MARCH 2015

5G - Vision for the next generation of connectivity

QUALCOMM®

Disclaimer

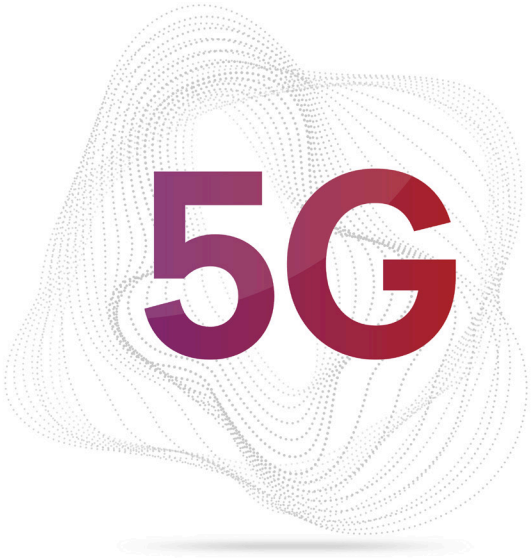
Qualcomm is a trademark of Qualcomm Incorporated, registered in the United States and other countries. All trademarks of Qualcomm Incorporated are used with permission. Other products and brand names may be trademarks or registered trademarks of their respective owners. This technical data may be subject to U.S. and international export, re-export or transfer ("export") laws. Diversion contrary to U.S. and international law is strictly prohibited.

References in this document to "Qualcomm" may mean Qualcomm Incorporated, Qualcomm Technologies, Inc., and/or other subsidiaries or business units within the Qualcomm corporate structure, as applicable.

Qualcomm Incorporated includes Qualcomm's licensing business, QTL, and the vast majority of its patent portfolio. Qualcomm Technologies, Inc., a wholly-owned subsidiary of Qualcomm Incorporated, operates, along with its subsidiaries, substantially all of Qualcomm's engineering, research and development functions, and substantially all of its product and services businesses, including its semiconductor business, QCT.

Qualcomm Technologies, Inc.
5775 Morehouse Drive
San Diego, CA 92121
U.S.A.

Contents



1 **Executive summary —** connecting, enabling, empowering

Generational shifts in the world of technology capture the imagination, and promising the opportunity to push the envelope and do things in entirely new ways. The story of 5G is no different, it will be a transformational force that enables new services, connects new industries, and empowers new user experiences for the next decade—and beyond.

5G promises to deliver much more than just higher data rates and more capacity. It targets new kinds of ultra-reliable, mission-critical services. Examples include, applications that will allow doctors to remotely control medical procedures or give consumers new levels of control over their homes or cars, and beyond. 5G aims to effectively connect virtually everything—from simple sensors to complex robots, all while further enhancing traditional mobile broadband service. That means next generation of applications, services and use cases will have extreme variation in requirements. To meet this challenge, 5G will require a whole new user-centric design that can scale and adapt to billions of connected things, provide new ways of connecting everything, and enhance cost and energy efficiency.

This user-centric design approach represents a new way of thinking about networks and devices. From a connectivity perspective, users will no longer be mere end-points, they will be integral parts of the network, creating “edgeless” connectivity. But it’s not only connectivity 5G is after, also computing and content need to be distributed closer to the actual user, be it, human, vehicle, machine or “thing” as it is sometimes referred to as.

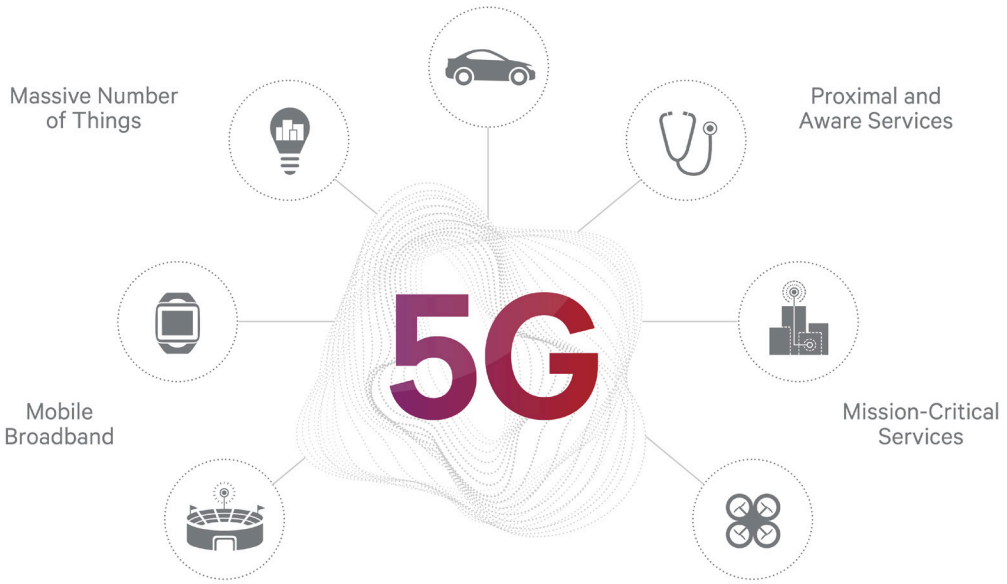
5G is envisioned to be a unified platform for all types of spectrum and bands, from low bands below 1 GHz to emerging higher bands like mmWave, supporting a wide range of new kinds of services, while offering opportunity for new deployment, subscription, charging and business models. A key enabler is a unified air interface design that is scalable and adaptable across all these spectrum and service types.

While 5G continues to be defined, with commercialization anticipated around 2020, 4G continues to evolve in parallel. Enhancements to 4G will bring new capabilities far beyond what is possible today, and steer LTE Advanced in the same transformational path envisioned for 5G. Multimode devices and simultaneous 5G, 4G, and Wi-Fi connectivity will allow for a seamless and phased 5G introduction. Furthermore, 5G’s single core network is envisioned to support 4G and Wi-Fi access, ensuring that operators’ current and future investments are protected.

The mobile industry ecosystem is intently focused on making the 5G vision a reality, and is working together on many fronts to invent the next generation of mobile experiences.

2 Not just a new generation, but a new kind of network

Mobile is already the biggest technology platform in the history. 3G introduced the concept of mobile broadband, and the popularity of smartphones combined with the advent of 4G resulted in the explosion of ever-increasing mobile data traffic that we call the 1000x mobile data challenge. Thanks to the rapid development of mobile computing and the robust LTE Advanced roadmap, the industry is on track to meet the challenge. The 1000x challenge is being addressed by 3G, 4G, and Wi-Fi, and through the growing deployment of small cells along with more spectrum.



Given that positive prognosis for the future, the question arises, why do we need 5G, and what can it do for us that 4G can't? The answer is that the vision for 5G is to not only provide better broadband with higher capacity and higher data rates at much lower cost, but also to address entirely new challenges that span far beyond, to enable new services, empower new types of user experiences, and connect new industries.

Looking beyond today's trends, 5G aims to connect virtually everything, to go beyond needs of what humans can currently perceive, to meet requirements for new classes of services, with new levels of reliability and latency, and to bring new capabilities for control, discovery, and awareness to life. A vision of this magnitude requires not just a new way of thinking but a different kind of a network. 4G LTE initially provided better mobile broadband, but LTE Advanced in many ways is already heading in the same transformational direction as 5G.

So, what does this new kind of network entail? Such a network could be defined by three characteristics:

SCALABILITY AND ADAPTABILITY

5G will have the ability to scale and adapt across an extreme variation of use cases such as uniform, fiber-like broadband everywhere (not just higher peak data rates) services; ultra-reliable, mission-critical services such as controlling the power grid or remote medical procedures (where failure is not an option); and connecting everything from simple sensors to complex robots, which also means supporting billions of ultra-low energy devices needing expansive coverage, at very-low data rates and at ultra-low cost.

USER CENTRIC DESIGN

The design approach for 5G is rooted in keeping the user at its center. Whether the user is a human, a device, or a "thing," it will bring content, connectivity, and computing close to the user. For connectivity, users are more than mere end points, they are integral parts of the network (offering "edgeless" connectivity). This distributed approach combined with virtualized network functions will not only reduce latency, but also significantly improve cost and energy efficiency, which are key objectives for any new-generation technology.

UNIFIED PLATFORM

5G will unify access across all types of spectrum and bands, unify all that has been added to 4G, (such as LTE broadcast), and improve upon new, broader dimensions (beyond that of previous generations) to enable a wide range of new kinds of services. And the unified platform needs to be scalable for new deployment, business and pricing models as well as be suited for realizing new breeds of applications, services and use cases. A key enabler in this is the unified air interface that is scalable and adaptable across all spectrum types and across an extreme variation of services.

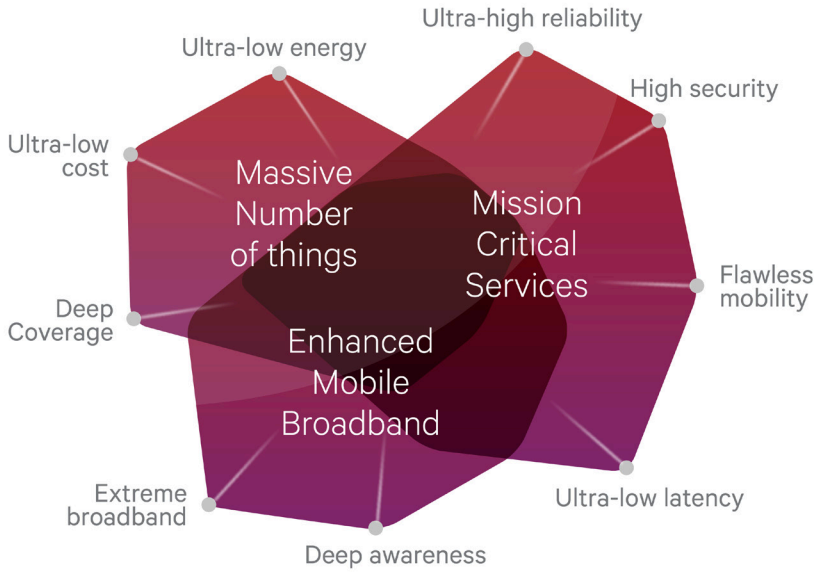
As evidenced by its defining characteristics, 5G is not just a new generation of technology, but a fundamentally new kind of a network needed to address the expanded connectivity needs of the next decade and beyond.

3 Scalability and adaptability across extreme variations of requirements

The stated aim of 5G is to enable new kinds of services, connecting new industries, and empowering new user experiences. The needs of existing and new use cases are vastly different on many dimensions. Extreme improvements in one dimension generally requires a tradeoff in another dimension. In other words, one can't get ultra-high reliability and ultra-low cost at the same time, so 5G has to scale up to right level of performance for one service, but scale down in cost for another service.

For example, new mission-critical services need highly-reliable links because failure is not an option and down time is absolutely not permissible. Ultra-low latency is a must because of the immediate nature of action needed. Finally, high security and flawless mobility are absolute requirements for many of these kinds of services.

On the other hand, when you consider the massive number of connected "things" anticipated in the future (e.g., integrated sensors in many personal, industrial, and enterprise applications), many of those things need to offer ultra-low energy consumption, years of battery life, deep coverage to reach very unconventional places, and relatively slow data rates, all at an extremely low cost.



At the same time, the next generation of mobile broadband services will have the ability to scale up and aggregate much wider spectrum in order to provide much higher performance and peak data rates, consistently high data rates uniformly across the coverage area, along with the ability to incorporate other dimensions of improvement. The addition of contextual awareness will enable differentiated services and enhance user experiences, but also allow the networks to be optimized for cost and energy efficiency. Case in point, if the network knows how the connectivity is to be used, e.g., for stationary use cases only, then the network does not need to provision for certain network functions needed for mobility. Having that capability will reduce costs and save energy. The key is that 5G will allow extreme use cases like these to coexist in the same unified 5G design, without compromising the performance of each other.

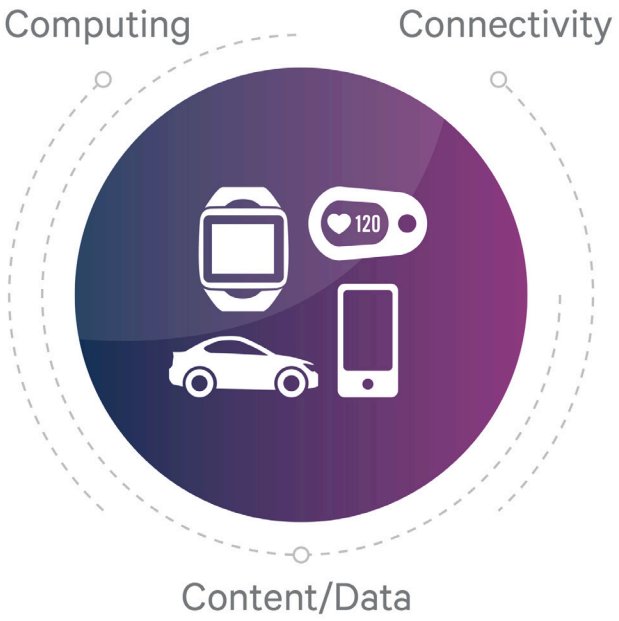
People have an uncanny ability to apply technology in unexpected ways; we are certainly not be able to imagine all the opportunities the ultra reliable, ultra-low latency and secure 5G link will enable in 2020. So apart from addressing extreme varieties of known use cases, it should also have the ability to scale and adapt to use cases that have yet to be imagined.

4 A user-centric design

To scale for billions of connected things, reduce latency, and improve cost and energy efficiency, 5G needs a holistic approach that keeps the user at the center. This means, bringing not only connectivity, but computing and content close to the user. Depending on the use case, the user could be a human with a device or wearable, a connected thing such as a sensor, or a connected vehicle such as a car. Bringing the connectivity, computing and content closer to the user is of paramount importance to provide instant and immersive visual and audio experiences based on real-time input from on-device cameras and sensors, on-device content (or content cached at the network edge), as well as a way to utilize new ways of discovering and connecting directly to relevant things around the user.

A good way to understand this user-centric approach is to contrast it with a traditional network-centric or cloud-centric approach (a.k.a. hub and spoke architecture). In these approaches, the network centrally controls of the system and orchestrates the connectivity to endpoints, and content flow to and between the endpoints, as well as with the external world.

With the user-centric approach, network intelligence and control are also distributed closer to the users—sometimes referred to as the "edge" of the network.



4.1 User-centric connectivity — where devices are no longer just endpoints

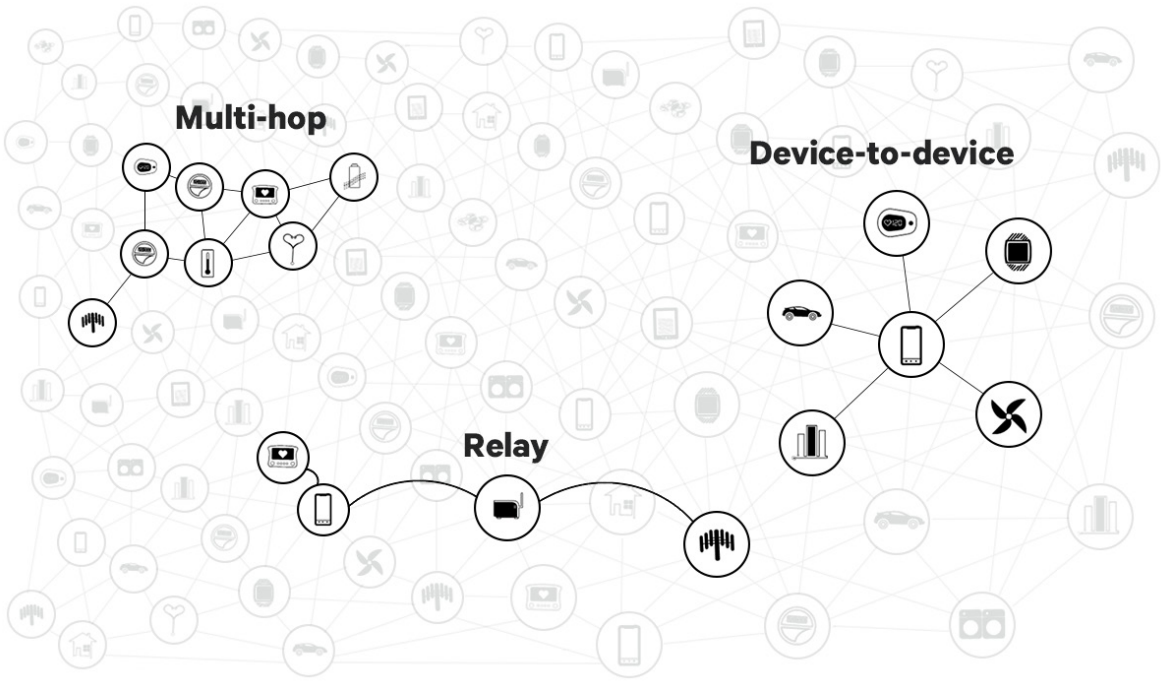
In a world with billions of connected things, 5G will make it possible for the user to connect to relevant things that are nearby and, in many cases that connection will be made directly, without having to go back and forth through a central network. In 5G where connectivity is user-centric, the user is no longer the endpoint of the network, but rather an integral part of it. New ways of connecting will be possible. Devices will connect with one another directly, for both discovery and communication.

Devices will “multi-hop,” relaying connectivity to things around the user (and the device), as explained below.

- Device-to-device connectivity seeks out (discovers) relevant information within proximity of the user, and has the ability to communicate directly with other devices. Already introduced in 4G, the proximal discovery concept will be leveraged and expanded further in 5G.

- Multi-hop is a mode of connectivity where devices act as hubs and relays for other devices, even forming a mesh network. It will be controlled by operators utilizing their licensed spectrum, as well as by users using unlicensed spectrum. A sample use case is in machine-to-machine (m2m) communication where a simple device lacks the power needed to reach macro towers or small cells. In such a scenario, other devices that are connected to the macros/small cell form a “multi-hop” or mesh network to extend the coverage and connect the unconnected device.

- Base stations with integrated access and backhaul will be important for further small cell densification, helping solve the challenges of installing fixed backhaul. Integrated access and backhaul is particularly useful for deployments that use higher spectrum bands such as mmWave.



Leveraging the user-centric connectivity approach, 5G can bring truly “edgeless” connectivity where the coverage of macro towers and small cells won’t be a limiting factor, and devices will no longer be mere endpoints.

In addition, edgeless connectivity will deliver a more uniform broadband experience everywhere—regardless of proximity to a base station. That new level of uniform broadband experiences will likely be more meaningful to users than theoretical claims about higher peak data rates. Other features that will help provide a more uniform broadband experience include spatial multiplexing techniques and beam forming, coordinated across nodes on a massive scale, along with receiver advancements. Advancements in these areas will also help increase network capacity—especially when combined with the ability to leverage more and wider spectrum, and with further optimizations for hyper-dense unplanned small cells. All this will enable 5G to build on the progress made by 4G in meeting the 1000x data challenge.

4.2 User-centric network — distributed and virtualized

Network virtualization goes hand-in-hand with the distributed architecture approach, where network functions are virtualized and, in many cases, distributed close to the user—in effect, closer to the "the network edge". This user-centric approach reduces cost, latency, backhaul needs, and energy consumption, and is essential to meeting the varying requirements of next-generation applications, services, and use cases.

The 5G network needs to leverage network virtualization and software-defined networking, anticipated to be introduced in many 4G networks ahead of 5G. The processing ability could be dynamically balanced between centralized and distributed based on the context—placing the control closer to the user for low-latency applications, and relying on centralized processing for other applications.

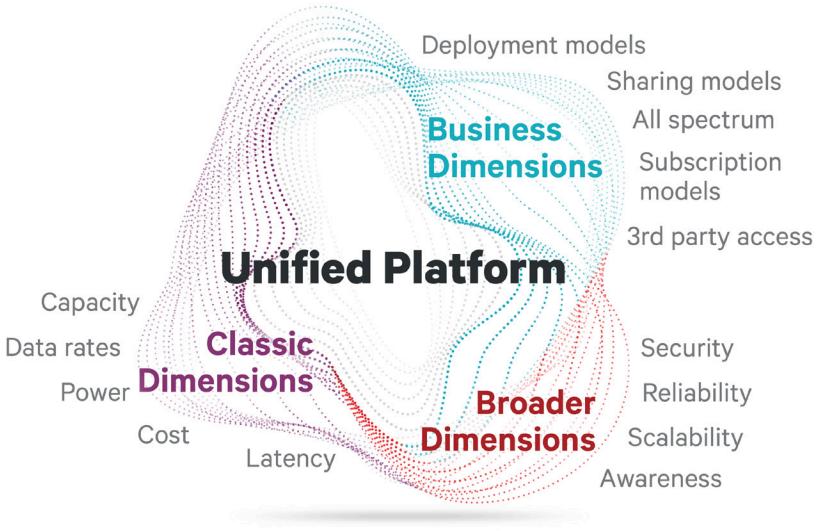
A key example of the value of this flexibility is when a mobile-capable device is engaged in a stationary use case. Leveraging the improved network awareness, the network understands the context and avoids the unnecessary setting up of network resources for full mobility. At the same time, the network is ready to rapidly bring mobility functions whenever the need arises, setting up control and user plane resources closer to the user to reduce latency. That virtualization enables more efficient scaling of the core network so that nodes can scale based on data and signaling loads, and cater to various deployment models; from hotspots and residential-type of deployments, to Local Area and Wide Area Networks.

5 A unified platform for expanded connectivity needs

The basic design principle of 5G envisions a platform that will unify access across all types of spectrum and bands; unify all of the types of connectivity that have been added to 4G (LTE broadcast, etc.). The unified platform will enable a range of new kinds of services and use case—apart from improvements in classic dimensions such as capacity and data rates—it will also target improvements on dimensions like security, reliability, awareness, and scalability. But, 5G will transform more than just technology. It will also transform businesses and industries, enabling new deployment models, infrastructure, and service sharing models, as well as new subscription models.

Imagine a third party service provider implementing its own virtualized network functions hosted by a shared 5G network that enables next-generation services to be quickly introduced. Or one, dynamic subscription for all of a user's connectivity and lifestyle needs such as his or her home, car, wearable device, etc. 5G could also enable new types of subscriptions for the massive number of connected things that consume small amounts of data. And it could make new services possible that don't need traditional provisioning or subscriptions, but are instead paid through by either the application service provider, or by the value created by a free services.

For operators, 5G will enable new business opportunities to host services and compete in the enterprise and residential environment while reducing costs (similar to the Wi-Fi deployment model for example), while continuing to provide full control and management of the network, users and services. Additionally, 5G can decouple different assets such as spectrum, network, processing, and secure billing, etc., so that operators can leverage these assets individually or mix and match some or all of those assets, to enable new business models. For example, the coverage and advanced processing capabilities of 5G could be used to host a new, vertical machine-to-machine service to compete with other low-cost deployments.

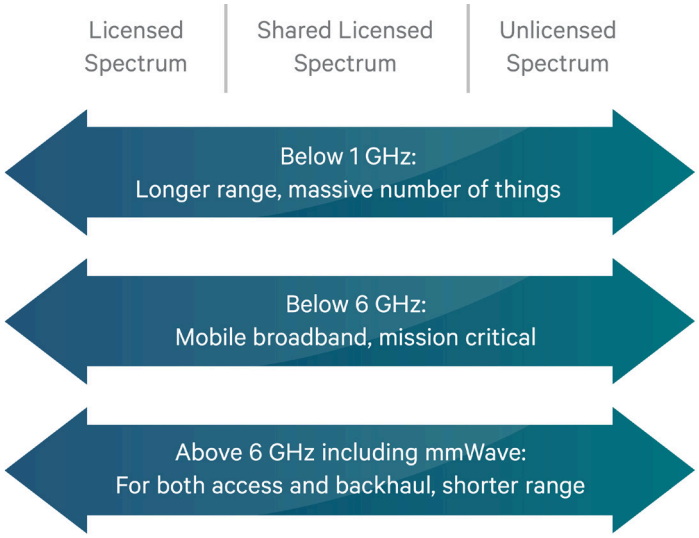


5.1 A Unified Air Interface for all spectrum and services

The unified air interface concept is a key enabler to the unified 5G platform. It will be scalable and adaptable for all spectrum types, be it licensed or unlicensed, for both higher and lower spectrum bands, and for all types of services and use cases. The unified air interface will need to support bands below and above 6 GHz, including the much talked about mmWave bands. The bands below 1 GHz offer longer range, which is essential to reaching the massive number of connected "things" in a cost-effective way. The bands below 6 GHz are needed for wide-area mobile broadband and mission-critical uses. The bands above 6 GHz are suitable for shorter range mobile broadband and target capacity deployments such as those for public venues and city centers.

Unlike 3G, which was defined by CDMA, and 4G, which was defined by OFDMA, 5G will not be defined as one multiple access variant, since it is envisioned to meet an extreme variation in services—to support all spectrum types and bands. However, the foundation of the unified air interface is envisioned to be based on OFDM(A) adapted to these extremes, with support for FDD and TDD to address paired and unpaired spectrum, but also support for shared and tiered spectrum approaches across licensed

and unlicensed spectrum. The unified air interface will, for example, need to use the time and frequency domains, orthogonal, and non-orthogonal domains, as well as synchronous and asynchronous domains to adapt and scale to different spectrum and services types.



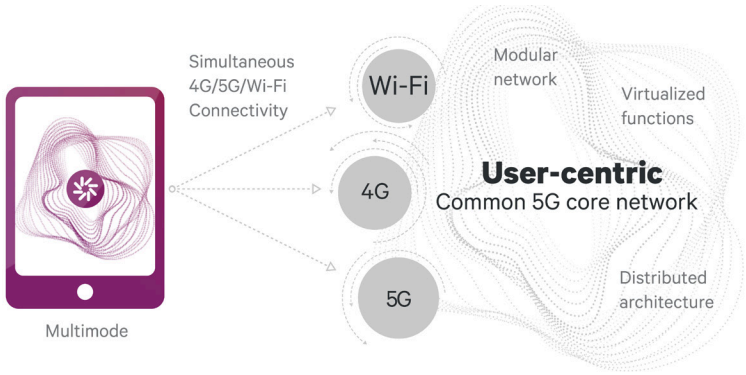
5.2 Leveraging 4G investments

As mentioned earlier, the scalable and flexible 5G core network will follow the user-centric philosophy to reduce cost, latency, backhaul needs, and energy consumption. One key contributor to these benefits is network virtualization, which goes hand-in-hand with the distributed architecture approach. Taking advantage of these techniques for 4G and Wi-Fi access creates the opportunity to achieve cost reductions. That is the vision—to have a single, common 5G core network that will also support 4G and Wi-Fi radio access. This also allows for the continued evolution of 4G and Wi-Fi in parallel with 5G, without burdening operators with the need to operate and maintain a legacy core network.

With a common core network and 3G/4G/5G/Wi-Fi multimode devices, comes the vision of simultaneous connectivity of 5G with 4G and Wi-Fi. This simultaneous connectivity builds on the “dual-connectivity” paradigm introduced in 4G, which allows the devices to connect and aggregate links from two networks at the same time (not just switching from one to the other or aggregating spectrum, but from the same base station as is done with regular carrier aggregation).

Simultaneous connectivity and a single core network also makes possible the seamless and phased introduction of 5G, allowing operators to continue to fully leverage their investments in 4G technology as well as Wi-Fi.

When it comes to deployment, as with previous generations, the availability of spectrum will govern how 5G networks are deployed. Phased build-outs could start using dedicated 5G spectrum below 6 GHz, or re-farmed 2G spectrum as it becomes available, and gradually add higher bands above 6 GHz (like mmWave) with hotspots for more targeted capacity deployments. However, it is important to note that access to lower bands is crucial when offering new kinds of 5G services on a wider scale, across the network.



To summarize, the vision of 5G is to not just provide incremental improvements and a few new capabilities—it is envisioned to be a modular platform that will scale from hotspots and residential-types of deployments to Local Area and traditional Wide Area Networks. It will also employ a fundamentally different approach, with a unifying platform to address the expanded connectivity needs of the next decade and beyond.

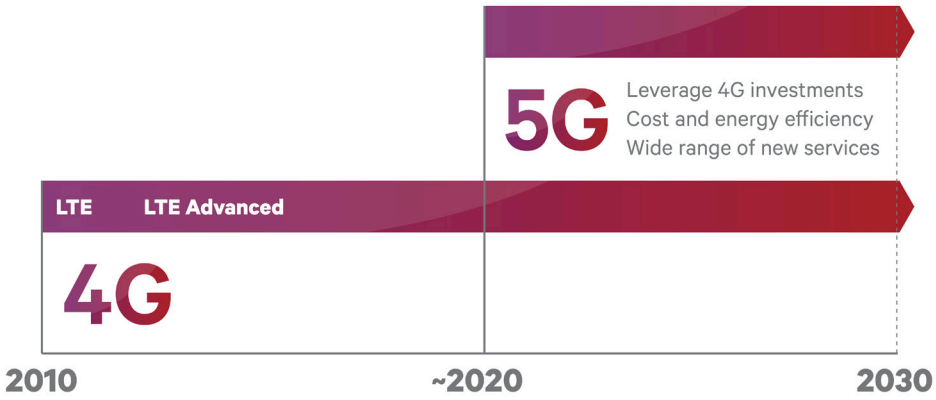
6 Driving 4G to its full potential, in parallel to 5G

4G LTE and LTE Advanced have had tremendous success and will continue to grow for the foreseeable future. While the definition of 5G continues (commercialization is anticipated around 2020), 4G will continue to evolve in parallel—bringing new capabilities that expand far beyond what is possible today. LTE Advanced is headed in the same transformational direction that 5G is headed, enabling new services, connecting new industries, and empowering new user experiences.

The evolution of LTE Advanced brings new types of connectivity and services, taking it beyond the traditional objective of simply providing enhanced mobile broadband. A few of the new flavors, such as LTE Direct, have already been standardized in Rel. 12, and a few more such as LTE-MTC (Machine Type Communications) are slated for Rel. 13 and beyond.

LTE-MTC breaks the traditional path of progressively increasing data rates, data capacity, latency, etc. Instead, it optimizes LTE to scale down in complexity to provide years of battery-life, low-data rates, and reduced device costs, which will enable even more

things (machines, sensors etc.) to connect. The Internet of Everything will not wait for 5G to happen, so LTE Advanced, along with other connectivity solutions like Wi-F and Bluetooth, will be further optimized to connect a massive number of things ahead of the advent of 5G.



LTE Direct brings an innovative, direct device-to-device discovery platform to market that can revolutionize proximity based apps and services. By addressing the biggest hurdles of proximity awareness—privacy and scalability—LTE Direct opens a new world of opportunities for many verticals such as social networking, mobile advertising, and more. Leveraging the power of user-centric connectivity and direct communication between devices, LTE Direct will continue to evolve in parallel with the launch of 5G. The evolution of LTE Broadcast goes beyond mobile TV. For instance, it's being considered as the candidate for terrestrial broadcast in Europe to address all kinds of TV receivers beyond just mobile devices such as TVs, set-top boxes, etc.

LTE in unlicensed spectrum (a.k.a. LTE-U and LAA in 3GPP Rel. 13) offers a unified and seamless option for operators to utilize unlicensed spectrum, by leveraging carrier aggregation and functionality to harmoniously coexist with Wi-Fi on a fair basis. This as an example of how LTE Advanced is progressing toward a unified platform for licensed and unlicensed spectrum, blazing the path for the unified platform envisioned for 5G, which will encompass even more advanced techniques, and new spectrum bands such as mmWave bands. The LTE Advanced evolution also has the opportunity to further reduce latency, which will be useful for mission-critical services. Since many of these services, such as aviation and medical procedures, have new or different regulations (other than telecomm regulations), the enhancements have to comply with them as well and help similar 5G services.

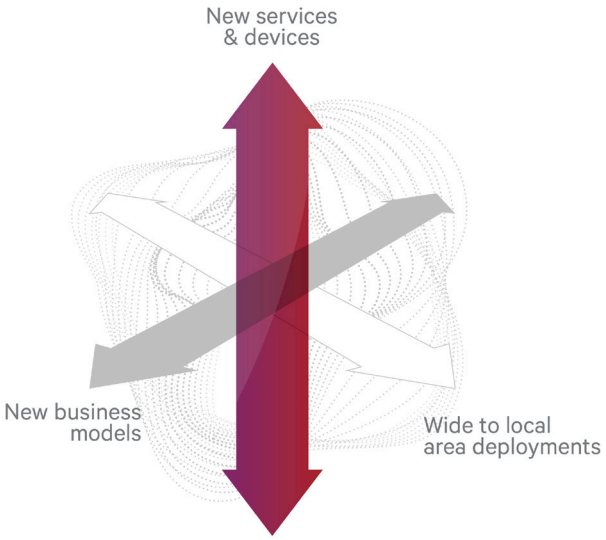
Spectrum sharing is another critically area of focus for both the evolution of 4G and the development of 5G. A case in point is underutilized government spectrum that cannot be released in a timely fashion or at all locations. That spectrum can still be utilized for 4G services through shared licensing regimes, on an exclusive basis. Licensed Shared Access (LSA) has already been adopted in the European Union, using harmonized spectrum like 2.3 GHz, but LSA is also needed to gain access to many higher bands such as spectrum around 3.5 GHz in the U.S.

So, while the conceptualization, definition and technology development of 5G is getting off the ground, LTE Advanced will continue to evolve in the same transformational way envisioned for 5G. Many of the ideas and features from LTE Advanced will be natively supported in 5G, and some new 5G ideas will also flow back to 4G. This, coupled with the seamless integration of 4G and Wi-Fi access networks with the 5G core network, ensures that operators can fully leverage their current and future investments in both technologies for a long time, even after introduction of 5G.

7 Conclusion

At the dawn of the new generation of wireless, the vision for 5G is still aspirational, yet deeply rooted in the collective wisdom gained though many years of technology development and commercialization. The extreme variations of anticipated needs for the next-generation is guiding its development. The vision is to create a new generation of technology that is scalable and adaptable enough to support new kinds (and levels) of services and use cases ranging from connecting simple sensors to mission-critical applications like remote control medical procedures to complex robots. The goal is not only to make mobile broadband faster and better, but to provide uniform, "fiber-like" broadband everywhere.

The same he user-centric approach is at the heart of 5G, where connectivity, computing, and content all come together, close to the user, be it a human, a vehicle, a machine, or a thing. From a connectivity perspective, these users will no longer be mere end-points, they will be integral parts of the network, creating "edgeless" connectivity.



5G is envisioned to be a unified platform to address the expanded connectivity needs of the next decade and beyond, not only providing the most appropriate connectivity, but also offering opportunities for new deployment models, sharing models, charging/subscription models. A key enabler is the unified air interface that is scalable and adaptable across all spectrum types, both below and above 6 GHz, licensed and unlicensed spectrum, and across an extreme variation of services.

Through its common single core network, 5G will support 4G and Wi-Fi access, as well as simultaneous 5G, 4G, and Wi-Fi connectivity with multimode devices enabling seamless introduction of 5G services, and protecting operators' investments. The vision for 5G is to usher in a new era in which connectivity, computing, and content become inseparable parts of every "body" and every "thing," making invisible magic happen. It aims to be a transformational force in enabling new services, connecting new industries, and empowering new user experiences of the next decade and beyond, where LTE Advanced is blazing a similar path—a transformative path forward.