TU Dresden uses National Instruments Platform for 5G Research

Wireless consumers' insatiable demand for bandwidth has spurred unprecedented levels of investment from public and private sectors to explore new ways to increase network capacity. Service providers, now deploying fourth generation networks, are already beginning to look toward and plan for fifth generation networks (5G) to meet the escalating demand. Researchers at TU Dresden (TUD) have begun investigations into 5G technologies using a graphical system design approach and National Instruments' software defined radio platforms. Using the NI platform, TUD researchers significantly compressed the time to transition from concept to prototype.

TUD researchers have an initial focus of improving the 4G networks' physical layer. Current 4G networks cover a variety of wireless standards and applications such as wireless local access networks also known as WiFi (802.11 a/g/n) and cellular (LTE). Both WLAN and cellular systems use OFDM (orthogonal frequency division multiplexing) as a broadband modulation transport in the physical layer. OFDM essentially breaks up broadband digital data to be transmitted onto several smaller carriers or subcarriers rather than transmit lots of data on a single carrier. Advantages of OFDM over conventional single carrier approaches include improved spectrum efficiency, and mitigation of multipath propagation interference that causes data errors and loss of signal. Another benefit of OFDM systems is that equalization on a narrow band subcarrier is computationally less taxing than broadband non-OFDM schemes. For more information on OFDM, please see this link (ref: http://zone.ni.com/devzone/cda/ph/p/id/150).

Although OFDM offers advancements over single carrier approaches such as improving network capacity, bandwidth and reliability; there are a few drawbacks.

1. OFDM when paired with an amplitude modulation scheme lowers power amplifier added efficiency (PAE), and thus consumes power resulting in batteries that lose their charge faster in mobile devices.

2. OFDM waveforms produce increased side lobe levels. OFDM subcarriers are shaped with rectangular pulses in time which causes very high side lobes of the corresponding frequency domain pulse. Higher side lobe level increases the noise and interference in adjacent channels inhibiting other devices to use that channel – potentially wasteful of available spectrum.

3. OFDM is also very sensitive in terms of carrier frequency offset, which requires sophisticated synchronization mechanisms to guarantee the orthogonality between the subcarriers.

TUD is exploring a new physical layer modulation transport scheme for wireless communication systems called GFDM or General Frequency Division Multiplexing as an alternative to OFDM to compensate for the above mentioned shortcomings. At a high level, GFDM builds on the OFDM concept including the multi-carrier framework but adds signal processing to both transmit and receive chains to improve operational performance. This new technique effectively applies pulse shaping filtering to each subcarrier to improve power amplifier efficiency or PAE[1] and to attenuate out of band radiation. Filtering each subcarrier requires additional processing, but with Moore's Law advancing the computational processing capacity through additional processing cores and with efficient Digital Signal Processing techniques, the tradeoff will inevitably become a net positive over time.

About the System

TU Dresden researchers began with a mathematical model of their GFDM algorithms in the transmit (Tx) and receive (Rx) signal processing context. Although it was difficult to envision the system simply from the model, NI worked closely with the researchers to define a system that met the following requirements:

1. Sufficient processing capacity

2. Easy to debug – both at a program and system level

3. Able to transmit and receive in the available spectrum and conform to existing spectrum regulations.

4. Extensible. Perhaps most importantly, the TUD researchers wanted to have an extensible platform – one that would scale into a multi-stream MIMO prototype capable of 8x8 or higher.

The prototype system uses a National Instruments PXI system which includes the following:

NI PXIe-1085, 18 slot PXI Express chassis

NI PXIe-8133 multicore, real-time embedded computer/controller

NI PXIe-7965R NI FlexRIO, Xilinx Virtex 5 Sx95T FPGA

NI 5791 RF Transceiver 200 MHz to 4.4 GHz

NI LabVIEW system design software and the following modules:

NI LabVIEW Full Development System
NI LabVIEW Real-Time Module
NI LabVIEW FPGA Module
NI LabVIEW MathScript RT Module

To model both Tx and Rx, two identical PXIe systems were built and separated by distance to model a real deployment. The prototype uses two PXI Express chassis that each house an embedded multicore real-time controller and up to eight NI FlexRIO FPGA modules with NI 5791 adapters. The NI 5791 is a full duplex RF transceiver capable of transmitting and receiving wireless signals from 200 MHz to 4.4 GHz with up to 100 MHz of continuous real-time bandwidth. The initial experiments use a SISO link; however, the prototype was designed to expand and the system to be expanded to accommodate up to 8 NI FlexRIO and NI 5791 modules to realize a complete 8x8 MIMO system for future work (see Figure 1: GFDM System Block Diagram).

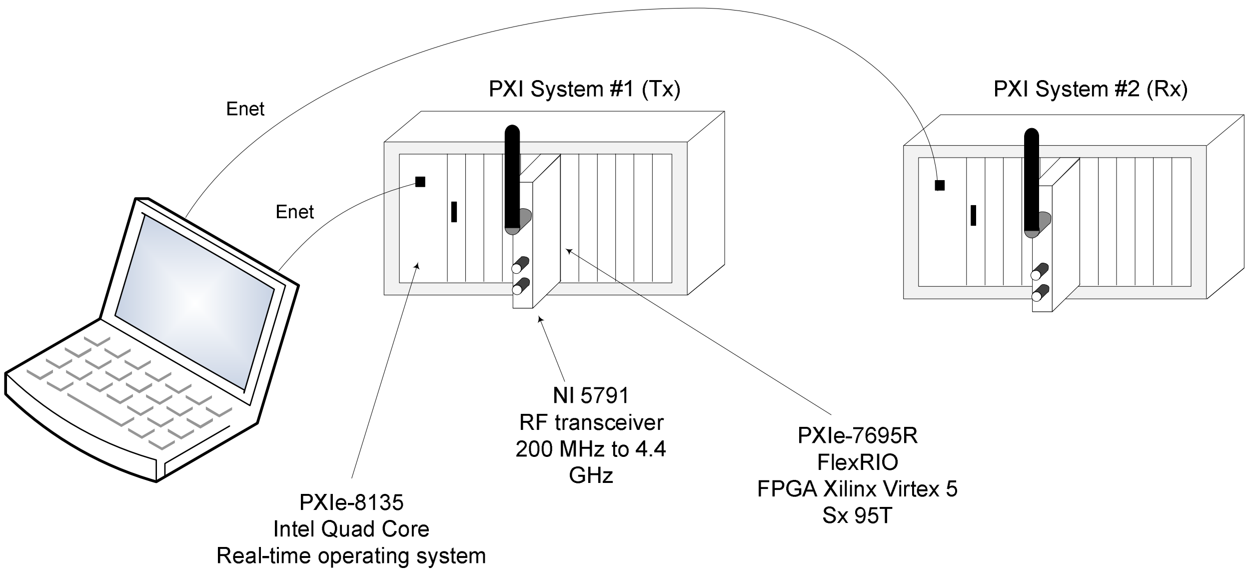

Figure 1: GFDM System Block Diagram

A host computer connects to the real-time controller via standard Ethernet. Each prototype system features significant computational processing capabilities with the Virtex 5 Sx95T for real-time signal processing for implementation of the physical layer, the real-time embedded quad-core computer, and the host computer. The GFDM algorithm was developed and simulated in a math tool on the host computer and then ported to the prototype using LabVIEW.

A Phased Approach

The TUD researchers chose a phased approach when moving from their math code to the hardware. The initial experiments on the prototype included moving the math code developed on the host using pure simulation to LabVIEW and verifying the results. The LabVIEW Mathscript RT module was used to cut and paste the text code into a LabVIEW graphical node and execute the text-based math code in LabVIEW with minimal modifications.

Once the results were verified or re-verified in LabVIEW, the algorithm was connected to the hardware. LabVIEW abstracts many of the hardware complexities of a software defined radio system by including intuitive APIs and drivers for all of the hardware input/output peripherals including the RF front ends. The task of connecting the simulation code to the hardware entails connecting the input data ports to the outputs available as graphical icons. The hardware abstraction simplified the integration task and the TUD researchers were able to quickly construct a non-real time test of the math code with minimal work.

The GFDM algorithm ran on the prototype hardware and performed to the simulation. The resulting transmit waveforms were acquired and analyzed. The side lode rejection improved substantially from a similar OFDM-only scenario by 20 to 30 dB[2] depending on the system configuration. The peak to average ratio on the subcarriers was measured and performed closely to simulated data.

To recap, the researchers at TUD transitioned their GFDM physical layer from simulation only to a working prototype in a few weeks. Although the prototype results matched the simulation – an impressive achievement – their work was not done. The goal of the initial investigation was to produce a real-world, real-time prototype. Real-time clearly indicates that the communication waveforms are constructed and sent over the air in real-time for a transmitter and acquired, demodulated and decoded on the receiver. To achieve real-time performance for this prototype, more work was to be done.

Achieving Real-time Performance

Building a prototype capable of demonstrating real-time actual performance can be very time consuming if not planned properly. The TUD researchers chose to model the fixed point implementation of the GFDM algorithm in LabVIEW before moving to the FPGA. In this way, the researchers were able to make tradeoffs in terms of precision and resources with the goal of matching the floating point simulation performance while efficiently using system resources. LabVIEW provides a natural environment for this type of transition as LabVIEW is a flexible and configurable system design software that enables researchers to build test benches and iteratively optimize the implementation (based on the parameters discussed above).

Although FPGAs provide powerful computational engines for the algorithm developer, they typically do not optimally offer floating point arithmetic processing capabilities. This means that researchers must convert floating point math algorithms to fixed point math before these algorithms can be deployed on an FPGA. TUD researchers had to encumber this same step, and they converted the math code to LabVIEW fixed point math and re-simulated.

With a fixed point model, the next phase focused on actually moving blocks of the transmit chain to the FPGA. Since graphical system design comprehends a heterogeneous multi-processing environment, the LabVIEW "G" language scales to the FPGA as a high-level description language. Once the algorithm is verified as a fixed point G representation, then a prudent approach is to segment the algorithm for deployment on the FPGA. The motivation for the segmentation approach is two-fold. First, by logically separating the algorithm and deploying parts of the algorithm bit by bit reduces risk and minimizes iteration. One of the more challenging aspects of FPGA design is to design and deploy within the constraints of the available FPGA resources and iterating incrementally provides a way to assess upfront the resource constraints with a design. Second, the larger the algorithm, the longer the time to compile, synthesize and place-and-route the FPGA design. Ultimately, an incremental approach to algorithm FPGA deployment may require iteration but by using an incremental approach the time to deploy may be reduced.

LabVIEW reduces the risk in deployment once the algorithms have been converted to fixed point simply by graphically highlighting the data flow so the algorithm designer can easily note where to "cut" the algorithm. With the a synchronous data flow model used by LabVIEW, the input data streams through the routing of wires intuitively highlights how to move blocks into the LabVIEW FPGA project as the connections retain their hierarchy and relationships. This graphical system design approach minimizes any rework as the data flows to FIFOs rather than a direct connection to a DSP routine or VI. In LabVIEW FPGA, the FIFO is a mechanism for buffering samples to match timing and data rates between routines, VIs, and / or intellectual property (IP) blocks.

Once the appropriate transmitter blocks were moved the FPGA, TUD researchers retested to see whether the results retained their accuracy once they moved them to the reconfigurable hardware target. With no significant deviation from the floating point model, TUD researchers were able to observe a significant increase in execution speed – the algorithm simply ran faster – and the real performance closely matched that of the initial simulation.

TUD researchers continued to move signal processing blocks to the FPGA until suitable real-time performance was achieved.

An Interesting Discovery

Moving from a floating point math model to a fixed point FPGA implementation took about 3 months of work. However, the TUD researchers did not simply do this to recreate their math simulation. In fact, while implementing the control code and data flow between the IP blocks the researchers added the ability to turn on and off subcarriers in real time either interactively or programmatically.

The initial scope of the research clearly focused on the development of the GFDM physical layer and implementing a real-time prototype. However, with the ability to programmatically turn on and off subcarriers the scope of the project expanded to exploring cognitive radio using GFDM. With the additional subcarrier filtering, TUD researchers noted that it may be possible to intersperse data between the subcarriers that are turned off on an adjacent user's communications channel. Effectively that spectrum is now free, but the real question is whether it is usable. With the additional filtering that GFDM offers, it may be possible to build a multi-user system to achieve superior spectral efficiency (see Figure 2) by using cognitive radio techniques to transmit and receive on disabled subcarriers. The use of adjustable pulse shaping filters in GFDM results in higher spectral efficiency and possible co-existence with legacy systems by using cognitive radio techniques to transmit and receive on available spectrum such as the TV white spaces.

Figure 2: GFDM waveform with subcarriers disabled.

Conclusion

TU Dresden researchers made significant progress in a very short amount of time. Using NI's approach to graphical system design enabled them to address and solve system issues early on in the prototyping process and removed bottlenecks uncovered in prototyping exercises. The PXI Express system using NI FlexRIO modules and an NI PXIe-8135 real-time controller provided ample computational capacity for the initial experiments with room to expand in the future to 8x8 MIMO. It also allowed them to explore cognitive radio concepts which extend beyond simple simulation as the system aspects are difficult, or even impossible, to model. With a working prototype and NI technology, TUD researchers are able to expedite their 5G research objectives to explore new methods never before explored in a single system and beyond simple math-based approaches and help address the impending bandwidth crisis

References:

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