NIST Activities in Wireless Coexistence

Communications Technology Laboratory
National Institute of Standards and Technology
Bill Young\(^1\), Jason Coder\(^2\), Dan Kuester, and Yao Ma

\(^1\)william.young@nist.gov, 303-497-3471
\(^2\)jason.coder@nist.gov, 303-497-4670
Wireless technologies sharing spectrum

• Multiple technologies in the same ISM bands
  • 900 MHz, 2.4 GHz, and 5 GHz
  • Standards based: IEEE 802.11, IEEE 802.15.4, etc.
  • Non-standards based: Radio-Frequency Personal Alert Safety Systems (RF PASS)
  • Standards under modification: LTE in the ISM band (LAA-LTE) [1]
  • Emerging applications: Body Area Networks (BANs), Smart Meters, etc.
  • New approaches to spectrum access: 3.5 GHz tiered access [2]
  • The Bring Your Own Device (BYOD) trend

What we mean by coexistence metrology

• Coexistence: “The ability of two or more spectrum-dependent devices or networks to operate without harmful interference.”[3]

• From the C63.27 Working Group on coexistence
  • Functional coexistence: the ability of the target of evaluation (ToE) to successfully perform its intended functions in the presence of other RF devices and other users of spectrum
  • Inhibitive coexistence: the potential of a ToE to inhibit the successful functioning of other users of spectrum

• Coexistence metrology: measurement of the mutual interaction and correlated impacts between multiple, heterogeneous communication systems.

Evaluating spectrum sharing algorithms

• How do we know a spectrum sharing algorithm is efficient?
• Will the algorithm be able to operate in the presence of other technologies?
• There is a growing need to answer such questions.
  • Rigorous testing methods are required
  • Numerical/Analytical testing
  • Radiated verification
Interference/coexistence impacts from complex modulated signals

• LTE interference example
  • LTE signal interfering with cable modems
  • LTE waveforms depend on the source block usage
  • Generate significantly different spectrum and corresponding impacts on the ToE

• Research focus
  • Generalize a waveform that covers the range of conditions

Voice LTE time plan over

20 MHz time plan for LTE
Impact of complex/modulated signals

• Using a direct-injection setup, we evaluated the impact of different signals on the same device, in the same configuration.
  • 20 MHz LTE, 10 MHz LTE both fully allocated
  • 10 MHz VoLTE-like signal
  • 61000-4-3 AM signal
• Device is looking at a single 6 MHz channel with the same center frequency.
• What characteristics of the signal are causing this behavior?
• Can we develop a generic signal for interference testing?
Research Ideas

• KPI – throughput, EVM, latency, jitter, BER, TOC (threshold of communication).
• Coexistence metrics -- POI (probability of interference),
• SIR (signal-to-interference ratio) sensitivity of DUT.
• CGD (cumulative gain distribution) – distribution of combined gain of antennas and channel.
Support ANSI C63.27 standardization effort and T&E
• Design analytical process to derive POI from measurement data
• Uncertainty analysis
Meeting the challenge of coexistence

• Collect information on real-world scenarios
  • Statistics on spectrum usage in the local deployment environment
  • Quality and comparability of data is critical

• Test and validate performance
  • Need relevant performance metrics
  • Inclusion of non-standard protocols via arbitrary RF waveforms

• Initial protocol design
  • Parameters set so that different, uncoordinated protocols minimize impact on each other
  • Required in IEEE wireless protocol development
RF environment of deployment must be understood

- Basic propagation behavior
  - Multipath and attenuation
  - Frequency dependence of building penetration

- Density of wireless devices
  - Number of items in the room, on the body, etc.
  - Network configurations e.g., ultra-dense networks [4]

- Spectrum activity
  - Power levels
  - Duty cycles

Research and develop a calibrated distributed spectrum monitoring system

• Collect RF environment data for coexistence test development

• Localized monitoring granularity
  • In-building, power plant, hospital room, stadium, etc.

• Supports 3.5 GHz tiered licensing research

Spectrum monitoring in a manufacturing facility - within the building and penetration into the building

wireless spectrum sensor
Key considerations in distributed spectrum monitoring system

• Type of data collected
  • Usage statistics based on power, channel occupancy, etc.
• Transceiver performance
  • Calibration, cost, density of distribution
• Relative timing between collection nodes
• Antenna or probe
  • Antenna impacts on measured quantity
  • Field probe versus antenna to obtain more fundamental values
Wireless Forensics: A Critical Component to Successful Spectrum Sharing

• Ability to share spectrum relies on “good neighbors”
• Adherence or enforcement of rules required for confidence in spectrum sharing approaches
• NIST research effort: Develop a set of metrology and analysis tools for wireless forensics
  • Collect spectrum data with a heterogeneous, distributed sensor network
    • Various cost and capability levels
    • Likely need to be self-organizing, dynamic in nature
  • Perform rapid signal deconstruction and localization
Testing a Spectrum Monitoring Network

• Spectrum monitoring system response tests are critical abutting incumbent use: the exclusion zone along coasts
• Need a mobile test platform to emulate radar from different points at sea
• Need to transmit *surrogate* radar test waveforms

UAV Test Platform Research

Capability goals:
• Fast, repeatable positioning in 3 dimensions
• Transmit calibrated, predesigned 3.5 GHz test waveforms
• Fly along coast - over water if needed
• Test spectrum monitoring system response
Implications of MIMO Technology on Coexistence

• Several different flavors to MIMO to consider
  • Simple 2-4 antenna element configurations
    • Relatively easy to support on user equipment
  • Multiple users of a single antenna array
    • Simultaneous transmission to multiple users
    • Large number of elements not necessarily required
    • Referred to as Multi-User MIMO (MU-MIMO)
  • Massive MIMO
    • Large number of antenna elements
    • Multiple propagation paths optimized to a point in a cluttered space, e.g., urban street.
  • No longer a simple point-to-point transmission path
Investigate the implications of MIMO on coexistence metrology

- Density of antenna elements affects the grating lobes, interference, and channel state information
- Multiple beams and users requires a more complex characterization of the interference source than an omni-directional pattern
- Antenna considerations beyond basic gain patterns need to evaluate the systems coexistence performance
MIMO coexistence testing

• Key architecture in recent and emerging communication systems, e.g., IEEE 802.11n, ac.

• MIMO systems utilizes the complex RF propagation environment to improve the robustness of the communication link
  • Diversity transmission and reception
  • Multiple uncorrelated communication channels between transmitter and receiver
  • Interference suppression in MU-MIMO

• Testing and analysis should incorporate the benefits of MIMO technology.
New Laboratory Facilities (opening Q2 2016)

• Large semi-anechoic chamber (~40’x23’x20’) with unique capabilities
  • Can convert into a fully anechoic chamber
  • Can obscure absorber with conductive fabric to create multipath conditions and simulate real-world environments
  • Optimized design enabling quality measurements throughout the volume
• Access to fully operational LTE network via node located in lab
  • Fiber link to LTE network core maintained by PSCR
  • Ability to test non-standard LTE frequencies and network configurations
• Full suite of MIMO capable transmit, receive, and analysis hardware
  • Arbitrary waveform generation, complex signal/protocol analysis
  • Capable of analyzing multiple independent networks (e.g., LTE and Wi-Fi or radar)
• Co-located reverberation chamber
  • Enables characterization in harsh, multi-path environments
  • Can be coupled to semi-anechoic facility
Communications Technology Laboratory

NIST Broadband Interoperability Test Facility: NBIT 1.0

- **eNodeBs**
  - Connected to PSCR LTE Evolved Packet Core

- **Multi-Channel Transceiver**
  - 4-Channels
  - 200 MHz instantaneous bandwidth
  - 100 MHz - 6 GHz
  - RAID System
  - Programmable FPGAs
  - MIMO capable
  - Expandable

- **Channel Emulator**
  - 4-Channels
  - Expandable to 16 channels
  - 160 MHz bandwidth
  - 100 MHz - 6 GHz
  - Custom fading

- **Single-Channel Spectrum Analyzer**
  - 320 MHz bandwidth
  - Up to 20 GHz
  - IEEE 802.11 a/b/g/n/ac
  - Bluetooth
  - FDD/TDD LTE, LTE-A
  - Custom pulse analysis
  - Real-time analysis capability

- **Single-Channel Signal Generator**
  - 160 MHz IQ bandwidth
  - Custom fading
  - Up to 20 GHz
  - IEEE 802.11 a/b/g/n/ac
  - Bluetooth
  - FDD/TDD LTE, LTE-A,
  - Custom pulse generation

- **Reverberation chamber**
  - System under test

- **Configurable Anechoic room**
  - Height =20’

- **NIST Broadband Interoperability Test Facility: NBIT 1.0**
  - eNodeBs Connected to PSCR LTE Evolved Packet Core
  - Multi-Channel Transceiver
  - Channel Emulator
  - Single-Channel Spectrum Analyzer
  - Single-Channel Signal Generator
  - Reverberation chamber

- **System under test**
  - 40’
  - 23’
  - 17’
  - 18’
  - 15’