The Rx for 5G RF

Tx-based National Instruments Previews LabVIEW Communications System Design Suite–an Integrated Approach for Advanced 5G Wireless Research

Executive Summary

The mobility and Internet of Things explosion has led to a severe wireless spectrum shortage, driving researchers to seek new ways to alleviate the bandwidth crunch. Wireless researchers now plan for a 5th generation wireless standard (5G), which is expected to provide a 1000x increase in network capacity and arrive at the end of the decade. To enable 5G, the wireless research community is seeking new ways to improve efficiencies in prototyping, validation and test of next generation technologies.

Software Defined Radios (SDRs) are a cost-effective way for communications system designers to develop rapid, easy to use prototypes. However, many of the solutions available today require multiple software tools and advanced parallel programming skills, create sub-optimal code generation, and use incompatible hardware, resulting in expensive and complicated system prototypes and lengthy software development timelines. As emerging 5G technologies push the bounds of radio, antenna and processing technologies, a better, seamless software and integrated hardware approach is needed.

Industry and academic leaders, including Nokia, NTT Docomo, Lund University, Alcatel-Lucent, and Technische Universität Dresden, have significant 5G research initiatives underway and are leveraging SDR technology to build their prototypes.

National Instruments (NI) offers a complete SDR portfolio and recently previewed a beta release of LabVIEW Communications System Design Suite (LabVIEW Communications), an integrated design tool for efficient prototype development by domain experts. Long known for its test and measurement tools, NI seeks to establish itself in the RF market as a design company. LabVIEW Communications paired with some interesting hardware targets should help NI differentiate from incumbent providers and build-your-own approaches.

Anticipating the Capacity Crunch

Globally, wireless devices are becoming pervasive and consume network capacity and bandwidth at accelerated rates. To meet these increasing demands, network service providers are rolling out fourth generation (4G) networks based on the Long Term Evolution (LTE) standard. LTE offers significant upgrades over 3G in terms of data throughput with up to five to six times faster peak rates. Most service providers plan to transition to LTE-Advanced, or 4.5G, which is expected to double the available bandwidth from LTE. However, the growth of mobile data traffic is not expected to subside, putting a significant long term crunch on both network capacity and bandwidth.

With this in mind, researchers set their sights on 5G, expected to roll out at the end of the decade and increase network capacity via increased bandwidth. 5G has the potential to positively impact almost all geographies with unprecedented data speeds. For those that have connectivity today, 3D movies and real-time HD streaming will be the norm. For emerging markets and rural areas, ubiquitous access will be life changing.

The consensus amongst 5G researchers is that no single “silver bullet” will lead to the necessary bandwidth expansion; a combination of advancements will be required to meet the 5G working goal of 1000x increase in network capacity. Some major areas of 5G research include:

- **Spectrum Availability**: Today, most current cellular networks operate in relatively narrow licensed bands below 2 GHz, where signals propagate reasonably far through free space, but where available spectrum is somewhat limited. Given the spectrum limitations below 2 GHz, researchers explore new frequency ranges that can support substantially larger capacity. Some of the most promising bands for future cellular networks are the millimeter-wave bands at 28 GHz, 38 GHz, and 72 GHz. Millimeter-wave bands offer substantially wider bandwidths and promise dramatically higher data capacity than cellular bands used today.
- **More Antennas:** Over the past decade, multiple-input and multiple-output (MIMO) technology has offered the opportunity to significantly increase channel capacity. The basic premise of MIMO is that through the use of multiple antennas, a span of allocated spectrum can support multiple data streams. The use of MIMO technology in today’s wireless standards grows and the next generation of cellular communications systems will likely use MIMO systems with substantially larger numbers of antenna elements (that is, “massive MIMO”).
- **New Waveforms:** 5G researchers investigate new and more efficient signal structures. For example, generalized frequency division multiplexing (GFDM) uses special filtering to improve interference into adjacent channels when compared to traditional orthogonal frequency multiple access (OFDM). In addition, technologies such as non-orthogonal multiple access (NOMA) multiplex use the power domain of a transmission for better spectrum utilization. GFDM and NOMA are but two examples of research into new signal structures designed to enable higher capacity into a given span of spectrum.
- **Heterogeneous Networks (“HetNets”):** Traditional base stations can be augmented with a large number of small cells such as femtocells and picocells. Small cells are effectively miniature base stations that can be used to improve coverage in challenging environments and increase the data capacity of the

network. In addition, improved Wi-Fi radios known as “carrier-grade” Wi-Fi can potentially augment cellular networks with additional data capacity.

Current Challenges in Wireless Design

Technically enabling 5G will require a several-year, multipronged approach involving academia with research test beds and teaching labs, major industry players developing prototypes and conducting field trials, standards body alignment, and government organizations researching signal intelligence, navigation, and next generation public safety radios. In all of these areas of research, wireless design involves multiple layers of optimization and tuning while maintaining compatibility with industry standard protocols.

During the wireless design process, researchers continuously look to find the quickest path from their newest algorithms to a working hardware signal. Moore’s Law provides increasingly faster processing capabilities (through parallelism and faster programmable logic, such as field programmable gate arrays (FPGAs)) which feeds commercialization of these new solutions. The intricacies of implementing new algorithms, however, increase significantly with each wireless generation. Protocols become more complex, there are more simultaneous users on the network, and the landscape of wireless designers change as a broader spectrum of products include wireless technology *(i.e*. smart devices, wearables, home automation, *etc.).*

Next generation wireless design also requires more advanced programming techniques to optimize algorithms. Optimizing for quality of result (QoR), microprocessor and DSP performance as well as optimizing for parallel hardware implementations such as FPGAs often results in the need to bring in programming and hardware design experts throughout the process. This causes resource bottlenecks, debugging headaches, additional expenses and extends prototyping timelines.

Another key challenge in system design involves accurate simulation. Wireless channels are fundamentally unpredictable, which means that perfect simulation of an elegant algorithm does not guarantee perfect system operation in the real world. In order to alleviate risk, designers develop prototypes of working systems with multiple design points. Historically, it has been difficult to find design tools that enable low cost, quick to implement and easy to reuse hardware prototypes. This scarcity of flexible tools adds time, money, and risk to the design process.

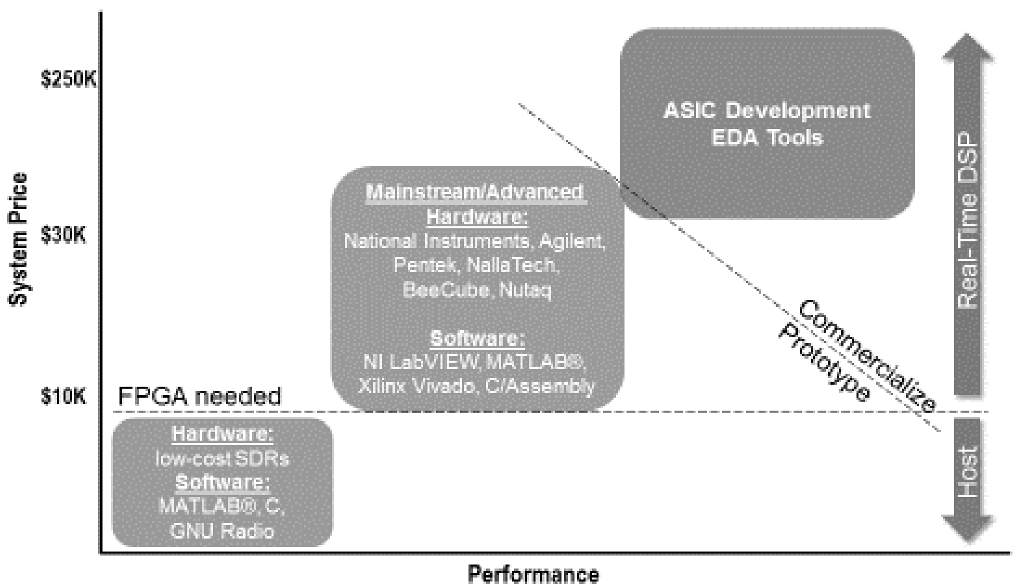
Prototyping with Software Defined Radios

In the past, communications system designers wanting to build prototypes used custom solutions or leveraged complex systems from their production test environments. These solutions included custom development boards with off the shelf or custom ASICs and traditional EDA tools. While still used today by design teams flush with advanced specialties and resources, this approach does not meet the need for the majority of designers looking to do rapid, low-cost prototyping.

SDRs have become the common category of platform used for communications system prototyping. SDR is a class of instrument that uses software modules running on generic hardware platforms to implement any radio function. A designer can literally make a generic hardware platform become a wireless communication device (*i.e.* cell phone tower, WiFi hot spot *etc*.) and transmit/receive (Tx/Rx) radio signals across a wide range of frequencies and modulation schemes defined by the user.

Figure 1 provides a high level overview of some of the SDR hardware and software solutions available in the market today.

Figure 1: Communication System Design Tool Landscape



Mainstream and advanced SDR systems include a range of disparate to comprehensive software and hardware solutions and the choices vary greatly, based on the required hardware sophistication and software experience. The low-end SDR solutions include low-cost hardware platforms with a set of basic function software and open source tools.

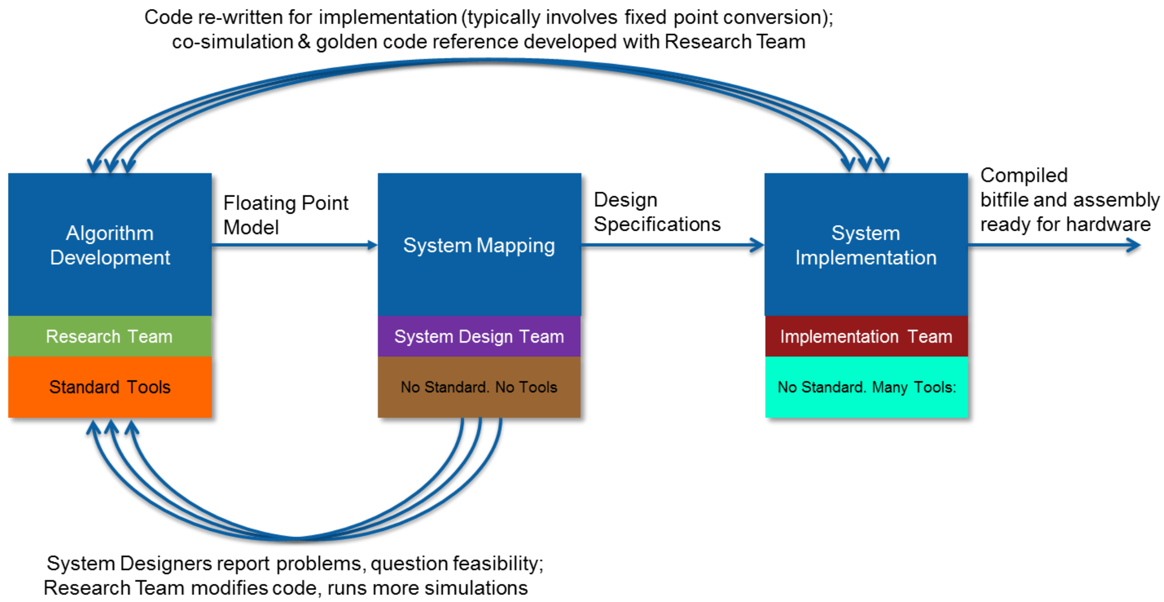
On the hardware side, traditional low-cost SDRs offer limited functionality and no FPGA capability, which makes these platforms unable to meet the needs of complex wireless design. Nutaq and Beecube offer a range of SDR's targeted specifically for RF design with various features/form factors, RF specific IP/reference architectures and plug-ins to common software tools. Pentek provides a range of boards for specific areas of RF design that can be leveraged to create a custom solution based on the specific RF test needs of the user. Nallatech has a series of off the shelf and custom platforms for FPGA development but provides a limited amount of RF-specific design IP and tools. Agilent offers a broad range of solutions for RF/wireless test, but their efforts are more focused on automation and test of current RF technologies, rather than low-cost, rapid prototype enablement for next generation protocols. The majority of these hardware vendors focus primarily on hardware design, leaving it up to the researcher to map together a set of 3rd party and open source software tools for various steps of the communications systems design progress.

The benefit of the SDR category of hardware is that SDRs are built with a common architecture allowing the algorithm designer to focus on software development rather than radio frequency (RF) details. However, in a communications system, the software is challenging to design and the majority of tools available today are disjointed, text-based math or processor-designed languages that need to be hand-optimized to meet specific system requirements.

GNU Radio is a free software development toolkit with signal processing blocks for SDRs and is widely used for wireless communications research. GNU Radio infrastructure is written entirely in C++ and many of the user tools are written in Python. MATLAB is a math-centric interactive environment for numerical computation, visualization, and programming, and is commonly used in communications system design for algorithm development and model creation. Xilinx Vivado is a development tool used for FPGA implementation, integration and verification with the Xilinx family of FPGAs. Other programming languages like C, C++ and assembly are also commonly used throughout the design process. While each of these software tools may serve a purpose for one or more steps of the communications design flow, none of these solutions provide end to end capability for the entire flow from algorithm creation to hardware prototype development. Parallel processing with FPGA increases performance of the algorithm, but also directly increases the system complexity–often requiring resources with very specialized skill. In addition to the challenges of algorithm design and optimization, most of these software tools don’t allow for straightforward mapping of the algorithm to the hardware system design, requiring multiple code rewrites as designers map their algorithms to various platforms.

Figure 2 provides an overview of the classical communications system design flow which requires disparate tools, separate design teams and a rigid feed-forward design cycle. This process necessitates multiple copies of the code in different representations, each of which are not backwards compatible putting considerable strain and inefficiency on the design team.

Figure 2: Classical Design Flow



The design needs for 5G–including complex research parameters, significant collaboration requirements, and the importance of prototyping–will provide an opportunity for researchers and designers to take a hard look at the existing landscape of available communications design tools. When evaluating today's design solutions with the 5G lens, MI&S believes the current state won't deliver on the 5G mobile experience end users demand. We want our 3D movies on our tablets, we require image libraries on our phones, and we insist on real-time visualization for our wearables. Fulfilling 5G expectations necessitates a new and different approach to designing these communication systems.

The National Instruments SDR Portfolio

Long known for its test and measurement tools, NI seeks to establish itself in the RF market as a design company. NI is pairing an emergent software experience with some interesting hardware targets to differentiate from incumbent providers and build-your-own approaches.

On the high end of hardware, NI smartly leverages its expertise in automated test and measurement systems and its ability to abstract low-level hardware programming (via LabVIEW FPGA) to provide a set of programmable hardware solutions. Vector Signal Transceiver (VST) and FlexRIO–both programmable with LabVIEW–target more sophisticated capabilities for advanced research.

On the low end, NI borrowed a page from the playbook of Ettus Research, a company it acquired in 2010, with the introduction of its own Universal Software Radio Peripheral (USRP) product line. USRPs connect to a host computer through a high-speed USB or Ethernet link, which the host-based software uses to control the USRP hardware and transmit/receive data. Ettus originally created the USRP category as a low-cost entry point for rapid prototyping for the academic world and its reach expanded into industry and the hobbyist/maker community. However, this platform had to evolve for advanced wireless research like 5G, where bandwidth is wider, transmit times are shorter, and protocols are more demanding. NI blurred the lines between the low-cost entry and high-end markets with the recent introduction of the NI USRP RIO product–which uses a customizable Xilinx Kintex 7 FPGA for high performance SDR prototyping.

A Promising Software Solution

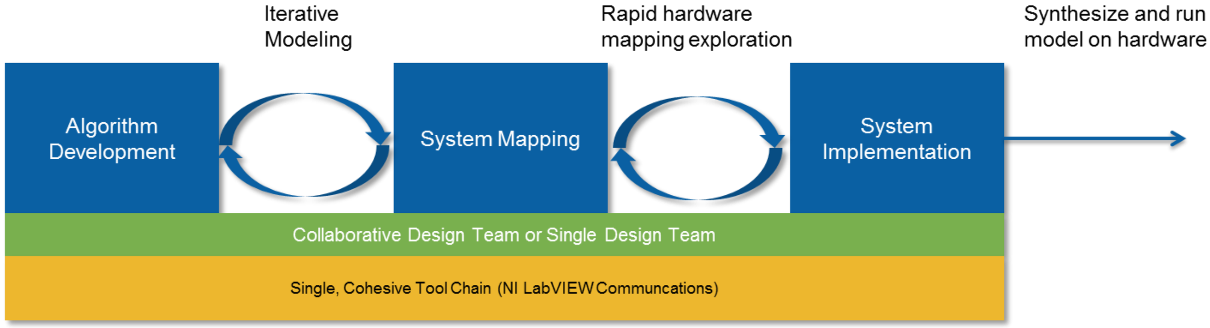
As with many industries in today's programmable world, the hardware solves just a fraction of the problem. Hardware that can scale from low-cost prototypes to high-end base station deployments isn't helpful if you don't have the software design tools to get performant algorithms deployed quickly.

NI demonstrated a beta release of their LabVIEW Communications System Design Suite (LabVIEW communications) as a tool to provide a more efficient way to explore, refine, and validate communications designs in real world scenarios. The most exciting element of this offering is rooted in the problem space we've discussed; 5G is in active research – it's undefined, unproven, and unknown. This means the ability to iterate quickly, explore productively and rapidly prototype is key. There isn't a turn-key package or solution for 5G, so programming tools optimized for a communications design engineer is essential.

Revising the typical design workflow–now with the LabVIEW Communications software–the designer is allowed to stay in a single environment, simulate the system, use multiple languages or tools to design an algorithm from a multi-rate diagram, to .m, to C code, or data-flow, and use that same environment and same algorithm to prototype on a desktop or hardware (FPGA) system–complete with in-product float-to-fixed conversion and compilation exploration tools.

Figure 3 represents the new communications system design flow using LabVIEW Communications software. By using a single software solution across the entire process, the design team can rapidly iterate on a single representation of the algorithms that can directly synthesize to hardware. The resulting design flow enables a more flexible and productive design experience because the separate design teams can now work in single context.

Figure 3: New Design Flow with LabVIEW Communications Software



This new approach is quite different than today's communication design experience. During the algorithm design and simulation process, LabVIEW Communications enables designers to take floating point models and express these designs intuitively, and furthermore synthesizes these designs directly to hardware, removing the burden of rewriting and revalidating code from the designer. As part of the modeling process, NI provides the IP designers expect for communications. This IP includes a set of ready-to-use reference designs for an 8x8 MIMO-OFDM, global positioning system (GPS) Simulation and RF Direction Finding/ Localization, and an extensive set of IP libraries to assist researchers in meeting their goal of rapid wireless prototyping.

LabVIEW Communications' built-in intelligent planning capability helps optimize algorithm mapping across various hardware resources (CPU, DSP, FPGA, *etc*.). For those resources like FPGA that do not have floating point processing, LabVIEW Communications includes a built-in float-to-fixed conversion engine that understands the context of the hardware platform. The software is also hardware agnostic, which–unlike the traditional tools–requires no code rewrites when mapping to various hardware platforms. The graphical canvas allows domain experts (communications engineers, control experts, and RF researchers) to program FPGAs themselves, eliminating the need to bring in specific programming expertise (*i.e*. VHDL, Verilog), saving time and money during the design cycle.

Collaboration is Key

Collaboration between industry, academia, government and technology providers will be critical to meet the goals of 5G by the end of the decade. NI partners with number of top academic and industry RF/Wireless researchers through its RF/Communications Lead User program to guide and define this new approach to communications system design. Partners in this program using LabVIEW for 5G research include Nokia/NTT Docomo for mmWave, Lund University for Massive MIMO and Alcatel-Lucent/Technische Universität Dresden for new candidate waveforms.

Call to Action

The wave of 5G design is upon us, driving the need for cost-effective and efficient wireless prototyping solutions. National Instruments is expanding beyond their traditional sweet spot of automated test and measurement to meet the needs of advanced communication design with their SDR hardware portfolio and planned introduction of their LabVIEW Communications System Design Suite of software.

For researchers who design next generation communications system technologies, MI&S recommends monitoring the progress of this potential disruptor in the coming months.

Important Information About This Paper

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