Gigabit Wireless: Solving the Wireless Bandwidth Crunch with 60GHz Millimeter-Wave Technologies

A SiBEAM, Inc. White Paper

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1. Summary

Millimeter wave technologies can provide the solution to the bandwidth crunch created by a growing number of Internet connected devices attempting to move ever-larger volumes of multimedia content across existing wired and wireless media. Operating at the unlicensed 60GHz frequency spectrum, a new breed of devices with integrated multi-gigabit transceivers are already delivering more bandwidth than those currently using the overcrowded 2.4GHz and 5GHz unlicensed bands. With multi-gigabit throughput, these devices are already delivering better services than the few hundreds of Mb/s available from today’s most advanced wireless products.

Many applications are expected to benefit from 60GHz millimeter-wave solutions. These include adding new capacity to the traditional Wi-Fi networks in your home and between office buildings for wireless data access and video streaming. And the same technologies are also demonstrating great promise as a wireless replacement for mechanical connectors in consumer electronics and mobile devices. These short-range wireless connectors enable sleeker, more robust products by eliminating bulky conventional connectors while purging the susceptibility to damages caused by exposure to water, humidity, dust, and other contaminants.

In order to meet the needs of a swiftly changing market, manufacturers are already beginning to migrate to millimeter-wave-based technologies. But risk factors must be considered for adoption, both in terms of selecting the right emerging standards, and choosing the right technology partner to assist in their implementation. This article will help you explore those choices by providing a concise overview of the technologies, applications, and implementation challenges facing manufacturers as they attempt to design products which will satisfy the needs of a bandwidth-hungry world.

2. 60GHz: The Next Frontier

Wi-Fi and Bluetooth wireless technologies, which made the mobile data revolution possible, have become victims of their own success. Originally intended to operate in the unlicensed 2.4GHz band, Wi-Fi's widespread acceptance quickly forced the Wi-Fi Alliance to define its operation for a series of channels located in the next globally available unlicensed band located at 5 GHz. Thanks to steady improvements in efficient 5GHz wireless protocols and radio architectures, Wi-Fi has been able to keep pace with the growing demand for bandwidth from laptops, tablets and other mobile devices.

2.1. Internet of Things (IoT) Changes the Game

With the recent promise of IoT, excitement is growing as smart devices from DTVs to coffee makers, to refrigerators will now be connecting to the Internet. As the number of wirelessly connected devices continues to skyrocket, the growing demand they create for both access and capacity will quickly outstrip what's available on the existing wireless spectrum. The problem is being compounded as wireless carriers offload increasing amounts of their multimedia traffic—their slices of the licensed cellular spectrum—to the "free" spectrum available in the Wi-Fi bands.

As a result, both of today's commonly-used ISM bands are rapidly approaching overload as a growing number of products and services compete for access to the same narrow slices of spectrum. Technical improvements under development can mitigate the problem, but cannot ultimately solve congestion issues, especially in apartments, offices, public spaces and other areas with high user density.

The logical solution to the growing congestion is the adoption of technologies and products capable of operating in the 60GHz (millimeter wave) region where the regulators such as FCC have designated a wide band of spectrum for unlicensed use by industries. With more than 7GHz of spectrum, broken down into four 1.8GHz channels, this new airspace provides 20X more bandwidth than its 5GHz counterpart.

2.2. Wireless Connectors – Not an Oxymoron

60GHz millimeter wave also gives device designers an innovative solution to the annoying problems caused by mechanical connectors. When used with low power RF with the appropriate antenna, a millimeter-wave data interface can serve as a so-called "wireless connector" which, at close proximity, provides more robust connectivity to replace today's mechanical connector solutions. In fact, SiBEAM has introduced a wireless connector solution that has demonstrated transfer rates of up to 12Gbp/s (full duplex). Known as Snap technology, it is intended as a replacement for most conventional data and video connectors, including all variations of USB 2.0, USB 3.0, HDMI, and DisplayPort.

Wireless connectors are especially valuable in mobile devices such as smartphones, tablets, and action cameras because they eliminate mechanical connectors, one of most failure-prone components in products, which are heavily used by consumers in many aspects of every day life. Besides creating an entry point for the pocket lint, sweat and other common contaminants, most mechanical connectors have a tendency to wear out or shear off their PCB mounts well before a product's batteries or electronic components have a chance to fail. Eliminating the case penetrations required by mechanical connectors allows designers to "life-proof" their products against water, dust, dirt, moisture and the occasional spilled coffee.

Using wireless connectors allows designers to create sleek, stylish products which would not be possible if they had to compromise their industrial designs by sacrificing precious space to mechanical connectors. In fact, mechanical connectors have already become a stumbling block in the design process as manufacturers struggle to meet the demand for ever-thinner tablets, mobile phones and other electronic devices. Even today, connectors can take up as much as half the height of a CE device.

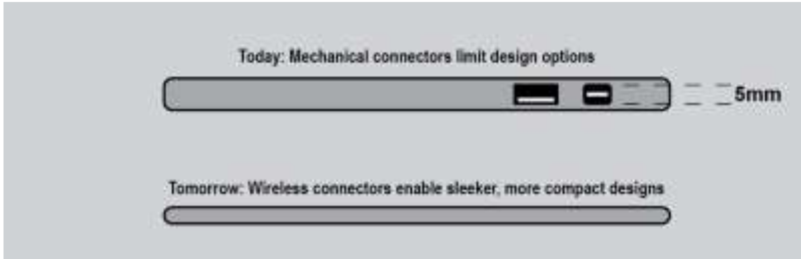

Figure 1. *Wireless connectors enable sleeker, faster, more reliable CE designs.*

Close proximity wireless connectors also eliminate the electromagnetic interference (EMI) problems designers face every day. EMI occurs when electrical signals run through any conductor, including wires and printed circuits but, in most devices, mechanical connectors are the largest source of this unwanted radio 'noise'. And at Gigabit speeds, suppressing connector-induced EMI so it does not interfere with other wireless functions becomes a major system level challenge for designers. This adds to both the overall system design effort and the unit cost of each device. By eliminating mechanical connectors, many system-level EMI issues are eliminated immediately. As we'll see shortly, wireless connector solutions such as SiBEAM's Snap technology help unlock CE designers' creativity, enabling them to develop sleeker, more functional mobile electronic products which are better able to survive the real-world conditions.

3. Applications & Market Opportunities

The unlicensed spectrum available at 60GHz can provide multiple gigabits of capacity which, when used wisely, is enough to satisfy user requirements for the foreseeable future. Many of the guidelines used to define these applications are based on millimeter-wave radio's unique propagation characteristics. These include:

- RF signals behave much more like light than conventional radio waves at millimeter-wave frequencies. Because of this, early implementations in the band were limited to line-of-sight applications. However, recent innovative techniques such as adaptive beam-forming and beam-steering have been implemented to provide a robust non line-of-sight experience consumers expect today.
- 60GHz signals are attenuated by oxygen, a phenomenon that can severely limit range. This problem must be overcome in order to deliver the wireless experience consumers expect, a task which requires system-level knowledge as well as radio and antenna design know-how.
- And, unlike 2.4 & 5GHz signals, 60GHz RF cannot penetrate most walls. This makes 60GHz technologies ideal for consumer experience that is contained in the same room.

At first glance, these issues might seem to limit the utility of the millimeter-wave band, but properly defined applications can turn these limitations into "features" which provide unique advantages to both users and manufacturers. These applications fall into three general categories, defined primarily by the distances they must span.

3.1. Gigabit Wireless Connectors

Wireless connectors, aka Close Proximity Data Links, provide high-bandwidth I/O in consumer electronics and computers at distances up to 10mm. One promising implementation of millimeter-wave interfaces is already available with SiBEAM's wireless Snap technology. Its high data throughput makes it ideal for creating wireless docking solutions or device-to-device synch connections. Boasting a 12 Gb/s aggregate throughput, Snap can completely replace the USB, HDMI, or DisplayPort connectors for data and video transfers. Snap is complementary to wireless power charging technologies, and when combined, Snap allows designers to create device form factors which are truly connector-free (Figure 2).

Figure 2. *Gigabit wireless connector applications*

3.2. Indoor Wireless Connections

Millimeter-wave technology can also be used to enhance today's Wi-Fi networks by adding much-needed wireless capacity. In fact, one of the most active standards efforts for these applications is IEEE 802.11ad, formerly Wireless Gigabit – or "WiGig" for short. The standard defines a new physical layer for 802.11 networks in the 60GHz spectrum and is poised to become the next-generation Wi-Fi to alleviate the anticipated congestion in current 2.4GHz and 5.0GHz spectra.

The current 802.11ad specification includes an enhanced version of the standard 802.11 Media Access Control (MAC) layer to support data rates of up to 7Gbits/s. With a complete standard in place and early-market products already available, 802.11ad certification programs are now being implemented by the Wi-Fi Alliance.

Figure 3. ***a)*** *Example use cases illustrating how 802.11ad extends Wi-Fi's versatility to the millimeter-wave band*
b) *Example use cases illustrating how WirelessHD provides "HDMI-equivalent" wireless connectivity between consumer electronic products.*

While the up and coming 802.11ad standard can carry video streams over IP-based packet protocol, products based on the 60GHz WirelessHD standard has been shipping for almost a decade. Created to stream video content between HD audio/video devices such as HDTVs, DVRs, PCs, mobile and other consumer electronics, products supporting the WirelessHD standard provides the same 1080p60 Full HD video and multi-channel audio experience at near zero latency expected from cables. WirelessHD technology's high capacity and low latency is well suited for uncompromised wireless video entertainment and highly interactive experiences such as wireless gaming and virtual reality applications. WirelessHD enables a “cable like” HDMI experience without the wires and utilizes the 7GHz channel to support data rates of up to 28 Gb/s while carrying both 2D and 3D formats as well as 4K video streams.

The first wave of WiHD-enabled laptops, smartphones, DTVs, video projectors and VR headsets are already on the market and have been well-received, thanks to the ease-of-use and performance they offer. For example, the LeTV’s MAX1 smartphone has garnered accolades and popularity in China, largely due to its integrated WiHD interface. Thanks to WiHD, users can wirelessly beam the games, movies or other video content playing on the MAX1 over to a video projector, LCD screen or other HD display. Users with non-WiHD-capable equipment can also enjoy the easy set-up and convenient operation afforded by a wireless connection with a WiHD-to-HDMI adapter, currently available from several manufacturers.

Both 802.11ad and WiHD compensate for the 60GHz band's line-of-sight propagation characteristics through the use of beam forming and beam steering between the transmitter and receiver ICs. Network processors along with RF IC integrated with phased array antennas increase the signal's effective radiated power and allows the wireless system to select the best available Tx/Rx path. In the case of WiHD, this technique has enabled products to support point-to-point, non-line-of-sight (NLOS) connections at distances of up to 10 meters.

Figure 4. *60GHz millimeter-waves spectrum's limited range and unique propagation characteristics help multiple standards peacefully co-exist within the same home, or even the same room.*

While created to support different protocols and applications, WiHD and 802.11ad products are expected to peacefully co-exist in the same home, and even the same room (Figure 4).

3.3. Gigabit Wireless Outdoor Links

Millimeter-wave technologies will also play an important role in future backhaul infrastructure applications that include next-generation 5G mobile broadband infrastructure, fixed access backhaul extension, and point-to point on-campus links where the 60GHz channel's wireless capacity and highly optimized RF link make it an ideal "wireless fiber" to replace today's fiber-based backhaul applications.

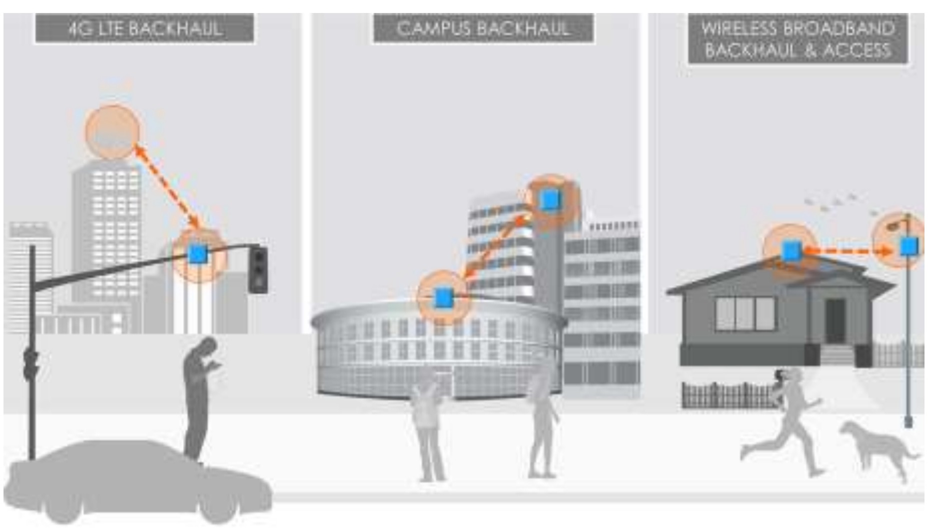

Figure 5. *60GHz Wireless Fiber Use Cases.*

At present, there are several approaches vying for market acceptance but most systems are currently based on some implementation of the IEEE 802.11ad standard currently being developed by the IEEE. In addition to the in-room applications mentioned earlier, this amendment to the existing 802.11 standard includes use cases intended to support long-reach links (up to 500 meters) in the 60GHz millimeter wave spectrum. It uses the same beam-forming techniques developed for 10m in-room connections to support several other use-cases including access point connections and out-door back-haul links.

4. Implementation Strategies

Entrepreneurs who wish to enter the emerging 60GHz markets must learn to manage the intricacies that come with a new technology. This section will help you navigate the partly-charted waters of the millimeter wave frontier. You'll be introduced to some of the potential perils, pitfalls and technological dead-ends awaiting the unwary developer. At the same time, we'll share some practical strategies for overcoming these challenges.

4.1. General Considerations

Go CMOS: Creating winning products for any of the markets discussed earlier requires the use of RF integrated circuits (RFFICs) to reduce assembly, test and manufacturing costs. Commercial devices capable of operating at 60GHz have been available for some time, but most RFIC makers have relied on exotic processes such as Gallium-Arsenide (GaAs) or silicon-germanium (SiGe) which allow only limited integration and cost-reductions. These higher solution costs will in turn limit the available market to low-volume applications which prevent any further scaling towards consumer-friendly pricing.

This dilemma has been eliminated as techniques to produce millimeter-wave devices using commodity-grade deep submicron CMOS processes are now available. By eliminating the need for exotic semiconductor processes, CMOS RFICs are helping bring the cost of millimeter-wave products to cost points suitable for the consumer electronics market.

5. Can you use an off-the-shelf solution?

If a suitable commercially available solution is available, it is frequently the best choice, especially for early-entry products. Existing RFICs can reduce both time-to-market and development costs, allowing you to devote your resources to adding features which will help differentiate your product.

Here are some things to think about before you commit to a particular off-the-shelf chip/chipset:

- What key usage cases are supported? Is it wireless video within the room? Or is it gigabits of data across a campus? Or is the need to transfer a lot of data in short distances but extremely fast? Usage case matters to the type of 60GHz technologies you choose.

- Is the product expected to connect to other branded products? In other words, are you providing end-to-end system (closed system) or does the product have to comply to an industry standard so it will operate with other brands supporting the same standard?
- Is your product battery operated or will AC power be available? Trade-offs between link throughput, distance travelled, antenna design, and component selection will depend on the power available and duration of the experience your product intends to delivers.
- What industrial design constraints will your product have? Any wireless design requires careful placement of the RF circuit within the system. 60GHz adds additional challenges due to the properties of short millimeter waves. In small form factors such as smartphones, heat dissipation and thermal management will add complexity as well.
- What is your overall budget? As with any project, cost plays significant role in technology selection. Depending on throughput, distance, form factor, and placement, different wireless components and system level implementation will determine the final cost.

5.1. Further considerations

Find the right partner: A winning strategy for the 60GHz frontier requires an experienced partner with the know-how, experience and customer support capabilities to put their client on a fast track to capturing market opportunities. SiBEAM, for example, is one of the few companies in the world that has mass produced millimeter-wave ICs in high-volume CMOS fabs for over a decade.

The company has a well-established "design for production" methodology which allows it to design and verify easily producible parts using commodity deep submicron CMOS processes. Part of its success can be attributed to SiBEAM's proven closed-loop design for production process where the device's production test vectors are created using inputs from collected data from the CMOS processes used. During production tests, the results produced by these highly-accurate test vectors are then used as feedback by designers who use it to fine-tune the design for optimal yield and performance.

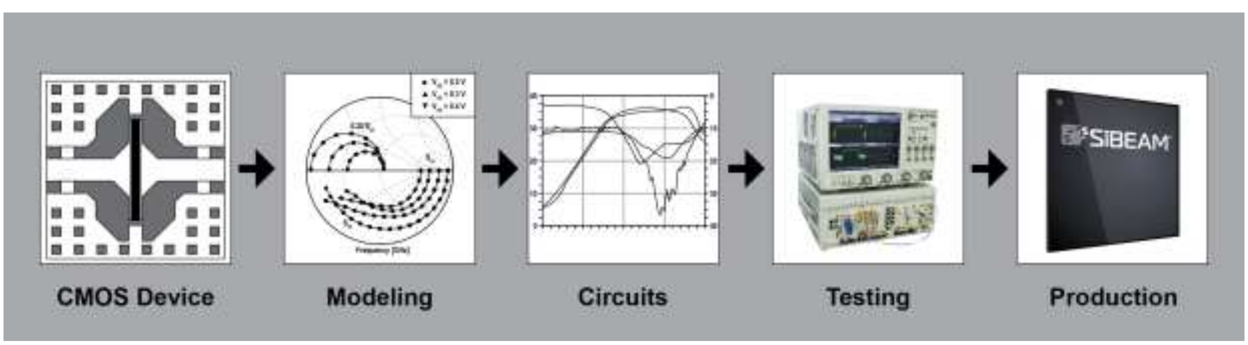

Figure 6. *The first half of SiBEAM's integrated design/production methodology employs test vectors generated using real-world characteristics of the particular CMOS process being used to fabricate the device.*

With over 10 years of millimeter wave RF experience, SiBEAM has a proven methodology that has been implemented in multiple process nodes. The methodology can also be migrated between process nodes at different manufacturing foundries.

Another key advantage of teaming with SiBEAM is the company's customer-focused development cycle. It provides "handshake-to-hardware" support through every phase of design, manufacturing, test and deployment such as:

- RF-related design issues including RF component placement and integration for optimum performance.
- Thermal management planning – heat dissipation (airflow, conductive thermal paths, etc.)
- Packaging and implementation
- Compliance testing:
  - FCC Part 15B – non-intentional emissions (EMI)
  - FCC Part 15C – Intentional emissions

6. Conclusions

With the 2.4GHz and 5GHz ISM bands approaching capacity saturation, the unlicensed portion of the millimeter-wave band offers a much-needed piece of open spectrum where wireless devices can enjoy new dimensions in capacity and access. Standards are already in place to define both indoor Wi-Fi service and outdoor long-haul links for point-to-point links as well as "last block" mobile access. Millimeter-wave technologies also show promise for use as ultra-short-range "wireless connectors" which eliminate the durability, EMI and industrial design issues associated with traditional mechanical connectors.

Advanced CMOS technologies are making it possible to unlock the potential of all these applications of the unlicensed 60GHz frequency spectrum in an economical manner but also introduce several significant engineering challenges. Even if an off-the-shelf component is employed, the RF component placement and integration, packaging, thermal design and testing issues require a great amount of in-house expertise, or a highly-experienced partner. With five generations of all-CMOS millimeter-wave devices already in the field and a well-established "design for production" methodology in place, SiBEAM makes an ideal partner to help you meet the challenges of Gigabit wireless networking.

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