MEETING 5G CHALLENGES FROM CODE GENERATION TO SPECTRUM CONGESTION

By Rick Nelson, Interim Chief Editor

5G research spans the gamut from algorithm development to carrier-acceptance test, as explained in a special report in our December issue.[1] In that article, industry experts including Ken Karnofsky, senior strategist, MathWorks, commented on trends in 5G technology and the challenges 5G presents. In a follow-up phone conversation, Karnofsky elaborated on topics including automatic code generation, helping engineering teams obtain the necessary skills and tools to meet 5G challenges, math-based visualization of propagation characteristics, scatterers in multipath environments, and issues related to spectrum congestion and coexistence.

Rick Nelson: **In our December special report on 5G, you commented, "Currently, the entire signal chain, from RF to baseband, can be implemented in a single programmable device or module. However, most engineering teams do not have incumbent engineers with the expertise to design and integrate these devices into a complete system." Are these devices FPGAs?**

Ken Karnofsky: It depends on whether the design is for a base station or mobile phone. Ultimately in many cases, once devices get into full production, they will become ASICs. In the early stage of base-station design there is a significant FPGA component. For handsets and mobile devices FPGAs can be used in emulators or prototyping systems, but of course the ultimate final product is going to be an ASIC in that case.

RN: **So, you can develop an algorithm in MATLAB and translate that to one of the FPGA design tools?**

KK: Yes, that is certainly one aspect of what we offer. The system architect will be working with a floating-point algorithm where they are not really concerned about the constraints of the physical device, but they want to understand the behavior and they might also simulate algorithms in the context of an end-to-end signal chain that could include RF impairments or aspects of the antenna characteristics, which are becoming more important with MIMO systems in 5G. Then often a couple of things can happen. For developing prototype systems there's definitely growing interest in automatically creating those prototype systems from the models, which would involve converting the abstract floating-point model to something that represents the fixed-point hardware. Some of the architecture could be implemented in hardware, and the last stage is generating the code for the implementation.

As the state-of-the-art for more production-system ASICs or FPGAs, we are seeing that automatic code generation is being adopted by some companies—it's more of a leading-edge type of process for particular IP blocks or algorithms within the system. But by and large the overall system is often hand-coded in VHDL or Verilog. I am not aware of anyone who is automating the implementation of an entire baseband modem—that's a tall order and is somewhere in our future—but for specific algorithms, we are definitely seeing more automatic code generation.

RN: **What are the advantages of hand coding?**

KK: There are established workflows, such as verification workflows, and existing tools and skill sets. Adopting a different methodology is something of a challenge and is not done lightly, even when there are compelling advantages for doing so. But also, there are aspects of the chip design that really have to do more with memory management and other types of components that to date have not really been a MathWorks focus. We are starting to introduce capabilities for modeling those parts of the systems, but automating the implementation is still in the future.

RN: **You have mentioned that engineering teams may lack needed expertise for 5G. How does MathWorks help with this—with training or by building more capabilities into the tools?**

KK: Some of both. One aspect we are seeing as 5G comes online is that there is a real need and demand for educating the engineering workforce, which may be familiar with LTE or other aspects of communication, but which is new to 5G. And some aspects of 5G in terms of the flexibility of the standard add a lot of complexity. And there are some new concepts that are of strong interest every time we engage with the customer. We've produced a short video series that we call "5G Explained"—it's a series of about 10 videos on various aspects of the 5G physical layer. And when we look at where people go on our website for information on wireless topics, the series has climbed into the top five pages—so there is clearly an interest in that topic, and we see it when we present that material at specific customer sites. Usually, we get a full room of people who are interested in 5G as well.

So that is one aspect. The other aspect is more about system modeling where the baseband meets the RF and antenna system. So that would involve beamforming architectures, using more digital algorithms like digital predistortion to compensate for impairments or nonlinearities in the power amplifiers, and the large bandwidths that are necessary to get the 5G data rates. These factors are really causing a rethinking and rearchitecting compared with the way things were done in LTE or previous types of systems. So, to design those algorithms, it's preferable to have a model of the other components so that you can evaluate the architectural tradeoffs. For example, in the beamforming space people are looking at all-digital architectures vs. hybrid digital and analog architectures, and there are both efficiency and cost reasons to take different approaches. Fully doing that type of cross-domain tradeoff isn't necessarily something which engineers have been trained on traditionally. The traditional tools available to them may be more circuit-oriented and tend to focus either on RF antenna propagation or DSP algorithms. How do you bring all those together? So that is one question we are answering, and one area we are certainly investing in is providing a modeling environment where you can put pieces together and get some insights earlier before you start building prototype hardware.

RN: **Is there a hardware-in-the-loop aspect to this, and if so, could you provide an example?**

KK: There is, to some extent. One example is a demonstration we put together in collaboration with National Instruments, where we have a model showing DPD together with a model of the power amplifier. The intent is not that we are delivering DPD IP. That is a very specialized task, and our customers want to create their own that's specific to their product. Our intent was to show a modeling approach, and in the demonstration, we took the DPD algorithm and instead of a model of the power amplifier we put the algorithm in the loop with some NI PXI test equipment and an actual hardware power amplifier. We pumped the test vectors through the test equipment, it drove the power amplifier, and we got the results back into MATLAB, where we could update the coefficients, etc. That's one HIL example. It provides the capability to validate the implementation vs. what was predicted in the model.

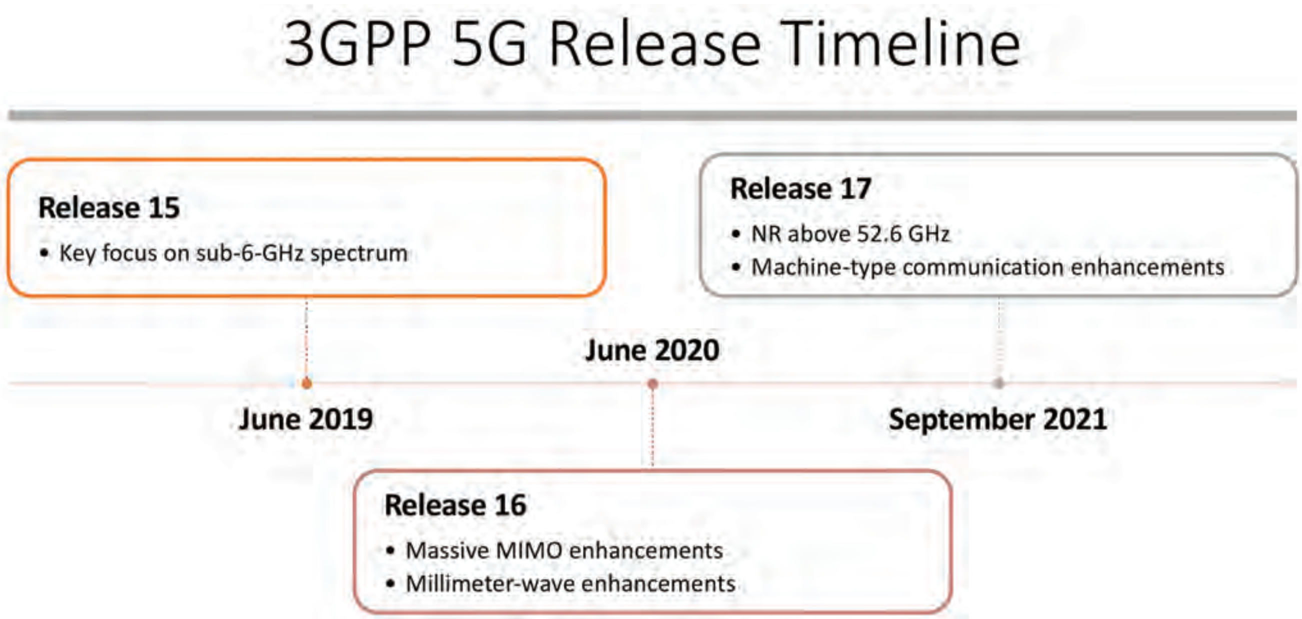
RN: **One expert quoted in my December report on 5G said there are two types of challenges with 5G: ones that have existed for previous cellular generations and ones that are completely new to 5G. Would you agree with that?**

KK: Yes, certainly. There are several technical drivers for that. One, I already mentioned the large bandwidths that actually introduce challenges in terms of making the RF technology operate in a linear fashion. The second one is massive MIMO. It's not happening right now in the early stages of 5G because Release 15 is primarily below 6 GHz. *[Editor's note: see the nearby 3GPP 5G Release Timeline.]* As you get into millimeter wave, the massive MIMO architectures are something that really hasn't been seen before.

The third one is in the digital baseband physical layer. The frame structure of 5G is extremely flexible by intent, so you can reuse the same structure to achieve high throughput, high-capacity systems, or you can dial it down so you have low latency and lower data rates for IoT and those types of applications. So, they are anticipating all these different use cases that have different requirements, and the result was a very flexible but complex frame structure that's driving up the number of scenarios or test cases that you need to evaluate. That definitely is a challenge both in terms of understanding but also in terms of the amount of time it takes actually code and validate the design and test it.

RN: **Once 5G networks have been deployed, is there an ongoing role for MathWorks to play in evaluations of quality of experience or coverage?**

KK: Yes, I would say so. An early indication of that is that we have recently introduced capabilities for visualizing and analyzing coverage using math-based visualization of propagation characteristics. So, you're



looking at coverage analysis, the strength of a link, and that type of thing. And then in millimeter wave, the types of channels use different technologies than are being used at lower frequencies.

It is not quality of experience *per se*, but channel modeling is an area that's really critical, and we see that the base-station providers and the carriers are equally interested in that and are trying to understand those propagation characteristics. What happens when you are in an urban area and your signal is bouncing off buildings or being absorbed by materials in ways you didn't have to worry about with lower frequencies? In LTE also there is an interest in that kind of scenario planning—where do I put my base stations, how does that affect coverage, what is the impact of terrain and buildings and those types of effects? So, we have introduced some capabilities in terms of the visualization and analysis, and I think we are certainly seeing an interest from customers that is motivating us to keep investing in that.

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RN: **In our December issue, in addition to the 5G report, we had an interview with one of your colleagues, Philipp Wallner, industry manager for industrial automation and machinery at MathWorks, who discussed the Industrial IoT.[2] He described a New Zealand energy company that continually (every 30 minutes or so) uses Simulink models to optimize the grid load and make sure the grid will continue to operate (for the next 30 minutes). It seems there should be something analogous for a 5G network.**

KK: Exactly. Can you design a network that will actually support this traffic? There is an interesting emerging interaction between the world of automated driving and autonomous vehicles and the next generation of wireless infrastructure. If you think about the extent to which the industry adopts the 5G version of V2X technology, or communication between vehicles, you want to be able to track mobility. If you were designing such a system you would want to know where the vehicles are, how fast they are going, what other sensor modes they are using to detect the presence of other vehicles or obstacles, and then how they are communicating with each other. And we see some interesting university research in this area. One university is doing this type of analysis from the perspective of fuel consumption. You can use vehicular communication networks to detect traffic patterns so you can brake more efficiently or accelerate more efficiently and basically optimize fuel consumption that way. I think it will have an impact on those designs just as vehicular communications is certainly a market for wireless technologies. It works both ways.

You also mentioned Industrial IoT. One customer just gave a talk at one of our MATLAB EXPO conferences that was about replacing Ethernet in factories with the new 802.11ax, sometimes called Wi-Fi 6. They are looking to see whether they can get low enough latency in a Wi-Fi system so that you can actually do industrial control using wireless technology as opposed to cables.

And they've done enough research to see that it is a promising proof of concept, and his talk was about how they are using MathWorks tools to do the modeling of the modifications they would need to make the standard able to achieve the required latency, and they are prototyping the proposed system on some programmable SDR type of hardware. It's not 5G, but 802.11ax is the Wi-Fi equivalent of 5G with many of the same issues relating to new antenna technologies influencing the design of the baseband and tradeoffs between throughput and latency. There are many of the same considerations—just in a Wi-Fi world, not a cellular world.

RN: **One industry expert said 5G is moving from the relative friendly trial phase to the much less friendly environments of commercial deployments. Would you agree with that?**

KK: Absolutely. I would say yes because there are large investment decisions and considerations regarding consumer acceptance and qualifications. The degree of testing that's required to achieve the quality of experience that the consumer wants is quite different from the testing you would do in a lab to determine whether one device can talk to another one successfully.

RN: **You have commented on the simulation of scatterers in multipath environments. Do you use real-world data for this?**

KK: We can bring in external sources where you can put terrain on the map so you have real data about elevation of mountains and other terrain aspects, and we recently introduced the ability to take open street-map data to put buildings on the map as well. We don't yet have the building properties, so you can't tell yet whether it's a glass building or a brick building, but you can tell that the building is there and how tall it is. Also, we introduced some ray-tracing technology—which is incorporated in channel models that are used to determine how something will reflect off a building surface and how that affects the reception. It answers the question, can you get a signal from point A to point B successfully in that type of environment?

RN: **What next, 6G?**

KK: Certainly, we try to stay in touch with the academics who are doing that type of work. And at the 2019 Brooklyn 5G Summit, the keynote discussed 6G.[3] So there is certainly research on 6G. But in the near term, there is still the 3GPP's Release 16, which is still 5G. What's more immediate in terms of what's next are the other use cases that were envisioned for 5G. So, we have mobile broadband that is starting to be deployed, but the low latency and massive IoT device use cases are really coming in Release 16, as is also more on the implementation of the millimeter-wave technologies. I think there are still a lot of decisions regarding Release 16, but it is wrapping up, so I think the main issues are pretty well understood. And there will be one more 5G release before the move into 6G.

One question involves practical considerations for the consumer of the technology who is thinking about an industrial setting or a sports arena or something like that. The question is whether to use 5G or the newer versions of Wi-Fi technology, which have some of the same goals as 5G. There both technical and business decisions that the consumers will have to make. There is discussion of private 5G networks on unlicensed bands, so do you go with a private 5G network or do you set up a next-generation Wi-Fi network? There is an emerging trend where evaluation of those alternatives is going to be an important consideration for the consumers of the technologies—each technology will end up finding its place, but it's not completely clear yet which one will win in which scenarios.

***RN:* Other thoughts?**

KK: We talked about scatterer-rich environments, but there is also just spectrum congestion. There are situations where there are incumbents and new technologies in the available spectrum, so we are hearing a lot from our customers about coexistence and interference mitigation as other engineering challenges. If you are transmitting and receiving one particular type of signal, how do you make sure that is done in a robust way given that there are lots of other signals in the same frequency bands that you have to deal with?

***RN:* Dynamic spectrum sharing (DSS) is one approach for getting 5G and LTE to coexist.**

KK: That's right. And we are seeing similar situations elsewhere. A couple of years ago there was the introduction of the Citizens Band Radio Service.[4] The FCC made available some spectrum that used to be and still is being used by Naval radars but is now available for LTE. So, if you happen to be in a port city where there are Navy ships and an LTE network that you want to use that spectrum for, some interesting spectrum-management problems arise. And that won't be the last example, I am sure. EE

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