Enhanced Wi-Fi - 802.11ax Decoded

Overview, Features, Use Cases and 5G Context

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DRIVING NEXT WIRELESS EXPERIENCE

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1. Executive Summary

Today, Wi-Fi is a household name, synonymous with delivering high capacity wireless services that are used to support the vast majority of smartphone data usage. This cost-effective technology, coupled with an open ecosystem, together with ease of upgrades that ensure backwards compatibility for all deployed Wi-Fi devices, has created an astoundingly successful market, which last year saw the deployment of over 3 billion new Wi-Fi devices [1]. However, the Wi-Fi industry isn't resting on its laurels. It is not complacent about its ability to continue to help support the tsunami of mobile data. With 802.11ax (11ax), the Wi-Fi industry is introducing, not just the next generation of Wi-Fi, not just a set of increments in terms of better throughput and coverage that improve all existing deployments, but fundamentally new sets of capabilities which can be used by the industry to address a whole new set of opportunities.

This whitepaper serves as an introduction to the key capabilities that are introduced in 11ax. More importantly, it translates these capabilities into the ability to improve existing deployments whilst simultaneously enabling a whole new set of use cases. Some of these use cases will be familiar to those who are following the development of 5G, and it should come as no surprise that this 11ax evolution is set to deliver systems that are ready to support key 5G requirements.

Finally, this paper looks at the economic advantage delivered with Wi-Fi and 11ax, contrasting the monetization opportunities with 5G/Cellular. It is demonstrated how leveraging the new capabilities delivered using 11ax, the Wi-Fi industry can look forward to a bright future where the technology continues to support the vast majority of mobile wireless data consumption.

2. Explosive Wi-Fi use supporting mobile data tsunami

There are currently 8 billion Wi-Fi devices in use, with an astounding 3 billion new Wi-Fi devices being added over the last 12 months [1]. Moreover, irrespective of recent advances in cellular technology.

Increased Demand for Connectivity - The appetite for increased connectivity is showing no signs of abating. It is forecast that by 2021 that there will be 3.5 devices and connections per capita [3]. This is driving rapid growth in mobile data traffic requirements, which are projected to grow at 47% CAGR over the next five years. This growth is coming from multiple different product categories with different key requirements; ranging from certain IoT use cases that require low data rates and low power consumption supported using small battery powered devices, through to Augmented Reality/Virtual Reality use cases that require extreme throughput and low latency.

Use of Unlicensed Spectrum – With nearly 70% of smartphone data being carried over Wi-Fi networks, it is clear that cellular deployments in licensed spectrum have not been able to keep pace with consumer demands for wireless data. This has led to the acceptance of Wi-Fi as an important complement to cellular access, and 3GPP's definition of its 5G Core Network re-enforces this with the ability to better integrate with Wi-Fi access networks as well as its 5G defined New Radio (NR). However, there is also a focus in 5G cellular to improve its competitiveness with Wi-Fi, including defining support for operation in un-licensed spectrum as well as adopting a more flexible authentication framework. While these investments may potentially pay dividends in the years to come, with the launch of 11ax equipment in 2018, Wi-Fi is already evolving to meet the ever-growing demand for wireless data.

3. Wi-Fi Evolution

Wi-Fi technologies have shown a continued evolution both in terms of features and data throughput. 11ax carries on this progression, delivering improvements over the existing 802.11ac feature set as well as introducing a number of significant new capabilities.

These new features include Multi-User (OFDMA/MIMO) support with flexible frequency-domain resource units (RU), scheduled transmissions, Target Wake Time (TWT), low latency, high density deployments, improved outdoor performance and better spatial re-use. Taken together, these features give 11ax a 4-times capacity improvement in dense deployments, along with higher efficiency and improved coverage and performance [4]**,** allowing better operator control in delivering services to meet ever increasing requirements for throughput, latency and connection density while supporting a range of next-generation use cases. These features are illustrated in the table below and further detailed on section 4.

Newly introduced 11ax features	Improved 11ax features compared to 11ac
Target Wake Time	Multi-User MIMO Downlink
OFDMA Uplink & Downlink	Flexible Channel Sizes
Transmission Scheduling (Service Provider Point of View)	Peak Speeds
Multi-User MIMO Uplink	Transmit Beamforming
Spatial Re-Use/Colour Codes	
Dual Band Frequencies (Standardized)	
Improved outdoor performance	
Support of New Frequency Ranges (6 GHz)	

Table 1: New and improved features compared to previous generations

A complete list of new and upgraded MAC and PHY features delivered in 11ax can be found in Appendix A and Appendix B.

4. Decoding Enhanced Wi-Fi – 11ax main features

The following table presents 1) the technical description for each of the umbrella features identified and 2) the business advantage/expected impact a service provider may achieve when deploying 11ax technology:

Feature	Description	Business Advantage/Impact
OFDMA Uplink & Downlink	Increases efficiency and reduces latency as several devices can communicate concurrently, with spectrum resource allocated proportional to needs.	Improves Wi-Fi performance, particularly in high density, high throughput environments (such as stadiums and auditoriums).
Transmission Scheduling	Scheduling allows transmissions to be orchestrated, users are scheduled so that data requests on the uplink do not clash with each other.	Better resource utilization and increased efficiency (latency). Service level assurances can be supported over the 11ax infrastructure.
Multi-User MIMO Uplink & Downlink	Increase channel capacity when servicing multiple simultaneous devices (up to 8x8). Multi-User uplink added to improve real-time traffic performance.	Serves up to 8 users simultaneously for a significant capacity boost. Addresses use cases from enterprise networks, large public venues and multi-dwelling buildings.
Peak Speeds	Faster modulation schemes up to 1024 QAM allows peak gigabit speeds (up to 4x-6x faster than 11ac).	Support new use cases such as UHD Video, AR/VR, and Next-gen e-Classrooms.
Flexible Channel Sizes and Resource Units	Channel sizes are chosen based on different applications (20/40/80/ 160MHz). 20 MHz channels may be further broken down into smaller 2MHz resource units.	More efficient IoT support (when lower data rates are required), allowing devices to use less power, or support greater coverage ranges.
Target Wake Time	Orchestrate specific times when clients wake from sleep to reduce access contention.	IoT low power (constrained) use cases are effectively addressed by significantly improving device battery life.
Spatial Reuse / Color Codes	Differentiates transmissions from neighboring networks. Allows APs to more efficiently share channel capacity.	Collision between signals from nearby networks are mitigated. Useful for venues such as retail malls, multi-dwelling units, etc.
Dual Band Frequencies	Support both 2.4 GHz and 5GHz – now standardized and works across both bands in a unified way.	All previous Wi-Fi generations are compatible and spectrum usage possibilities expand.
Increased Guard Interval and Cyclic Prefix	Increase guard intervals up to 3.2 us and longer cyclic prefix reduces inter-symbol interference.	Improves outdoor deployments, specifically enhances range/ performance.
New Mid-amble	Mid-amble used to improve performance in presence of Doppler.	Improves outdoor deployments, specifically enhances performance in moving environments.
New Frequency Ranges	11ax supported frequency ranges have been extended to include the 6 GHz band.	Enabling new swathes of spectrum to be leveraged for delivering improved performance.

Table 2. 11ax features technical description and business advantages / impact

5. Delivering 5th Generation Capabilities

These enhancements to Wi-Fi's capabilities are occurring at the same time the cellular ecosystem is defining the evolution of its wireless access system, targeted at supporting the 5G requirements laid down by ITU for IMT-2020. These IMT-2020 requirements target

improvements in spectrum utilization, achievable data rates and other characteristics for 5G radio access relative to previous generations of wireless technology [5].

Critically, previous analysis by the WBA has illustrated how the evolution of Wi-Fi specified in 802.11.ax is able to meet or exceed several of the core IMT-2020 requirements [6], facilitating the support of a number of “5G use cases” using Wi-Fi access technology and bringing Wi-Fi performance in line with 5G requirements. WBA’s recent white paper looking into the Role of Wi-Fi and Unlicensed Technologies in 5G Networks has illustrated how using enhanced Wi-Fi as part of the roadmap to 5G can lead to significant benefits, as illustrated in Figure 1.

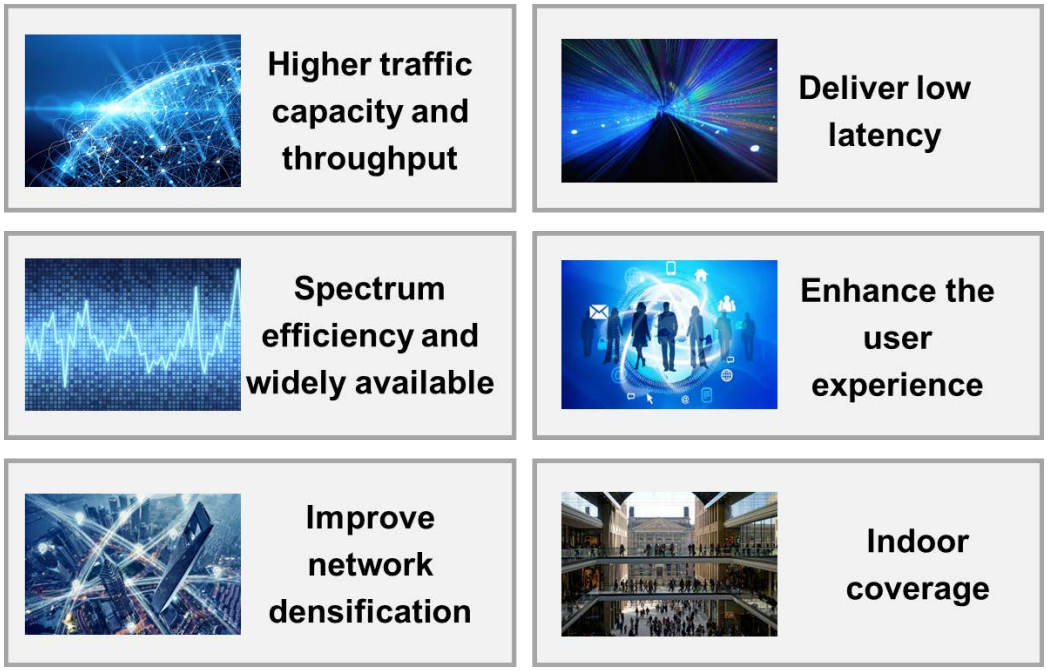

Figure 1. Wi-Fi – 11ax & 5G combined power

However, being “5G-capable” represents more than being able to meet a set of throughput and density requirements. Already we have seen Wi-Fi integrated into key 5G concepts such as ETSI’s Multi-Access Edge Computing architecture. Furthermore, the WBA has recently published collateral demonstrating how Wi-Fi networks are already being sliced to enable support for multiple use-cases on a common infrastructure. Hence, it should come as no surprise that Wi-Fi evolution is ready to support 5G capabilities and use cases. Figure 2 compares Wi-Fi capabilities delivered with 11ac and 11ax defined functionalities.

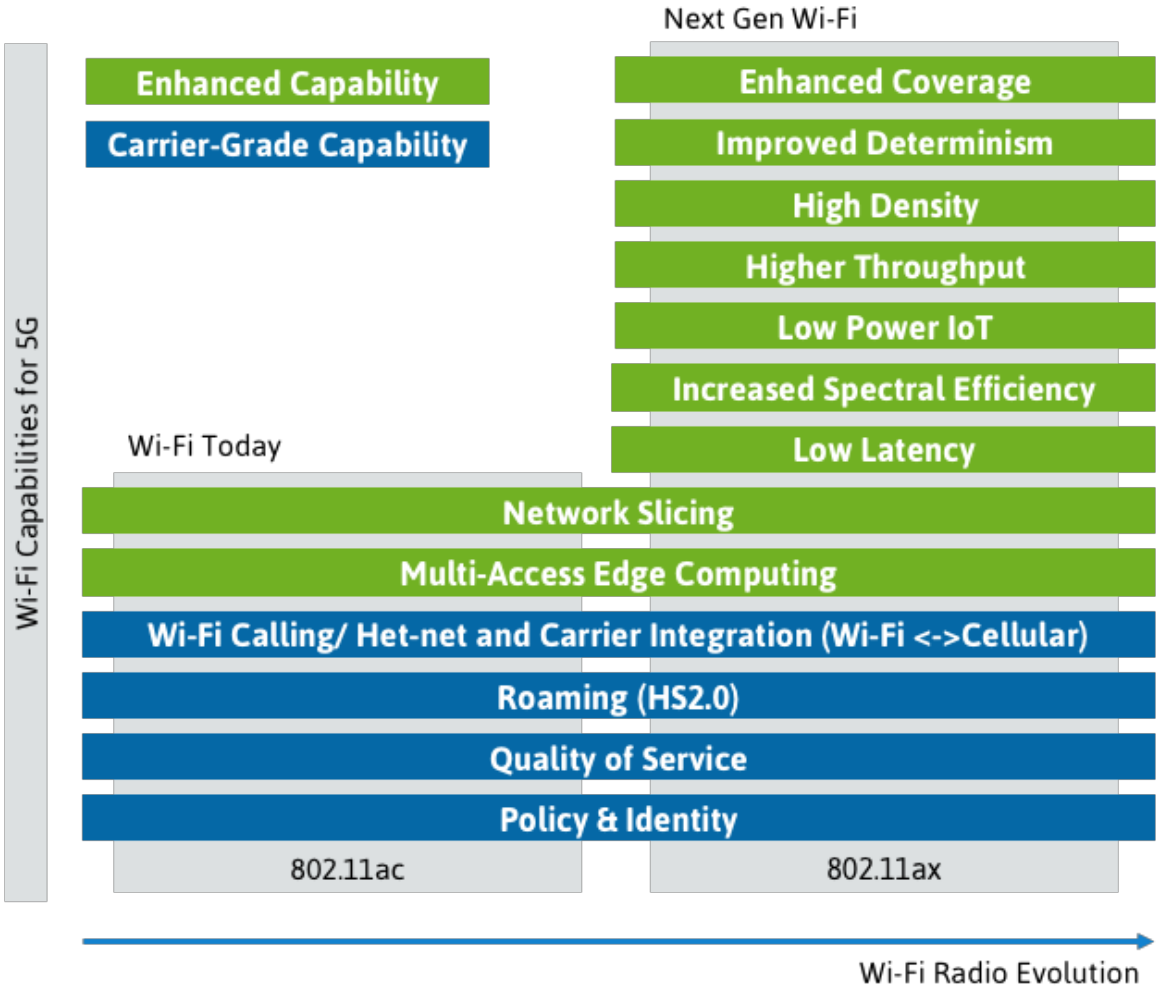

Figure 2. Wi-Fi capabilities for 5G delivered with 11ac & 11ax

6. Key 11ax Enabled Use Cases

From a vertical use case perspective, 11ax delivers new and improved capabilities for addressing a broad range of verticals, including:

1. High Density Deployments

- Increased network performance in high density networks is one of the primary goals of 11ax. Leveraging 11ax multi-user scheduling and BSS coloring, service providers deploying Wi-Fi in high density areas, such as stadiums, airports, train stations, shopping malls and college campuses, can greatly benefit from 11ax, enabling more devices to be supported whilst delivering a better user experience.

2. **Transportation**
    - Lower latency and increased determinism enable managed service providers to support automated vehicle use cases, for example, supporting improved control and management of Automated Guided Vehicles (AGV) within industrial environments.
    - Improved outdoor performance enables Wi-Fi deployments to better serve connected car use cases, allowing Wi-Fi to offload the delivery of firmware-over-the-air (FOTA) updates from the cellular network.
    - The increase guard intervals and mid-ambles defined in 11ax enhances the ability to support payment and ticketing services, enabling vehicles travelling faster through automated barriers and so allowing quicker traffic flows.
3. **Retail (Shopping malls)**
    - Moving forward, the new 11ax frame structure is targeted as being used as the foundation for delivering improved accuracy for Wi-Fi based location determination. Existing Wi-Fi retail use cases that leverage location, including dwell time analytics and targeted advertisement systems will benefit from such improvements.
4. **Enterprise**
    - Almost all enterprises are carpeted with Wi-Fi, and demand for Wi-Fi in enterprise is increasing with growing number of devices and more bandwidth hungry applications. With 11ax delivering improved efficiency and network performance, managed service providers can offer better data connectivity to serve high productivity needs, supporting the evolving workspace needs of the enterprise.
    - With the resource allocation and scheduling support of 11ax, in building voice services with Wi-Fi Calling experience is significantly improved, whilst simultaneously enabling 11ax to sustain a larger number of simultaneous voice calls over extended coverage areas.
5. **Entertainment (Stadia)**
    - The higher throughput, lower latency and improved determinism of 11ax enables the deployment of AR/VR services throughout next-generation sporting environments.
    - Service providers can leverage the pervasive coverage to enable new immersive experiences that use a broad range of advanced applications and services such as AR/VR, 8K/360-degree videos, all with more predictable performance.

6. **Smart Cities (Outdoor)**
    - With the enhanced throughput, extended range, and improved interference immunity capabilities, service providers can use 11ax for enabling last mile point-to-point or point-to-multipoint wireless links.
    - The high-density capabilities integrated into 11ax, enable service providers to deploy systems able to support the extreme IoT densities that have been called out as key 5G system requirements.
    - The cell-site densification that is accompanying 5G build out is also going to drive innovative approaches to delivering last mile connectivity to the myriad of urban cell-sites. Smart city deployments of 11ax can be leveraged to support the backhaul for hyper-dense 5G deployments.
7. **Smart Villages/Last Mile**
    - The higher throughout and increased range of 11ax make it suitable for delivering last mile connectivity solutions, offering alternatives to conventional copper and fiber-based solutions.
    - The ability to support the significant portion of devices still operating using 2.4 GHz enables 11ax operators to offer investment protection coupled with ease of adoption.
8. **Residential (Single and multi-dwelling units)**
    - The increased throughput and improved range enhances the quality of experience of residential Wi-Fi users.
    - Service providers supporting deployments in Multi Dwelling Units, are able to more effectively use of the spectrum via BSS coloring to allow more throughput and less contention between neighbors.
    - The ability of 11ax to support multi-channel widths for simultaneous users, facilitates the deployment of mesh network to extend the coverage of residential networks as well as being able to seamlessly support low power IoT use cases on converged architectures.
9. **Industrial**
    - Operating in new 6GHz spectrum enables 11ax systems supporting industrial automation to be isolated from the impact of massive adoption by other enterprise users.
    - The improved determinism, lower latency, longer range and higher throughput will facilitate the use of 11ax for supporting Wi-Fi based industrial automation use cases.

10 IoT

- This is a core use case which benefits significantly from the features that are made available by .11ax, ranging from narrow dedicated channels and power saving options to target wake time features. 11ax allows IoT devices to make greater use of the Wi-Fi service that only require lower data rates, longer range, while also delivering further power consumption gains.

11. Mobile broadband

- Through the benefits provided from the new .11ax standard an improved, more complete, service both indoors and out is offered, with aggregation supporting more simultaneous users, enhancing data rates and providing better support for voice calling.

7. 802.11ax Business Advantages

When deciding on their future strategy for delivering next generation wireless services, service providers need to consider a variety of issues, including:

- Size of ecosystem support
- Compatibility with existing networks and devices
- Re-usability of management platforms
- Densification and scalability capabilities
- Broad device support supporting consumer and IoT segments
- Spectrum availability and regulations
- Cost of equipment

With 11ax, Wi-Fi is well positioned to address all of these critical aspects. The new 11ax capabilities can be used by service providers to deliver “5G use cases” in a very cost-efficient manner. Moreover, already leveraging free, global and widely available spectrum at 2.4 and 5 GHz, Wi-Fi and 11ax is set to benefit from new spectrum allocations in 6 GHz, to support the future scaling requirements of wireless systems.

The remainder of this section describes specific advantages offered by 11ax technology.

7.1. Investment Effectiveness

Perhaps the greatest factor in the success of Wi-Fi is the effectiveness of the economic investment. Retailers, manufacturers, service industries, transportation and communities around the world have recognized the basic 'economic value' realized with Wi-Fi solutions.

There are four key drivers of this high Return on Investment (ROI):

1) Low Cost of Deployment

   Access Point (AP) devices are available with a wide range of prices and features; from low cost home devices for less than $30 to enterprise class devices that can cost more than $300, there is a solution optimized for every application. In fact, there are more than 20,000 different wi-fi devices on the market today, far more than any other wireless technology. The low cost and diversity of Wi-Fi devices enables new applications to emerge, providing value to nearly every market on the planet from agriculture to zoology.

2) Return on Investment of Unlicensed Spectrum

   In the US alone, over $525 Billion dollars of economic value has been attributed to Wi-Fi technology [8]. The unlicensed spectrum bands in 2.4 and 5 GHz provide the medium for this remarkable economic engine, with Wi-Fi providing the technology that enables multiple users to efficiently share the spectrum with each other, and in some cases, with primary spectrum users of other technologies. Plans to provide more unlicensed spectrum for continued expansion of Wi-Fi solution should enable this key capability to continue to be a key differentiator into the future.

3) Customer/User value of ubiquitous access

   Clearly, customers find value in wireless access to the internet. So much so that they will change their shopping, airline and cable operator based upon the quality, quantity and cost of internet access. Many retailers have successfully translated this customer value into increased sales by wining customers over with simply better 'free wi-fi' services.

   These public services have become so ubiquitous in our society that we are now surprised to find a coffee shop, restaurant, shopping mall, airport, hotel, etc. that do not offer this service! Many retailers (airlines, hotels in particular) have realized that the deployment and operational costs can be covered by supporting alternative value chains, meaning that they no-longer need to charge their users for the Wi-Fi connection.

4) Service based economic model rather than access based

By 2025 the economic value of Wi-Fi in the US is forecasted to exceed $850 Billion [8]. Zero dollars of that economic value is based upon user paid 'access' to the spectrum or Wi-Fi. Access to Wi-Fi is 'free' because the economic model is based upon the value of the services provided rather than the access. Wi-Fi networks are monetized using a variety of techniques, that can range from delivering footfall analytics to retailers, to delivering enhanced fan experiences to stadium visitors. This is a vital and key differentiator over cellular service economics, which are all about users paying for access and the cost of spectrum.

The resulting consequences to investment and deployment of services between cellular services and Wi-Fi is dramatically different. In the cellular model, deployment is dependent upon, and limited by, the vertical market investment strategy of only a few mobile carriers. By contrast, Wi-Fi networks are deployed by carriers, but over 90% deployments are made by thousands of industries, retailers, communities and individual users and limited only by the value realized in those deployments.

7.2. Time to Market

At the time of writing, the ratification timeframe for the 11ax standard is targeted for Q4 2019. However, as with previous Wi-Fi standards, multiple WBA members will deliver forward-compatible "pre-11ax" products prior to ratification [7].

With so many new capabilities being delivered in 11ax, it is expected that the ramp in deployments will mean that 11ax will lead 5G by several years, as illustrated in Figure 3. Moreover, the backwards compatibility guarantees, means that the existing device ecosystem can be seamlessly supported using the very latest equipment, not a characteristic available to 5G New Radio deployments. The result is that even by 2025, the GSMA is predicting that fewer that 15% of global mobile connections will use 5G technology [9], compared with 11ax which is forecast to be used in over 70% of the enterprise-class Wi-Fi shipments by 2022 [10].

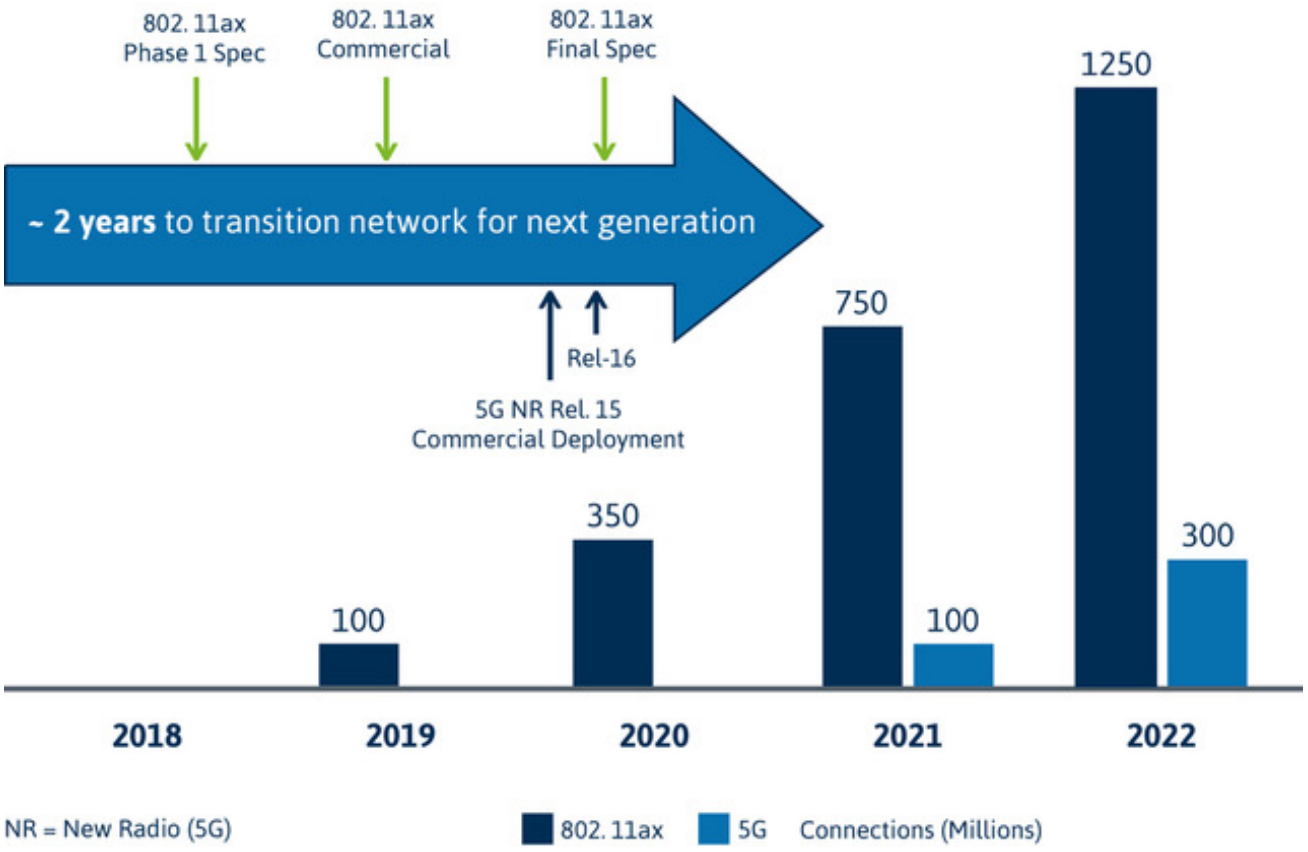

Figure 3. Uptake of 5G and 11ax based on the number of connections (Source: ABI (11ax) [11], GSMA (5G) [12])

7.3. 11ax Capacity and Density Improvements

While Wi-Fi has long supported dense deployments, reliability has been a challenge for installations in highly-congested areas like transportation hubs, stadiums and shopping malls. This is because the overhead associated with large numbers of devices contending for the network overwhelms the Wi-Fi protocol. This issue will worsen as the number of consumer and IoT devices grows and the demand for data increases.

With the launch of 11ax, Wi-Fi addresses these protocol limitations, achieving up to four times capacity improvement. This is based on several major technological innovations, including OFDMA, which allows dynamic allocation of spectrum to multiple devices, improved scheduling to ensure efficient use of the airwaves and improved spectral re-use allowing overlapping Wi-Fi networks to co-exist.

8. Summary

This short whitepaper serves as an introduction to the key capabilities that are introduced in 11ax.

Whereas some may view 11ax as “just the next evolution in Wi-Fi technology”, this paper has introduced its key functionalities and illustrated how not only does 11ax improve the capabilities of all existing Wi-Fi systems, but will deliver a raft of new features that enable Wi-Fi operators to address a whole new set of use cases. The paper translates these features into clear business impacting advantages for the Wi-Fi community.

Some of these new use cases addressable using 11ax technology will be familiar to those who are following the development of 5G, and it should come as no surprise that this 11ax evolution is set to deliver systems that are ready to support key 5G requirements.

Finally, this paper looks at the economic advantage delivered with Wi-Fi and 11ax, contrasting the monetization opportunities with 5G/Cellular. It is demonstrated how leveraging the new capabilities delivered using 11ax, the Wi-Fi industry can look forward to a bright future where the technology continues to support the vast majority of mobile wireless data consumption.

8.1 Next Steps – WBA’s work stream details

WBA has recently started a new work group “Enhance Wi-Fi 11ax” to examine and decode the key 11ax features for various operator deployment scenarios, provide 11ax guidelines and requirements for operator networks.

WBA is taking the lead in analyzing the 11ax and its importance for the operator community and showcase the “operator-grade” capabilities of 11ax systems.

WBA is working on developing test cases to have early trials of 11ax in end-to-end real-life operator networks with the participating WBA vendors and operator members. It will cover the key use cases in different verticals as highlighted above with the main objective of ensuring 11ax is trialled and ready for operators’ deployments.

WBA invites the broader industry to take advantage of 11ax program to validate the compelling technical and business benefits of 11ax.

For more information contact the WBA Program Management Office (pmo@wballiance).

Appendix A – Mapping PHY Features

			Matching w/ 11ax Section 2 & Annex "decoding IEEE 11ax features"		
	PHY Features	**New / 11AC Improve**	**High Level Feature 1**	**High Level Feature 2**	**High Level Feature 3**
1	SU MIMO: SU MIMO with >= 2 spatial streams	**AC Improve**	Peak Speeds		
2	HE_SU preamble format in HE SU PPDU	**New**	Peak Speeds		
3	DL OFDMA	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
4	HE_MU preamble format used in HE MU (DL) PPDU	**New**	OFDMA Uplink & Downlink	Multi-User MIMO Uplink & Downlink	Transmission Scheduling
5	UL OFDMA	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
6	UL MU-MIMO (up to 8 users)	**New**	Multi-User MIMO Uplink & Downlink	Peak Speeds	
7	HE_TRIG preamble format used in HE TB (UL) PPDU transmitted in response to Trigger frame	**New**	OFDMA Uplink & Downlink	Multi-User MIMO Uplink & Downlink	Transmission Scheduling
8	Time, frequency, and power pre-correction for UL OFDMA and UL MU-MIMO	**New**	OFDMA Uplink & Downlink	Multi-User MIMO Uplink & Downlink	Transmission Scheduling
9	DL MU-MIMO (up to 8 users)	**New**	Multi-User MIMO Uplink & Downlink	Peak Speeds	
10	Tx Beamforming (DL) with SU	**AC Improve**	Peak Speeds		
11	Packet Extension	**New**	Increased Guard Interval/Cyclic Prefix/Symbol Time/Frame Duration		
12	MCS 10-11 in payload of HE SU, HE MU, and HE TRIG PPDU	**New**	Peak Speeds		
13	MCS for HE-SIG-B transmission used in HE MU PPDU	**New**	OFDMA Uplink & Downlink	Multi-User MIMO Uplink & Downlink	Transmission Scheduling
14	HE-LTFs with short and long GI in HE SU PPDU, HE MU format, and HE TRIG PPDU: (6.4us LTF, 0.8us GI),(6.4us LTF, 1.6us GI),(12.8us LTF, 3.2us GI)	**New**	Increased Guard Interval/Cyclic Prefix/Symbol Time		

			Matching w/ 11ax Section 2 & Annex "decoding IEEE 11ax features"		
	PHY Features	**New / 11AC Improve**	**High Level Feature 1**	**High Level Feature 2**	**High Level Feature 3**
15	HE-LTF/GI Combination in HE NDP (6.4 us LTF, 0.8 us GI), (6.4 us LTF, 1.6 us GI), and (12.8 us LTF, 3.2 us GI)	**New**	Increased Guard Interval/Cyclic Prefix/Symbol Time		
16	Channel Width: 20MHz in 2.4 GHz band	**AC Improve**	Dual Band Frequencies		
17	Channel Width: 20MHz, 40MHz, 80MHz, and 160MHz in 5GHz band	**AC Improve**	Dual Band Frequencies		
18	20MHz-Only STA operation in wideband OFDMA	**New**	Transmission Scheduling	Target Wake Time	OFDMA Uplink & Downlink
19	6 GHz support	**New**	Support of New Frequency Ranges		
20	Extended range	**New**	Transmission Scheduling		
21	Mobility (Doppler) support	**New**	Transmission Scheduling		

Appendix B – Mapping MAC Features

			Matching w/ 11ax Section 2 & Annex "decoding IEEE 11ax features"		
	MAC Features	**New / 11AC Improve**	**High Level Feature 1**	**High Level Feature 2**	**High Level Feature 3**
1	Basic trigger frame	**New**	HE UL MU Operation	Transmission Scheduling	
2	HE MU UL operation using UL OFDMA	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
3	HE MU UL operation using UL MU MIMO	**New**	HE UL MU Operation		
4	UL MU sensing rules: CS Required indication in trigger; ED sensing and NAV consideration requirement	**New**	HE UL MU Operation	Transmission Scheduling	
5	Channel Access Rules for Trigger-based PPDU transmission	**New**	HE UL MU Operation		
6	MU EDCA Parameter for channel access	**New**	HE UL MU Operation	Transmission Scheduling	
7	Beamforming Report Poll (BRP) - Trigger variant	**New**	HE UL MU Operation	Transmission Scheduling	
8	Tx beamforming (MU) Sequence Trigger-based sounding	**New**	HE UL MU Operation	Transmission Scheduling	
9	MU_BAR Trigger variant	**New**	HE UL MU Operation	Transmission Scheduling	
10	DL MU PPDU followed by BlockAckReq or MU-BAR variant soliciting a BlockAck frame response	**New**	HE UL MU Operation	Transmission Scheduling	
11	MU-RTS Trigger variant	**New**	HE UL MU Operation	Transmission Scheduling	
12	MU-RTS and CTS procedure	**New**	HE UL MU Operation	Transmission Scheduling	
13	BSRP Trigger variant	**New**	HE UL MU Operation	Transmission Scheduling	
14	Trigger frame format: BSRP trigger variant in S-MPDU or non-A-MPDU	**New**	HE UL MU Operation		
15	Trigger frame format: BQRP trigger variant	**New**	HE UL MU Operation		
16	Trigger frame format: GCR MU BAR	**New**	HE UL MU Operation		
17	Trigger frame MAC padding	**New**	HE UL MU Operation	Transmission Scheduling	
18	HE Variant of HT Control	**AC Improve**	Flexible Channel Size*		
19	Receive Operating Mode	**AC Improve**	Flexible Channel Size		
20	Transmit Operating Mode	**New**	Flexible Channel Size		

			Matching w/ 11ax Section 2 & Annex "decoding IEEE 11ax features"		
	MAC Features	**New / 11AC Improve**	**High Level Feature 1**	**High Level Feature 2**	**High Level Feature 3**
21	HE Variant of HT Control: UL MU Response Scheduling Control Subfield	**New**	Flexible Channel Size		
22	HE Variant of HT Control: HE Link Adaptation Control Subfield	**New**	Flexible Channel Size		
23	HE Variant of HT Control: Buffer Status Report Control subfield	**New**	Flexible Channel Size		
24	HE Variant of HT Control: BQR A-Control	**New**	Flexible Channel Size		
25	HE Variant of HT Control: RDP A-Control	**New**	Flexible Channel Size		
26	HE MU DL operation using DL OFDMA	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
27	DL MU PPDU soliciting an SU PPDU response which contains ACK/C-BA/M-BA	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
28	DL MU PPDU soliciting and HE Trigger-based PPDU response which contains ACK/C-BA/M-BA	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
29	Acknowledgement (ACK/C-BA) in DL OFDMA MU PPDU in response to UL data transmitted in MU PPDU	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
30	Acknowledgement (M-BA) in SU PPDU in response to UL data transmitted in MU PPDU	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
31	Multi-STA Block ACK	**New**	OFDMA Uplink & Downlink	Transmission Scheduling	
32	Compressed BA (C-BA) variant in BlockAck (BA) Frame with A-MSDUs ACKed=256	**New**	Peak Speeds		
33	Tx beamforming (SU) Sequence: DL Non-trigger based Sounding	**AC Improve**	Transmission Scheduling		
34	HE Sounding (Tx beamforming Sequence): UL Non-trigger-based Sounding for SU Type feedback	**New**	Sounding Enhancements		

*Also referred to as Fast Control Signaling

			Matching w/ 11ax Section 2 & Annex "decoding IEEE 11ax features"		
	MAC Features	**New / 11AC Improve**	**High Level Feature 1**	**High Level Feature 2**	**High Level Feature 3**
35	HE Sounding (Tx beamforming Sequence): Trigger-based sounding for Full and partial BW SU-Type feedback	**New**	Sounding Enhancements		
36	HE Sounding (Tx beamforming Sequence): Trigger-based sounding for Full BW MU-Type Feedback	**New**	Sounding Enhancements		
37	HE Sounding (Tx beamforming Sequence): Trigger-based sounding for partial BW MU-Type Feedback	**New**	Sounding Enhancements		
38	HE Sounding (Tx beamforming Sequence): Trigger-based CQI-Only for partial and full BW Feedback	**New**	Sounding Enhancements		
39	TXOP based RTS enablement	**New**	Network Efficiency	Transmission Scheduling	
40	A-MPDU in a HE Triggered-based PPDU	**New**	Peak Speeds	OFDMA Uplink & Downlink	Transmission Scheduling
41	Multi-TID A-MPDU in HE SU PPDU, HE MU PPDU, and HE TB PPDU	**New**	Peak Speeds	OFDMA Uplink & Downlink	Transmission Scheduling
42	Target Wake Time (TWT) and its variants	**New**	Power Save	Transmission Scheduling	
43	Spatial Reuse Operation	**New**	Spatial Re-Use/Colour Codes		
44	HE Dynamic fragmentation	**AC Improve**	Peak Speeds		
45	Multi-BSSID: Multiple BSSID enhancements	**AC Improve**	Network Efficiency	Transmission Scheduling	
46	Power Save: Intra PPDU power save	**New**	Power Save		
47	Power Save: Cascade Indication	**New**	Power Save		
48	Power Save: Target Tx Time of Trigger frame for Random Access	**New**	Power Save		
49	Power Save: Opportunistic Power save	**New**	Power Save		
50	ER SU PPDU Operation	**New**	Longer Range		
51	6GHz operation	**New**	Support of New Frequency Ranges		
52	20MHz-Only STA operation in wideband OFDMA	**New**	Power Save		

			Matching w/ 11ax Section 2 & Annex "decoding IEEE 11ax features"		
	MAC Features	**New / 11AC Improve**	**High Level Feature 1**	**High Level Feature 2**	**High Level Feature 3**
53	80MHz STA operating in 160MHz OFDMA	**New**	Network Efficiency		

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ACRONYMS AND ABBREVIATIONS

ACRONYM / ABBREVIATION	DEFINITION
AGV	Automated Guided Vehicle
AR	Augmented Reality
BAR	Block Acknowledgment Request
BQRP	Bandwidth Query Report Poll
BRP	Beam Refinement Protocol
BSRP	Buffer Status Report
BSS	Basic Service Set
BSSID	Basic Service Set Identifier
CAGR	Compound Annual Growth Rate
C-BA	Compressed Block Acknowledgement
CQI	Channel Quality Indication
CS	Carrier Sense
CTS	Clear to Send
ED	Energy Detection
EDCA	Enhanced Distributed Channel Access
FOTA	Firmware over the air
GCR	GroupCast with Retries
GI	Guard Interval
HE	High Efficiency
HS2.0	Hotspot 2.0
HT	High Throughput
IoT	Internet of Things
LTF	Long Training field
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIMO	Multi-Input Multiple-Output
MPDU	MAC Protocol Data Unit
NDP	Null Data Packet
NR	New Radio

OFDMA	Orthogonal Frequency Division Multiple Access
PPDU	PLCP Protocol Data Uni
QAM	Quadrature Amplitude Modulation
RDP	Reverse Direction Protocol
RoI	Return on Investment
RTS	Request to Send
RU	Resource Unit
STA	Station
SU	Single User
TB	Trigger Based
TCO	Total Cost of Ownership
TID	Traffic Identifier
TWT	Target Wake Time
TXOP	Transmission Opportunity
UHD	Ultra-High Definition
VR	Virtual Reality

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