The 5G Paradox

The Need for More Offloading Options in the Next-Generation Wireless Era

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This white paper is meant to be an educational tool and reflects the views of the authors.

Abstract

This report explores the need for additional bandwidth and offloading techniques at the dawn of the fifth-generation (5G) wireless communications era. Even though 5G brings new spectrum to market, the sheer number of devices and connections that will proliferate from this game-changing technology will require continued offloading techniques from the macrocellular networks to bring the network closer to the end user, thereby making the macrocellular network operate efficiently. The paradox of 5G is that although it provides more bandwidth, it will also support so much more data usage that even more offload is required. Along with unlicensed Wi-Fi technology that uses the 2.4 GHz and 5 GHz frequencies, newly available Citizens Broadband Radio Service (CBRS) spectrum will be required to handle the expected heavy demands from people and machines.

Introduction

Each generation of wireless technology has revolutionized how people communicate and consume content. Second-generation cellular networks, for example, allowed people to text one another. Third-generation networks enabled far greater mobile broadband data. Fourth-generation networks enabled mobile video usage without frustrating delays. Fifth-generation cellular networks are expected to enable another revolution, transforming how people and machines communicate and even how industries do business. 5G network deployments are expected to provide significant economic and efficiency gains in the markets where they are deployed. Smart-factory and smart-city applications, autonomous vehicles and machines, and telemedicine applications are just a few of the examples where 5G technology is expected to impact a range of industries.

As such, 5G cellular networks will bring with it a paradox once it is deployed. Even as 5G networks will bring more spectrum to market, the massive amounts of new connections that will be available could overwhelm networks once billions of diverse devices connect to the 5G networks. So even as new spectrum comes to market, operators will continue to need to use offloading techniques to keep the macrocellular network operating efficiently. Already, Wi-Fi networks are used to help alleviate some of this data congestion in hopes of providing a seamless customer experience both outdoors and indoors. That practice will continue as wireless demand increases, driven not only by people but also machines that use wireless technology to communicate with each other. The ability to leverage a variety of licensed and unlicensed spectrum across multiple frequencies using various technologies, along with techniques to increase overall transmission bandwidth, remains an essential part of the answer to meeting the demand for mobile connectivity.

Wireless operators have paid the federal government billions of dollars to use licensed spectrum to deliver connectivity and content to mobile users and use unlicensed Wi-Fi connectivity to augment that delivery. But the two technologies are different. Cellular networks use licensed spectrum, which means only service providers can manage the spectrum. Wi-Fi networks use unlicensed spectrum, which means anyone can use it.

Market Status Today

The large-scale deployments of fourth-generation (4G) LTE technology by cellular operators brought about a change in behavior that some have called a "mobile first" mindset. Forrester Research labels this as "the expectation that a person can get what they want in their immediate context and moments of need."[1] Simply put, people turn to their mobile devices for answers to their questions.

As more people simultaneously use mobile broadband with increasingly heavy data demands, such as video, cellular operators needed to address the increased traffic on their networks. As such, operators have used techniques such as carrier aggregation to increase bandwidth. Manufacturers are planning to install cellular chipsets that support recently freed-up shared frequencies in the 3.5 GHz CBRS band in end-user devices.[2] Some wireless service providers have indicated they are willing to work with third-party CBRS and Wi-Fi operators to mitigate their capital expenses while offering the highest possible quality of service to their customers.

Several stakeholders have an interest in aggregating wireless service using Wi-Fi, CBRS and other potential technologies. These include enterprise customers, wireless service providers, third-party neutral host companies, and original equipment manufacturers. This report will delve into the nature of the technologies available to meet this need and identify potential gaps that stand in the way of alliances among these stakeholders.

WHAT IS CELLULAR?

Cellular networks – also called mobile networks – are wireless wide area networks (WWANs). These are the networks created by cell sites, also called macrocellular towers and other broadcasting technologies. The equipment enclosed at those sites generates the cellular radio-frequency (RF) signals that propagate for miles. Cellular carriers (also called mobile operators or wireless service providers) lease RF spectrum from the federal government under agreements that let them use certain blocks of spectrum for a number of years. The Federal Communications Commission (FCC) manages the spectrum, arranges the auctions, and establishes the rules for how wireless and wired networks, carriers and equipment vendors operate, interact and provide service in the United States.

The Case for Offloading

The amount of mobile data traffic on cellular networks is skyrocketing, and data usage is expected to continue increasing for the foreseeable future. Americans used a record 15.7 trillion megabytes of mobile data in 2017, nearly quadrupling since 2014.[3] Service providers are looking for ways to relieve congestion from data traffic by moving some of it onto local, in-building networks while maintaining the quality customers expect from the overarching cellular network. Today, customers experience this while connecting to Wi-Fi hotspots when they enter a business or other establishment. In some cases, wireless operators have installed Distributed Antenna Systems (DAS) or small cells to move traffic off the macrocellular network and onto their DAS or small-cell networks. For more information on DAS and small cells, see here: https://wia.org/resource-library/distributed-antenna-systems-das-mid-tier-markets.

WHAT IS WI-FI?

In contrast to cellular, Wi-Fi is a wireless local area network (WLAN) based on the IEEE standard "802.11." For Wi-Fi, "local" means that the signal only carries about 300 feet. There are several versions of Wi-Fi. In the fall of 2018, the Wi-Fi Alliance changed its naming convention to make it easier for customers to understand. The newest iteration of Wi-Fi is "Wi-Fi 6." Wi-Fi also uses RF spectrum – the unlicensed 2.4 GHz and 5 GHz bands. Unlicensed means that anything can use the spectrum, which also means that it is shared spectrum. With shared, unlicensed spectrum, interference among multiple networks can be a problem since the networks in the same area are using the same spectrum bands. While each individual Wi-Fi network can operate in different radio channels, this only reduces interference; it does not eliminate it.

For service providers, offloading data traffic frees network capacity while continuing to provide the level of service their customers expect. Retailers, businesses and landlords find value in facilitating data traffic offload by providing their patrons and residents the connectivity they need, where and when they need it. People expect ubiquitous wireless connectivity everywhere they are, and buildings without mobile connectivity may be less attractive to enterprises and tenants.

Offloading allows customers to make and receive calls and texts over Wi-Fi or other local connections. Often the handover to a Wi-Fi network is seamless and customers aren't even aware they are making a Wi-Fi call. Indoor, offloaded networks benefit customers by providing a seamless, out-of-the-box experience using their existing phone and phone number and extending connectivity into areas where cellular and public-safety networks often don't reach. Future improvements in Wi-Fi calling will provide a seamless handover between available Wi-Fi and LTE networks along with high-quality voice and next-generation calling features.

Technology Roadmap

Several technologies exist or are emerging that can facilitate offloading cellular traffic onto small, localized networks, with the primary candidates being Wi-Fi, CBRS and 5G. Each provides different benefits and limitations for the stakeholders in the wireless ecosystem, including enterprises, service providers, third-party operators and integrators, and original equipment manufacturers. Following is an explanation of each technology:

Wi-Fi

Wi-Fi is a well-established wireless architecture used by most cellular customers. Several versions of Wi-Fi are planned to be interoperable with Orthogonal Frequency Division Multiplexing (OFDM)-based services in the 5G world. Because of the lower cost of deploying and using fixed Wi-Fi networks for voice and data services, and the continued move to IP-based voice services, Wi-Fi networks play an important role to support the ever-growing demand for wireless broadband.

CBRS

In 2015, the Federal Communications Commission (FCC) established a new CBRS band for shared wireless broadband use by authorizing the 3.5 GHz spectrum band (3550 MHz to 3700 MHz) which had previously been allocated exclusively for the U.S. Navy and other Department of Defense (DoD) entities.[4] CBRS uses TD-LTE and supports voice, text and high-speed data technologies much like LTE does on other cellular frequency bands. However, the FCC has decided to allocate CBRS spectrum to owners (and users) in a slightly different method than traditional cellular – where operators lease large holdings covering miles of various geography – and Wi-Fi, which is completely unlicensed. Instead, the spectrum will be assigned and used individually by various users. When the spectrum is not being used, it may be "recycled" and assigned to different users.

The 150 megahertz of CBRS shared spectrum falls into three user categories: incumbents (DoD); priority access licenses (PAL); and general access licenses (GAL). There are several services that assist in coordinating access to this spectrum. Spectrum Access System (SAS) is a cloud-based service that coordinates access to the shared spectrum, enforcing priorities and modeling the RF environment. Environmental Sensing Capability (ESC) incorporates environmental sensors deployed in strategic locations near naval stations, mostly along coastal regions, to detect incumbent activities.

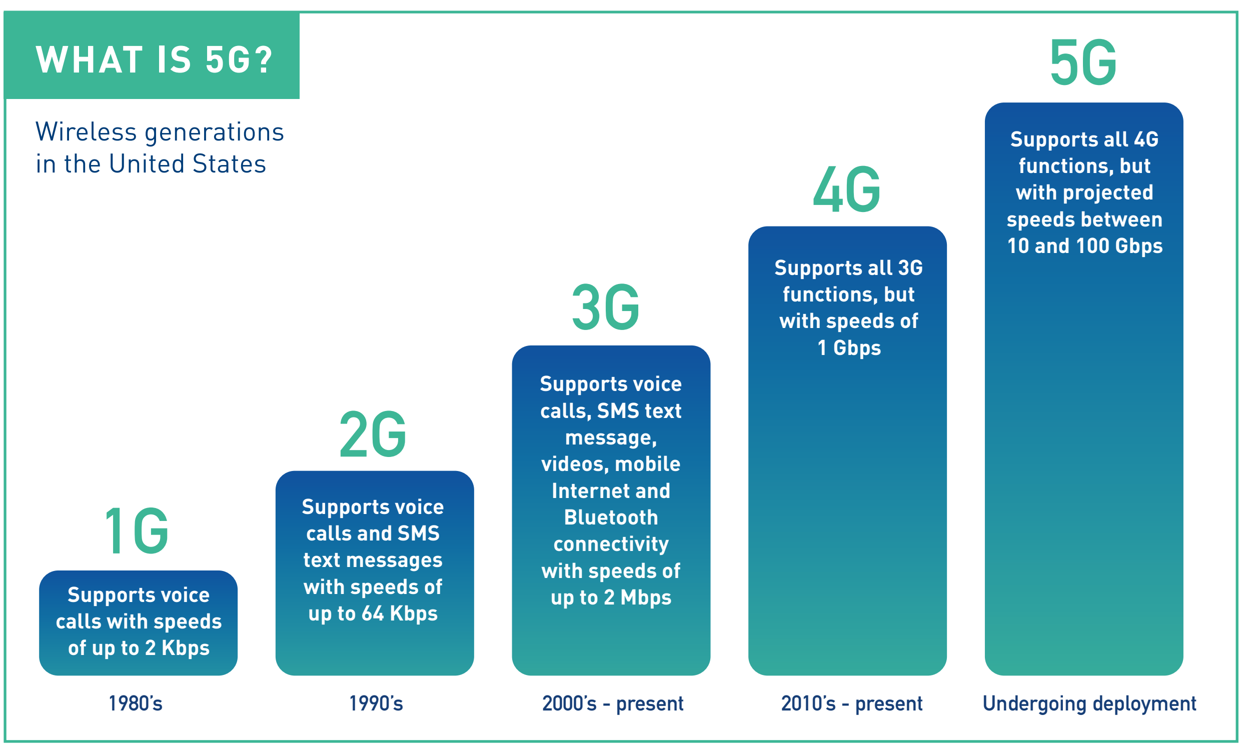
Incumbents, including U.S. Naval Radar and DoD personnel, get permanent priority as well as site-specific protection for registered sites. Priority Access License (PAL) holders can pay a fee to request 10-megahertz licenses on a county-by-county basis for 10 years. Up to seven 10-megahertz licenses can be awarded in one county. General Authorized Access (GAA) encompasses the rest of the spectrum, which will be open to GAA use, and coexistence issues will be determined by SAS providers for spectrum allocation.

CBRS offers a variety of potential advantages to stakeholders:

- It can allow nontraditional carriers to enter the wireless market.
- The propagation characteristics of the 3.5 GHz spectrum allow it to be deployed similarly to Wi-Fi networks and installed in a floor-by-floor fashion inside of buildings.
- LTE's superior quality, performance and security bodes well to transition Wi-Fi routers into CBRS-compatible gateways.
- CBRS is supported by a variety of stakeholders, including the CBRS Alliance, the Wireless Innovation Forum, Software as a Service vendors, radio and handset OEMs, wireless carriers and cable operators, mobile virtual network operators and neutral-host providers.

5G

5G is the next generation of wireless broadband networks being standardized by the ITU's Third Generation Partnership Project (3GPP).[5] Large-scale commercial deployments are expected to begin in 2019-2020 timeframe. 5G advancements include faster data speeds, lower latency, increased bandwidth per unit, support for more connected devices, and reduced energy usage. The immediate use case for 5G will be enhancement to fixed broadband service and mobile broadband with higher speeds and lower cost per megabit for in-building and outdoor coverage, enterprise/teamwork collaboration, and augmented/virtual reality (AR/VR). As service rolls out, Machine-to Machine (M2M), Massive Internet of Things (MIoT), and Mission Critical Services (MCS) will take on an increasing share of 5G services and greater importance to the economy.



Source: WIA

Enterprise Customer Considerations

Wi-Fi

Enterprise customers have a strong interest in using Wi-Fi technology to augment connectivity. Traditionally, most IT organizations used Wi-Fi to improve mobility within buildings strictly for data applications. With the advent of Voice over Wi-Fi (VoWiFi), mobility has crossed over into voice applications. VoWiFi reduces overall costs associated with making international calls and alleviates roaming and toll charges. Most technical decision makers have experience with wireline infrastructures, so using technologies like Wi-Fi is a natural progression into mobility for traditional Local Area Network (LAN)-minded decision makers.

This transition to supporting mobile voice services also coincides with a trend at several corporations to invoke mobile device management strategies. Bring Your Own Device (BYOD) is now part of the enterprise culture, embraced by companies interested in reducing costs and providing employees increased flexibility. BYOD and VoWiFi offer enterprises a diversified way to enable their employees to stay connected. Although there are cost savings associated with these new solutions, networks to support BYOD programs and VoWiFi need to be enhanced. Wi-Fi network design needs to prioritize data and voice traffic to ensure a high quality of service. Enterprises will also have to ensure their networks support all major wireless service providers.

CBRS

There is potential for tremendous benefit for enterprises to use CBRS to help support their communication requirements. Internet of Things (IoT) applications and devices can automate, track and sense elements in all areas of operations to help drive efficiencies in corporate operations. Traditional IoT applications that were supported by wide area networks or Wi-Fi can be phased into a CBRS network if an enterprise or third-party provider attains the licenses for development and use.

Offload from the wireless service provider network is one advantage of CBRS. To the enterprise end user, a CBRS network provides enhanced signal and data throughput in an indoor and corporate-campus outdoor environment. Analysis shows that users can achieve data speeds of up to 1 Gigabit per second indoors, and speeds can be five to 10 times higher in outdoor applications near the enterprise. Outdoor deployments will require the user to have line-of-sight access with service towers supporting the new CBRS network.

Independent radio sources and backhaul advantages are part of the network topology that are more economical to meet the needs of the enterprise. Capacity resources at the radio amplifier layer along with the air interface help control class and quality of service more effectively. Wi-Fi users may find a better experience on CBRS networks. Backed by LTE technology, the inter-compatibility of this technology – which is also used by wireless service providers – may offer a better user experience. Data speed and consistency of service may be seen with devices running over CBRS frequencies.

5G

The enterprise segment will take advantage of 5G in several ways to augment current technology offerings used in their operations. IoT devices and systems will be able to automate processes. Asset management, sensory devices and other IoT applications, such as energy management, lighting and security, will be implemented to drive efficiency into a customer's return on investment (ROI) model. Examples of IoT vertical markets include hotels, hospitals, high-rise buildings, light industry, airports, corporate headquarters and campuses, retail locations and stadiums. IoT deployments are expected to reduce operating expenses within the enterprise. 5G network enhancements are expected to accelerate the IoT deployments at a much faster rate. Connected devices are estimated to number in the billions within the next three years.

As IoT becomes more pervasive, it will require supporting architecture in a low-powered, low-latency environment. The RF environment will need to support antennas situated close to the end user — or at the edge of the network. With a "close to the antenna" architecture, the network will be more responsive to shifts in capacity and high data throughput or low latency, providing an immediate response — a key requirement in 5G. By doing so, networks can shift capacity and network support from one area to another depending on where mobile devices are located. This action is defined as virtualization, where all 5G network components can be in multiple areas to support edge computing. This will drive network architecture to be more responsive and operate more efficiently.

As the RF environment is lower in power to reduce noise and to improve latency for immediate response in an IoT environment, one key component to 5G architecture will require active network components to be closer to the antenna. OEM equipment likely will become located near the antenna to support large bandwidth requirements if needed.

Service Provider Considerations

Wi-Fi

Cellular operators have long embraced Wi-Fi as an offload strategy, and several major carriers are supporting the Wi-Fi Alliance's Passpoint service, which automatically moves users to a Wi-Fi service when available.[6] Visitors from different nations whose cellular providers have no roaming agreements or technology compatibility with U.S. terrestrial networks already use Voice over Wi-Fi when coming into the United States to avoid expensive roaming fees. While some automated soft handovers are available today, as LTE-A releases 16, 17 and 18 roll out and IP-based hard handovers become possible, the seamless use of indigenous Wi-Fi networks for stand-alone and aggregated sessions will enable BYOD users with capped data plans to roam onto any open, available networks.

The current number of Wi-Fi access points deployed for wireline backhaul delivery is not robust enough for wireless service providers to deploy current 4G LTE wireless services, and not ubiquitous enough in rural areas. The lack of fiber and Gigabit ethernet availability from a population and geographic perspective is one side of the shortage; the other is that there is not enough bandwidth delivered to the available access points. However, in most places where backhaul is available and in use to support Wi-Fi services, more access points can be added easily and inexpensively in the near term. In the longer term, the number of wireline access points and the maximum amount of bandwidth deliverable to each of them will have to increase to keep pace with the amount of data consumed on the network. For example, the University of New Mexico has more than 400 deployed access points with 1 GB to each port and from 10 GB to 40 GB for the backbone.

CBRS

CBRS offers cost-effective LTE solutions for both indoor and outdoor applications, and network operators are looking to use CBRS as another method to offload cellular data traffic. As cellular carriers upgrade and expand their networks for 5G, they are also looking for new ways to offload capacity. There are various technologies and methods for capacity offloading, such as Wi-Fi, small-cell densification and carrier aggregation, and using CBRS technology is being planned as well. Because it is an LTE-based technology, CBRS offers network operators a high level of network quality, performance and flexibility compared with Wi-Fi for network offloading. For example, carriers with PAL licenses will be able to use CBRS in 10-megahertz channels, allowing network operators to use carrier aggregation to increase network capacity as well as improve data speeds. Recent changes by the FCC have increased carrier confidence in their ability to deploy CBRS effectively, increasing the level of investment and usage expected.

CBRS offers carriers roughly 150 megahertz of spectrum for LTE capacity. It has advantages over Wi-Fi related to security, emergency calling, SMS support and roaming. It also can be an option if small-cell deployments are not practical. In addition, CBRS has better RF propagation than other 5G technologies that are expected to operate in the 5 GHz (and higher) range.

Wireless service providers considering CBRS will find some key benefits for today's networks, including enhanced capacity for current networks using LTE for 4G services at different frequency bands. The 3.5 GHz band can also be used in transition plans to 5G networks. The CBRS structure also might transform the approach of managing frequency bands to enable 5G radios to work in a shared-spectrum environment, an approach backed by the 3GPP. The CBRS band could also be used to synchronize services with international operators, enhancing international roaming and providing better coverage for subscribers.

5G

5G will provide a dramatic shift in network architecture for wireless service providers. The recent acquisition of high-frequency bands between 1 GHz and 3 GHz will result in smaller wavelength propagation characteristics. This necessitates network designs that are smaller in coverage footprint but will also help support a very dense network that will be low powered and achieve very low noise in the 5G environment.

RF design engineering efforts will require a “hub-spoke” concept that moves centralized processing into areas closer to the antenna. Each spoke will align with each deployed antenna location. This concept can also load balance processing into the distribution network as signals move closer to the antenna. This design approach will yield a higher performing 5G network but also require a more complex architecture with active network components closer to the antenna — or the network’s edge.

Another key requirement for 5G networks is network densification, where concentrated antenna footprints will support high bandwidth and low latency. The hub-spoke design approach will help achieve densification in an efficient manner and produce a high-quality signal allowing mobile devices to be responsive. The ability to detect mobile device usage, especially in high-demand, constant transmit-and-receive environments, will allow wireless service providers to shift network capacity to those areas immediately. Virtualized network elements and edge processing can be utilized to support this high-demand 5G architecture.

With this type of dense network architecture, there will be a heavy utilization of fiber and structured cabling solution assets to support connectivity to antenna locations. This is necessary to transport signals to core-network processing and edge-computing devices, and to help achieve high-quality network performance in low-powered, low-latency environments. Third-party operators are well positioned to secure access to key customer locations and to help wireless service providers with connectivity. These operators will become instrumental to the 5G ecosystem as they provide ancillary support for network infrastructure and services to the wireless service provider.

As the 5G network evolves and the network deployment strategy to densify signals becomes pervasive, the need to utilize qualified professionals becomes even more essential. RF integration companies will be heavily utilized to provide services for all areas of installation, monitoring and commissioning of 5G networks. With more active components introduced into the 5G network and edge-computing devices used for 5G service delivery, there will be a high demand for skilled field resources. Intelligent network resources will require training for engineers and technicians on new platforms to help optimize, monitor and maintain new 5G networks.

OEM Considerations

Wi-Fi

The Original equipment manufacturer (OEM) ecosystem for Wi-Fi products is well established and continuously upgrades equipment as the technology advances. Hundreds of companies are part of the Wi-Fi ecosystem, according to the Wi-Fi Alliance, which notes that more Wi-Fi devices exist than there are people on earth, and half of the Internet's traffic is carried over Wi-Fi networks.[7] Thus, the OEMs operating in the Wi-Fi space likely will continue to move forward with upgrades and product specifications.

CBRS

OEMs are analyzing the emerging CBRS band and see benefits like those seen by enterprises and operators. The marketplace will need to drive demand from consumers and enterprise end users. Service providers likely will monitor network growth and capacity utilization to help drive business cases for OEMs to bring development efforts in this space.

Industry associations and the FCC are certifying devices and radios today. The largest vendors in the CBRS ecosystem include the wireless network radio manufacturers — Nokia and Ericsson — and enterprise network infrastructure manufacturers — Cisco and Ruckus, among others. The network layer both from the wireless network manufacturers and enterprise needs to co-exist and work toward a technical framework of compatibility. This is will ensure a seamless mobility network transfer and high quality of service.

OEMs will be influential in the development of mobile devices that drive early adoption on the CBRS networks. Key chipset manufacturers driving the early discussions include Intel and Qualcomm. Smartphone and computer makers are eagerly awaiting the network requirement definitions so that several of these devices can be enabled with embedded chipsets to support CBRS. This introduces a competitive environment to ensure the economies of scale are reached and affordable price points are available to consumers and enterprise end users.

Several issues need to be addressed to achieve device marketplace delivery timeframes. Network operators are still working to define the network layer specifications and to deliver an effective deployment strategy. Current handset manufacturers that dominate the marketplace also have strong relationships with network operators. Samsung, for example, is a key proponent in the CBRS space and its adoption is critical at the early stages to introduce CBRS. Apple has yet to throw its hat into the ring, but the hope is that once mass adoption occurs, the company will join. The goal is to infuse the marketplace with chipsets in modems for IoT and enterprise applications and then to phase in mobile devices and smartphones.

5G

OEMs are instrumental in the adoption of 5G network deployments. As in past wireless network generations, synergies are needed between the wireless service provider and equipment manufacturers to achieve proper network performance. Key 5G requirements to support virtualization and densification design approaches will re-define traditional methods of equipment architecture. This will also change network equipment deployment strategies.

As active equipment moves closer to the antenna, OEMs will be challenged to design systems with components that will be smaller in size with high performance. This tradeoff will be the key differentiator among equipment suppliers and features will be defined to support 5G metrics. Performance metrics will be tied to densifying RF signal in low-latency and low-powered environments.

There are distinct advantages for 5G to be in the higher frequency range. As 5G networks move into frequency bands above 1 GHz to 3 GHz or higher, the ability to manufacture smaller equipment is possible. The need for localized RF coverage will result in lower power, low-noise amplifier technology — both at the front end and the back end of the 5G network. OEMs will be confronted with the challenge to support some form of open architecture to simplify network design. Wireless service providers will drive this requirement. Current examples include the move by radio manufacturers to start introducing baseband unit (BBU) architecture to integrate directly with distributed antenna system (DAS) architectures. This evolution of integrating existing network architectures will continue to grow in the 5G network evolution.

Conclusion

The wireless ecosystem must address growing mobile data traffic demands, whether generated by humans or machines in IoT applications. Offloading cellular traffic will be key for addressing growing demands on carriers' networks. Wi-Fi, CBRS and 5G networks are among the existing and emerging solutions to meet this need.

A variety of stakeholders are watching the developments in this space, including enterprises, which will require reliable and secure networks to keep employees connected and systems running smoothly and efficiently. Service providers and network operators must make use of a variety of technologies and networks to ensure all customers have a high-quality experience. OEMs are crucial to bringing forth the best possible networks and user equipment to facilitate the growing demand for mobile data.

About the Authors

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Greg Najjar is the Director of Business Development at ADRF, responsible for establishing new strategic relationships and providing enhanced coverage solutions for partners and customers. He has 20 years of experience developing and leading technology-driven teams, focused on business operations, project management and engineering. Prior to joining ADRF, Greg worked at Sprint for 19 years as the Director of Custom Network Engineering, where he managed a team of engineers and project managers that focused on deploying 3G and 4G solutions. While at Sprint, his teams were responsible for the company's top enterprise and government customers, as well as large venues, airports, stadiums and special events such as the NBA All Star Game, Super Bowl and Presidential Inauguration. He also maintained national responsibility for Sprint's strategy and budget, RF design and deployment of technology solutions (DAS, Wi-Fi, and small cells) for all Public Venue, Enterprise In-Building customers, Sprint Retail Stores, Special Events and NASCAR races. Greg holds a Bachelor of Science degree in Electrical Engineering from Northeastern University in Boston.

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Mark Reynolds is Associate Director at the University of New Mexico IT department, where he is involved in the engineering, design, installation and implementation of many voice, data, cellular, security and video deployments. Mark has been in higher education for 35 years with experience in telecommunications since 1973, with 45 years in voice, data, security, facilities, RF and management. Before joining the University of New Mexico in 2003, Mark served as the Operations Manager for the voice, video, security system and data networking, engineering and design at New Mexico Tech in Socorro, N.M., for 20 years. His notable accomplishments at UNM include heading up a large, complex project to upgrade the campus' existing communications technology; a distributed antenna system deployment; and designing, managing and supporting every aspect of telecommunications for the university.

Don Bach, Boingo Wireless

Don Bach is a seasoned telecom executive who has spent the last three decades engineering cellular networks. He currently serves as the Director of Sales Engineering for Boingo Wireless' DAS and small cell business, where he is responsible for overseeing the RF design of the company's cellular networks at large public venues around the world. He previously held leadership positions at Verticom and SAC Wireless. Bach's early career began as a technician in the public safety and LMR two-way radio industry, after he graduated from the Electrical Engineering program at DeVry University in 1986. In 1994, he became a system performance engineer on the iDEN Network by Fleet Call, which was later renamed Nextel. He spent 22 years in a variety of RF engineering positions at Nextel, which was acquired by Sprint in 2004. In 2007, Bach left Sprint to start a regional RF Engineering and implementation company focused on DAS networks. In 2012, he sold the company to SAC Wireless. SAC Wireless was purchased in 2014 by Nokia Networks. Bach is an active member of the Wireless Infrastructure Association (WIA) and plays a key role in authoring numerous WIA white papers on wireless deployment trends and next-generation mobile networks.

Luke Lucas, T-Mobile USA

Luke Lucas is Senior Manager of Engineering Business Development & Build Your Own Coverage (BYOC) for T-Mobile USA. His focus is on enterprise and in-building coverage, furthering the role of wireless in buildings as a 5th utility-like service. In his role, Lucas is involved with smart building and smart city technologies, 5G wireless and the relationship between enterprises installing infrastructure and the connection to T-Mobile signal source and backhaul. He has been with T-Mobile for more than two decades, previously in regional development manager roles. Prior to joining T-Mobile, Lucas was a real estate manager for Pacific Bell Mobile Services' wireless network in San Diego. Lucas holds a degree from the Sol Price School of Public Policy at the University of Southern California and a Master of Real Estate Development from USC's Lusk Center for Real Estate.

Endnotes

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