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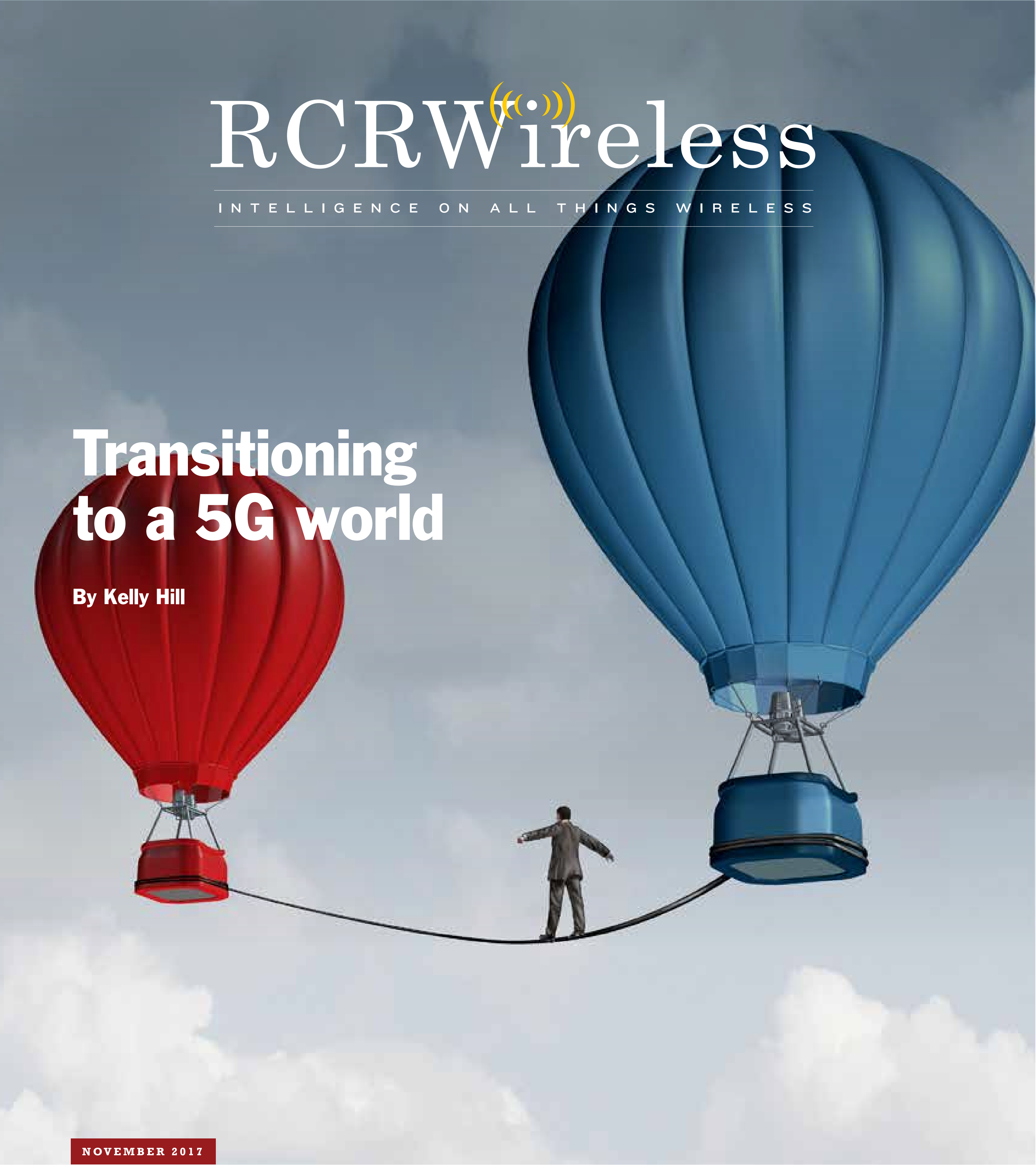


Transitioning to a 5G world

By Kelly Hill

NOVEMBER 2017

The telecommunications industry is barreling toward "5G" at a breakneck pace, with new pre-standard tests and trials announced nearly every week. Network equipment manufacturers, academic researchers, carriers and other technology vendors have spent the last few years preparing for the next generation of cellular systems, with the aim of ramping up research and development and early testing and trials to explore various aspects of "5G" technology.

5G is coming even faster than originally expected. In December, the first official specification from the Third Generation Partnership Project is expected to be released; 5G New Radio will finally make its standardized debut – although like Long Term Evolution, 5G will continue to evolve and be refined in the coming years.

Some features considered "5G" technology are being applied to LTE even as they are being debated in 3GPP.

In the lead-up to standardization, companies across the industry, university researchers and government programs have all been involved in an industry-wide effort to determine what will make up 5G systems, and how those systems will ultimately function optimally in order to reach the much-hyped promise of 5G.

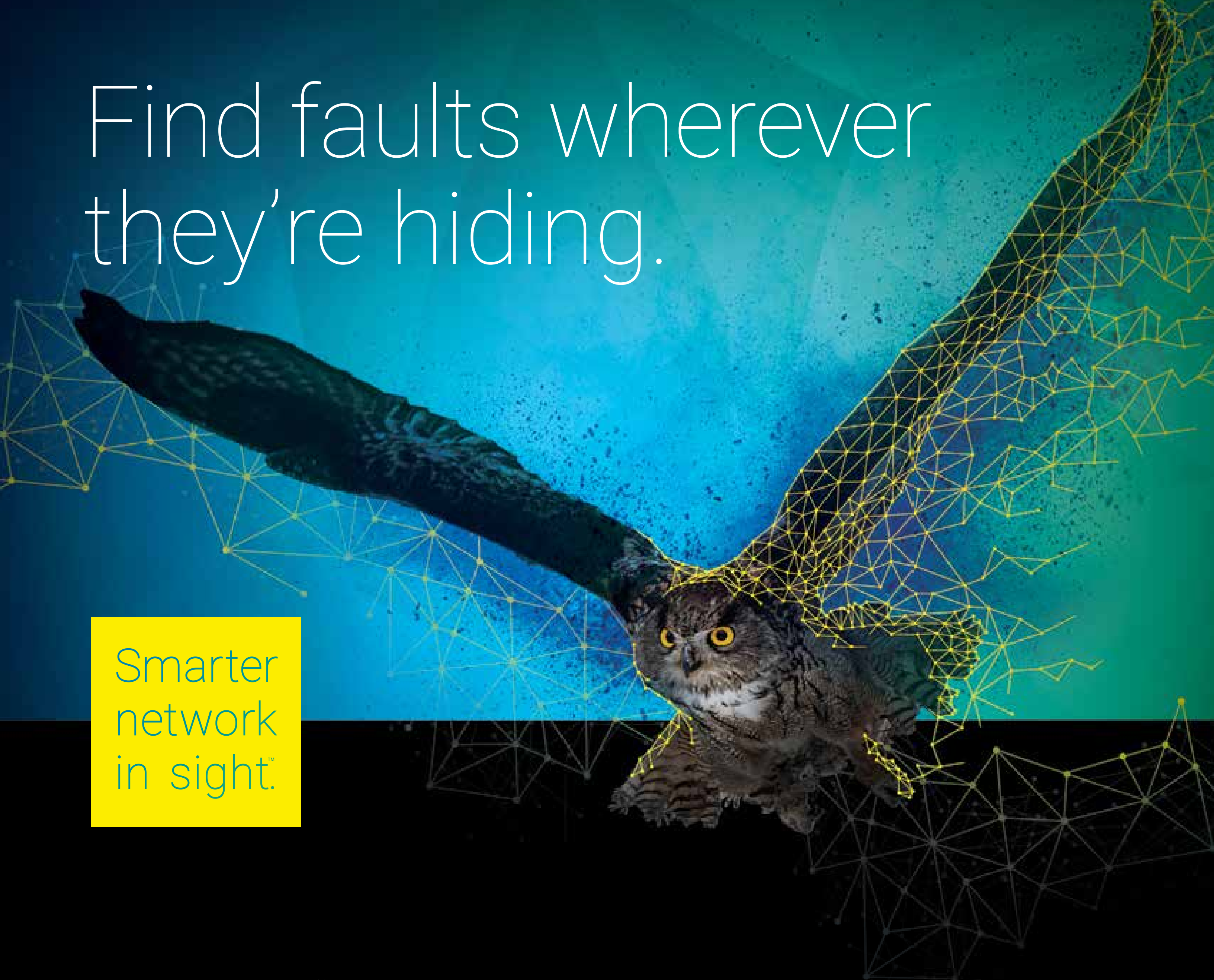
This report looks at how the transition from LTE to 5G is shaping up; the major technology approaches that will migrate and shift from 4G to 5G; and how test equipment and approaches have to change in order to support 5G, from the chipset and device to the air interface, network architectures and network software.

5G trends and expectations

Hype is certainly high for 5G, given that the industry is still technically in a pre-standard phase and that standalone 5G systems are still some time off. But the level of interest, and many of the results of ongoing tests and trials, are promising. Ericsson's second annual 5G Readiness survey of operators found that 78% of respondents were involved in 5G trials in 2017, compared to 32% last year – and 28% expect to deploy 5G in 2018.

"The industry is moving faster than maybe we thought we'd be able to," said Saul Einbinder, VP of venture development for Spirent Communications. "3GPP is basically pulling out every stop they can think of to get the [non-standalone] spec ready by the end of this year." 5G, he added, "feels a little bit more real."

Analysts have rosy expectations. TechNavio has forecast that the global 5G equipment market will see "tremendous growth and will post a staggering [compound annual growth rate] of more than 32%" until 2020. Accenture has estimated that the economic impacts of 5G could be up to $500 billion in Gross Domestic Product growth, including 850,000 direct jobs over seven years of build-out and another 2.2 million indirect jobs across communities. According to a recent GSMA study, more than 30% of Europe's mobile connections are expected to be running on 5G networks by 2025 – a forecasted 214 million connections, five years after networks are estimated to be turned up in 2020. SNS Research estimates that for the fixed wireless access use case being explored by carriers including Verizon and AT&T, "5G-based FWA subscriptions are expected to account for $1 billion in service revenue by the end of 2019 alone" and grow at a CAGR of 84% between 2019-2025.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Surveys of 5G awareness and deployment intentions show keen interest. A survey of senior executives at service providers and enterprises commissioned by Ixia earlier this year found that almost 100 percent of the participating organizations intend to leverage "5G" wireless technologies, with plans to evaluate and/or roll out 5G capabilities in the next 12 months — and 13% say they've already deployed 5G networks, despite the technology not yet being officially standardized. Asked about their 5G exploration and adoption plans, 96% of the organizations said that they plan to leverage 5G technologies and that 67% of them "have evaluated or will evaluate 5G technologies in the next 12 months" — of that 67%, 40% reported that they had already begun assessing 5G technologies. While 13% reported that they had already deployed 5G networks, another 31% said that they would be deploying a 5G network in the next 12 months. Overall, 34% said that they would be releasing a 5G offering publicly within 12 months.

The Ixia survey found that telecom, tech and financial services were the top three industries

5G Snapshot: Recent News

Nearly every day, it seems, another company announces a new "5G" test, trial or product. Here is a snapshot of recent 5G-related testing announcements during the month of October.

- Verizon is working on massive MIMO with Ericsson. In a test in Irvine, Calif, the two companies used a 20 megahertz channel of AWS spectrum to support 16 radios connected to an array of 96 antennas.
- Multiple T-Mobile US executives have said that as the carrier begins to roll out its newly acquired 600 MHz holdings, that the radios will be software-upgradable to 5G.
- The Chinese government has confirmed its plans to complete its second phase of 5G testing by the end of this year and expects to have prototype products by June 2018. Five companies, including Huawei and ZTE, have built 15 stations for 5G testing in Huairou District in Beijing.
- ZTE and French telecom group Orange announced a partnership to jointly work on 5G use case development, including testing a 5G core network, standalone architecture, end-to-end network slicing and 5G overlay architectures. ZTE plans to build a 5G innovation and research center in L'Aquila, France.
- South Korean operator LG U+ worked with Huawei on a field test on 4G/5G dual-connectivity, which linked a 3.5 GHz base station with a 28 GHz base station to achieve a downlink rate of about 20 Gbps. The tests took place at an LG U+ 5G testbed in Seoul.
- Nokia has signed an agreement with Russian operator Rostelecom to set up a 5G pilot project zone in the Skolkovo Innovation Center tech area near Moscow.
- KT recently re-confirmed that it expects to launch commercial 5G services in 2019, with a pilot network to be available at the 2018 Olympic games in PyeongChang. KT has already signed an infrastructure access agreement with Korea Expressway Corp. for access to major roads and facilities in PyeongChang, and plans to launch the trial service network in February 2018 with five months of testing prior to launch.

behind the interest in 5G, and the top three drivers pushing the interest in 5G were identified as the desire for more flexible and scalable networks, cited by 59% of those surveyed; customer demand (55%) and market leadership (46%). Meanwhile, a CTIA-sponsored survey of more than 500 executives in healthcare, transportation, energy, and manufacturing found that most believe that wireless is increasingly important, with 80% indicating that they think 5G will have a positive impact on their businesses.

Gearing up for transition

Despite all that hype and hope, however, 5G isn't going to spring into ubiquity overnight. The move to 5G is a long-term transition, not the flip of a switch. Much like 2G networks still exist alongside 3G and 4G networks, Long Term Evolution is expected to be just that: long term.

"5G will not replace LTE," Rysavy Research concluded in an August report for the GSMA. "In most deployments, the two technologies will be tightly integrated and co-exist through at least the late-2020s." Many of the capabilities that will make 5G so effective are appearing in advanced forms of LTE. As Mike Murphy, CTO of North America for Nokia, puts it, there is a general theme that "a main idea starts in 4G and is institutionalized in 5G."

Some of those "main ideas" include:

Radio Access Network technologies including carrier aggregation and higher-order/massive MIMO. What started with two-component-carrier CA, with 20 MHz channels, is evolving to three, four and five component carriers in LTE. Adnan Khan, senior business development manager for wireless products at Anritsu, said that some carriers are even exploring going beyond official specifications to look at six component carriers. In 5G, the channel widths become dramatically wider but the general idea remains the same. Gigabit LTE is often being achieved with the integration of unlicensed frequencies. Likewise, relatively simply 2x2, 4x4 and 8x8 MIMO in LTE scales up in 5G to massive MIMO implementations. MIMO represents a 50% to 5x increase in network capacity, depending on whether it is deployed in an FDD or TDD context, according to Paul Challoner of Ericsson, speaking at

Source: Vodafone

Vodafone has its first live trial of 5G massive MIMO at the Sinan Erdem Dome in Istanbul in June of this year.

the recent Competitive Carriers Association conference.

Luke Ibbetson, chief engineer for group research and development at Vodafone, said that the operator is exploring massive MIMO "with a view toward 5G, but it's being lightly applied back into 4G as well. We're able to start to get some early and very real-world experience of how well massive MIMO works before we get to 5G, because we can see how well it works when it applies to LTE. We're already starting to get a much more calibrated view of what ... massive MIMO can bring."

A focus on a software-centric, automated, virtualized network. The virtualization of the network is well underway, with or without 5G. But the flexibility and automation of 5G essentially assumes a software-defined, virtualized network, said Nokia's Murphy. Virtualization, Ibbetson said, "is happening anyway. It doesn't have to be heavily coupled with 5G." Automation is going to be key, he added, but it has many components: SON, SDN, orchestration and analytics, as well as mobile edge computing, all of which are being implemented in LTE. "Network slicing" in 5G aims to fulfill the promise that granular "quality of service" was supposed to achieve in LTE, but which has ended up being largely limited to prioritizing voice over LTE traffic. Viavi Solutions CTO Sameh Yamany said that Viavi considers some internet of things deployments to be contributing toward architectural changes via virtualization – some IoT deployments are being done with virtualized Evolved Packet Core elements in order to segment the traffic, which is essentially a network slice, he pointed out. Kalyan Sundhar, VP of mobility, virtualization and applications at Ixia, said that while the move to virtualized networks and MEC is well underway, the devil is in the details of deployment. For example, he said -- how easy is it to deploy virtual nodes, with multiple versions? What are the fault tolerances? What happens when one goes down? Those are some of the things operators are figuring out now, as they slowly virtualize portions of their networks.

Access architecture changes, including fiber proliferation and mobile edge computing. As Viavi has talked to its largest operator customers, Yamany said, they are thinking about network splits and architectures for 5G within an LTE Advanced Pro context.

"They understand that 5G or no 5G, how you want to do the densification of some areas of the network to include virtualization as well as maximizing bandwidth at the same time – you're going to have to do the split anyhow. 5G or no 5G, the split is happening," Yamany said. "I can tell you that right now, most of the focus, if you talk about the physical network design, is in time synchronization," Yamany added. When functions are being moved from where they have typically resided in the network, to another place, whether there is aggregation or disaggregation involved, the synchronization is key to proper functionality. "If you don't do it right, it will destroy the latency of your application," he said. Forward-looking operators have already started assessing the qualifications of their circuits to see if they can support 5G-level latency. He estimated that the industry is "about 50% there" and that by the end of 2018, he expects to see "more and more qualified networks for 5G." Right now, he added, the focus is not necessarily on reaching 1 millisecond latencies, but coming close – 2-3 milliseconds as a target. Nokia recently demonstrated 2 millisecond latency between a base station and a handset in an LTE context, with SK Telecom.

Kin-Yip Liu, senior director for systems engineering and segment marketing for Cambium Networks, agreed that operators are thinking hard about their architectures and fronthaul options now, with an eye toward 5G. "This is an area with multiple options for engineering and management, as well as for testing to understand the fronthaul and different split options," he said. "The real trade-off is, what is the fronthaul available and what kind of services do you plan to support? – and then to see if you can live with that fronthaul." If it isn't up to par, he said, operators will have to make different split choices. Sundhar said that the structures that operators are exploring now, in terms of MEC and C-RAN, what they put at the edge and in the core, is "a bit at a time, slowly moving toward the ultimate goal of what they want to do in 5G."

With all of those areas yet to be fully realized in LTE, it's no wonder that in some regions – Europe in particular – network investments are still focused on 4G. Even in the U.S., where AT&T is proceeding with 5G mmwave fixed wireless trials, the carrier earlier this year dubbed its project to bring LTE Advanced Pro features to 20 cities by the end of the year "5G Evolution". Ibbetson of Vodafone said that the carrier has been involved with industry and university work to explore 5G, but it is currently focused on evolving its network in a number of ways: programmability, lower latency, reliability and being able to orchestrate services more rapidly across a fully virtualized core network, and expand the use of mobile edge computing.

"There are actually many things that we're looking to deliver across an evolved version of our 4G network," he said. He said that the addition of narrowband IoT and LTE-M to Vodafone's network "allows us to start to address some of the more extreme use cases, the very, very low-power constraints but send data over very long distances or [to objects] buried in the ground. … We're busy deploying NB-IOT capability around multiple markets as we speak."

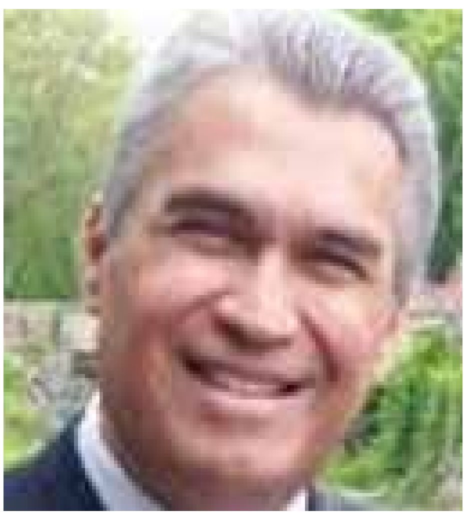
He said that LTE gives the carrier a chance to see how close to 5G it can get with 4G in the context of mobile edge computing and low latency, for instance. "We've had a very good experience in LTE in terms of it being much more capable than 3G ever was."

"Although the industry is preparing for 5G, LTE capabilities will continue to improve in LTE Advanced Pro through the rest of the decade," Rysavy wrote. "Many of these enhancements will come through incremental network investments. Given the scope of global wireless infrastructure, measured in hundreds of billions of dollars, offering users the most affordable service requires operators to leverage investments they have already made. 5G will eventually play an important role, but it must be timed appropriately so that the jump in capability justifies the new investment."

5G test evolution

Test capabilities for every aspect of 5G have to be available at costs the market can support, in order to support operators, network equipment vendors, chipset and device makers and software vendors as they push forward into 5G.

According to TechNavio, the global marker for general test equipment is expected to grow a nearly 5% per year until 2021 and reach $6.58 billion, driven in part by the emergence of 5G systems. With a 4G/5G spec coming soon and commercial launches on the horizon, testing capabilities will need to move from a primary focus on research and development and small-scale, prototype-based testing to support a ramp-up of manufacturing, network planning and deployment.



"It's a 10-x change in the frequency – not only in the frequency, but 10x in the bandwidth. So test equipment needs to be made available to support not only the frequency, but the bandwidth."

Jeorge Hurtarte, Product Manager, Litepoint

Jessy Cavazos, industry director with Frost & Sullivan's test and measurement practice, disagrees that 5G is an evolution: when it comes to millimeter wave, she said, the technology jump truly is a revolution rather than an incremental step.

Although mmwave has been used in aerospace and defense, she added, it has been considered "quite exotic" for consumer wireless purposes. "Changing that frequency level, you can't just push a button and now a signal analyzer can test at 60 GHz or handle the bandwidth required of those signals," she said. "It's a significant challenge ahead of the industry."

"It's a 10-x change in the frequency - not only in the frequency, but 10x in the bandwidth," pointed out Jeorge Hurtarte, product manager at test company LitePoint. "So test equipment needs to be made available to support not only the frequency, but the bandwidth" - up to 2 GHz.

Hank Kafka, VP for analytics and access architecture for AT&T, pointed out that the jumps from 2G to 3G to 4G revolved largely around working in similar, sub-6 GHz bands and adding new features to improve efficiency and speed. 5G, he said, is a much larger generational leap because it involves both new technology and new bands at millimeter wave

"We're trying to understand [millimeter wave] for a lot of different reasons, and one of the reasons it to get the standards right. The characteristics of millimeter wave can shape how you want to shape certain aspects of the standards, which is one of the reasons to start really early on it and start the testing and measurement of it, so you can understand it better."

Hank Kafka, VP for analytics and access architecture, AT&T


Source: YouTube

An image of AT&T 5G mmwave equipment from a fixed wireless access trial.

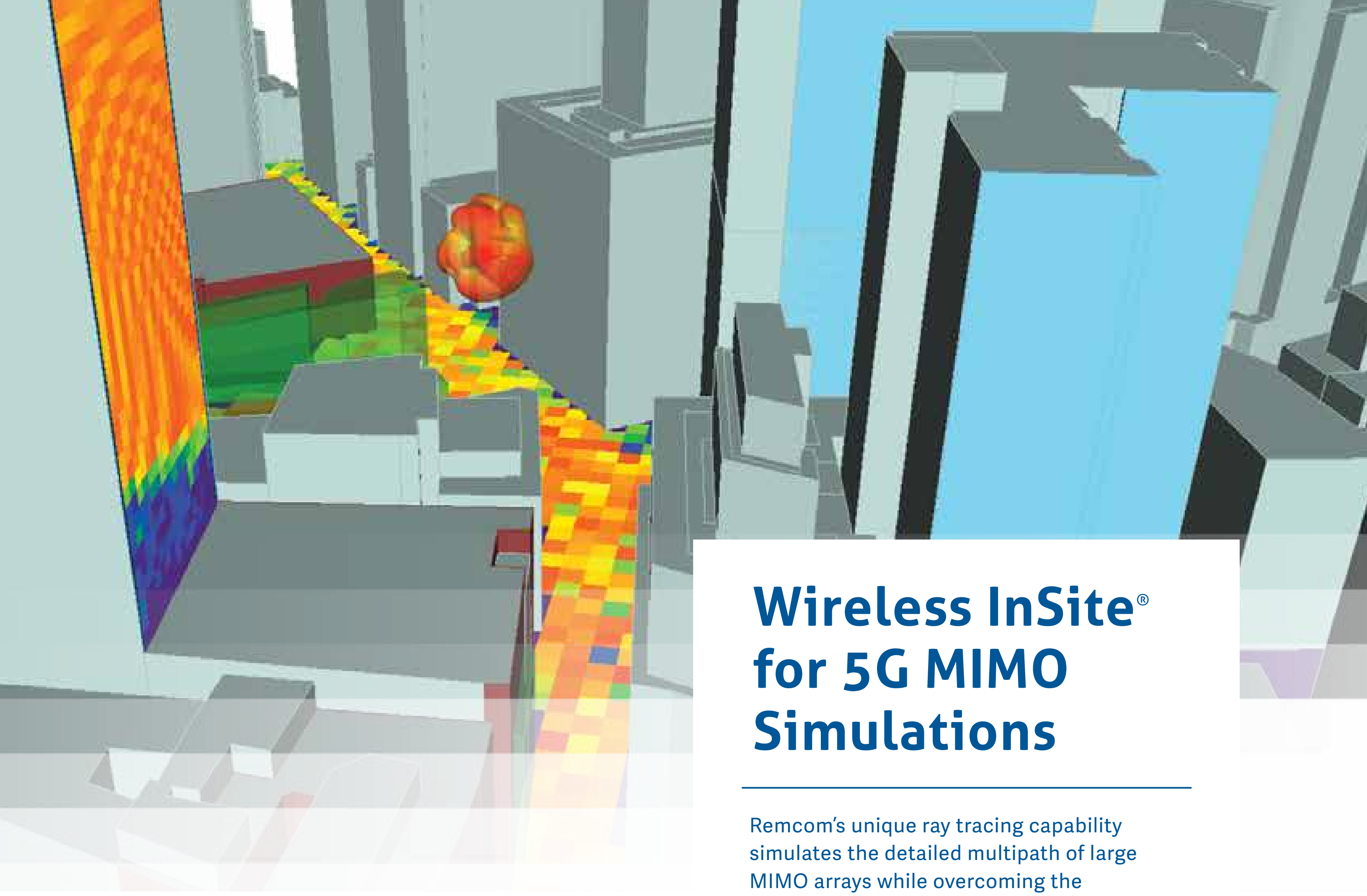

Source: NI/AT&T

AT&T developed the "Porcupine" antenna with NI to do real-time, detailed 5G channel sounding.

frequencies. "Millimeter wave has a lot of interesting characteristics," he said.

"We're trying to understand it for a lot of different reasons, and one of the reasons it to get the standards right," Kafka said. "The characteristics of millimeter wave can shape how you want to shape certain aspects of the standards, which is one of the reasons to start really early on it and start the testing and measurement of it, so you can understand it better. The second reason is to help understand the best way to use it, and how to build and design networks and get it out in the real world. Those have kind of been the themes behind what we're doing, starting over a year ago with lab testing of systems."

Kafka said that AT&T has explored a number of potential frequency bands in the lab, from sub-6 GHz all the way up to 73 GHz. Beyond its commercial trials, the carrier has focused its testing efforts on filling gaps in knowledge about the mmwave spectrum environment. That has led to some interesting, custom test equipment and set-ups. One of the instruments that AT&T is using



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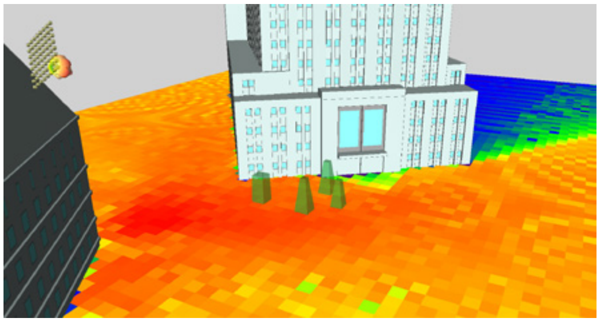

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to get better channel visibility in mmwave was its Porcupine 5G channel sounder, developed in partnership with National Instruments. The Porcupine takes very fast measurements of multiple paths and the delay environment, Kafka said, likening the instrument to "a high-speed microscope" that provides detailed insights on angle of arrival and reflections. "We saw a need to measure things faster and in real-time," he said.

AT&T also saw a need to better understand how long-term seasonal changes, such as foliage cover, would impact 5G networks. At one of its campuses, the carrier built a long-term outdoor test system with a number of transmitters and receivers — some line-of-sight, others behind trees — so that it had better insight and data into how weather events and seasonal changes affected mmwave transmission.

"This gives us the other extreme from the 150-millisecond measurements [of the Porcupine]," Kafka said. "We're not getting that detailed view of every ray and reflection, but we are getting a view of, this is what is happening in general on the signaling, and it's set up so that we can measure not just the intended direction of the signal, but the stuff that is going on between the sites so you can see what happens to the background noise and interference aspects as well."

He said that thus far, that test system has yielded information about the effect of rain and weather as well as insights about propagation in relation to different types of trees, all of which will be important as 5G networks evolve into planning phases.

Hurtarte sees four specific challenges for test in a 5g context: supporting high frequencies with 1-2 GHz bandwidth; supporting radiated, OTA testing for devices which cannot support cabled test; the need to test multi-antenna arrays; and the need for enclosed OTA testing for beamforming. "They're all related," he added.

Hurtarte noted that while the military has a long history of using mmwave frequencies, "it is definitely a recent phenomenon" for commercial wireless operators. LitePoint has solutions at both 28 and 39 GHz, two of the bands most widely expected to support 5G NR. In order to conduct OTA testing, Litepoint utilizes a horn antenna that captures the energy coming from the device under test from a range of 60 centimeters or so, he said, in order to work in the far field to see if each antenna is working at the specific power level and phase that it is supposed to.

Still, a number of features from LTE will also carry over into 5G test. Those include:

Support for many bands. John Smee, VP of engineering for Qualcomm Technologies, said that the LTE expansion of band support to dozens of bands would likely surprise the tech community of a decade ago, when a tri-band phone was considered a "world phone". KT, for example, plans to support two different frequencies from the get-go in its 5G network: 3.5 GHz as an anchor with better propagation, complemented by 28 GHz in dense areas. Given that networks are expected to initially be 4G/5G networks, testing will have to continue to support LTE alongside 5G.

Test automation and modular equipment. In previous generations, testing often relied on tests that had to be walked through one-by-one, with many manual adjustments and rotations. "Now, it's automated test cycling through a huge number of combinations," Smee said, particularly when it comes to over-the-air testing in a millimeter wave context, with beamforming and beam-tracking. "That's something that's being taken to the next level [in 5G]," he said. This improves the amount of time spent on 5G testing, which is a big concern given the enormous increase in the number of scenarios that could be tested, versus the bare minimum that must be tested to ensure quality.

"Given the number of antennas **…** things can get out of hand pretty quickly," he said. "You can't haul in a dozen channel emulators – whereas in a 4G context, maybe you had one or two. It doesn't scale to support that."

Cavazos said that due to pressures on test as a cost center and the need for flexible systems, she expects to see more modular test equipment based on open standards such as PXI and xIE.

Flexibility and efficiency. Smee of Qualcomm said that while the chipset company is keenly focused on initial 5G support for the features of the standard that are of most interest to operators, 5G will evolve in much the same way that LTE has. "Over time, as the firmware is updated at the base station and **…** as the standard marches forward, you more fully exercise the numbers of scenarios and configurations," he added. "So one of the important things is **…** exercising a relatively full subset of the standard such that to ensure that the devices will be deployed for a long time and be successful, even as the deployment evolves and new configurations and more dynamic operation comes into play.

"We do pay attention very closely to the efficiency of the testing, such that we can scale more quickly," Smee said. He added that the very technology evolution that enables 5G, will also enable 5G testing. "As the technology moves forward, not only is the data rate and user experience and latency that … the end users are going to feel, but … what is emerging and provides that same technological march forward, is what enables us to test more scenarios in the faster period of time."

Flexibility must extend not only to the range of future features that can be tested, but to the ability to rapidly adapt to new frequencies in which 5G NR might be deployed. Hurtarte of LitePoint noted that although "millimeter wave" tends to be treated as one category, there are significant differences between the components and frequency planning needed at 28 GHz versus 39 GHz. In addition, although some frequencies are widely agreed upon, there are other frequencies that may get the nod for 5G use: 24 GHz in China, possibly 40-43 Ghz and possibly even above 70 GHz.

The next World Radio Conference, which weighs in on the use of global frequency bands, isn't until late 2019. "Here we are in late 2017, we're two years away from the ITU/WRC decisions – so test equipment providers need to be very alert to are being considered, with new bandwidth that could be possibly the same or higher than 1 GHz, and be able to be flexible," Hurtarte said. "The systems need to be flexible and to quickly respond to the possible new frequencies and bandwidth."

Luckily, as Smee of Qualcomm put it, "As technology marches forward, it's not like the test industry is stuck with a certain, non-evolving path."

Out of the lab and into deployment

With mmwave 5G systems expected to start deployment in 2019, the testing focus is rapidly shifting from one of early trials based on prototypes, to the question of what changes will be necessary for large-scale manufacturing, network planning and network deployment. Those tools, in many cases, are still in very early stages or don't yet exist – or they'll need to be simplified so that production workers and field techs can operate them with minimal training.

In a manufacturing environment, several factors in particular stand out for 5G test needs: lower costs, faster testing capabilities, and the ability to be integrated into production lines without radical changes.

"People aren't going to re-engineer their manufacturing lines to have a bunch of 3-meter chambers all over the place," Einbinder said. Much of the work is still being conducted in OEM and infrastructure company and carrier labs; commercial labs will start becoming more involved once there is an actual standard and certification processes through bodies such as the Global Certification Forum and the PTCRB. Hurtarte noted that OTA testing will require the use of chambers that can be closed; are insulated;

5G Snapshot: Emulator Project At New York University

Testing and verifying designs for millimeter-wave prototypes is an ongoing challenge for the industry as it moves into 5G. Engineers need to understand how 5G mmwave prototypes will behave in a wide range of challenge propagation scenarios, which is typically accomplished through an emulation approach.

Led by post-doctoral fellow Aditya Dhananjay, an NYU research team including professors Sundeep Rangan and Dennis Shasha has developed a channel emulator that emulates not only the wireless channel, but the multi-antenna front-ends on the devices themselves. Commercial off-the-shelf components for the project were donated by National Instruments.

Dhananjay is researching a new approach to a channel emulator, the box that transmits radio frequency signals as if they had gone out into the real world via antenna and provide insight into reflections, Doppler shifts and other behavior. Channel emulation has always been an important part of RF research and development, but it becomes staggeringly complex in 5G scenarios – particularly in the context of millimeter-wave phased arrays for massive MIMO. Dhananjay said that the cost and computational complexity of emulation for 5G mmwave systems is increased by a factor of 1,000 and no commercial 5G mmwave emulators exist on the market today.

"The bottom line is, you can't take the approach for 3G and 4G and simply scale it up for the 5G use cases, because of the increasingly high cost," he said.

Dhananjay instead has worked on developing a channel emulation approach in which beamforming is emulated on both the transmit and receive sides, along with the wireless channel itself. The transmitting and receiving devices provide their beamforming vector information; the transmitting device also provides the pre-beam-formed signal, and the emulator sends the processed signal, modified by the channel conditions, to the receiving device, while supporting more than 2 gigahertz of real-time bandwidth and can support hundreds of antenna elements on devices under test. The 5G channel emulator has already been demonstrated with 64-element devices under test at the Brooklyn 5G Summit and NI Week.

"Another relatively unknown factor in the 5G mmwave space is an understanding of channel dynamics. In other words, when blockages take place, how correlated are all the signal paths between the transmitter and receiver?" NYU Ph.D. student Chris Slezak, he added, is in the early stages of that exploration and expects much clearer understanding of mmwave channel dynamics in the near future.

and potentially may need to have other features, such as the ability to change temperatures or rotate the device inside. He said that initial production for 5G is expected next year and that scale will ramp up in 2019 and 2020. Part of this will depend on if or when millimeter wave makes it into large-scale devices such as consumer smartphones, versus other applications such as industrial IoT. If they need chambers, how big will they have to be? Perhaps, he said, testing can be shifted to the near-field instead of the far-field, which could mean smaller chambers.

Field testing for network design, validation and optimization is an entirely different conundrum, as equipment must be portable and the short range of mmwave frequencies will impact the efficacy of drive testing.

"Field testing is going to have to get more refined," Einbinder said. While drive testing has been used to assess network quality and for coverage mapping, 5G coverage will be so localized that "every couple hundred feet, the coverage is different. ... If we think about how the industry talks about coverage today, I think that mindset is going to be challenged – the red maps and blue maps you see today. Those maps aren't going to really have relevance when it comes to 5G coverage," he said, because of how localized it will be and how long it is likely to take to build out sites. Some necessary test and planning tools for mmwave fixed wireless deployments "are not readily available off-the-shelf," according to Nivi Thadasina, senior director of engineering, Samsung Networks, which has been involved in a number of 5G trials for fixed wireless access. "We had to spend a lot of R&D on coming up with tools that were able to make the predictions not only in terms of very creative channel models, but in the ability to do RF planning." In particular, Thadasina said, "our challenge is, how can I go achieve some type of [service level agreement] and be able to provide the same assurance not only to our customers, but Verizon to the end user?" Being able to come up with tools that could create "zones of the SLAs that we can achieve minimum bit rate guarantees" was important. Another issue is qualifying neighborhoods, he said. Once the planning is done and the base station installed, how does a specific address know that speeds it can receive? This is a fundamentally different problem for service providers than wireline service. "We had to come up with other qualification tools in order to see the same picture from the end user standpoint, to come back with those predictions," Thadasina added.

In the lab, said Paul Denisowski, applications engineer at Rohde & Schwarz, capabilities to handle wide bandwidths and demodulate those signals "is expensive, but it does exist. The real challenge is, how do you do that in the field, or do you want to do that in the field?" Jeremy Cline, product manager for mobile test at Rohde & Schwarz, noted that field testing gear has long had 20 MHz front-ends, so it is a giant jump to go to 100 MHz channels in the field. However, he added, the company has learned from its work on Verizon's 5G TF that "we don't have to look at the whole signal," but that analyzing synchronization signals in the middle of the channel provides sufficient information.

5G's biggest challenges

So all the kinks in those components of 5G will get worked out in LTE and the transition will be a

Source: Samsung

Source: Samsung

A Samsung 5G small cell and customer premise equipment.

piece of cake, right? Not exactly. There are some major challenges to the success of 5G, which are all interrelated: the move to mmwave, the need for ultra-density, and the question of when the economics of 5G will actually work well enough to take off.

The first of those is perhaps the most obvious: the move to higher frequencies. While low, mid-band, and millimeter-wave frequencies are all expected to be used for 5G, mmwave presents enormous engineering and network planning challenges. Mmwave provides the huge bandwidths that are needed for fast speeds and high capacity, but the higher the frequency, the shorter its range and more susceptible it is to being easily blocked and reflected (thus the need for beamforming in order to focus the energy more tightly). Seasonal foliage, energy efficient glass windows with special coatings, and standard housing materials all present effective barriers to mmwave reaching indoors to customer premise equipment, operators and vendors have found in their field testing.

Denisowski pointed out that fixed wireless is one thing, but moving objects are another. Obstruction, not radiating sources of energy, is likely to be the main cause of interference in 5G systems: vehicles driving back and forth, or even wind farms can scatter microwave radiation.

"It's things like that, that people never thought about," he added. "It is very, very quiet up there" not filled with baby monitors like other spectrum. "If they deploy at 600 MHz, it'll be the same as always." Denisowski also noted that the cells themselves will be very small in 5G. "If you see something there that's interfering, it's right there, a dozen meters from you. It's not going to be horribly far away." So it may mean easier pin-pointing of interference sources – but it could also potentially mean more sites are affected by a single interferer.

Density of foliage "plays a big role," said Thadasina of Samsung, which has been working with a number of carriers on 5G trials. "What we found is that for the mmwave signal, as it penetrated through trees, the thickness of the trees matters. Initially the impedence offered by foliage is linear, but beyond a certain density it is no longer linear ... it kills the signal." Building materials are well-known to play a role in transmission from outdoors to indoors, he added, but the angle of incidence does as well. The difference between 30 degrees to 60 degrees to 90 degrees can create additional impedance, Thadasina said, "some of those things make it challenging in terms of closing the link." Moisture levels play a role as well, he said – tests were

5G Snapshot: The Fiber Predicament

Fiber is fuel for 5G, and its prevalence is increasing. SNL Kagan found earlier this year that global fiber residential investment increased sharply in 2016, and that fiber is on track to reach 1 billion subscribers by 2021. Meanwhile, in the U.S., Vertical Systems Group reported that 49.6% of multi-tenant and enterprise buildings had access to fiber last year, compared to only 10% in 2004.

Telecom operators have made fiber investments a major focus: Verizon, for instance, spent much of 2017 boosting its fiber access as part of its One Fiber initiative. The carrier put $1.8 billion into acquiring XO Communications' fiber assets, then followed up with fiber supply deals with Corning ($1.05 billion over three years) and Prysmian ($300 million over three years). CenturyLink recently closed on its $34 billion acquisition of Level 3, which will increase CenturyLink's fiber network by approximately 200,000 route miles. In Europe, Vodafone plans to invest $2.39 billion over the next few years in boosting gigabit-capable infrastructure, including fiber and upgrades to its cable network.

Thomas Neubauer, VP of business development and innovation at TEOCO, said that fiber is one of several areas of investments that service providers are making with 5G in mind, as a direct challenge to the cable industry with fixed wireless access. "That's going to happen, no question about it," he said. "That is a business case that will work out for them and soon become a billion-dollar business."

Deloitte said earlier this year that it expects to see $130 billion-$150 billion in "deep fiber" investment in the U.S. over 5-7 years, due to a combination of broadband competition, ensuring 5G readiness, and expanding fiber into new areas.

While all that spending sounds encouraging, there are a number of practical issues that will make fiber deployment challenging and underscore the need for careful consideration of emerging network architectures, according to Yvon Rouault, technology advisor in the office of the CTO at test company EXFO -- particularly as network speeds increase.

"Transporting more than 10 Gbps on the fiber ... is not easy on very long distances," he said, due to phenomena such as dispersion and phase modulation which significantly impact the bit-error rate. To account for that, Rouault said, "very probably, we'll see an explosion of mini-data centers, or maybe virtual machines running very close to the antenna site for some specific use cases."

Complexity isn't limited to architecture planning, either. "It's also the roll-out of the access," Rouault said. Systems designed for 10 Gbps speeds, with commensurate bit error rates, can struggle to deal with radical increases in speed. He recalled that one EXFO customer who was moving from 10 Gbps with an excellent BER to 100 Gbps – and once the speed was increased, "there was no signal at all ... The connection was essentially burning the transmitter and the receiver didn't receive anything."

"Backhaul is not ready for 100G, but they will need it," Rouault said, while fronthaul is moving to 10 Gbps and will eventually need to be faster as well, in order to support expected 5G latency demands -- which will pose issues if fronthaul needs to be more than 10 km in distance. "People are totally underestimating this. We're preaching this right now to operators, to convince some of them not only to accept it but to understand it." He said that Verizon in particular has been an operator that understands the future problems and is already doing dispersion testing, for example, so that it can confirm that its network is 5G-ready without the need to re-test later.

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Yvon Rouault, Technology Advisor, EXFO

In addition, Rouault said, optical fiber installation is already problematic, with connectors often not cleaned properly or fiber quality going untested until problems are discovered later. "We see people who have no clue what they're doing," he said. "Fiber is just like an electrical cable for them." One U.K. operator, he said, had to go back and re-do a quarter of its new cell sites and delay its launch of LTE-Advanced for several months due to fiber issues that weren't discovered until late in the deployment process – impacting both cost and time to market. In an even more dense 5G roll-out, the need to get fiber deployment right the first time will be crucial.

conducted in New Jersey this past winter during heavy snow in order to study the effects on the link of heavy snowfall – and other sites happened to be up and operating during Hurricane Harvey, he added, so they tried to get data from them for observation.

Even the mid-band, which carriers like KT are planning to use as a better-propagating anchor in a 5G network that utilizes both 3.5 GHz and 28 GHz, will need far more sites than macro networks have had to have, to this point in cellular evolution for outdoor coverage. Right now, said Lindsay Notwell, VP of carrier and international business at Cradlepoint, the industry is starting to more tightly integrate the use of 5 GHz in a license-assisted access context. CBRS "is nice" at 3.5 GHz, he added, "but that's still worse than the old 2.4" [GHz] in terms of propagation characteristics: shorter range, less ability to penetrate.

"I tell the carriers, you don't know what you're up against [at 3.5 GHz], let alone at 26 and 39 GHz," Notwell said. "The best space to solve the speed problem is in the worst from the spectrum standpoint."

Given the constraints of the spectrum, then, denser networks are critical to 5G at the mid-band and mmwave. But that presents an enormous investment in fiber and site acquisition (see sidebar: The Fiber Conundrum). Murphy of Nokia said that operators should expect that, depending on which frequency they deploy in, they will need 2.5 to 10 times as many sites as they have now. That's a tall order, especially given that small cell sites in cellular frequencies can take 18 to 24 months to get site approvals – scaling small cells has been hard enough in LTE, with the market moving much more slowly than analysts had predicted or carriers would like.

"It's going to take a long time," Einbinder said. "Constructing a cell tower is hard. A micro-cell has a lot of the same issues": power and fiber and access to a site, which a community may be reluctant to grant – California, for instance, recently rejected a measure passed at the state level that would have streamlined processes for small cells.

That means some major changes are going to have to happen in order to make the numbers work for widespread 5G deployment at mmwave. It also means that when operators like T-Mobile US talk about being able to deploy 5G NR at 600 MHz, without the need for such intensive densification, "that has got to be having a major impact on how the other folks in the North American market are looking at where they're going to be a year from now," Einbinder said.

However, Einbinder thinks that some communities will take initiative and want to be 5G economic centers. While that's encouraging for operators, it may also mean that 5G coverage maps look very different from the familiar red, blue, yellow and magenta maps indicating nationwide coverage. "The resulting coverage maps might have a lot more to do with [communities] than any economic or technological drivers – it's going to be driven by local preference."

Cord-cutting is helping to drive the momentum of 5G, said Notwell. "I truly believe, based on many of our customer conversations, that they can't wait – because they see this as a way to get to market faster, to give them more flexibility and to actually lower their costs."

However, FWA may not be quite as compelling as originally

expected. While early work estimated that as many as 40 to 50 homes could be covered by a single fixed wireless site, according to Rouault of EXFO, that number has turned out to be around five in testing because of the complexity of beamforming necessary to support multiple homes. “It’s not at the point we would say the verdict is out,” Rouault added. “The technology is proven to work, but to make the business case work, the scale is the problem right now.” He added that other considerations are also continuing to be explored, such as the final architecture of the customer premise equipment: from a CPE modem placed inside the house, an intermediate step of an antenna on the outside of the house is connecting to a modem inside the house, rather than just an inside modem.

Ericsson’s 5G readiness survey found that between 2016 and 2017, the focus of 5G business planning shifted from primarily seeing consumers as the opportunity to a broader range of business case drivers. In 2016, 90% of respondents said that their 5G planning was focused on serving consumers directly. In 2017, that had changed to serving specialized industry segments (58%), business users (56%) and consumers (52%).

So the biggest question is where a breakthrough is going to happen that becomes the point at which 5G becomes a more attractive investment than LTE. “What can 5G do that other systems can’t? This is where there is no clear answer,” said Hemant Minocha, EVP for device and IoT at TEOCO. There is no 5G requirement for IoT, he points out, and the business case hasn’t yet been proven out for ultra-low latency (not to mention that LTE is capable of lower latency than it has achieved to this point in networks). Network slicing may be of limited use in some regions where net neutrality restrictions apply. LTE, he added, “goes quite a long way, and some operators are saying, ‘How can we get more out of 4G and delay 5G, because it’s going to be really complex in the high bands?’” 5G will have to prove itself in order to earn investment.

“Really, I think the biggest challenge you have at the moment is more about how we smoothly deploy the network, where we start to build capabilities and make sure that the investment we’ve already made in the 4G network is leveraged to the maximum extent,” he said.

Key takeaways:

- The industry is moving quickly toward 5G, with momentum in testing and trials. The first official 5G specification from 3GPP is expected in December, with a protocol-focused release coming in the spring of 2018.
- Many features and architectures in LTE, particularly gigabit LTE, will both underpin future 5G networks and provide lessons learned in making 5G systems work. These include dense fiber deployment, higher-order and massive MIMO, network slicing, virtualization, and mobile edge computing
- The biggest challenge for 5G lies in a millimeter-wave based RAN, with significant challenges ahead for designing and deploying a workable, optimized and profitable mmwave network on a large scale.
- Testing equipment is expected to become more modular, with higher channel bandwidth capabilities and more flexibility to support an evolving 5G ecosystem.

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