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The term “end-to-end” often accompanies discussions of 5G, taking many different forms and meanings. As we get ever closer to commercial 5G launches, we hear vendors and operators alike discussing end-to-end 5G connections, end-to-end 5G network slicing, end-to-end 5G platforms and even end-to-end 5G testing ecosystems. The term is, appropriately, important for conveying that 5G is more than just a “technology.” And yet, for all the talk of “end-to-end 5G,” the radio access network (RAN) innovations have largely dominated early 5G messaging and announcements.

An overwhelming focus on 5G RAN innovation is understandable; from massive MIMO, full-duplex communications, a new air interface and the use of mmWave spectrum, 5G looks to break open new RAN territory in ways that previous generations of cellular technologies had not even considered. There’s a lot of work that needs to be done on the RF front if 5G is to deliver on its many promises.

But 5G networks and services won’t be built from RAN solutions alone. They will require new innovations and technology evolutions that span a service provider’s RAN, core, and broader IT infrastructures. To this end, we have examined some of these technologies – mobile edge computing, NB-IoT, data analytics and network slicing – in a series of blog posts that looked at them through the framework of core 5G use cases and the viewpoints of diverse 5G ecosystem participants. The list of blog topics was far from exhaustive but provided a glimpse into some of the important technologies that will be key to building 5G – technologies that don’t always get the attention they should within a 5G context.
### 5G Technologies and Use Cases

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Given a less-than-exhaustive list of technologies and a limited treatment of each one – within the context of our earlier blogs – it’s worth taking some time to look more closely at these technologies, along with several others that will be key to any end-to-end 5G solution. Beyond digging deeper into their operation, new viewpoints from additional industry participants will help to illustrate their significance and the way in which the larger 5G industry – service providers, vendors and would-be users – views them.
Circa 2016, any wireless network technology that can attach itself to autonomous driving applications as well as Pokémon GO is bound to attract considerable buzz. The fact that Mobile Edge Computing (MEC) is also considered a prerequisite for 5G has only helped to raise its profile.

● **What It Is:** Kicked off as an ETSI Industry Specification Group (ISG) in December 2014, MEC looks to enable cloud computing capabilities at the edge of the RAN – at the base station or an aggregation point like a controller – with an open, standardized environment supporting the integration of diverse applications across multi-vendor solutions.

● **Why It Matters to 5G:** Edge-caching pioneer Saguna’s example of MEC supporting Pokémon GO might seem like a frivolous use case, but it’s instructive. With storage and compute at the edge of the network, the latencies required for online gaming, not to mention 5G critical communications use cases – e.g., autonomous driving – can be met in a way that they could not with a centralized cloud architecture. At the same time, edge-based analytics play to 5G’s massive IoT demands while RAN awareness supports optimal mobile broadband experiences.

● **Who Cares About It:** With nearly 50 members, the MEC ISG has captured the interest of everyone from service providers (e.g., AT&T, NTT DoCoMo and Orange) and system vendors (e.g., Huawei, Nokia and ZTE) to software and component players (e.g., IBM, Intel and Red Hat). More than interest, products have already been introduced such as Intel’s Network Edge Virtualization (NEV) – and corresponding SDK which is meant for testing MEC application and services. Pre-standards trials and demos by carriers including Deutsche Telekom (assisted driving), China Mobile (edge video orchestration) and EE (video orchestration and crowd safety) are also underway and point to interest well in advance of 5G commercialization.
Data Analytics

From predicting World Series winners to predicting critical infrastructure failures, there’s no shortage of major aspirations envisioned for big data. When leveraged in support of artificial intelligence and machine learning, some of those aspirations may well be realistic – particularly with 5G as a tool for harnessing new data inputs.

- **What It Is:** The term “big data” technically refers to the analysis of extra large data sets in search of trends or patterns. Often, however, it’s used as a proxy for basic data analytics or the acquisition/examination of data in order to draw actionable conclusions, potentially driving artificial intelligence (systems capable of performing tasks traditionally requiring human intelligence) or machine learning (self-teaching systems).

- **Why It Matters to 5G:** To some extent, data analytics underscore all core 5G use cases; consider data in support of optimal broadband user experiences, or the data generated from massive and critical IoT communications. In reality, however, the connection is less about analytics fueling 5G use cases and more about 5G fueling analytics use cases. With 5G support for massive IoT, this is patently obvious. Enterprises have begun leveraging “big data” to better support their business objectives; 5G should help support them in managing the huge amounts of data they generated and enabling real time insights. Just as important as 5G network innovations like MEC and network slicing, analytics can be prioritized as needed and run where needed (core vs. edge of the network), opening up new models that weren’t possible before.

- **Who Cares About It:** With data driving the fundamental 5G use cases, any would-be 5G provider cares about data analytics. Beyond use cases, however, data analysis will be key to getting 5G networks up and running.

As Nokia underscored with its AVA cognitive services platform, increasing network complexity (as you’d expect with 5G) makes robust data analysis critical to efficient network operations via service and maintenance automation. It’s only natural, then, that the 5G Infrastructure Public Private Partnership (5GPPP) has a project – Cognet – dedicated to “Autonomic Network Management based on Machine Learning” supported by partners including IBM, Orange and Telefonica. Advanced data analytics capability will allow entities to mine insights from their businesses and equipment, while using use deep learning capability to predict use and solve problems.
There is a fundamental contradiction in the way NB-IoT is often positioned. On one hand, it is very much a 4G technology – an LTE evolution designed to support IoT proliferation. At the same time, NB-IoT is routinely called out as “paving” the way to 5G.

Yet as much as any 4G technology technically paves the way for 5G, the connection with NB-IoT gets clearer when you consider its fundamental purpose in relation to 5G use cases.

- **What It Is:** A low power WAN (LPWAN) technology standardized as part of the 3GPP’s Release 13, NB-IoT is a component of LTE-Advanced Pro. More importantly, it allows LTE spectrum and LTE base stations to support scalable IoT business models thanks to a focus on low-cost, low-power, energy-efficient (long battery life), and broad coverage connectivity.

- **Why It Matters to 5G:** It is not wrong to consider NB-IoT as just another access technology that will help to enable IoT, alongside things like Bluetooth, WiFi and wired connections. It’s also true that narrowband 5G will improve on NB-IoT’s capabilities. In the here and now, however, NB-IoT promises to support up to 100,000 devices per cell, with deep penetration (underground, in-building), and low-cost devices that can live ten years or more under battery power. Where support for massive IoT connectivity is a core 5G use case, NB-IoT gives service providers an opportunity to begin exploring new IoT use cases and building IoT businesses, prepping for the additional capabilities 5G will bring in the future.

- **Who Cares About It:** There’s a major force behind NB-IoT standardization. It’s not surprising that Huawei predicted 2017 as a year of mass NB-IoT rollouts at its MBB Forum last November. Joined by Nokia and Ericsson, it’s also not particularly unexpected that major LTE RAN vendors have high hopes for the technology. But with the fact that China Mobile is running trials this quarter, Vodafone announced its European launch plans in October (only months after standardization completed) and T-Mobile Netherlands launched services at the same time, highlights that vendors aren’t the only ones interested. And what to make of operators like Orange and SK Telecom launching NB-IoT alternatives like LoRa? The fact that Orange has committed to launch NB-IoT and SK Telecom is an active member of the GSMA’s NB-IoT Forum signals that the two technologies are far from mutually exclusive.
The concept of network slicing hasn’t been around for long, but over the course of its relatively short (several years) life, two things have become clear. One, it’s seen as a key component of future 5G core network architectures – responsible for enabling 5G to execute on the promise of cost-effectively supporting a myriad of diverse use cases. Two, it’s evolved from a “concept” into something much more concrete – driven by operator and vendor activity.

- **What It Is:** Much like SDN-driven service chaining which stitches together disparate functions, network slicing promises to connect disparate network capabilities across the RAN, core and transport layer to create a virtual network “slice” tuned to the demands of a specific use case - without over-provisioning resources that may not be needed.

- **Why It Matters to 5G:** Ericsson was one of the earliest vendors to talk about network slicing and, while simplistic, its visual representation conveys the link to 5G rather elegantly. Where 5G is about supporting diverse use cases, multiple network resources will need to be invoked to deliver on diverse use case requirements. And where 5G is supposed to enable new business models and service creation across various industries, support for dynamic slice creation and parallel (independent) operation – with APIs to support third-party slice creation and management – will be critical. Doing all of this cost-effectively benefits from the move towards virtualization where resources can be scaled up (or down) in tandem with service demands.

- **Who Cares About It:** Recognized as a core component of 5G network architectures, it’s fair to say that every operator planning for, or even just investigating, 5G has an interest in network slicing. That’s why there’s been no shortage of trade show and commercial demos this year (e.g., Huawei and Deutsche Telekom, Nokia and Vodafone, Ericsson and SK Telecom). At the same time, as called out in a 5G Americas White Paper on Network Slicing supported by Intel and Ericsson, network slicing experimentation can begin with 4G networks leveraging service-specific public land mobile networks (PLMNs), multi-operator core network (MOCN) features, overlap EPC deployments and dedicated core (DECOR) features for network selection, making it relevant to more than just 5G-focused service providers. This network slicing technology can make it possible to slice the software workload across the network, from radio access to the cloud, allowing the network to operate in a flexible way so that speed, capacity and coverage can be allocated in slices and meet the need of specific use cases.
Against the backdrop of IoT and 5G transformations, we often hear of telco-IT transformations, recognizing the reality that service provider networks need to embrace IT principles in order to compete effectively. Beyond simply happening in tandem, however, service provider IT systems will need to evolve if they hope to deliver on 5G’s promises.

- **What It Is:** As service providers integrate IT capabilities into their networks, it will become increasingly may become difficult to make a meaningful distinction between a service provider network and an IT network in the future. Looking to the impact on 5G rollouts and operations, a handful of IT and computing capabilities take center stage: cloud and data center architectures, OSS/BSS assets, and IT operations principles.

- **Why It Matters to 5G:** The timing of 5G commercialization means that 5G networks will be built in tandem with broader service provider adoption of IT architectures and principles; the move towards virtualization and cloud-native network functions will only continue to intensify over the next few years. These moves will extend into the RAN with virtual RAN deployments. Add to this the delivery of more and more user applications from the cloud and the implication is clear. 5G will require new generations of computing gear and a continuing embrace of service provider IT network transformation.

- **Who Cares About It:** The last few years have seen the introduction of server solutions from telecom networking heavyweights like Ericsson and Nokia. Technology enablers like Intel argue that this demonstrates the coming convergence of telecom and IT. Why? With or without 5G, there’s a tacit recognition that service provider networks will increasingly embrace the cloud, and IT solutions more broadly. 5G, however, brings new IT networking requirements beyond the virtualization of network functions or the dominance of the cloud. OSS/BSS architectures, for example, will need massive transformation if they hope to scale in line with IoT use cases while managing new RAN complexity with enhanced self-organizing network (SON) techniques and opening up to new verticals (including third-party defined slicing). It’s an impressive undertaking, but also a necessary one for any service provider hoping to offer differentiated services that satisfy the performance, security and cost requirements of an array of enterprise and applications.
Use of unlicensed spectrum has long been part of 5G discussions, often focused on millimeter wave technologies (involving high frequencies that are unlicensed, or “lightly licensed”). A slew of other technologies aimed at using unlicensed spectrum has also sprung up in recent years. Though not strictly considered 5G tech, they are likely to play an important role in 5G networks.

● **What It Is:** New RAN technologies harnessing unlicensed spectrum include LTE-Unlicensed (LTE-U), License-Assisted Access (LAA), LTE/WLAN Aggregation (LWA), LTE/WLAN integration with IPSec tunnel (LWIP) and MulteFire (see table). The first four – LTE-U, LAA, LWA and LWIP – all combine unlicensed transmission with a licensed connection in different ways. And the fifth, MulteFire, is unique in its use of LTE in unlicensed spectrum without the need for SIM identification.

● **Why It Matters to 5G:** As operators consider the infrastructure investments needed to keep up with 5G capacity demands, spectrum threatens to be a bottleneck from a cost-per-bit perspective given a finite supply and high price. Unlicensed spectrum promises to open that bottleneck cost-effectively. Because many operators have concerns about the quality of service provided over unlicensed spectrum (given its vulnerability to interference), technologies that use unlicensed spectrum as a supplement to more exclusive airwaves strike an appealing compromise. And the variety of technologies proposed – some better for harnessing deployed WLANs, some better for leveraging LTE RANs – provide further flexibility. This mix of spectrum (licensed and unlicensed) is a good fit for 5G’s ability to “slice” the network for varying service needs. MulteFire, meanwhile, should make it easier for alternative service providers – neutral host players, or enterprises themselves – to deploy LTE networks, reflecting the diversity and enterprise relevance of 5G.

● **Who Cares About It:** LAA, LWA and LWIP are all included in 3GPP RAN standards, and some have been offered commercially by major RAN vendors (e.g., Ericsson’s LAA-enabled RBS 6402, Nokia’s LAA/LWA-enabled Flexi Zone Multiband G2 Pico). Meanwhile, the MulteFire Alliance launched in late 2015 with the goal of promoting the nascent technology and encouraging the development of an industry ecosystem to support it; today its members include Intel, Ericsson, Huawei, Nokia, Comcast, SoftBank and others.
The need for additional 5G spectrum is often addressed by calls for new spectrum, whether licensed or unlicensed. Spectrum scarcity pressures are also driving operators to explore other approaches, including spectrum sharing systems which may be less costly than dedicated spectrum while providing more interference protection than unlicensed spectrum.

- **What It Is:** Spectrum sharing systems include multiple tiers of users, including “incumbent” licensed users and other tiers. Europe’s work on licensed shared access (LSA) systems represents a two-tier solution (incumbents and other licensees). In the U.S., the citizens broadband radio service (CBRS) model represents another example. Here, operators are granted conditional use of spectrum in the 3.5-3.6 GHz range currently occupied (often infrequently) by the federal government. While incumbent use of the spectrum is protected, a spectrum access system (SAS) allows others to use the spectrum by: (a) buying three-year primary access licenses (PAL) for 10-MHz channels in specific census blocks, granting protection from non-incumbents or (b) using general authorized access (GAA) channels with certified devices without paying for a license, but without interference protection.

- **Why It Matters to 5G:** To make 5G a reality, operators need more than more spectrum; they need cost-effective spectrum. Sharing models like CBRS aim to be cost-effective while opening up new business models: opportunistic use cases for spectrum based on criteria like geography or time; supporting different priority-based use cases thanks to PAL and GAA tiers; encouraging innovation thanks to radio neutrality within CBRS bands; delivering flexibility which could encourage participation by diverse stakeholders – fixed and mobile service providers, property owners and enterprises.

- **Who Cares About It:** Industry stakeholders launched the CBRS Alliance in August 2016, and multiple mobile access vendors have promoted plans to offer solutions enabling CBRS, including Intel, Nokia, Ruckus Wireless and SpiderCloud (a Cisco partner). In addition, Google has plans to administer CBRS licenses, and startup Federated Wireless, with $22 million in funding, has demonstrated investor interest the opportunity. Moreover, the opportunity to target new stakeholders and use cases is important here. Recall that a key 5G promise is to serve enterprise verticals in numerous ways that previous Gs did not; quickly and cost-effectively drilling into these verticals, with the help of spectrum-sharing, will be crucial for 5G operators.
With 5G on the horizon and LTE continuing to evolve, service providers around the world are asking a series of important questions. What will 5G deliver that 4G cannot? Given the costs of deploying LTE, will the performance benefits of 5G be worth the investment? What lessons can we learn from rolling out 4G that can help to drive maximum value from 5G deployments?

They are fair questions.

In many ways, the migration to 4G and the migration to 5G will have a lot in common. Both promise to support IoT scalability and higher bandwidth communications at the same time. Both involve air interface and antenna innovations that introduce fundamental new capabilities and potentially new costs. Both benefit from core network evolutions and the introduction of IT principles like virtualization and data analytics into the telecom network. Neither can be built by focusing only on one part of the 4G or 5G ecosystem – silicon, devices, RAN, core and services – alone.

Where 5G diverges from 4G is in addressing a broad array of use cases and, in the process, a broad array of industries – opening up new business models beyond connectivity in the process. To be fair, as 4G networks were first being launched, it was argued that they could be a foundation for evolving cellular beyond a “dumb pipe.” And yet, for the most part, LTE has been positioned as little more than a faster version of 3G where circuit-switched connectivity has given way to IP. 5G holds out a unique opportunity for wireless networks to be more than “pipes,” finally executing on the promises and hopes we first started discussing over a decade ago.

For 5G to be successful on this front, however, 5G network builds need to be looked at holistically. A focus on the licensed RAN needs to be paired with unlicensed and shared RAN innovations that can push 5G deeper into the enterprise. The core must embrace the cloud in order to align with new industry targets and the cloud must be pushed to the network edge in order to meet those industries’ requirements. The network must be virtualized to ensure flexibility and to ensure analytics-driven insights that support new use cases.

Perhaps most importantly, for 5G to be successful in its aspirations, service and technology providers deploying it need to think holistically about their 5G networks and engage proactively with the enterprises that will benefit from 5G. Whether the focus is on capabilities like network flexibility, security and responsiveness, or specific use cases like augmented/virtual reality, autonomous driving and big data analytics possible, beginning with enterprise demands and working back towards end-to-end network requirements will be critical if 5G is to live up to its promise.

**Conclusion: Building a Holistic 5G Network**
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