SIERRA WIRELESS WHITE PAPER

5G for Enhanced Mobile Broadband is Here.

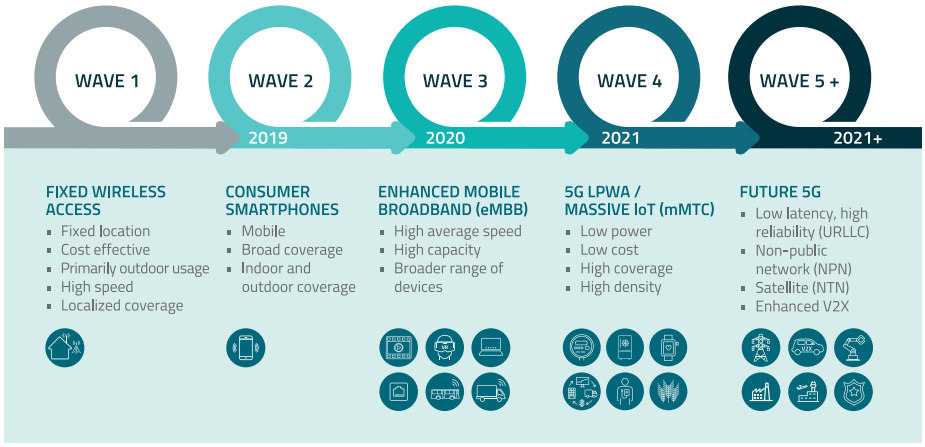
An expert guide to where we are and where we're going next.

As part of the transition to 5G, enhanced Mobile Broadband (eMBB) for the IoT is becoming a reality. 5G cellular networks are evolving quickly with the deployment of more 5G spectrum bands, Dynamic Spectrum Sharing (DSS) in low bands, and the evolution from Non-Standalone (NSA) operation to Standalone (SA) operation. All this serves to deliver high-speed data wherever people want it, but because the evolution of cellular networks is ongoing and complex, it can be hard to anticipate how these changes will affect the expected performance of a design. Our common-sense guide to 5G for eMBB cuts through the noise and guides you through this evolution, so you know what's here now and what's still on the horizon.

Enhanced Mobile Broadband is the Third Wave of 5G

It's important to place eMBB in the broader context of 5G as a whole, because 5G isn't happening all at once. It's arriving in waves, with each new wave building on the last. Each wave brings with it an added level of capability and targets a different set of use cases.

The first two waves, Fixed Wireless Access (FWA) and Consumer Smartphones, have already happened, and the third wave, for eMBB, is happening now. The fourth wave, for Massive Machine Type Communication (mMTC) will follow after eMBB, and the fifth wave will bring Evolutionary and Revolutionary Enhancements.



The following is a quick overview of each 5G Wave.

- **Wave 1: Fixed Wireless Access (FWA).**
  The first 5G wave delivered high-speed broadband cellular connectivity to private homes and businesses using the new 5G radio access technology standard called New Radio (NR). FWA was chosen as the first wave of 5G because it's a compelling alternative to wired access and because the deployment could happen quickly.

  FWA can be commercialized within small locales (e.g. neighborhoods) and only needs outdoor coverage. It also doesn't need mobility support. Demand for FWA has been strong, because it's a viable – and in many cases a far less expensive – alternative to the fiber optic and other cable-based internet access formats used for "last mile" connectivity. FWA customers consume large volumes of data each month, and that means FWA requires very high capacity. Meeting these capacity requirements necessitated deployment of 5G's new mmWave bands, despite the complexity of this approach.

- **Wave 2: Consumer Smartphones.**
  The second wave addressed strong worldwide demand for 5G smartphones. It was the next logical step after FWA and enough of a task to qualify as its own wave of 5G deployment. Deploying 5G for smartphones required networks to do three things. First, they had to evolve to provide broader, more ubiquitous coverage, at least in major cities. Second, they needed to provide broader in-building coverage, and third, they had to provide full mobility support.

Every major smartphone OEM now offers at least one model with connectivity that uses NR, and network operators worldwide are now running 5G services aimed at letting consumers take advantage of their upgraded devices.

Providing in-building coverage required using lower RF bands, but given the limited amount of lower-band spectrum, in-building 5G coverage is not always available.

Wave 2 succeeded in meeting its goal of enabling mobility support, and access to NR coverage improved where people frequently use data – at home, the office, city centers, entertainment venues, public transport – but by the end of Wave 2, NR was still not nearly as ubiquitously available as LTE.

- **Wave 3: enhanced Mobile Broadband (eMBB)**
  The third wave, which began in 2020, builds on the underlying network of 5G smartphones, and has hardware vendors and operators expanding their scope to address use cases involving other mobile device form factors, such as mobile routers, tablets, laptops, automobiles, and gaming consoles.

  The goals of Wave 3 are similar to those of Wave 2, for smartphones, but with the need to deliver higher average speed and higher capacity at more locations, on a broader range of devices. The improvements for Wave 3 are possible mainly due to the deployment of NR in more spectrum, especially in the Sub-6 bands that support many eMBB applications. The use of Dynamic Spectrum Sharing (DSS), which lets carriers allocate more or less the same LTE spectrum to NR devices, is helping to enable sub-6 band deployments. Another aspect of Wave 3, the deployment of the new 5G Core Network (5GCN), brings latency improvements and enables wireline responsiveness in wireless environments.

  With 5G eMBB, everyday experiences can move to a new level of interaction and immersion. For example, a router using 5G cellular feels as responsive or more responsive as one using wired access. This allows organizations to justify the use of 5G routers for primary or failover operation when the primary wired access system fails or is shut down for servicing. 5G eMBB also means training environments become more realistic with ultra-high-def video, gaming becomes more exciting with lower-latency connections, technicians get assisted guidance when repairing equipment, consumers get product demos directly from boxes on shelves, and tourists get visual commentary by pointing their mobile devices at an attraction.

eMBB improves what we do today, while enabling new experiences

- **Wave 4: Massive Machine Type Communication (mMTC)**
  The fourth wave will begin to address the massive Machine Type Communication (mMTC) use cases. mMTC connectivity is designed to be low cost, low power, high coverage and have massive capacity. The massive capacity is needed to support the hundreds of billions of smart sensors and other unmanned edge devices that are expected to join the Internet of Things (IoT). Many of these IoT devices will come from smart city and supply chain activities, such as lighting and road signs, waste management, meter reading, asset tracking, and structural and environmental monitoring.

  IoT operation is already covered by today's versions of LPWA technologies, LTE-M and NB-IoT. But the 5G versions of LTE-M and NB-IoT, as defined by the 3GPP's Release 15, improve low-power performance and increase capacity to meet the anticipated high-density requirements of machine-to-machine operation on a truly massive scale.

- **Wave 5: Evolutionary and Revolutionary Enhancements**
  The last 5G wave, Wave 5, will bring a collection of emerging use cases including enhanced Vehicle to everything (eV2X), Ultra-Reliable Low-Latency Communications (URLLC), and extended reality (XR), as well as a collection of nascent deployment modes include NR Unlicensed (NR-U), Non-Public Networks (NPN), and Non-Terrestrial Networks (NTN).

  The URLLC use case, which goes by several names, including the industrial IoT and Industry 4.0, includes subordinate use cases, such as industrial automation (e.g. with advanced robotics), and remote health care (e.g. remote surgery). URLLC represents one of the most difficult new use cases of NR to deploy, because it requires extremely low latency (e.g. < 1 ms) and ultra-high reliability (e.g. 99.999%). Providing these attributes in the device and in the network are technically very challenging and very expensive, making the business case for URLLC as yet, unproven.

  The enhanced Vehicle to Everything (eV2X) category takes Vehicle to Everything (V2X) to the next level, and in some ways is a subordinate use case of URLLC because it also needs low latency and improved reliability. eV2X will make it possible to support advanced platooning (closely grouping vehicles), remote driving, and self-driving vehicles, all with advanced crash-avoidance mechanisms.

  The Extended Reality (XR) use case, which includes Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR), is also still in its infancy. Today, these activities are usually supported by Wi-Fi connections. The main challenge in operating XR over a 5G connection, is being able to provide the required low latency and high data rates at a cost the market can accept. XR over 5G has many other challenges however including thermal dissipation, edge-computing capabilities, miniaturization, battery life, and antenna designs to minimize RF exposure, which is also referred to a Specific Absorption Rate (SAR).

5G Non-Public Networks (NPNs) are an improved deployment model where devices are capable of accessing private networks as well as public networks and are typically operated by a mobile network operator. NPNs are used to provide enhanced security, guaranteed Quality of Service (QoS) for URLLC and other use cases, coverage for remote areas, access to local content, and 5G service without fees for hotels, businesses, stadiums, and campuses.

Running LTE in unlicensed spectrum (e.g. 2.4GHz and 5GHz ISM bands) is done today using the License Assisted Access (LAA) feature of LTE. But LAA requires constant assistance from the public LTE network, so it only works when the device is in public LTE coverage and requires a monthly subscription. In 2020, 3GPP standardized a feature for NR called NR Unlicensed (NR-U), which lets NR run purely within unlicensed spectrum. This makes it much easier to deploy NPN or private networks since there is no spectrum license needed for NR-U.

It is expected that, by the end of 2021, the 3GPP will have completed specifying the required changes to NR, LTE-M, and NB-IoT to support access over satellite links, in what are called Non-Terrestrial Networks (NTN). An NTN deployment will be able to provide worldwide cellular coverage, including very remote locations at sea and in oceans, deserts, mountains, jungles, and forests. The decrease in cost to launch satellites, especially nano Low Earth Orbit (LEO) satellites, plus the decrease in cost of NTN end devices that use high-volume cellular chipsets, makes a strong business case for NTN deployments.

Enhanced Mobile Broadband Makes Use of NR and the 5G Core Network

NR FOR SPECTRUM AGILITY

The new 5G radio access technology standard called New Radio (NR) can be deployed in more spectrum than any previous generation of cellular including LTE. NR supports operation in Sub-6 bands and mmWave bands. The Sub-6 bands refers to spectrum between 400 MHz and 6 GHz, while millimeter wave (mmWave) bands are between 24 GHz and 52 GHz. This greatly expands capacity and helps increase data rates.

- **NR in Sub-6 bands – Well suited to eMBB**
  NR in sub-6 bands is a good option for eMBB use cases, especially those eMBB products transitioning from LTE. For people who have experience working with LTE, NR in Sub-6 bands will feel fairly familiar. Since the frequencies used for a Sub-6 band deployment are similar to those used for LTE, the antenna design for NR is similar to LTE. This makes it easier and faster to migrate LTE designs to NR designs operating in Sub-6 bands. Even the certifications are similar, so the steps needed to finalize a NR sub-6 product design are recognizable.

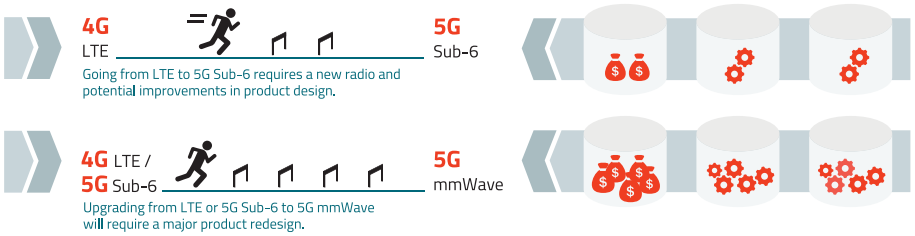
Sierra Wireless delivers innovation in NR deployed in Sub-6 and mmWave bands

An important development for NR in Sub-6 bands, particularly in the United States, is operation in the Citizen Band Radio Services (CBRS) portion of the spectrum, at 3.5 GHz. Previously reserved for certain military uses and satellite ground stations, the CBRS band is available as of 2020 for the cellular use. The licensing model for CBRS is relatively complex, with several levels, but cellular operators and private networks alike are expected to use the band. CBRS for private networks is well suited for enterprises with critical communications requirements, and is also likely to be used in convention centers, sport stadiums, energy and mining operations, manufacturing plants, agricultural sites, and shipping ports. Since many edge devices don't support the CBRS bands yet, using a gateway or router equipped with NR can provide a bridge from CBRS service to a Wi-Fi access point. The CBRS spectrum is, for now, only available in the U.S., but other countries are likely to allocate portions of their own mid-band spectrum for use by private networks.

- **NR in mmWave bands – Better for outdoor, non-mobile use cases**
  The aspect of NR that presents one of the biggest learning curves for everyone – from network operators and solutions providers to OEMs considering deployments – is operation above 24 GHz, in the mmWave part of the spectrum. Working in the mmWave spectrum presents physical realities that are hard to escape. The unique characteristics of mmWave operation mean integrators need to take extra care during design, manufacturing, and certification to ensure the mmWave antennas perform properly. Also, given the big jump in speed due to the wide spectrum the mmWave bands offer, USB 3.0 is no longer fast enough so integrators may have to work with new host interfaces and drivers, such as PCI Express (PCIe). There are new certification processes to learn as well, based on over-the-air testing, because mmWave can't go through standard cables or connectors.

- A number of mobile operators have invested in mmWave, and are working to expand their deployment, but the trend is toward using mmWave more for fixed wireless access (FWA) than for mobile scenarios. The wide mmWave bands can carry a huge amount of data, but they have very limited range so the cost of installation can go up quickly if too many base stations are needed to cover a given area. Also, the mmWave signal travels best through air and clear glass, but fails to penetrate walls and tends to bounce off objects. As a result, mmWave

is better suited to support broadband access in outdoor locations where a lot of people access data at once – such as event spaces, stadiums, and large corporate or university campuses – basically wherever it's economical to deploy lots of 5G base stations.



Plan your 5G path carefully.

5G Core Network (5GCN) for a Service-Based Architecture

At the same time that device hardware is evolving to take on 5G use cases, the back-end core network is changing to support 5G, too. Alongside NR is a new 5G Core Network, often referred to as the 5GCN, which is designed to give the operational capacity, efficiency, and performance needed to support 5G uses cases.

5GCN uses a more flexible – and more modern – service-based architecture. It supports the use of popular web-based RESTful APIs to interconnect network elements, and this makes it easier to add new services. 5GCN is designed to be easily deployed in the cloud, using virtualization, and supports new and existing cloud-based applications.

5GCN easily supports different types of cellular technologies. As of 2020, it supports NR, LTE, LTE-M and NB-IoT technologies.

TWO WAYS TO CONNECT

Early in the 5G specification process, the 3GPP predicted it would take at least a year longer to specify 5GCN than NR.

- **Non-Standalone (NSA) mode**
  So as not to delay rollouts of NR, the 3GPP specified a way to connect a NR base station to a legacy LTE core network called the Evolved Packet Cores (EPC). This interim 3GPP architecture is referred to as Non-Standalone (NSA) mode. A drawback of NSA operation is that it requires the use of EN-DC, or E-UTRA NR Dual Connectivity, which requires the device to operate two radios simultaneously, one for LTE and one for NR. As a result, to get 5G service, the device needs to connect to an LTE base station on one band (e.g. a mid-band frequency) and a NR base station in another band (e.g. a low-band frequency). To avoid intermodulation issues, the LTE and NR bands need to be several hundreds of MHz apart, and this greatly restricts the number of bands that can be used. This band restriction, on top of the need to have simultaneous coverage of both LTE and NR, seriously limits NSA ability to provide 5G coverage.

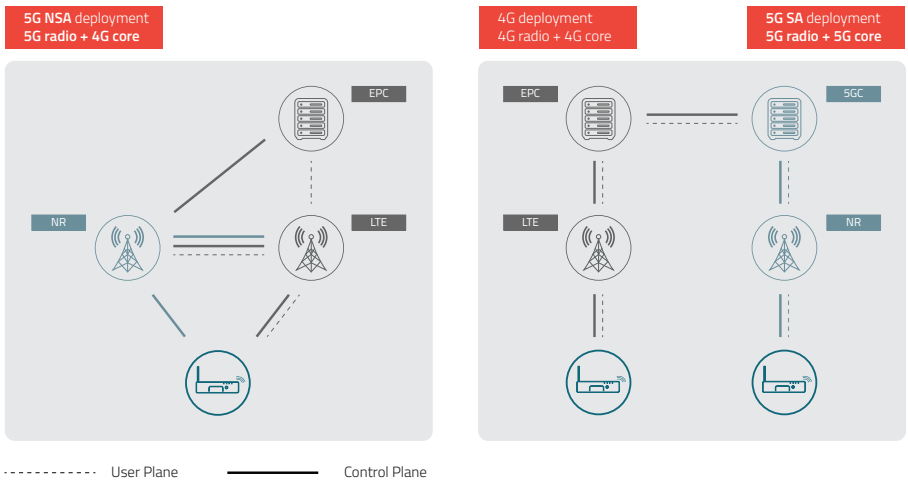
Networks are evolving from NSA to SA. Sierra Wireless eMBB products fully support both SA and NSA modes. Sierra Wireless can help guide you through the options.

- **Standalone (SA) mode**
  When a NR base station connects to a 5GCN, the architecture is referred to as Standalone (SA) mode. SA offers several advantages over NSA. Most importantly, SA can operate without LTE coverage so it's likely to be available more often. From an end-user standpoint, SA offers lower latency and longer battery life, and from an enterprise standpoint, it presents a better option for local breakout, making it easier to optimize latency and security in private networks.

  The latency can be as much as 40% lower on SA compared to NSA, making it better suited to latency-sensitive applications like video conferencing, video calling, web browsing, remote computing, and gaming. SA also helps operators deploy and run their networks more efficiently because it supports improved virtualization. Since the 5GCN also supports legacy Radio Access Technologies (RATs), carriers have the option to transition their networks to using only a 5GCN, which greatly reduces operational costs.

  One issue with SA is that if NSA is available, NSA can provide higher speed because it can aggregate both the LTE and NR bands, whereas SA is restricted to aggregating only NR bands. This will become less of an issue over time, because NR will eventually be deployed on all LTE bands, using the Dynamic Spectrum Sharing (DSS) feature described later in this white paper.

At present, the conversation around NSA versus SA is not either or, but when. NSA is a transitional mode that will eventually give way to SA, but this will take time. NSA will only really go away when SA is available everywhere, when NR is deployed in most bands, and when all NR devices support SA. Unfortunately, some of first NR devices deployed – that is, those associated with the first two waves of 5G – only supported NSA mode which makes it difficult to decommission NSA support. In the meantime, while NSA and SA are both still present, a good approach for many customers is to support both NSA and SA. This ensures the best connection possible when the carriers upgrade their networks to support SA. Sierra Wireless eMBB products fully support both SA and NSA modes.



NSA and SA setups.

Networks are evolving to support DSS. Sierra Wireless eMBB products have completed comprehensive DSS interop testing. Sierra Wireless can help guide you through the options.

USING A 5G NON-PUBLIC NETWORK (NPN)

To support the wireless communication requirements of mission and business-critical operations, organizations may choose to run on a private cellular network. These private networks are physical or virtual cellular systems that make it easier to ensure availability and reliability, privacy, and allow for greater control over security mechanisms and access privileges. Deployment options and government licensing policies for using a private 5G network can vary from region to region, so it's best to partner with a 5G technology provider with experience building and operating private cellular networks.

Advantages of a 5G NPN

- Virtualization simplifies deployment of the 5GCN
- NR devices support mid-bands available for private use
- Lower latency than LTE

DYNAMIC SPECTRUM SHARING (DSS) FOR LTE/NR CO-EXISTENCE

As mentioned above, full SA deployment will only be possible when NR is deployed in most bands. Dynamic Spectrum Sharing (DSS) will help with this a great deal because it allows LTE and NR to operate simultaneously in the same band, with the right amount of resources being dynamically allocated to each one based on demand. This is a major departure from previous generations of cellular, because it means there is no need to set aside spectrum to make room for NR.

When 3GPP was designing NR, the DSS feature was not an afterthought, but instead was a critical design decision made very early in the process. DSS is made possible by the fact that NR uses the same transmission format (OFDM) as LTE, and because NR can schedule around legacy LTE broadcast signals (MIB, SIB, CRS) very efficiently. Using DSS, a base station scheduler can dynamically decide every 1ms, based on demand, whether to schedule LTE, NR, or both on the available band. In the early stages of the 5G rollout, where NR devices are relatively rare and demand is low, most of the spectrum can be still allocated to LTE users. Over time, however, as NR devices become more common and demand increases, DSS automatically allocates more spectrum to NR users.

DSS not only speeds up NR deployments, but is also good for LTE. DSS gives LTE a longer lifespan because it removes the need for operators to shut down and re-farm LTE bands to deploy NR. The same is true for LTE-M and NB-IoT, because DSS allows NR to operate in the same spectrum as LTE-M and NB-IoT.

Some carriers, especially those with less mid-band spectrum, have embraced and deployed DSS, while others have avoided it. There are concerns over complexity, and there were interoperability issues with some of the NR devices introduced in Waves 1 and 2, but with Wave 3 things have stabilized. All of Sierra Wireless' eMBB products fully support DSS and have been rigorously tested against interoperability issues.

Enhanced Mobile Broadband Needs High-level Security

With 5G sending more and more data across the network at higher speeds, and bringing exponentially more devices online, there is greater risk of losing or leaking sensitive data or falling victim to data breaches. These added risks make it all the more important to run the right security mechanisms on top of 5G. Working with trusted technology providers who understand these new vulnerabilities and are prepared to manage them would make the job easier.

Effective security requires an orchestrated multi-layered approach to defense, with multiple security layers on top of the 5G cellular service that protect the integrity of the system, from device, to network, to cloud, to end application. Effective security also includes continuous work with OEMs and carriers to ensure best security practices are followed. Here are the primary layers of security when it comes to securing a 5G eMBB deployment, and a summary of how Sierra Wireless handles each:

Sierra Wireless uses an orchestrated multi-layered approach to security

- **Secure boot**
  Ensures that firmware used to boot the device is authentic, comes from a trusted source, and hasn't been tampered with. For maximum protection, Sierra Wireless stores the private keys and any Private Key Infrastructure (PKI) used to authenticate images offline, in an encrypted state, in DigiCert vaults. Unique key pairs are generated for each signing operation and the private key is immediately destroyed. All secure boot signing operations are recorded, audited, and limited. Since the image-signing process is highly sensitive, Sierra Wireless uses strict auditing and only grants signing privileges to designated senior Sierra Wireless developers at our head office in Richmond, Canada.

- **Vulnerability management**
  The National Vulnerability Database (NVD) has more than 1000 new entries each month.

  To best manage vulnerability in our products, we follow industry-recognized MITRE guidelines and employ a system that monitors the NVD in real time to match new vulnerabilities to our existing products, and automatically generate trouble tickets to investigate/remediate the issues in all affected products.

- **Code quality**
  To avoid the coding errors and bad coding practices that make software susceptible to attack, Sierra Wireless documents all cryptographic mechanisms that are sanctioned for use in our products, and this coding standard is reviewed every 12 to 18 months. We also automatically check against the coding standard as part of the code review process.

- **Device-to-cloud security**
  As data travels from device to cloud, it traverses a number of different network entities that may not provide the customer's required level of security. To ensure end-to-end protection, especially on public internet connections, Sierra Wireless uses DTLS 1.2 with mutual authentication. Our devices are also provisioned with unique, cryptographically secure keys in the factory, and go through a bootstrap process to provision new, unique, random credentials every 90 days. Plus, we use cryptographically secure device identities when initiating connections to the cloud.

Start Your 5G Future with Sierra

At Sierra Wireless, our design teams are committed to the success of your 5G project in all its forms. Working alongside our customers, our 5G specialists focus on quick, secure deployment, so everyone can reap the rewards of mobile broadband.

- **Technology & Expertise**
  With over 25 years of cellular IoT experience, a history of innovation and active participation in defining 5G standards, Sierra Wireless provides you with the advanced technology and expertise required to move to 5G.

- **Partnerships across the ecosystem**
  Given our industry partnerships across the ecosystem, we can help you pull the right pieces into place to deploy your 5G initiative successfully.

- **Commitment to quality and security**
  Sierra Wireless is an established and trusted player in the IoT space and is committed to ensuring that our products and solutions meet the highest quality and are designed to be as secure as they can be.

To learn more about our unique dedication to success with 5G for mobile broadband, visit us at www.sierrawireless.com/5G

About Sierra Wireless

Sierra Wireless (NASDAQ: SWIR) (TSX: SW) is the leading IoT solutions provider that combines devices, network and software to unlock value in the connected economy. Companies globally are adopting IoT to improve operational efficiency, create better customer experiences, improve their business models and create new revenue streams. Whether it's a solution to help a business securely connect edge devices to the cloud, or a software/API solution to help manage processes associated with billions of connected assets, or a platform to extract real-time data to make the best business decisions, Sierra Wireless will work with you to create the right industry-specific solution for your next IoT endeavor. Sierra Wireless has more than 1,300 employees globally and operates R&D centers in North America, Europe and Asia.

For more information, visit www.sierrawireless.com.

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