NIST Activities in Wireless Coexistence

Communications Technology Laboratory

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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

[1{3GPP, "LTE in Unlicensed Spectrum" June 2014, http://www.3gpp.org/news-events/3gpp-news/1603-lte_in_unlicensed.
[2]http://www.fcc.gov/rulemaking/12-148

What we mean by coexistence metrology

- Coexistence: "The ability of two of 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.

[3]IEEE Std 1900.2TM - 2008, IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems.

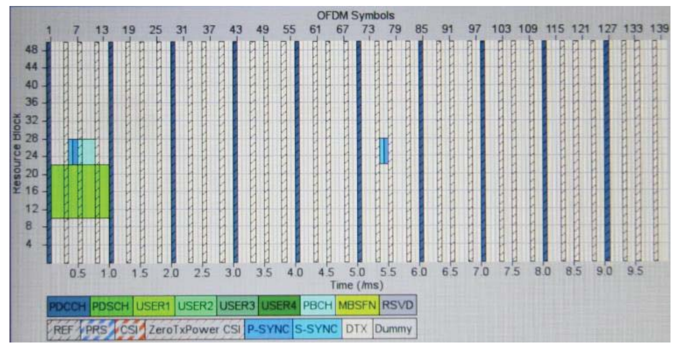
Evaluating spectrum sharing algorithms

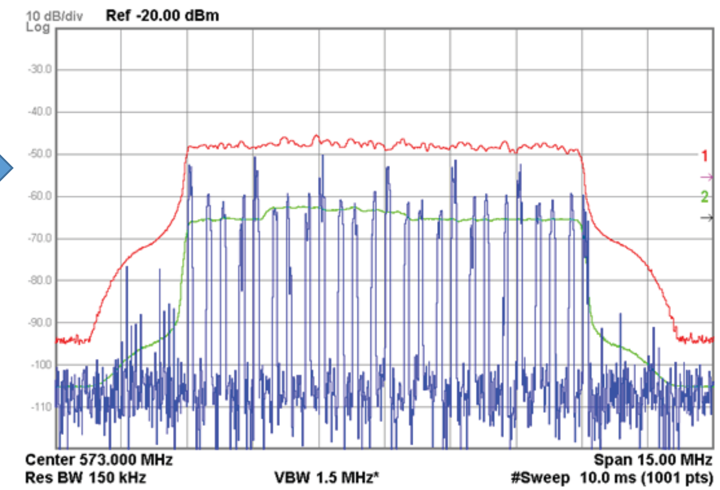
- How do we know a spectrum sharing algorithm is efficient?
- Will the algorithm be able to operate in the presence of other technologies?
- There is a growing need to answer such questions.
  - Rigorous testing methods are required
  - Numerical/Analytical testing
  - Radiated verification

Interference/coexistence impacts from complex modulated signals

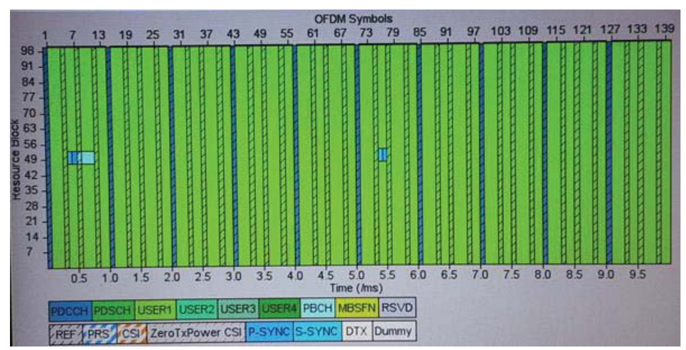
- LTE interference example
  - LTE signal interfering with cable modems
  - LTE waveforms depend on the source block usage
  - Generate significantly different spectrum and corresponding impacts on the ToE
- Research focus
  - Generalize a waveform that covers the range of conditions

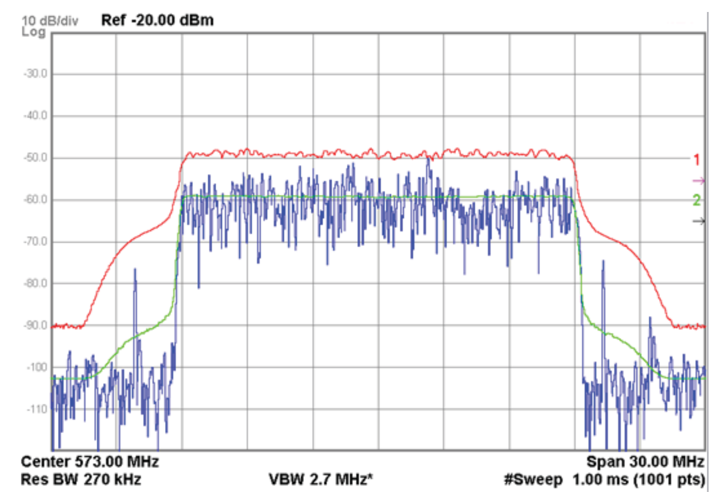
Voice LTE time plan over





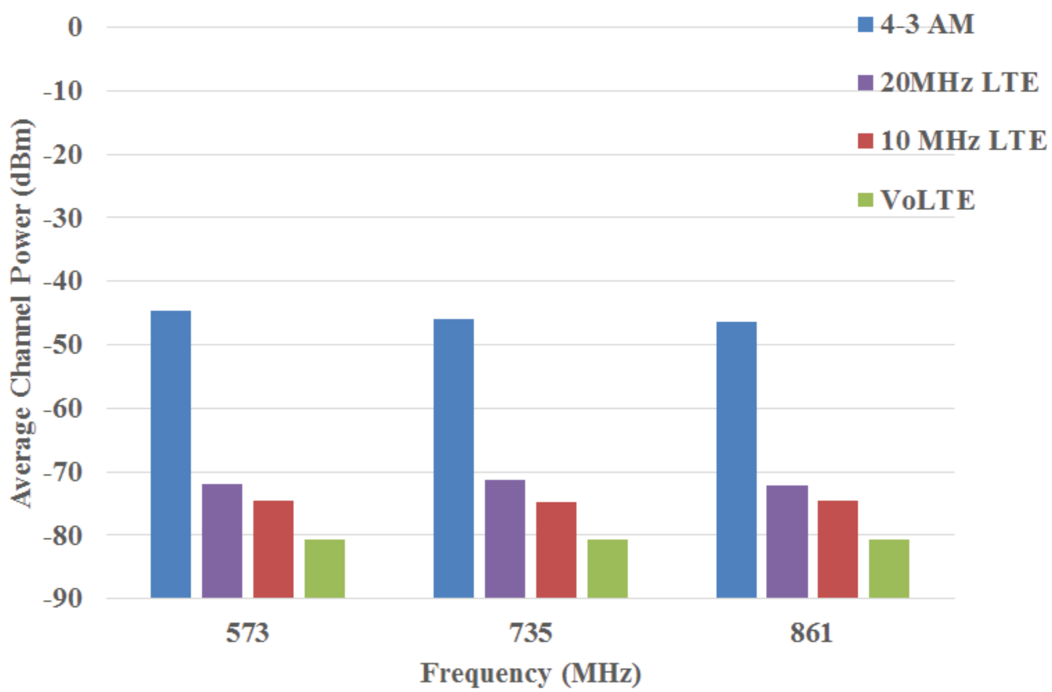
20 MHz time plan for LTE





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?



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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

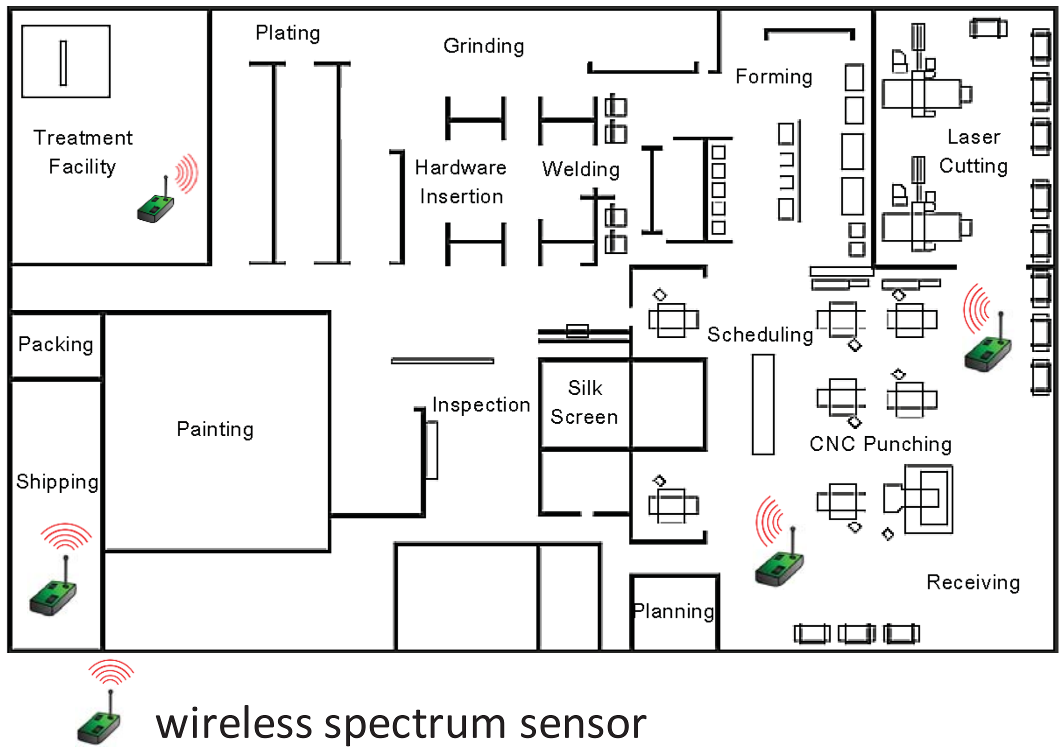
RF environment of deployment must be understood

- 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

[4]E. Obregon E, Sung Ki Won, and J. Zander, "On the sharing opportunities for ultra-dense networks in the radar bands," Dynamic Spectrum Access Networks (DYSPAN), 2014 IEEE International Symposium on , vol., no., pp.215,223, 1-4 April 2014.

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

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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 *<u>surrogate</u>* radar test waveforms

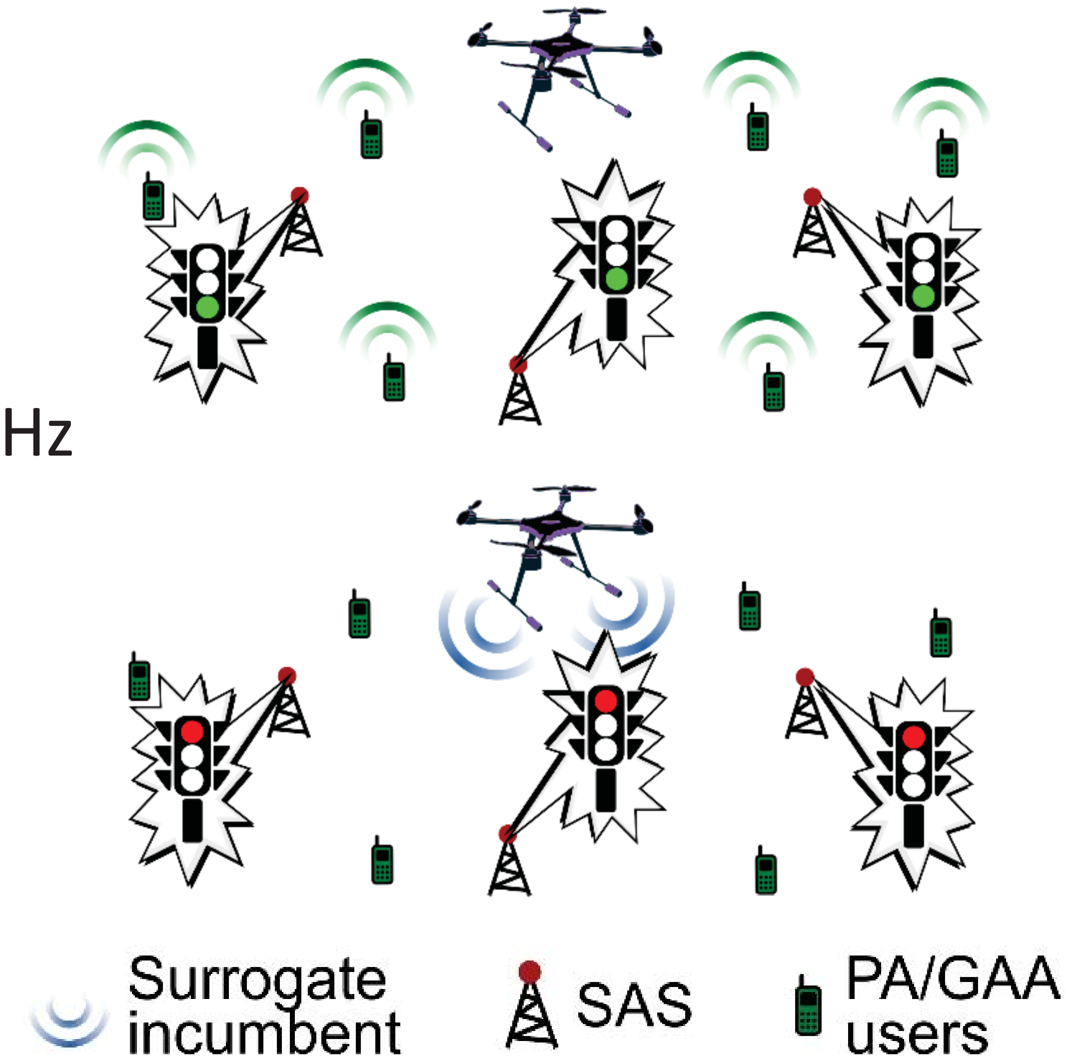
Ex: Middle west coast shipborne radar exclusion zone Blue line– current revised exclusion zone (ITS/NTIA)[5]

[5]NTIA Technical Report TR-15-517 3.5 GHz, "Exclusion Zone Analyses and Methodology," June 2015.

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



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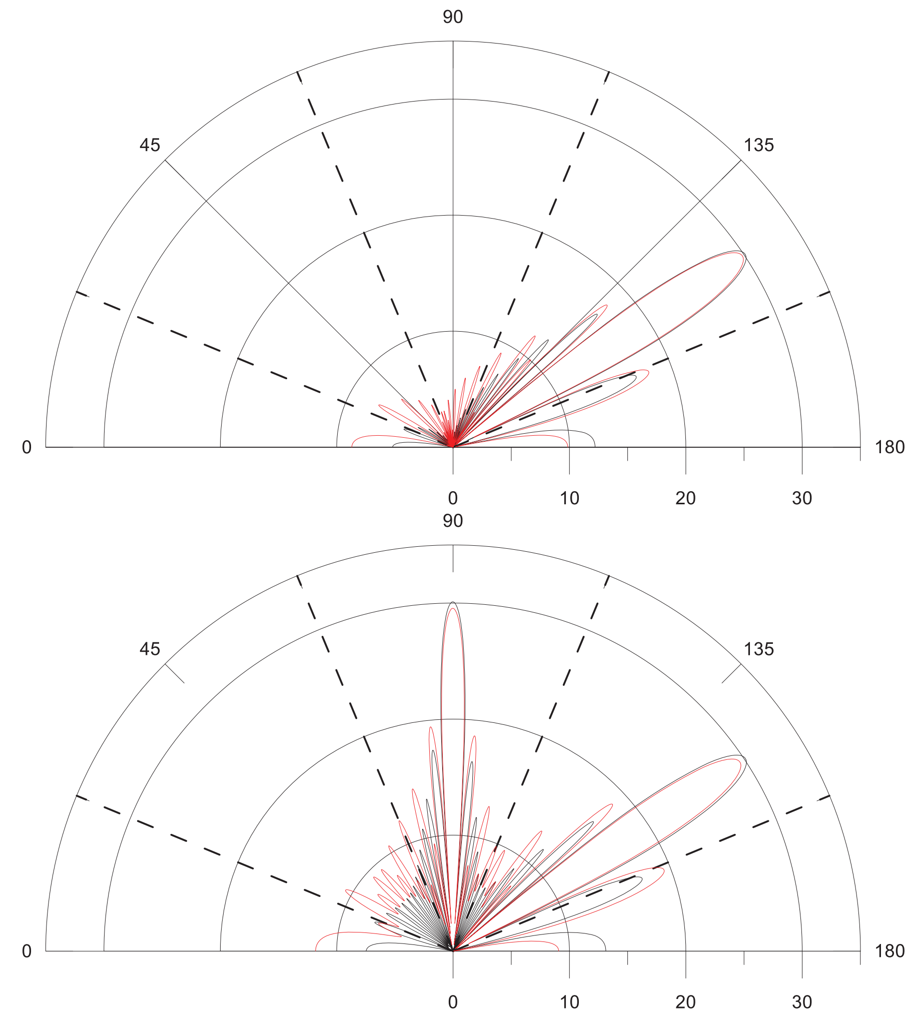
Implications of MIMO Technology on Coexistence

- 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



32 element array with one bad element. One and two beam excitations.

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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

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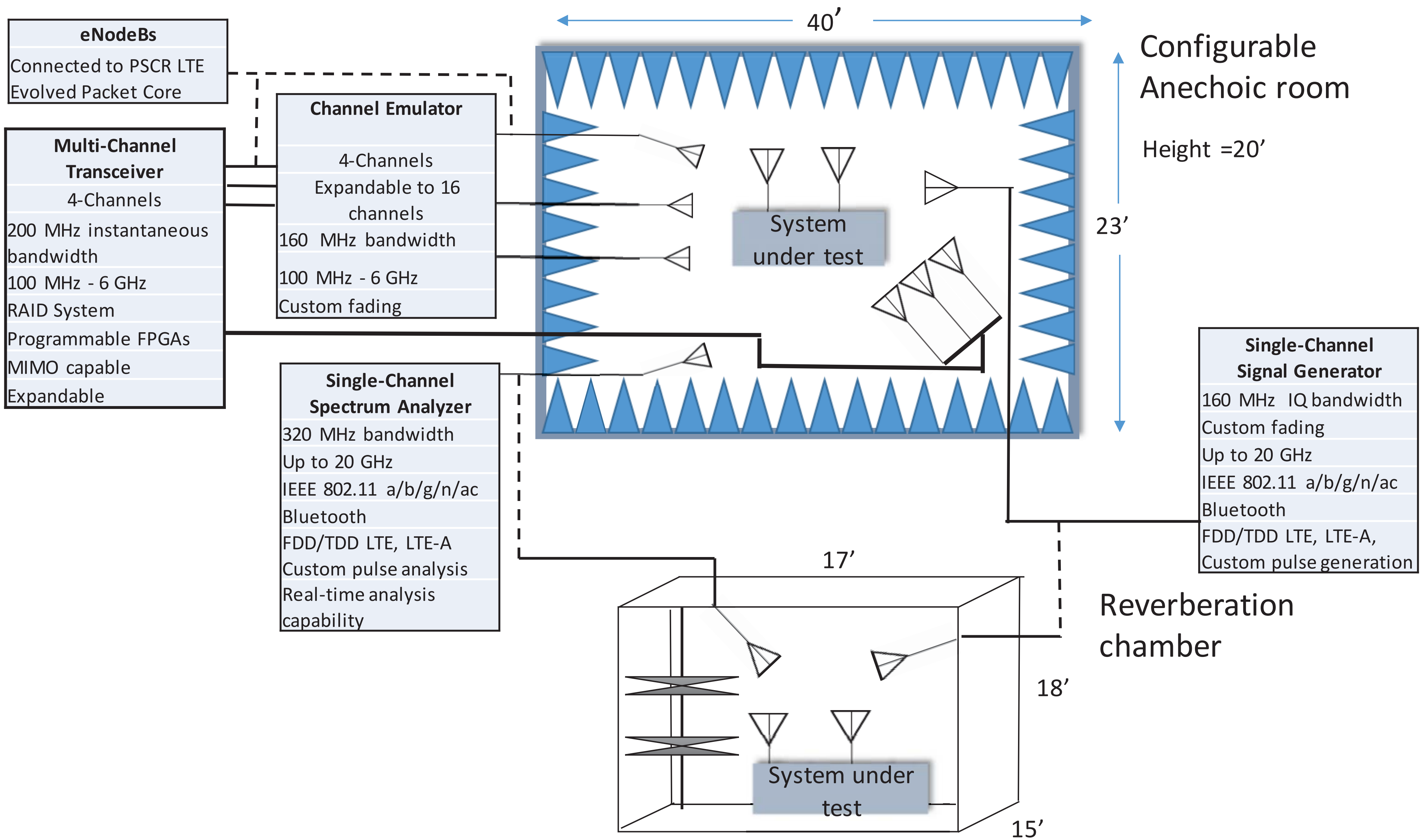
NIST Broadband Interoperability Test Facility: NBIT 1.0



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