How Wi-Fi Continues to Evolve to be The Solution to Wireless Data Demand

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NEED FOR SPECTRUM DRIVEN BY WIRELESS DATA DEMAND

The demand for wireless data continues on its dramatic growth trend, driven by streaming video to wireless devices. According to Cisco’s 2019 Visual Networking Index, overall mobile data traffic is expected to grow to 77 exabytes per month by 2022, a seven-fold increase over 2017 as seen in Figure 1. Additionally, mobile data traffic will grow at a CAGR of 46 percent from 2017 to 2022, driven by increasingly smarter devices capable of higher data speeds and hence more data-hungry applications.

Figure 2 shows that as the home becomes increasingly connected, the demand for data capacity is exploding.

The critical nature of spectrum to wirelessly carry all of this data, is shown by the recent FCC Auction 107, when over $81 billion was paid for 280 MHz of spectrum in the U.S. Resonant highlighted the need for more spectrum in the recent white paper (Maximizing Spectral Efficiency to Overcome A Spectrum Deficit in a 5G World – PDF download), and fortunately there are alternatives to complement licensed spectrum usage, in particular, off-loading capacity to unlicensed spectrum.

LICENSED VS. UNLICENSED SPECTRUM

Unlicensed spectrum expands the capacity available to mobile network operators (MNOs). Currently, unlicensed spectrum is the foundation for a number of wireless local area networks (LANs), scientific and short-range consumer use (Wi-Fi, Bluetooth, ultra-wideband (UWB), etc.). The advantage of unlicensed spectrum (see Figure 3) is that it is free for all to use, however it has limited range when compared to licensed spectrum to minimize interference issues. The relative lack of regulation also means there are no guarantees for quality of service and security.

Mobile operators can offload data traffic from their licensed spectrum to unlicensed Wi-Fi networks as seen in Figure 4. Initially operators were resistant to moving users onto Wi-Fi networks because of the negative revenue implications and relatively unmanaged frequency situation. However, the widespread availability of Wi-Fi functionality on smart devices, the potential for an overall improved quality of service and the ability to stream video to smartphones in dense environments was actually driving customer retention.
**WHAT IS Wi-Fi?**

Wi-Fi is not an acronym; it is a brand name that serves as an interoperability seal of approval. The IEEE 802.11 standard defines the protocols that enable communications with current Wi-Fi-enabled wireless devices, including wireless routers and wireless access points (APs). The standards operate on varying frequencies, deliver different bandwidth, and support different numbers of channels.

More recently, to add specificity to the term Wi-Fi, the naming convention includes a number. For example, technology that is compliant with 802.11ax is called Wi-Fi 6. This nomenclature also aligns more closely to the different generations of licensed cellular technologies (i.e. 4G, 5G).

Wi-Fi differs from other wireless technologies, including Bluetooth and the wide-area cellular networking used by wireless service providers. In basic terms, Bluetooth is utilized for short-range wireless connections, for example, from a smartphone to a speaker or headphones. Wi-Fi is used for LAN connections, such as in a home or office setting. Longer-range connections use wide area, cellular networks, such as 4G or 5G. While some of these technologies can overlap with each other, the distance comparison is generally accepted differentiation between the technologies.

**ADVANTAGES OF Wi-Fi 6 AND Wi-Fi 6E**

Although the maximum theoretical data speed of Wi-Fi 6 at 9.8 Gbps is a nice boost over the 3.5 Gbps of Wi-Fi 5, it is really more about maintaining high speeds as more and more devices are added to the network. With Wi-Fi 5, the effect of multiple devices requiring high speed wireless connectivity – for example, one person on a video call, one person streaming a movie and one person gaming – has an immediate impact on the network. This is sometimes seen

<table>
<thead>
<tr>
<th>Standard</th>
<th>Launch Date</th>
<th>Frequency (GHz)</th>
<th>Bandwidth (MHz)</th>
<th>Max. Data Rate (Mbps)</th>
<th>Modulation</th>
<th>MIMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiFi 1</td>
<td>802.11b</td>
<td>1999</td>
<td>2.4</td>
<td>20</td>
<td>11</td>
<td>HR-DSSS</td>
</tr>
<tr>
<td>WiFi 2</td>
<td>802.11a</td>
<td>1999</td>
<td>5</td>
<td>20</td>
<td>54</td>
<td>OFDM</td>
</tr>
<tr>
<td>WiFi 3</td>
<td>802.11g</td>
<td>2003</td>
<td>2.4</td>
<td>22</td>
<td>54</td>
<td>OFDM/2/5/3</td>
</tr>
<tr>
<td>WiFi 4</td>
<td>802.11n</td>
<td>2003</td>
<td>2.4/5</td>
<td>20/40</td>
<td>600</td>
<td>OFDM</td>
</tr>
<tr>
<td>WiFi 5</td>
<td>802.11ac (Wave 1)</td>
<td>2013</td>
<td>5</td>
<td>20/40/80</td>
<td>1730</td>
<td>64-QAM</td>
</tr>
<tr>
<td>WiFi 5</td>
<td>802.11ac (Wave 2)</td>
<td>2015</td>
<td>5</td>
<td>20/40/80/160</td>
<td>3460</td>
<td>256 QAM</td>
</tr>
<tr>
<td>WiFi 6</td>
<td>802.11ax</td>
<td>2020</td>
<td>2.4/5/6</td>
<td>20/40/80/160</td>
<td>9600</td>
<td>1024 QAM</td>
</tr>
</tbody>
</table>

The term “Wi-Fi” caught on because it was simpler than trying to keep up with the “alphabet soup” that was created by the names of each subsequent standard for the technology as it evolved. Oddly, 802.11b was developed before 802.11a, and then it evolved into 802.11g, 802.11n and other letters. Instead of having users memorize which letters they were using on a particular device to see if it would connect, people just started to refer to the entire technology as Wi-Fi.
in videoconference “switch off your video,” messages, or a blue circle buffering and lag. Wi-Fi 6 may not increase the data speed to a single device, but it will allow the same high data speed for multiple devices, which is critical as we add more Wi-Fi connectivity to the home and office.

This increase in the ability to handle more devices results from two technologies incorporated into Wi-Fi 6: multi-user, multiple input, multiple output (MU-MIMO) and orthogonal frequency division multiple access (OFDMA).

**MU-MIMO** is the use of multiple antennas, so that multiple data streams can be transmitted and received simultaneously. MU-MIMO is currently used in Wi-Fi 5, but only for four devices at a time. In Wi-Fi 6, MU-MIMO allows communication for up to eight devices at a time. As an analogy, consider shipping canals that can now have eight container ships simultaneously sailing to destinations rather than four.

**OFDMA** allows the delivery of data to multiple devices at the same time. Back to the above analogy, once the container ships dock at their destinations, the individual containers can be allocated to multiple customers.

Other benefits of Wi-Fi 6 include lower latency because of the better “packing” of data within the signal, improved battery life, and a significant security protocol upgrade in WPA3 (the first in almost a decade).

Figure 6 provides a summary of Wi-Fi 6 benefits:

<table>
<thead>
<tr>
<th>Wi-Fi 6 Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>More, consistent device connections</td>
</tr>
<tr>
<td>Improved security</td>
</tr>
<tr>
<td>Increased IoT connectivity</td>
</tr>
</tbody>
</table>

**SO, WHAT IS WI-FI 6E?**

When Wi-Fi 6 was first announced, it was limited for use within the 2.4 GHz and 5 GHz unlicensed frequency bands. However, in April 2020 the FCC announced that it was opening up 1200 MHz of unlicensed spectrum in the 6GHz range. Since the same encoding and channel widths are used as Wi-Fi 6, this would not be Wi-Fi 7. But the large bandwidth of 1200MHz available at 6 GHz is a major and significant differentiator from the lower frequencies. Therefore, the decision was made to name the support of the new unlicensed, 6 GHz frequency band with Wi-Fi 6 technology, “Wi-Fi 6E,” with the “E” representing “extended.”

**FIGURE 7**

Benefits of Wi-Fi 6E

**FIGURE 6**

<table>
<thead>
<tr>
<th>Wi-Fi 6Benefits</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>More, consistent device connections</td>
<td>Higher data-rates (especially for multiple devices)</td>
</tr>
<tr>
<td>Improved security</td>
<td>Extends battery life</td>
</tr>
<tr>
<td>Increased IoT connectivity</td>
<td></td>
</tr>
</tbody>
</table>
Significant growth in Wi-Fi 6E is anticipated because of the combination of such large bandwidth and the upgraded technologies of Wi-Fi 6, as shown in Figure 8.

**FIGURE 8**
Wi-Fi 6E unit shipment growth in millions of units

![Graph showing Wi-Fi 6E unit shipment growth](source: IDC)

This is an extremely important development for the global proliferation of Wi-Fi. Bandwidth is the lifeblood of wireless networks (discussed in this Resonant white paper), as evidenced by the recent auction 107 which generated over $81 billion in proceeds for the use of 280 MHz of spectrum. Even with this new licensed spectrum, a Resonant spectrum usage model predicts a significant deficit moving forward (Figure 10 below).

**FIGURE 10**
Licensed spectrum surplus and deficits due to rapidly growing data demand

![Graph showing surplus/deficit](source: Resonant)

**Wi-Fi FREQUENCY, CHANNEL WIDTH AND INTERFERENCE MANAGEMENT**

Until recently, Wi-Fi operated in two unlicensed frequency bands - 2.4 GHz (2.401 GHz-2.483 GHz) and 5 GHz (5.170 GHz-5.330 GHz and 5.490 GHz-5.835 GHz). However, as discussed previously, in April 2020 the U.S. FCC allocated a massive swath of spectrum for a new unlicensed band at 6 GHz (5.925GHz-7.125 GHz), with many other countries looking to follow suit as shown in Figure 9 below.

**FIGURE 9** - Map of countries and their Wi-Fi 6E adoption status

![Map showing Wi-Fi 6E adoption](source: Wi-Fi Alliance)

The unlicensed block of spectrum allocated in the US at 6 GHz is over four times the amount allocated in the auction and will be essential for cellular offload to preserve a positive consumer experience.
Within a particular set of frequencies allocated for unlicensed use, there are a set of “channels” of specific bandwidths (20 MHz, 40 MHz, 80 MHz or 160 MHz). The larger the channel bandwidth, the higher the data speed. Given the total frequencies available at 2.4 GHz, 5 GHz and 6 GHz, the non-overlapping options are limited at 2.4 GHz but dramatically increase at the higher frequencies (see Figure 11).

TPC is used to prevent outdoor APs from interfering with airport radar systems in the 5 GHz band. When initiating communication, devices set their transmit power at a level low enough to “hear” each other, but not too high as to interfere.

LPI has reduced power levels and is for indoor use only. Although the large bandwidth allocated at 6 GHz is very attractive, there are already incumbents licensed to use parts of this spectrum (mainly fixed satellite services). To avoid potential interference, APs for use in this spectrum are LPI, while outdoor APs have standard power. In order to manage these outdoor nodes, AFC is introduced.

AFC ensures that a new access point will consult a registered database of existing users to confirm that its operation will not impact registered users.

However, none of these techniques address potential interfering signals outside of the unlicensed frequency band that can produce in-band harmonic “noise,” and worse case, cause saturation of the low-noise amplifier (LNA) and “blocking” of the required signal. This is the function of filtering, to attenuate potential interferers, to a point that they do not generate in-band noise.

The interference challenge for Wi-Fi has two distinct elements – interfering signals from incumbents within the unlicensed band, and interfering signals outside of the unlicensed band, which cause harmonics within the band. The challenge is different for the AP and the user equipment.

Dynamic frequency selection (DFS), transmit power control (TPC), low power indoor (LPI) and automated frequency coordination (AFC) define how in-band interference is managed in Wi-Fi.

DFS is all about radar detection and avoidance within the unlicensed band. If a device detects a radar signal in the channel, it will monitor other channels and, if available, jump on one of those channels. The 2.4 GHz band is free of radar, so this only applies to the 5 GHz band.

FIGURE 11
Wi-Fi spectrum allocation and non-overlapping channel packing

<table>
<thead>
<tr>
<th>Band</th>
<th>No. of Channels</th>
<th>BW</th>
<th>Outdoor - AFC</th>
<th>LPI</th>
<th>Outdoor - AFC</th>
<th>LPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 GHz</td>
<td>59</td>
<td>20 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>40 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>80 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>160 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 GHz</td>
<td>25</td>
<td>20 MHz</td>
<td></td>
<td>DFS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>40 MHz</td>
<td></td>
<td>DFS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>80 MHz</td>
<td></td>
<td>DFS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>160 MHz</td>
<td></td>
<td>DFS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>3</td>
<td>20 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>40 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6 GHz is very attractive, there are already incumbents licensed to use parts of this spectrum (mainly fixed satellite services). To avoid potential interference, APs for use in this spectrum are LPI, while outdoor APs have standard power. In order to manage these outdoor nodes, AFC is introduced.
WHAT IS A FILTER AND WHY IS IT IMPORTANT?

The proliferation of 4G LTE networks, the deployment of new 5G networks and the pervasive nature of Wi-Fi are driving a dramatic increase in the number of radio frequency (RF) bands that wireless devices must support. Each band needs to be isolated using filters to keep the signal in the right “lane.”

As more wireless traffic takes advantage of 5G and Wi-Fi in the 3 GHz - 7 GHz frequency range, interference between the bands will jeopardize the coexistence of these advanced wireless technologies and limit their performance. Thus, higher performance filters will be required to maintain the integrity of each band. Further, the limited number of antennas available in both mobile devices and APs will transform architectures to increased use of antenna sharing, which will further escalate filter performance requirements.

And as the volume of traffic increases, the requirements to allow essential signals to pass with even lower loss will grow, preventing battery drain and increasing data speeds.

Different acoustic wave filters are most suitable for different applications, as shown in Figure 13 below. Resonant XBAR-based filters are optimum for wide bandwidth and high frequency functions, the most challenging being the new Wi-Fi 6E application, with a bandwidth of 1200 MHz and maximum frequency of 7.125 GHz.
**Wi-Fi AND 5G COEXISTENCE**

The issue of Wi-Fi and 5G coexistence has already been recognized:

“5 GHz band for Wi-Fi which is essential for smartphones sits between the 4.5 GHz and 6-7 GHz bands. If these frequencies are to be fully utilized, each bandwidth would need a steep filter.

Also with n77 and n79, a high-performance filter would be needed at the same time, since band gap of 200 MHz is too narrow to be utilized fully.”

– Navian Research Report
(slide 62, RF Devices/Modules for Cellular, 2018-2019)

As seen in Figure 14, there is only a 200 MHz separation between n77 and n79, and a 150 MHz separation between n79 and 5GHz Wi-Fi 6. Filters for these bands will need to have a high rejection to mitigate interference between the 5G and Wi-Fi bands, enabling maximum bandwidth operation, preventing Wi-Fi signals from bleeding into the n79 data path and vice versa.

**RESONANT XBAR® SOLUTION**

Filters designed for previous Wi-Fi requirements are not suited to these new filtering challenges, hence a new filter design was required. Resonant’s XBAR filters provide the wide bandwidth, high frequency operation, low loss and high power capability necessary for 5G and Wi-Fi.

**FIGURE 15**

Filters required to prevent interference and allow coexistence/operation for these bands

Source: Navian, Inc. All rights reserved.

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**FIGURE 14**

Separation between n77, n79 (5G) and Wi-Fi spectrum
XBAR is a bulk acoustic wave (BAW)-based resonator technology that can be used to create filters that deliver the performance needed for Wi-Fi and 5G networks, and also offering best-in-class performance for UWB applications.

XBAR resonators consist of a single crystal, piezoelectric layer, with a metal interdigital transducer (IDT) on the top surface. The metal traces excite a bulk acoustic wave within the piezoelectric, the primary frequency and coupling characteristics being determined by the physical dimensions and properties of the piezoelectric.

Filter technologies, such as surface acoustic wave (SAW), temperature compensated surface acoustic wave (TC-SAW), solidly mounted resonators-bulk acoustic wave (SMR-BAW) and film bulk acoustic resonator (FBAR), from previous wireless applications can be extended in bandwidth and to higher frequency. But this comes at the expense of other critical parameters, such as loss and power durability. Alternatively, multiple filters can cover the wide bandwidths, either as a hybrid with non-acoustic filters or in multiple sections.

XBAR can be used to create a filter that meets the following requirements for Wi-Fi frequency bands:

- **Wide bandwidth** – up to 1200 MHz
- **High frequency** – > 5GHz
- **High power** – to compensate for poor propagation at high frequency
- **Low loss** – to maximize the signal efficiency
Non-acoustic approaches to address wide bandwidth and high frequency filters

**FIGURE 17**

Non-acoustic approaches to address wide bandwidth and high frequency filters.

Multi-Band Switching Approach

However, this compromise will always be higher cost, larger size and lower performance than an XBAR solution. In the Figure 18 comparison, the hybrid integrated passive device (IPD)/FBAR Wi-Fi 6E filter provides interference protection only against signals in the 5 GHz unlicensed band, and not to 5G sub-6 GHz or UWB, while the XBAR Wi-Fi 6E filter protects the Wi-Fi 6E band against all of the potential interference issues.

**FIGURE 18**

Comparison of measured performance of XBAR-based and hybrid Wi-Fi 6E filter

*As Measured by: Pacific Electronics Services*
XBAR Wi-Fi filters do not require any compromise, providing low loss (<2dB across entire 1200MHz passband), high rejection (>35dB) and high power capability as shown in Figure 19.

This high-performance filtering will result in the highest data speeds, lowest delay and best coverage. In the pandemic’s remote work environment, everyone has encountered the experience of stalled video on a Zoom call, lag in video games and lost connectivity at the house perimeter. New Wi-Fi technology, combined with new wide bandwidth frequencies, protected with state-of-the-art filtering will provide the solution moving forward.

**LET’S NOT FORGET ABOUT Wi-Fi 7**

One of the advantages of Wi-Fi is the speed at which new generations of technology can be released and certified, relative to cellular technology. Despite the recent certification of Wi-Fi 6 in 2019, certification of Wi-Fi 7 devices is expected in early 2024. Current proposals for Wi-Fi 7 or Wi-Fi Extremely High Throughput (EHT) include support for wider channel widths (320 MHz), higher order modulation schemes and multiband aggregation to permit higher data speeds of up to 30 Gbps (approximately three times that of Wi-Fi 6). This will only exacerbate the filter problem, as different Wi-Fi bands are combined on the same antenna.
CONCLUSION

Wireless data demand continues to explode, driven by the pandemic’s work from home environment, new device types and data hungry applications.

In order to support this demand, spectrum is critical for capacity and data speeds. Wi-Fi complements cellular in meeting this demand, and the latest advances in Wi-Fi 6 and massive addition of spectrum makes Wi-Fi even more attractive and is expected to continue this growth pattern. Wi-Fi coexistence challenges with 5G though, require new filters designed to alleviate these issues. The Resonant XBAR filters provide the optimal solution for Wi-Fi 6E.