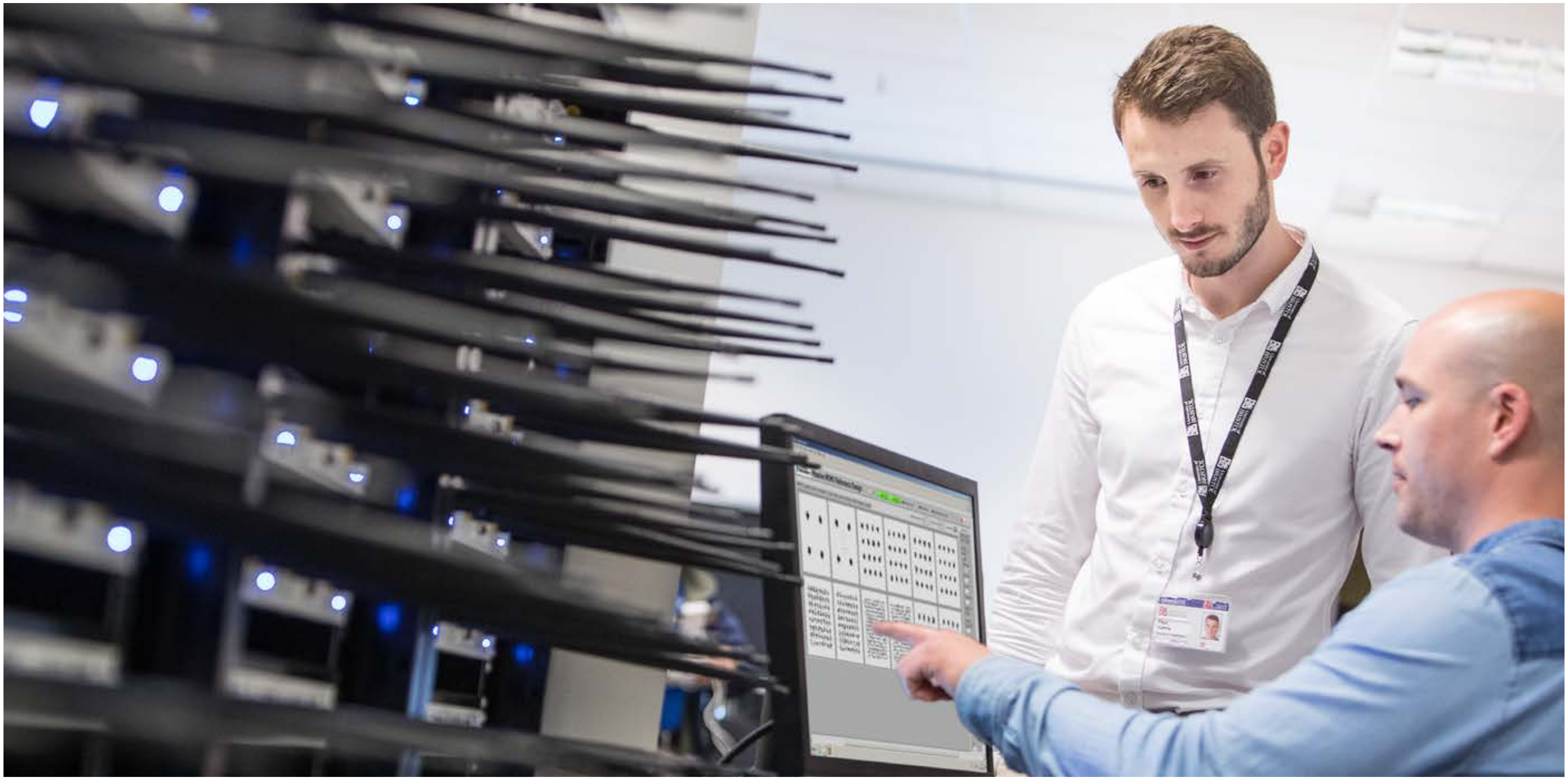
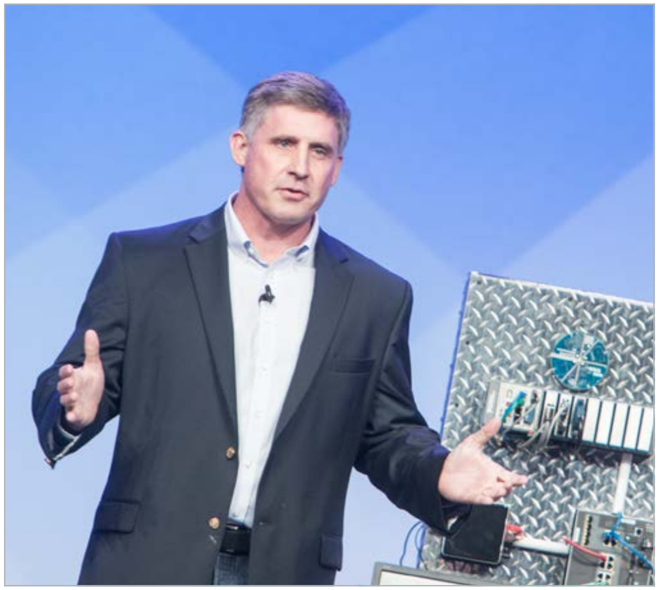
Wireless Research Handbook: 3rd Edition

BUILD 5G WIRELESS NETWORKS AND SYSTEMS WITH SOFTWARE DEFINED RADIO





JAMES KIMERY | DIRECTOR OF MARKETING,
SDR AND WIRELESS RESEARCH, NI

NI software defined radio solutions integrate hardware and software to help scientists and engineers rapidly prototype high-performance wireless systems. NI works with researchers worldwide to advance wireless research, and their use cases are fascinating and inspiring. This book includes incredible examples of how researchers transformed their novel wireless research ideas into real working prototypes.

I would like to thank all our lead users from around the world who continue to inspire us to build and evolve our platforms. You set the bar ever higher and ultimately help the wider research community innovate faster!

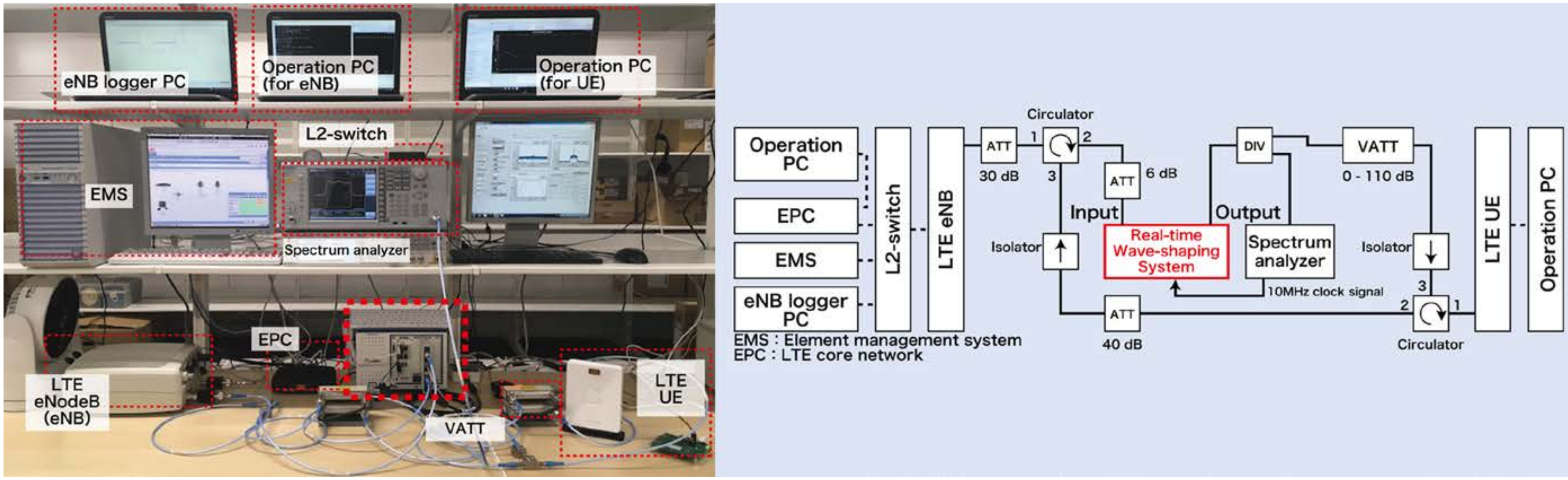
For additional information on these use cases and ways to innovate faster, please feel free to contact me and visit ni.com/sdr.

james.kimery@ni.com

About the SDR and Wireless Research Team

With a common goal of rapidly moving from theory to prototype, NI established lead user programs to accelerate next-generation research in controls, mechatronics, robotics, and wireless communications. Established in 2010, the wireless communications lead user program includes numerous research institutions examining advanced wireless system concepts. Many researchers around the world are making significant contributions in advancing wireless technologies through standardization and commercialization based on the foundational work completed by the lead user program.

Table of Contents



Flexible Waveform Shaping Based on UTW-OFDM for 5G and Beyond

Easing the Transition From 4G Systems to 5G and Beyond Systems

Digital Communications Laboratory, Department of Communications and Computer Engineering, Kyoto University

KYOTO UNIVERSITY

www.dco.cce.i.kyoto-u.ac.jp/en/

Read the Entire Research Paper

USER PROFILE

Dr. Keiichi Mizutani is an assistant professor in the Graduate School of Informatics at Kyoto University. He earned a doctorate in electric and electrical engineering from the Tokyo Institute of Technology in 2012. Mizutani researches physical layer technologies in 5G and beyond systems, white space communications, dynamic spectrum access, and wireless smart utility networks. He also participates in IEEE 802 standardization activities.

Dr. Takeshi Matsumura is an associate professor in the Graduate School of Informatics at Kyoto University and a senior researcher in the Wireless Systems Laboratory at the National Institute of Information and Communications Technology (NICT). He earned a doctorate in nanomechanics engineering from Tohoku University in 2010. Matsumura's research interests include white space communications, wireless wide area networks, and 5G mobile communications.

Dr. Hiroshi Harada is a professor in the Graduate School of Informatics at Kyoto University and an executive research director at NICT's Social ICT Research Center. He researches software defined radio, cognitive radio, dynamic spectrum access, wireless smart utility networks, and broadband wireless access systems. He is a member of the board of directors for the Dynamic Spectrum, Wi-SUN, and WhiteSpace alliances and the author of Simulation and Software Radio for Mobile Communications.

THE CHALLENGE

We needed to develop a comprehensive evaluation system that implements our proposed universal time-domain windowed OFDM (UTW-OFDM) in an actual LTE system to demonstrate feasibility and practicality. Implementing the UTW-OFDM requires modification and/or customization of the modem IC, which is costly and time-consuming. In addition, IC-based implementation constrains the flexibility of the experimental evaluation during which we need to optimize parameters for various conditions.

THE SOLUTION

We developed the Real-time Wave-shaping System shown in Figure 2 with off-the-shelf LTE components. Using this system, we successfully conducted the world's first demonstration of a UTW-OFDM-based LTE system. Our proposed UTW-OFDM can reduce the OOBE by about 20 dB at channel edges without any throughput deterioration. Our results also showed that the UTW-OFDM is highly compatible with the conventional CP-OFDM since we established the communication link without modifying the receiver. All in all, the proposed UTW-OFDM can help smooth the transition from 4G systems to 5G and beyond systems.

The Real-time Wave-shaping System, which includes the RF transceiver unit, the baseband signal processing unit, and the control unit, can be easily designed and implemented using the NI platform and solutions. We incorporated LabVIEW software as a graphical system design tool and FlexRIO hardware to create a systematic software defined radio development platform. We reduced the development cost by more than 90 percent, and the development period was only three months.

WHAT'S NEXT

We are evaluating system performance using a fading emulator, assuming a real communication environment. In parallel, we will soon perform field experiments to emit radio waves by attaching antennas to the UTW-OFDM-based LTE system.

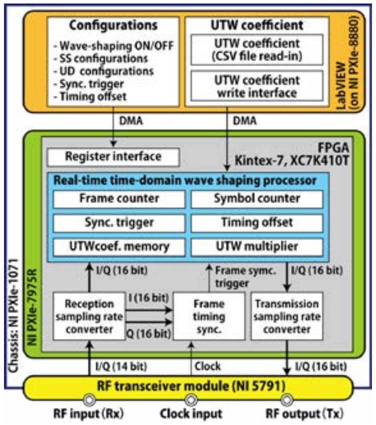


Figure 1. Block Diagram of the Real-Time Wave-Shaping System

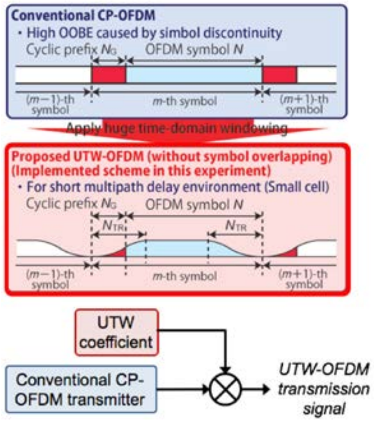


Figure 2. Generation of Proposed UTW-OFDM Transmission Signal

> "Thanks to the NI platform that integrates software and hardware solutions, we successfully developed an emulation system capable of real-time wave shaping at a reasonable cost even in a university laboratory. We demonstrated our proposed UTW-OFDM based on the LTE system. This achievement proved that the real-time emulation of upcoming signal processing technologies is no longer a dream but a reality."

Dr. Hiroshi Harada, Kyoto University

Flexible Real-Time Waveform Generator for Mixed-Service Scenarios

TECHNISCHE UNIVERSITÄT DRESDEN

owl.ifn.et.tu-dresden.de/GFDM

Read the Entire Research Paper

Providing a Unified FPGA Implementation for On-the-Fly Reconfigurable Waveform Generation

Martin Danneberg; Ahmad Nimr; Maximilian Matthe; Shahab Ehsan Far; Ana-Belen Martinez; Zhitao Lin; and Prof. Dr. Gerhard Fettweis, Vodafone Chair for Mobile Communications Systems, Department of Electrical Engineering and Information Technology, TU Dresden

USER PROFILE

Martin Danneberg received his master's degree in electrical engineering from TU Dresden in 2013. Since September 2013, he has led the research activities for the EU projects CREW, eWINE, and ORCA as a member of the Vodafone Chair. His professional interests include nonorthogonal waveforms for future communication systems, especially FPGA-based prototype implementations of flexible multicarrier modulation schemes.

Prof. Dr. Gerhard P. Fettweis earned his doctorate from RWTH Aachen in 1990. Since 1994, he has served as the Vodafone Chair Professor at TU Dresden, with 20 companies from Asia, Europe, and the United States sponsoring his research on wireless transmission and chip design. In Dresden, he has spun out 11 start-ups and set up funded projects generating close to a half billion euros.

THE CHALLENGE

Wireless networks operating in unlicensed bands suffer because multiple radio technologies share one frequency resource, which causes cross-technology interference. However, to connect all applications, various technologies must be supported in industrial scenarios. One step toward solving those challenges is to use a unified flexible physical layer (PHY) chipset and connect it with multiple chipsets to interlink the different wireless nodes. Since a single flexible chipset is used, its signal processing parameters must be reconfigured quickly to emulate the different radio access technologies.

THE SOLUTION

The Vodafone Chair for Mobile Communications Systems at Technical University Dresden used NI rapid prototyping SDR tools and the LabVIEW Communications System Design Suite to develop a flexible PHY transmitter based on real-time FPGA processing. The prototype supports waveform generation for diverse systems such as WiFi, Bluetooth and ZigBee, LTE, and 5G. Moreover, the implementation is runtime-configurable, meaning that the frame structure can be changed arbitrarily between frames without delaying the ongoing transmission. Such flexibility is mandatory for optimally using available time-frequency resources by aligning different services in time and frequency without delay when switching between different waveforms.

WHAT'S NEXT

We will verify the implementation in real applications such as seamlessly switching between streaming and low-latency services. Moreover, we will unify the FPGA interface implementation to ease the host-side configuration.

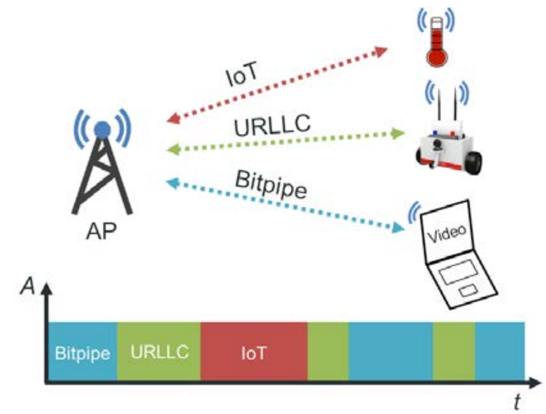


Figure 1. Flexible PHY Transmitter Services

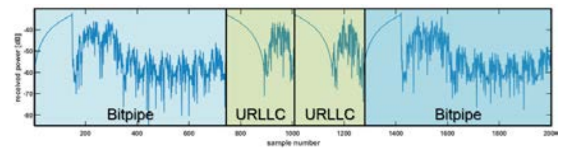


Figure 2. Transmit Waveform for Bitpipe and URLLC

> "The prototype supports waveform generation for diverse systems such as WiFi, Bluetooth and ZigBee, LTE, and 5G. Moreover, the implementation is runtime-configurable, meaning that the frame structure can be changed arbitrarily between frames without delaying the ongoing transmission."

Martin Danneberg and Gerhard Fettweis, Technical University Dresden

In-Band Full-Duplex SDR for MAC Protocol With Collision Detection

Dr. Sofie Pollin, Professor; Dr. Tom Vermeulen, Solution Engineer; and Seyed Ali Hassani, PhD Researcher, Networked Systems Group, KU Leuven

www.esat.kuleuven.be/telemic/research/NetworkedSystems

Read the Entire Research Paper

USER PROFILE

Dr. Tom Vermeulen obtained his bachelor's and master's degrees in electrical engineering from KU Leuven in Belgium. He researched in-band full-duplex SDR under the supervision of Dr. Sofie Pollin in the Networked Systems Group. In 2016, as a visiting scholar at UCLA, he worked on simultaneous transmissions and collision detection. He obtained his doctoral degree and joined Proximus in 2017.

Seyed Ali Hassani obtained his bachelor's degree in electrical engineering from Arak Azad University in Arak, Iran, in 2008. He then worked as an R&D engineer in industry to gain his professional experience. Hassani earned his master's in information technology/signal processing from Tampere University of Technology in Finland in 2016. He is a doctoral candidate at KU Leuven focusing on vehicular networking.

Dr. Sofie Pollin obtained her doctorate at KU Leuven in 2006. She returned to imec to become a principal scientist in the green radio team in 2008. In, 2012, she became an assistant professor in the electrical engineering department at KU Leuven. Pollin researches networked systems that require networks that are more dense, heterogeneous, battery powered, and spectrum constrained.

THE CHALLENGE

Because the number of wireless devices has been increasing rapidly over the last year, ultra-efficient protocols are needed to share the spectrum fairly and efficiently. Wireless networks also must satisfy latency constraints and minimize energy consumption.

THE SOLUTION

We exploited the bidirectional capability of in-band full-duplex radio to detect signal collisions and interference. As soon we determined a MAC frame was erroneous, we aborted the frame transmission to save spectrum and energy resources. Basically, full-duplex technology enables a radio to transmit and receive simultaneously and in the same channel. We can use this listen-while-transmit capability to assess the channel in transmission time. In this case study, we implemented a real-time collision detector based on the statistical evaluation of the received signal. Our novel Full-Duplex Carrier Sense Multiple Access with Collision Detection (FD CSMA/CD) MAC can improve the network throughput fivefold and reduce the energy consumption by 50 percent, as noted in our presentation "Performance Analysis of In-Band Full-Duplex Collision and Interference Detection in Dense Networks," at 2016 IEEE Annual Consumer Communications Networking Conference. For prototyping, we accelerated our implementation using NI USRP devices and the LabVIEW Communications System Design Suite.

WHAT'S NEXT

We are working on improving the sensitivity of the collision detector using deep learning. We hope to provide experimental results for a network of five full-duplex-capable nodes to support outdoor scenarios.

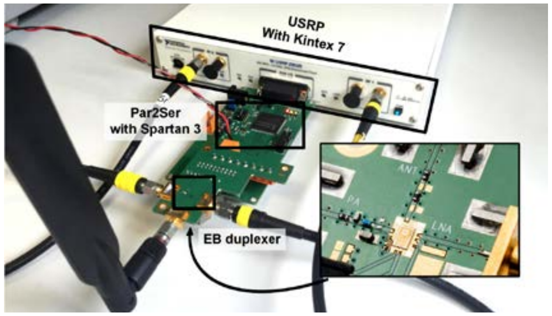


Figure 1. Full-Duplex-Capable SDR Device Integrating an Analog Interference Cancellation Solution From imec

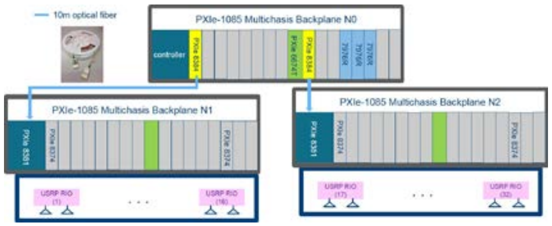


Figure 2. The Implemented Prototype Using the LabVIEW Communications System Design Suite

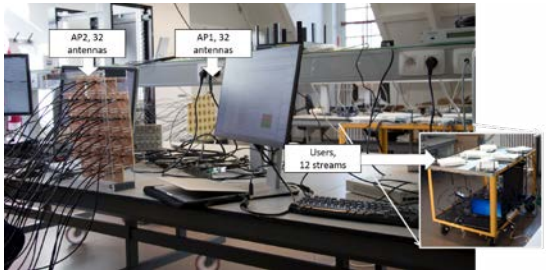


Figure 3. Using the novel collision detection method, network throughput is increased more than a factor 2.

"KU Leuven is one of the first research institutes to develop an in-band full-duplex testbed. In addition to duplicating the link throughput with this technology, researchers aim to enhance the reliability of the wireless network."

Dr. Sofie Pollin, Networked Systems Group, KU Leuven

Bandwidth-Compressed Spectrally Efficient Communication System

Conducting Software Defined Radio Design and Over-the-Air Transmission of Spectrally Efficient Frequency Division Multiplexing (SEFDM) Signals

Waseem Ozan, Dr. Ryan Grammenos, Hedaia Ghannam, Dr. Paul Anthony Haigh, Dr. Tongyang Xu, and Prof. Izzat Darwazeh, Institute of Communications and Connected Systems, Department of Electronic and Electrical Engineering, University College London

UCL

www.ucl.ac.uk/iccs/
www.ee.ucl.ac.uk

Read the Entire Research Paper

USER PROFILE

Waseem Ozan earned his MSc degree in wireless and optical communications in 2015 with distinction from the Department of Electronic and Electrical Engineering at University College London (UCL). He rejoined UCL in January 2016 as a doctoral student on a UCL-funded studentship to work on a new signal format developed jointly by UCL and Princeton University.

Dr Ryan Grammenos is a senior teaching fellow in the Department of Electronic and Electrical Engineering at UCL. He graduated with an engineering doctorate from UCL in 2013 focusing on the mathematical modelling and hardware realisation of novel communication transceivers. Grammenos' research interests are signal processing for communications, software defined radio, and the Internet of Things.

Professor Izzat Darwazeh is the chair of Communications Engineering and the director of the Institute of Communications and Connected Systems at UCL. He has been teaching and researching communications circuits and systems for over three decades and has published widely in these areas. He works as a consultant to various industries and governmental and legal organisations worldwide.

THE CHALLENGE

Billions of devices will soon be connected to the Internet in line with the vision of the Internet of Things (IoT). This means 5G must make highly efficient use of the wireless spectrum. Spectrally efficient frequency division multiplexing (SEFDM) has the potential to make better use of the spectrum through bandwidth compression but at the cost of higher levels of interference. Our challenge was to create a real-time testbed, on a popular platform, for SEFDM to be investigated widely.

THE SOLUTION

We demonstrated the world's first real-time SEFDM system using USRP RIO and the LabVIEW Communications System Design Suite. The key innovation was in the deployment of a novel real-time channel estimation and equalisation algorithm, combined with a real-time iterative detector. Our system compressed transmitted signal bandwidths by up to 60 percent to offer significant bandwidth savings relative to the multicarrier signals used in current communication systems. By working with various modulation formats, the system allowed for testing in 5G scenarios. We used two USRP devices, one for the transmitter and the other for the receiver. We programmed the transmitter and receiver using LabVIEW and then directly programmed the FPGAs to facilitate speed and flexibility. We implemented over-the-air testing using antennas and completed more demanding tests using a channel emulator.

WHAT'S NEXT

Multiantenna systems will be constructed and bandwidth will be extended to transmit at much higher frequencies (mmWave) and deploy in real-life scenarios with multimedia signals. We will be able to compare these systems with existing wireless standard systems and show their advantages.

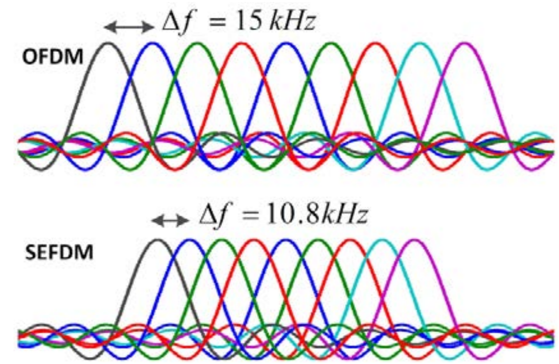


Figure 1. Squeezing OFDM Data in Less Bandwidth

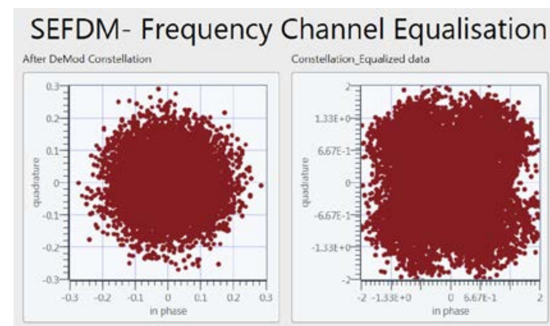


Figure 2. Symbol Decoding Before and After Channel Equalization

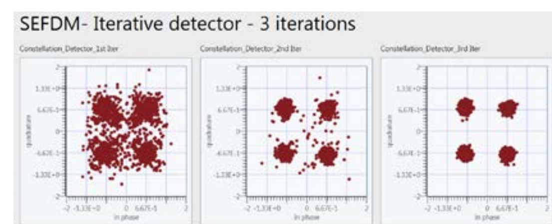


Figure 3. Symbol Decoding After Iterative Detection

"We have been developing the SEFDM communication system for over a decade. The flexibility and ease of use of USRP devices and the collaboration with NI allowed us to examine SEFDM in realistic environments and report the world's first over-the-air transmission. Our designs and software are available to the NI user community to experiment and hopefully innovate with these signals."

Professor Izzat Darwazeh, Director of the UCL Institute of Communications and Connected Systems, London-UK

World-Leading Parallel Channel Sounder Platform

www.wise.sh
www.sim.ac.cn

Building 64x64 MIMO Parallel Channel Sounder Hardware Based on the CDMA Method Using NI PXI Modular Instruments and Post-Processing Software

Haowen Wang and Dr. Yang Yang, Shanghai Research Center for Wireless Communications

USER PROFILE

Haowen Wang is a senior engineer at the Shanghai Research Center for Wireless Communications (WiCO). He received bachelor's and master's degrees in computing and software from Fudan University in Shanghai in the People's Republic of China. As a LabVIEW champion, he has more than 13 years of LabVIEW development experience. His interests include RF data acquisition, channel measurement, and verification and test solutions.

Gui Yunsong is a senior system engineer at the Shanghai Institute of Microsystem and Information Technology (Chinese Academy of Sciences). He has worked as a senior baseband algorithm engineer in Huawei for many years. He has 15 years of experience in wireless communication system design. In recent years, his research has focused on 5G communication demo system design using the SDR platform.

THE CHALLENGE

As the number of transmitting and receiving antennas increases, it is crucial that we capture dynamic channel characteristics and develop realistic channel models to achieve spectrum and energy efficient design (SEED) objectives in future wireless networks. This difficult task includes:

- Picosecond-level synchronization across multiple channels
- Real-time storage of multiple raw channels of measurement data
- High-speed parallel calibration methods to compensate for nonideal channel responses
- High-accuracy channel parameter estimations based on aliasing MIMO channel signals

Figure 1. MIMO Parallel Channel Sounder Platform

THE SOLUTION

We developed our parallel channel sounder platform using NI products for sub-6 GHz spectrum and millimeter wave. It supports 8x8 paths (can be extended to 64x64) and 200 MHz/ch bandwidth under sub-6 GHz and supports 2x2 and 2 GHz/ch bandwidth at the millimeter-wave band. Our platform addresses the above challenges with the following features:

- **Picosecond-level synchronization**—To achieve accurate AoA/DoA estimation, we designed a synchronization method to limit misalignment across all TX/RX channels to around a 30 ps reference like NI-TClk technology.
- **51.2 Gbps parallel data streaming**—Our DMA-FIFO-based data-streaming method can take advantage of the huge bandwidth of the backplane bus and use zero-copy technology to effectively reduce delay by avoiding extra copies and state transitions.
- **High-speed calibration method**—Different from traditional methods, our MIMO calibration can quickly achieve a MIMO RF channel's response by transmitting a PN sequence through a MIMO coupler, whose frequency response is measured before, separating at the receiver side only once.
- www.wise.sh—We set up an online shared open channel measurement database for research. It features all the data measured by the parallel channel sounder platform.

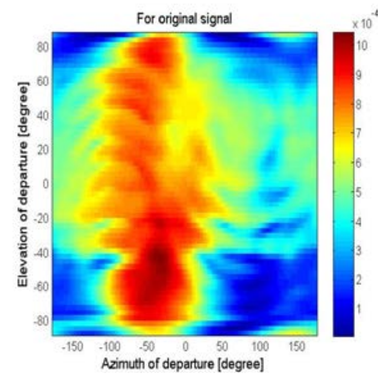
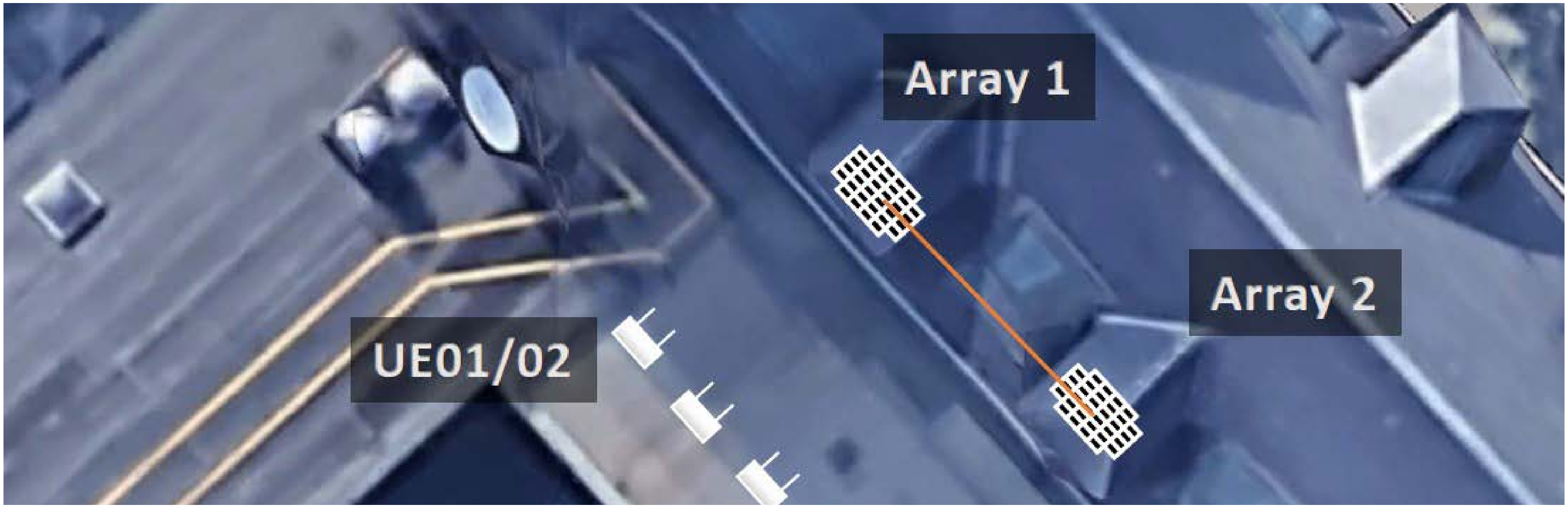


Figure 2. Calibration Verification in Space Domain Parallel SAGE Algorithm

WHAT'S NEXT

In terms of software, we will finish verifying estimation results by comparing the results from measurement with ray-tracing software. In terms of the sounder platform, we will extend the system to 64x64 channels under sub-6 GHz and extend to a 110 GHz channel sounder at the millimeter-wave band.



Distributed Massive MIMO: Algorithm for TDD Reciprocity Calibration

Liesbet Van der Perre, Guy A. E. Vandenbosch, and Sofie Pollin, Professors; Cheng-Ming Chen and Andrea P. Guevara, PhD Researchers; and Vladimir Volskiy, Postdoctoral Researcher, Networked Systems Group, KU Leuven

KU LEUVEN

NETWORKED SYSTEMS

www.esat.kuleuven.be/telemic/research/NetworkedSystems

Read the Entire Research Paper

USER PROFILE

Cheng-Ming Chen received his master's degree from GICE in NTU, Taiwan, in 2006. He has worked as a baseband design engineer for WiMAX and LTE in ITRI and a senior system design engineer at BRCM, where he mainly focused on Wi-Fi receiver performance verification. He is a doctoral candidate at KU Leuven investigating real-world propagation characteristics of distributed Massive MIMO with an NI testbed.

Dr. Sofie Pollin obtained her doctorate at KU Leuven in 2006. She returned to imec to become a principal scientist in the green radio team in 2008. In, 2012, she became an assistant professor in the electrical engineering department at KU Leuven. Pollin researches networked systems that require networks that are more dense, heterogeneous, battery powered, and spectrum constrained.

THE CHALLENGE

We need a large-scale Massive MIMO channel model. We know that distributed Massive MIMO exploits diversity more efficiently and can potentially offer much higher probability of coverage, but we still face the challenges of backhaul, synchronization, and time division duplex (TDD) reciprocity calibration. Our work focuses on an algorithm to improve TDD reciprocity calibration for equally distributed collocated arrays.

THE SOLUTION

We created the distributed systems by connecting our two 32-antenna testbeds to the main chassis with a 10 m optical fiber cable using NI USRP RIO, LabVIEW Communications Systems Design Suite, and MIMO Application Framework. We can use the hierarchical-based calibration method to address the huge dynamic range between the channel gain of intra subarrays and inter subarrays. To increase diversity and array gain during intercluster calibration, we can apply maximum ratio combining and maximum ratio transmission. Therefore, unlike when using the conventional method, we can collect all multiple input single output (MISO) gain in one shot during intercluster calibration. We can use distributed antenna arrays to help decorrelate closely collocated users in both LoS and NLoS scenarios.

WHAT'S NEXT

We want to emulate the pilot contamination effect using two cells that share the spectrum. Based on the channel characteristics, we can efficiently assign pilots in two virtual cells and reduce pilot contamination. We can also use frame structure modification to reduce pilot contamination. With the virtual two-cell testbed, we can evaluate the performance in the real world.

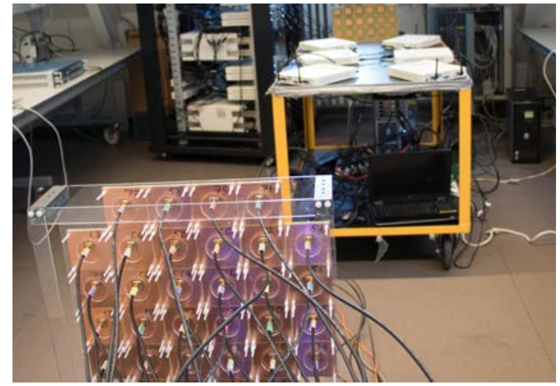


Figure 1. Indoor Channel Characteristics for Closely Located Users With Distributed Massive MIMO

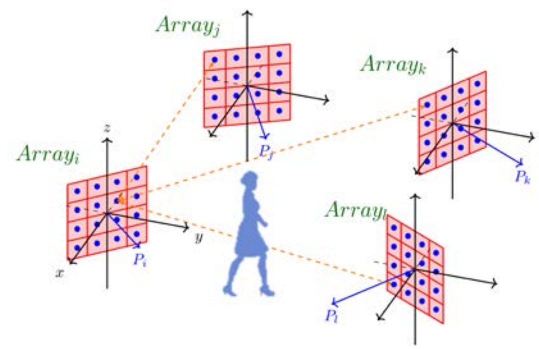
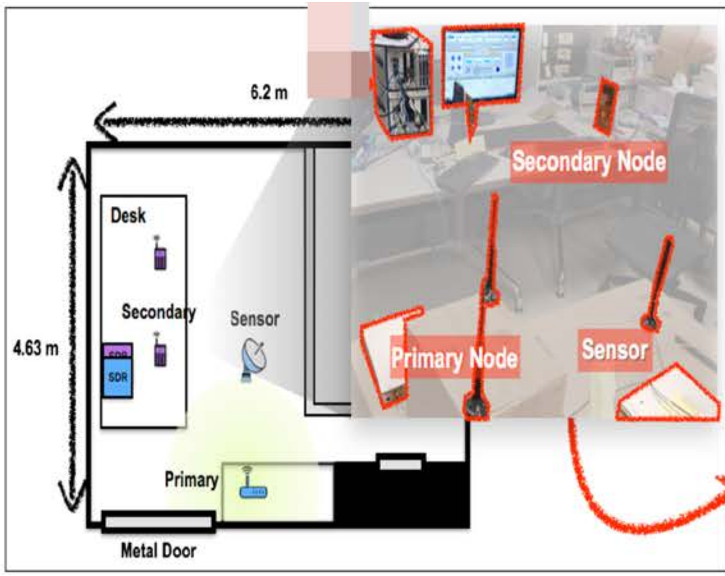
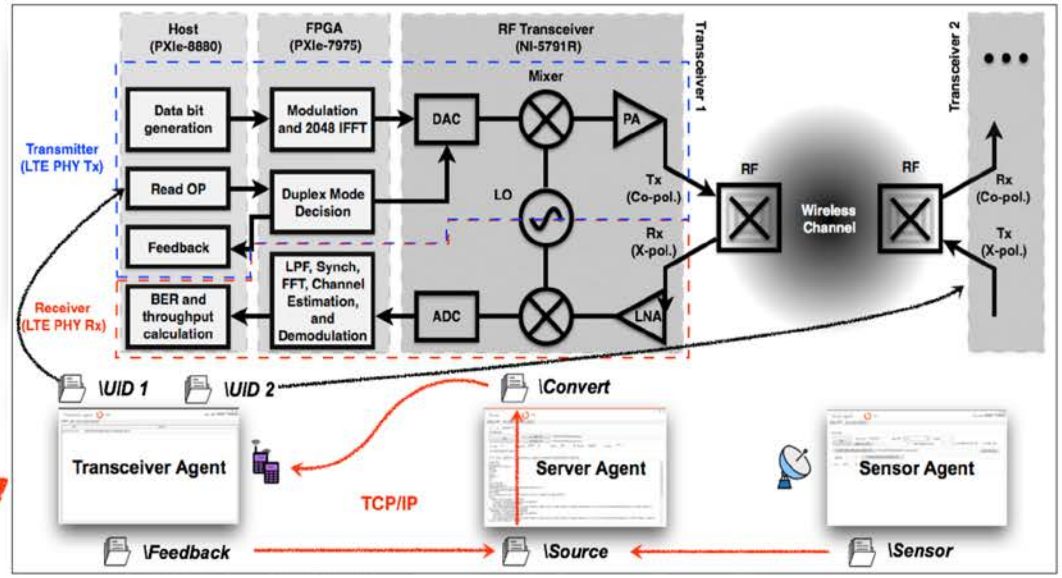


Figure 2. Distributed Massive MIMO TDD Reciprocity Calibration: Fading, Shadowing, and Gain Difference Between Intra and Inter Cells

"KU Leuven is the first research institute to distribute a real-world Massive MIMO testbed. By doing this, researchers dig into the potential that macrodiversity gain provides by using a distributed system to increase system capacity."

Dr. Sofie Pollin, Networked Systems Group, KU Leuven





Wideband/Opportunistic Map-Based Full-Duplex Radios

YONSEI UNIVERSITY

www.cbchae.org

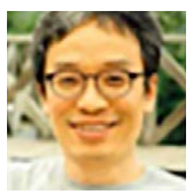
Using Spectrum/Spatial Sensing-Based Wideband Full-Duplex Radios and Opportunistic MAP-Based Flexible Hybrid-Duplex Systems in Network Sharing

Soo-Min Kim, Dr. Seong-Lyun Kim, and Dr. Chan-Byoung Chae, Yonsei University

Read the Entire Research Paper

USER PROFILE

Soo-Min Kim is a doctoral student at Yonsei University in Seoul, Korea. His research interests are prototyping algorithms and real-time software defined radio architectures of next-generation wireless communication networks. Kim was awarded a full scholarship from the Korean government's Ministry of Science, ICT and Future Planning (MSIP).



Dr. Seong-Lyun Kim* is a professor of wireless networks in the School of Electrical and Electronic Engineering at Yonsei University. He manages the Radio Resource Management and Optimization Laboratory and the Center for Flexible Radio. He was an assistant professor of radio communication systems in the Department of Signals, Sensors, and Systems at the Royal Institute of Technology in Stockholm, Sweden.

Dr. Chan-Byoung Chae is the Underwood Distinguished Professor at Yonsei University. He was a visiting associate professor at Stanford University in 2017. Before joining Yonsei, he was with Bell Laboratories, Alcatel-Lucent from 2009 to 2011. He was a postdoctoral research fellow at Harvard University from 2008 to 2009 after earning his doctorate in electrical and computer engineering from The University of Texas at Austin in 2008.

*This case study features joint work with Dr. Seong-Lyun Kim at Yonsei University.

THE CHALLENGE

We tried to alleviate the spectrum crunch by canceling out self-interference, optimizing pilot patterns and synchronization, and defining proper decisions based on an opportunistic map (OP MAP).

THE SOLUTION

We created the first implementation of OP MAP-based flexible hybrid-duplex systems in sensor-aided cognitive radio networks to maximize system throughput and spectral efficiency. It offers stochastic geometry-based OP MAP calculation with LTE-based full- and half-duplex radios based on the LabVIEW Communications LTE Application Framework.

SYSTEM SCENARIO

The system features a sensor-aided mode, specifically for Internet of Things (IoT) applications, based on device-to-device (D2D) communications. We can use a full-duplex technique to enable more efficient network sharing. We also can conduct testbed experiments indoors and network simulations for outdoor scenarios. The system uses one sensor-based opportunistic algorithm with random MAC decision making.

SYSTEM ARCHITECTURE

The system architecture is designed to sense the interference level at a sensor's location. It converts the sensing database to an OP MAP to determine whether to transmit the signal. It distributes the OP MAP from the server to secondary nodes to allow the operation of hybrid-duplex radios (full-duplex, half-duplex, and silence modes).

WHAT'S NEXT

Now we are enlarging our algorithm to make a more practical implementation that can manage multiple users with full-duplex radios. Also, we are applying it to wideband matters to achieve high system throughput and verifying results by comparing it with 3D ray-tracing software.

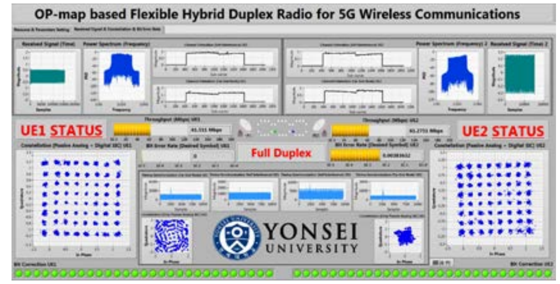


Figure 1. Block Diagram of Our Proposed Platform

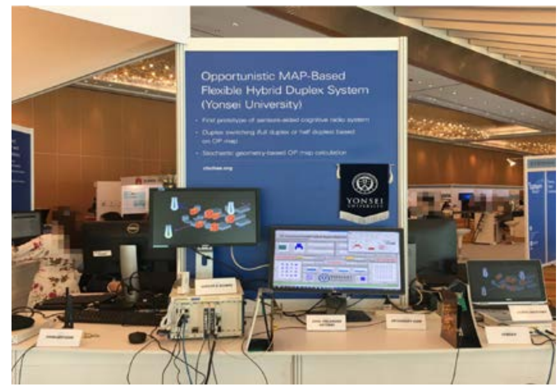


Figure 2. Real-Time Demonstration at IEEE Globecom in Singapore in December 2017

> "Yonsei started implementation research in 2012, and now we have actively been working on several topics such as full-duplex radios, waveform generation, a lens antenna-based mmWave platform, and machine learning-based 5G/6G systems. We believe that what we do here using NI platforms can change 5G/6G worlds."

Soo-Min Kim and Dr. Chan-Byoung Chae, Yonsei University

An Experimental SDR Platform for In-Band D2D Communications in 5G

Max Engelhardt and Dr. Arash Asadi, Technische Universität Darmstadt

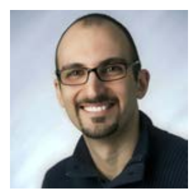
SECURE MOBILE NETWORKING

seemoo.tu-darmstadt.de

Read the Entire Research Paper

USER PROFILE

Max Engelhardt holds a master's degree in IT security from Technische Universität Darmstadt in Germany. He works as a student assistant at the Secure Mobile Networking Lab (SEEMOO). His research interests include security in wireless networks, 5G cellular networking, device-to-device (D2D) communication techniques, and software defined radio (SDR) prototyping.



Dr. Arash Asadi received his doctorate in telematics engineering from Carlos III University of Madrid (UC3M) in 2016. He joined SEEMOO at Technische Universität Darmstadt in March 2016 as a postdoctoral researcher. His research interests include 5G cellular networking, millimeter-wave communication, D2D communication techniques, and SDR prototyping.

THE CHALLENGE

D2D communications has been shown to significantly improve spectral and energy efficiency in cellular networks; thus, it is considered a key feature in forthcoming 5G networks. Despite growing research interest on this topic, academia is still lacking important tools to evaluate and further explore the potential of D2D communications under realistic conditions. This is especially true for in-band D2D communications, for which the D2D link must use licensed cellular frequencies.

THE SOLUTION

We based our experimental SDR platform on the NI USRP RIOs and LabVIEW Communications LTE Application Framework, which we extended to allow one eNodeB to serve multiple user equipment (UE) devices simultaneously using orthogonal frequency division multiplexing access (OFDMA). We further extended the framework's UE design to feature multiple OFDMA-multiplexed uplink transmissions and an uplink receiver. These extensions enabled us to use part of the uplink spectrum for a D2D channel between UE devices. Our system can operate in one of two modes. In Legacy Downlink Mode, the eNodeB transmits each UE device's payload data directly to the respective UE. In D2D Relay Mode, it sends both UE devices' payload data to the UE device with the better downlink channel, which then relays the other UE device's payload via the D2D channel. Our eNodeB features a lightweight, quality-aware scheduler that allows dynamic switching between the two modes based on reported channel qualities.

WHAT'S NEXT

To further improve our platform, we are exploring the integration of outband frequency bands into our system and decentralized scheduling approaches, during which UE devices can organize D2D transmission in the absence of cellular infrastructure.

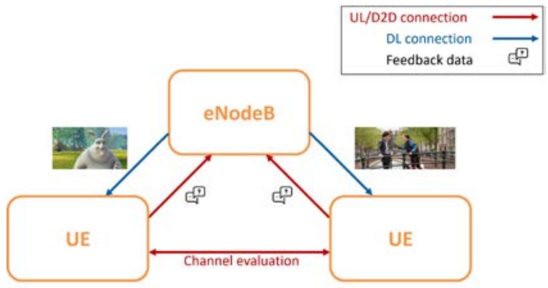


Figure 1. In Legacy Downlink Mode, each UE device receives its payload directly via the downlink channel.

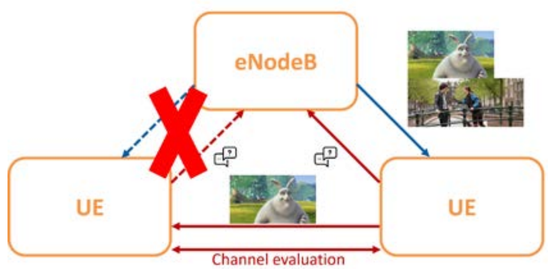
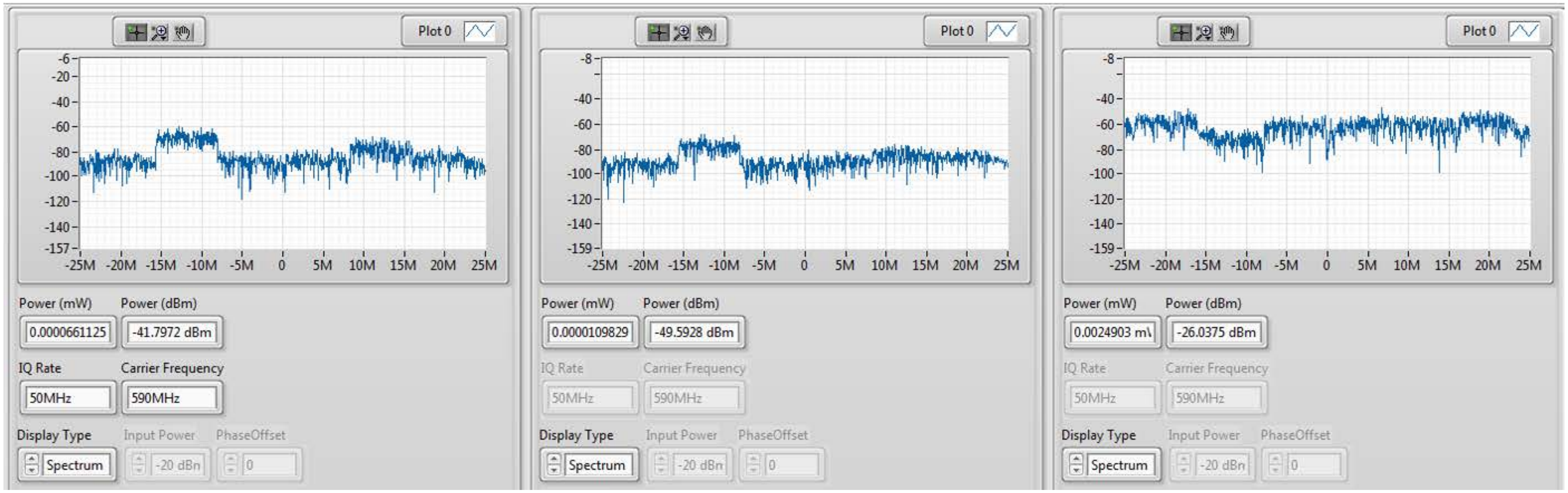


Figure 2. In D2D Relay Mode, the UE device with the better downlink channel handles both UE devices' traffic by relaying the other UE device's payload data via the D2D channel.

"National Instruments' LabVIEW platform definitely accelerates SDR prototyping, but so do many other SDR platforms. What differentiates National Instruments from others is the support given for our new ideas by the team, including R&D. The support is priceless for researchers exploring beyond the limits of today's technology."

Dr. Arash Asadi, Technische Universität Darmstadt



Wideband Multi-channel Signal Recorder for Radar Applications

Warsaw University of Technology

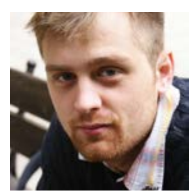
www.elka.pw.edu.pl/

Achieving Multisite Synchronous and Coherent RF Signal Acquisition and Recording With a LabVIEW Application When Synchronized to a GPS Time Reference

Bartosz Dzikowski, Marcin Baczyk, Łukasz Maślikowski, and Jedrzej Drozdowicz, Institute of Electronic Systems, Warsaw University of Technology

USER PROFILE

Bartosz Dzikowski received his Dipl. Ing. degree in technical physics from Nicolaus Copernicus University in Toruń, Poland, in 2013, and his master's degree from the Warsaw University of Technology in 2016. He is a LabVIEW developer and a doctoral student at the Warsaw University of Technology.



Marcin Kamil Baczyk obtained his master's degree in 2011 from the Faculty of Electronics and Information Technology at the Warsaw University of Technology. His research interests include digital signal processing for radar and radar experiments carried out both in the laboratory and outdoors, including ground-scattering measurements. He works on inverse synthetic aperture radars, passive radar, and radar tomography.

THE CHALLENGE

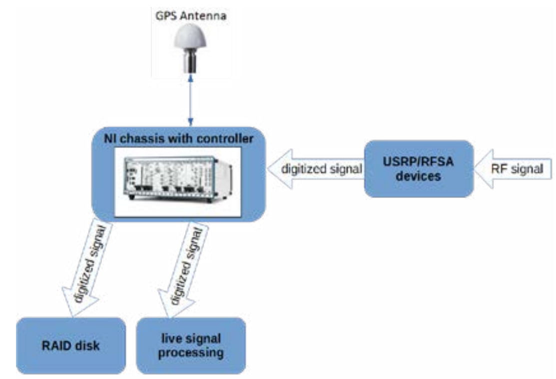
To conduct radar research, we needed to acquire RF signals coherently from multiple channels. We also had to know how to stream that acquired data to disk for offline analysis or implement online live processing, which involves handling gigabytes of data per second. In applications like multistatic radars, we needed a multisite and coherent RF recording not only to synchronize channels at one site but also to synchronize channels and provide high-phase stability across different sites that can spread over many kilometers.

THE SOLUTION

We developed the wideband multichannel signal recorder, which is a LabVIEW application that coherently acquires RF signals from NI devices. The recorder provides waveform streaming to a RAID disk and enables us to preview signals and their spectra before and during the acquisition. It supports up to 10 measurement channels of NI-RFSA or NI-USRP devices. When we use NI PXIe-6674T (timing) and PXIe-6683H (GPS) modules, we can synchronize the measurement system to the GPS time reference and trigger it precisely at a given time. This allows multisite synchronous and coherent RF recording, which is particularly important in multistatic radar research. Moreover, the application works with the NI-PXImc driver software interface, which allows online data streaming to a processing unit and implementing a real-time radar. NI hardware and our LabVIEW recorder make building a radar faster, cheaper, and easier.

WHAT'S NEXT

Users can create their own measurement scenarios, implement a processing procedure to create an online radar, or stream recorded waveform to a RAID disk and analyze it offline. In the future, more acquisition devices will be supported to increase bandwidth and offer a range of possibilities.



System Scheme




Passive and Active Radar Imaging

Designing and Testing Passive and Active Synthetic Aperture Radar (SAR) Demonstrators With NI Software Defined Radio (SDR) Hardware

Damian Gromek, Dr. Piotr Samczynski, Piotr Krysik, and Krzysztof Kulpa, Research Lab on Radar Techniques, Institute of Electronic Systems, Warsaw University of Technology

Warsaw University of Technology

www.elka.pw.edu.pl/

Read the Entire Research Paper

USER PROFILE

Damian Gromek received his master's degree in electronics from the Warsaw University of Technology in Poland in 2011 and has been a doctoral candidate there ever since. He is working as a research assistant, and his research interests are radar signal processing, active and passive SAR, and passive radar.

Dr. Piotr Samczynski received his bachelor's and master's degrees in electronics and doctorate degrees in telecommunications all from the Warsaw University of Technology. Dr. Samczynski's research interests are in the areas of radar signal processing, passive radar, synthetic aperture radar and digital signal processing.

THE CHALLENGE

We needed to design and test innovative active and passive SAR demonstrators in a short amount of time. SAR allows us to obtain a 2D image of the ground landscape. The classical SARs are active radars, which illuminate the targets using their own transmitters. The new trend in radiolocation is passive radar technology, which uses an existing net of transmitters of opportunity to illuminate the target for imaging purposes.

THE SOLUTION

By combining NI SDR hardware with commercial off-the-shelf (COTS), we could quickly design and test active and passive radars. During our research, we tested both passive and active SAR imaging technologies. In both solutions, we built the demonstrators using NI USRP hardware. We built an active radar as a frequency modulated continuous wave (FMCW) radar. In this solution, one Tx channel emits signals and the second Rx channel receives radar echoes. This results in a 2D image of the ground landscape. In the second, passive radar solution, the USRP uses only the Rx channels of USRP devices to collect reference signals from DVB-T transmitters of opportunity, and we used surveillance signals reflected from targets. We've validated both demonstrators in real conditions using an airborne platform as a radar carrier.

WHAT'S NEXT

The higher bandwidth of the generated signal gives the higher range resolution; therefore, the solutions with 1 GHz and higher bandwidths are most interesting. In addition, we're interested in the higher bands for active radars (for example, X and K bands).

Figure 1. Airborne Active SAR Image

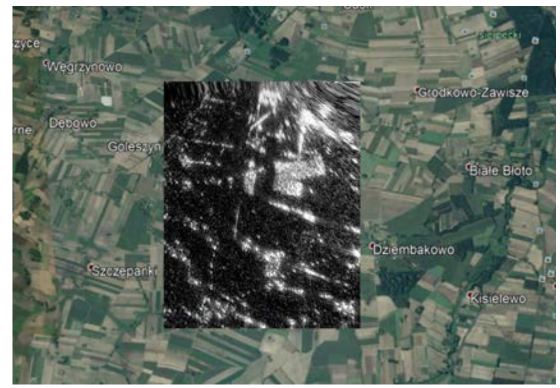


Figure 2. Airborne DVB-T Transmitter-Based Passive SAR Image

Multiantenna Technology for Reliable Wireless Communication

AALBORG UNIVERSITY
DENMARK

www.es.aau.dk/

Comparing Multiantenna Techniques for V2X and UAV Communications Using Live LTE Network Signals Recorded by a USRP-Based Channel Sounding Measurement Setup

Madalina C. Bucur, Tomasz Izydorczyk, Dr. Fernando M.L. Tavares, Carles Navarro-Manchon, Gilberto Berardinelli, and Preben Mogensen, Wireless Communication Networks Section (WCN), Department of Electronic Systems, Aalborg University

USER PROFILE

Dr. Fernando M.L. Tavares received his master's degree from the University of Brasilia in Brazil and his doctorate degree from Aalborg University in Denmark. Both degrees focused on wireless communications. He is an assistant professor at the WCN at Aalborg University and visiting researcher at Nokia Bell Labs Denmark. His research interests include MIMO, interference management, and advanced transceiver design.

Tomasz Izydorczyk received his master's degree in mobile communications from Telecom-ParisTech/Eurecom. His thesis focused on unlicensed spectrum extensions for NB-IoT. In 2016, he was a research intern with Intel Mobile Communications. He is pursuing a doctorate degree supervised by Preben Mogensen at Aalborg University. His research interests include the potential use of MIMO techniques for URLLC and UAV communications.

THE CHALLENGE

Multiantenna signal combining techniques like minimum mean square error (MMSE) improve signal reception performance, but they don't work well in highly interfered scenarios. Alternatively, multiantenna receivers estimating the direction of arrival (DOA) of incoming signals can tell the difference between desired and interfering contributions, which enables efficient beam steering toward the intended direction(s). The emergence of new use cases for vehicular communication presents new opportunities to exploit advanced multiantenna techniques on the user equipment (UE) side. We aimed to experimentally validate the potential of such techniques for vehicle and drone use cases.

THE SOLUTION

We designed a USRP-based channel sounding measurement setup (Figure 1) with a 16-antenna circular array to estimate the spatial characteristics of the radio channel. We used it for measurements in a variety of vehicular scenarios (for V2X, the equipment was installed on a van; for UAV, it was lifted up 40 m high by a crane). The setup was designed to estimate the DOA of live LTE signals so we could derive the spatial distribution of intercell interference in a real LTE network. The measurement methodology consisted of recording I/Q samples and post-processing them to extract the cell-specific reference symbols (CRS) from the LTE time-frequency grid. Then we used the channel estimates to approximate multipath components (direction, power, and delay) from desired and interfering signals using algorithms such as MUSIC and SAGE.

WHAT'S NEXT

We will compare beamforming techniques (digital/analog) with multiantenna signal combining solutions. Then we will use that set of measurements to derive the statistical information for the spatial interference distribution. The goal is assessing the effective benefits of large antenna arrays on the UE side in real scenarios.

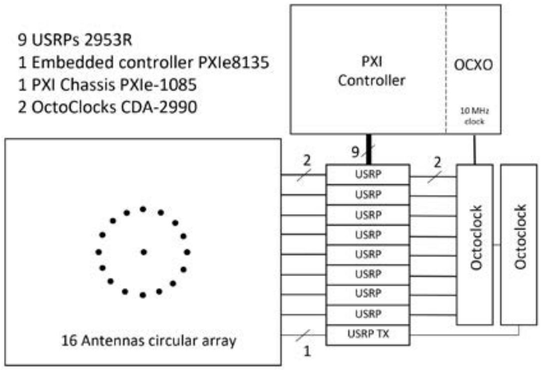


Figure 1. Measurement Setup Schematic

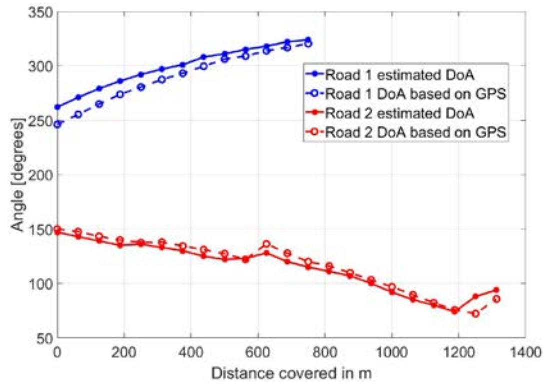
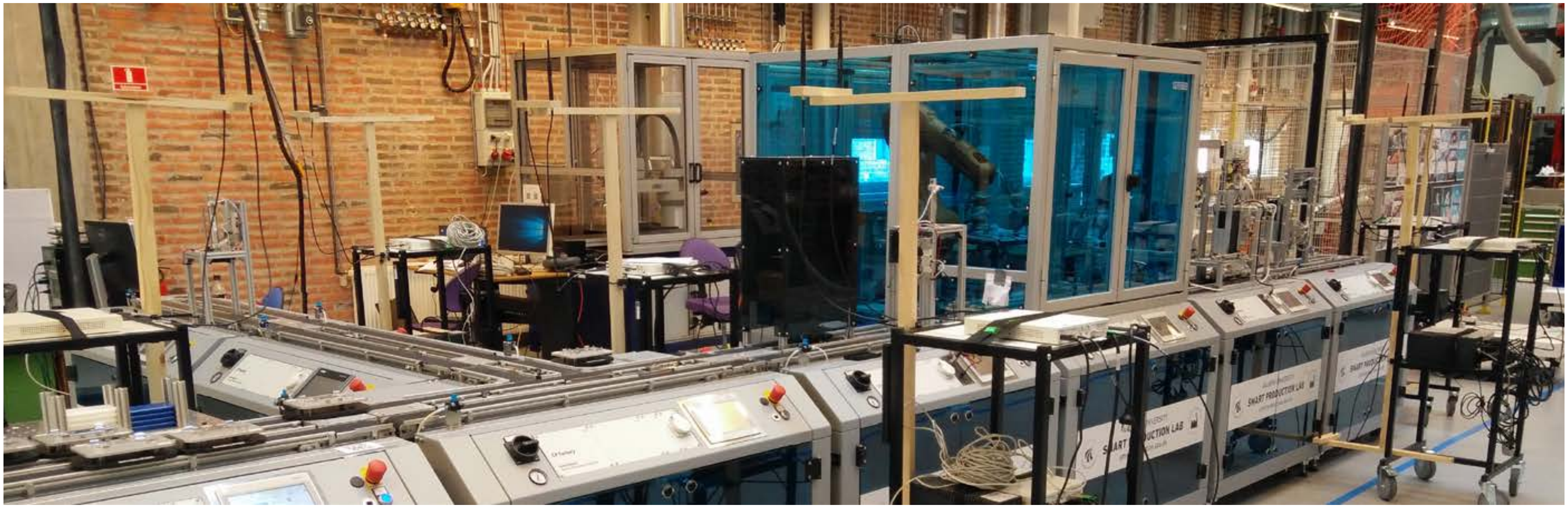


Figure 2. DOA Estimation (Preliminary Drive Test)

> "Novel experimental research to test beamforming techniques for new use cases is very important for the development of future UAV and V2X products and mobile services. The unique method proposed by Aalborg University is an interesting new strategy that complements simulation studies with empirical data from unpredictable real-life network conditions."

István Z. Kovács, Wireless Networks Specialist, Nokia Bell Labs



Radio Propagation Analysis for the Factories of the Future

Analyzing the Lower Percentiles of Radio Channel Statistics (Ultra-Reliable Regime) With Limited Effort Using Multinode Multiantenna Channel Sounding

Dereje A. Wassie, Emil J. Khatib, Dr. Ignacio Rodriguez-Larrad, Gilberto Berardinelli, Troels B. Sørensen, and Preben Mogensen, Wireless Communication Networks Section (WCN), Department of Electronic Systems, Aalborg University

AALBORG UNIVERSITY
DENMARK

www.es.aau.dk/

USER PROFILE

Dereje Assefa Wassie received his bachelor's degree in electrical engineering from Jimma University in Ethiopia and his master's degree in telecommunication engineering from Aalborg University in Denmark. He is pursuing a doctorate degree in wireless communication from the Department of Electronic Systems at Aalborg University. His research interests include measurement system design and the experimental analysis of 5G communication concepts.

Dr. Ignacio Rodriguez-Larrad received his doctorate degree in wireless communications from Aalborg University. He is a postdoctoral researcher at the same institution, working in close collaboration with Nokia Bell Labs. His main research interests are radio propagation, channel modeling, ultra-reliable and low-latency communications, and industrial IoT. He is a corecipient of the 2017 IEEE VTS Neal Shepherd Memorial Award.

THE CHALLENGE

The Fourth Industrial Revolution aims to make factories smart by coordinating disparate cyber-physical systems. Wireless technologies (key enablers for flexibility, cost reduction, and mobility in the factories of the future) must therefore provide reliable communication among the different agents. Because industrial environments are complex radio propagation scenarios, predicting the performance of wireless systems requires measurement campaigns that are extensive enough to capture rare events in the tails of the channel statistics (ultra-reliable regime).

THE SOLUTION

We developed a channel sounding testbed using NI hardware (USRP-2953) and LabVIEW software. The testbed was composed of 12 transceiver nodes with 4x4 MIMO capabilities. With a TDMA transmission scheme, we measured the channel responses between all the testbed nodes at 2.3 GHz and 5.7 GHz carrier frequencies using 24 MHz wideband sounding signals. By performing only a few redeployments, we acquired many spatially relevant samples with limited effort. For example, covering all possible combinations over 24 spatial positions, which takes six redeployments and approximately three hours, we obtained a total of 24 x 23 x 16 = 8832 independent radio link samples. With this number of samples, we obtained insights on the channel statistics close to the 10-4 percentile, which is representative of the 99.99 percent of spatial availability.

WHAT'S NEXT

We will perform more measurements in industrial scenarios. Because we designed the testbed to be flexible, these new measurements can encompass different frequencies, different antenna configurations, and different frame structures for the TDMA transmission. Furthermore, we are developing additional features for experimental verification of envisioned 5G technology components within the H2020 ONE5G project.

Figure 1. Overview of Node Setup and Measurement Plan

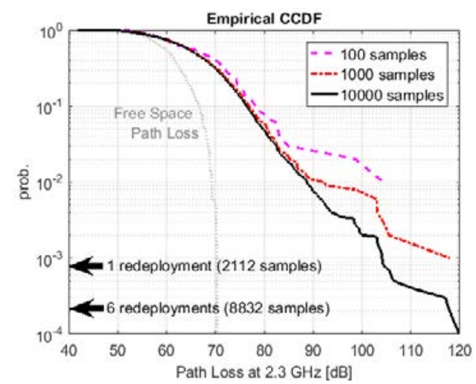


Figure 2. Smart Production Lab Measurement Results

"Experimental radio propagation research in industrial environments is a timely and important topic for understanding and designing future wireless solutions for the Fourth Industrial Revolution (as presented in this study). Understanding the tails of the radio propagation distributions down to the very low probability levels will be particularly important for designing wireless systems to offer ultra-reliable low-latency communication solutions for which even rare events are important."

Klaus I. Pedersen, Radio Research Team Leader, Nokia Bell Labs

Shared Software Communications Resource Hub

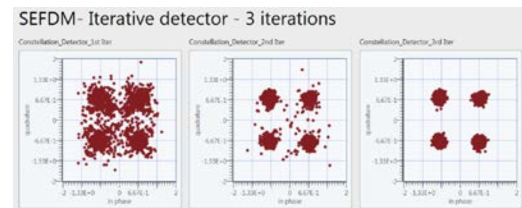
Maximizing Value and Productivity: Application Examples

Leading researchers from around the world have offered free, downloadable code to the public. Because of this, developing applications no longer requires months of work. Access these application examples and begin building your wireless communications applications using NI software defined radio solutions.

KU Leuven, a leading wireless network systems research group led by Dr. Sofie Pollin, is focused on developing applications for heterogeneous, battery-powered, and spectrum-constrained wireless networks. The software has been used to implement in-band full-duplex communications with CSMA/CD.

Download the Free LabVIEW Code

University College London, a leading communications and connected systems research group led by Dr. Izzat Darwazeh, is focused on developing applications for spectrally efficient frequency division multiplexing (SEFDM) communications. The software has been used to implement SEFDM with compressed bandwidth.



Download the Free LabVIEW Code

TU Darmstadt, a leading research group in the Secure Mobile Networking Lab led by Dr. Arash Asadi, is focused on developing applications for in-band device-to-device (D2D) communications. The software has been used to add multi-UE support for the LabVIEW Communications LTE Application Framework as well as D2D communications.

Download the Free LabVIEW Code

LabVIEW Communication System Design Suite includes next-generation LabVIEW packaged with relevant add-ons specifically created to help you rapidly develop, prototype, and deploy wireless communications systems with software defined radio (SDR) hardware.

Try 1 Month Free