues but can leverage the crisis to leapfrog to novel business models. Business telecoms have been hit by the slowing economy, particularly in the area of new business with increases in unemployment, business closures and an overall decrease in economic activity. For Wi-Fi this is particularly impactful in the public and guest Wi-Fi space.

Excluding home gateway providers, some equipment vendors will have to deal with deferred orders in the medium term; however, as their value proposition looks stronger than ever, they have opportunities to strengthen their long-term positioning. Internet services have been the stars of lockdown economies and lifestyles and will benefit from permanently changed behaviors.

[2] https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

4.2 Operators & Identity Providers

In the past few years, carrier Wi-Fi has become a natural part of both network and business strategies for mobile network operators (MNOs) and wireline operators such as cable providers. For cable operators, especially in the US and western Europe, Wi-Fi has taken center stage in wireless/mobility strategies with the proliferation of managed home-spots and public hotspots.

Wi-Fi Roaming

Wi-Fi access has been widely accepted by operators globally, and it has evolved to complement mobile networks and is used for roaming, extending coverage, increasing customer loyalty and to avoid more costly cellular networks. Participation in the roaming ecosystem by non-traditional telcos has also increased the commercial opportunity. The WBA has done significant work to facilitate seamless Wi-Fi roaming between the various stakeholders. Its' work includes the WRIX (Wireless Roaming Intermediary eXchange) which offers a modularized set of standard service specifications to facilitate commercial roaming between operators. Wi-Fi roaming will also be facilitated by the OpenRoaming federation as more participants join this global Wi-Fi network.

Essential attributes of carrier-grade Wi-Fi – such as wider roaming, subscriber management, and improved QoS and security – will enable new services including high quality voice services, location and proximity, smart city, consumer IoT, quad play services and HetNets.It is also important to highlight that sometimes Wi-Fi is not only the best choice, it is the only choice – for example on airplanes and cruise ships and using non-cellular devices such as laptops and other devices.

Wi-Fi Offloading

One of the main solutions to meet the increasing demand for bandwidth has long been leveraging Wi-Fi networks, which enables operators to scale capacity to meet their subscribers' needs. With advances in Wi-Fi standards, quality of experience of Wi-Fi in dense public environments such as airports, public transportation, retail, healthcare, smart cities, stadiums with many concurrently connecting devices and IoT connections has improved greatly. Globally, there will be nearly 628 million public Wi-Fi hotspots by 2023, up from 169 million hotspots in 2018, according to research provided by Cisco.

For MNOs, carrier Wi-Fi was initially used to offload cellular traffic to reduce cost and to relieve pressure on the macro network. However, with an increase of reliability and security of Wi-Fi deployments due to the next-generation hotspots, many carriers have made Wi-Fi central to their business models and incorporated it into their overall customer experience strategies. Wi-Fi helps reduce churn and generate new revenues from roaming or expanded service bundles. As 5G networks start to be deployed, wireless carriers will continue to need offloading techniques to keep the macrocellular network operating efficiently.

In many cases, the transition between Wi-Fi and cellular connection happens automatically, without end user intervention or even awareness of how they are connected to the wireless network. This paradigm will become even more necessary as the world evolves to 5G. The ability to leverage a variety of licensed and unlicensed spectrum across multiple frequencies using various technologies, along with new techniques to increase overall transmission bandwidth will be essential to meeting the demand for mobile connectivity.

4.3 In-Home

As we saw previously, managing quality of broadband experience in the home has become even more a priority for most service providers in this age of COVID-19 and Wi-Fi is at center stage of that effort. Most operators are motivated to provide managed Wi-Fi for free to reduce opex and improve their net promoter score, while a few attempt to monetize it or include it as part of their premium packages. Managed Wi-Fi is the foundation for the connected home. The reality is that operators cannot guarantee a quality of experience for Wi-Fi in the home unless they can monitor and optimize that Wi-Fi connection through a number of tools that constitute managed Wi-Fi. Education of consumers is essential so they can understand and value the notion of managed Wi-Fi. Increasingly, security of all connected devices in the home including IoT will require a higher level of permanent protection and sophistication that only service providers can bring.

Wi-Fi enables the connected home

In recent years we've become increasingly used to connecting everyday devices in our homes to the internet and to each other to make the places we live more comfortable, economical, entertaining, and safe. As the technology underpinning this revolution in how we live continues to get faster and more powerful, we can expect home automation and artificial intelligence to offer domestic help in new and innovative ways. One of the headaches of putting together a smart home is undoubtedly the competing range of platforms and standards. Increasingly, manufacturers of smart home devices need to ensure their products and services will work on platforms provided by Amazon, Google, Samsung, and Apple to capture the broadest customer base.

Innovation to solve the integration between connectivity platforms requires home Wi-Fi to work seamlessly with IoT. There are a number of ongoing initiatives to create a more agile CPE, one with an open-source, agnostic, middleware between the cloud and the home devices. The benefits of making code available to others include faster development time, faster time to market, and more cost-effective implementation.

With Wi-Fi 6 in the home, faster networks don't simply mean a quicker transfer of data between devices, or between devices and the cloud. It also means increasingly sophisticated applications, utilizing bigger, faster data streams, become a possibility. Devices such as smart thermostats and automated security systems will have access to more varied and up-to-date information with which to make the predictions their usefulness is built around.

IoT and Security Trends
Connected devices and IoT nodes are built with no or poor security, giving intruders access into the home network and possibly personal data. Since these devices connect and interconnect from the router/gateway provided by the operator, a solution can provide an added layer of security embedded in the middleware and SDK app.

Vendors are developing solutions using AI and ML to detect intrusions and abnormal activity, such as a camera wanting access to the smart lock. Nevertheless, the majority of service providers are still at the early stage of any comprehensive cybersecurity offering and will face an uphill battle to educate their subscribers about the benefits of protecting their connected home if they hope to monetize new services beyond parental control. In other words connected homes will become increasingly smart as machine learning and AI become the norm. In-home smart healthcare offers the potential to reduce some of the stress put on traditional healthcare channels – doctors and hospitals – that is inevitably caused by increasing life expectancy and a growing elderly population.

WBA's In-Home Wi-Fi Program
The WBA 's In-Home Wi-Fi Industry Guidelines 2019 identified the gaps in current in-home Wi-Fi standards and highlighted the need for intelligent network optimization. The WBA aims to tackle the challenges that have contributed to inconsistent performance in the home, including a lack of uniform coverage and visibility into the in-home Wi-Fi experience.

More recently the WBA outlined the recommended industry guidelines and best practices for operators to achieve high-quality In-Home Wi-Fi. With building construction and layout having a material impact on coverage of Wi-Fi within a home, it was identified that homes increasingly require Wi-Fi networks comprised of multiple access points. The complexity of delivery and management of these access points can ultimately impact performance and customer satisfaction.

In the latest stage of WBA's In-Home Wi-Fi program, the WBA is building on its previous report with the goal of extending it to define the standards that create the ultimate in-home Wi-Fi experience. An executive summary which provides an understanding of its scope, use cases, and path towards interoperability testing is **available for download**.

4.4 Enterprise verticals
Wi-Fi has become a critical and ubiquitous connectivity tool for enterprises of all sizes and Industries, furthered by the swelling usage of Wi-Fi enabled BYODs. For many businesses, Wi-Fi is mission critical to operational success. While home users may tolerate a Wi-Fi outage (albeit not without frustration), hotels, schools, hospitals, corporations, and many other organizations cannot. We expect that a number of verticals and brands which deal with the public, from hotels, convention centers, stadiums, retails and restaurants, will start joining WBA OpenRoaming to provide their customers and guests with automatic and secure Wi-Fi across multiple locations. In the following sections, we discuss guest expectations in a number of professional settings and how the technology is responding to those new requirements.

4.4.1 Hospitality & Stadia

Wi-Fi tops the list of factors influencing booking decisions by hotel guests. With 89% of respondents to Hospitality Technology's survey[3] citing this amenity as a decision factor, free Wi-Fi is more important than even the ability to see photos and videos of the hotel before booking (84%) and ease of the online booking process (81%).

a. Hotel guest experience

While Wi-Fi is a key influencing decision by hotel guests when booking, guests expect their Wi-Fi to be secure, seamless and fast, as well as being free. Most large hotels understand the value of integrating Wi-Fi into their guest hotel experience from check-in to sending coupons for drinks by the pool. Wi-Fi provides hotels with a marketing and analytics platform for their guests and also a tool for their staff to be more productive in their tasks. To remain relevant, hotel brands are continuing to invest in technology and there is interest, despite COVID-19 in WBA's OpenRoaming framework to benefit their guests with automatic and secure Wi-Fi connection across locations. This becomes even more pertinent with the issues surrounding MAC randomization.

b. Guest experiences in conference and stadia

Just as when a guest enters a hotel and expects to connect to a Wi-Fi hotspot, the same is true during a conference or sport event in a stadium. Those venues are highly challenging radio frequency environments and are considered high-density, with many users and devices. Typical high-density scenarios include both permanent deployments – such as airports or stadiums – and temporary ones, for concerts and special events. Some of the features that make Wi-Fi valuable in those high-density settings include:

- Social sharing during the event
- A branded user experience to boost awareness
- Targeted messages and marketing- if the user agrees
- Opportunities for feedback
- Access to vital customer analytics

4.4.2 Retail (inc. coffee shops and F&B)

Consumers are always online. Online retail powerhouses, such as Amazon, are setting the bar very high for the physical retail experience as customer expect the same kind of easy and rich journey. Retailers as well as food and beverage services are increasingly adopting guest Wi-Fi to satisfy their customers' expectations and leveraging it as part of an omnichannel strategy. According to the "2019 Annual Customer Engagement Technology Study" the majority of hotel guests (84%) and restaurant diners (56%) say that access to free Wi-Fi drives their booking and dining decisions.

[3] Customer Priorities for Booking Hotel Rooms with Free Wi-Fi a Major Driver (HT 2017 Lodging Technology Study)

It is important for businesses to embrace guest Wi-Fi to stay relevant, and guest Wi-Fi provides them with a firm foundation for nurturing brand loyalty, increasing customer satisfaction, and gaining a better understanding of customers' behaviors and preferences. For larger brands like Starbucks or McDonald's, Wi-Fi is an essential part of their business both to attend their customers as well as enable their staff to remain productive. Back office systems for inventory, purchasing, sales, etc. are essential to run a business. Integrating those systems to Wi-Fi enables owners and staff to run their operations more smoothly.

4.4.3 Aviation (Airlines, airports and supporting infrastructure)

Wi-Fi is also part of the overall travel journey from start to finish, including arriving at the airport, boarding the plane, during the flight and on arrival at the final destination. In the US, more than 90% of the largest airports now offer free Wi-Fi because travelers and those who frequent airports for one reason or another want (and expect) it. Free Wi-Fi in airports is typically a loose term as it is usually only available for 15-30 minutes after which you need to pay or watch an advert, and this can be extremely frustrating. The model needs to evolve to incorporate a free option that allows a certain level of speed sufficient for email, browsing and social media. Then those that wish to use the Wi-Fi for more heavy lifting, such as streaming video or handling large files, are likely to be happy to pay for a premium service. The onboarding process needs also to be streamlined in favor of a unique seamless approach that does not involve multiple and confusing steps. The WBA OpenRoaming federation aims at solving that issue by allowing federation members to trade with each other using a standard technical framework that simplifies onboarding, roaming and security.

WBA Program Guidelines

In May of 2019, the WBA released a detailed white paper[4] on in-flight connectivity which lays out the different deployment scenarios and what methods can be used to improve the overall user experience on board. The paper looks at the various onboarding and authentication methods and encryption methods, as well as the overall infrastructure needed to support in-flight Wi-Fi.

In the next year, we expect the business models to evolve – for example, DT has enabled free Wi-Fi on Lufthansa flights for all their broadband customers. We will also see trials running of OpenRoaming as part of the Wi-Fi federation. These developments are due in large part to the growing realization that Wi-Fi is - and should be - part of the 'normal' flight experience.

4.4.4 Smart Transportation & Connected Vehicle

As the world becomes increasingly urban, densely populated areas will face dramatic and seemingly intractable transportation issues. Static Wi-Fi hotspots in stores, restaurants, hotels, and other fixed locations cater to user demand for wireless connections at dots on a map. The next stage is to offer Wi-Fi or guest Wi-Fi capability along the travel lines that join up those dots. Use cases in transportation include:

[4] https://wballiance.com/resource/in-flight-connectivity/

- Display of travel timetables
- Location maps
- Listings and features of local spots of interest
- Nearby shopping and restaurant services
- Notifications to users on any changes of itinerary or available services
- Prevention of access to explicit content or content likely to consume too much bandwidth (audio or video streaming and downloads) in the public areas of the transportation network
- Provision of a fair and reliable Wi-Fi service

The Connected Vehicle is already a reality. Vehicles increasingly are being equipped with embedded connectivity to the extent that more than 125 million connected car shipments are expected by 2022. According to Counterpoint Research. There has been significant industry focus on the capabilities enabled by using wide-area cellular connectivity to support connected-vehicle use cases that require always-on and ubiquitous network connectivity.

However, as a WBA white paper entitled "**The Connected Vehicle Understanding the Wi-Fi Opportunities and Use Cases**" discusses, there is potential for complementary use cases in which vehicle-to-cloud connectivity can benefit from opportunistic connectivity delivered by using Wi-Fi systems. The analysis highlights striking commonalities between the requirements associated with the multi-RAT connected smartphone and the multi-RAT connected vehicle, as well as the benefits of applying well established Wi-Fi roaming concepts, originally defined for smartphone use cases, to nascent connected-vehicle roaming scenarios. Those services better served by Wi-Fi include real-time over the air updates as well as telematics, remote services and other communications to and from the vehicle.

4.4.5 Industrial

In the past, operational teams (OT) have been skeptical about industrial wireless. In fact, some have deployed miles of cable to avoid it. This approach is expensive and time-consuming. However, with facilities increasing focus on digital transformation, wireless lays the foundation necessary to begin down this path.

Traditionally, Wi-Fi has not been very present in the industrial environment, but things are changing thanks to the features provided by Wi-Fi 6. Industrial environmental conditions more demanding than in an office environment, with extreme temperatures, dirt, dust, moisture, shock, and vibrations. Industrial grade chipset have improved (passive) cooling and sturdy design to ensure reliability and longevity under these adverse conditions. Other industrial environments such as assembly plants or foodo production will less harsh conditions still bring their own set of challenges in terms of radio frequency environment that will require Wi-Fi 6 capabilities.

Wi-Fi 6 brings new improvements for dense environments characterized by numerous IoT devices and moving parts. As we discuss in the Mettis trial (see appendix), reliable and effective industrial wireless is possible, but it requires careful planning and the process is more complex than in enterprise settings, but purpose-built industrial wireless products and design can aid in making it successful.

4.4.6 Healthcare

The majority of hospitals and clinics have poor indoor cellular coverage, and mobile operators are only focusing on the largest and most profitable ones. Indoor solutions such as DAS are too complex and costly for smaller venues and mid-tier buildings. Like any other professional environment, hospitals require proper connectivity where visitors, healthcare professionals and patients can roam anywhere throughout the facility while providing continuous, accurate, and real-time monitoring. In addition diagnostic activities, such as scanning and ultrasounds, are already being investigated. This vision can only become reality through the integration of Wi-Fi technology as an integral part of a hospital's IT systems.

Wi-Fi and Connected Devices Can Improve Patient Care

The first obvious area to exploit the power and functionality of Wi-Fi is with connected medical and non-medical devices. This includes smart beds, monitoring devices, and testing devices like MRI and X-ray equipment. When equipped with Wi-Fi, these devices can connect with a central database or system that automatically update patients' electronic medical records. Wi-Fi 6 brings the capabilities needed to provide robust connectivity in those challenging and changing RF environments where medical devices and patients are constantly moved around, creating obstacles to good signal propagation.

Wi-Fi Helps Track & Monitor Medical Equipment

Hospital administrators can also use Wi-Fi to monitor and track key assets such as medical equipment. For example, tagging a wheelchair or other piece of mobile asset can provide administrators with a real-time view of where that equipment is located anywhere throughout the facility. This detailed knowledge helps reduce equipment theft and misplacement. Also, knowing where equipment is being used provides administrators with useful analytics about how the hospital functions.

4.5 Smart Cities

For many cities around the globe, Wi-Fi is a natural choice to start delivering Internet access to unconnected citizens. Wi-Fi is often the technology that is used to underpin the initial use cases and deployments in smart city projects, creating an affordable platform on which further applications can be layered and providing access to services.

Use cases for cities are many and varied, regardless of whether or not they include some form of Wi-Fi. Cities are beginning to explore the development of wide grids of coverage by combining different networks through roaming services, given to citizens as a single credential that can be used across a variety of networks. These grids can be managed directly by the city's authorities or by a third party. For Services Providers (SPs) and cities, there is an opportunity to harness people's familiarity and acceptance of Wi-Fi to create new services and products, encouraging additional roaming usage and revenues. A managed Wi-Fi roaming service, including guest Wi-Fi for both visitors and citizens, can greatly improve the overall user experience. Cities are already expressing an interest in joining the WBA OpenRoaming federation as part of their visions for connected citizens.

5. Wi-Fi Technology Trends

5.1 Wi-Fi Standards Evolution

Just as the diversity of wireless use cases, and the demands they make on networks, is exploding, so a radical expansion of Wi-Fi capabilities is underway to meet those demands. The centerpiece of this transformation is Wi-Fi 6, based on IEEE 802.11ax standards, which delivers a step change in Wi-Fi capabilities and performance.

At the beginning of 2020, the Wi-Fi Alliance announced new branding of Wi-Fi 6E in reference to the spectrum extension to the existing Wi-Fi 6 standard capable of supporting all-new 6 GHz frequencies (5.925-7.125 GHz).

In April 2020, the Federal Communications Commission made the opening of 1200 MHz official for use by unlicensed devices in the 6 GHz band. The rules are designed to allow unlicensed technologies, such as Wi-Fi, to operate in the band without interfering with the operation of the licensed services which will continue to use this spectrum. The UK, Brazil, South Korea and other countries have followed suit and the trend will continue.

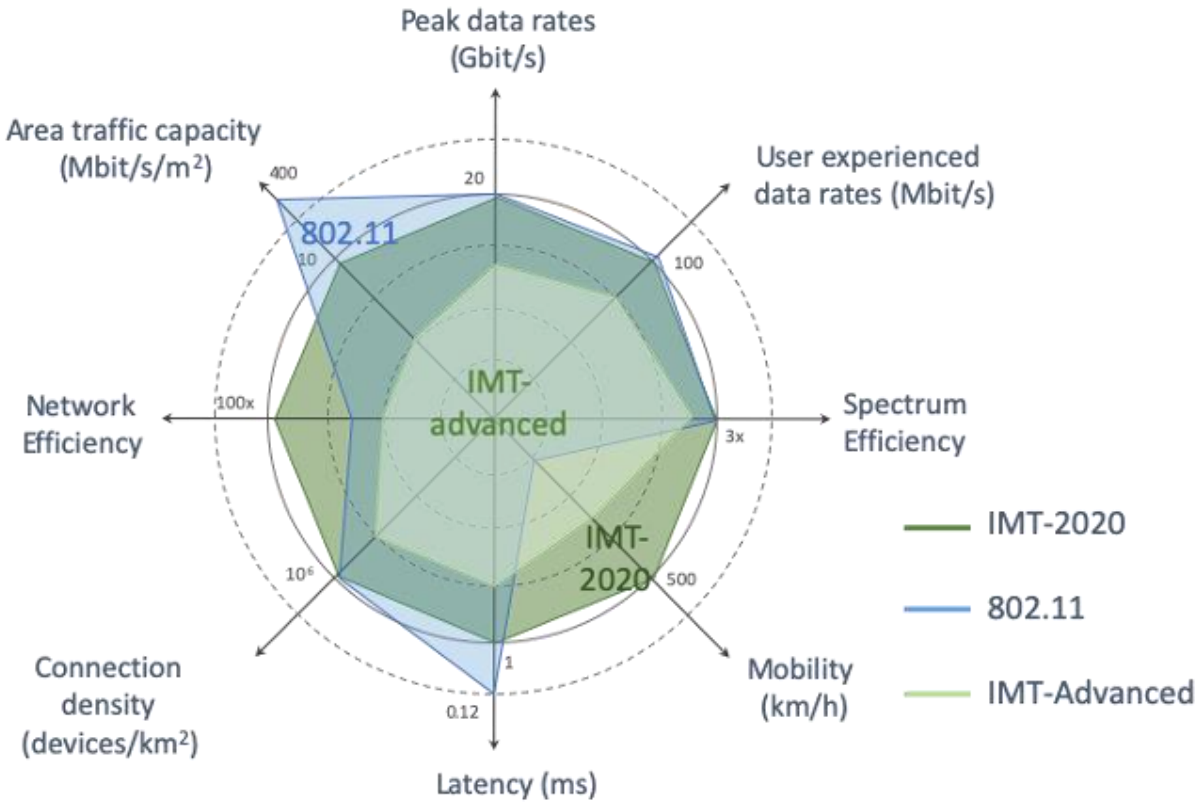
Routers will have wider channels to work with to accommodate more devices at higher throughput rates. Wireless Broadband Alliance research[5] shows the use cases that survey respondents believe will deliver the most benefit with the combination of Wi-Fi 6 and 6 GHz spectrum. Seventy-two percent (72%) said the biggest consideration is that 6 GHz spectrum won't have traffic interference from legacy Wi-Fi devices. More than 65% of respondents want to use 6 GHz spectrum to enable applications that require high bandwidth and low latency, such as augmented and virtual reality (AR/VR) and gaming on Wi-Fi 6 devices.

5.1.1 Wi-Fi 6 & 6E

Wi-Fi 6 has true 5G capabilities, including support for multi-gigabit speeds, massive device density and very low latency. The graph below shows the enhanced 802.11 capabilities compared with those of IMT-2020 and IMT-Advanced.

[5] WBA Annual Industry Report 2020

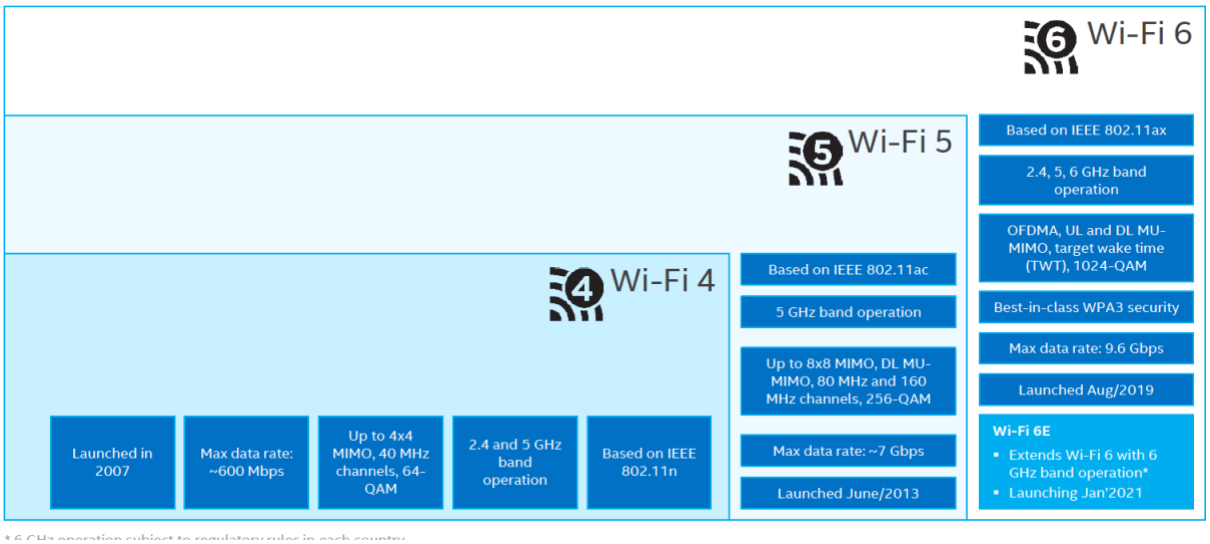
Figure 1: **802.11 capabilities compared**



Source: WBA, Unlicensed Integration with 5G Networks Whitepaper

Not only does it boost performance, but it is readily deployable for a huge array of use cases. The Wi-Fi community has worked to turn an impressive core standard into a fully deployable, monetizable platform. With publications like the new **Wi-Fi 6 Deployment Guidelines and Scenarios**, the WBA eases the path for service providers to deploy networks that are optimized for many different markets and applications, and so have far greater commercial potential than previous platforms. Networks based on Wi-Fi 6 can be sliced; they can support service level agreements (SLAs) in terms of throughput, latency, traffic prioritization and other requirements; and they remain backwards compatible with previous Wi-Fi generations, which protects investments and ensures a huge installed user base from day one.

Figure 2: Current generations of Wi-Fi



Source: Intel

Wi-Fi 6 uses a combination of technologies, including OFDMA and 1024 QAM modulation to improve spectral efficiency and boost not just speed, but support for large numbers of devices in a confined area. In early trials, that capability has mainly been demonstrated in stadium environments, but device density is also important in the home, where many appliances and previously dumb devices will start to be connected to the home hub, and where several users may be consuming high quality video, gaming or augmented and/or virtual reality (AR/VR) at the same time. Target wake time enables devices to determine when and how frequently they send or receive data, extending battery life for devices like IoT sensors. This is especially salient, as 26 billion IoT devices will be online by the end of 2020. Basic Service Set (BSS) coloring will enable increased capacity in dense environments by increasing frequency reuse between BSS's. BSS Coloring is a method for addressing this medium contention overhead due to overlapping basic service set (OBSS) and spatial reuse. 802.11ax radios can differentiate between BSS's by adding a number (color) to the PHY header and new channel access behavior will be assigned based on the color detected.

Wi-Fi 6E

As discussed in detail in section 7.1, the opening of the 1200 MHz of spectrum in the 6GHz is an historical event which will open up many use cases which requires vast amounts of spectrum and throughput such as VR and AR. Access to the 5.925 – 7.125 GHz band—referred to as the 6 GHz band—is very important to the future of Wi-Fi innovation. The rules are designed to allow unlicensed devices, such as Wi-Fi, to operate in the 6 GHz band without interfering with the operation of the licensed services which will continue to use this spectrum.

"Extending Wi-Fi into the 6GHz spectrum band can provide more Wi-Fi capacity than all the other bands put together," WBA CEO Tiago Rodrigues explained. "What's more, using Wi-Fi 6 technology in the extended band (also known as Wi-Fi 6E) will deliver higher speeds, low latency and service levels that are equivalent to 5G networks and be able to support the widespread, low-cost, use of advanced business, industrial and consumer applications.

The WBA confirmed that its early trials of **Wi-Fi 6E achieved speeds of 2Gbps** as well as consistent two-millisecond low latency connections - a major step up from current Wi-Fi technology. Carried out in San Jose, California, by WBA member companies Broadcom Inc. and Intel Corporation, the trials demonstrated that Wi-Fi 6E can meet the needs of industrial and consumer applications of virtual and augmented reality technology.

The WBA has been leading a series of successful Wi-Fi 6 trials across different verticals including Industry 4.0, residential, education, transportation hubs, sports stadiums etc. and these are now extending to Wi-Fi 6E and additional verticals. WBA member and partner companies taking part in the trials include Aruba, a Hewlett Packard Enterprise company, Boingo Networks, Broadcom Inc., CableLabs, C-DOT, Cisco, Comcast, GlobalReach Technology, IBwave, Intel Corporation and SK Telecom.

"Wi-Fi 6E technology is designed to deliver performance in highly congested places," said Tiago Rodrigues, CEO of WBA, "and the next phase of our trials will prove that performance in real world locations. These trials will demonstrate the application and the benefits of the technology in live environments and through this accelerate the adoption and creation of new business opportunities enabled by the opening of the 6 GHz spectrum to be used for Wi-Fi services."

5.1.2 Wi-Fi 7

Wi-Fi 6 is just now arriving in phones, laptops and network equipment. But the IEEE has been working on the next generation 802.11be Extremely High Throughput (EHT) with an overall goal of improving the quality of experience for real-time applications. Once certified, 802.11be will bear the name of Wi-Fi 7 as the successor to Wi-Fi 6. With speeds as high as 30 gigabits per second, the next generation of Wi-Fi 7 promises better streaming video, longer range and fewer problems with traffic congestion. Wi-Fi 6's MU-MIMO lets network equipment makers build access points with an eight-antenna arrangement, but Wi-Fi 7 will handle 16, which opens the door for coordinated multiuser MIMO (CMU-MIMO). In the new standard, access points will have a much tighter coordination beyond just roaming.

With the development of technologies such as 8K Ultra High Quality Videos (with 7680x4320 pixels or four times as many pixels as a 4K TV and 16 times as many as a 1080p TV) and high-resolution VR (Virtual Reality) or AR (Augmented Reality), the throughput of traffic per person will increase to hundreds of megabytes. The IEEE standards development group recognizes the need to improve Wi-Fi transmission delay and jitter for real-time applications, including games, VR, external office apps, cloud computing, and medical use cases, with delays to be lowered to less than 1ms.

There are currently hundreds of candidate features being considered to be part of the new standard and the 11be project has incorporated very ambitious goals related to higher nominal data rates, higher spectrum efficiency, better interference mitigation, and providing RTA[6] support. However, the main candidate features that have been discussed are:

- 320 MHz bandwidth and more efficient utilization of non-contiguous spectrum,
- Multi-band/multi-channel aggregation and operation,
- Multi-Access Point (AP) Coordination (e.g. coordinated and joint transmission), with a goal of reducing overlapping basis service sets (BSS) and minimize collisions over the air
- If needed, adaptation to regulatory rules specific to 6 GHz spectrum.

A second tier of innovations being considered includes:

- 16 spatial streams and Multiple Input Multiple Output (MIMO) protocols enhancements,
- Enhanced link adaptation and retransmission protocol (e.g. Hybrid Automatic Repeat Request (HARQ))

[6] Real time applications

The following table highlights the main innovations IEEE 802.11 be will bring to Wi-Fi:

Figure 3: Main Innovations of IEEE 802.11be and Candidate Features.

Target / Innovation	Nominal Throughput	Interference Mitigation	Spectrum Effeciency	Real-Time Applications
EHT PHY	4096 QAM, 320 MHz, 16x16 MU-MIMO		EHT Preamble	
EDCA with 802 TSN Features				IEEE 802 TSN, Faster Backoff, New Access Categories, TXOP capturing
Enhanced OFDMA		Preamble puncturing	Multi-RU, Direct links	Enhanced UORA
Multi-link Operation	Multi-link Architecture	Synchronous Channel Access	Virtual BSS	Asynchronous Channel Access, Packet Duplication, Queue Management, Dynamic Link Switching
Channel Sounding Optimization			Implicit Sounding, Explicit Feadback, Channel Estimation	
Advanced PHY	Full Duplex		HARQ, NOMA / SOMA	
Multi-AP Cooperation		Null steering, Co-OFDMA, CSR	Distributed MU-MIMO, Multi-AP Sounding	Joint Reception

Source: Current Status and Directions of IEEE 802.11be, the Future Wi-Fi 7-May 2020

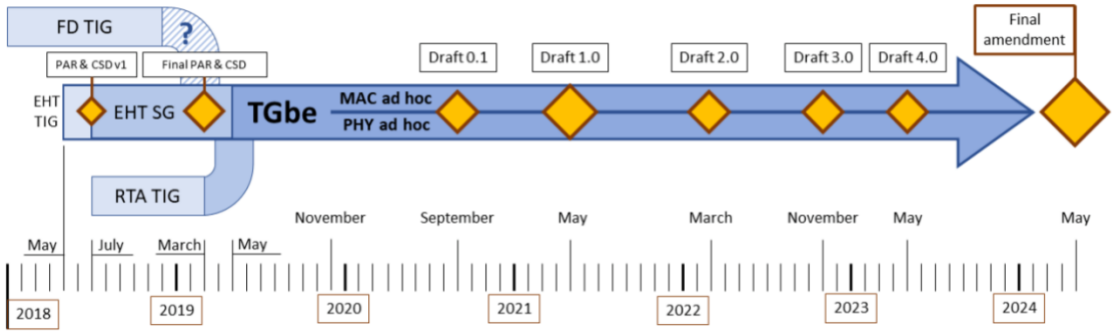
The implications of these technological innovations will have a profound impact on real-time applications which are very bandwidth intensive and require very low latencies such as virtual reality applications, 8K video or online gaming and the many new use cases which will flourish in the years ahead.

In terms of timeline, the Project Authorization Request (PAR)[7] for 802.11 be has been approved and a first draft version is expected by early 2021 followed by a series of drafts which will culminate in May 2021 with a letter ballot. This will be followed by a series of reviews, changes, and votes, leading to a final 802.11 working group and board approval by May 2024. However, we should not expect Wi-Fi 7 devices to enter the market until at least 2025 or later and by early adopters only.

[7] PARs define the scope, purpose, and contact points for a new project.

See details in the following figure:

Figure 4: Timeline of the 11be standardization process.



Source: Current Status and Directions of IEEE 802.11be, the Future Wi-Fi 7-May 2020

One more important issue related to Wi-Fi 7 is its coexistence with 3GPP technologies of cellular networks operating in the same unlicensed frequency bands. To study the coexistence issues related to Wi-Fi and cellular networks, IEEE 802.11 launched a Coexistence Standing Committee (Coex SC). The task of Coex SC is to establish contact with 3GPP to set up synchronous work. Despite many activities and even a joint workshop with both 3GPP and IEEE 802.11 participants in July 2019 in Vienna, no technical solutions have been approved yet. It is conceivable that IEEE 802 and 3GPP do not want to change their own technologies to make them aligned with the concurrent one. So, at the moment, it is not clear which of the solutions discussed within Coex SC will become a part of Wi-Fi 7.

As a reminder, the WBA and NGMN **published in 2019 a joint report on RAN Convergence** about the benefits of greater interworking between the two roadmaps. The report[8] identifies various use cases where the optimal solution would be an integrated 5G/Wi-Fi approach, as well as highlighting the challenges to achieve that. The key hurdles to leap are:

- Tighter integration of Wi-Fi access within 5G networks
- Network manageability and policy control,
- Enablement of Wi-Fi-only devices in a converged environment.

[8] https://wballiance.com/resource/ran-convergence/

5.1.3 Evolving and emerging standards

In addition to the main track of high-rate wireless local area networks, Wi-Fi evolution includes several niche projects. The various use cases keeping the IEEE busy include Wi-Fi deployments for last mile access using millimeter waves at 60GHz (802.11ay), indoor location (802.11az), and 2 low power applications (802.11ba and 802.11ah which are "parallel amendments). The increase in technical capabilities of existing technologies also drives new standards, with technologies like MIMO and OFDMA being incorporated into new standards.

These new 802.11 amendments are under development to meet expanding market needs and leverage new technologies:

- 802.11be – Extremely High Throughput (evolution to ax for 2.4GHz and 5/6GHz operation).
- 802.11ay – Support for 20 Gbps in 60 GHz band.
- 802.11ba – Wake up radio. Low power IoT applications- 802.11 ah (Halow) is already completed but certification work is now ongoing at the Wi-Fi alliance
- 802.11az is Called Next Generation Positioning (NGP) and will address the needs of a "Station to identify its absolute and relative position to another station or stations it's either associated or unassociated with."
- 802.11bb was created for light based communications.
- 802.11bc provides enhancements for broadcast services.
- 802.11bd provides enhancements for Next Generation V2X

To review each specific amendment is outside of the scope of this report. Readers are invited to consult the relevant IEEE documents[9].

The IEEE is also working on a new project for WLAN sensing under the 802.11 bf amendment. A project incubated within the WBA by Cognitive Systems is described in the Wi-Fi sensing section. Sensing will use the HY and MAC features of IEEE 802.11 stations to obtain channel measurements that characterize the environment in which the stations operate. Measurements obtained with WLAN sensing are used to enable applications such as presence detection and gesture classification, among others as we describe in the Wi-Fi sensing section, an area in which the WBA issued a detailed white paper. The capabilities introduced in the 802.11 bf amendment will be evaluated in a set of deployment scenarios, including residential, enterprise, indoor, and outdoor, which are applicable to the main expected applications.

5.2 OpenRoaming and positioning with industry standards

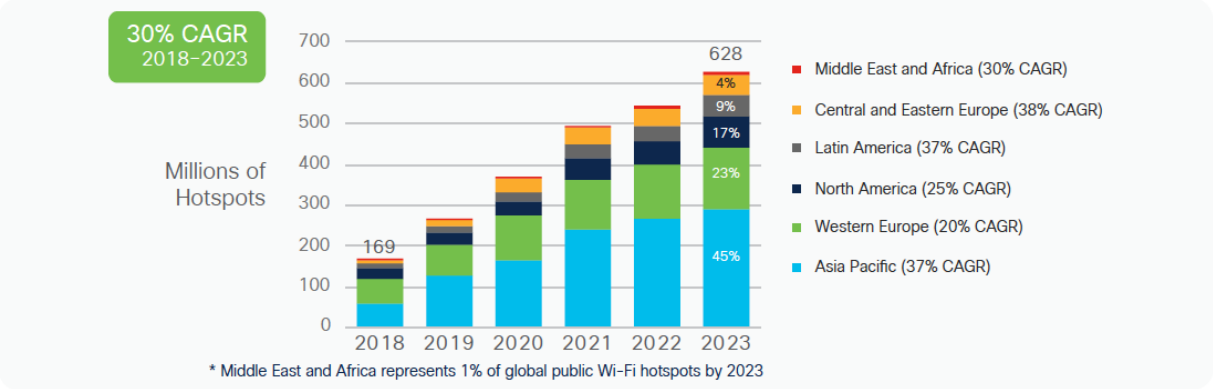
Public and guest Wi-Fi are exploding in numbers and popularity. Mobile operators have fine-tuned their ways to offload cellular traffic through curated public hot spots and providing their customers with seamless roaming offerings. Fixed and cable operators have extended their value offering by providing their fixed customers access to millions of hotspots. Businesses and brands are now using guest Wi-Fi as part of their omni strategy for marketing and sales.

[9] https://www.ieee802.org/11/Reports/802.11_Timelines.html

As we will see in later sections, there is much innovation happening in the public Wi-Fi space to harmonize and secure the connectivity journey to these hotspots while finding the right balance between convenience and privacy as MAC randomization becomes a default setting. This is increasingly important as Governments & public authorities are ever more concerned with cyber-crime and security over public Wi-Fi networks.

According to Cisco annual internet report published in February 2020 for which Maravedis provided the Wi-Fi related hotspot and homespot projections, there will be nearly 628 million global public Wi-Fi hotspots by 2023, up from 169 million in 2018 and global Wi-Fi 6 hotspots will grow 13-fold from 2020 to 2023 and will be 11% of all public Wi-Fi hotspots as shown in the figure below:

Figure 5: Hotspot projections



Source: Maravedis, Cisco Annual Internet Report, 2018–2023

However public Wi-Fi hotspots continue to be characterized by a lack of coordination, integration, security and an inconsistent on-boarding experience. Establishing multi-peer roaming agreements and standards between network providers has been a challenging process – making it difficult to scale relations and services. To materialize its vision of an integrated global Wi-Fi network, the WBA announced it took ownership from Cisco for OpenRoaming to make it a global standard for public Wi-Fi networks.

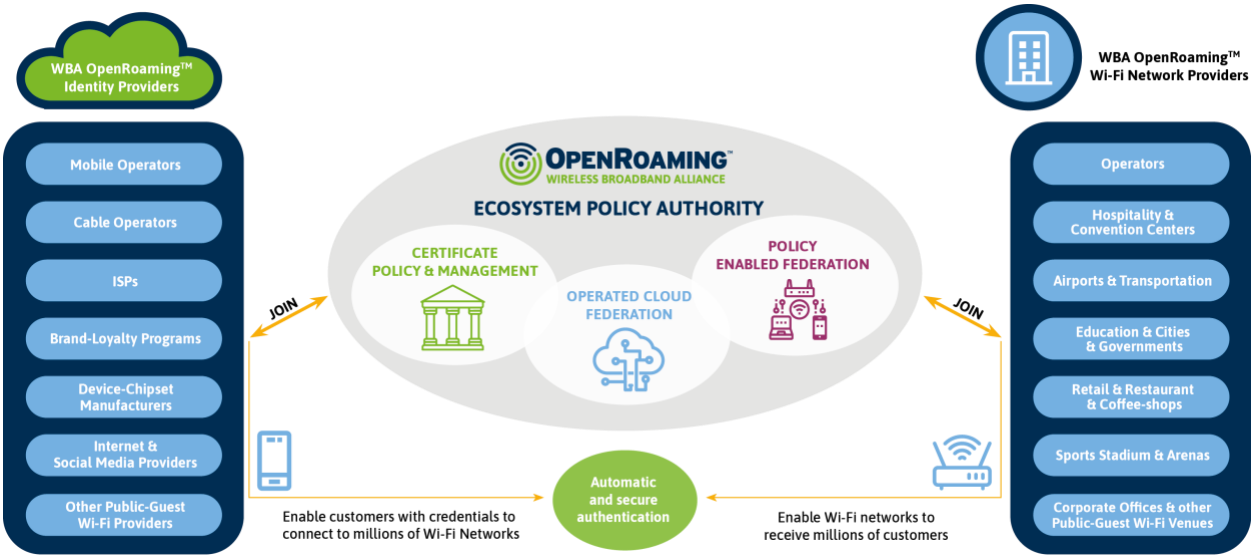
5.2.1 OpenRoaming

OpenRoaming is effectively a service, a product and a standard. It brings together a federation of trusted identity providers, allowing users to join any network managed by a federation member. The network is able to automatically authenticate devices by using established identity providers, such as a service provider, device manufacturer, cloud ID, or even loyalty memberships. Industry leaders including Boingo Wireless, Cisco, GlobalReach Technology, Intel, Korea Telekom, and others have pledged support for OpenRoaming.

OpenRoaming encompasses three key elements:

- Cloud federation: creates a federation of networks and identity providers to enable automatic roaming and user onboarding on Wi-Fi. Based on WBA's Wireless Roaming Intermediary eXchange (WRIX) standards to scale and facilitate different business models under a harmonized framework.
- Cyber Security: enables simple, secure and scalable Wi-Fi connections amongst different organizations that are part of WBA OpenRoaming. Allowing automatic and secure roaming between millions of networks, nationally and globally with secured interconnection and encrypted communications.
- Network automation: defines an automated roaming consortium codes framework (RCOI) to support policy provision on devices and networks. Organizations that manage a Wi-Fi CERTIFIED Passpoint®-enabled network may become part of the WBA OpenRoaming federation.

Figure 6: Elements of OpenRoaming



Source: WBA

WBA OpenRoaming automatically authenticates devices by using established identity providers, such as a service provider, device manufacturer, cloud ID or even loyalty memberships. WBA OpenRoaming allows users to roam between Wi-Fi networks seamlessly and securely without the use of splash pages or sign-in screens. For users who are customers of these 'identity providers' this means they will simply automatically connect. It is based upon a set of industry standards including WBA's Public Keying Infrastructure (PKI Radsec) for secure exchanges, Wireless Roaming Intermediary Exchange (WRiX), Wi-Fi Alliance's Wi-Fi CERTIFIED Passpoint®, amongst others, that provide enhanced security and enable the federation to scale quickly. With the WBA now in full control of the development, promotion and administration of OpenRoaming, the vision of a Wi-Fi global network is closer to becoming a reality as public-guest Wi-Fi connectivity barriers are removed and new business models are enabled.

One example of new business models is Orion Wi-Fi from Google, which is a platform that enables real time settlement between venue owners and network operators. As of today (Oct 2020), Orion Wi-Fi is interoperable with OpenRoaming and is a "pre-standard" implementation of OpenRoaming Settled for MVNOs to augment capacity.

The application of the OpenRoaming technology also extends beyond smartphones. Companies are already trialing OpenRoaming for autonomous and connected vehicles, and commercial developers are using OpenRoaming and location analytics tools to better understand how shoppers, patrons or employees are utilizing their space. For more details on OpenRoaming please refer to **OpenRoaming website**.

5.2.2 Industry roaming standards

The WBA has done a lot of work to facilitate seamless Wi-Fi roaming between the various stakeholders. As a reminder, its work includes the WRIX (Wireless Roaming Intermediary eXchange) which offers a modularized set of standard service specifications to facilitate commercial roaming between operators.

WRIX

This WBA standard includes WRIX-i (Interconnect), WRIX-l (Location) WRIX-d (Data Clearing) and WRIX-f (Financial Settlement). Each of these can be deployed by Visited Network Providers (VNPs) and Home Service Providers (HSPs) either in-house or through an intermediary WRIX service provider. The latest release of WRIX includes support for EAP authentication providing the transport and indicating which radius attributes to use. This specification recommends Network operators support the following EAP methods: EAPSIM, EAP-AKA, EAP-TLS, and EAP-TTLS. Other EAP methods may be supported transparently by the VNP but are not part of this specification.

The next generation for roaming

Key enablers of the seamless access and hand-off which makes a combined Wi-Fi/cellular offering attractive are the combination of the WRIX platform now enhanced with new capabilities detailed in the OpenRoaming section and Passpoint on the access point and device. These complementary standards emerged from the Wireless Broadband Alliance and the Wi-Fi Alliance respectively and have started to enjoy some adoption over the past two years. This has often gone hand-in-hand with Wi-Fi providers' moves to upgrade their infrastructure to fully carrier-class capabilities in order to support the same quality of experience (QoE) on Wi-Fi as on cellular.

On the device side, Release 2 of Passpoint introduced new capabilities that standardize the provisioning and lifecycle management of user credentials, such as how they are securely provisioned, stay valid, and are used in network selection and service policy enforcement. Release 2 also provided flexible and automatic remediation of client devices if subscriptions are updated or policy changed.

Release 3 of Passpoint, launched in April of 2019, introduced four new capabilities:

- Simplified online sign-up: drives a common provisioning methodology across vendors using a single SSID—or the "name of the network" as seen by users—to simplify deployment and configuration
- Venue-specific information: allows a device to obtain relevant local information about a venue to inform the user of available services provided by the operator
- Expanded enterprise-level security: supports WPA2™-Enterprise and next generation WPA3™-Enterprise for a strong level of authentication and connectivity
- Operator-specific policies: provides a streamlined solution for acceptance of terms and conditions when in public hotspots

5.2.3 Captive portals, big data and analytics

Public Wi-Fi networks rely upon short-term or temporary internet access and, as such, they commonly begin new connections by using a Captive Portal mini-browser (CPMB). A captive portal is a web page (also called a splash screen) displayed before the user can access the internet using a desktop or mobile device or can also be displayed after it has been authorized to access the internet. The portal also provides customized access to guest users through its splash page. The login data can be collected and repurposed for marketing purposes. Captive Portal controls data usage on the network and provides legal protection as users may be required to agree to terms and conditions set by the business or local authorities.

Each platform in the market has a native version that is "baked" into the operating system (OS). Commercial browsers like Firefox and Chrome include this support to detect and navigate the Captive Portal. This mode incorporates a web view that is pushed to the client and has limited capabilities for branding, advertising or other monetization tactics, and it also has limited capabilities for special authorization processes and paid access.

The WBA published a detailed white paper entitled **Captive Network Portal Standards** which describes existing use cases and issues with users' experience (UX), presents practices to consider and provides suggested guidelines for future features that can be adopted as a unified standard by client devices, client manufacturers and network hardware manufacturers.

The WBA work aims at providing support to the following issues:

- Bring awareness of CPMB limitations and the fragmented use cases across platforms and manufacturers
- Simplify the deployment and operation of free public Wi-Fi networks based on ad monetization
- Solve technological problems related to the organization of paid access through online payment
- Solve technological problems related to secure credential enrollment, such as extensible authentication protocol-transport layer security (EAP-TLS) for enterprise or Passpoint profiles
- Solve technological problems related to secondary, browser-based authorization gestures, such as push-based multifactor authentication (MFA) solutions, short message service (SMS) verification and fast identity online (FIDO2).

Beyond connectivity, Wi-Fi provides the opportunity to collect and monetize big data. The premise is that access to Wi-Fi is offered in exchange for the user data. While the question of how to use analytics to monetize the data is a critical one, the answer is not always straightforward. The Economist recently suggested that data is the new oil. The combination of increasing volumes of data and the emergence of machine learning is making the data easier to use and thus more valuable.

In terms of data privacy, it is important to provide Internet access that's complies with GDPR, especially for public Wi-Fi networks. The WBA is addressing technical challenges and identifying business strategies to engage with users via the captive portals to analyze user behavior, simplify the Wi-Fi roaming experience and generate insight of different monetization tactics while meeting the evolving regulatory and privacy measures that are taking place.

5.3 Wi-Fi Enablers

As Wi-Fi standards continue to evolve, new technologies are forming around the new hardware and enabling new use cases based on Wi-Fi.

5.3.1 Wi-Fi Sensing

In Wi-Fi Sensing, radio information obtained during signal processing is used to detect environmental changes caused by motion of objects, pets and people. In many cases, the primary information extracted from the radio for Wi-Fi Sensing is the channel frequency response and/or the received signal strength.

Computing this quantity is a typical function of any Wi-Fi receiver, as it enables a mechanism to compensate for the distortion introduced by the wireless channel. Wi-Fi Sensing builds upon these mechanisms, allowing any Wi-Fi device to perform sensing to learn about changes in the environment. The WBA has released a comprehensive white paper on this topic entitled "**Wi-Fi Sensing: a new technology emerges**" which provides an overview of the Wi-Fi Sensing technology, classifies the Wi-Fi Sensing use cases and requirements, and identifies the gaps in Wi-Fi standards that, if addressed, would lead to the enhancement of the technology and ease of deployment. Results of trials will be released during Q4 2020 and will be used for used to facilitate the release of product features and interoperability.

Using one or multiple collaborating Wi-Fi devices to sense the environment and detect motion has many benefits and enables many new business opportunities. Network providers can utilize information made available through sensing to provide a new set of services to customers. Hardware original equipment manufacturers (OEMs) and chipset vendors can add Wi-Fi sensing as a feature to differentiate products. Advances in signal processing and feature extraction algorithms produce even more detailed information. As Wi-Fi sensing technology matures, new and more complex use cases are enabled. Those use cases include home monitoring, elderly care, energy management, remote operator troubleshooting, wake-on-approach, gesture recognition and much more!

In order to make Wi-Fi Sensing a viable and ubiquitous technology, standardization is needed. Wi-Fi technology has long been recognized for creating an infrastructure in which backward compatibility, interoperability and scalability are fundamental. The current state of Wi-Fi Sensing relies on a single device in a network using proprietary interfaces and application programming interfaces (APIs), which ultimately limit or restrict the technology. There are new Wi-Fi Sensing capabilities that, if introduced into the standard, could improve efficiency and provide a catalyst for a new way in which Wi-Fi can be utilized. The WBA Wi-Fi Sensing group has compiled a series of recommended next steps to align industry players around enabling and expanding the reach of Wi-Fi Sensing technology in the marketplace and ultimately the IEEE has agreed to include Wi-Fi sensing in the next release of the standard.

We provide more insights of Wi-Fi sensing in the case study section of this report showcasing the deployment of Wi-Fi motion by Cognitive Systems.

5.3.2 Multi Access Point Solutions for In-Home Wi-Fi

Wi-Fi is the most widespread access technology to connect to the Internet within the home environment. To this end, operators have realized that they must own the Wi-Fi experience in the home, provide a quality of service expected by customers, and deliver an excellent Wi-Fi performance that is achieved by adopting best practices. In 2019 the WBA outlined in a **white paper** the current Wi-Fi landscape and the recommended industry guidelines and best practices for operators to achieve high-quality In-Home Wi-Fi. With building construction and layout having a material impact on coverage of Wi-Fi within a home, it was identified that homes are increasingly needing Wi-Fi networks comprising of multiple access points, which can bring the complexity of delivery and management, ultimately can impact performance and customer satisfaction.

There are different approaches and elements to solving the home Wi-Fi performance and coverage issues. Each vendor has its own approach and "secret sauce" comprised of algorithms sold in modules to perform the essential functions needed to solve the problem. However, most approaches recommend using multiple access points (MAP) especially in homes larger than 2000 square feet (200 square meters).

In this latest WBA program for in-home Wi-Fi, the WBA has divided its research initiative into functional areas of: operation, deployment, management & diagnostics. The WBA provides methods and challenges of installing Wi-Fi solutions in home environments, that consist of more than one access point, to enable whole home coverage and optimal performance a reader will find multi-AP functionality using the basket of Wi-Fi Alliance certifications and amendments along with recommendations from leading vendors that are active with the WBA.

5.3.3 Mesh Wi-Fi

Multi-access point (with or without mesh) networks seek to solve problems with coverage, largely within the home. Wireless mesh network devices (Mesh STAs) form links with one another, over which mesh paths can be established using an ad hoc mobile routing protocol. A key aspect of this architecture is the presence of multi-hop wireless links and routing of packets through other nodes towards the destination nodes.

In the traditional approach to mesh, hops introduce latency and reduce throughput. Several vendors seek to provide their own methodology to solve the issue of the coverage/capacity trade-off.
At the same time, mesh network gateways with a core gateway and either nodes or repeaters that go with it become increasingly available. In many cases, the package consumers get has three or four devices. The underlying principle is simple: a centralized gateway architecture with a multi-node mesh solution provides coverage throughout the home, with nodes placed, for instance, on an upstairs floor, the main floor, and maybe the garage or a basement, creating a resilient network. Therefore, if one node goes down, another one is available in the mesh. Solutions in the market deliver a network management layer with a unified control plane that allows for a dynamic resource management, self-optimizing to avoid/reduce interference, band steering, and load balancing.

Repeaters are becoming more and more popular as consumers become aware of new ways to improve their home coverage and experience by themselves or through their operators offering. In regions like Latin America, operators are seeking ways to lower the cost of pods to $40 from $80 a unit to include MAP in their home Wi-Fi offerings.

The Wi-Fi Alliance released its specification 1.0 for multi-access points (MAPs) in June 2018. The purpose of this specification was to enable interoperability across Wi-Fi access points (APs) from different vendors in a Wi-Fi network deployment comprising multiple APs. This specification defines the control protocols between Wi-Fi access points (APs), as well as the data objects necessary to enable onboarding, provisioning, control, and management of multiple APs. This specification also defines the mechanism to route traffic between Wi-Fi access points within the multi-AP network.

5.3.4 AR and VR

Virtual reality (VR)—where users wear a headset and are fully immersed in computer-generated environments—has been developed to meet design, marketing, education, training, and retail needs. Augmented reality (AR)—where computer images are superimposed onto the user's view of the real world through a screen or headset—is a more complex challenge, as it requires the software to "see" what is in front of it.

Most people's first experiences with VR and AR today are likely to be in gaming and entertainment. These applications require vast amounts of throughput and very low latencies, while the average home broadband delivers well under 100 megabits per second. Increasingly VR and AR use cases expand beyond entertainment, as educational experiences in VR and AR will continue to become increasingly common throughout 2020 and beyond especially with COVID-19. For now VR/AR is still mostly used for gaming in the home by early adopters.

In education, the immersive nature of VR means that pupils can engage with learning in fun new ways, and AR brings new flexibility to on-the-job training. Already, students can take a trip through time to visit the ancient Romans, or through space to experience conditions on other planets. But as the technology moves away from niche and becomes part of the fabric of everyday education, we're likely to see growth apart from simply providing "experiences," into solving problems with current education systems.

In business, AR/VR will see a lot of traction for solving real problems remotely. For example, in industrial environments, VR/AR will be used to monitor, inspect or repair complex, expensive or hazardous systems as illustrated in the Mettis case study in this report.

Wi-Fi 6 uses a combination of technologies—including OFDMA and 1024 QAM modulation—to improve spectral efficiency and boost not just speed and latency, but support for large numbers of devices in a confined area. In early trials, that capability has mainly been demonstrated in stadium environments, but device density is also important in the home, where many appliances and previously dumb devices will start to be connected to the home hub, and where several users may be consuming high quality video, gaming, or AR/VR at the same time. Still, no matter how wide the broadband pipe or powerful the access point, real performance must be reflected at the device level, and that performance can be degraded by a number of issues.

5.3.5 Artificial intelligence and machine learning

Artificial Intelligence (AI) and its favorite child, machine learning applied to Wi-Fi, promises to solve a significant problem—the cost of troubleshooting the many potential connection problems that can occur from many possible sources.

The intelligence and algorithms sit both at the edge on the device, as well as in the cloud where a large number of devices are feeding the machine-learning algorithm in a virtuous circle which makes it more accurate and valuable to anticipate and fix new problems.

Artificial Intelligence will allow the key characteristics of problems in the Wi-Fi network to be picked out from the big data that is the mass of traffic data, fix known problems directly, analyze trends in performance, and predict future requirements to avoid problems altogether in the future. This would allow the Wi-Fi network management system to constantly add to its knowledge base, extend its repertoire of known problems and solutions, and raise standards of user experience even higher.

AI can provide the analytics to make IT smarter, solve network issues faster, and make engineers more efficient. AI is particularly helpful with event correlation, which enables IT to not just fix a problem, but also quickly laser-in on the source of the problem so it doesn't keep happening. Once a baseline is established, AI can use anomaly detection and other features to avoid many common problems, such as DHCP, RADIUS, and security problems.

5.3.6 Wi-Fi & IoT

As the Internet of Things (IoT) gathers pace, there will be far greater demand for machine-to-machine (M2M) connections, many of them wireless. These will have even greater varieties of performance requirements, reflecting the vast number of different use cases that may emerge under the umbrella of IoT.

No single technology will address all these requirements, and there is a long list of wireless IoT protocols. This is likely to consolidate over time, but there will certainly be a need for at least one open, standardized technology for several key IoT profiles. These profiles vary by the degree to which they support:

- Ultra-low-power vs moderate power
- Long-range vs local range vs very short range
- Low data rate vs moderate data rate
- Ultra-low latency vs low latency
- Critical availability vs standard availability
- Unlicensed vs licensed spectrum

(Note: Some proprietary protocols are likely to continue to be used in specialist environments like public safety or railways.)

Wi-Fi has the advantage of addressing a very wide variety of profiles because of the proliferation of its family of standards. This means it will play a role in most IoT environments, alone or interworking with more specialized protocols, or with cellular. Some IoT applications, such as vehicular services, or video-based apps like connected security cameras, will need the bandwidth of the wireless broadband network, implemented to enable other requirements such as low latency (In critical environments this may take place in a private network or slice).

Wi-Fi 6 is uniquely placed to support broadband and narrowband IoT applications from a common platform that can work at varying levels of power consumption and signal range. Wi-Fi 6 introduces a new feature called Target Wait Time (TWT) that allows access points to negotiate with sensors and devices to agree when they should wake up to transmit data. As a result, devices can sit quietly in a deep sleep for long periods of time, significantly reducing current power consumption, which in turn increases battery life. This could extend the battery's lifespan to multiple years, allowing sensors to collect data in the field for much longer periods.

Wi-Fi 6 also comes equipped with orthogonal frequency-division multiple access (OFDMA), which enables bandwidth within channels to be segmented, enabling multiple devices to receive data in the same time frame. Like other Wi-Fi 6 features, OFDMA reduces power consumption. The benefits here are twofold. With lower power consumption, developers can create smaller sensors with even smaller batteries. Alternatively, they could simply choose to keep the battery as is while benefiting from the reduction in power consumption, improving the sensor's longevity. As IoT expands and more sensors are deployed (think automotive and other widespread applications), the tech would be impossible to maintain if the batteries needed to be changed every month.

LPWAN

Low power wide area network (LPWAN) connections are a particularly interesting example of the need for multiple technologies for IoT, potentially with Wi-Fi, the most ubiquitously installed in networks and devices, as a unifying link. For example smart meters in the home or the enterprise can be backhauled using Wi-Fi .This is the main area, along with the well-established WPAN standards, where there are non-Wi-Fi technologies operating at scale in an unlicensed spectrum. Wi-Fi and LoRaWAN are two of the most adopted unlicensed technologies and together they address a large proportion of IoT use cases. The approaches for these technologies are disrupting private-public business models and also enabling participation in 5G success. The WBA and the LoRa Alliance have published **a joint white paper** to demonstrate how these two widely deployed IoT Connectivity technologies can be utilized in tandem to effectively support a vast array of use cases. Since then both organizations have focused on a series of trials, the first phase of which has been published in October.

While it is important to have a diversity of technologies to support the widely varying requirements of IoT, it is also essential that these technologies can interoperate seamlessly to avoid creating islands of communication, as these would severely restrict the ability to create a broad platform in which different applications can exchange data easily.

5.3.7 Multi-Access Edge Computing (MEC)

Reflecting the natural evolution of mobile Base Stations and the Radio Access Network (RAN), Multi-access Edge Computing (MEC) first emerged as an ETSI Industry Specifications Group (ISG) in early 2016. Originally defined as Mobile Edge Computing, the descriptor was updated in September, of that year, to reflect the fact that the same concepts described in the early requirements were relevant to fixed wireless, Wi-Fi and wireline access.

Multi-Access Edge Computing infrastructures allow the implementation of software-only mobile functions or Software-as-a-Service (SaaS) applications that operate entirely within a standardized virtualization platform which is deployed in or close to the network edge.

MEC is a natural development in the evolution of mobile base stations and the convergence of IT and telecommunications networking. Multi-access Edge Computing will enable new vertical business segments and services for consumers and enterprise customers. Use cases include:

- video analytics
- location services
- Internet of Things (IoT)
- augmented reality
- optimized local content distribution and
- data caching

WBA's 5G Project identified the evolution of Mobile Edge Computing towards Multi-Access Edge Computing (MEC) to better reflect noncellular operators' requirements, including Wi-Fi. MEC Computing provides an IT service environment and cloud computing capabilities at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to subscribers. The aim is to reduce latency, ensure highly efficient network operation and service delivery, and offer an improved user experience.

WBA is taking the leading role to define a set of services for Wi-Fi and working with ETSI MEC Industry Specification Group (ISG) to ensure that the MEC APIs are suitable for supporting Wi-Fi use cases. In this project, the WBA will include the analysis of the use cases that necessitate the exposure of radio network related information from Wi-Fi access networks, and possible definition of an Radio Network Information Service (RNIS)API for supporting Wi-Fi use cases. The industry will benefit from the finding of issues associated with exposing and/or normalizing different delays and/or averaging algorithms which will likely need cross industry analysis, including:

- Practical MEC objective and deliverable
- Analysis of the use cases that necessitate the exposure of radio network related information from Wi-Fi access networks
- Recommendation on the MEC arena, setting the scene for future work
- Possible definition of an RNIS API for supporting Wi-Fi use cases

5.4 Wi-Fi 6 & 5G – Convergence & key milestones

With the development of Wi-Fi 6, and now the roadmap to Wi-Fi 7, the capabilities of Wi-Fi technologies are coming closer than ever before to those of the cellular platform. This is a result of the expanding requirements for wireless connectivity, and the fact that both major wireless standards are extending their remit in order to address these requirements, and thus broaden the business model for service providers.

So, in the first decade of the century, 2G and 3G were primarily wide area, highly mobile, outdoor and voice-centric; while Wi-Fi primarily supported local area, ambulatory and data-centric applications, with a focus on indoor usage. And of course, there was no overlap in the type of spectrum the technologies occupied. The overlap in capabilities was limited, and to some extent the two technologies became complementary, especially in terms of consumers' usage of both connections for different purposes.

In the past few years, the distinctions between the two platforms have blurred considerably. There are implementations of Wi-Fi that reach far longer distances than previously, while Voice over Wi-Fi and enhanced mobile hand-off support are examples of innovations that have made Wi-Fi look more like cellular. Conversely, the cellular networks have taken their lead from Wi-Fi in areas such as very high capacity broadband and support for dense indoor or outdoor hotzones. In the Wi-Fi 6/5G era, the technologies are becoming even closer.

The converging scope of the two families of standards inevitably means that their deployers and ecosystems are also coming closer. This could result in two outcomes – a clash between two communities chasing the same business; or a deepening focus on the two technologies being deployed in a complementary fashion, allowing service providers to take advantage of the strengths of both, in order to achieve the optimal experience for users and enterprises, while leveraging the scale of two ecosystems to maximize innovation, device availability and cost/performance optimization.

The WBA has clearly placed its weight behind the second outcome, seeking to drive cooperation, coexistence and, where appropriate, convergence with 5G NR, not just in terms of technical specifications, but in terms of deployment models and ecosystem alignments. Its stance was clearly set out in its landmark white paper, RAN Convergence[10], published with the NGMN. This argued powerfully for the commercial benefits of convergence, in terms of specific use cases where the optimal solution would be an integrated approach.

It has since built on that foundational paper to work with members to define requirements and use cases in greater detail and strengthen the relationships with key partners which will help to drive convergence forward in a practical, use case-centric way. It places the emphasis firmly on 'how' to integrate the networks in order to enable new commercial opportunities in residential, hotspot and enterprise environments (see section 5).

[10]https://www.ngmn.org/publications/all-downloads.html?tx_news_pi1%5Bnews%5D=722&cHash=70783520ca9bf1cb376f5b5d54e44677

In 2020, despite the impact of the pandemic on standards development and industry cooperation processes, there has been significant progress to meet the requirements set out in that white paper. Many powerful players within the Wi-Fi community have developed technologies that bring Wi-Fi and 5G closer together at various layers from silicon to core and policy control; and the latest set of 3GPP 5G standards, Release 16, builds on progress already made in Release 15 (the first 5G standards) to address Wi-Fi integration in the core and RAN. The IEEE, Wi-Fi Alliance and 3GPP have increasingly developed standard interfaces to support interconnection, and links to a common core for authentication, policy control, traffic shaping and back office services.

Existing developments:

- The Passpoint-improved Wi-Fi network discovery and selection and supported SIM-based log-in and seamless authentication across Wi-Fi and cellular.
- The 3GPP's access network discovery and selection function (ANDSF) was developed as an option for the 4G evolved packet core (EPC), as an enabler of intelligent network selection between 3GPP and non-3GPP access networks. It is also supported and evolved in 5G EPC and fully 5G Core Network (5G CN) standards.
- The 3GPP has developed hand-off and interworking specifications—such as TWAG (Trusted Wireless Access Gateway) and non-trusted access.

5G era developments:

ANDSF and TWAG have been criticized for being complex to deploy and have had limited adoption by the cellular community, while other solutions required specific architecture designs and device implementations on the Wi-Fi side, adding to cost and complexity. VoWiFi and non-seamless offload have been the main integration technologies deployed at scale in the 4G era.

There is optimism that this will change in the 5G era, in which convergence with Wi-Fi will be more important to support emerging use cases in environments such as smart factories, driving the refinement and uptake of convergence enablers. Critically, the 5G core has been specified from the start to be access-agnostic and will commonly be deployed in cloud-native technology, which will simplify the configuration of multi-access systems including network slicing. And there is a broader transition, from Release 15, from node-based structural network design to functional design, in the access as well as the core. Both of these aim to support access-neutral architectures, in which devices can connect via any connectivity type seamlessly, and in which networks are configured around software-based programmable functions, not physical nodes.

3GPP Releases 15 and 16 will continue to support access to the 5G core for trusted and non-trusted 5G access networks, and the new standards have focused on improving secure transport for the 5G control plane and data plane over non-3GPP access. Key specifications include:

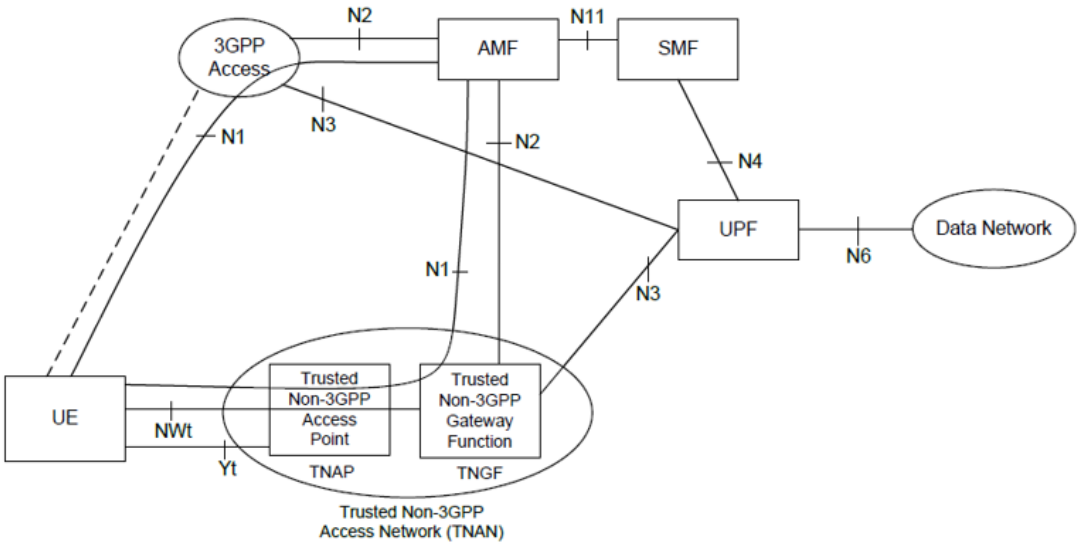
Release 15

- Further integration of untrusted Wi-Fi access.
- The key gateway interface is Non-3GPP Inter-Working Function (N3IWF). This allows 5G NR and non-3GPP access to link to the 5G core using the same N3 user plane interface and the same N2 control plane interface, with the N3IWF terminating N2 and N3 interfaces if non-3GPP access is in play.

Release 16

- Integration of access for trusted Wi-Fi and wireline networks, in elements such as residential or enterprise gateways.
- The role of N3IWF will be taken by Trusted WLAN Gateway Function (TNGF) in Release 16. This exposes the N2/N3 interfaces and enables the UE to connect to the 5G Core over the Wi-Fi access
- Specification of Access Traffic Steering, Switching and Splitting (ATSSS), which enables data sessions to run over one or more concurrent accesses.

Figure 7: Trusted Wi-Fi integration in 5G system architecture, Release 16



Source: 3GPP TS 23.716 clause 7.1.2

6 Role of Wi-Fi among other radio access technologies & 5G

6.1 Wi-Fi alignment with 5G and 5G NRu

As noted in section 4, there is increasing commonality in the technical capabilities and the targeted use cases for Wi-Fi 6 (and in future, Wi-Fi 7), and the 3GPP's 5G standards. In the latter case, Releases 15 and 16 of the 5G standards for New Radio and 5G Core Network (5GCN) are now finalized, despite a few months' delay incurred because of pandemic disruption. Release 17 will follow in 2021. Release 16 is the most significant set of 3GPP standards to date in integrating Wi-Fi into the cellular platform as a fully trusted access, almost on an equal footing with 4G/5G. For its part, the Wi-Fi community, led by the WBA and the Wi-Fi Alliance, has been investing significant effort into aligning Wi-Fi 6 with 5G's capabilities and ensuring the two can work in a harmonious and complementary fashion.

This alignment goes well beyond bare specs, of course. The rising recognition that Wi-Fi 6 and 5G NR are complementary in demanding environments such as manufacturing, campus networks and cities is driving development of convergence, and a broader alignment of capabilities and roadmaps, with a view to achieving common platforms to support future developments such as multi-network slicing. In this environment, a virtual network slice would be automatically configured for a particular service or user, instantly calling up all the relevant functionality, and relying on the best combination of connectivity for the job, whether Wi-Fi, 5G or wireline.

The full vision of network slicing will take some years to realize but is worth mentioning as a good example of the ultimate end-game of converged environments in which all available connectivity can be harnessed seamlessly and optimized for a particular task.

This will help to support convergence and coexistence between licensed and unlicensed spectrum technologies, which are increasingly important considerations for operators' business objectives. In this year's WBA survey 52% of respondents said convergence was critical or very important to their business strategy, and 57% said the same about coexistence (see Chapter 9.2).

Achieving convergence will be helped by the increasingly common cause that stakeholders in the Wi-Fi and cellular markets are adopting. This is leading to vendors developing common, access-neutral platforms and controllers, and chip designers integrating multiple radios in the most cost- and power-efficient way. It is also driving alignment between the Wi-Fi and 5G NR roadmaps at every layer, from chips to RAN to core.

It is also important that 5G New Radio Unlicensed (5G NRu) is being specified, in 3GPP Releases 16 and 17, to ensure coexistence with Wi-Fi and other technologies, where they may target the same bands, such as 6 GHz. Unlike unlicensed 5G technologies, which were defined late in the day and with Wi-Fi coexistence added retrospectively, the 5G work has focused from the start on avoiding harmful interference or other impacts for Wi-Fi.

According to 3GPP, the main safeguards being baked into specs and requirements are that any 5G device in unlicensed spectrum must:

- Comply with lower power emission requirements that limit signal propagation and in-band interference, constraining the coverage area
- Share spectrum with incumbent users, adding technical complexity to 5G terminals so that all devices can coexist
- Make use of Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC) techniques to facilitate coexistence, like Wi-Fi devices do today
- Likely adopt the LTE or 4G coexistence techniques, such as Listen Before Talk (LBT), to work side-by-side with Wi-Fi devices

These cooperations are happening because both communities are targeting the requirements of a whole new breed of wireless applications, such as factory automation or virtual reality entertainment, which would previously have required wireline connections, or would not have existed at all. That means that both Wi-Fi 6/7 and 5G New Radio (NR) have developed capabilities such as very low latency response, which are necessary for such use cases. That has led to the two platforms aligning far more closely in terms of their key capabilities, and of course, the emergence of implementations of 4G for unlicensed or shared spectrum bands has further blurred the lines – 5G NR standards for shared spectrum were ratified in the most recent set of 3GPP radio specifications, Release 16.

As stated previously, this similarity of commercial purpose could put the Wi-Fi and cellular communities into competition with one another, but in fact there is broad recognition – strongly encouraged by the WBA, NGMN, Broadband Forum and other influential partners – that the new use cases are so demanding that they will often be optimally supported by a combination of technologies with different key strengths.

Crucial to making it relatively simple and cost-effective to deploy multi-RAT networks is the fact that the 5G Core Network (5GCN) was devised from the start to be access-neutral. That means that, when cellular operators start to deploy 5G Standalone networks, which require the 5GCN, from 2020, the ability to integrate non-cellular access will be in-built. It will be further simplified by the cloud-native nature of most 5G core deployments. These cores will be fully programmable and based on containerized functions that can be configured and reconfigured flexibly, allowing a Wi-Fi access, for instance, to be added quickly and all its requirements supported automatically.

The 5G standards also specify a more flexible authentication and policy control framework than existing for 4G, while Wi-Fi is also included from day one into architectures devised for central 5G concepts such as slicing and edge computing. For instance, the initial cellular focus on ETSI's Mobile Edge Computing (MEC) platform was broadened to include other access, and the initiative renamed Multi-access Edge Computing.

So, this is not just a question of allowing two separate wireless networks to interoperate smoothly. It is about the two communities behind these standards developing a common vision, targeting similar requirements – such as very low latency, time-sensitive networking (TSN), or critical availability – in complementary rather than competing ways.

Many vendors are contributing their own ways to align and integrate the networks. For instance, Nokia has developed the Beacon 6 Wi-Fi/5G FWA (fixed wireless access) gateway, which works by offloading 5G traffic to Wi-Fi and fiber networks. Beacon 6 combines the strengths of fiber-to-the-home and 5G using Nokia's new low latency Lightspan MF-2 fiber access node, and harnesses developments in Wi-Fi 6 to allow service providers to offload 5G traffic in the home seamlessly.

As detailed above in 5.2.1, many vendors and other stakeholders have pledged support for OpenRoaming, which is both a service, a product and a standard. It brings together a federation of trusted identity providers, allowing users to join any network managed by a federation member. The network is able to automatically authenticate devices by using established identity providers, such as a service provider, device manufacturer, cloud ID, or even loyalty memberships. Industry leaders including Boingo Wireless, Cisco, GlobalReach Technology, Intel, Korea Telekom, and others have pledged support for OpenRoaming and are in the process of trialing and deploying commercial implementations.

Aruba HPE recently launched the Aruba Air Slice, which allows enterprises to segment their Wi-Fi networks and assign different services to different channels, to improve quality of service; and Aruba Air Pass, which support seamless hand-off between cellular and Wi-Fi networks at the enterprise edge. This allows enterprises to leverage existing Wi-Fi infrastructure to support multi-network experiences, with radio resources dynamically allocated depending on the needs of a particular task.

Many vendors agree that edge computing is a particularly strong driver for convergence between Wi-Fi and 5G, as the kind of applications that are being developed for the enterprise edge often require a combination of challenging wireless connectivity requirements such as very low latency and very high security.

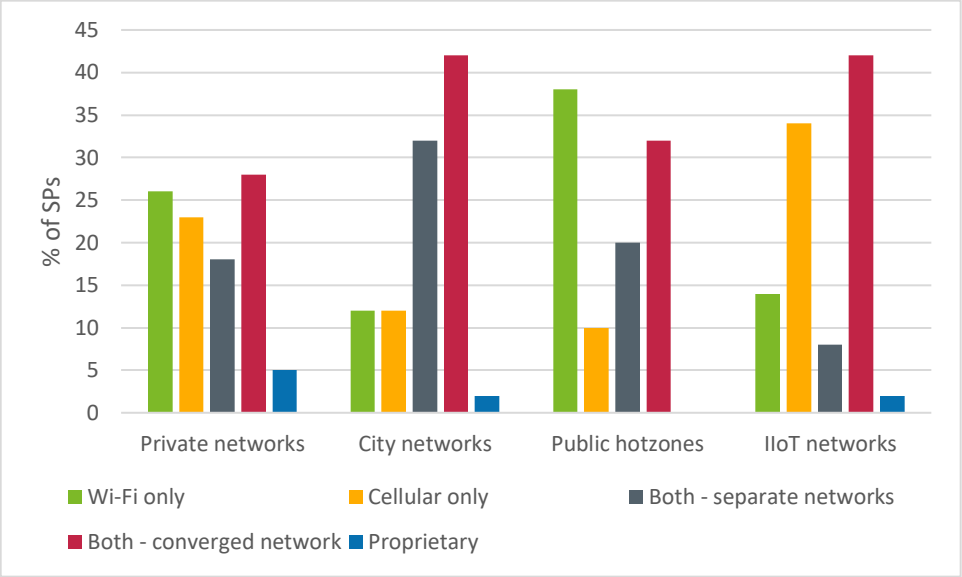
Indeed, very low latency is perhaps the best example of how the capabilities of Wi-Fi 6 and 5G standards are increasingly in alignment. That may make the technologies competitive in some scenarios, but more importantly for deployers, it means they can adopt an access-neutral strategy that supports the best balance of features, costs and spectrum, in the confidence that both access options can support key requirements such as low latency and high availability.

This was demonstrated in March 2020 when the WBA held a first phase of Wi-Fi 6E trials, enabled by WBA members, Broadcom and Intel. These tests showed that use of the 6 GHz band could support the low latency required for the demanding use cases identified under the 5G MMTC (massive machine-type communications) category such as mobile gaming, virtual and augmented reality (VR/AR) applications, and low latency Industrial IoT. During the trials involving Broadcom and Intel, two millisecond latencies were consistently achieved, approaching the levels promised for 5G.

As WBA director Bruno Tomas said in an interview with RCR Wireless: "Finally, there is a new interface that allows the carrier to really say that Wi-Fi is just one more radio in their aggregate strategy. When you attach to those networks, you are using all the services you would use in 5G on the Wi-Fi connection."

A survey by Rethink Technology Research, conducted in July 2020, indicates that service providers are also moving to a multi-RAT approach, along with the supplier ecosystem and standards organizations.

Figure 8: Preferred approach to deploy new or expanded wireless networks by end of 2023



Source: Rethink survey of 96 service providers (MNOs, Wi-Fi SPs, enterprise operators etc)

This survey sees a dual-network approach being favored by 74% of service providers in the city environment, 46% for private networks, 52% for public hotzones, and 50% for Industrial IoT networks. In all cases, more operators are interested in a fully converged network with common controllers or core, rather than running two networks separately with offload and handover.

6.2 Role of Wi-Fi in the IoT space

The emergence of the Internet of Things (IoT) will be an important driver, in the 2020s, for demand of wireless connectivity. This will need to be ubiquitous and support many different capabilities to accommodate the huge diversity of IoT applications and services. There will be a myriad of different combinations of high or low bandwidth, low power or ultra-low power, low latency or ultra-low latency, and so on. One generic network will not be a viable way to support the IoT, especially in industrial environments such as the Industry 4.0 platforms, or in smart cities. A combination of wireless technologies will be required, which can be mixed and matched flexibly, often via common controllers, in order to deliver the optimal cost and capabilities for a particular use case.

Wi-Fi has an important role to play in IoT. It has an incumbent role in IoT applications for the smart home, the smart city and many enterprise environments because it is already so widely installed and supported in devices. The challenge has been to expand the capabilities of Wi-Fi wireless broadband systems in order to support other requirements such as very low latency, while retaining compatibility with the huge Wi-Fi device and gateway installed base.

This is done in three ways – by adding new capabilities to the Wi-Fi standards themselves, with developments like HaLow; by ensuring interoperability and integration with cellular standards such as NB-IoT and 5G (see above); and by interworking with other IoT-specific standards that have achieved some critical mass for certain markets, in unlicensed spectrum.

Both the Wi-Fi and 5G platforms have a parallel set of specifications for wireless broadband, and for low power, wide area networks (LPWANs), which mainly support IoT and machine-to-machine services. For the latter, Wi-Fi has HaLow (based on the 802.11ah standard) and 802.11 ba for low power IoT applications, and 3GPP has the 4G-based LTE-M and NB-IoT. There are other LPWAN options in unlicensed spectrum too, such as LoRaWAN, and in many scenarios, multiple connectivity options may work together, connected by common gateways. HaLow is an example of a technology which can extend the capabilities of the core Wi-Fi platform when applications require particularly low power, low bandwidth and long range connections, but still allows deployers to remain within the 802.11/Wi-Fi framework for components and APIs.

In both cases, the LPWANs will have a migration path to new generation successors. For instance, there will be a full 5G implementation of NB-IoT in Release 17, but for the next few years at least, most operators will support 4G-based LPWANs alongside 5G broadband networks, integrating them in the core. They can take the same approach to integrate HaLow (or other LPWAN options) with 5G, especially for operators which do not plan to deploy LTE-M or NB-IoT.

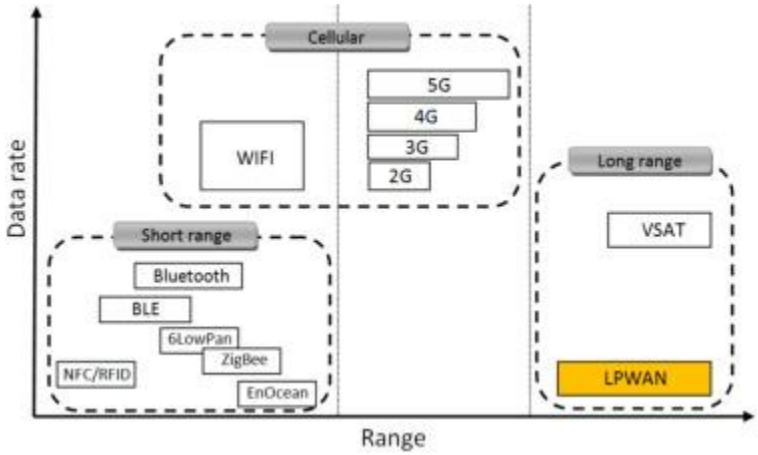
In Wi-Fi and 4G/5G, operators can deploy both broadband and LPWAN services using the same underlying radio technologies, and they can increasingly combine Wi-Fi and cellular options too. The other LPWAN technologies are specific to that environment, so are either deployed as dedicated networks for M2M services or have to rely on interworking with Wi-Fi or cellular for applications that require both broadband and low power/low bandwidth tasks.

The main independent LPWAN contenders are LoRaWAN and Sigfox. Both secured customers at an earlier stage than the 4G or HaLow solutions, so have a certain level of incumbency in some markets. This is particularly true of LoRaWAN, which supports a broader set of use cases than Sigfox and is designed to be deployed and managed by operators in a similar way to carrier Wi-Fi and 5G (Sigfox is mainly offered as a managed service for specific applications such as smart metering).

The wide area IoT network market is at a very early stage, and in many cases the early deployments are largely to upgrade existing 2G-based M2M systems. But there is significant growth expected - a recent report from Valuates estimates that the LPWAN market will grow in value from $440m in 2018 to

$6.44bn by the end of 2025, representing a CAGR of 46.5%.[11] Most analyses of this market agree that it will be very different from the traditional wireless broadband world – multiple access networks will be used from day one, not primarily to expand capacity, but to support the myriad different services and associated connectivity requirements that the IoT will drive. Just as domestic IoT applications in the smart home already rely on Wi-Fi interworking with several other standards, including Bluetooth Low Energy (BLE), ZigBee and cellular, so many industrial and public LPWANs will be based on intelligent coordination of several networks, with Wi-Fi 6 and HaLow both playing an important role.

Figure 9: Mapping of IoT connectivity technologies.



Source: Science Direct[12]

6.3 How does Wi-Fi play with CBRS and when should each be used?

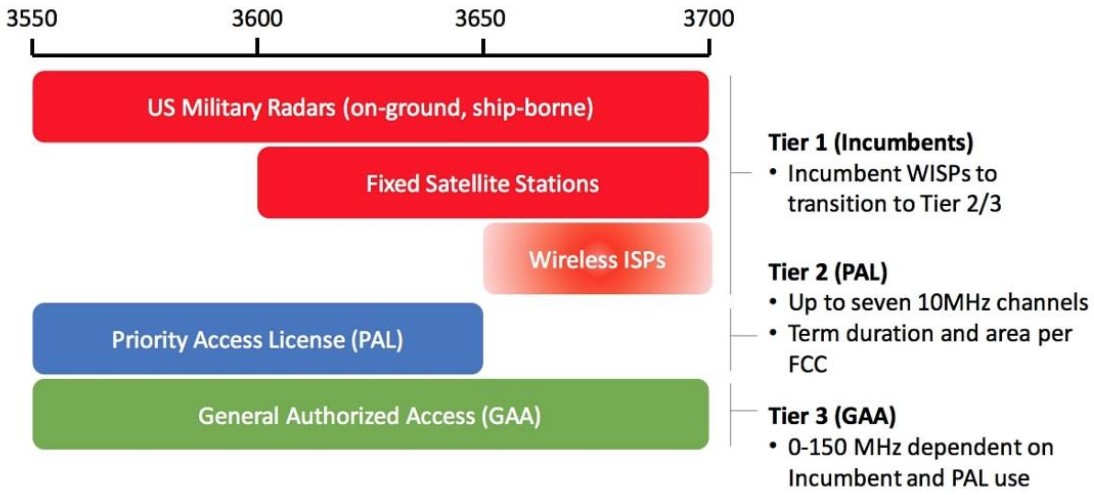
One obvious area of convergence and alignment between Wi-Fi and 5G is in spectrum. The days when Wi-Fi lived in unlicensed spectrum, and cellular in licensed, ended when standards were devised for LTE to run in license-exempt bands, primarily 5 GHz. There were three main variations – LTE-Unlicensed, LTE Licensed Assisted Access (LAA), and MulteFire (the last of these significant for not requiring an anchor in licensed spectrum, meaning it could be deployed by non-MNOs). There was considerable tension between the Wi-Fi and cellular industries amid fears that LTE would cause congestion and interference in bands where Wi-Fi was well-established. However, uptake of the unlicensed LTE systems has so far been very limited – in most cases, MNOs have found more mature solutions in licensed bands when they have needed additional downlink capacity; and non-MNOs have mainly stayed with Wi-Fi.

[11] https://www.prnewswire.com/news-releases/low-power-wide-area-network-lpwan-market-size-is-projected-to-reach-6440-million-by-2025--valuates-reports-301113207.html
[12] https://www.sciencedirect.com/science/article/pii/S2405959517302953

That situation will change again with the emergence of flexible spectrum licensing schemes such as the USA's CBRS (Citizens' Band Radio System), in the 3.5 GHz band (3.55 GHz to 3.7 GHz). CBRS is a three-tiered system managed by Spectrum Access Systems (SAS) based on geolocation databases and other tools for dynamically allocating channels to users. The SAS ensures that priority goes to those occupying the top two tiers – incumbent federal users, and below them, holders of licenses (priority access licenses or PALs). The auction for the PALs has just concluded and is expected to result in the major MNOs adding to their spectrum assets, but also in some new entrants and wireless ISPs securing spectrum.

If users from these two tiers are not using all the available channels, the SAS will allocate them to users from the third tier, general authorized access (GAA), and there is also a band of spectrum dedicated to GAA use. GAA aims to provide superior protection from interference and congestion than fully unlicensed bands such as 2.4 GHz, because of the SAS system, but it does effectively add a new source of unlicensed bandwidth to the market.

Figure 10: he FCC 3 Tier Shared Spectrum Licensing Structure



Source: FCC

It is a sign of the new spirit of convergence in the wireless market that the tensions that accompanied the emergence of LTE-U are largely absent now that the first CBRS GAA devices and services are going live in the USA. The cellular community has shifted its development and lobbying efforts away from sharing 5 GHz with Wi-Fi (and others), to focusing on unlicensed or lightly licensed bands where 4G and 5G can be the primary users. Likewise, discussion of Wi-Fi expanding into CBRS has largely faded and the Wi-Fi industry is heavily focused on the 6 GHz extension band (see section 7.1). There are some calls by MNOs for regulators to allocate some 6 GHz spectrum for 5G, and the 3GPP has approved 6 GHz as a band for unlicensed 5G, but in most cases, the consensus is that the 5G ecosystem should focus globally on extensions to the C-band spectrum around 3.5 GHz to 4.2 GHz, and on encouraging other countries to emulate the USA in adopting flexible schemes that can stimulate 5G adoption (see sections 7.2 and 7.3).

The result is that both the major wireless technologies are receiving a significant new allocation of open spectrum (in which they are the primary users – regulation is generally technology neutral). In both cases, the first moves have come from the USA, but are likely to be emulated in many other major markets. One result is that, for the first time, cellular technologies are likely to be deployed at scale in general access spectrum. Initially, 4G will be the only candidate for CBRS deployment, since the standards for 5G New Radio Unlicensed (see section 7.3) have only just been finalized and will not appear in significant numbers of devices and equipment until the second half of 2021. But 5G devices for licensed CBRS spectrum are already ready to launch, so the timescale to support 5G in CBRS GAA is likely to be short, assuming there is sufficient operator demand.

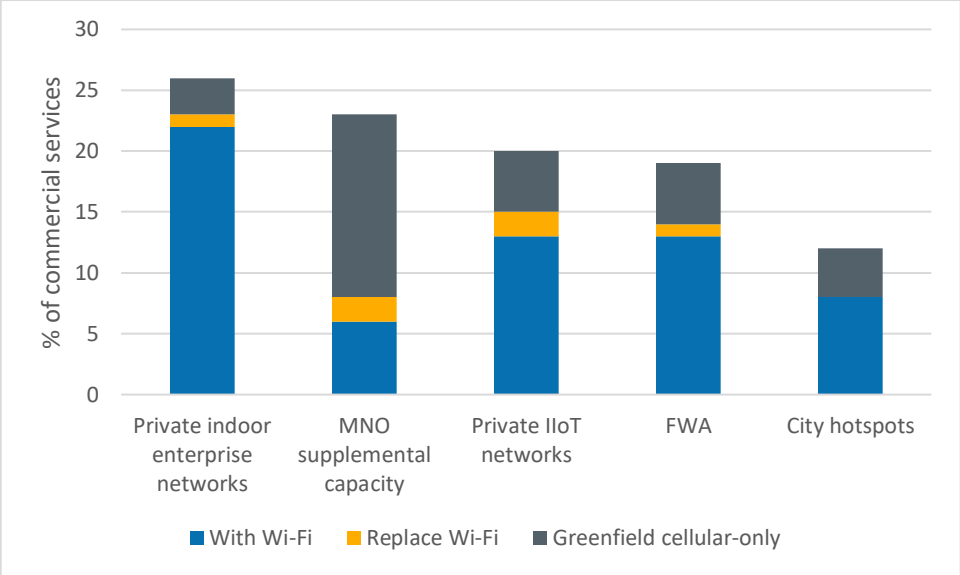
That demand looks set to come from a variety of quarters, if the early trials and deployments of 4G CBRS technology (branded OnGo by the CBRS Alliance) are a guide. Between January 2020, when the FCC authorized full commercial deployments, and the end of June 2020, 79 models of CBRS base stations had been approved, along with 80 client devices, and there are five SAS administrators in place. The first commercial deployments, according to the CBRS Alliance, have fallen into three main categories:

- Private networks deployed by enterprise service providers, mainly in the education, healthcare and manufacturing sectors
- Supplemental downlink capacity for MNOs' licensed 4G networks
- Fixed wireless access (FWA) services (new or expanded) provided by WISPs, especially in rural areas

A July 2020 survey and model by Rethink Technology Research indicates that the top five categories of deployment in GAA CBRS spectrum up to the end of 2023 will be private networks for indoor enterprise environments; additional wide area capacity for MNO licensed networks; private networks for industrial IoT applications (indoor or outdoor); fixed wireless access (FWA); and urban public hotspots. Figure 11 shows the degree to which these deployments will take place alongside Wi-Fi, with the service provider expecting to converge the CBRS connectivity with existing or new Wi-Fi networks.

Launch of commercial services in the top 5 categories in CBRS GAA spectrum between 2020 and end of 2023 – relationship with Wi-Fi. Rethink model based on survey of 92 US-based service providers.

Figure 11: Role of Wi-Fi in CBRS deployments



Source: Rethink Research

A dual-connectivity model is overwhelmingly favored, especially by non-MNOs building private, enterprise or WISP networks. When asked for the advantages of having Wi-Fi as well as CBRS, the leading answers from the survey respondents were:

- the prevalence of Wi-Fi devices
- the opportunity to maximize capacity by using both 5 GHz and 3.5 GHz spectrum
- specific capabilities of Wi-Fi 6 including very high data rates
- superior support for multi-operator services
- the improved total cost of ownership.

On the latter point, TCO efficiencies can be achieved by using existing Wi-Fi, where that exists, rather than serving all requirements with a new CBRS network; and even where the network is fully greenfield, as in some IIoT scenarios, many respondents believe there will be superior cost of capacity if they can tap into more spectrum bands, and into the huge Wi-Fi ecosystem (assuming that embraces dual CBRS/Wi-Fi products).

So why have CBRS at all? The answer is clear for an MNO, which will welcome the opportunity to add to its overall 4G or 5G capacity with unlicensed spectrum. At least with current technology, interoperability will be more seamless if it uses a single radio platform rather than Wi-Fi offload, although as access-neutral 5G cores become deployed, the distinction will blur.

For non-MNOs such as private network operators, enterprises, neutral hosts and WISPs, the survey showed that CBRS was expected to add or enhance the following capabilities, improving overall performance and quality of service, especially in business-critical environments:

- Full, high speed mobility with intelligent traffic management
- Strong support for indoor/outdoor environments such as campuses
- Highly developed quality of service parameters and mechanisms
- Simplified handover to an MNO's network for wide area coverage and roaming

6.4 Private LTE aligned with Wi-Fi

These findings clearly show that CBRS is regarded as a complement to, not a replacement for, Wi-Fi in its most disruptive environment, private networks. That leads to the wider question of private networks in any country or band. As flexible spectrum options emerge for 4G and 5G around the world, will there be a similarly convergence-centric approach from service providers? And while the advantages of having Wi-Fi 6 alongside 5G are clearly articulated by the CBRS respondents, in which scenarios are there similar advantages to having cellular technology rather than Wi-Fi alone?

Private cellular networks have traditionally existed mainly for very critical applications, using dedicated spectrum and infrastructure, and semi-proprietary technology. Examples include public safety, railway transport and air traffic control services. Some Industries, such as energy utilities in some countries, have had their own spectrum. In the 4G era, there was a push to move these expensive networks into general purpose technology and spectrum, with developments such as the UK's Emergency Services Network (ESN), which will eventually replace the proprietary TETRA.

Outside these national or international, mission critical deployments, most private enterprise wireless networks have been based on Wi-Fi.

Now, private cellular networks are on the rise again, and may be deployed by specialized enterprise operators (many of which also deploy enterprise Wi-Fi), or by separate divisions within a telco or MNO. They are on the ascendant because many Industries want control over the performance, security and response capabilities of their connectivity, as they look to adopt wireless technologies at far greater scale than before. This adoption is driven by:

- Digital transformation initiatives, which require ubiquitous connectivity and high quality of service to support Industry 4.0 and other emerging types of service
- Replacement of wireline networks to support greater flexibility and mobility of staff, robots and other assets
- Increasing relocation of data and applications from traditional data centers, or from the central cloud, to the edge, which requires ubiquitous low latency connectivity

Such trends will drive significant growth in deployment of private LTE and 5G networks. The biggest investments in private cellular will be seen in industrial environments, according to many studies, including recent forecasts from Mobile Experts[13]and ABI Research[14] Here, Industry 4.0 applications often play to the key strengths of cellular, such as its wide area and global reach, its high mobility, its eSIM-based ease of access, and (especially from Release 17 of the 3GPP standards), its ultra-low latency. These capabilities will be important for emerging applications such as AI-driven robotics, smart automated logistics and drone-based critical infrastructure monitoring, which are frequently cited as drivers for adoption of 5G, together with edge computing.

These are high value applications and will attract significant investment, but they are relatively specialized. The vast majority of private enterprise networks, especially indoors, will remain Wi-Fi only, according to most studies – even by cellular players. Where Wi-Fi is already installed, the enhanced capabilities of Wi-Fi 6 and Wi-Fi 7 will meet the requirements of the majority of enterprises and applications.

Growth in private cellular will be seen in greenfield sites that have previously had no wireless connectivity (or no connectivity at all, outside office environments); and in connected enterprises that are considering radically new use cases for wireless connectivity. Here, enterprises and their service providers will be making a choice without existing investments to consider. In many cases, Wi-Fi will still meet all their needs and will nearly always offer lower TCO because of its huge ecosystem and installed base.

There are few scenarios where Wi-Fi will be unnecessary, except for an application that is running entirely outdoors and over a wide area or does not require significant data capacity. In most scenarios, 5G's indoor performance will not be adequate for high performance applications such as industrial VR.

But there are use cases where cellular technology provides enhanced or complementary capabilities. These mainly relate to very specialized applications such as mobile robotics, and to ubiquitous coverage. Both these are difficult business cases to make for the MNO, whose economics rely on very high usage of a fairly generic network, rather than investment in applications or locations which have relatively low usage levels, but very high-quality requirements.

The enterprise needs to support cellular and Wi-Fi together are described above in the CBRS context but remain consistent when other private cellular markets are studied. The desire to add private cellular to the mix is mainly driven by services that have extremely high or demanding requirements for fast mobility, extremely low latency and guaranteed QoS (where 5G is running in a licensed band). In majority of cases, an existing Wi-Fi site can support its needs by upgrading to Wi-Fi 6, but in some extreme applications, 5G will go a step further.

[13] https://www.prnewswire.com/news-releases/private-lte-and-5g-market-will-triple-to-10b-by-2025-301002633.html

[14] https://www.abiresearch.com/press/a-new-brand-of-private-network-operators-and-private-spectrum-for-enterprises-put-telcos-enterprise-ambitions-at-risk/

Release 16 introduces many of the features that will support such requirements, including:

- A 99.9999 (six nines) percent reliability rate, equivalent to fixed industrial Ethernet
- Selective partitioning for mission-critical processes
- Evolution of coordinated multipoint (CoMP) to support redundant paths in areas with metal obstructions such as cranes or automated vehicles
- Density of one million devices per square kilometer, 10 times greater than 4G. BASF's main production facility in Ludwigshafen, Germany, currently has 600,000 networked sensors and devices, but its target is six million
- Sub-millisecond latency.

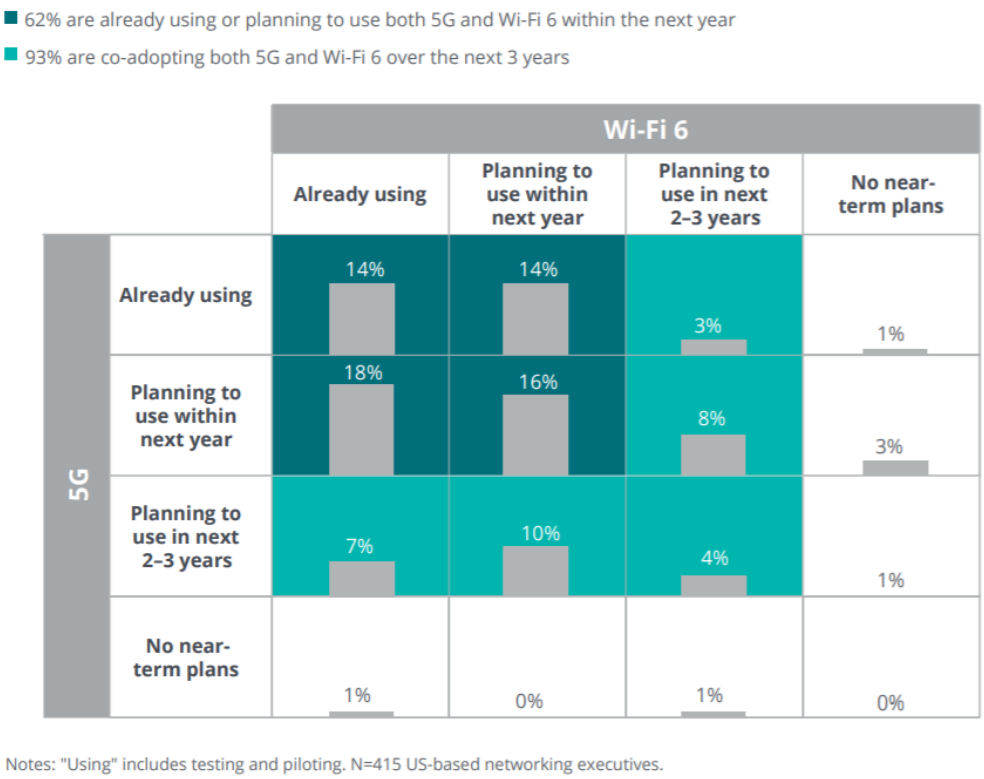
Other considerations relate to coverage – seamless handover to an MNO network supports global roaming and ubiquitous coverage, which is critical for some voice and IIoT applications such as emergency response. Cellular alone may also be best-suited to reaching remote locations such as mines. Ubiquitous coverage is a key driver for private cellular deployment – reaching remote locations, as well as every indoor or outdoor corner of a city, including underground car parks, for instance.

These capabilities will complement those where Wi-Fi remains superior, including ease of deployment and use, high bandwidth, device availability, cost-effective TCO.

The adoption of multi-radio private networks will become more common in environments with these features, while combining Wi-Fi and cellular (public or private) will be central to many enterprises' next generation connectivity strategies, as a study by Deloitte indicates[15]

[15] https://www2.deloitte.com/content/dam/insights/us/articles/6664_Next-gen-wireless/DI_Enterprises-building-their-future.pdf

Figure 12: Enterprise NGN strategies



Source: Deloitte's Study of Advanced Wireless Adoption.

6.5 Automatic Frequency Selection

Eventually, as discussed in 6.1, the industry should arrive at a converged network where a choice of access is almost a default. In that scenario, the value for service providers is shifted up the stack to the core network, supporting capabilities like slicing, and the automation and orchestration layer, which will coordinate all the different virtualized networks.

There are several technology steps already being taken along that path. One is automatic frequency selection (AFS), and the associated technology of dynamic frequency selection (DFS). AFS is a directed method in which the operator provides a set of channel frequencies, which are checked by the AFS algorithm. At boot, the device scans all the configured frequencies and connects to the one with the best relative received signal strength (RSSI). In a multi-network environment, this could also decide on the best connection, whether it is a Wi-Fi or cellular one. AFS techniques are at the heart of the spectrum access systems used to manage access priorities in CBRS and similar schemes.
Meanwhile, DFS is a legally required feature for devices that share spectrum with critical applications such as 5 GHZ radar.

7 Spectrum & Regulatory trends

The range of spectrum bands which will be useable by wireless broadband technologies is increasing, along with innovations in antenna design and modems. The opening of the 6GHz band for Wi-Fi is a major spectrum development which coincides with the release of Wi-Fi 6 technology. Other new bands are being freed up or shared by incumbents, like 3.5 GHz in the U.S., while others are new options, such as 60 GHz for WiGig. Systems to support interference-free shared access, such as geolocation databases and cognitive radios, will evolve into fully dynamic access platforms in future.

7.1 6 GHz extension for Wi-Fi

Access to the 5.925 – 7.125 GHz band—referred to as the 6 GHz band—is very important to the future of Wi-Fi innovation. On April 23, 2020, the Federal Communications Commission made the opening of 1200 MHz official for use by unlicensed devices in the 6 GHz band (5.925-7.125 GHz). The rules are designed to allow unlicensed devices, such as Wi-Fi, to operate in the 6 GHz band without interfering with the operation of the licensed services which will continue to use this spectrum.

The 6 GHz band is currently set aside for licensed users, including carriers and Mobile Virtual Network Operators (MVNOs) who have deployed thousands of point-to-point microwave links to backhaul network traffic. Lightweight management of spectrum usage in the band through a spectrum controller will allow unlicensed and licensed users to co-exist, maximizing spectral efficiency.

The FCC decision nearly triples the amount of spectrum available for Wi-Fi and allows so-called "Low Power Indoor" (LPI) operation right across the 6 GHz range of frequencies. The extreme width of the band means there will be space for a total of seven 160 MHz channels. Routers will have wider channels to work with to accommodate more devices at higher throughput rates.

Figure 13: GHz Sub-Bands

Device Class	Operating Bands	Maximum EIRP	Maximum EIRP Power Spectral Density
Low-Power Access Point and Subordinate Device (indoor only)	**U-NII-5** (5.925-6.425 GHz) **U-NII-6** (6.425 - 6.525 Ghz)	20 MHz: 18 dBm EIRP 40 MHz: 21 dBm EIRP 80 MHz: 24 dBm EIRP 160 MHz: 27 dBm EIRP 320 MHZ: 30 dBm EIRP	5 dBm/MHz
Associated Client Device	**U-NII-7** (6.525 - 6.875 Ghz) **U-NII-8** (6.875 - 7.125 Ghz)	20 MHz: 12 dBm EIRP 40 MHz: 15 dBm EIRP 80 MHz: 18 dBm EIRP 160 MHz: 21 dBm EIRP 320 MHZ: 24 dBm EIRP	-1 dBm/MHz

Source: Broadcom

7.2 Co-ordinated Shared Spectrum Models

In order to protect the incumbent operators in the 6 GHz—i.e., microwave links from MNOs, utilities, public safety, and transportation, as well as broadcast auxiliary service and cable television relay service—the FCC requires the use of an automatic frequency selection. Unlicensed use of the 5925-6425 MHz and 6525-6875 MHz sub-bands will be subject to control by an automated frequency coordination (AFC) system, described further below, while unlicensed use of the other two sub-segments is proposed to be limited to lower-power and indoor-only use without the need for database coordination.

Figure 14: AFC Regulations

Device Class	Operating Bands	Maximum EIRP	Maximum EIRP Power Spectral Density
Standard-Power Access Point (AFC Controlled)	**U-NII-5** (5.925-6.425 GHz	36 dBm	20 MHz: 23 dBm/MHz 40 MHz: 20 dBm/MHz 80 MHz: 17 dBm/MHz 160 MHz: 14 dBm/MHz 320 MHZ: 11 dBm/MHz
Associated Client	**U-NII-7** (6.525 - 6.875 Ghz)	30 dBm	20 MHz: 17 dBm/MHz 40 MHz: 14 dBm/MHz 80 MHz: 11 dBm/MHz 160 MHz: 8 dBm/MHz 320 MHZ: 5 dBm/MHz

Source: Broadcom

Because the incumbent services in U-NII-5 and U-NII-7 bands are fixed, the FCC proposes to allow unlicensed use at standard power outdoors and indoors subject to an AFC system. The agency "envision[s] the AFC system to be a simple database that is easy to implement."

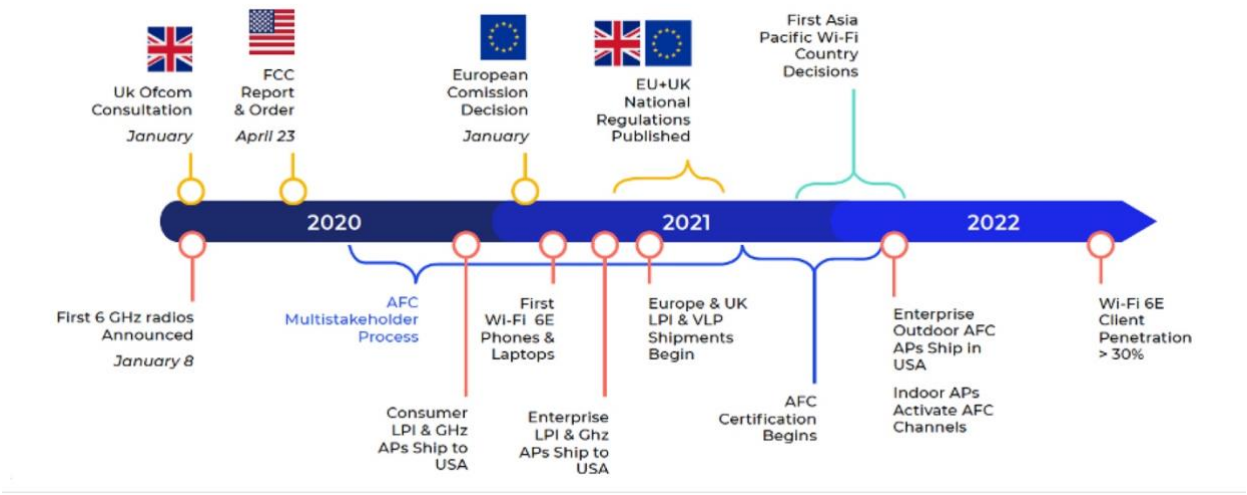
AFC exists primarily for outdoor applications but will also apply for higher power indoor usage such as in large warehouses or residential multi-dwelling units. Access points will require a geolocation technology and some way to communicate to the AFC outside of the protected bands. The AFC will be required for indoor higher-power operation above LPI limits and indoor higher-power mobile clients.

Incumbent Point-to-Point microwave links and FSS earth stations are fixed, highly directional, and seldom change location or operating parameters. Like the TV Bands Database, the AFC "System Operator" is simply enforcing protection zones around static incumbent links based on incumbent-provided licensing data that will be continually updated. A grant to operate a Wi-Fi access point at a location is therefore a one-to-one calculation that is easily verified based on incumbent data.

The AFC system operator will regularly update information on incumbent receivers stored in databases maintained by the FCC, which it will use to automatically calculate and enforce protection contours sufficient to protect Point-to-Point links, denying requests to operate where the Radio LAN's emissions exceed an interference threshold into any individual incumbent link. Automated frequency coordination allows incumbent services to add sites or modify their networks, since FCC databases will continue to be updated by incumbents as they do now. Radio LAN channel permissions will expire automatically if not renewed within a period provided in the FCC's rules.

The FCC is expected to finalize the rules for 6 GHz unlicensed operation this year, with a number of countries in the European Union and in Asia expected to follow suit by 2022. However, the EU will not allow outdoor operations, as most EU countries do not publish their spectrum use databases for national security or confidentiality reasons. Canada is expected to largely adopt the FCC rule. Private 5G networks will also be contenders for that band.

Figure 15: 6 GHz Rollout Timeline



Source: Aruba

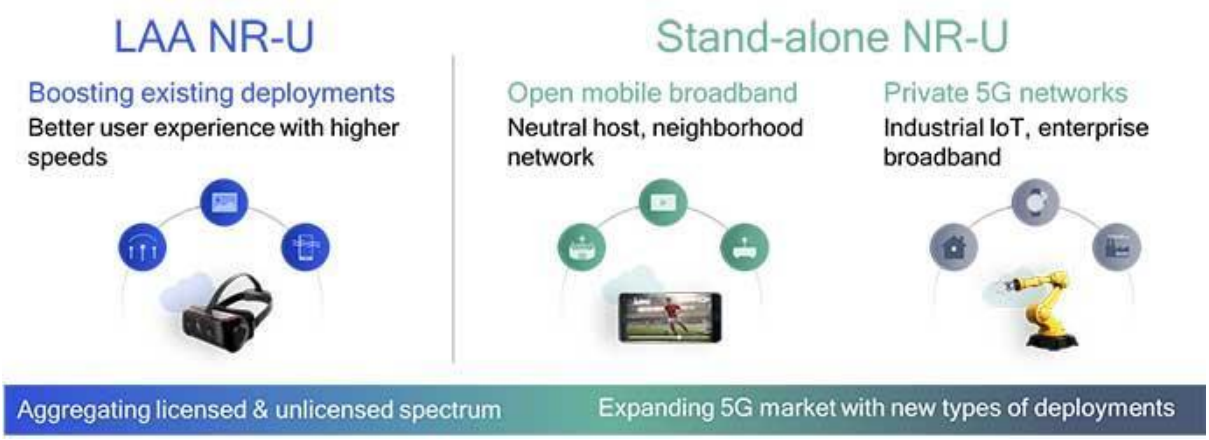
Dynamic spectrum approaches—such as Television White Space (TVWS) regulation and, more recently, Citizens Broadband Radio Service (CBRS) in the U.S.—have emerged as an alternative approach to spectrum assignment. As CBRS is deployed for LTE, the concept of spectrum sharing will extend to new bands and use cases. The CBRS auction closed on August 2020 with over $4.5 billion in gross proceeds with over 20,000 licenses won.

7.3 Regulatory & spectrum framework for 5G with unlicensed bands

3GPP Release 15 covered enhancements to LTE operations in unlicensed spectrum (see Chapter 6.3), including enhancements to unlicensed spectrum offloading systems, as well as work on standards for use of LAA/eLAA for the CBRS band in the USA.

Release 16 includes standards for use of unlicensed spectrum for 5G networks. In its December 2018 meeting, 3GPP agreed to kick off a work item with a view to including support for 5G NR unlicensed spectrum (NR-U) in Release 16. The work item includes support for licensed-assisted access NR-U (using anchor channels in LTE or 5G NR) and for stand-alone NR-U (with no LTE anchor). It also covers use of unlicensed spectrum at 6 GHz, to complement the existing spectrum at 5 GHz.

Figure 16: The 5G New Radio-Unlicensed initiatives within 3GPP.



Source: Qualcomm

Another important distinction in the 5G standards is between asynchronous and synchronous sharing of unlicensed frequencies. Channel access to the 5 GHz band is asynchronous to support the huge number of active devices, but in virgin mobile spectrum such as CBRS, or the lightly licensed industrial bands in the UK and Germany, there may be enough spare capacity to dedicate part of the band to synchronized access. While asynchronous maximizes usage of spectrum by allowing devices to hop onto any available channel, synchronous sharing can support applications such as industrial control, which require coordinated multi-point and ultra-low-latency. The idea behind synchronized sharing for 5G NR-U is to coordinate access between different network nodes in the same way as in licensed bands to improve predictability and QoS.

There are other efforts being driven by the CBRS Alliance or the 3GPP, to reduce interference in shared bands and bring 5G NR-U QoS as close as possible to that of licensed 5G. For instance, the CBRS Alliance is introducing time slot synchronization, which can be combined in 5G NR-U with partitioning of guaranteed resources for a particular operator or application; vertical sharing between operators at different priority levels in tiered schemes like CBRS; and support for spatial division multiplexing (SDM) and coordinated multipoint transmission (CoMP) to increase spectral efficiency and support more consistent user experience at the cell edge.

The new sharing techniques envisaged for 5G NR-U are shown in Figure 17.

Figure 17: Flexible NR spectrum sharing framework.

Source: Qualcomm

Technologies in high frequency unlicensed bands such as 60 GHz for WiGig will also have an important role to play in 5G addressing many of the challenges of using millimeter wave spectrum. 60 GHz V-Band is a particularly appealing option for FWA service providers. Unlike the lightly licensed 70/80 GHz E-Band, the 60 GHz band is unlicensed in countries like the United States, and therefore, is accessible to a wider range of providers. Additionally, the 14 GHz of contiguous spectrum in this band offers more bandwidth than any other licensed or unlicensed mmWave band. Further, the 60 GHz band has chipsets and technology currently available on the commercial market.

The allocation of additional unlicensed or shared spectrum for wireless broadband has been heavily driven by the USA, but regulators in many markets where capacity crunches are threatened are following suit. In most cases, spectrum is opened up on a technology neutral basis, but different technologies tend to gravitate to different bands (see section 6.3).

Figure 18: Key bands available, or under consideration, for either assisted or standalone 5G NR-U

Source: 3GPP

These bands, in the 5 GHz and low 6 GHz range, will require significant coexistence with Wi-Fi. This threatens to create tensions in some scenarios but compared to the early days of LTE-Unlicensed, there is high recognition that the Wi-Fi and cellular Industries should cooperate to reduce any potential damage to overall wireless QoS, in pursuit of a converged wireless platform that will support the maximum number of use cases and service providers. In that context, the ability to use the same spectrum could enhance interoperability and the evolution of common, multi-RAT equipment and devices. A 3GPP study group is examining an architecture, for instance, in which Wi-Fi and 5G devices would connect to a single distributed antenna system (DAS), that in turn would support both licensed and unlicensed spectrum.

Another important aspect of regulatory policy towards shared spectrum in 5G is growing support for unlicensed or lightly licensed access to shared airwaves on a local basis. The UK, Japan and The Netherlands are examples of countries which have announced rules to stimulate the deployment of 5G services for industrial locations, or remote locations. These are areas where the business case is hard to make for the MNO, but clearly a private network operator cannot afford to buy licensed spectrum to support specialized enterprise or rural requirements.

The UK regulator, Ofcom, has introduced two new schemes, which are typical of those being considered by many countries. These are Local Access licenses and Shared Access licenses. The former consists of low cost, three-year licenses (technology neutral) to run services in any bands where MNOs have networks, but where there is spare capacity at any given time or place.

The latter applies to the 1.8 GHz, 2.3 GHz, 3.8-4.2 GHz and 24.25-26.5 GHz bands (the last of these for indoor use only. Licenses will be available at low cost (about £80 per 10 MHz per year) and will entitle organizations to use the spectrum on a first come first served basis, coordinated by a spectrum management framework administered by Ofcom. As in CBRS, there are low power and medium power licenses, the former geared to indoor and enterprise use, the latter to rural.

7.4 Security, privacy and identity management developments in Wi-Fi networks and how these are being addressed

Privacy and security concerns are growing everywhere as stories of massive data breaches make the headlines. Wireless as a medium is prone to breach and espionage, and both citizens and politicians are increasingly wary about privacy and security issues for both humans and connected machines.

7.4.1 Privacy with MAC randomization

Mobile devices are equipped with Wi-Fi which sends probes to nearby access points as a way to connect indoors. As part of the general protocols of Wi-Fi, a station is given tools to discover what access points serving SSIDs might be near so that it can make a good choice for its next association. A station can send out a query to the surrounding 802.11 wireless world to find out what access points are nearby and access points hearing that request can respond.

The information in these frames can allow a mobile device's location to be tracked. Particularly, included in the probe request message is the source address of the originating station so that an access point can address the probe response to that station which is identified by its unique MAC address. The problem of course is that MAC addresses can be used to tracked, traced, followed thus raising privacy issues.

Vendors are introducing MAC randomization in their operating systems where MAC addresses change every period of time - for example, every 24 hours, or every time a device is disassociated from the Wi-Fi network. Each vendor is taking its owns approach to the issue.

Figure 19: MAC randomization status as of August 2020

Operating System	Supports MAC Randomization	Default Status	Network Based Per SSID	Time Based
Apple iOS 13	NO			
Apple iPadOS 13	NO			
Apple iOS 14 (*3)	YES	ENABLED	ENABLED	
Apple iPadOS 14 (*3)	YES	ENABLED	ENABLED	
MacOS 10.15: Catalina	NO			
MacOS 10.16: Big Sur (*2)	NO			
Android 10	YES	ENABLED	ENABLED	
Android 11	YES	ENABLED	ENABLED	NO (*1)
Windows 10	YES	DISABLED	OPTIONAL	OPTIONAL (24 hours)

*1 - A developer option called 'enhanced MAC Randomization' introduces time based
*2 - Correct at time of publication (macOS 10.16 is still in BETA phase)
*3 - BETA 4 removed the 24 hour rotation, which had been introduced previously

globalreach

Apple, which refers to MAC randomization as private Wi-Fi, is implementing changes to its iOS14 Beta version by defaulting their mobile devices to use randomized MAC addresses with the local bit set in non-associated probe requests. This means Apple will create a new MAC address for each new SSID but not BSSID and as a result should not affect applications relying on MAC address in the home.

MAC randomization will also be implemented in future Android Beta versions, for instances where the MAC address will change every 24 hours. However, given that Android allows much more diverse product differentiation when compared to iOS, not all Android devices have implemented access to the same level of privacy features. Windows devices are also dependent upon the hardware of the laptop for the exact features supported. Randomized MAC addresses are used for probing while a laptop is unassociated by default, though a user can disable that feature.

MAC Randomization may be a concern for some parties because a device's MAC address has been used as a definitive way to identify a device for many purposes and that assumption is not necessarily valid in the future. For privacy issues, random MAC addresses in associated and non-associated states are both relevant. In terms of impact of the network and related use cases, the non-associated state is less problematic. The following are some examples of use cases which require MAC identification:

- Home network with multiple SSIDs
- Parental control offered in 802.11 routers is usually based on the MAC address of the device.
- Customer Support and Troubleshooting is based on MAC address
- Home automation require MAC address
- Airport security queue measurement
- Retail store customer flow analysis
- Detection of rogue devices in the network

The WBA is working with members and other industry bodies to identify the impact of future O/S releases on the Wi-Fi experience from DHCP list exhaustion to the impact on captive portals and will share knowledge with its members to mitigate the impact of new software releases.

Wi-Fi 6 and WBA OpenRoaming both address security issues on public and guest Wi-Fi networks.

7.4.2 Privacy with GDPR

The EU General Data Protection Regulation (GDPR) was adopted by the European Parliament in April of 2016 and became enforceable on May 25, 2018. It is now well implemented and understood by businesses and consumers. The regulation applies to the collection, processing, and movement of personal data for individuals residing in thirty-two European states (twenty-eight EU states + four other European states). GDPR impacts, for example, guest Wi-Fi practices, in that vendors will need to provide tools to get end users' consent to use their personal data for marketing. Venue managers and brands will also want to give end users transparent access to that personal information.

7.4.3 Security

Security in public Wi-Fi networks is critical and has been gaining ever more visibility across Governments and public bodies. Wi-Fi Protected Access (WPA3) was introduced by the Wi-Fi Alliance in 2018. To address the increased security requirements from user access, new use cases, and the IoT in the smart home, and in event and enterprise venue such as hotels, stadiums and airports. We expect WPA3 to become more widely adopted this year and the list of **WPA3 capable devices** is already quite long. Key capabilities of WPA3 include:

- WPA3-Personal: more resilient, password-based authentication even when users choose passwords that fall short of typical complexity recommendations. WPA3 leverages Simultaneous Authentication of Equals (SAE), a secure key establishment protocol between devices, to provide stronger protections for users against password guessing attempts by third parties.

- WPA3-Enterprise: offers the equivalent of 192-bit cryptographic strength, providing additional protections for networks transmitting sensitive data, such as government or finance. The 192-bit security suite ensures a consistent combination of cryptographic tools are deployed across WPA3 networks.

Organizations can add Passpoint service to any existing SSID that uses WPA2 or WPA3 authentication. All these options use the WPA2/WPA3-Enterprise 802.1X protocol which protects credentials and encrypts over-the-air traffic. With OpenRoaming, security is inherently built in as part of the standard,
The WBA is actively working to extend Passpoint to IoT applications to support dynamic IoT roaming and streamline authentication and interoperability. This builds on the ranking of the IoT as the most likely application to drive the next wave of network and traffic growth. Unlike cellular, Wi-Fi 6 is backwards compatible with previous devices, and the WBA believes that Wi-Fi is in a prime position to tackle continuous consumer demand for data and to power the IoT boom and the security requirements in the home, enterprise and public venues.

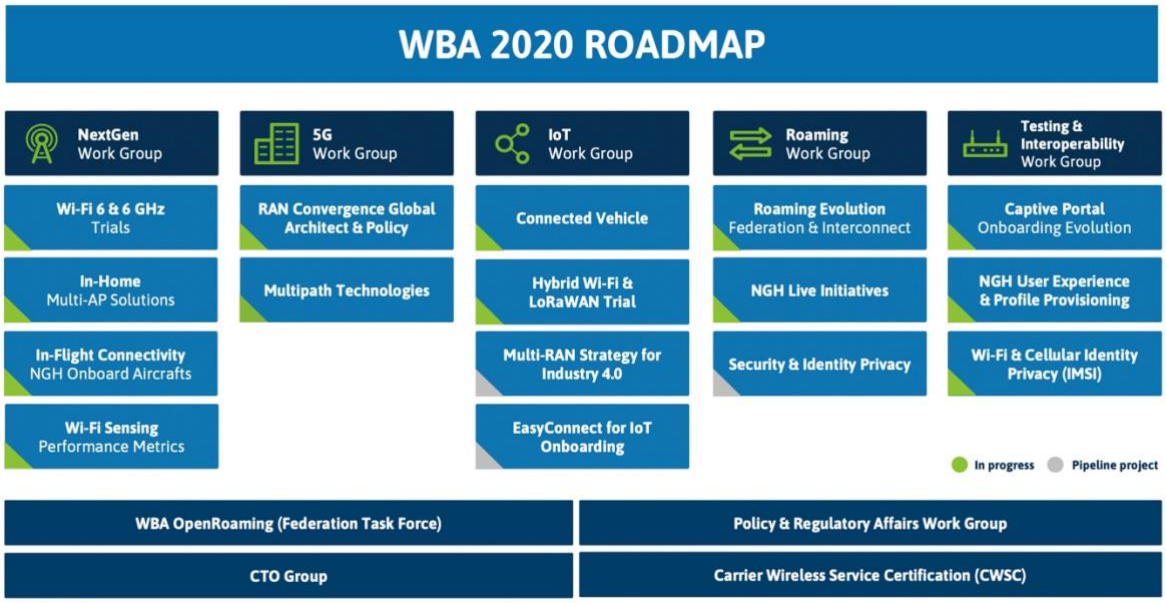
8 WBA Resources and current works

With billions of 'people & things' becoming increasingly connected, the need to combine the potential of unlicensed and licensed wireless services has become an imperative for the operators, cities, high-density venues and players focused on key market opportunities such as IoT, Big Data and 5G.

The deliverables of WBA projects aim to resolve business issues and enable collaborative opportunities for service providers, enterprises and cities, enabling them to enhance the customer experience on Wi-Fi and optimize business opportunities that are being built on evolving technology and commercial developments. It aims to harness its experience of creating seamlessly interconnected wireless services in new and emerging areas.

WBA's program initiatives support the development of services and support infrastructure to drive the industry forward. WBA work areas include advocacy, industry guidelines, trials and certification. Its key programs include NextGen Wi-Fi, 5G, IoT, Testing & Interoperability, Roaming and Policy & Regulatory Affairs, with member-led Work Groups dedicated to resolving standards and technical issues to promote end-to-end services and accelerate business opportunities.

Figure 20: 2020 WBA programs and projects



Source: WBA

To accelerate the adoption of new Wi-Fi generations, drive industry engagements and address business opportunities transversal to industry verticals supported by the Wi-Fi industry. WBA provides industry guidelines, use cases as well as a platform for end-to-end trials based on a comprehensive test plan and deployment guidelines. The latest releases include **In-Home Wi-Fi Industry Guidelines**, **In-Home Wi-Fi – Use Cases**, **Wi-Fi Sensing Whitepaper**, **In-Flight Connectivity whitepaper**, **Captive Network Portal Standards**, **The Connected Vehicle Whitepaper**, **Wi-Fi 6 Deployment Guidelines & Scenarios** and **Understanding The Global Implications Of Wi-Fi 6 & 6GHz** whitepaper.

WBA works closely with industry bodies to examine new business opportunities for 5G / Wi-Fi RAN Convergence which can be better enabled through the convergence and interworking and address Wi-Fi and 5G convergence in verticals such as enterprises, industrial 4.0, IoT, public hotspots, connected cities and residential access. The latest releases include and joint whitepaper with NGMN - **RAN Convergence Whitepaper**.

To provide a 'better' Wi-Fi experience for consumers and businesses and ultimately opens up opportunities for broadband and the Internet of Things (IoT) connectivity across business verticals, WBA manages and oversees the operation of the **OpenRoaming** federation which creates the framework to connect billions of users and things to millions of Wi-Fi networks globally. OpenRoaming is a Wi-Fi federation that offers an automatic and secure connection of billions of devices to millions of Wi-Fi

networks and provides a new global standards-led approach, removing public-guest Wi-Fi connectivity barriers and bringing greater convenience and security to the wireless ecosystem.
The latest releases to enable Roaming set up and user experience include **PKI RadSec – Operator Deployment Guidelines**, **PKI & RadSec End-Entity Deployment Guidelines** and **Wi-Fi Roaming Standard – WRIX Umbrella Document.**

WBA also works with LoRa Alliance and released the **Wi-Fi & LoRaWAN® Deployment Synergies Whitepaper** which illustrates new business opportunities for Mobile operators, enterprises, cities and other key Internet of Things (IoT) market players that are created when Wi-Fi networks that are traditionally built to support critical IoT are merged with LoRaWAN® networks.

As an organization, WBA will continue to help our membership and the industry, to accelerate better Wi-Fi services by removing barriers and ensuring that our members are well-positioned to take advantage of the huge growth and revenue opportunities. This will help Wi-Fi continue its status as the most widely-used wireless data technology.

8.1 Wi-Fi 6 and 6E Program

With the release of Wi-Fi 6, 2020 gives us a glimpse of the true capabilities of the most powerful iteration of Wi-Fi. The **Work Groups and Project teams** have driven many new use cases with trials and deployments taking place over the year, and end-users begin to get a taste of Wi-Fi 6's potential as new devices are shipped with its out-of-the-box advanced capabilities.

Most recently, WBA has been leading a series of successful **Wi-Fi 6** trials across different verticals, including Industry 4.0, residential, education, transportation hubs, shopping venue, etc. and these are help to accelerate the overall adoption of Wi-Fi 6 services.

According to WBA CEO Tiago Rodrigues, WBA believes that extending Wi-Fi into the 6GHz spectrum band can provide more Wi-Fi capacity than all the other bands put together. Wi-Fi 6 technology in the extended band (also known as Wi-Fi 6E) will deliver higher speeds, low latency and service levels that are equivalent to 5G networks and be able to support the widespread, low-cost, use of advanced business, industrial and consumer applications. Hence, in terms of the capability and capacity of networks, Wi-Fi 6E, will rewrite the rules of what is possible.

The WBA has taken a leadership role to establish realistic deployment guidelines for Wi-Fi 6 and 6E in a number of verticals including industrial and is conducting no less than 27 different Wi-Fi 6 & 6E trials across the world as show in the table below. The objective of the trials is to test the capabilities of Wi-Fi 6 and 6E in real world scenarios, report the trial results within the ecosystem in order to raise confidence in the new technologies. This is a way to fast-track adoption of Wi-Fi 6 for operators leveraging carrier-grade capabilities.

For more details about the **Wi-Fi 6 Report**

8.2 WBA OpenRoaming - One Global Wi-Fi Network

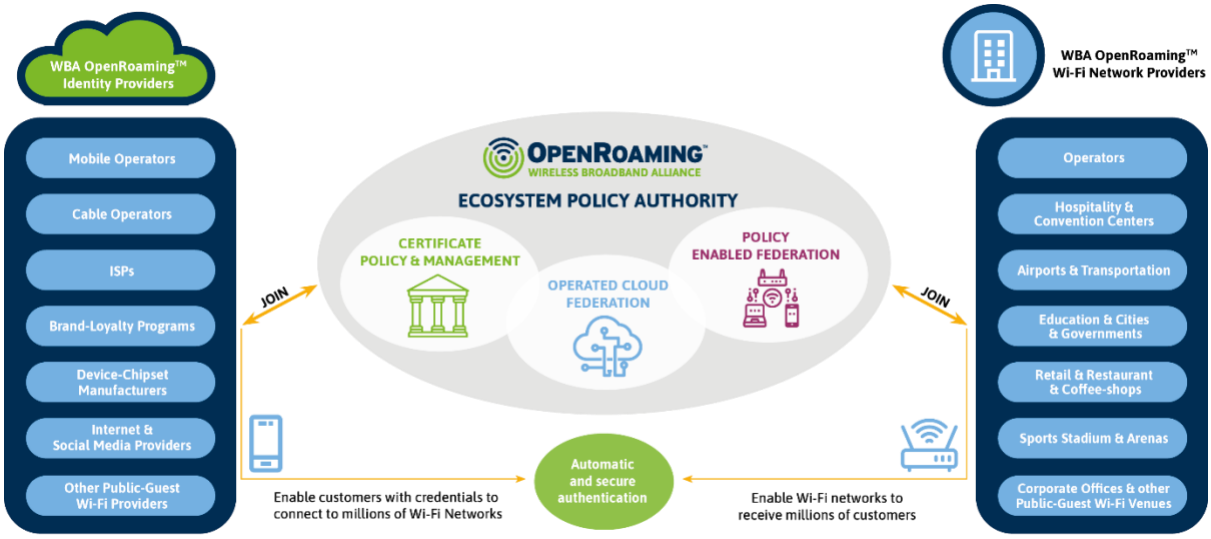
WBA OpenRoaming is a roaming federation service enabling an automatic and secure Wi-Fi experience globally. With WBA OpenRoaming™, we are creating an open connectivity framework for all organizations in the wireless ecosystem to power new opportunities in the 5G era. It encompasses three key elements:

WBA OpenRoaming™ Dimensions	WBA OpenRoaming™ Components & Standard & Technical specs
Cybersecurity Service 	• Manages secure public keying infrastructure (PKI) / RadSec Technology for certificates policy, management and broker services • Supports dynamic & static interconnection technologies
Cloud Federation 	• Operates centralized federation policies and global identifiers for Wi-Fi networks & identity providers • WBA unique Wi-Fi network identifier (WBAID) for federation partners • Wireless Roaming Intermediary eXchange (WRIX) standard enables roaming services harmonization and multiple business models
Network Automation 	• Manages automated roaming consortium codes and policy provisioning mechanisms • Utilizes Passpoint® technology

8.2.1 Seamless Onboarding User Experience with WBA OpenRoaming

WBA OpenRoaming transforms the Wi-Fi experience for consumers and businesses and ultimately opens up opportunities for broadband and the Internet of Things (IoT) connectivity across business verticals, including retail, hospitality, education, smart cities, automotive and aviation, among many others. Devices simply connect automatically and securely on to the WBA OpenRoaming network.

8.2.2 How does WBA OpenRoaming work?



OpenRoaming brings together a federation of networks and identity providers, allowing users to join any network managed by a federation member. Companies who join OpenRoaming provide assurance that their Wi-Fi networks automatically interoperate between each other to deliver an automatic and secure connected Wi-Fi experience.

Learn more about WBA OpenRoaming™, visit ***www.openroaming.org***

8.3 The Dawn of the Wi-Fi 6 & 5G Era

Wi-Fi and cellular are the two most predominant wireless technologies in the World and this will continues to be the case with Wi-Fi 6 and 5G. It will be the job of organizations like the WBA – and the wider wireless industry – to drive awareness and help operators and network providers to extract the strongest capabilities of each technology and use them to create better and more advanced networks with the lowest CAPEX/OPEX and the best ROI and performance for customers.

In 2021, as the number of connected devices around the world continues to increase at a stunning rate annually, the convergence of Wi-Fi 6 and 5G will help network providers have a more compelling business model and address the continuous data 'tsunami' that will only get stronger as time goes by. WBA will continue to make Wi-Fi better and undertakes programs and activities to address business and technical issues, as well as opportunities, for member companies such as extending use cases and Wi-Fi trials to AR/VR, OpenRoaming for IoT and private 5G.

9 Appendix

9.1 Appendix 1 – Case studies

9.1.1 Case Study 1 Industrial Wi-Fi with Mettis

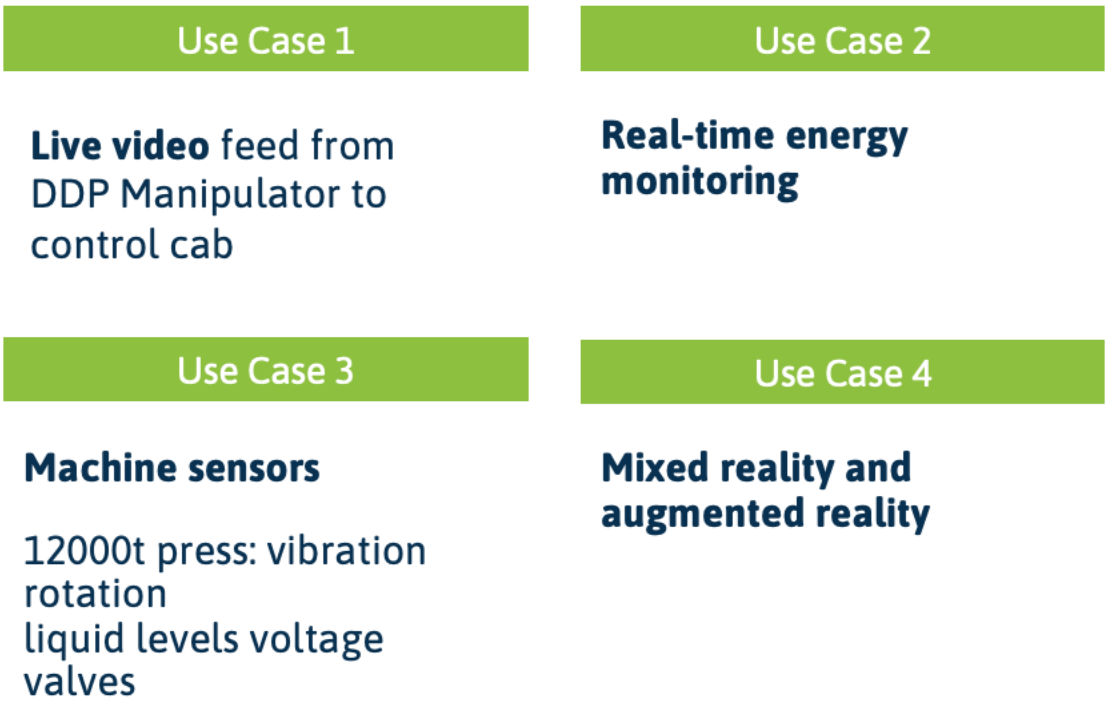
In the spring of 2019, the Wireless Broadband Alliance (WBA) announced the world's first Wi-Fi 6 Industrial Enterprise and IoT trial with Mettis Aerospace, as part of its ongoing Wi-Fi 6 program. Mettis Aerospace supplies companies such as Airbus, Boeing and Rolls-Royce. The Mettis factory also lies within the region selected by the UK Government as a 5G test bed for manufacturing. The WBA test results clearly demonstrate the important role Wi-Fi 6 can play within the broader 5G ecosystem.

The main objectives of the Mettis trial are:

- Promote and validate the Wi-Fi 6 technology and its complementary to 5G technologies
- Validate in a real life environment the capabilities of Wi-Fi 6 for the Industrial 4.0 Manufacturing
- Develop a repository of Wi-Fi 6 use cases and test plans
- Mobilize the different stakeholders in the Wi-Fi 6 Industry around the Trial

Phase One
In December 2019, the WBA completed the phase one trial of Wi-Fi 6 infrastructure and services at the Mettis Aerospace factory in the UK. The trial was the first of its kind in the world and an important part of the WBA's Wi-Fi 6 test and development program. Tests included applications of 4K video streaming, large scale file transfers, messaging and voice/video communications as well as the first stage of IoT sensor and mixed reality testing. Previous implementation tests with Wi-Fi failed to work in Mettis' challenging factory environment. During the trial, speeds of 700 Mbps using 80 MHz channels were achieved and low latency applications, like video calling and video streaming, performed well with results below 6ms. These results proved that Wi-Fi 6 infrastructure can operate well in the presence of interference and noise in a complex and challenging factory environment as well as deliver high quality services for monitoring and maximizing machinery performance, minimizing downtime, and improving communications on the factory floor.

Figure 21: Mettis use cases



Source: WBA

"The Wi-Fi 6 infrastructure installed as part of the trials has exceeded our expectations in terms of performance, reliable connectivity and consistent coverage across the target area," said Dave Green, Head of IT, Mettis Aerospace. "We are seeing immediate benefits in terms of the data we're now able to collect and use. Moving forward, we will be able to vastly increase the data we collect from devices across our business, enhancing our manufacturing processes, reducing variability and increasing productivity."

The trial took place at the 27-acre Mettis Aerospace facility in the West Midlands in collaboration with WBA member companies including Broadcom, Cisco, iBwave and Intel as well as Concurrent Engineering and Keysight. The Wi-Fi 6 technology had to prove it was able to provide total connectivity across the factory floor and enable improved synchronization of factory floor machinery and equipment with centralized monitoring and control systems. This required the Wi-Fi network to deliver real-time high bandwidth communications, with very low latency and clear prioritization of data across a large-scale, complex factory environment.

Phase Two:
Phase Two of the trial will start in September 2020 and focus on further tests of the Mixed reality applications and IoT sensing of key assets using an experimental license in the newly 6GHz from Ofcom. During phase two, target wake time sensor availability (IoT) will be measured along with interference analysis and AP device capacity. It may use up to 320MHz of spectrum from an experimental spectrum license by Ofcom in the 6GHz band and will showcase Wi-Fi 6E capabilities for AR/VR and a variety of sensors such as temperature monitoring.

Phase Three:

The objectives for Phase three are still being defined and additional use cases will be identified, and work will go on for at least another twelve months. The result will be a white paper which describes what worked and what didn't and help quicken the deployment of Wi-Fi in industrial environment.

9.1.2 Case study 2: Wi-Fi Sensing with Cognitive

Cognitive Systems : Leading the Road to Standardization for Wi-Fi Sensing

Cognitive Systems is a Canadian company which has developed a Wi-Fi sensing technology for use in a variety of use cases including home monitoring. Its technology called Wi-Fi Motion™ 'sees' motion by detecting and interpreting changes in Wi-Fi signals, and offers a completely new way of using Wi-Fi. The technology doesn't "see" things like furniture and walls, but detects disturbances in Wi-Fi signals, and is therefore unaffected by visual obstacles or low-light conditions.

Wi-Fi Motion transforms a home's wireless network into a highly accurate motion detection system with no additional hardware, allowing for a more affordable and seamless set up compared to traditional home monitoring products. Cognitive Systems received a $7.3-million boost from the federal government as part of a $41-million investment in quantum computing and AI machine learning.

WiFi Motion leverages existing connections from the access point(s) to the WiFi client devices (e.g., Amazon Echo, Smart plugs)

The following are some of the limitless future possibilities of Wi-Fi Motion:

- **Security:** Unexpected motion (intruder)
- **Home Awareness:** Expected motion (kids are home, housekeeper stayed 2.5 hours)
- **Eldercare:** Lack of expected motion (elderly parent does not awake), vitals monitoring, preventative health
- **Wellness Monitoring:** Sleep quality, activity levels
- **Smart Home:** Automatically turn on lights, adjust temperature when arriving home
- **Limitless Future Features:** Breathing detection, people counting, control IoT devices with hand gestures, rental property monitoring

The Road to Standardization

Cognitive Systems software was first launched into Plume's "Motion Aware" at CES 2020 as part of their Smart Home 2.0 suite of intelligent services. This was accomplished following a long integration process which required a considerable amount of engineering work from silicon to cloud. As a result of this first integration, Cognitive Systems concluded that a more efficient way was needed if Wi-Fi sensing was to reach its full potential. The partnership with the WBA became the foundation to implement a standardized approach to implement Wi-Fi sensing, involving chipset vendors, OEMs and service providers.

For Cognitive Systems, being first-to-market came with responsibilities and challenges including developing a common set of standards for Wi-Fi sensing from defining a set of APIs for silicon vendors, to developing KPIs and methodology for testing. Cognitive Systems was instrumental to the production of the WBA white paper which is referred to in section 4.3.1 of this report. The white paper discusses the steps needed to reach its full potential in the market. Cognitive Systems aims at integrating its features into ISPs own applications

Privacy Issues

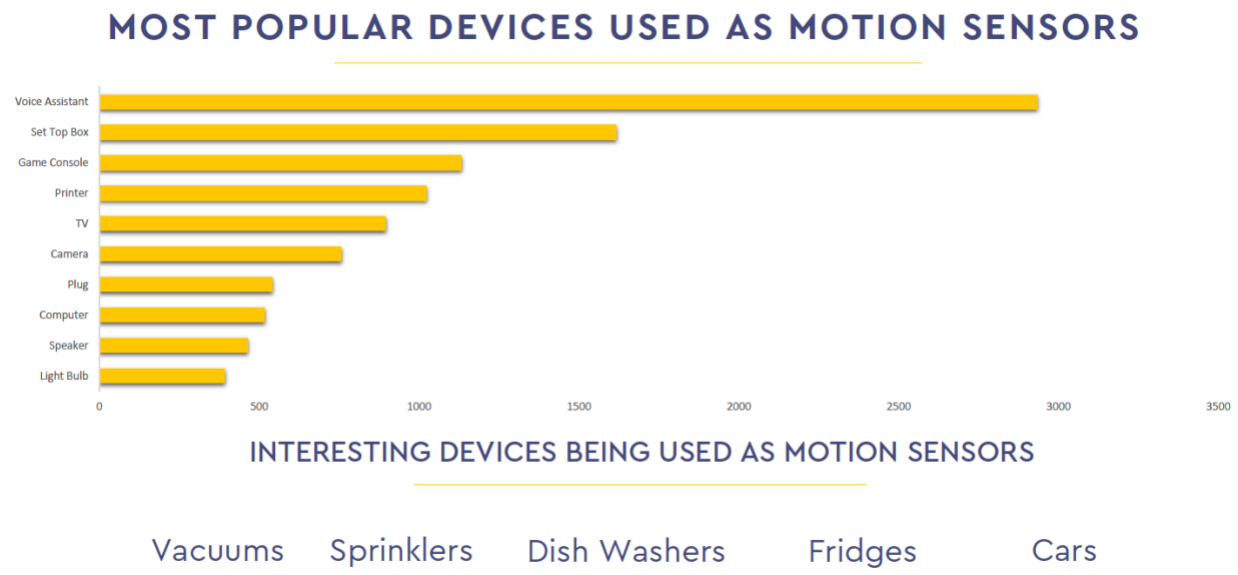
Privacy is a top concern for most consumers when evaluating smart home and security systems. Cognitive Systems, in addition to developing an inherently private technology, is committed to working within the industry to set standards and guidelines around Wi-Fi Sensing technology. Wi-Fi Motion can learn behavior patterns using AI to enable smart home conveniences without the need for invasive cameras and microphones. Wi-Fi sensing works on associated devices and is thus not affected by MAC randomization yet. This could become an issue if future MAC randomization releases affects un-associated devices. A more detailed discussion is included in section 7.4.1 on privacy.

Next Steps

Within the WBA, Cognitive Systems is currently working with CableLabs to provide detailed testing of its platform for home monitoring applications such as home security and IoT integration of devices. The goal is to develop procedures to verify and validate that the systems conform to an agreed-upon standard. This requires developing a methodology but will also require the development of standardized tools to facilitate testing. The results of the trial with CableLabs which is planned to be completed in late October 2020 will be shared in a WBA publication during the final quarter of 2020. This will be a huge milestone in developing the technology and growing its acceptance.

Initial research performed with an early user group provided some insights about what devices can benefit the most from the sue of Wi-Fi sensors as shown in the figure below:

Figure 22: Most popular devices used as motion sensors



Source: Cognitive

Longer-term goals include gaining standard support and defining required features. The majority of these requirements already exist in the IEEE standard, but real-life implementation provides key lessons to refine small but important details. As new features are added into the standards, improvements can begin making their way into the sensing algorithms to fully utilize what is available. ISPs will then be able to tap into a whole new market opportunity which includes a variety of use cases from security to eldercare.

9.1.3 Case study 5 Boingo MDU Wi-Fi

Case Study: Boingo's Managed Wi-Fi for MDUs

In this case study, we dive into Boingo's managed Wi-Fi service for multi-dwelling units (MDUs) and explore how this service is a win-win for all stakeholders involved.

MDU Stakeholders
According to the 2018 estimates from the US Census Bureau, there were 35 million households living in MDUs spread over a little more than 800,000 buildings. This represents a big market which Boingo has decided to tap into with its managed Wi-Fi service model.

The MDU market is not only large, but it can also provide better economics than service to single-family units, especially for wireline providers who already provide broadband access to the building. Large MDUs that have tens or hundreds of residents require very large broadband pipes and high SLAs. Most residential users today experience their broadband with Wi-Fi, so ensuring high quality of experience Wi-Fi is a key factor when considering leasing a unit.

In terms of connectivity, residents in MDUs value the ability connect seamlessly and securely with an easy onboarding process without having to deal with a traditional cable provider and related long-term contracts. Residents can thus attach their broadband/Wi-Fi connectivity to their lease and not worry about cord cutting. Quality Wi-Fi has become an even more essential service for residents who are now working and studying from home because of COVID-19 social restrictions.

Residents also value the ability to roam seamlessly from their unit to common areas such as the pool or lobby. In campuses, millennials expect high throughputs and low latency to be able to do gaming and high quality streaming video throughout their campus. Great Wi-Fi drives resident satisfaction which in turn translates into longer leases and gold star property reputation.

For property owners, there are also ample benefits to subscribing to Boingo's Wi-Fi. They can offload all the technical complexity of managing the network while being able to use and monetize their Wi-Fi. We present a short case study featuring Investment Property Advisors (IPA) who were able to monetize their managed Wi-Fi. Boingo removes any friction for property owners to enjoy a first class, latest generation network:

- 5G & IoT ready – designed to power digital locks, security cameras, smart thermostats, etc.
- 24/7 network insights
- Increased NOI & property value and creates a new source of revenue

Property Owners Take Control
Boingo provides property owners with an easy-to-use and yet powerful network management system that enables remote Wi-Fi management of MDU properties. The platform called "Ground Control" is Boingo's proprietary, web-based platform that supports a wide range of remote management activities, including the ability to:

- Register and maintain users and devices
- Monitor bandwidth usage and network performance
- Message residents about events, property announcements, and maintenance appointments
- Check the status of support tickets in real time
- View and print channel lineups
- Enable or suspend resident services remotely

This platform enables relevant staff at the property to conveniently access real-time analytics and tools to seamlessly manage network performance, track network maintenance requests, and directly communicate with residents.

Wi-Fi in Times of COVID-19
As the industry navigates the COVID-19 crisis, Ground Control helps property managers to communicate with residents without knocking on doors or coming in physical contact, thus respecting social distancing. Property managers can determine occupancy at their property based on Wi-Fi usage.

A Profitable Service: The Case of Investment Property Advisors
Investment Property Advisors (IPA) is using Boingo's managed Wi-Fi and data solutions to attract multi-family housing residents and increase revenue. IPA was able to monetize the guest Wi-Fi feature and marketing tools to engage the right audience and turn visitors into residents.

In one of its properties, Uptown East (a stylish U.S. apartment community in Valparaiso, Indiana), IPA experienced a marked increase in both qualified leads and newly signed leases thanks to Boingo's guest Wi-Fi feature. The free guest Wi-Fi in this property and coffee shop creates a list of prospects, who use the guest network, which were then offered special incentives to move in through a targeted email campaign. The targeted marketing strategy has attracted a significant number of new residents, boosting IPA revenue at Uptown East by more than $70,000.

Conclusion
Boingo comes with the expertise of a wireless company that has been in business for twenty years, providing secure networks to airports, the military, and many other large venues like the World Trade Center and Soldier Field. Boingo serves 2,200 rental communities totaling 300,000+ users residing in properties ranging from single-story buildings to high rises.

Boingo is an expert which builds networks that are future-flexible through a constant focus on R&D and best practices. Boingo can deploy next generation Wi-Fi 6, edge computing, or CBRS and ensure that MDU properties are IoT-ready. Boingo enables MDUs to become fully converged network environments for the benefit of all their stakeholders.

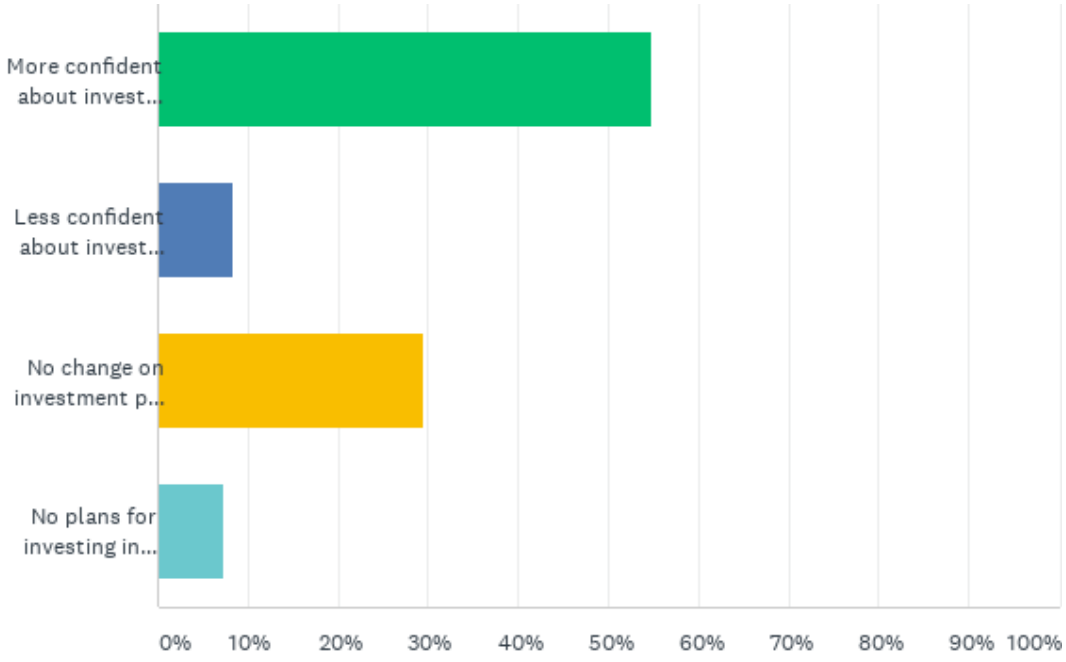
This year's annual WBA survey, as always, highlighted some interesting trends in the changing patterns of technology and business case evolution. As in previous studies, some trends are continuations of previous years' developments, such as the rising diversity of monetisation strategies for Wi-Fi; while others have clearly shifted the goalposts compared to a year ago, such as Wi-Fi 6E.

Confidence to invest is rising despite the pandemic:

One development that was not foreseen in the 2019 survey was the coming of the COVID-19 pandemic. It is a testament to the importance of connectivity in supporting the response to the crisis – in enabling people to work and communicate from any location, for instance – that the Wi-Fi industry has continued to grow in confidence despite the global challenges. Although almost half of respondents (47%) said the pandemic had had a negative impact on their overall business operations, the confidence to invest in Wi-Fi and other unlicensed technologies had grown all the same.

In total, 55% of respondents said their confidence about investing in Wi-Fi had grown over the past year, while only 8.4% had less confidence (Figure 23). This is an even stronger result than in the 2019 survey, when 43% said they were more confident about investing than in the previous year. That implies that investing in the latest Wi-Fi capabilities is seen as a way to help the business to remain resilient under pressure.

Figure 23: How has your confidence towards investing in Wi-Fi changed over the last 12 months?



With regard to other unlicensed technology, confidence is also growing, at about the same rate as in 2019 – in both studies, 37% said they were more confident about investing than a year earlier.

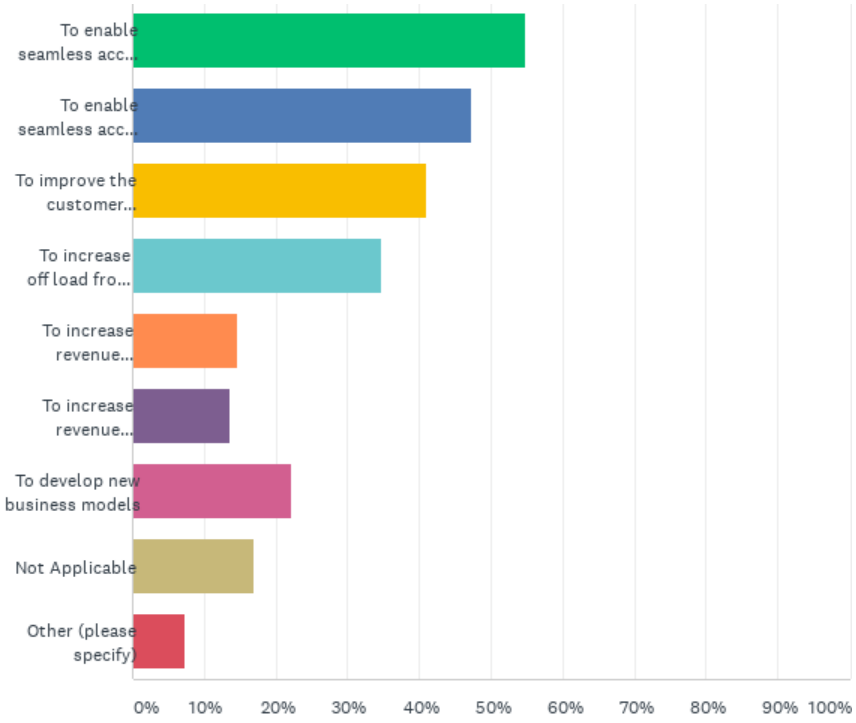
Passpoint, roaming and convergence are important drivers of that confidence:

One of the most important enablers of a robust, monetizable Wi-Fi network is support for the WBA's Passpoint technology, now greatly enhanced by OpenRoaming. In total 43% of respondents said they have already deployed a Passpoint-compliant network, such as OpenRoaming, or plan to do so within a year, while 22% would do so in 2022. This was in line with stakeholders' plans in 2019, though it is notable that, a year ago, more than one-third still did not have a date in mind to implement Passpoint, whereas in 2020, plans and timelines were far more concrete.

There are many drivers of this interest (see Figure 24), but the three which emerged as most important in the survey were:

- To enable seamless access between Wi-FI and licensed networks (55% placed this in their top three)
- To enable seamless access across different networks - roaming (47%)
- And to improve customer quality of experience and so reduce churn (41%)

Figure 24: Please select the top 3 drivers for investing in a Passpoint-compliant network



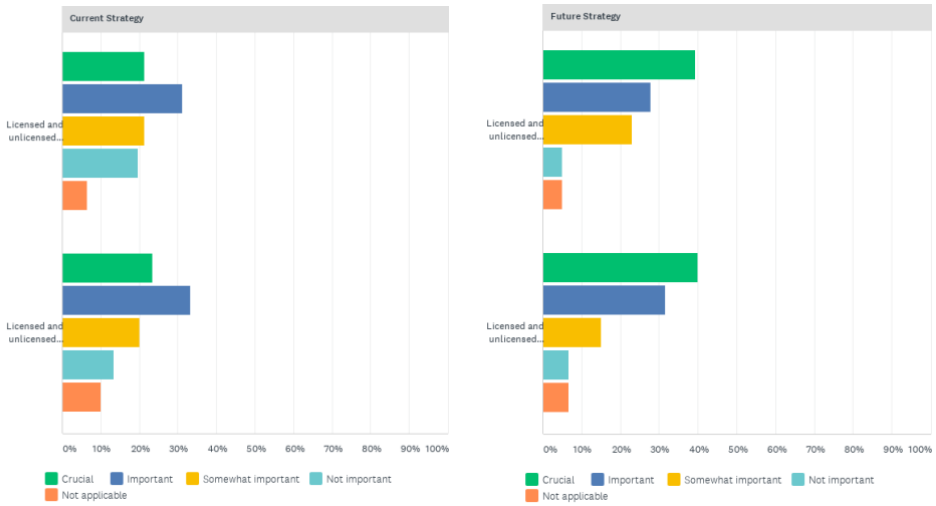
These top drivers were in line with last year's priorities, indicating that multi-network roaming and the quality of experience that can enable are consistent fundamentals in the Wi-Fi business model. Indeed, many service providers and their suppliers are looking beyond roaming between different networks and considering closer convergence and coexistence, particularly with licensed technologies. Convergence allows the strengths of each type of connectivity to be combined to deliver an optimum customer experience (see section 5.4 for more on convergence).

Respondents were asked how important licensed/unlicensed convergence (e.g. aggregation paths, integration) and coexistence (e.g. handover techniques, radio resource management) were to their current and future strategy.

Currently, 52% said convergence was critical or very important to their business strategy, and that figure rose to over 67% with regard to future strategy (for the latter, 39% said convergence would be critical).

As for coexistence, almost 57% said it was critical or very important now, while 72% said the same for the future, with 40% deeming it critical.

Figure 25. Please rate the importance of licensed and unlicensed convergence and coexistence in your current (left) and future (right) network strategy



Much of the positivity about convergence and coexistence relates to delivering a superior user experience, which in turn affects KPIs such as churn reduction and customer satisfaction. This is an ongoing trend – in the 2019 study, 44% already said coexistence would be a key enabler of improved customer experience.

Coexistence will often be achieved through partnership, but some service providers plan to deploy multiple networks themselves. The most common will be LTE, which has already been deployed by 58%, a figure that will rise to 69% in the early 2020s. This will be followed by new variations of the Wi-Fi technologies, particularly in high frequency spectrum (46% of respondents expect to deploy Wi-Fi in millimeter wave spectrum in the coming few years). About half expect to deploy 5G in licensed spectrum, but only 38% in unlicensed spectrum.

By far the most deployed technology, however, will be Wi-Fi 6/6E, with over 65% having already implemented the latest Wi-Fi standard, or planning to do so before the end of 2021. Only 10% have no plans to deploy it at all, indicating the significant momentum building behind this platform.

Wi-Fi 6/6E has an impact on the business model in many ways. Some of these are technological. Some capabilities of the new standard are seen as important to enabling a more efficient, cost-effective and high performance network. Those which are highlighted most by the respondents are OFDMA modulation on both downlink and uplink, which is considered an important improvement by 59% of stakeholders, followed by higher peak speeds and access to new spectrum bands.

The latter is, of course, particularly relevant when it comes to the 6 GHz band, which is being opened up for wireless broadband services in the USA and other markets, with hopes of a global approach (see Chapter section 7.1.6 for more on 6 GHz). About 72% say 6 GHz is critical or very important to their Wi-Fi business – similar to last year - and 40% say the new spectrum will expedite their overall roll-out and expansion of their networks. Some of these hopes will be met where the right regulatory decisions are made – 62% rated additional allocation of 6 GHz spectrum as a very important regulatory issue for their business, only outdone by one other regulatory concern, about security and privacy.

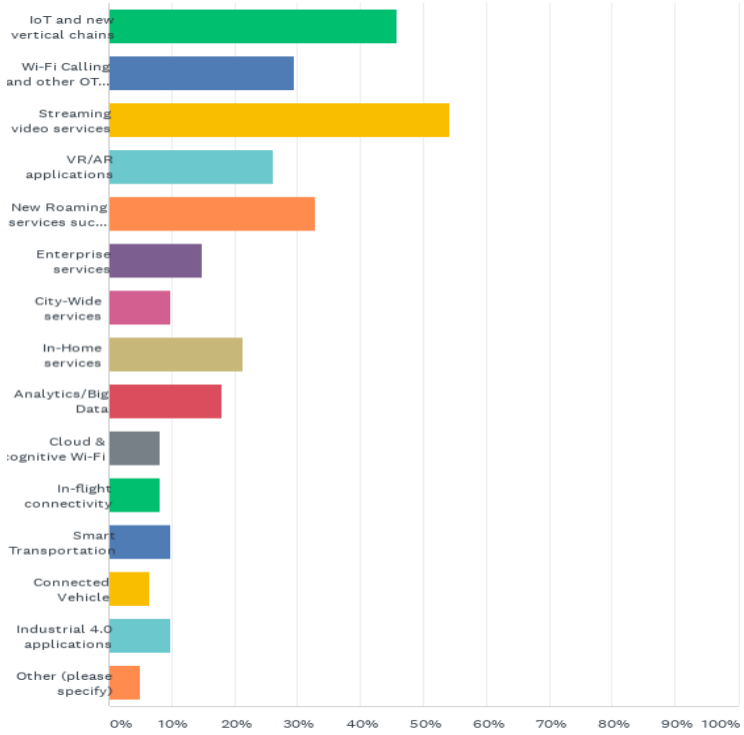
Network advances will support new use cases:

Of course, the reason for the intensifying interest in additional spectrum, convergence and technical capability is that the enhanced networks will support new or improved experiences and services, which can be monetized.

Looking back over previous WBA annual surveys, a clear trend is that the use cases and revenue streams that Wi-Fi will support have proliferated every year. This is enabled by technical progress such as the Wi-Fi 6 features like Multiuser MIMO, and driven by customers' ever-increasing usage of wireless connectivity for every aspect of their lives and work.

When asked to name the top three applications and services that would drive network and usage, respondents focused on a long list of diverse use case categories, but there were some clear leaders (see Figure 26). Streaming video services were cited as a top three network driver by 54% of the stakeholders, followed by IoT and new vertical chains (46%) and new roaming services, such as OpenRoaming (33%).

Figure 26. Please select the top 3 future applications and services most likely to drive overall network and traffic growth



This result shows some development in thinking since a year ago, when IoT, though highly rated, was seen as an opportunity for up to three years' time, while the leading immediate use cases, in addition to streaming video, were Wi-Fi Calling and general enterprise services.

Emerging technologies will help to enable many of these applications, or to improve their cost to operate, or their quality of user experience. Gone are the days when Wi-Fi was purely a connectivity network – now it can be surrounded by many other technologies which work together to enable service diversity.

Edge computing is a hot topic, and 57% believe multi-access edge computing (MEC) will lead to new use cases for Wi-Fi. Other technologies which the survey indicates will be commonly adopted in the coming few years range from new digital identity solutions to AI analytics to blockchain. The most important innovations remain those with a close relationship to the connectivity itself however, led by OpenRoaming, which 46% plan to deploy, private networks in the CBRS spectrum (in the USA), and Wi-Fi Sensing.

The services that these advances support can be divided into three categories where the survey indicates the greatest focus – in-home Wi-Fi, enterprise and vertical industry services, and urban and outdoor connectivity.

In-home Wi-Fi:

Many of the highlighted use cases relate to enterprise, IoT or outdoor usage, but in-home Wi-Fi is an important element of the overall business model. This year, it emerged in sixth place in terms of its likelihood to drive more traffic and business, down from fourth a year earlier, probably because the patterns of usage in the home are well understood and growth rates reasonably predictable.

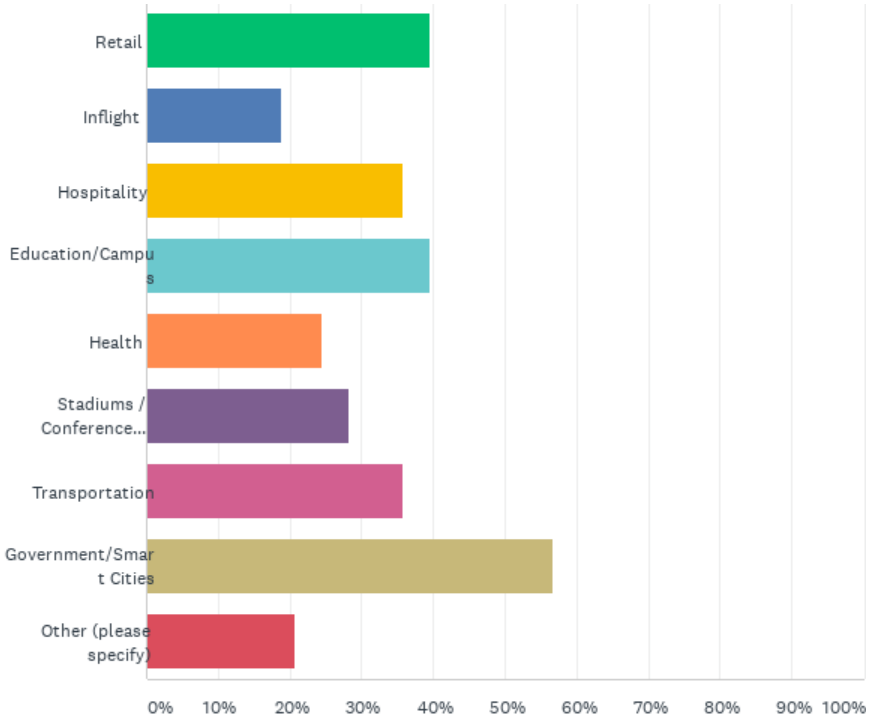
This does not mean there is declining interest in home Wi-Fi. Two-thirds of respondents support in-home services, with managed services such as video distribution or home IoT being the most commonly offered (43%), followed by guest networks (31%) and home office services (26%). In the 2019 study, managed Wi-Fi was even more dominant, with 52% offering it, but home office services were not in the top three, a likely impact of the pandemic.

Home users are demanding, and respondents indicate there are gaps that need to be filled to deliver the optimum experience customers want. Improvements in quality of service (QoS) control, end-to-end security and multi-access point/mesh deployments are all considered important areas for improvement. Last year, the ability to support multi-AP/mesh was the leading in-home gap, and this year's result suggests that the impact of EasyMesh, in particular, is helping service providers optimize their in-home experience.

Industrial and enterprise business models:

The monetization models for Wi-Fi are moving well beyond generic broadband connectivity for enterprises, and service providers are working with partners to develop optimized services and tailored applications for specific industries (see Figure 27). The top three industry verticals targeted by the 2020 survey respondents are government (56% placed it in their top three) followed by retail and education or campus networks (39% apiece).

Figure 27: What are your business's top 3 target verticals, ranked by importance?



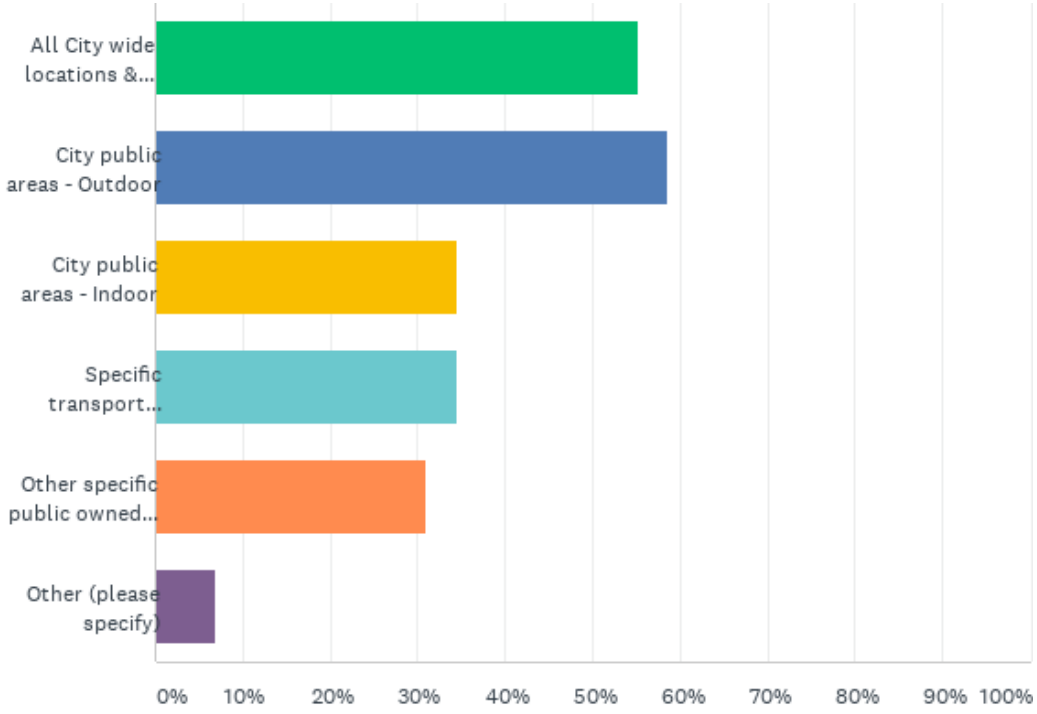
This represents a significant change in priorities since last year, when the most significant target verticals were Wi-Fi in office buildings (in the top three for 66%), hospitality (63%), industrial/manufacturing (45%), and healthcare (39%). The office and hospitality categories are very traditional ones for Wi-Fi, so the change is likely to reflect the maturity of those established models, and the service providers' quest – enabled by new technology and spectrum – to add new industries with high growth potential to their models.

Urban services and city Wi-Fi:

One reason why government is such an important target vertical is that it includes smart cities, which have been a strong basis of Wi-Fi commercial growth and innovation for years, driven and shaped by the WBA's smart city initiatives. Traffic growth is still anticipated all over the complex landscape of cities, despite temporary slowdown in usage in offices and retail malls because of the pandemic. But looking ahead to the coming few years, respondents expect to support traffic growth in may settings, led by train stations and airports, which 21% believe will be a top three driver of growth, followed by enterprise locations, malls and outdoor hotzones.

Indeed, 55% of respondents are involved, or plan to be involved in a city-wide Wi-Fi deployment, with almost half of those having already initiated the roll-out. Within urban environments, over 58% support outdoor Wi-Fi connectivity (see Figure 28). Nearly all respondents have deployments in multiple city locations which can include indoor spaces or transport hubs (35% are active in each of these) and venues owned by private enterprises such as convention centres (31%).

Figure 28: Wi-Fi deployments by area deployed



Monetization strategies and challenges:

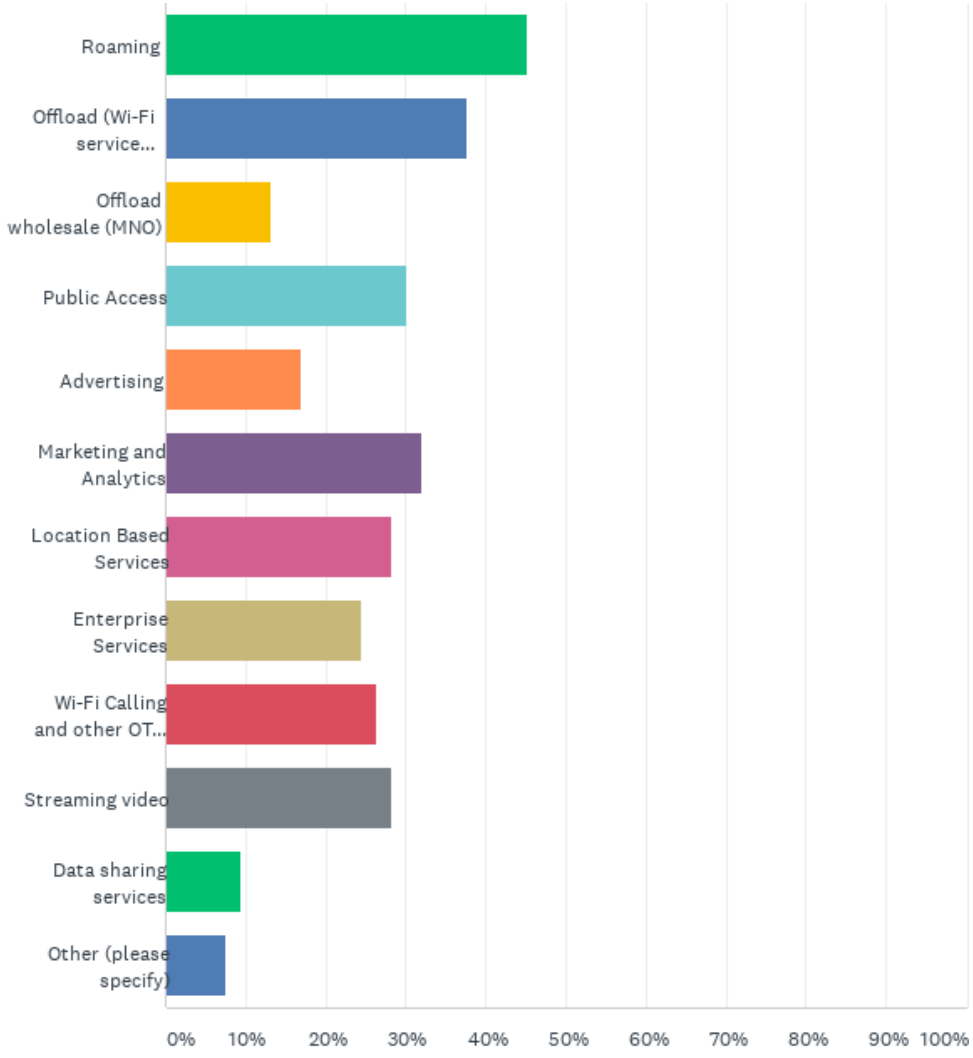
In all these settings – home, enterprise or urban – there are many ways in which service providers can monetize their networks.

Roaming is at the heart of the business model for many players as Figure 29 indicates. This has been a constant theme since the early days of WBA's activities to facilitate roaming and interworking, and this aspect of the Wi-Fi business case has been significantly enhanced by innovations like Passpoint and OpenRoaming. In the 2020 survey, 45% placed roaming in their top three monetization strategies for the coming year, up from 43% a year ago. That was followed by offload (Wi-Fi SP) on 38% and marketing and analytics on 32%. Last year's top three were analytics, enterprise services and roaming in that order.

In public city networks, roaming is especially important – 48% said they offered city Wi-Fi roaming services, or would launch them before the end of 2021, and over half of those planned to provide the services free to end users, perhaps supported by sponsorship or wholesale fees.

Of course, simply providing connectivity is still the foundation stone of the business model. In public city Wi-Fi networks, 72% place connectivity for all users in their top three service priorities, followed by big data analytics and support for specific smart city services.

Figure 29: Please select the top 3 Wi-Fi monetization strategies in terms of importance for the next 12 months



Despite the many, and expanding, options for monetizing Wi-Fi networks, there are still challenges. When asked to name their top three challenges, the respondents were focused, above all, on capex and opex costs, with 66% considering this to be a commercial challenge.

This was well ahead of the next most-cited challenge, which was how to improve customer quality of experience (49%) – something which has been considerably improved by recent developments in spectrum and Wi-Fi capability, as we have discussed. Next on the list came availability of the most capable devices; interoperability of licensed and unlicensed spectrum technologies; and security and privacy concerns.

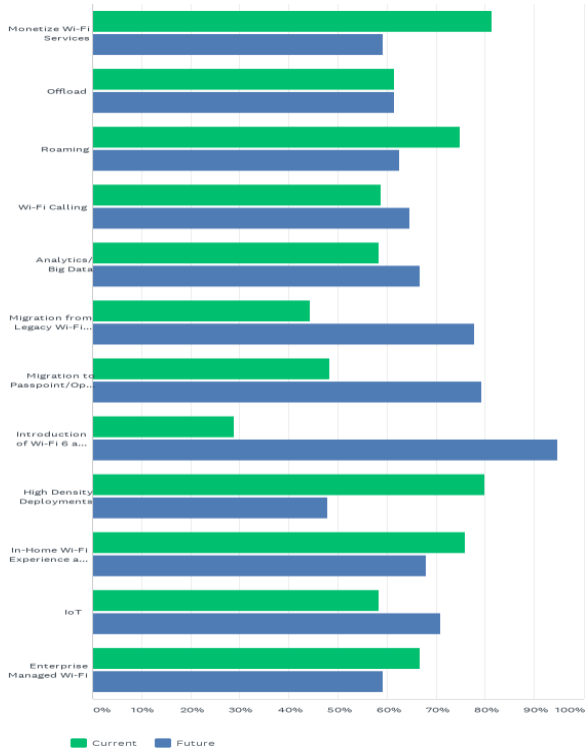
Conclusion – the Wi-Fi platform will continue to expand

To conclude, Wi-Fi is important to different businesses in many different ways, and the richness and diversity of services it enables are growing in line with new spectrum, standards and business models. Figure 30 sums up the many ways in which Wi-Fi will continue to evolve and grow its capabilities to support a wide range of business models.

In their current businesses, the respondents value Wi-Fi particularly highly for supporting services which can be monetized (81% placing in their top three); for enabling very dense deployments, which in turn facilitate additional use cases (80%); and – a strong theme throughout the report this year – for its roaming capabilities (75%).

Looking ahead to future expansion of their models, while those capabilities will remain important, respondents are heavily focused on the next phase of the Wi-Fi platform's development. A full 95% say that the combination of Wi-Fi 6's introduction, with 5G convergence, will be important to their businesses. This is followed by migration to Passpoint/OpenRoaming (79%) and migration to Wi-Fi 6/6E (78%).

Figure 30: In relation to Wi-Fi which top 3 areas are most important to your business?



These final results highlight how the Wi-Fi platform is constantly evolving and so enabling additional services and business cases. Despite the challenges of 2020, the clear roadmap to next generation standards - with enriched spectrum, roaming and convergence – is clearly instilling high levels of confidence in Wi-Fi to support a very wide range of applications and revenue streams in the coming year.