End-to-End Mission Critical Push-to-Talk.

Nemergent Solutions SL
Sonim Technologies, Inc.

2018 PSCR Public Safety Broadband Stakeholder Meeting | NIST

June 6th, 2018 San Diego, CA

Acronym Glossary

- AMBE = Advanced Multi-Band Excitation
- AMR-WB = Adaptive Multi-Rate Wideband
- API = Application Program Interface
- APN = Access Point Name
- ARQ = Automatic Repeat Request
- AS = Authorization Server
- CP = Cyclic Prefix
- CSM = Channel Switching Module
- CQI = Channel Quality Indicator
- DSP = Digital Signal Processor
- eMBMS – Evolved Multimedia Broadcast Multicast Services
- eNB – E-Ultran Node B
- EPC = Evolved Packet Core
- EPA = Extended Pedestrian A model
- ETSI = European Telecommunications Standards Institute
- ETU = Extended Typical Urban model
- EVS-SWB = Enhanced Voice Services – Super Wide Band
- FCC = Federal Communications Commission
- FEC = Frame Error Concealment
- FEC – CA = Frame Error Concealment Clean Audio
- FFO = Federal Funding Opportunity
- GBR = Guaranteed Bit-Rate
- GUI = Graphical User Interface
- HARQ = High Availability Resolution Queue
- HTML = Hypertext Markup Language
- IdMS = Intelligent Data Movement Service
- KPI = Key Performance Indicator
- LMR = Land Mobile Radio
- MCPTT = Mission Critical Push-to-Talk
- MCS = Modulation and Coding System
- MIMO = Maximum Input Maximum Output
- MSDC = Multicast Services Device Client
- OAM = Operations, Administration, and Maintenance
- OFDM = Orthogonal Frequency-Division Multiplexing
- OFDM NR = Orthogonal Frequency-Division Multiplexing New Radio
- PRB = Physical Resource Block
- ProSe = Proximity Services
- PS = Public Safety
- PSCR – Public Safety Communications Research
- PSIAP = Public Safety Innovation Accelerator Program
- PSN = Public Safety Network
- QCI = QoS Class Identifier
- QoS = Quality of Services
- RI = Rank Indicator
- SDK = Software Development Kit
- SDR = Software-Defined Radio
- SESB = Static Equal Sized Blocks
- SIP = Session Initiation Protocol
- SINR = Signal-to-Interference-Plus-Noise-Ratio
- SRS = System Requirements Specification
- SW = Software
- XDMS = XDM Server
- UE = User Experience
- UI = User Interface

PSCR

Agenda.

- Project objectives
- Client UE/ application
- MCPTT servers
- Functional & performance testing
- Test deployments
- Dissemination
- Project summary
- Demonstration
- Q & A


sonim®
WE SERVE THE PEOPLE
WHO SERVE US

Public Safety Innovation Accelerator Program (PSIAP)

- **Project objectives**
- Client UE/ application
- MCPTT servers
- Functional & performance testing
- Test deployments
- Dissemination
- Project summary
- Demonstration
- Q & A

Project Objectives

Statement of Work

- Middleware for MCPTT Client Integration on Android UE
  - LTE-level support
  - Application-level support
  - Mission Critical Experience / UI
- MCPTT Service Implementation (next slide)
- Testing
  - Protocol testing
  - Interoperability testing
  - System integration tests / KPI
  - Field tests

Sonim Technologies, Inc.
PSIAP - Project: End-to-End Mission Critical Push-to-Talk: beginning June 1 2017
NIST # 70NANB17H179

G = June 1st

Table 1: Project Deliverables and Timeline Revised

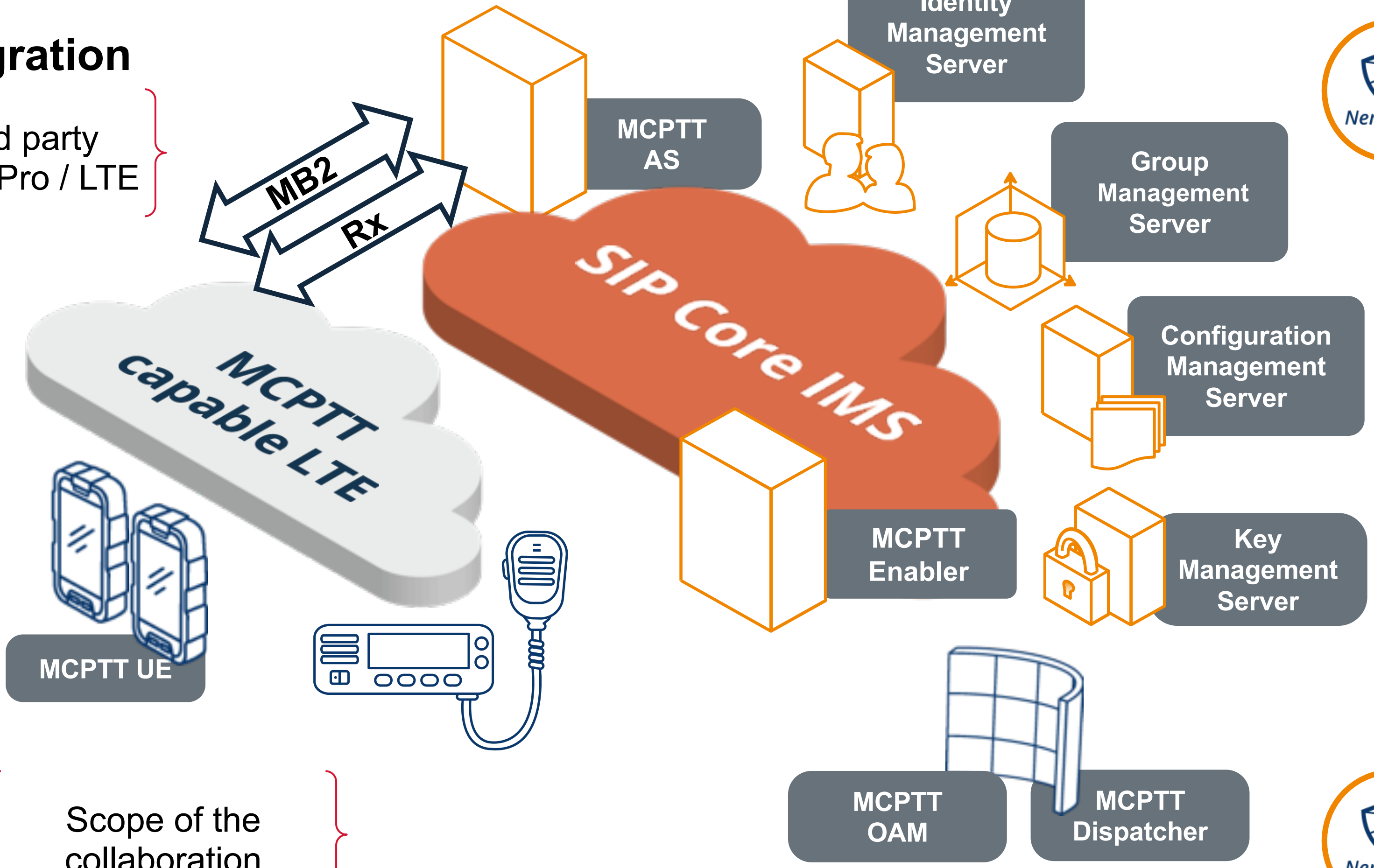
Section	Deliverable	Owner	Date
Section 3.1.1	**Service Integration**		
	PTT App Integration on UE	Sonim/Nemergent	G+ 2W
	ISIM API/APN for data connection	Sonim/Nemergent	G+ 14W
	MCPTT Integration - Service Level	Nemergent	G+ 40W
	QCI integration / Broadcast Services	Sonim/Nemergent	G+ 40W
	E2E Broadcast Services SDK	Sonim	G+ 52W
	Service Level Integration SDK Pkg	Sonim	G+ 52W
Section 3.1.2	**Mission Critical Experience**		
	PTT Key integration / SDK	Sonim	G+ 2W
	PTT Android framework modifications	Sonim	G+ 14W
	PTT SDK / guide	Sonim	G+ 40W
	PTT Audio path demo	Sonim	G+ 52W
	CSM - Generic API	Sonim	G+ 14W
	CSM Accessory Prototype for UE	Sonim	G+ 30W
	MCPTT integration with CSM	Sonim	G+ 40W
	CSM SDK Pkg	Sonim	G+ 40W
Section 3.2	**MCPTT Server Components**		
	First Release of MCPTT System	Nemergent	G+ 2W
	Second Release of MCPTT Management Servers	Nemergent	G+ 30W
	Second release of MCPTT AS	Nemergent	G+ 40W
Section 3.3	**Testing**		
	Integration Testing (Definition)	Nemergent/Sonim	G+ 14W
	Interoperability Testing	Nemergent	G+ 52-70W
	Field Testing	Sonim / Partner	G+ 52-80W
	Test Reports	Sonim	Per milestone

Technical objectives

Own development
Evolve R2016 to R2017

Integration

Third party
LTE-A Pro / LTE



Evolve ongoing developments

To be developed

Not initially considered

WE SERVE THE PEOPLE WHO SERVE US

Scope of the collaboration

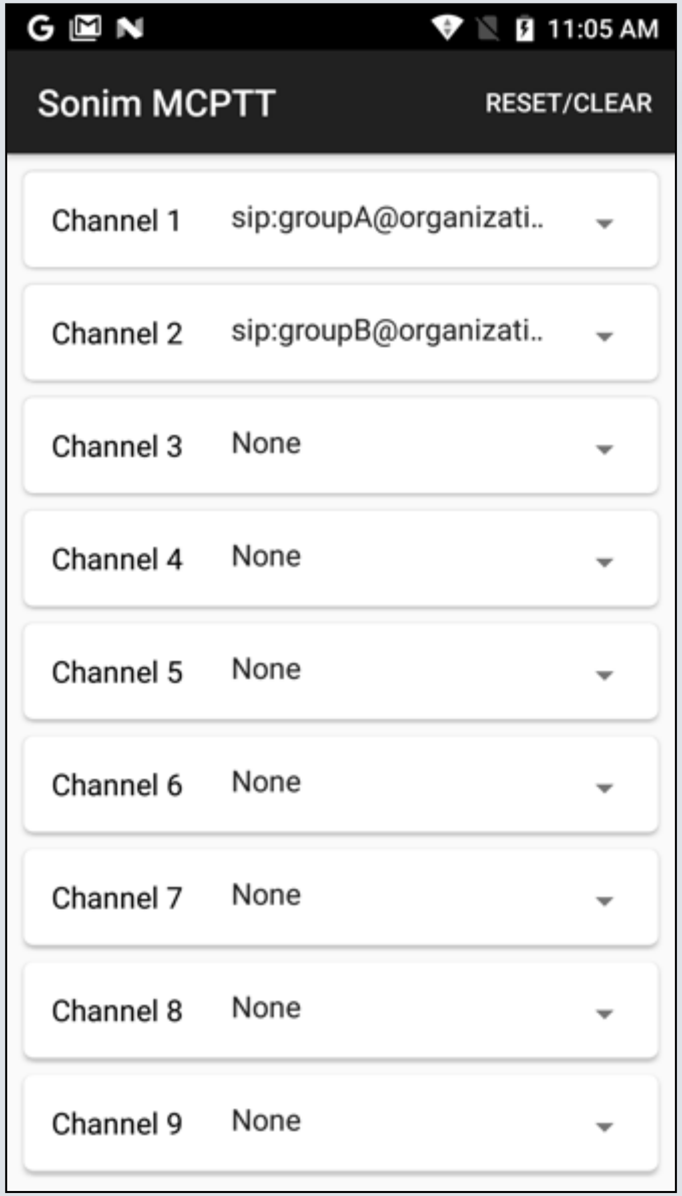
Public Safety Innovation Accelerator Program (PSIAP)

- Project objectives
- **Client UE/ application**
- MCPTT servers
- Functional & performance testing
- Test deployments
- Dissemination
- Project summary
- Demonstration
- Q & A

CSM SDK

Channel Switching Module (CSM) SDK APIs

- Allows any developer to use the SDK to write a MCPTT application that can interact with the CSM connected to the device
- Connect/ Disconnect events
- Channel Switching events
- Current Channel Selected



MCPTT client with CSM SDK

Sonim MCPTT client uses this SDK to allow a user to easily switch between groups by turning the rotary knob.

User can assign any channel to any existing group.

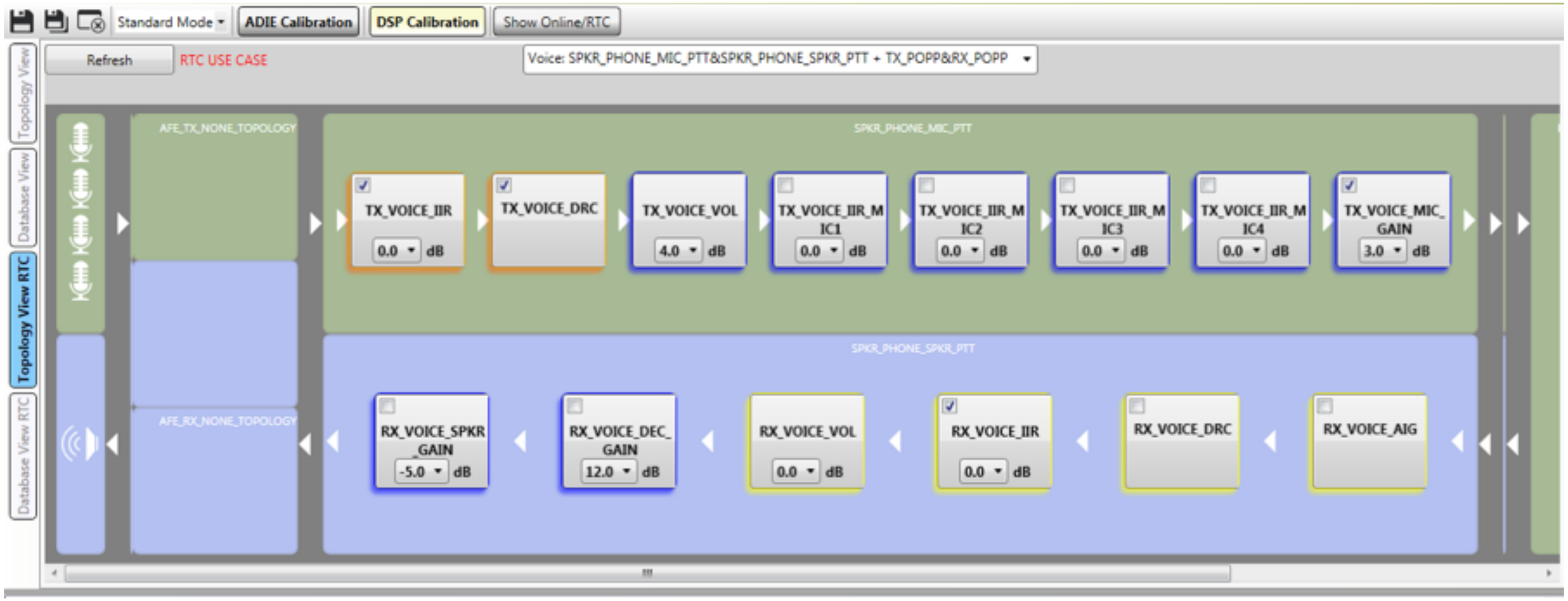
Physical Button Integration APIs

- Long press of the yellow button puts MCPTT in emergency mode
- Any calls made thereafter are emergency calls with higher priority

Physical Button Integration APIs

- Long press of the red button starts a PTT call to a pre-defined emergency contact or group

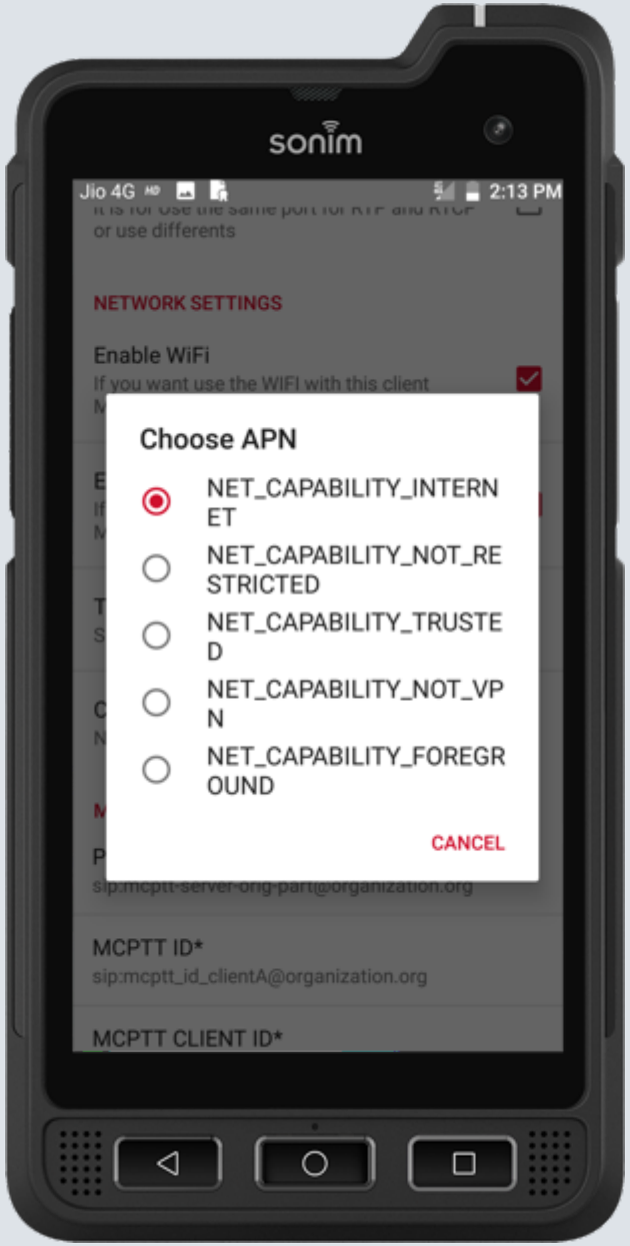
Audio Quality Improvements



New Audio Calibration DSP Profile for MCPTT on Sonim XP8 device

Provides great audio clarity even when speaker is in noisy environments

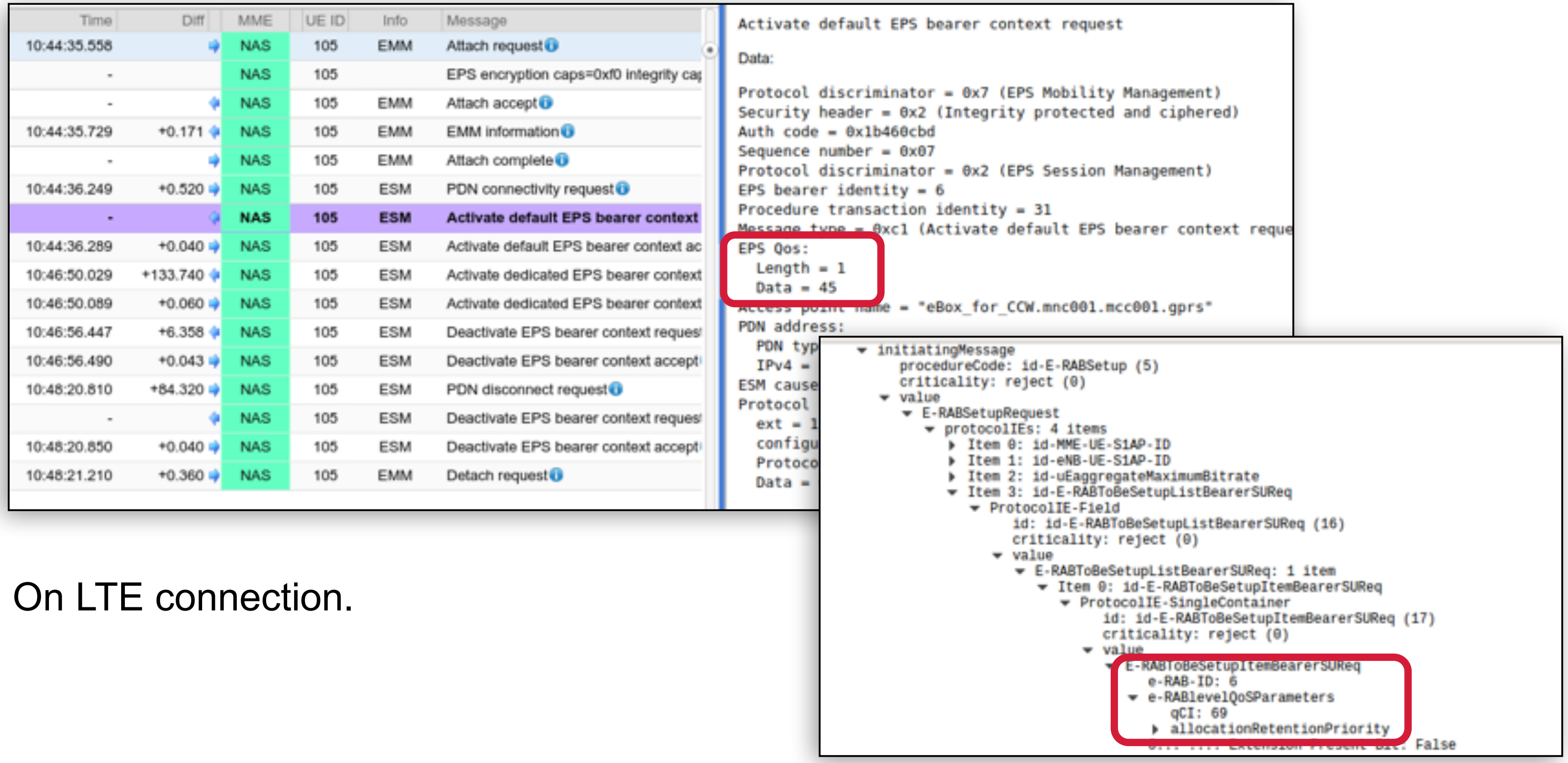
Tuned for MCPTT use case



QCI Integration

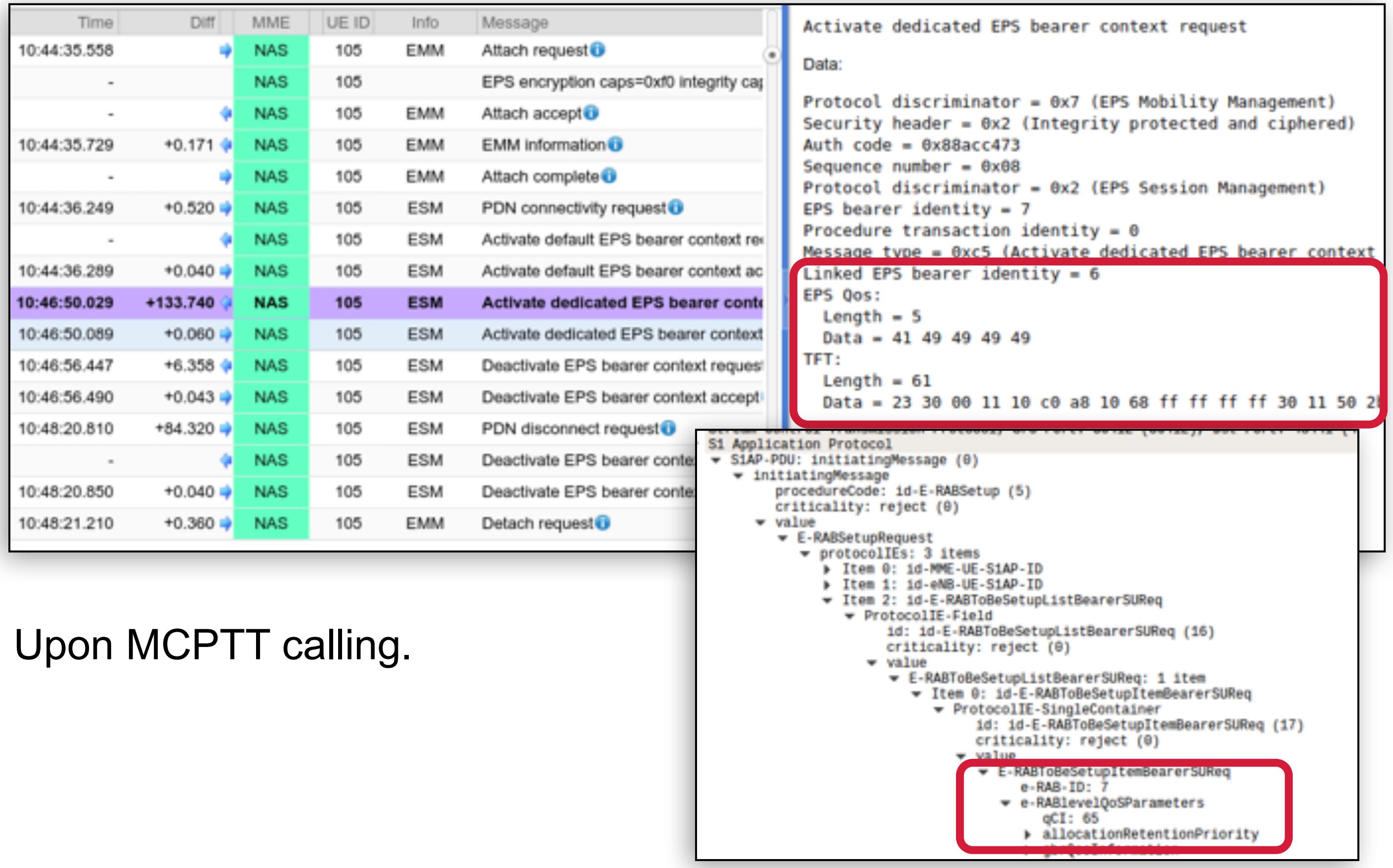
- XP8 support QCIs for MCPTT specifically QCIs 65/66/69/70
- Successfully validated QCI 65 and 69
- Option in MCPTT Client to choose any APN type for QCI mapping

QCI Integration – Default MCPTT signaling bearer (QCI 69) in the APN



On LTE connection.

QCI Integration – Dynamic establishment of MCPTT media plane bearer (QCI 65)

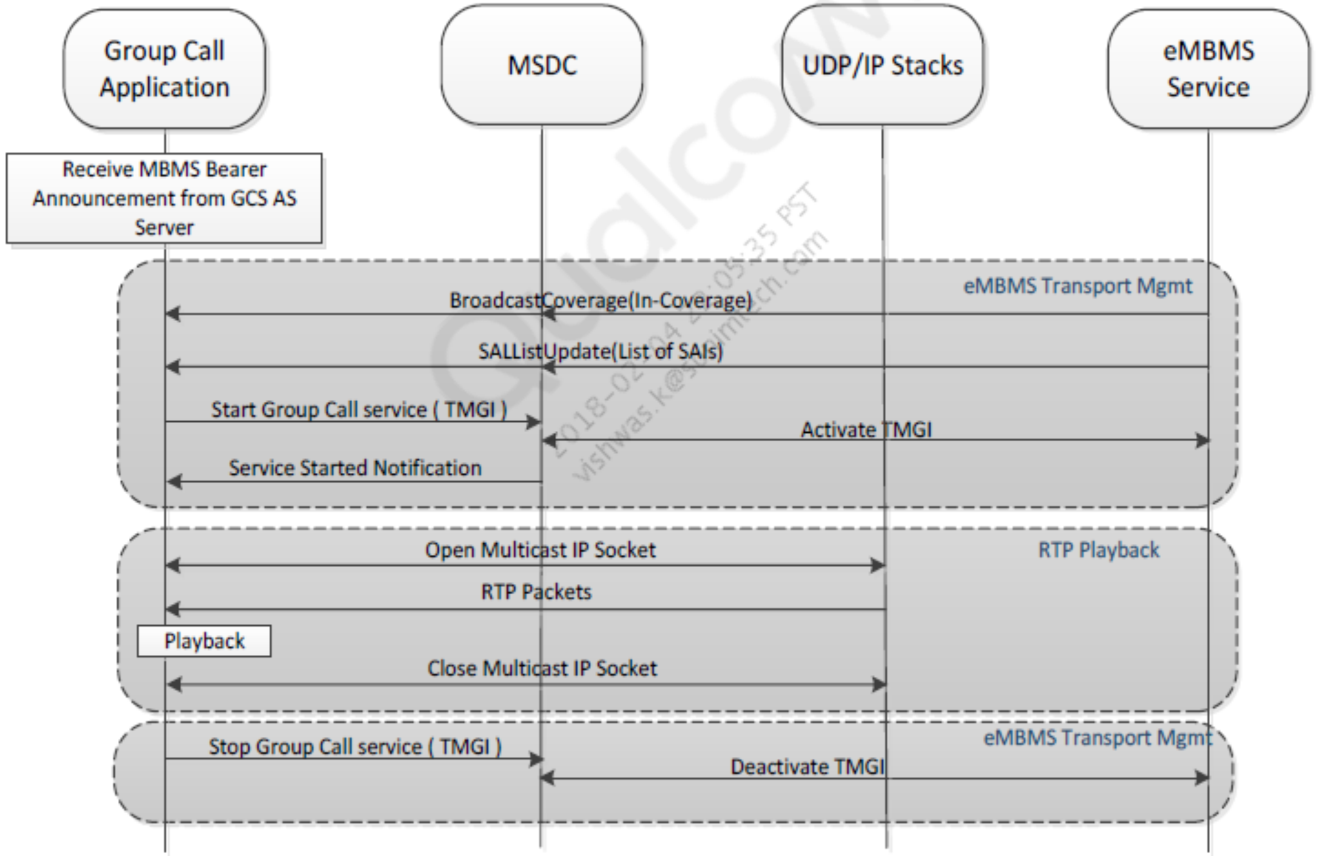


Upon MCPTT calling.

eMBMS Integration using QC Middleware

Qualcomm MSDC API used for eMBMS

Group Communication Service Startup and Playback



Public Safety Innovation Accelerator Program (PSIAP)

- Project objectives
- Client UE/ application
- **MCPTT servers**
- Functional & performance testing
- Test deployments
- Dissemination
- Project summary
- Demonstration
- Q & A

Nemergent / Solutions

Located in Bilbao, Basque Country, Spain.

Founded in January 2017.

Next generation Mission Critical communications

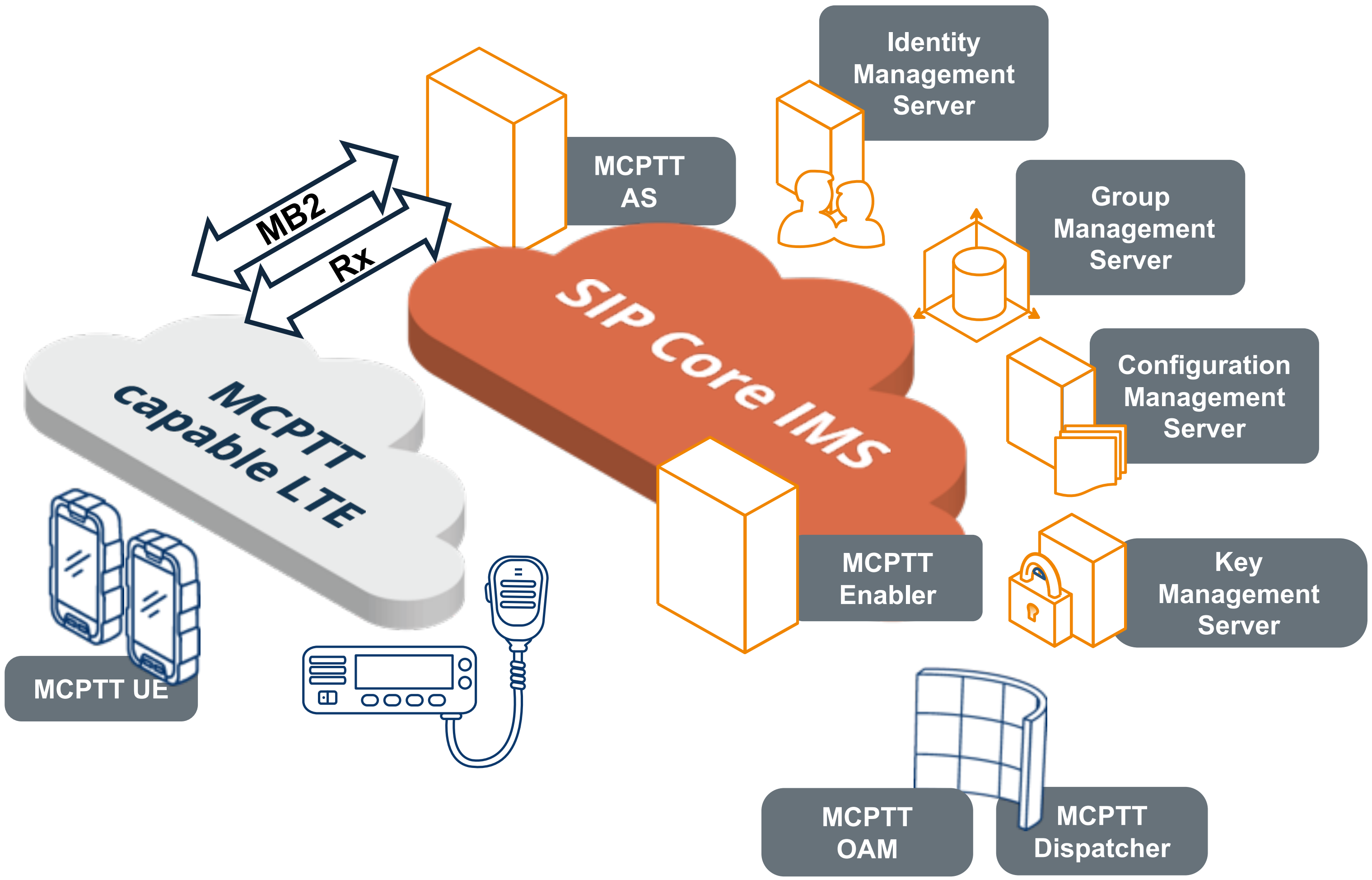
- 3GPP R13 MCPTT
- 3GPP R14 MCVideo & MCData

MCPTT Application Server

MCPTT AS >= 3GPP v13.3.0

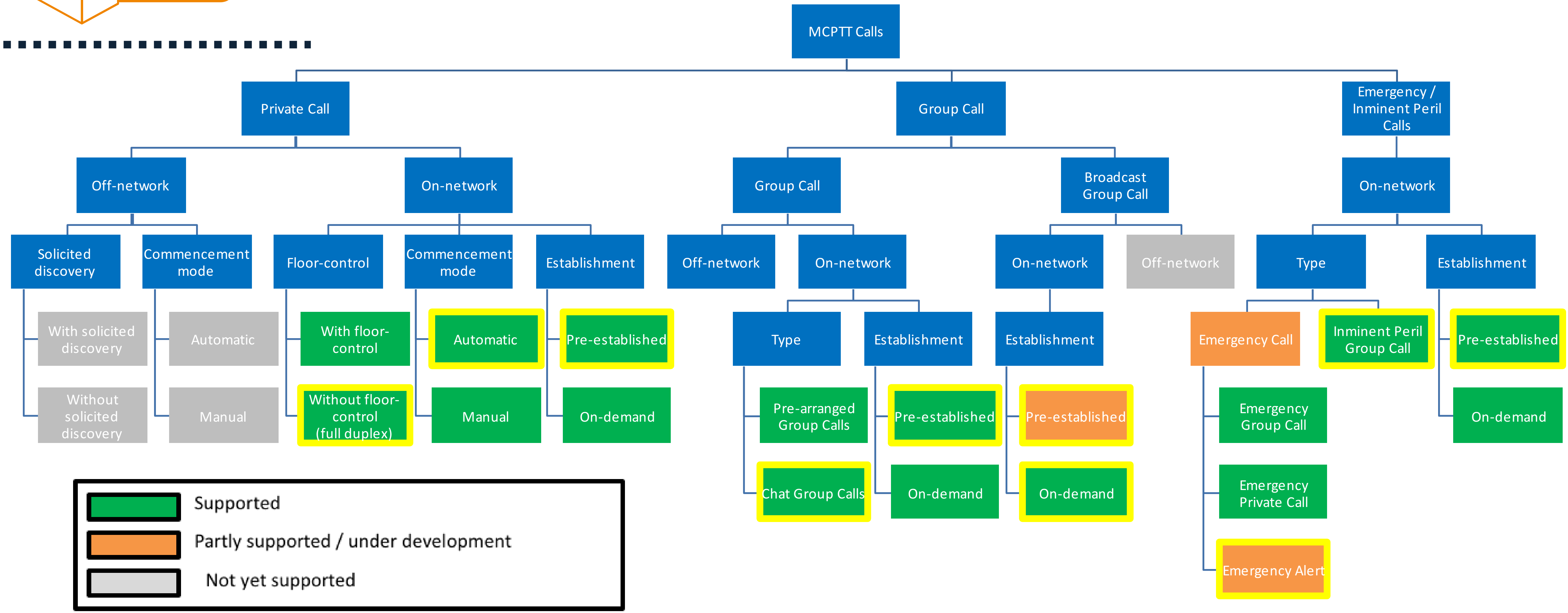
- MCPTT Authentication & Authorization
- Group Affiliation
- MCPTT Location
- New call types
- CSC interfaces to Management Servers
- QoS & eMBMS - Rx & MB2 interfaces
- Enhanced media forwarding
- MCPTT ciphering (initial support)
- SW troubleshooting & debugging

Technical evolution

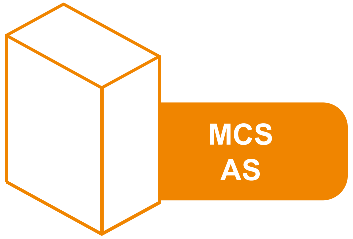


MCPTT Application Server

Technical evolution



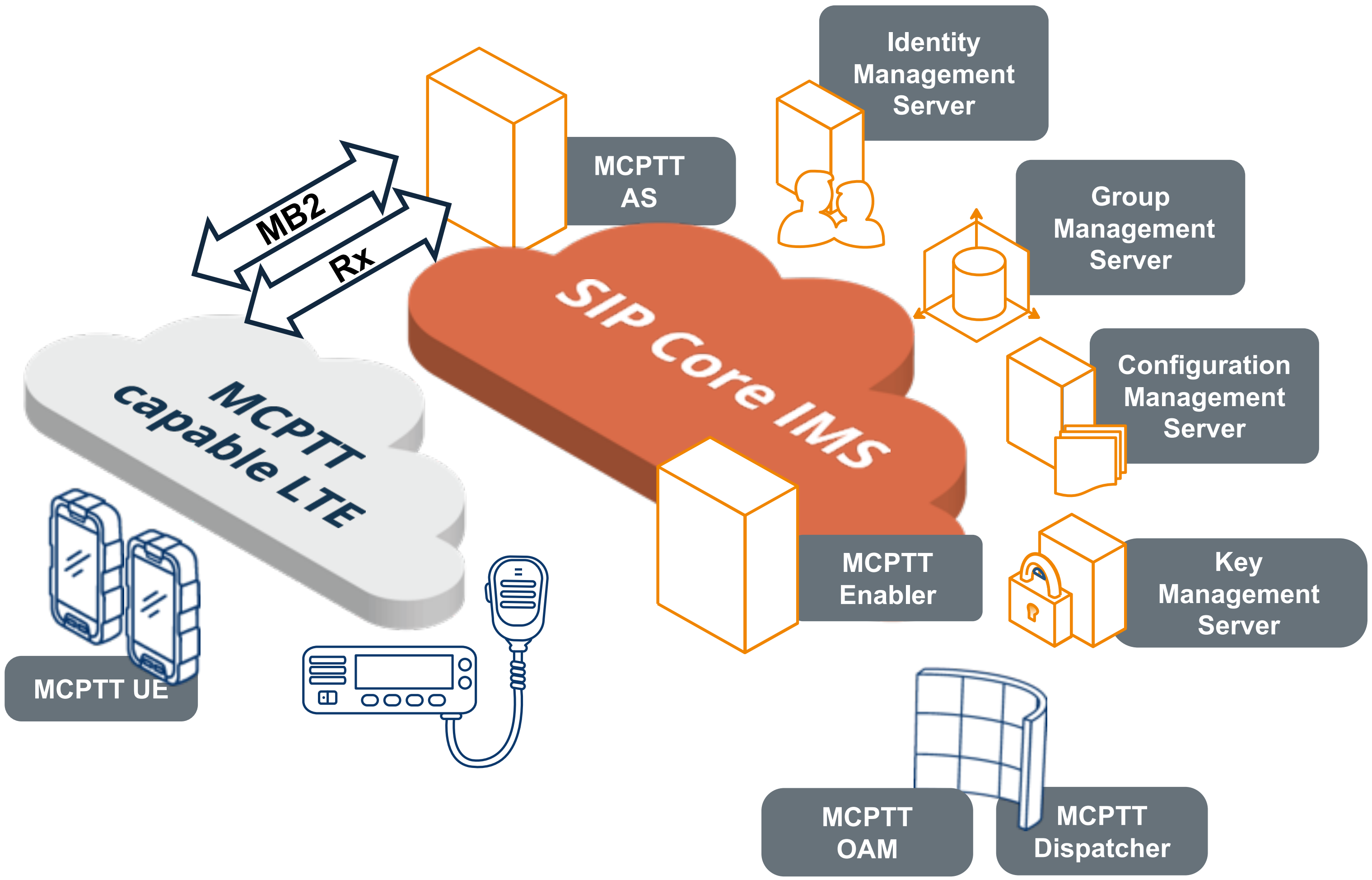
R14 MCS Application Server



3GPP R14

- Common Core Services
- R14 Authentication & Registration
- MC-Data (One-to-one & Group)
- Standalone SDS over SIP
- FD using HTTP
- MC-Video
- Private calls
- Group call signalling

Technical evolution



Management Servers

IdMS

- Initial R13 OpenID Connect for MCPTT
- Update to R14

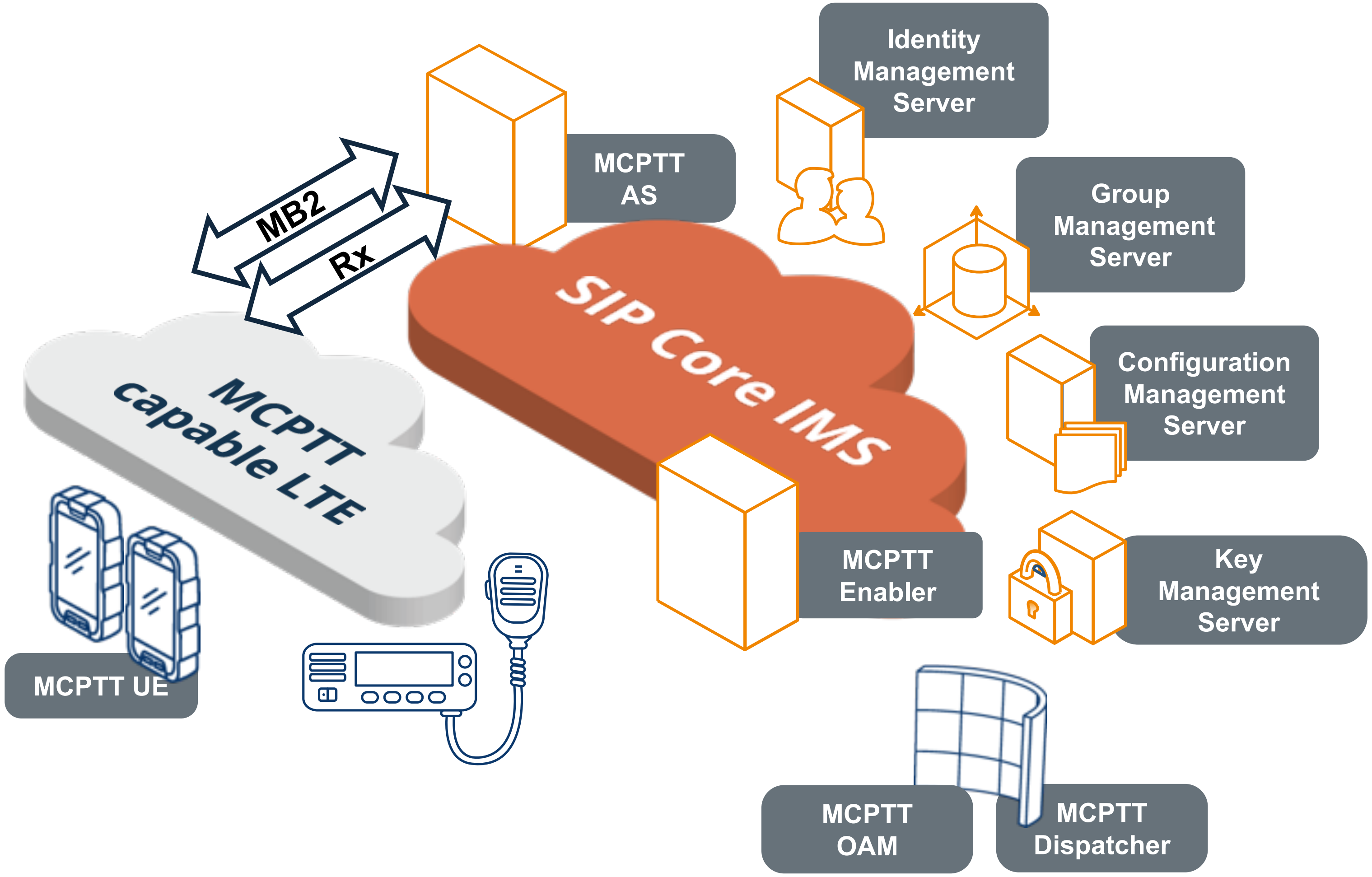
CMS **GMS**

- R13 XDMS with SIP and HTML interfaces
- MCPTT Managed Objects
- Update to R14

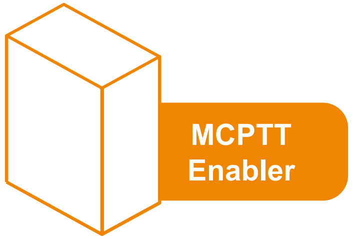
KMS

- Initial R13 key distribution support

Technical evolution



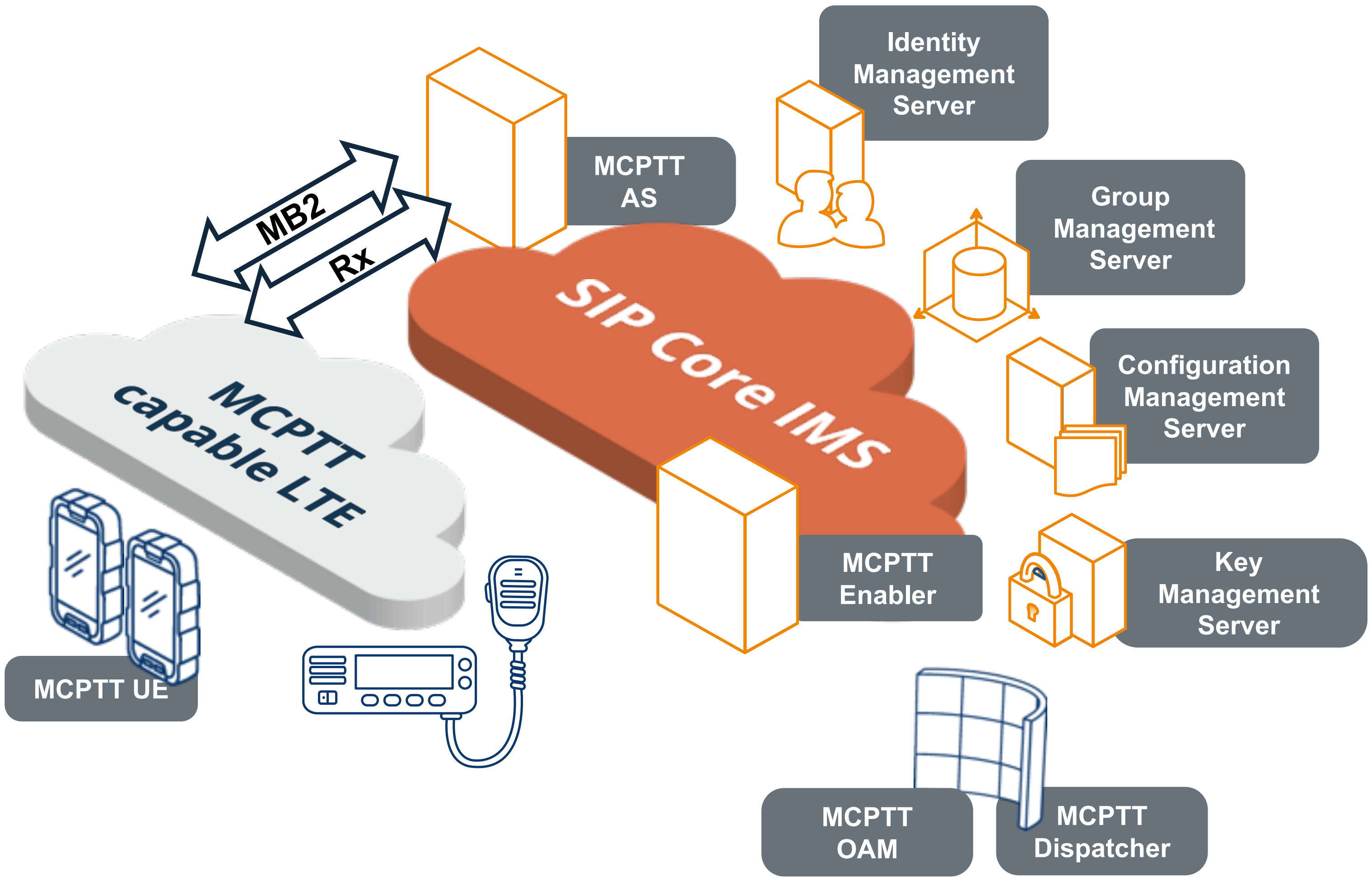
New component – MCPTT Enabler



3GPP R13

- Northbound - Standard MCPTT
- OAM API
- Southbound – Web friendly API
- OAM interface
- User administration
- Group administration
- Dispatch interface
- Call handling
- Location GUI

Technical evolution



Public Safety Innovation Accelerator Program (PSIAP)

- Client UE/ application
- Technical work
- **Functional & performance testing**
- Test deployments
- Dissemination
- Project summary
- Demonstration
- Q & A

Protocol & Interoperability testing

Official interoperability testing

STANDARDS

1st ETSI MCPTT Plugtest (June 2017)


ETSI World Class Standards

Certificate of Participation

awarded to

Nemergent Solutions S.L.

for their attendance at the Plugtests event for

1st MCPTT PLUGTESTS

Sophia Antipolis, 19th to 23rd June 2017

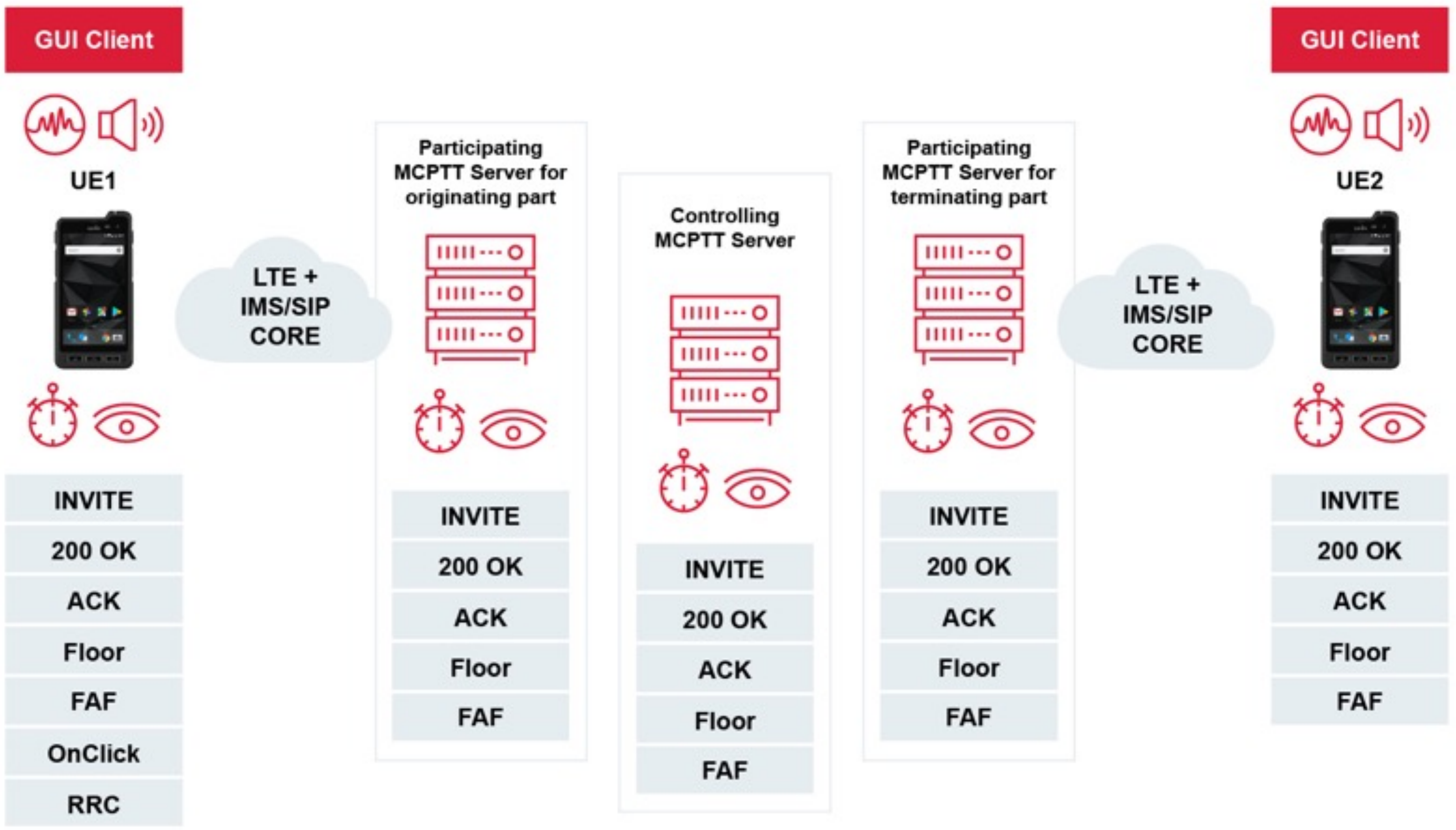
2nd ETSI MCPTT Plugtest (June 2018)

In Process…

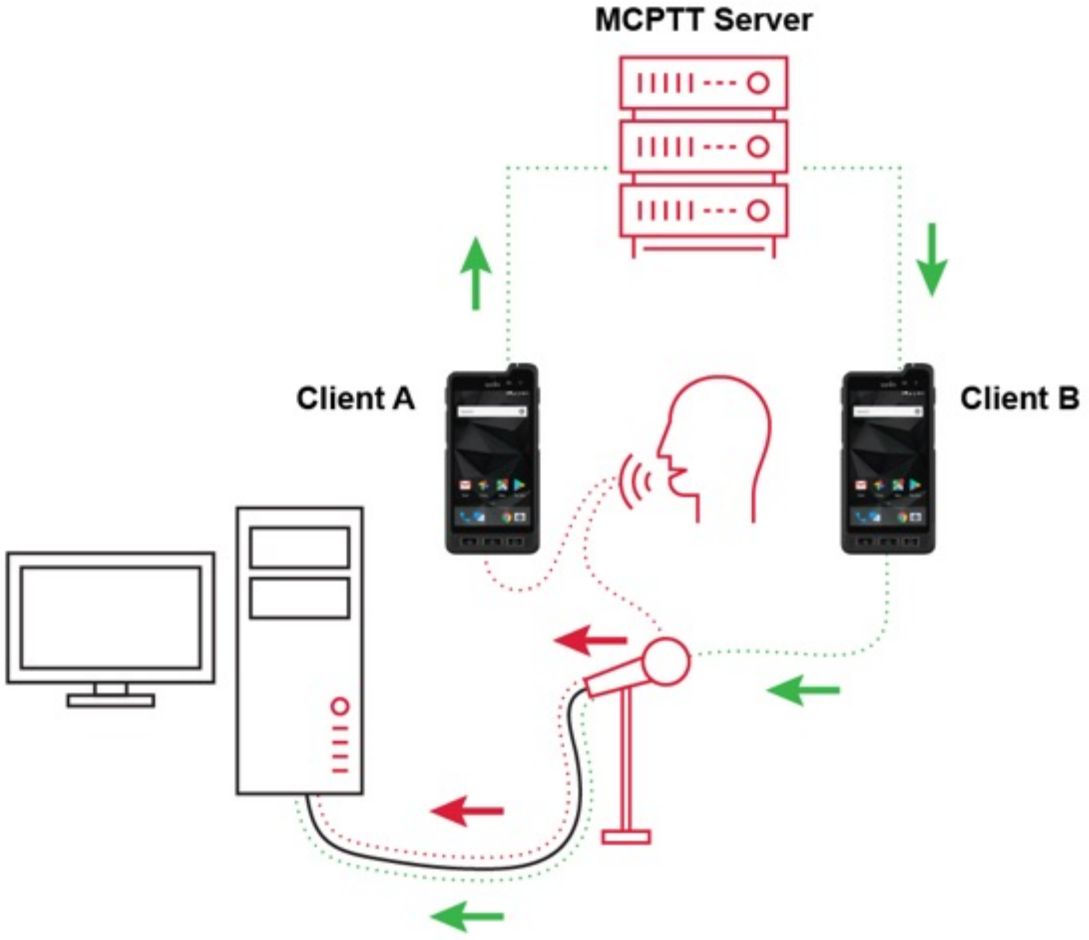
Additional testing

- Different LTE EPC PCRF's & eMBMS's
- Other MCPTT client SDKs
- Other Public Safety UEs

KPI measurements (I) - On-site KPI measurements



KPI measurements (II) – Lab KPI measurements



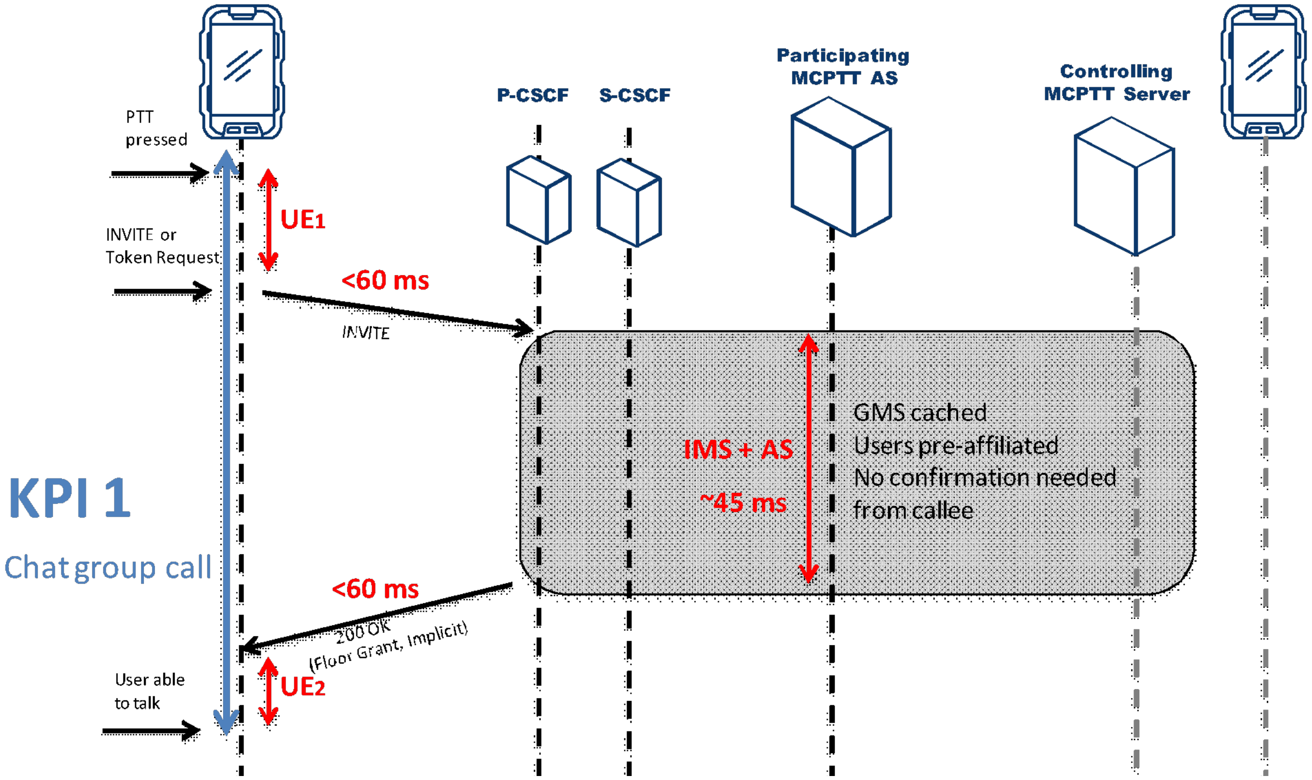
Performance testing

Target KPIs

MCPTT KPIs	**Threshold**	**Likelihood**	**LTE Packet Delay Budget**
MCPTT KPI 1 – Access Time	< 300 ms	95% of all MCPTT requests	< 60 ms
MCPTT KPI 1 – Access Time (Emergency)	< 300 ms	99% of all MCPTT requests	< 60 ms
MCPTT KPI 2 – End-to-End Access Time	< 1000 ms	N/A	< 60 ms
MCPTT KPI 3 – Mouth-to-Ear Latency	< 300 ms	95% of all voice bursts	< 75 ms
MCPTT KPI 4 – Late Call Entry Time (encrypted calls)	< 350 ms	95% of all Late Call entries	< 60 ms
MCPTT PESQ	MOS-LQO ≥ 3.0	N/A	N/A
MCPTT POLQA	MOS-LQO ≥ 3.0	N/A	N/A

Performance testing

KPI Measurements – KPI 1



Interim outcomes:

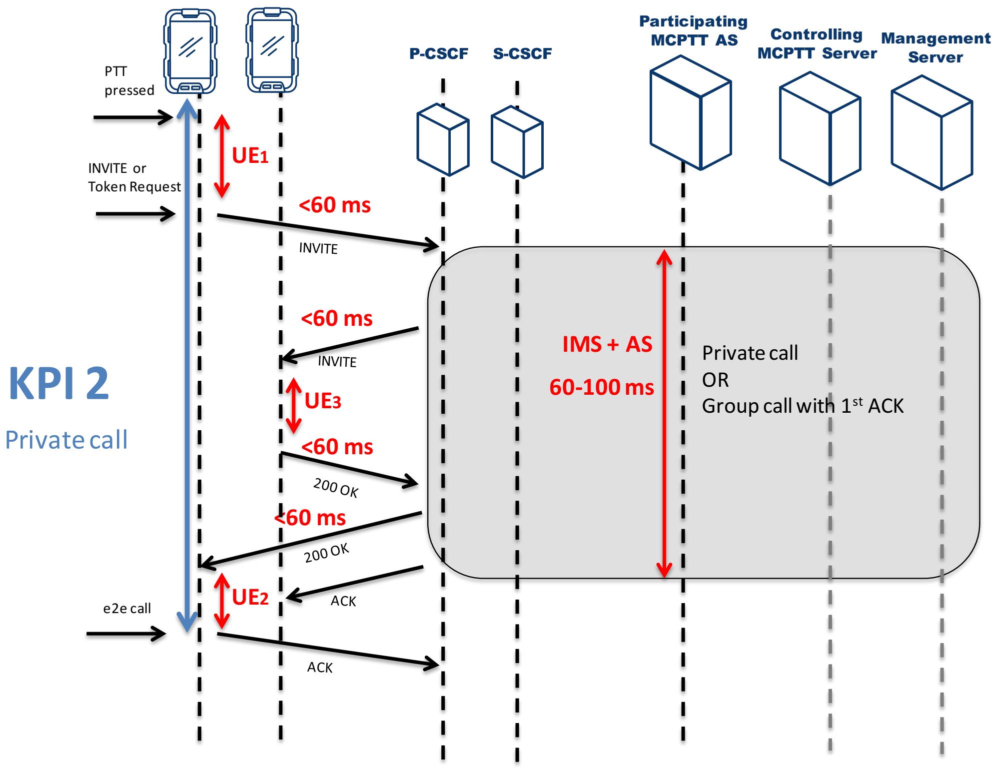
- Android OS
- Good performance in protocol execution
- Higher delays due to modern GUI
- Requires tailored code flows

$UE_1 + UE_2 < (300 – 2*60 – 45 =)135ms$
Dependence on the Android GUI

SDK → UE_1 ~ 30ms
Full GUI → UE_1 ~ 110ms

Performance testing

KPI Measurements – KPI 2



UE1 + UE2 + UE3 < (1000 – 4*60 – 100 =)660ms
Initial measurements… KPI 2 < 700 ms

Interim outcomes:

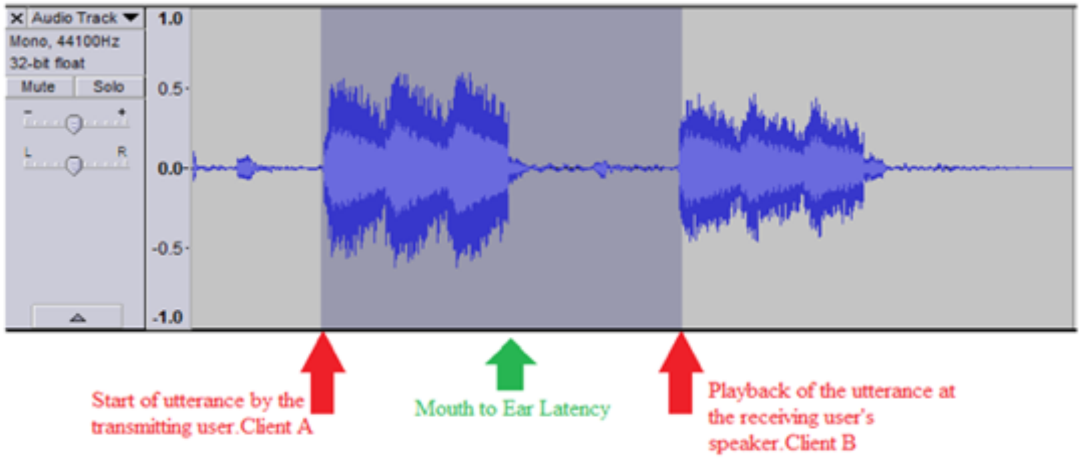
- Easier to cope with

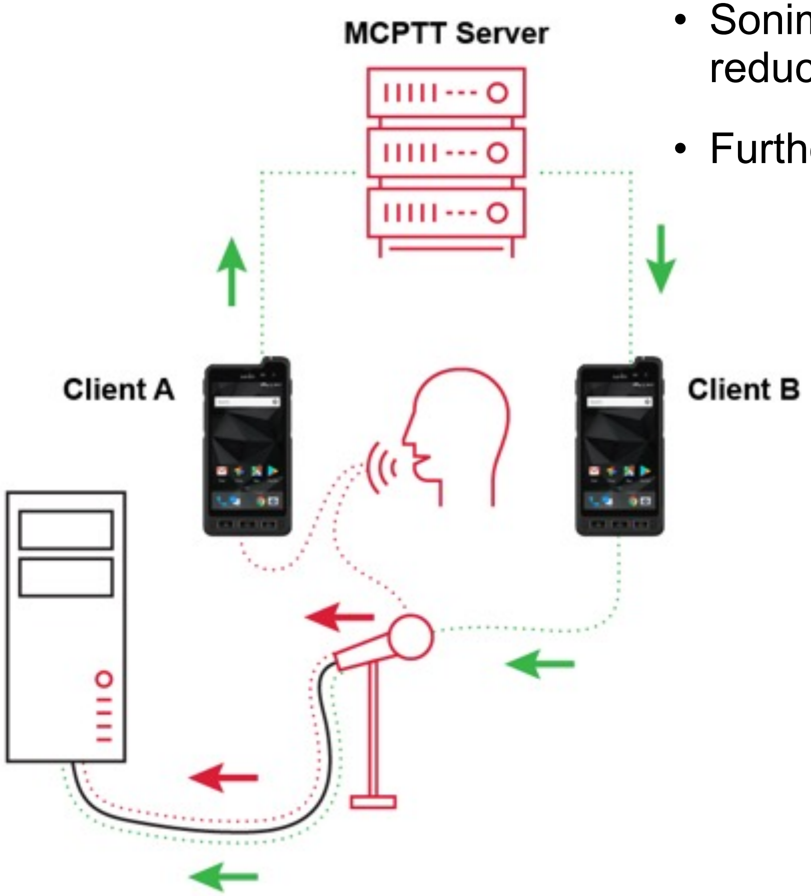
Performance testing

KPI Measurements – KPI 3

KPI 3 – Mouth to ear latency

Average time in seconds = 0.450 (over LTE)





Interim outcomes:

- Sonim XP8 has shown significant reduction in the audio loopback
- Further enhancement needed

Public Safety Innovation Accelerator Program (PSIAP)

- Client UE/ application
- Technical work
- Functional & performance testing
- **Test deployments**
- Dissemination
- Project summary
- Demonstration
- Q & A

MCPTT servers in work

PSIAP AWARDS

Mission Critical Open Platform (MCOP)

OpenFIRST

Test deployments

- Online servers for MCOP testing
- Integration with ExpWay EPC
- Online servers for SRS testing
- Integration with SRS LTE
- Nemergent Linux MCPTT client

PSIAP

NIST / PSCR Labs Boulder, CO

- Onsite deployments
- Remote support

Public Safety Innovation Accelerator Program (PSIAP)

- Client UE/ application
- Technical work
- Functional & performance testing
- Test deployments
- **Dissemination**
- Project summary
- Demonstration
- Q & A

PSIAP work

Dissemination

EVENTS

Denver, CO
August 2017

APCO 2017
August 13-16 | Denver, CO

- Multi-technology PTT system
- Mutualink core
- Nemergent MCPTT
- SONIM XP7

PSIAP work

EVENTS

Madrid, Spain
November 2017

PSCEurope
Public Safety Communication Europe

- Speaking slot
- Demo corner
- Onsite servers
- SONIM XP7

Dissemination

PSIAP work

Dissemination

EVENTS

Barcelona, Spain
February-March 2018

MOBILE WORLD CONGRESS
BARCELONA 26 FEB-1 MAR 2018

- MCPTT + MCVideo demos
- Onsite + Online servers
- SONIM XP7 + XP8 UEs

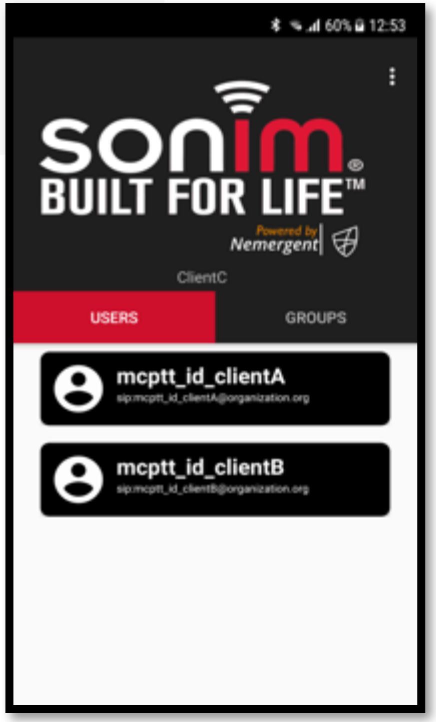
PSIAP work

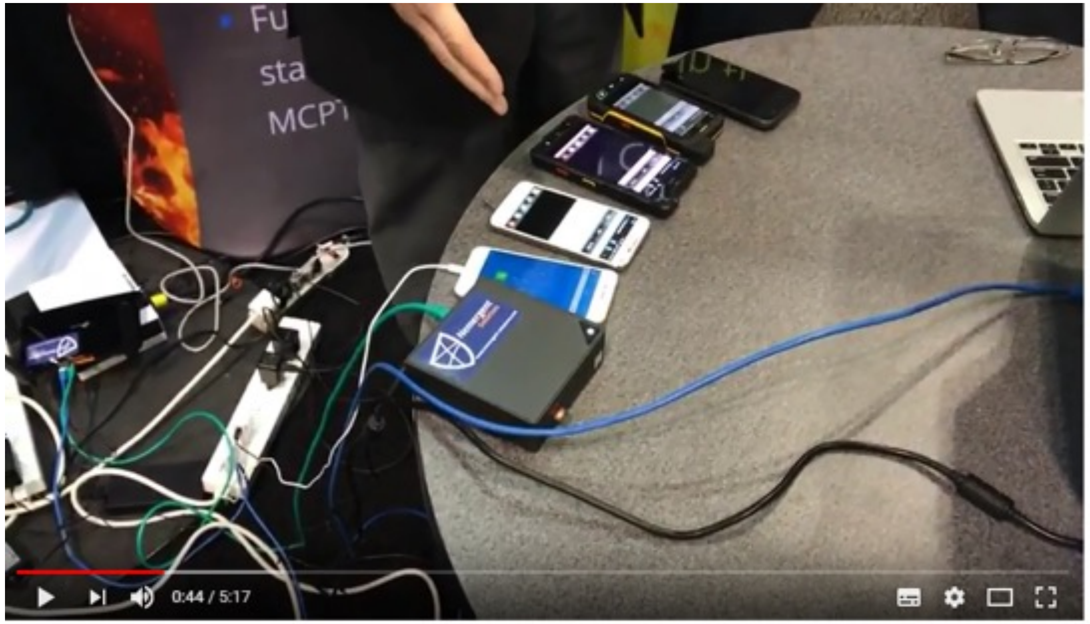
EVENTS

Orlando, FL
March 2018

INTERNATIONAL WIRELESS COMMUNICATIONS EXPO

- MCPTT + MCVideo demos
- Onsite + Online servers
- XP8 + SONIM branded GUI





PSIAP work

EVENTS

TCCA CRITICAL COMMUNICATIONS SERIES 2018

Berlin, Germany
May 2018

Dissemination

- Nemergent booth
- MCPTT + MCVideo + MCData
- Onsite servers + LTE
- XP8 with MCPTT QCIs

Public Safety Innovation Accelerator Program (PSIAP)

- Client UE/ application
- Technical work
- Functional & performance testing
- Test deployments
- Dissemination
- **Project summary**
- Demonstration
- Q & A

Project Objectives Revisited

First Year Progress – Highlights – Platform Integrations

- Server side
  - Full 3GPP R13 compliant servers with QoS and eMBMS support
  - Ongoing evolution to R14
- Client side
  - Hardware button integration for PTT, Yellow and Red keys
  - Channel Selection Module SDK and Integration on MCPTT client
  - DSP Audio calibration for MCPTT, resulting in enhanced audio clarity and noise cancellation
  - QCI Integration
  - eMBMS integration using Qualcomm middleware
- KPI measurements

Sonim Technologies, Inc.
PSIAP - Project: End-to-End Mission Critical Push-to-Talk: beginning June 1 2017
NIST # 70NANB17H179

G = June 1st

Table 1: Project Deliverables and Timeline Revised

Section	Deliverable	Owner	Date
Section 3.1.1	**Service Integration**		
	PTT App Integration on UE	Sonim/Nemergent	G+ 2W
	ISIM API/APN for data connection	Sonim/Nemergent	G+ 14W
	MCPTT Integration - Service Level	Nemergent	G+ 40W
	QCI integration / Broadcast Services	Sonim/Nemergent	G+ 40W
	E2E Broadcast Services SDK	Sonim	G+ 52W
	Service Level Integration SDK Pkg	Sonim	G+ 52W
Section 3.1.2	**Mission Critical Experience**		
	PTT Key integration / SDK	Sonim	G+ 2W
	PTT Android framework modifications	Sonim	G+ 14W
	PTT SDK / guide	Sonim	G+ 40W
	PTT Audio path demo	Sonim	G+ 52W
	CSM - Generic API	Sonim	G+ 14W
	CSM Accessory Prototype for UE	Sonim	G+ 30W
	MCPTT integration with CSM	Sonim	G+ 40W
	CSM SDK Pkg	Sonim	G+ 40W
Section 3.2	**MCPTT Server Components**		
	First Release of MCPTT System	Nemergent	G+ 2W
	Second Release of MCPTT Management Servers	Nemergent	G+ 30W
	Second release of MCPTT AS	Nemergent	G+ 40W
Section 3.3	**Testing**		
	Integration Testing (Definition)	Nemergent/Sonim	G+ 14W
	Interoperability Testing	Nemergent	G+ 52-70W
	Field Testing	Sonim / Partner	G+ 52-80W
	Test Reports	Sonim	Per milestones

Legend
- TBD
- Completed
- In Progress

Objectives for 2018-2019

Better KPI

Better UI and UX

Presence and Location Integration

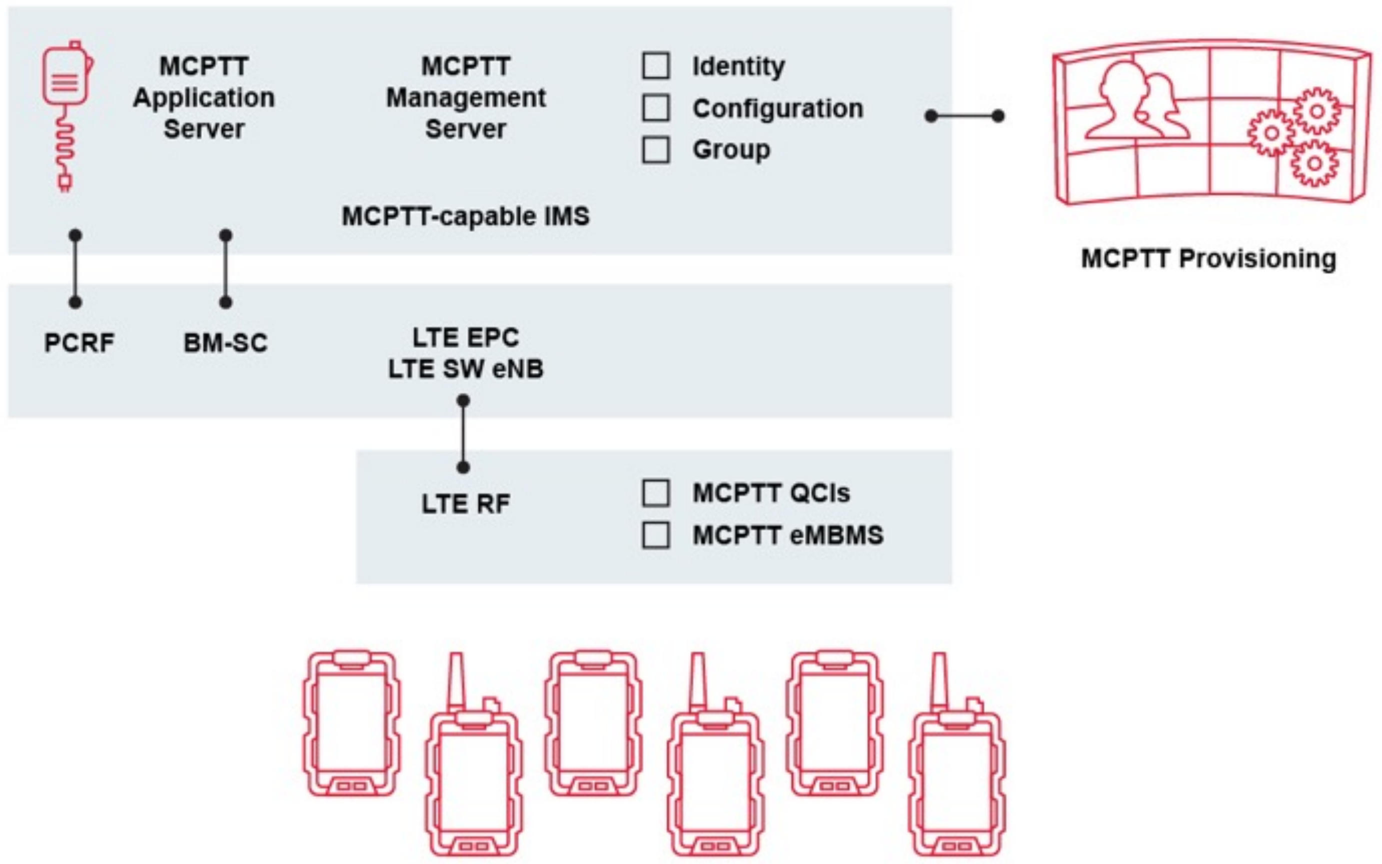
Contacts and Group Management

Rigorous Testing for Mission Critical Readiness

Public Safety Innovation Accelerator Program (PSIAP)

- Client UE/application
- Technical work
- Functional & performance testing
- Test deployments
- Dissemination
- Project summary
- **Demonstration**
- Q & A

Small scale / Portable demo



Portable MCPTT + IMS system

SW-based SDR LTE system

MCPTT compliant UEs

3GPP QoS support - QCI 65 and 69

3GPP eMBMS support

MCPTT GUIs (client, OAM, dispatch)

Protocol traces

Public Safety Innovation Acceleration Program (PSIAP)

- Client UE/ application
- Technical work
- Functional & performance testing
- Test deployments
- Dissemination
- Project summary
- Demonstration
- Q & A

NIST National Institute of Standards and Technology U.S. Department of Commerce
PSCR

sonim WE SERVE THE PEOPLE WHO SERVE US

Robert Escalle
Vice President

r.escalle@sonimtech.com
www.sonimtech.com

Nemergent / Solutions

Jose Oscar Fajardo
CEO

joseoscar.fajardo@nemergent-solutions.com
www.nemergent-solutions.com

Thank you.

National Institute of Standards and Technology
U.S. Department of Commerce

PSCR

sonim

Nemergent / Solutions

PSCR

Coverage, Capacity, & Resilience Enhancement in Limited Public Safety Network

Hyeong-Ah Choi, Amrinder Arora, Yanxiang Zhao; Gokhan Sahin; Wei Cheng

The George Washington U.; Miami U.; U. of Washington Tacoma

PSCR

AGENDA

- Project Overview
- LTE Multicast for Public Safety Networks
- Dynamic Coverage for First Responders
- Q&A

PSCR

Project Overview

- Objectives: To support communications for First Responders (FRs) through
  - Extending Coverage and Capacity
  - Real-time Scheduling of Relay Operation (on/off) and Coordination
  - Enhancing LTE Multicast Capabilities for PSN
  - QPP-Integrated Resource Allocation in LTE Multicast

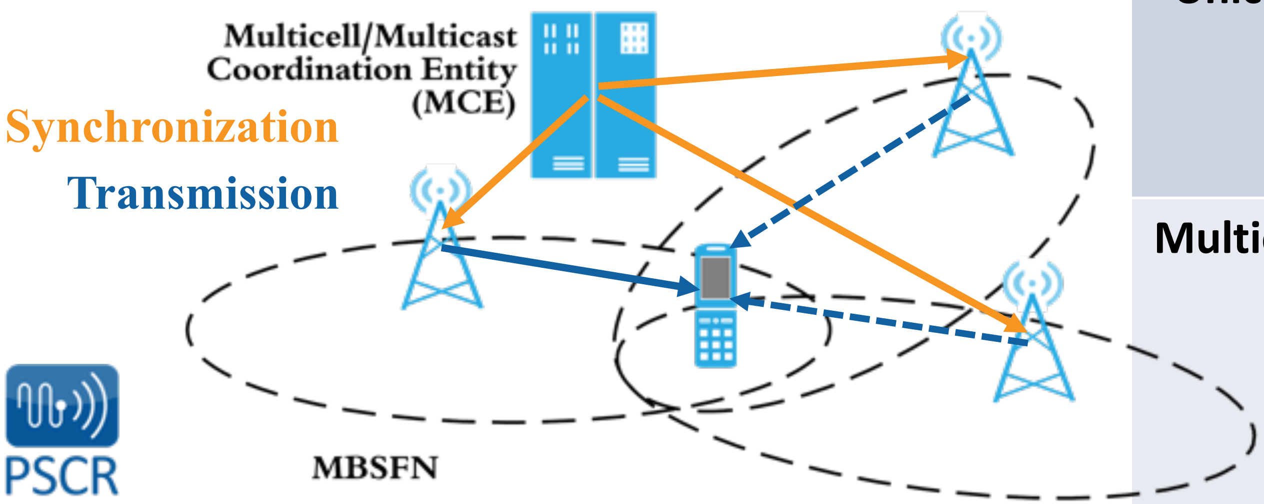
- Main Tasks
  - Investigation of prudent use of relays and mobile eNBs to support FRs through trajectory and placement optimization, and real-time scheduling of relay operation and coordination
  - Investigation of PSN-specific LTE Multicast incorporating QoS, prioritization, and preemption (QPP) for Mission-Critical Communications (MCC)

LTE Multicast in PSNs
Overview

- **P**ublic **S**afety **N**etwork
  - 700 MHz Spectrum by FCC
  - 10 MHz Bandwidth
- Spectrum Efficiency
- PSNs
  - Significant group traffic expected
  - Potential benefits from group communications, instead of transmitting identical contents through point-to-point communications
- **Goal**: To utilize LTE Multicast through optimized resource allocation

LTE Multicast in PSNs

- LTE 3GPP Standard, **e**nhanced **M**ultimedia **B**roadcast/**M**ulticast **S**ervice (eMBMS)
  - Transmission Mode: **M**ulticast/**B**roadcast **S**ingle **F**requency **N**etwork (MBSFN)
- **Merits**
  - Avoid transmitting identical contents multiple times
  - Improve SINR especially at cell edge
- **Issues**
  - Base Stations (BS) need to be tightly synchronized
  - Temporal and phase delays of arriving signals at UE side



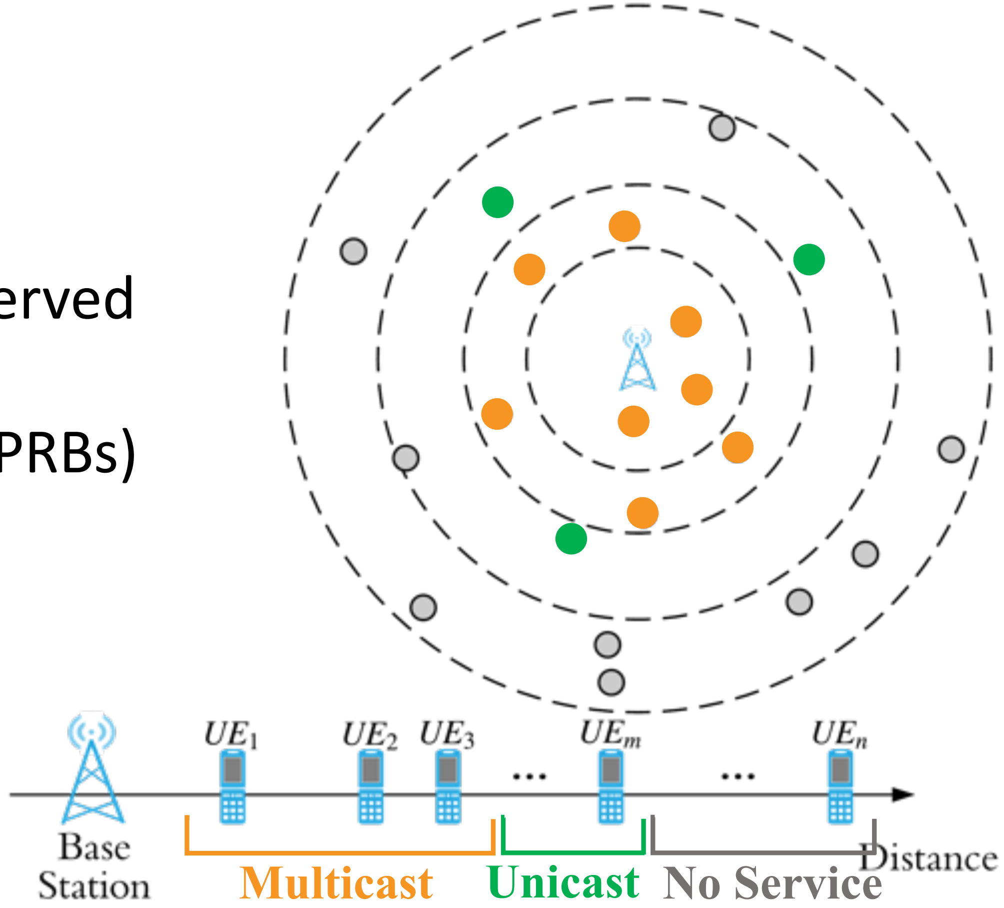
	Benefit	Overhead
Unicast	• MIMO utilized (higher Spectrum Efficiency)	• Same contents transmitted multiple times
Multicast	• Inter-cell Multipath Effect • Higher coverage area	• No MIMO capability • More Reference Signals for Synchronization, etc. • Extended CP (~15% less OFDM Symbols utilized)

PSCR

Optimal Allocation of MBSFN Resource

- Single Cell
- Non-Congested Situation
- **Goal**: To minimize the total number of MBSFN resources being used (in terms of PRBs) in order to serve all UEs within service area
- Congested Situation
- **Goal**: To maximize the number of UEs being served given an application with required Bit Rate and available MBSFN resources (in terms of PRBs)
  - Define $f_U(u_i)$ as number of PRBs needed to serve the $i^{\text{th.}}$ UE through Unicast
  - Similarly, define $f_M(u_i)$
  - **Observation**: $f_U(u_j) \leq f_M(u_j)$

- Single MBMS Service
- UEs may be served with Multicast or Unicast



PSCR

Optimal Allocation of MBSFN Resource
Main Results

1. Linear-time Optimal Algorithm

2. Linear-time Optimal Algorithm for Prioritized UEs
   - Quality of Service, Priority and Preemption (QPP)
     1. Lower priority UEs can be served only after all UEs of higher priorities being served
     2. Given the policy above satisfied, the goal is to maximize the number of UEs with Multicast or Unicast service

3. Linear-time Optimal Algorithm with Preemption Enabled
   - Remove active sessions of lower priority UEs to serve higher priority UEs
     - Removal is done in such a way that guarantees the number of UEs still being maximized

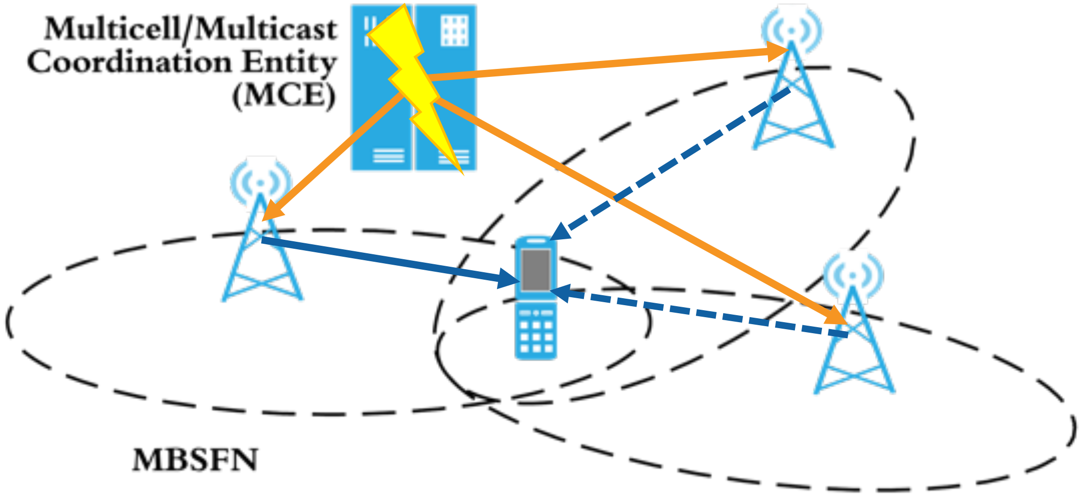
Optimal Allocation of MBSFN Resource
Significance of our Results

- Priority/QoS Key Parameters [FirstNet]
  - To manage priority access to the network (or cell)
  - To manage priority allocation of network (or cell)
    - ❖ Our algorithm can manage priority allocation for the MBSFN application
  - To ensure application performance during time of congestion/overload
    - ❖ Our algorithm can manage preemption of the MBSFN application users
  - To re-assign or preempt connected cell resources

Run Algorithm at MCE*

Synchronization

Transmission



Optimal Allocation of MBSFN Resource Algorithm

Algorithm 1 Optimal Allocation of MBSFN Resource in Single Cell

Input: UE Info. (*CQI*, *RI*), R

Output: Maximum Number of UEs with Multicast or Unicast Service

Compute q_0; // q_0 denotes the Maximum Number of // UEs Served with Unicast-only

$max \leftarrow q_0$;

$m \leftarrow 1$;

while $(f_M(u_m) \leq R)$ **do**

  if $(f_M(u_m) + F_U(m+1, max) \leq R)$ **then**

    $q_m \leftarrow max$;

    $A_m \leftarrow R - f_M(u_m) - F_U(m+1, max)$;

    $i \leftarrow q_{m+1}$;

    while $(f_U(u_i)) \leq A_m$ **do**

      $q_m \leftarrow i$;

      $A_m \leftarrow A_m - f_U(u_i)$;

      $i \leftarrow i + 1$;

    end while

    $max \leftarrow q_m$;

  end if

  $m \leftarrow m + 1$;

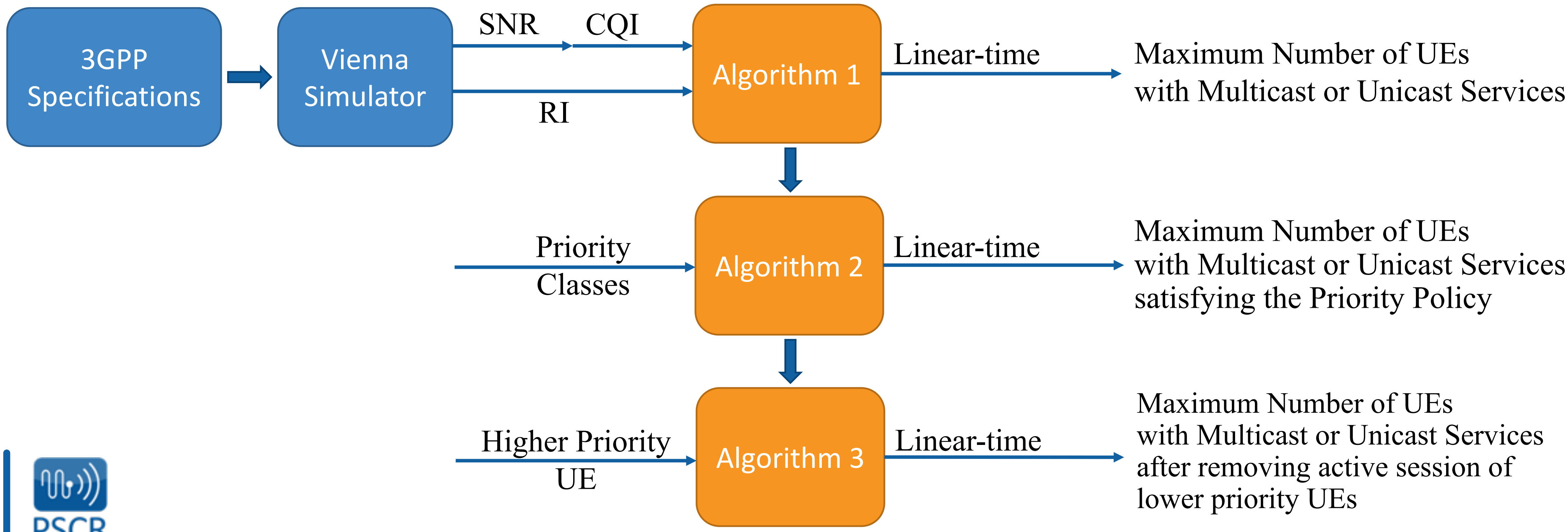
end while

return max;

PSCR

Optimal Allocation of MBSFN Resource Simulation Results

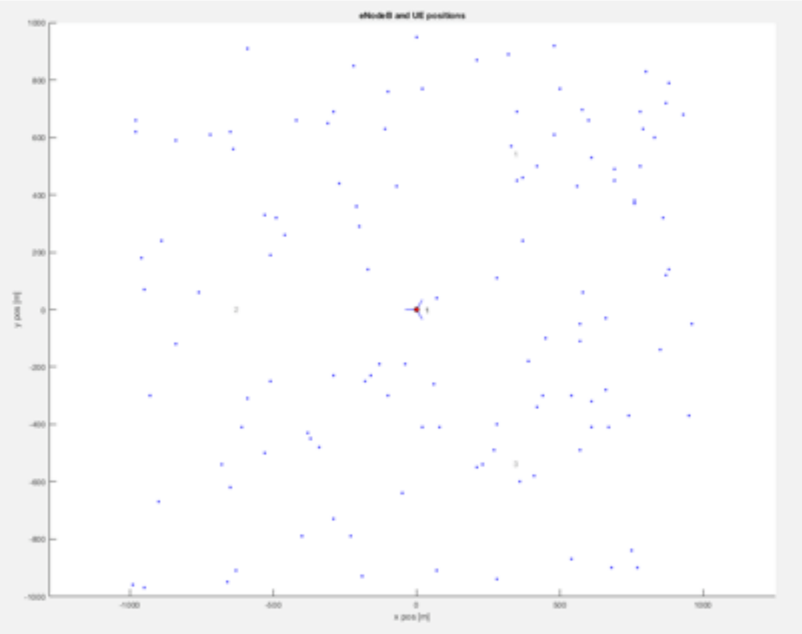
- Simulation Environment
  - Vienna LTE-A Downlink System Level Simulator implemented in MATLAB

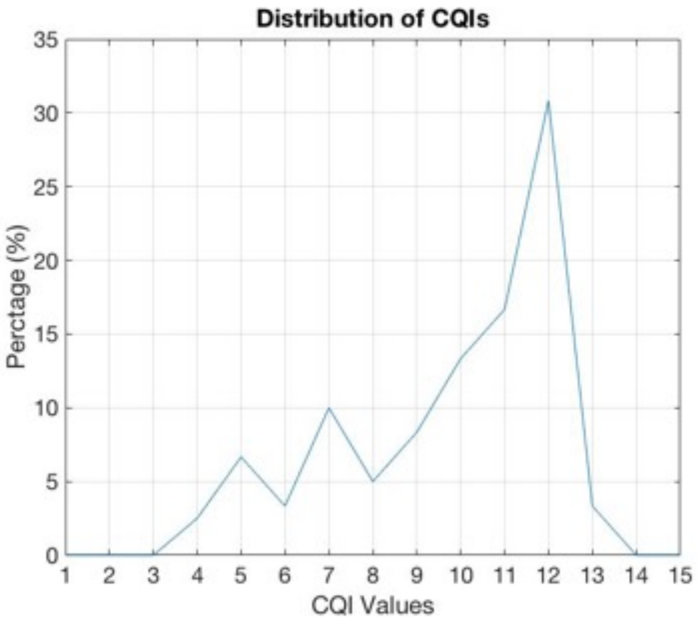


PSCR

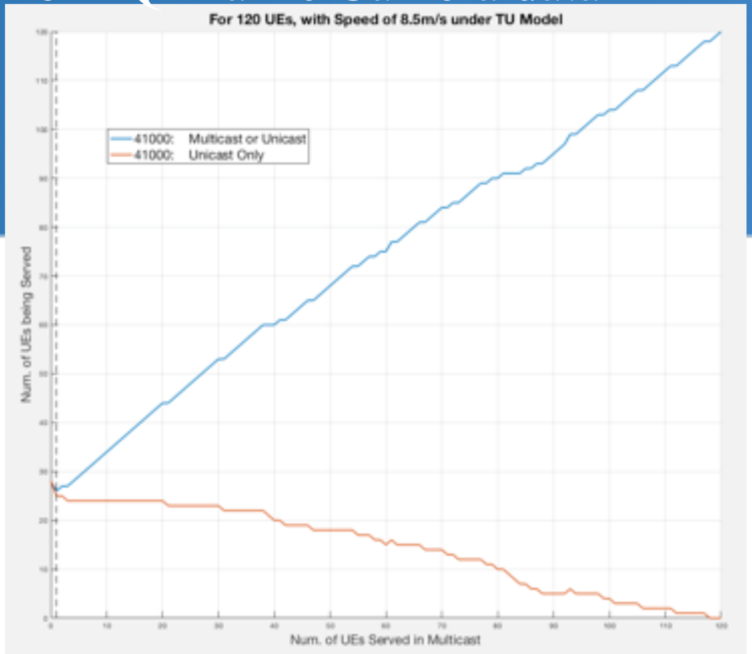
Optimal Allocation of MBSFN Resource Simulation Results

- Simulation Parameters
  - 120 UEs
  - $R = 500$ (10 ms period; 1 LTE Frame length)

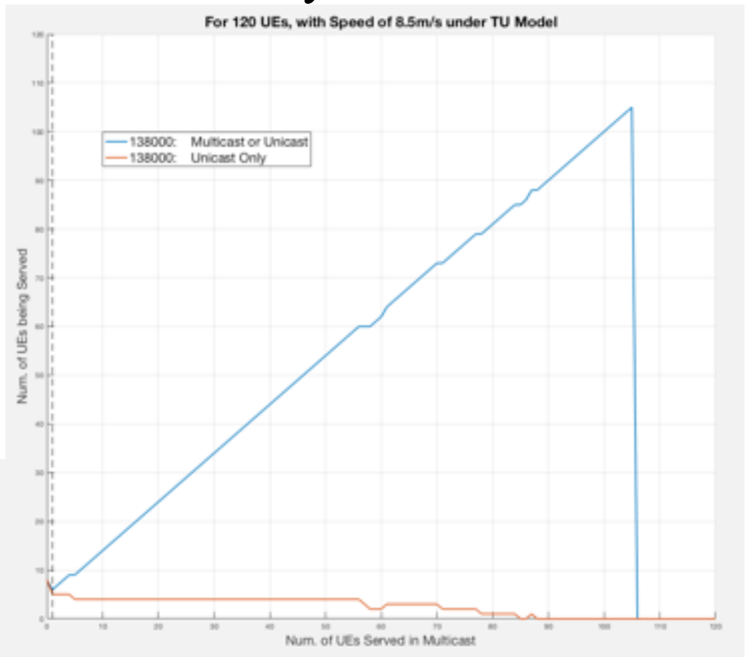




For LQ Traffic Camera data



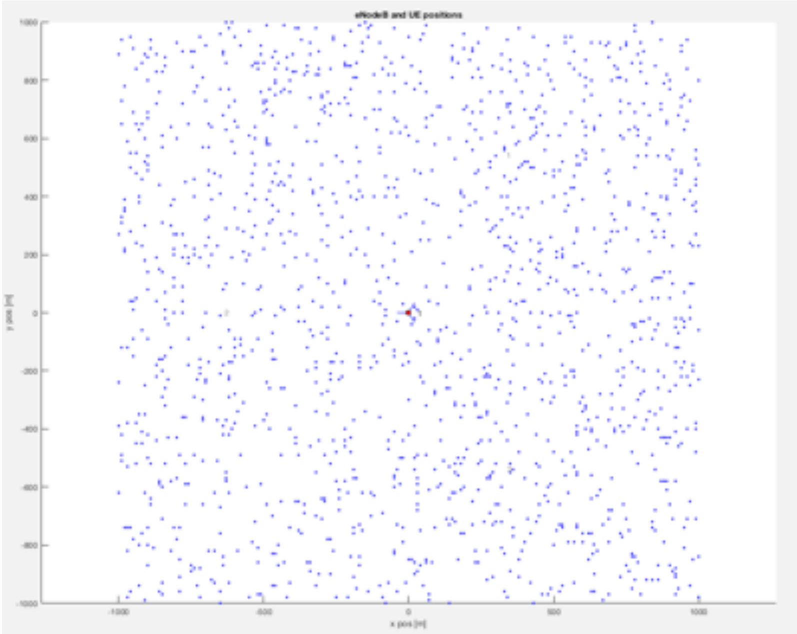
For Telemetry data

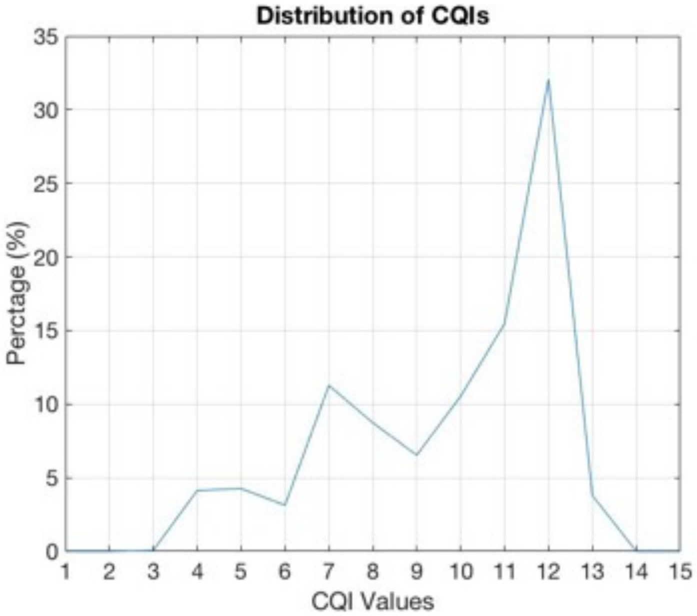


PSCR

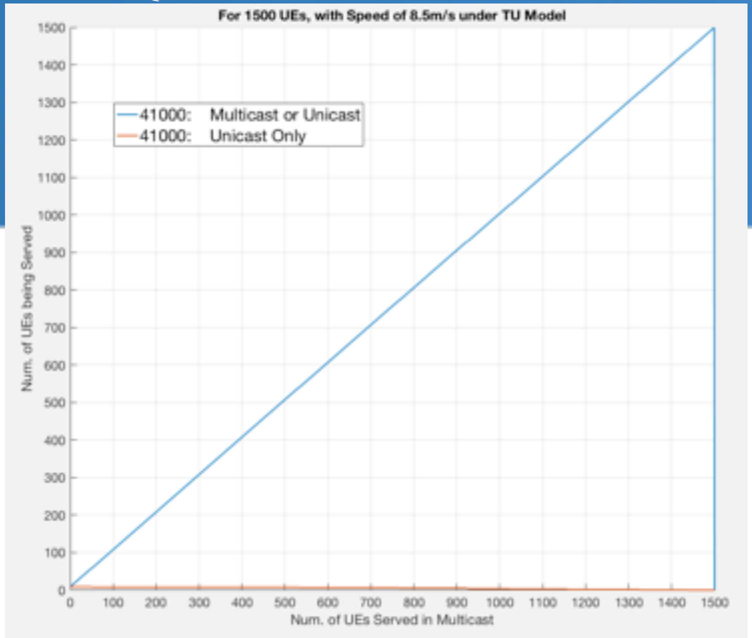
Optimal Allocation of MBSFN Resource Simulation Results

- Simulation Parameters
  - 1500 UEs
  - $R = 500$ (10 ms period; 1 LTE Frame length)

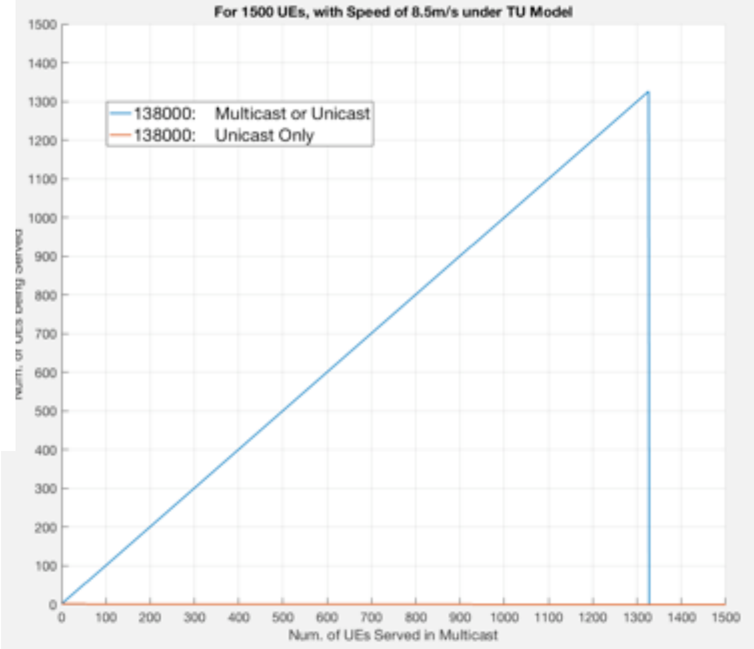




For LQ Traffic Camera data



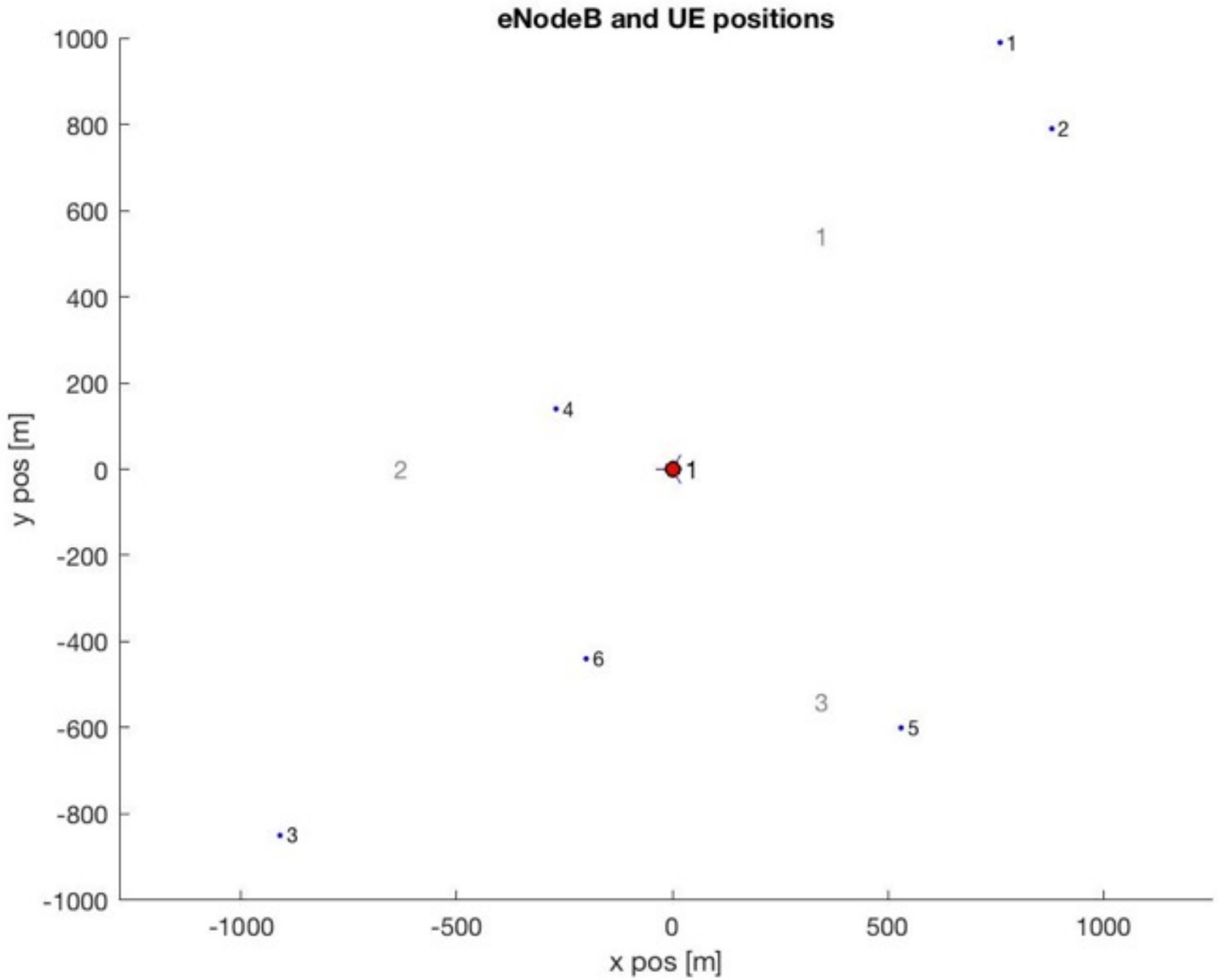
For Telemetry data

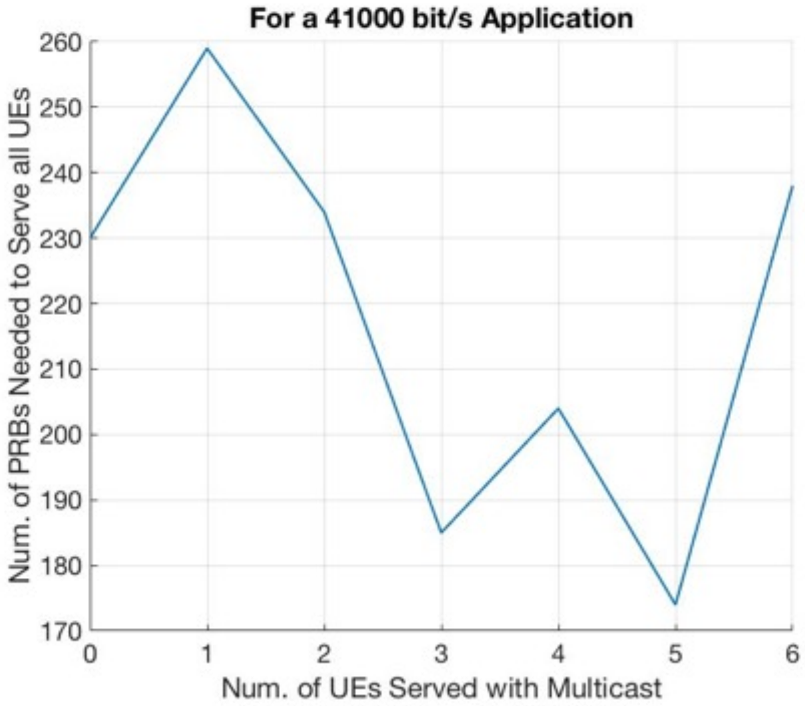


PSCR

Optimal Allocation of MBSFN Resource Simulation Results

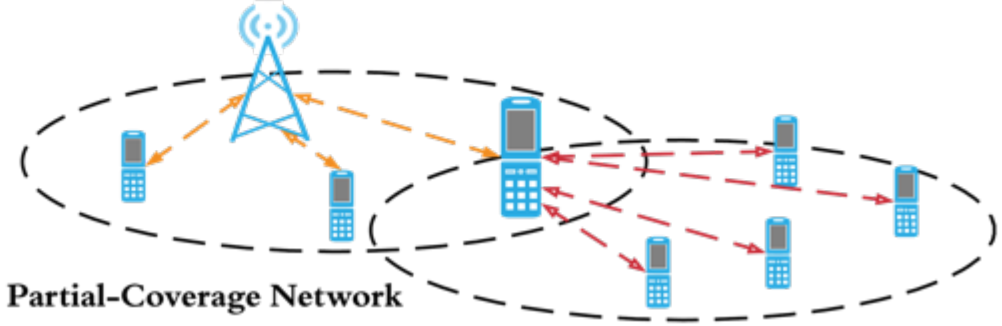
UE	CQI	RI	$f_M(u_i)$	$f_U(u_i)$
1	5	3	238	71
2	9	3	103	30
3	9	3	103	30
4	13	2	54	25
5	13	1	54	49
6	13	2	54	25

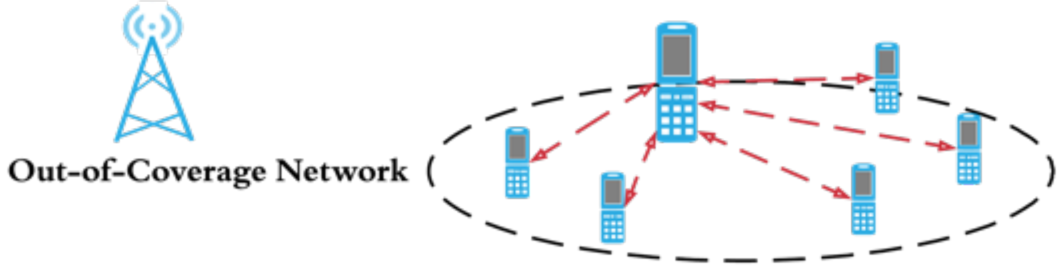




Year-2 Plan

- Multi-Cell MBSFN
  - Revisit single-cell condition: $f_M(u_j) \geq f_U(u_j)$
  - Complete investigation* on inter-cell multipath effect
  - Optimal algorithms
- Off-Network
  - Two Coverage Scenarios
  - 3GPP ProSe Specification
  - Optimal algorithms
    - Uplink and Sidelink Transmissions





Dynamic Coverage for First Responders

- Limited Wireless Network Access
- LTE Framework Mobile Base Station
- Optimal Locations for Base Station Deployment
- Mobility and Priority Analysis

Introduction

- First Responders (FRs) may not have wireless network access due to catastrophic scenarios
- Mobile Base Stations (mBS) under LTE framework, with little modifications, can provide wireless services for FRs

- **Dynamic Nature**: FRs move around; mBS can also be re-located
- **Our Focus**: Optimal location(s) to deploy the mBS in order to maximize the number of FRs served with their corresponding Bit Rate requirements

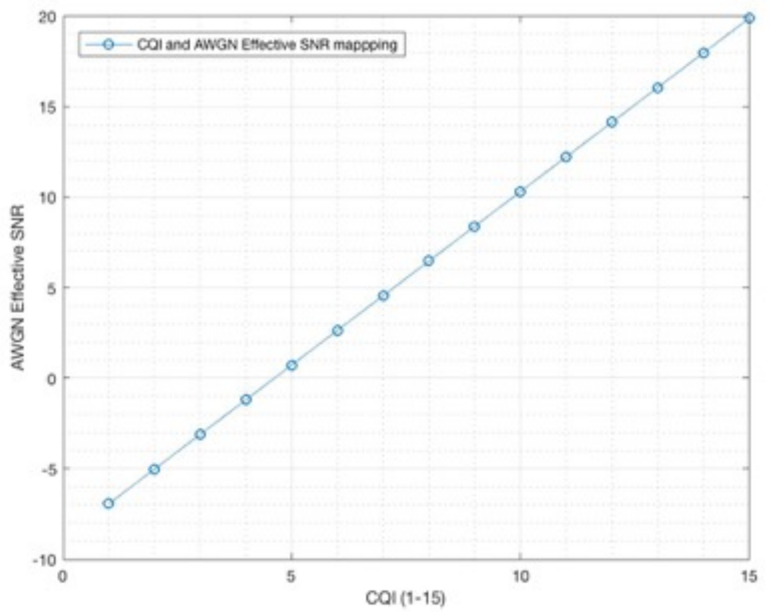
- Take into account application priority classes and user priority classes

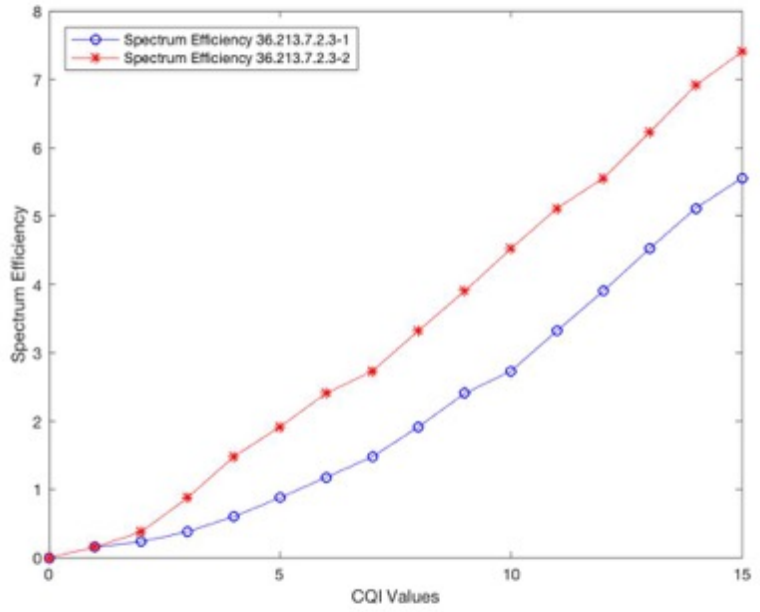
Accommodating Different Operational Policies – Quantification Mechanism

- User Priority
  - Immediate Peril, Responder Emergency, Out-of-service, etc.
- Application Priority
  - Mission Critical Voice, Audio and Video Streaming, etc.
- Operational Policy Constants for each user/application class combination
- Identify UEs for which the Bit Rate requirements are met
- Weighted sum of Operational Policy Constants

Evaluating a Placement

- Establish the UE-mBS affiliations
- Calculate SINR → CQI → Spectrum Efficiency → Bit Rate
- Evaluate if Bit Rate meets the requirement
- Evaluate the Weighted Satisfaction Score





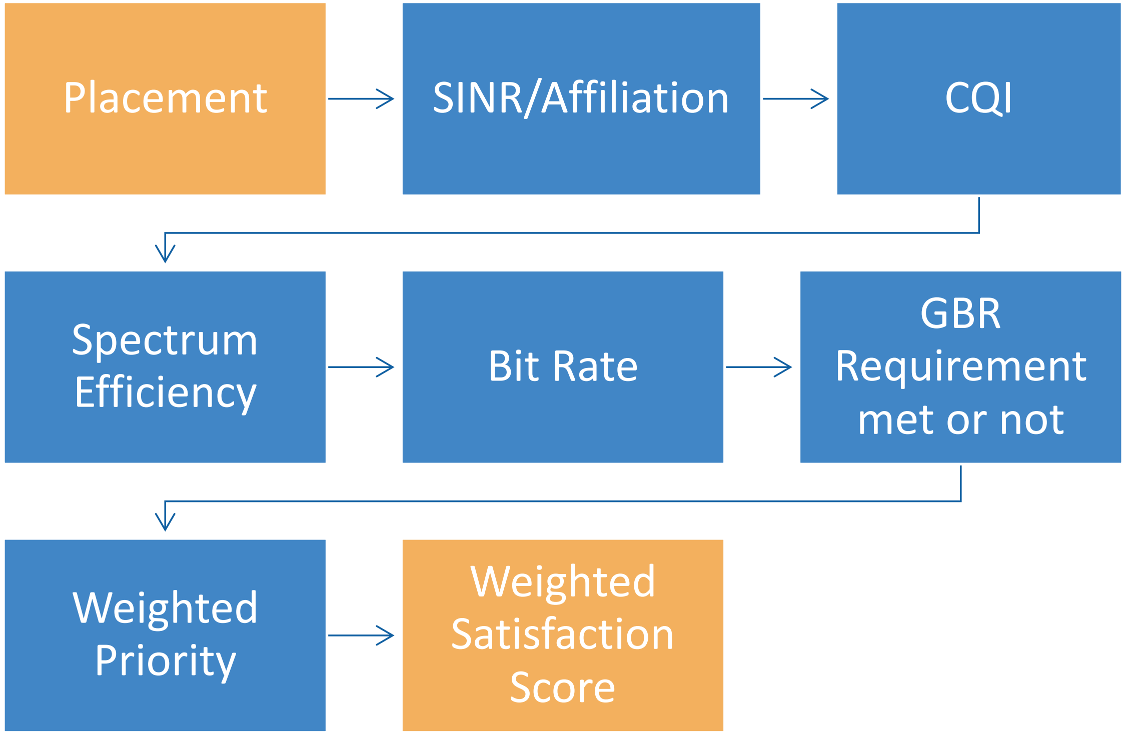
Upper figure: Vienna DL System Simulator

Lower figure: 3GPP 36.213.7.2.3-1,2

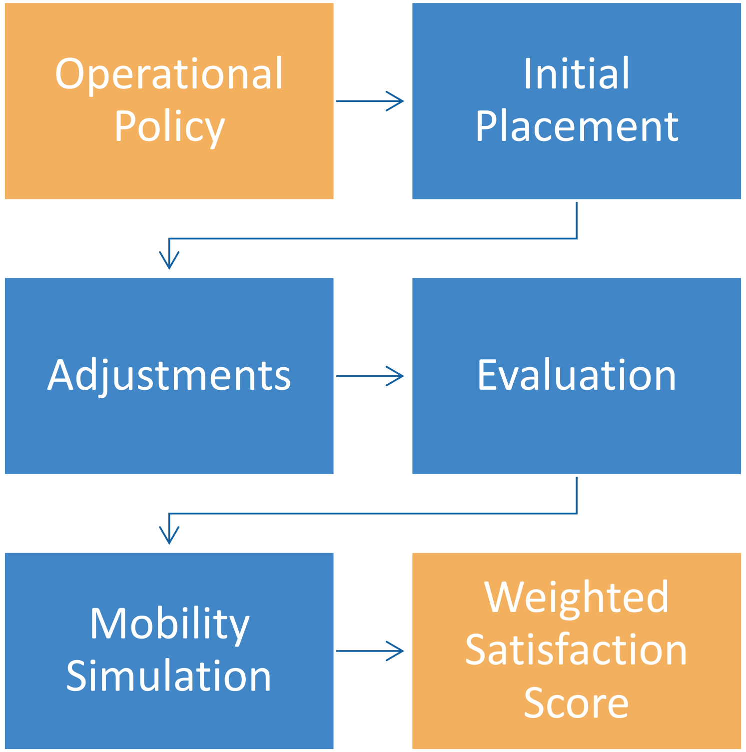
PSCR

Structure of the Simulator

Placement Evaluation

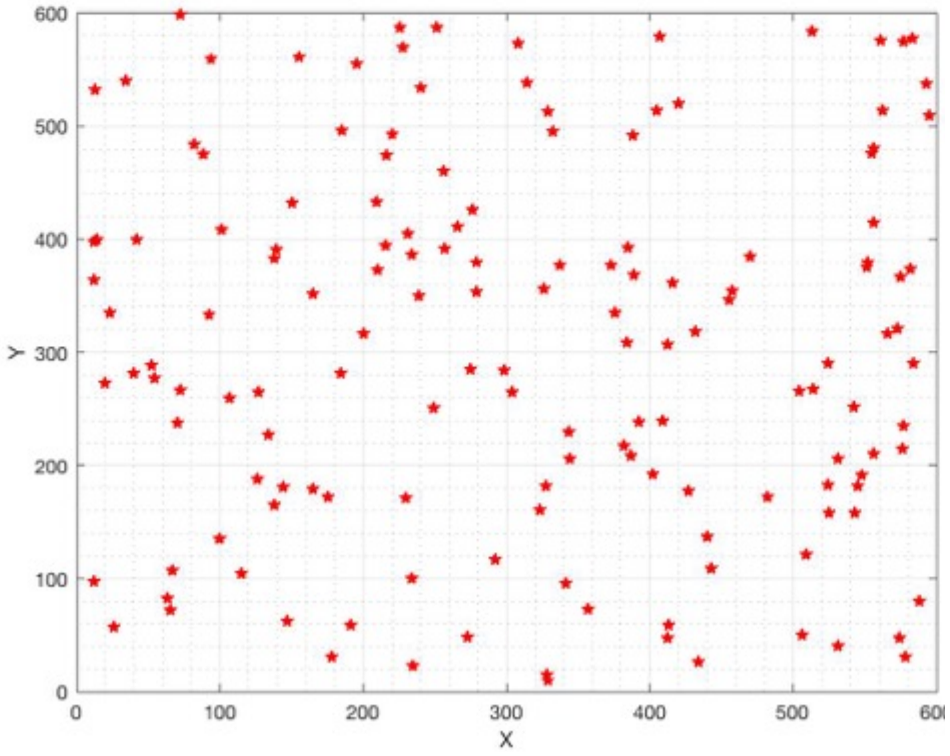


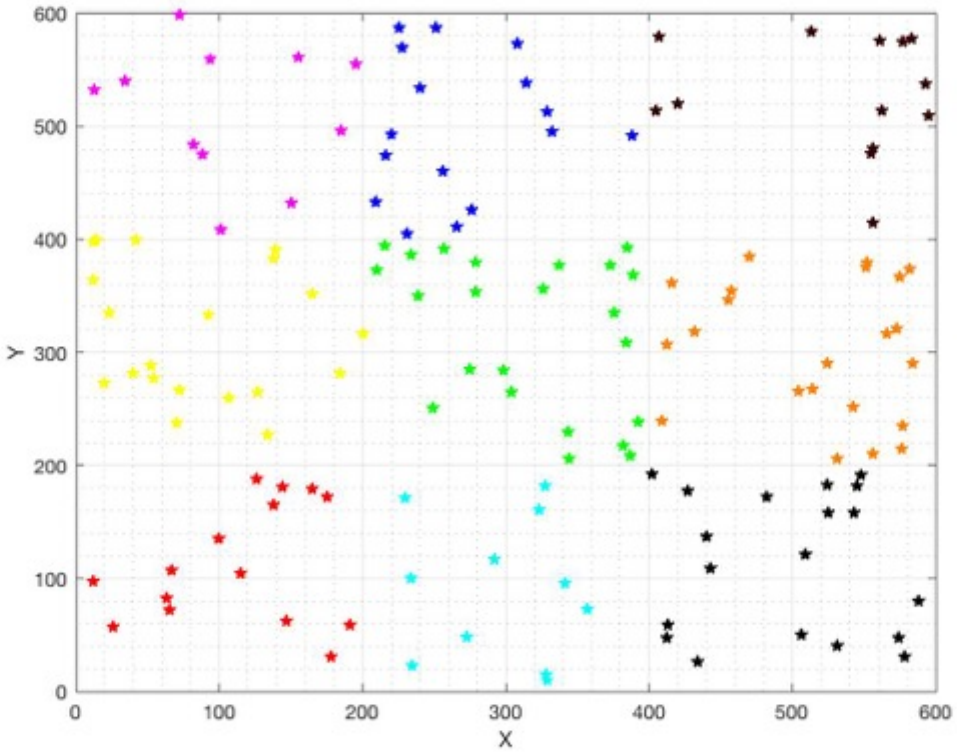
Placement Calculation



Comparing Placement Algorithms

Static Equal Sized Blocks // Baseline

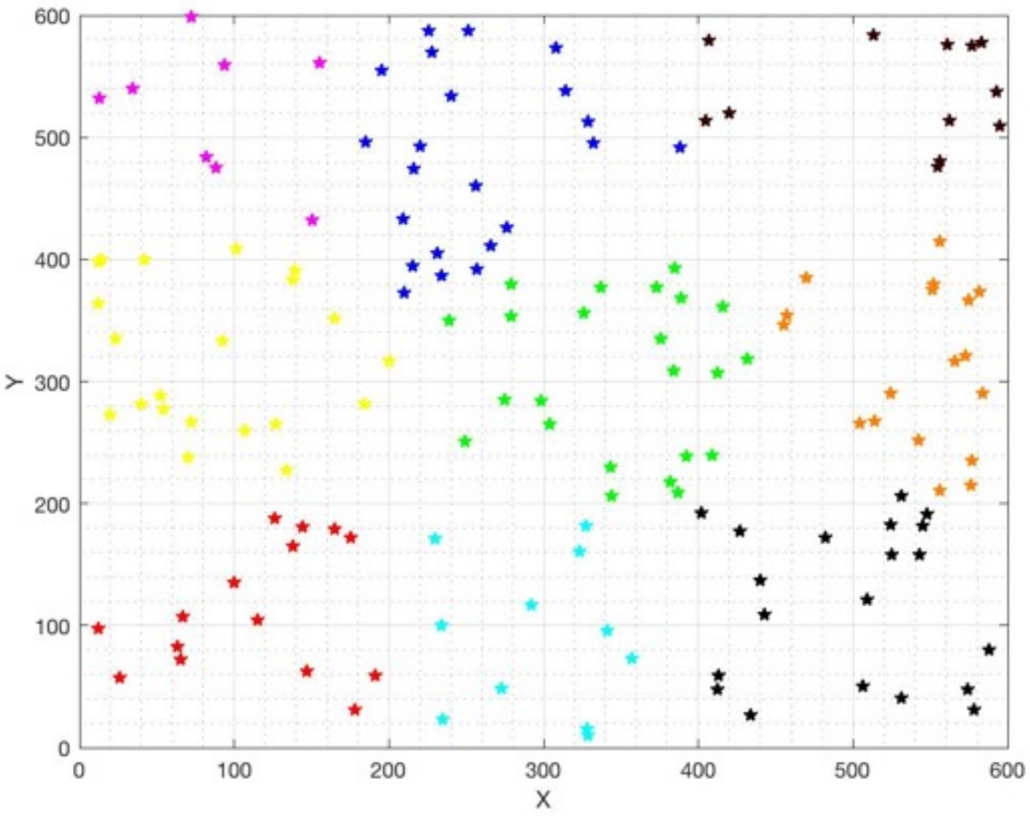




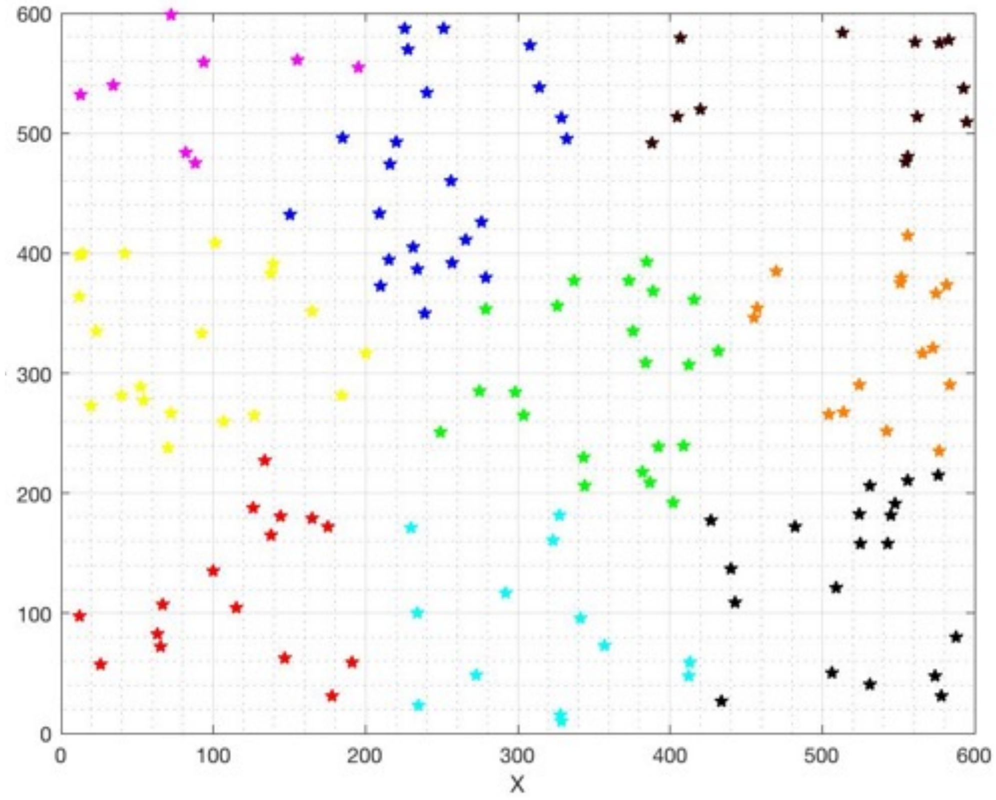
PSCR

Comparing Placement Algorithms

k-Means (Distance)



GBR and priority weighted k-Means



Weighted k-Means

- Disadvantage of k-Means
  - Some UEs have very low SINR with their affiliated mBS
  - These UEs may have higher priority classes

- k-Means doesn’t take priority into account
- Weighted k-Means Clustering attempts to eliminate those scenarios

Empirical Results

- Simulation over 100 scenarios

Number of FRs	Number of mBS	SESB	k-Means	Weighted k-Means
50	4	409.53	508.91	582.36
100	4	815.72	916.41	997.38
150	4	1239.5	1333.5	1410.1
150	9	2522.8	2771.4	2954.1

Understanding Movement Dynamics

- UEs (FRs) move around due to operational requirements
- One mBS placement that is optimal at one time instant may no longer be optimal at the next instant
- Weighted Satisfaction Score after movements
- Cost classes of mBS – Different base stations may have different costs in order to be moved around (and associated time delays)
- Depending on the mBS cost classes, we calculate a placement that performs well when taking the mobility of UEs into accounts

PSCR

Empirical Results - Dynamic Nature

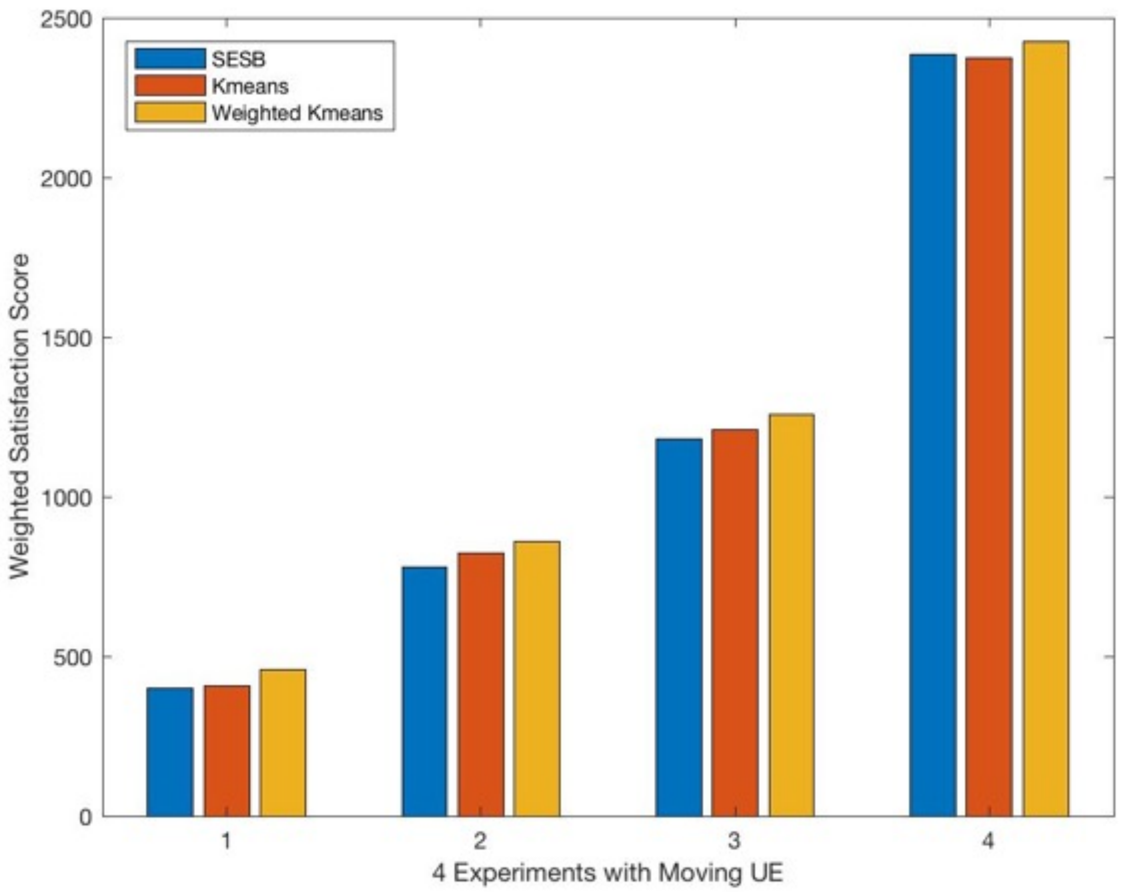
- Simulation over 100 scenarios with moving UEs

Number of FRs	Number of mBS	SESB	k-Means	Weighted k-Means
50	4	399.77	408.3	459.73
100	4	777.57	823.32	860.92
150	4	1181.4	1208.1	1258.9
150	9	2385.0	2374.6	2423.5

Results Snapshot

- Moving and re-affiliating UEs by closest mBS, weighted k-Means still performs the best, with little advantage over SESB which doesn't take UE locations into account

- Overall, both k-Means and its weighted version degrade significantly with the movement of the UEs



PSCR

PSCR

Q & A


PSCR
THANK YOU
COLORADO
SPRINGS
5

“PROXIMITY SERVICE EVALUATION & EXTENSIONS”
IMPROVING BROADBAND DIRECT COMMUNICATIONS

PSCR Grant Funded (Commerce Dept.)
1 June 2018

HARRIS® TECHNOLOGY TO CONNECT, INFORM AND PROTECT™

PSIAP ProSe

Description/ key features

- Developing profiles and extensions to ProSe that align its capabilities with First Responder expectations and needs

Key success factors

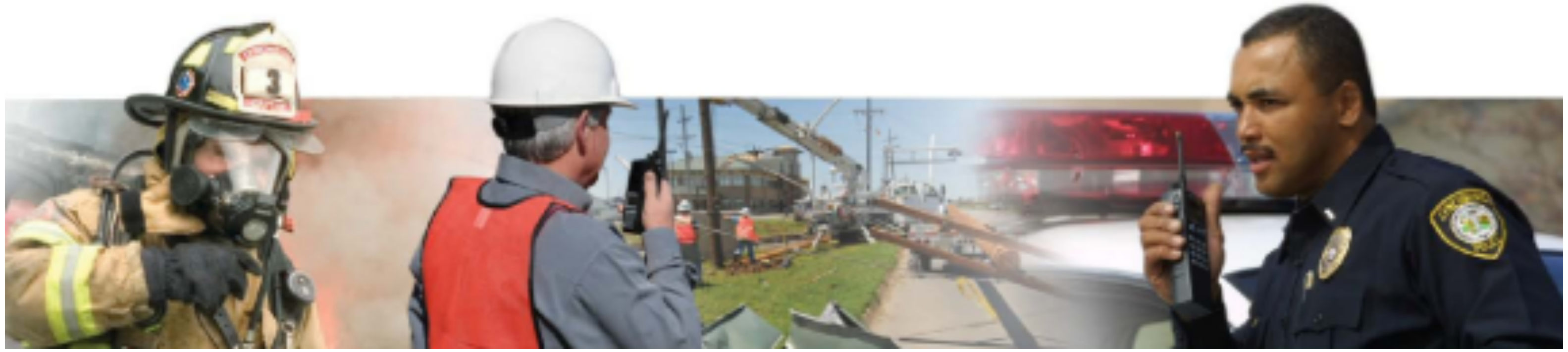
- Matching the reliability and coverage of existing LMR direct communication capabilities
- Enabling new services with ease of use, continuity across network domains, and data services via PS profiles and extensions

Market

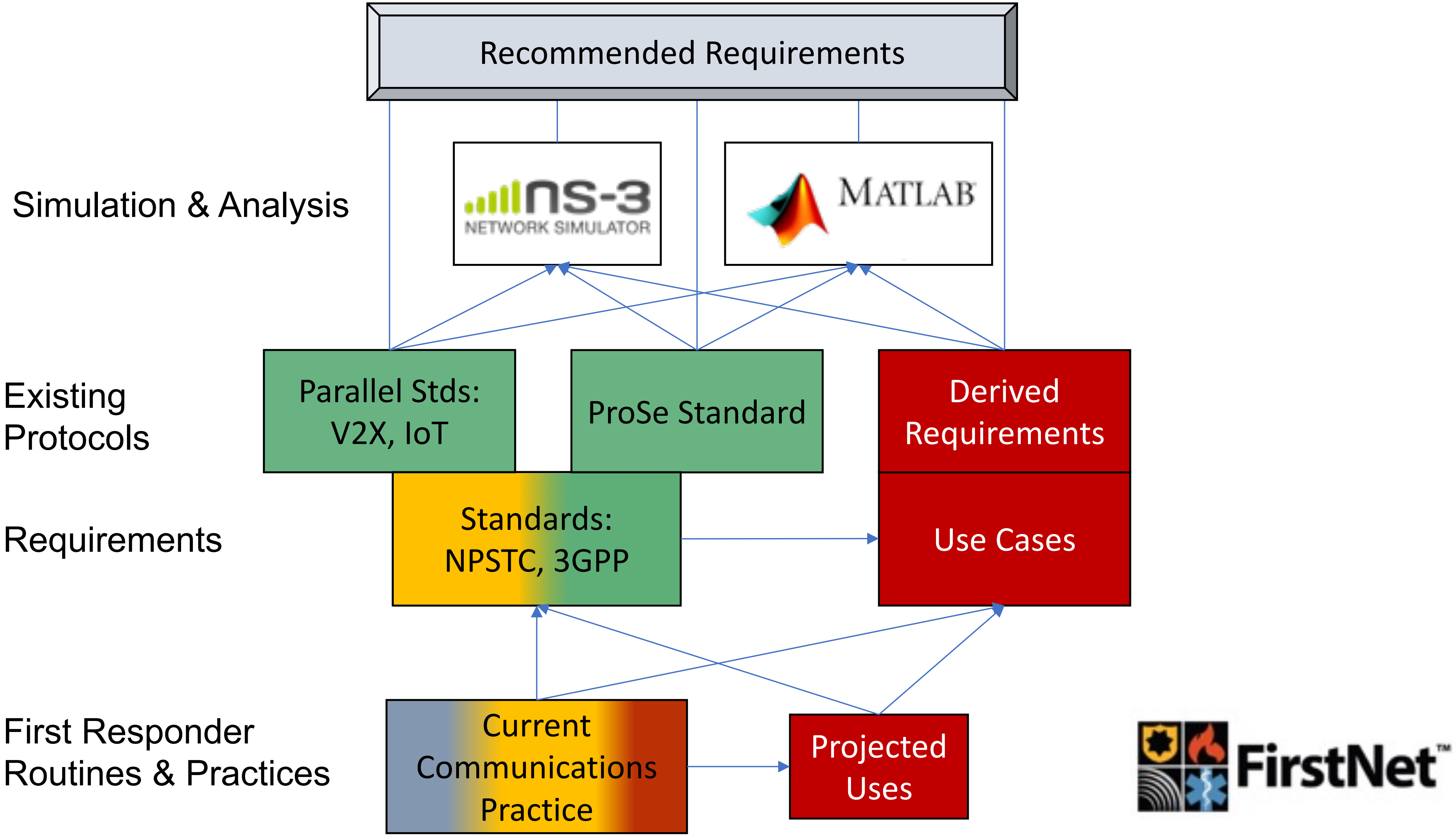
- Direct communication is required for all public safety communication systems
- ProSe is the only broadband direct communication standard designed to address this requirement

Research approach

- Use cases
- Physical layer simulation
- Synchronization
- Group ARQ transmission
- Upper layer research
- Demo
- Questions?



Method



Recommended Requirements
Simulation & Analysis
ns-3
NETWORK SIMULATOR
MATLAB
Existing
Protocols
Parallel Stds:
V2X, IoT
ProSe Standard
Derived
Requirements
Requirements
Standards:
NPSTC, 3GPP
Use Cases
First Responder
Routines & Practices
Current
Communications
Practice
Projected
Uses
FirstNet™

LTE-direct standards development/ releases

ProSe

R11 High Power UE for B14
March 2013
Improved UL coverage for PS/ ProSe benefits (Regulatory challenge with portables)

R12 Study/ Initial ProSe
March 2015
Multicast communications/ no ACK/ no relays/ limited discovery

R13 eProSe
March 2016
Unicast communications/ HARQ/ multiple bands/ network relay and priority support (PS)

R14 FeProSe
June 2017
Study on FeProSe network relays for IoT & wearables
(power consumption focus) / ProSe conformance requirements

Release 15 FeProSe
September 2018
Limited normative work: network relays for IoT & wearables

Chipset availability uncertain (shared carrier required in US)

V2X

R13 V2X
March 2016
Feasibility study based on ProSe PC5 (ProSe waveform)

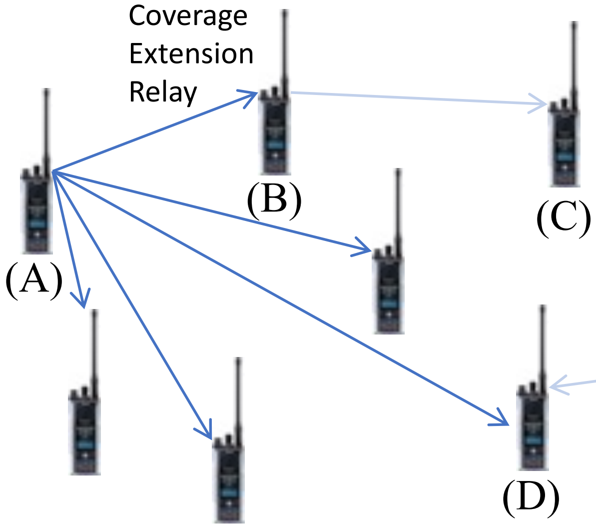
R14 V2X
June 2017
Sept 2016 RAN announces initial spec with enhancements before R14 date
Sept 2017 Qualcomm announces trials of 9150 chip set
High power devices allowed for the service

Release 15 5G
September 2018
Multi-carrier aggregation/ 64 QAM / power Class 2/ extended sensors
Support for: platooning, advance driving, remote driving

Chipset trials underway (dedicated carrier now; R15 shared)

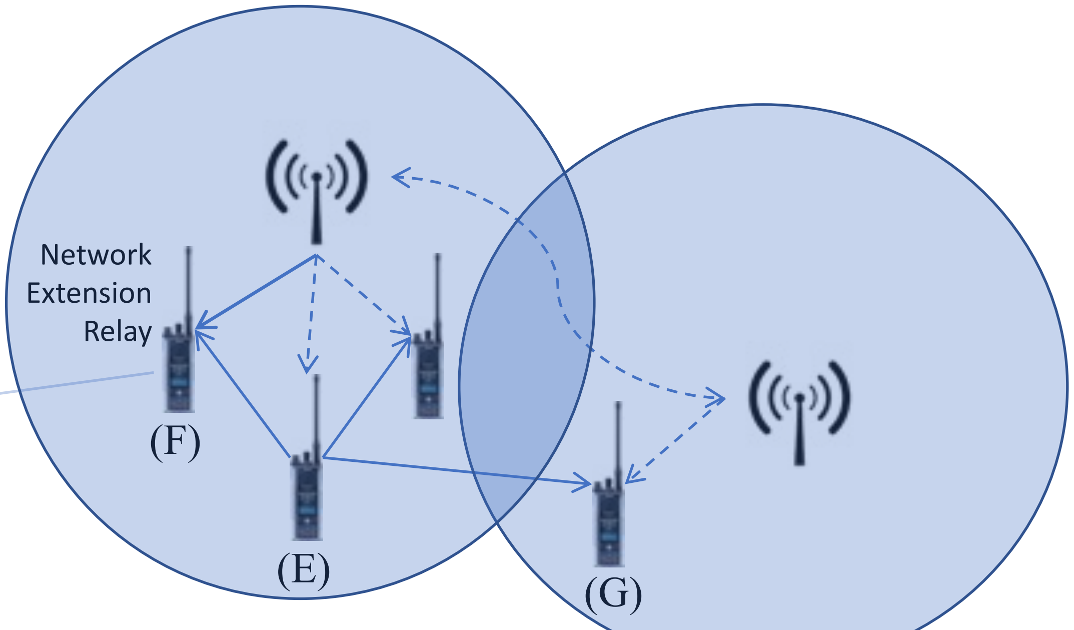
Proximity service communication

Out-of-network
direct communications
(public safety only)

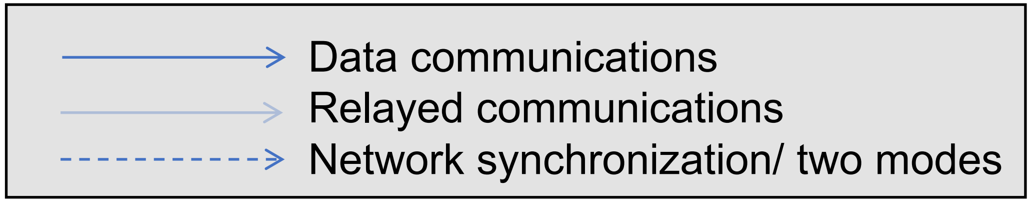


Mode2: provisioned Tx resource pool
(time & frequency allocations

In-network
direct communications



Mode1: eNB scheduling
Mode2: provisioned Tx resource pool (PS only)



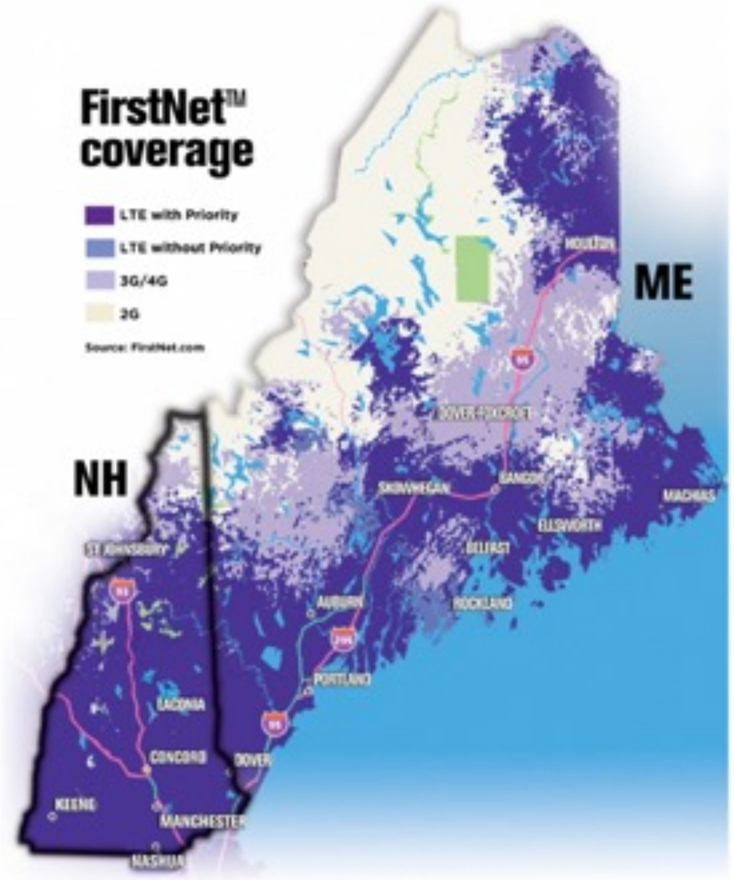
Similar or greater RF link distances to legacy capabilities

- Serves sparse communications without supporting nodes or relays
- Communications distances should not be limited by protocol

Reliable communications

- Should occur quickly after power on
- Should be unaffected by device movement
- Should be limited by physics not protocol

Mission Critical Communications

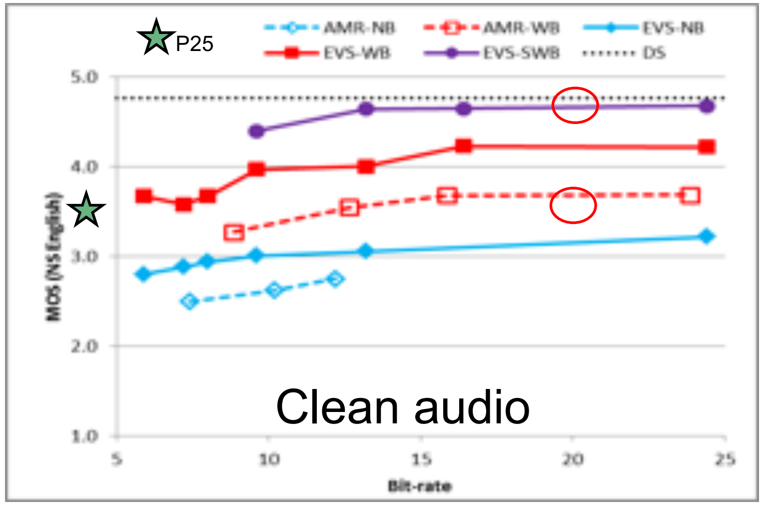


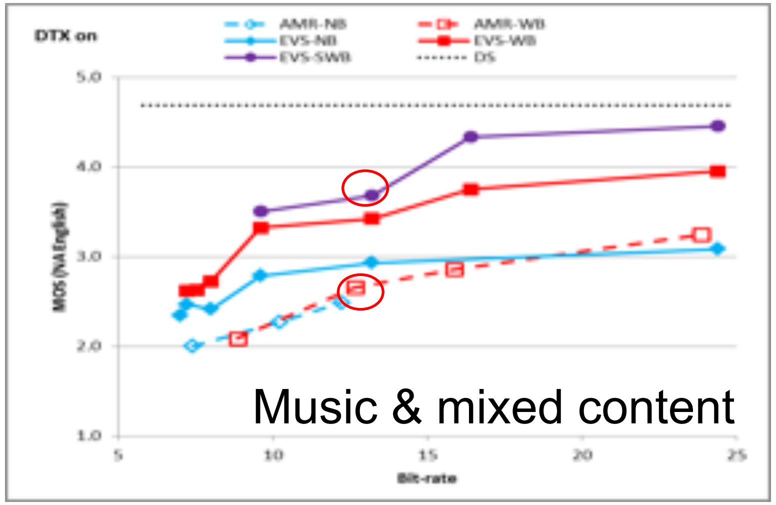
Legacy P25: AMBE 3.6 kbps

- Perceived challenges: audio quality & performance with acoustic noise

3GPP Codec evaluations focus on these issues

- Performance in noisy audio conditions
  - The claim is made that AMR-WB will have acceptable performance when noise cancellation is applied.
  - EVS –benefits from dynamically coding in voice and waveform models
- AMR-WB – mandatory recommended CODEC: 12.65 kbps: 2% FEC
- EVS-SWB – recommended optional CODEC: 13.2 kbps: 8% FEC CA

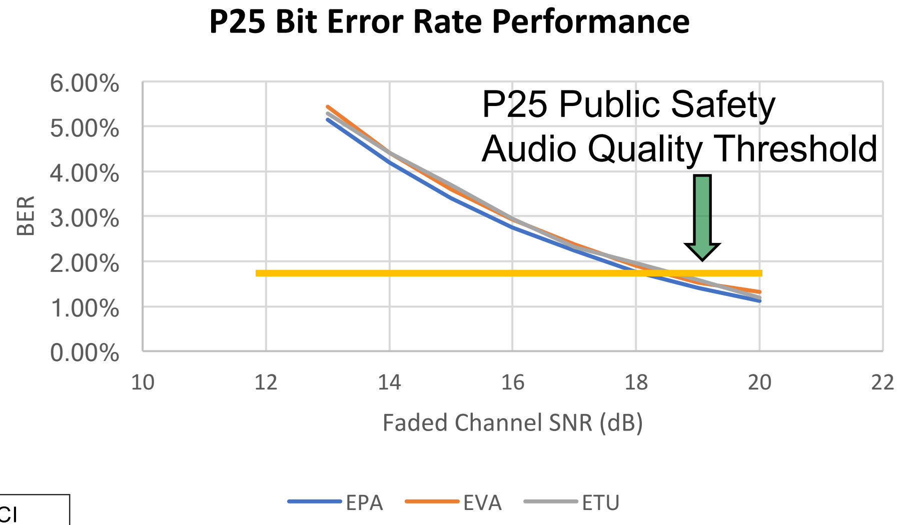


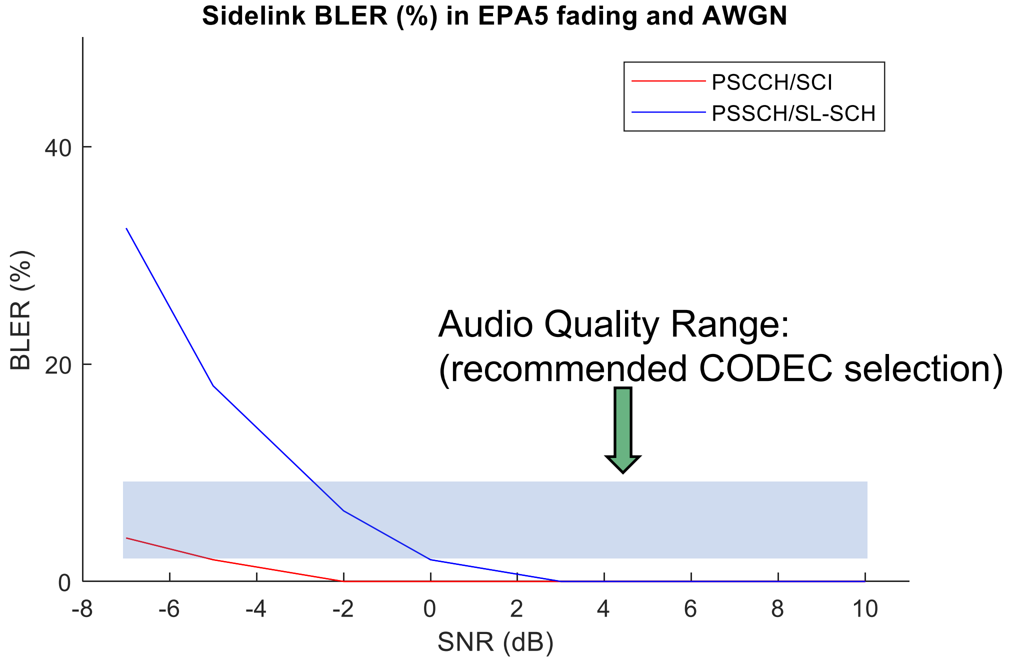


Simulated performance

Direct Communications Range

- P25
  - Fixed range
- ProSe
  - Throughput dependent





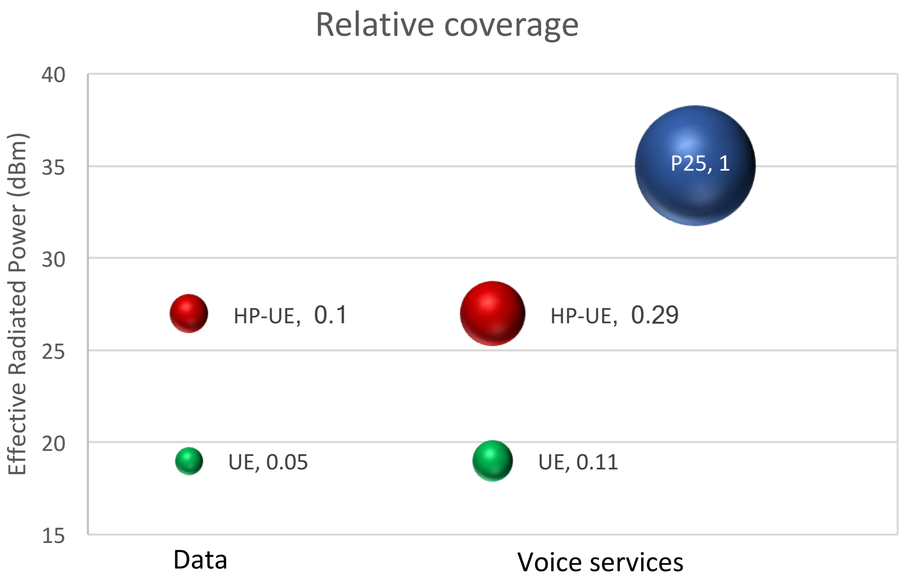
Relative coverage

Basis for coverage comparison between P25 and ProSe

- Represents best case scenario
- Coverage decreases with increasing throughput for data services

	P25 Portable	Portable	HP-UE Portable
Nominal Tx Power	35	23	31
MIMO	1x1	1x2	1x2
Rx Effective IF Bandwidth (kHz)	6	360	360
Rx Noise Figure (dB)	6	7	7
Faded Performance Threshold DAQ3.4 (dB)	17.7	-2.2	-2.2
Maximum RF Coupling Loss (dB)	147.5	136.6	144.6
Antenna Efficiency. (dB)	0	-4	-4
Maximum Link Loss	147.5	128.6	136.6
Radial Coverage Relative	1.00	0.34	0.53
Area Coverage Relative	1.00	0.11	0.29

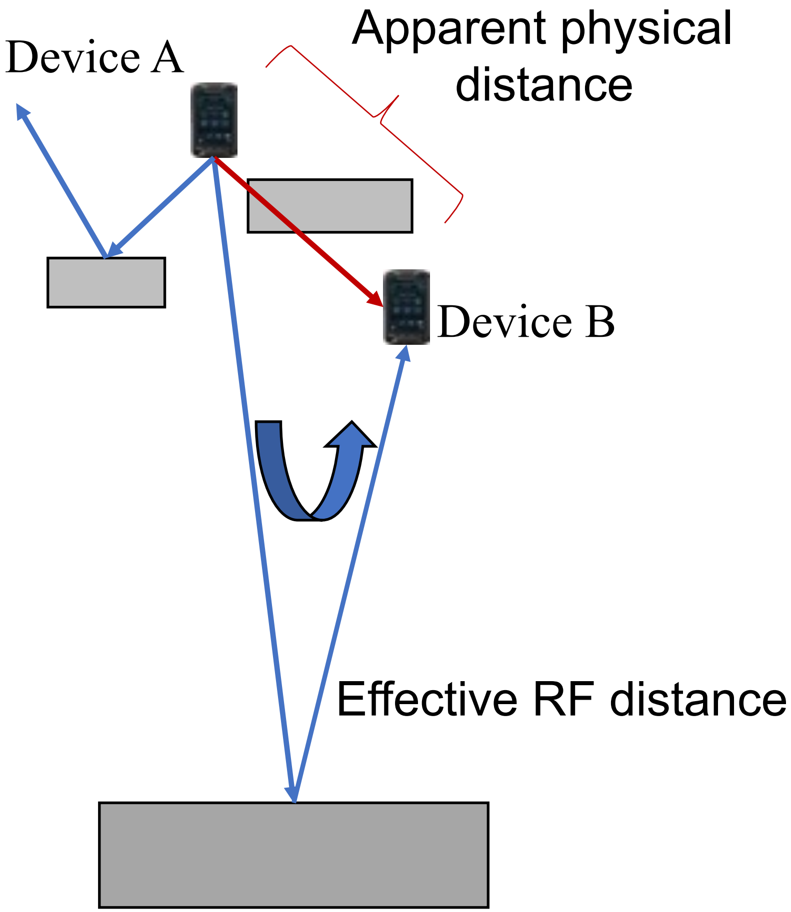
Internal antenna



Staying within the standards

- **High power UE (standardized for band 14)**
- **High efficiency antennas**  VS. 
  - Integrated antennas generally have much lower efficiencies
- **Singular transmission scheme in time (configuration)**
  - For example: single service per ProSe period (40 msec.)
  - Counter example: Video, Text, and Voice as separate physical packets
- **Lower rate voice CODECs**
  - For example: P25

Apparent physical distance vs. RF distance



The effective RF distance can be many times the apparent physical distance

ProSe propagation delay tolerance is a function of configuration.

- By default the distance is ~ 1500 feet.
- Operation beyond this distances is subject to reduced receiver performance.

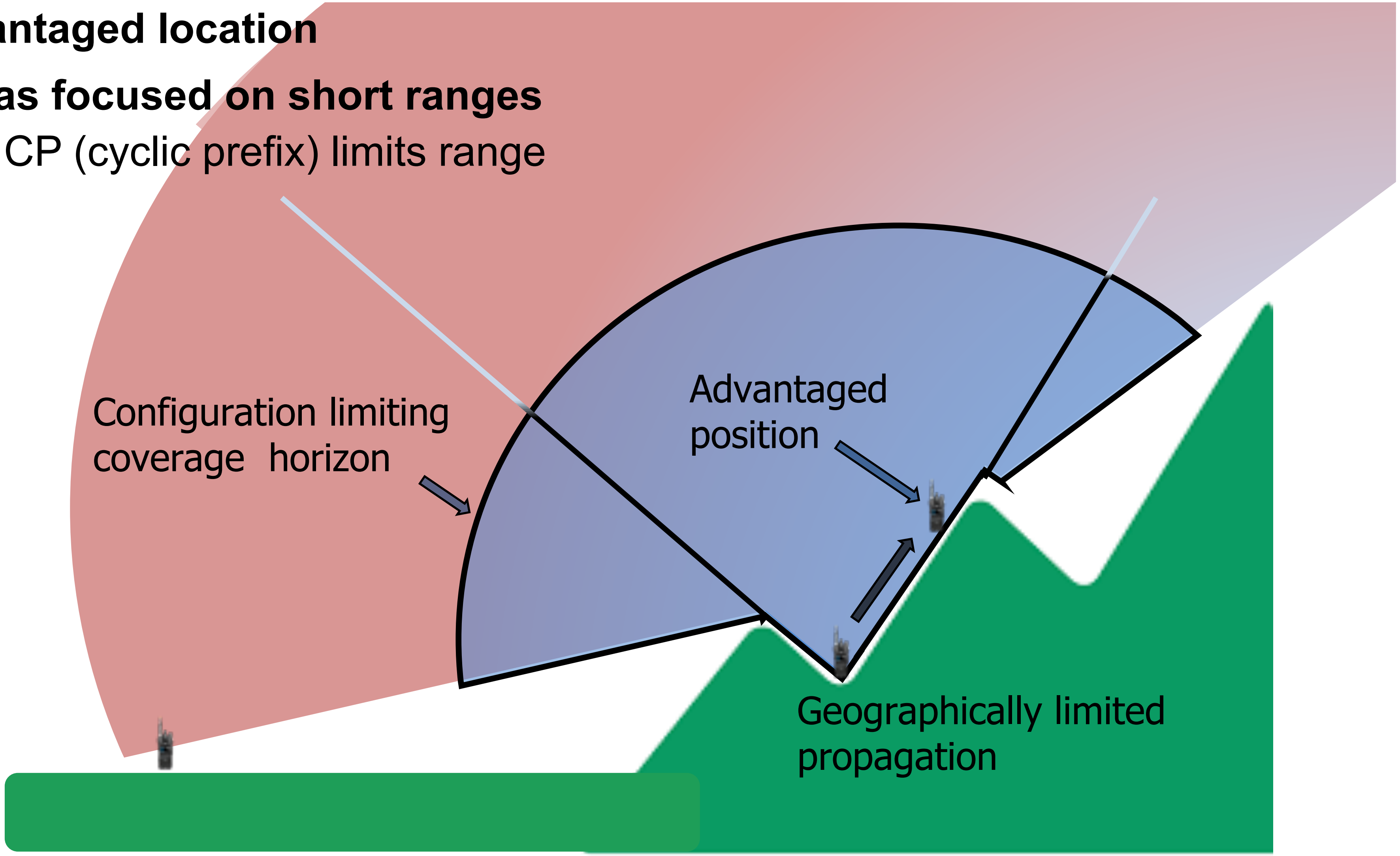
Reliable operation out to propagation limits.

Line of sight propagation

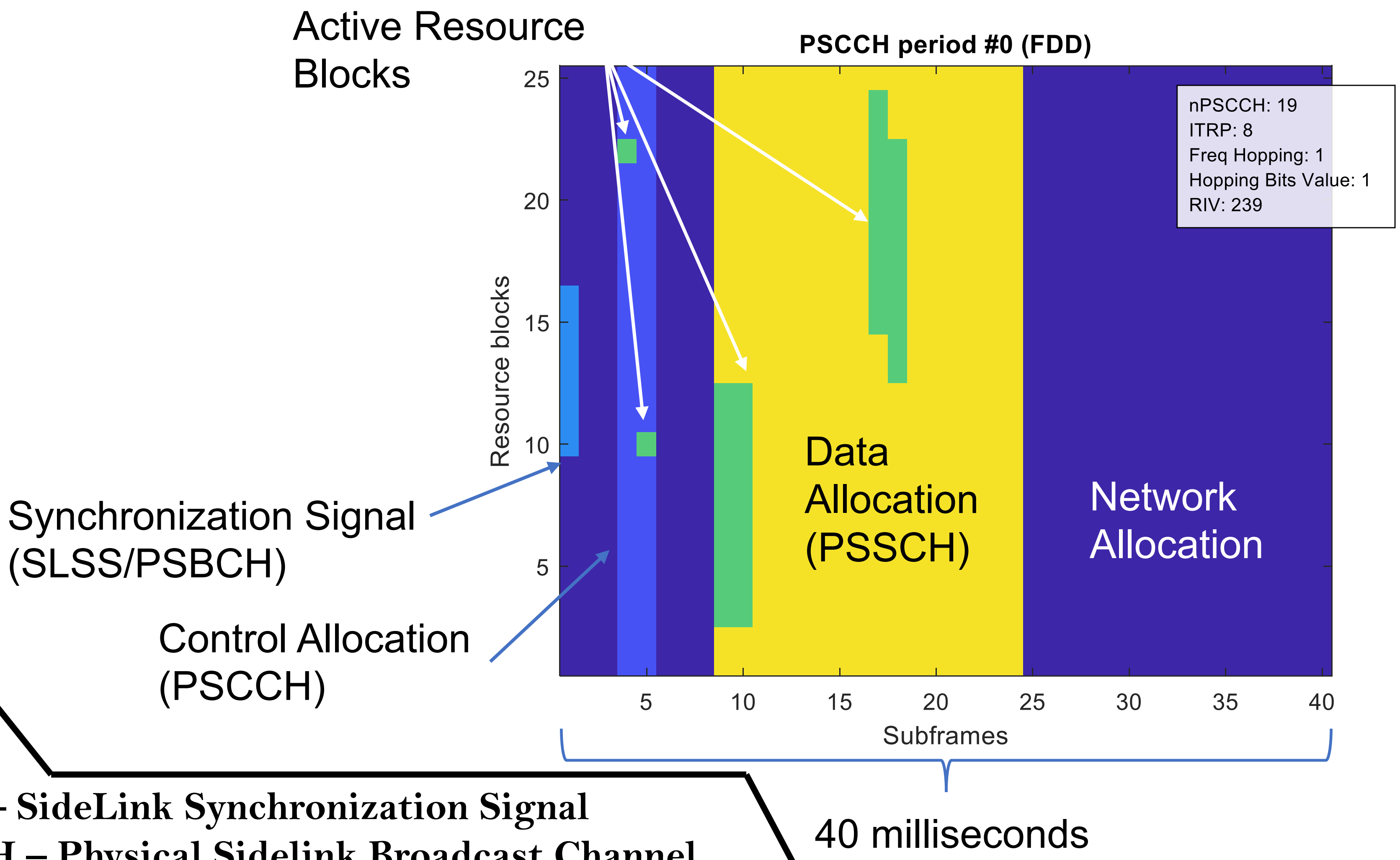
Communication by advantaged location

3GPP standards work has focused on short ranges

- Default configuration of CP (cyclic prefix) limits range of protocol



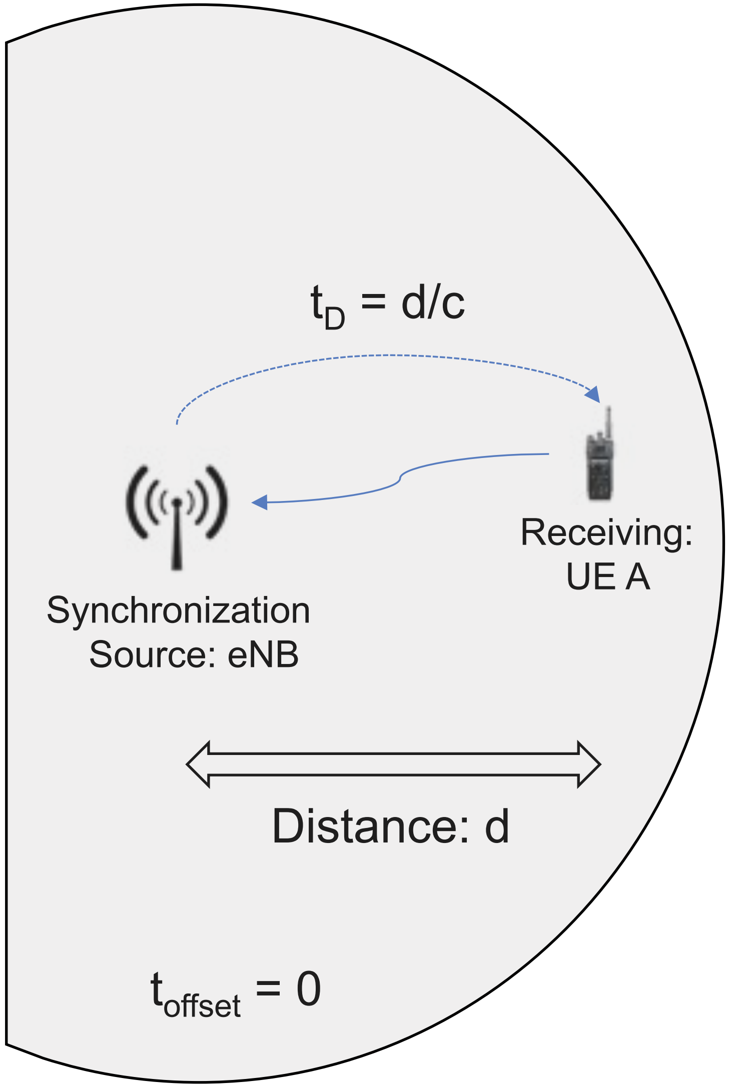
Typical structure of ProSe signals



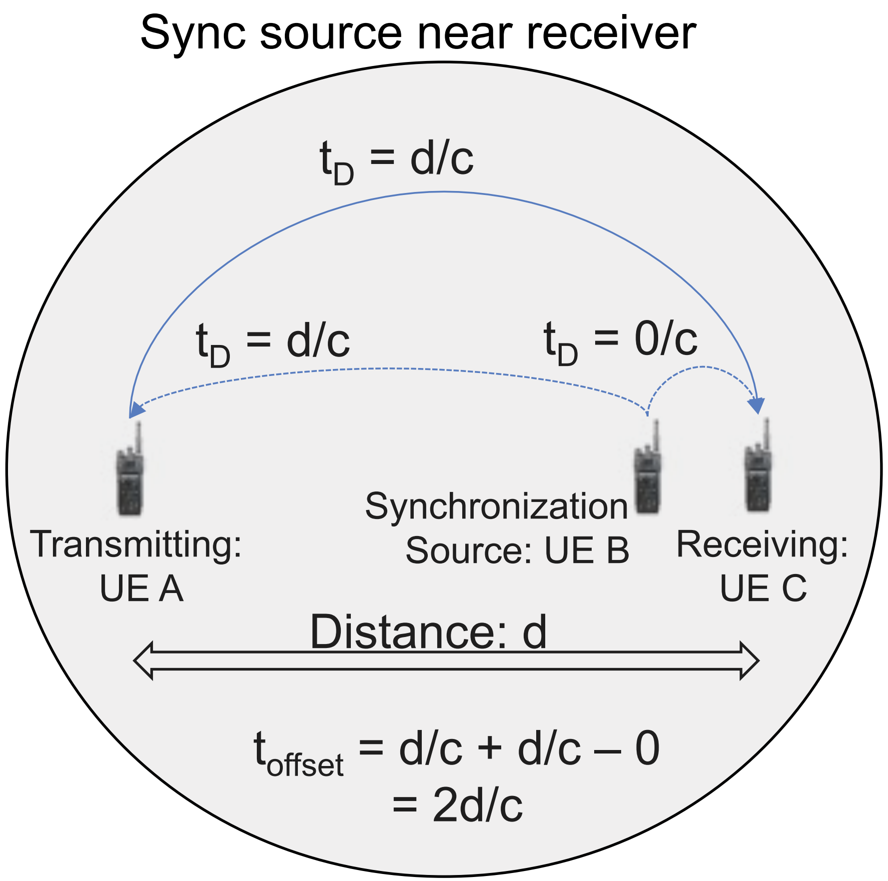
SLSS – SideLink Synchronization Signal
PSBCH – Physical Sidelink Broadcast Channel
PSCCH – Physical Sidelink Control Channel
PSSCH – Physical Sidelink Shared Channel

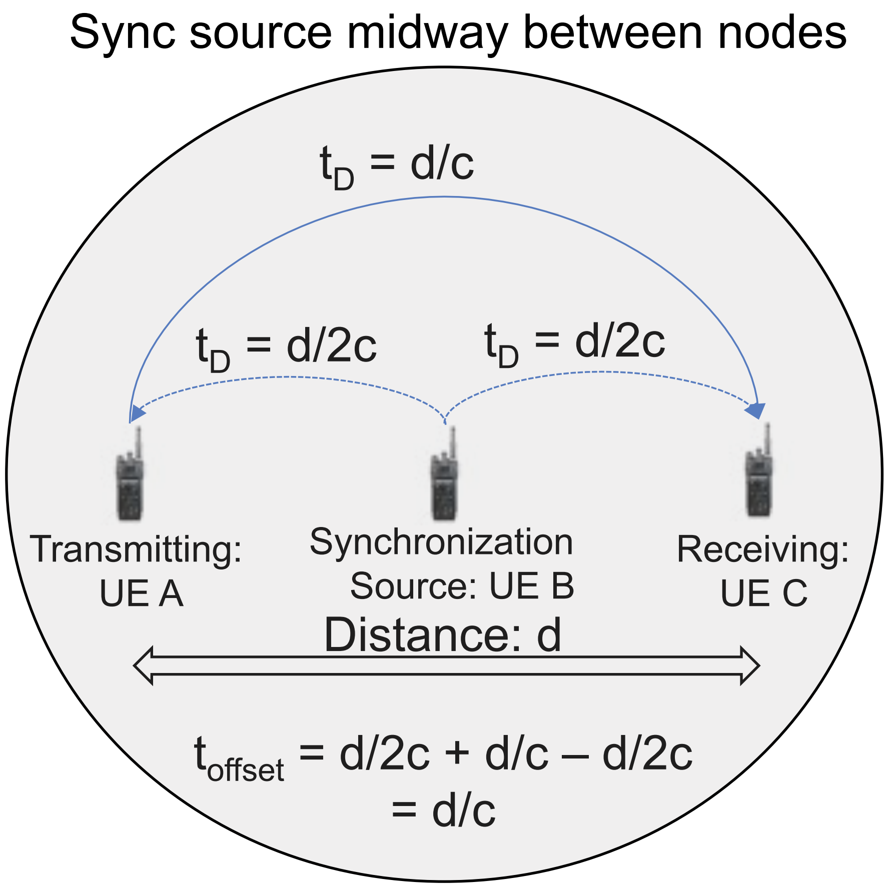
Time offset in non-ProSe operation

1. UE A synchronizes
2. UE A sends initial Tx
3. eNB delay for each UE
4. eNB sends message to UE
5. UE A transmits early
6. eNB receives messages time aligned



Timing offset in ProSe communications

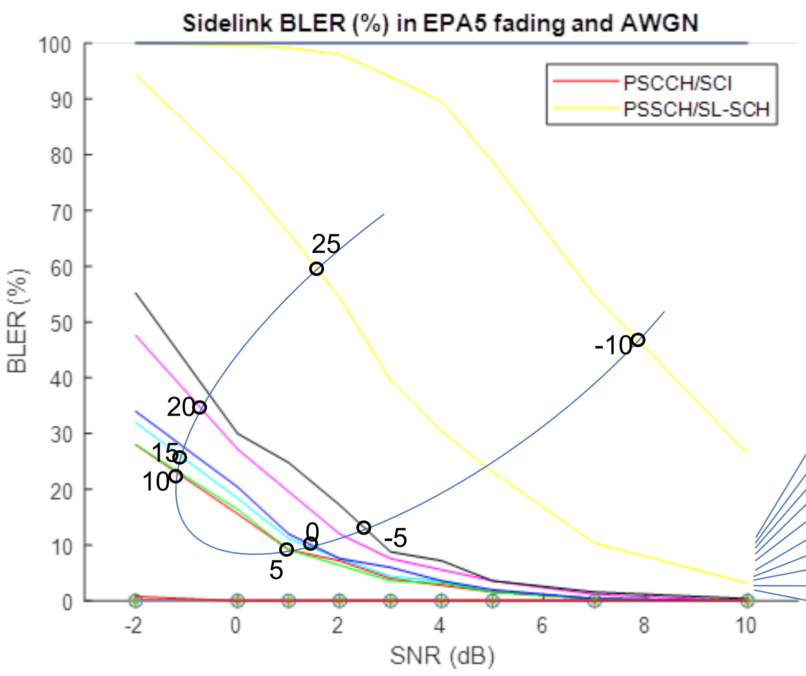


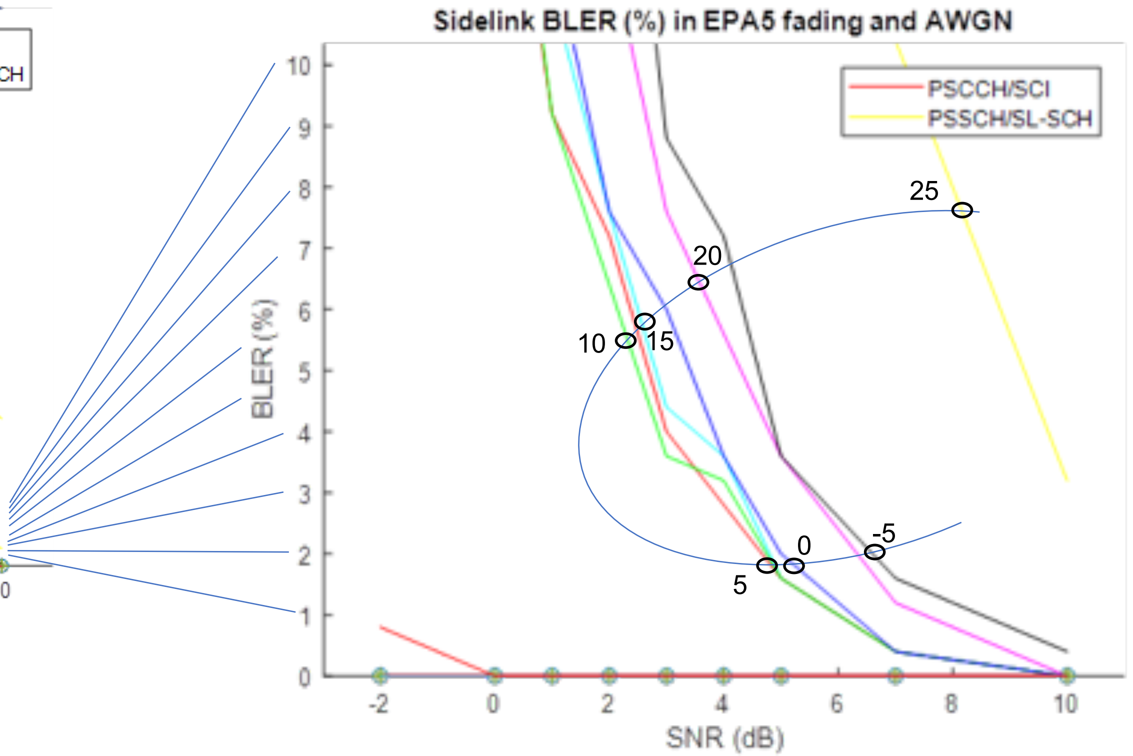


Synchronization offset by sync. source position

1. Near receiver: 2d/c
2. Midway between nodes: d/c
3. Near transmitter: 0
4. Is transmitter: 0
5. Is receiver: a) 0 (adds sync. source)
   b) 2d/c

BLER as a function of timing offset in samples

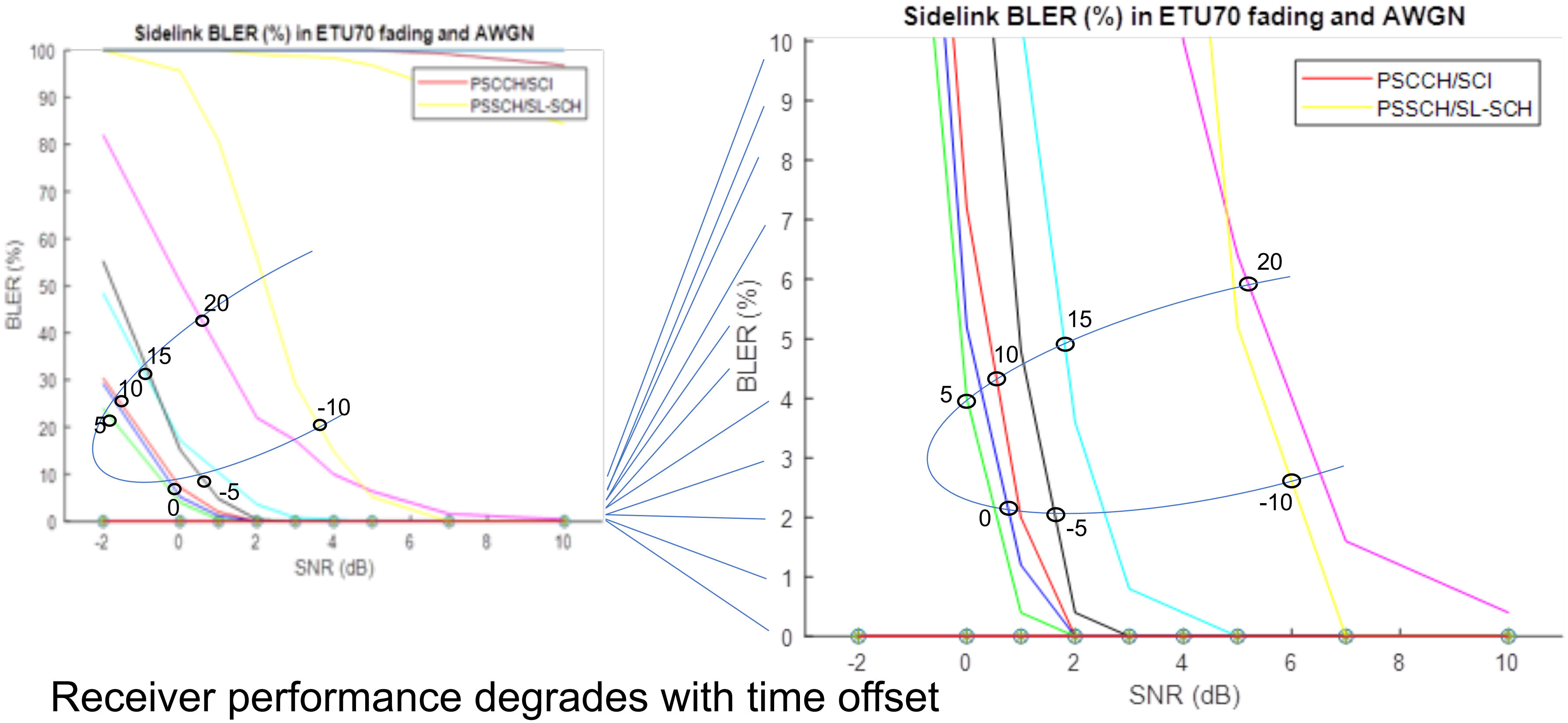




Receiver performance degrades with time offset

- Standard cyclical prefix
- ~40 samples per mile
- Best performance ~ 3/8 mile with EPA5 fading

BLER as a function of timing offset: ETU



Receiver performance degrades with time offset

- Standard cyclical prefix
- ~40 samples per mile
- Best performance ~ 1/4 mile with ETU70 fading

Delay offset mitigation

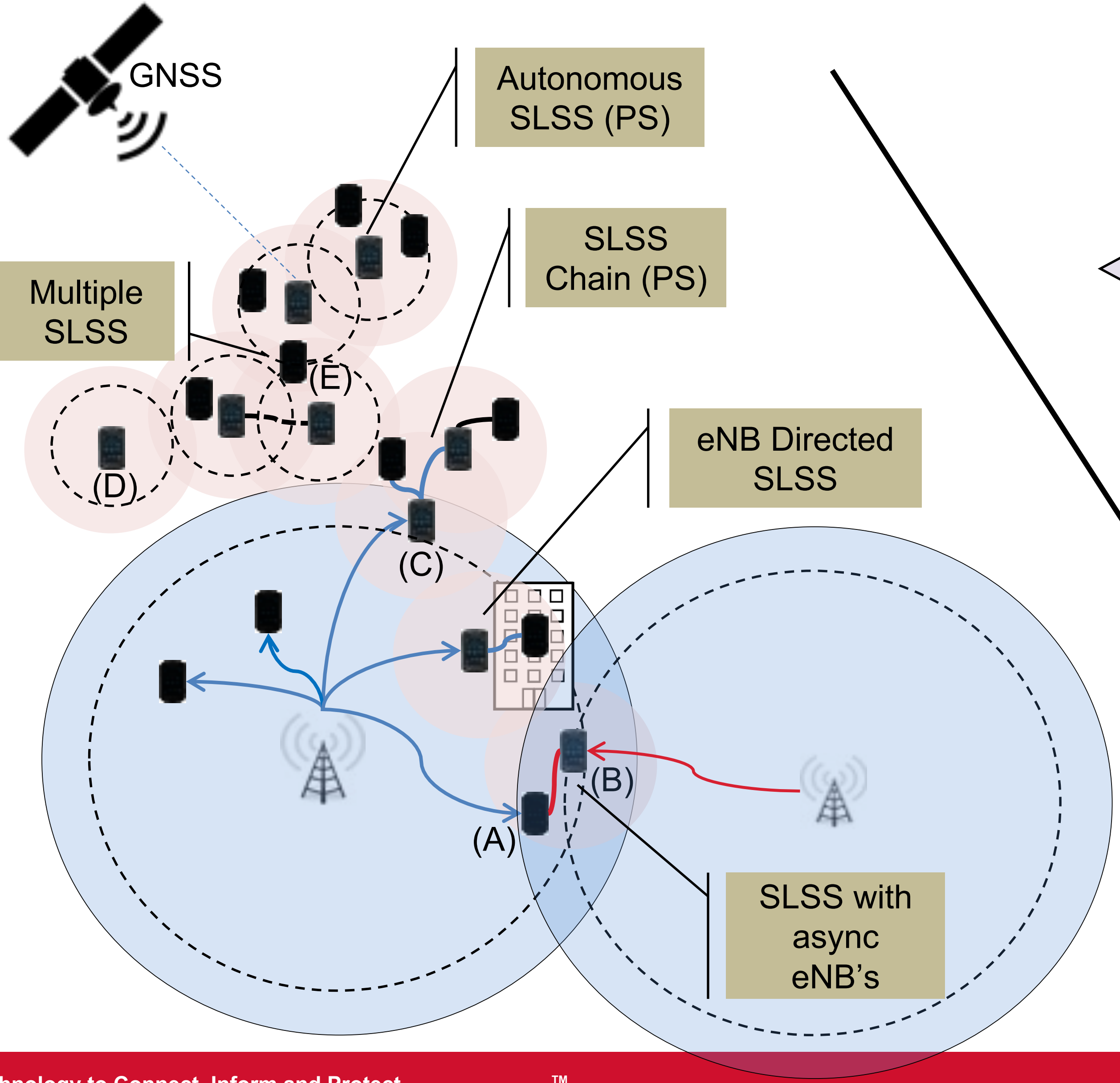
Setting the cyclic prefix to extended

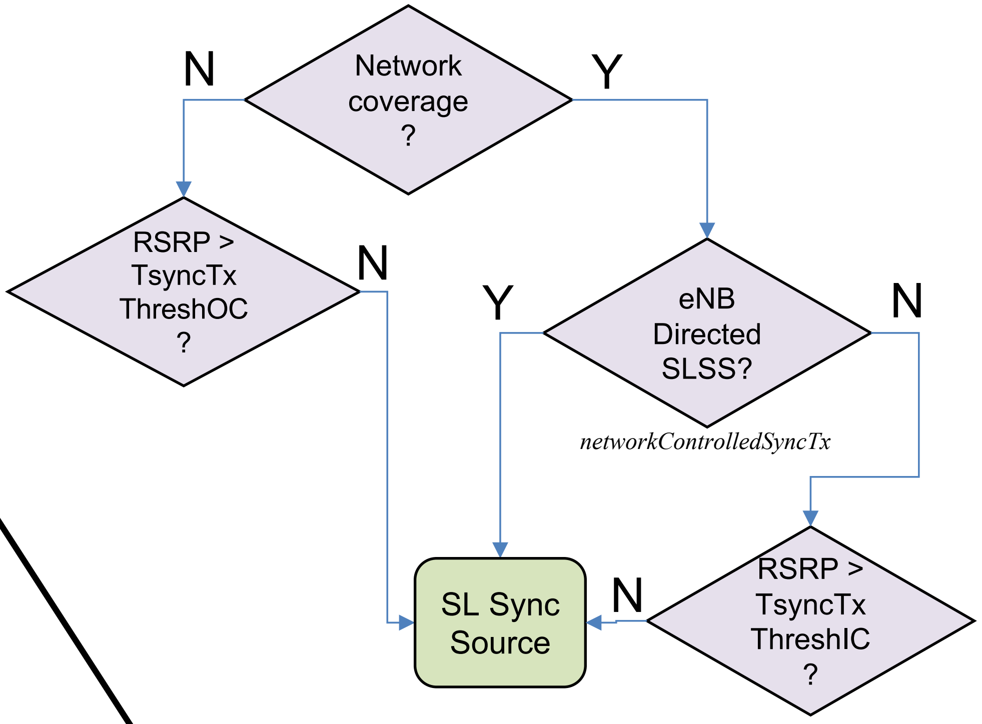
- Allows ~ 3 miles of delay offset
- Reduces throughput by: 14%

Blind searches for proper timing

- No loss in throughput
- Reduces battery life

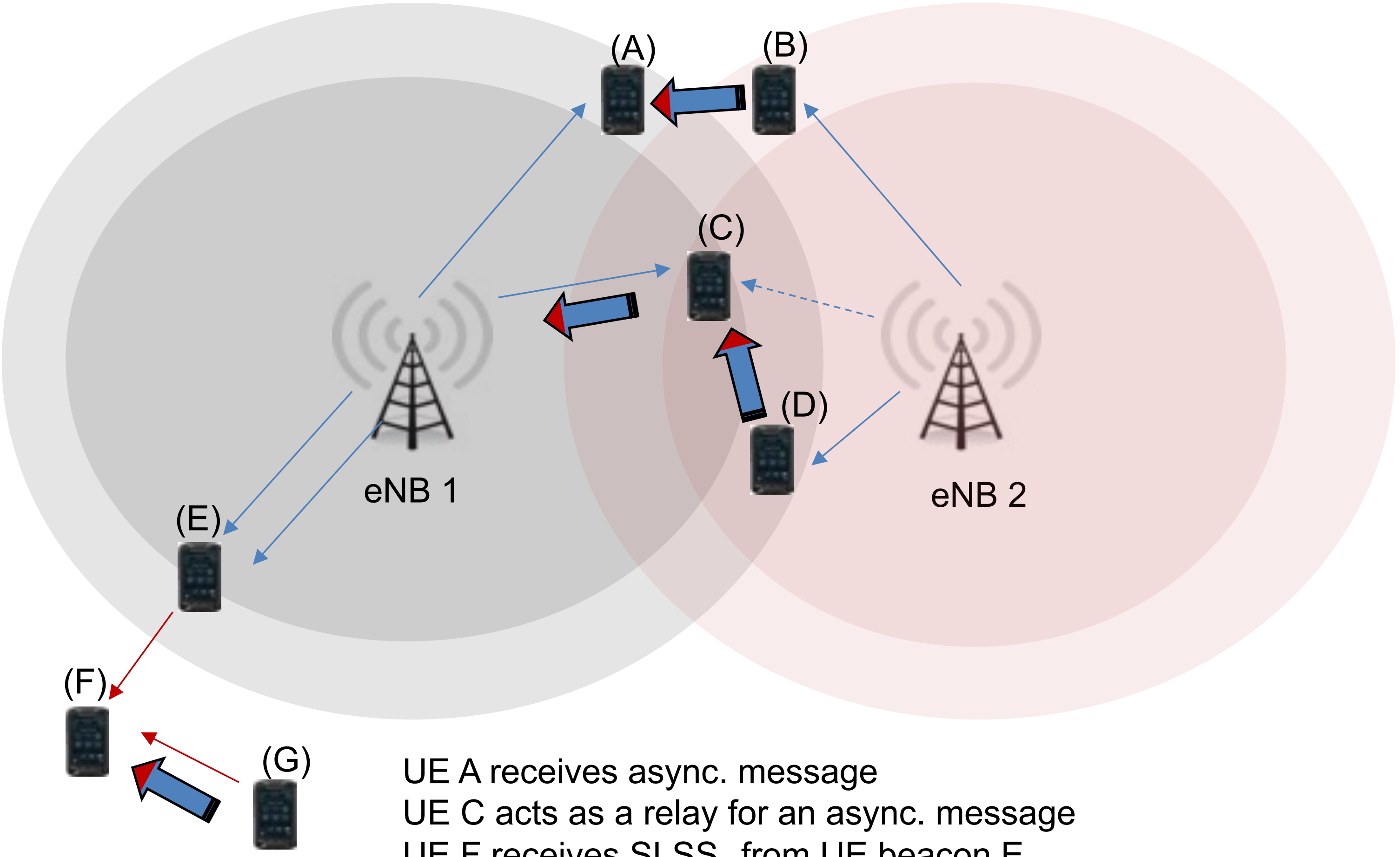
Sync source use cases & determination





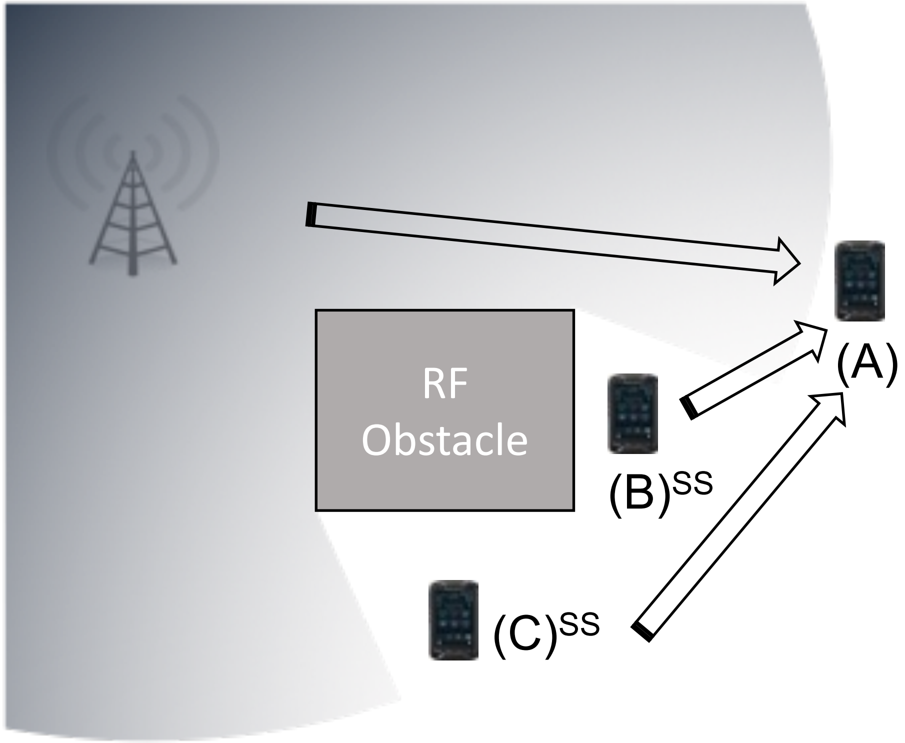
Note:
1. Off network sync shown in black
2. ProSe devices may receive multiple SLSS

Synchronization sources



UE A receives async. message
UE C acts as a relay for an async. message
UE F receives $SLSS_1$ from UE beacon E
UE F receives $SLSS_2$ & message from UE G

Multiple sync sources



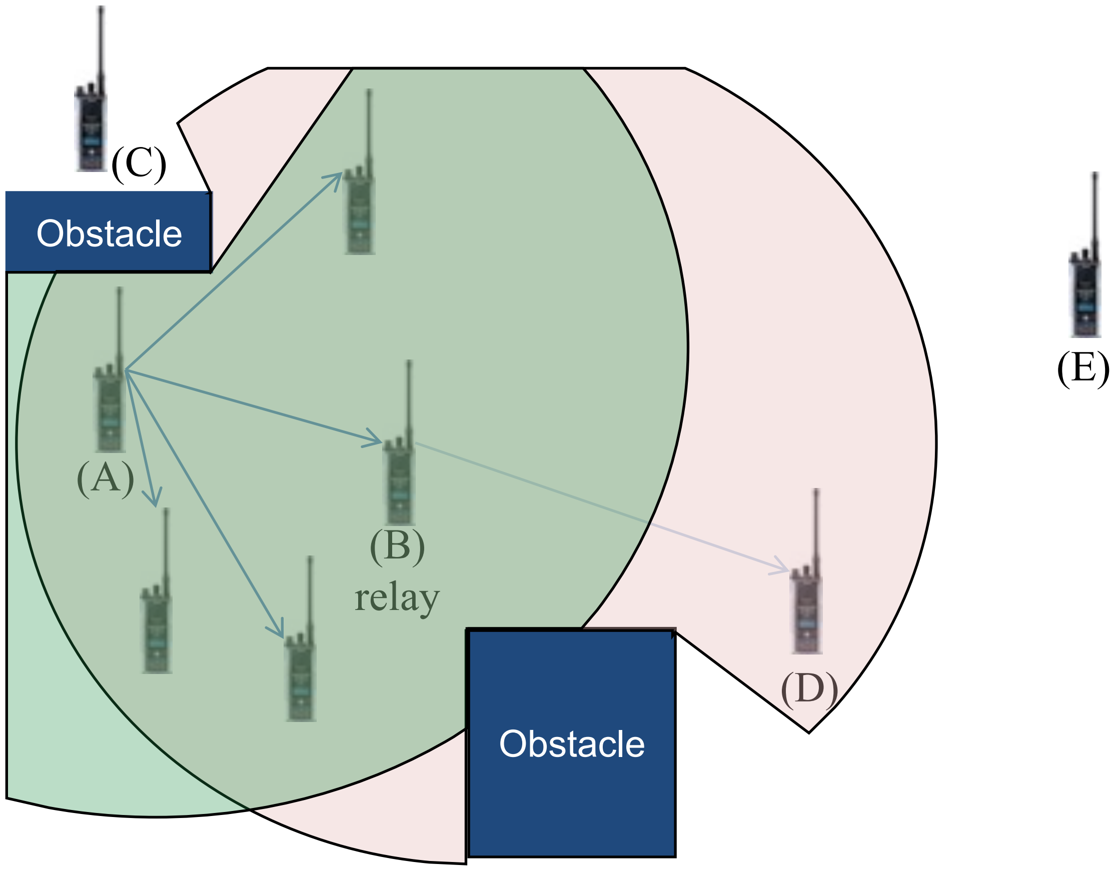
Each device may receive multiple synchronization sources

- It tracks them
- A receiver must search sync sources
  - To minimize missed messages
  - Each sync. source reduces battery life

Managing the sync source life cycle

- Identifying mergeable sources
  - Pruning sources
- Sync sources can evolve their timing to merge sources

Coverage extension relay



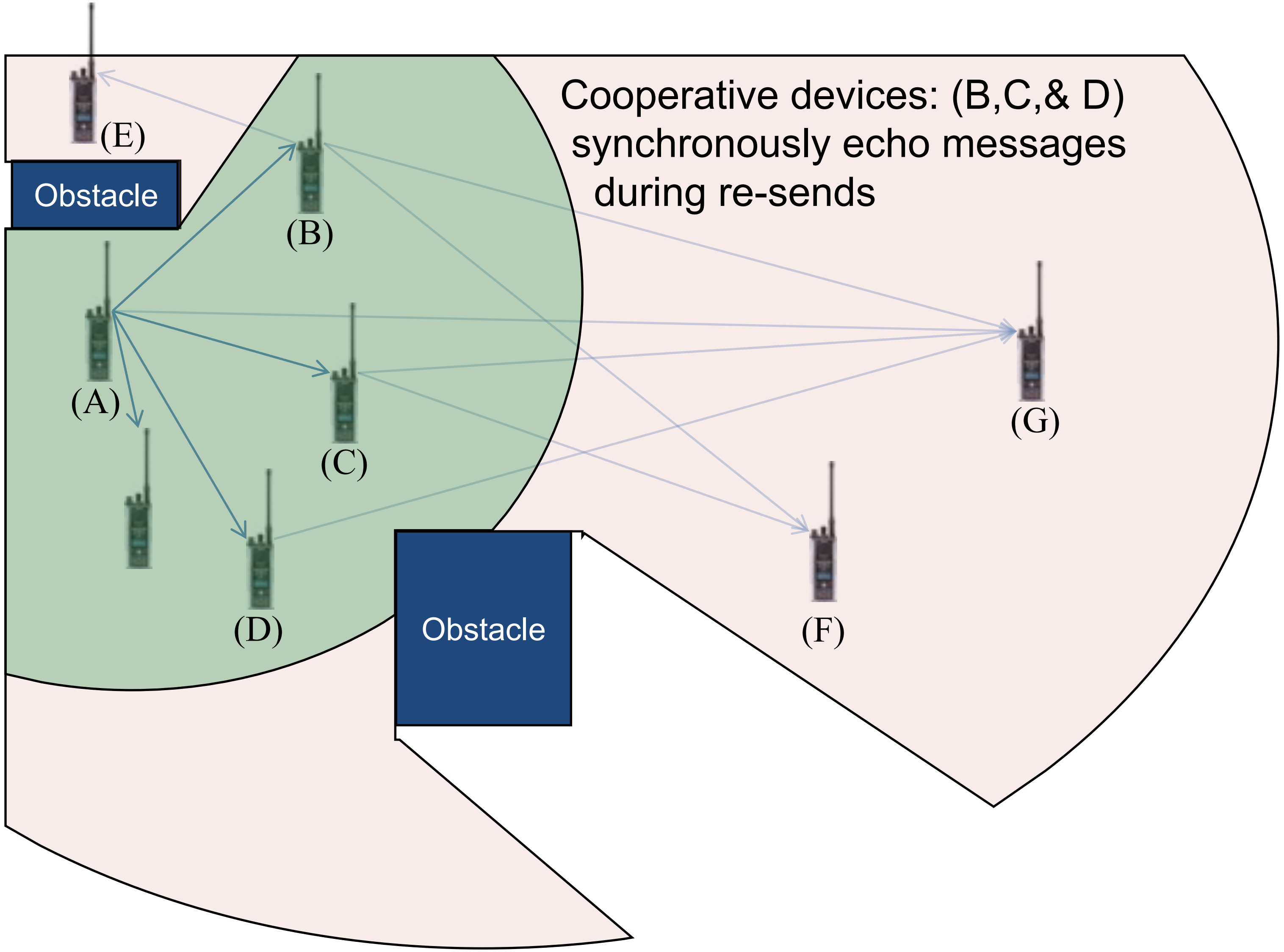
Benefits

- Extended range
- Lessons obstruction effects

Disadvantages

- Twice as many radio resources
- Quasi-static deployment
- MIMO capabilities not fully utilized

Cooperative communication (example)



Benefits

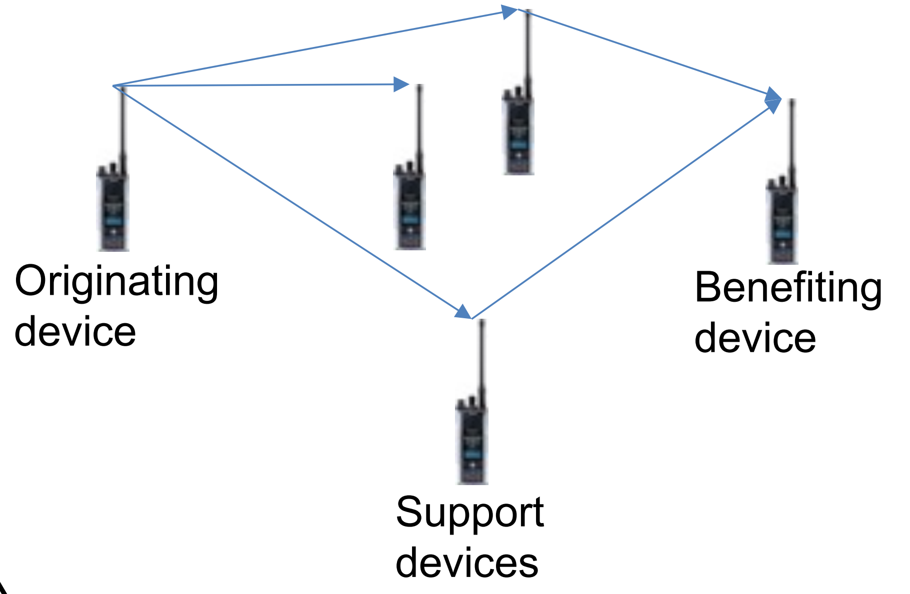
- Higher effective transmitter power
- Diversity: M x 2
- Dynamic cooperative communications
- Improves communication with obstructions

Challenges

- Managing congestion

Cooperative support algorithm

Each device acts independently



Configuration
- System policy
- Local policy

Priority
- Protocol
- Application

Radio Metrics
- Signal quality
- Signal loading

→ CSA (Cooperative Support Algorithm) → Transmission Support Decision

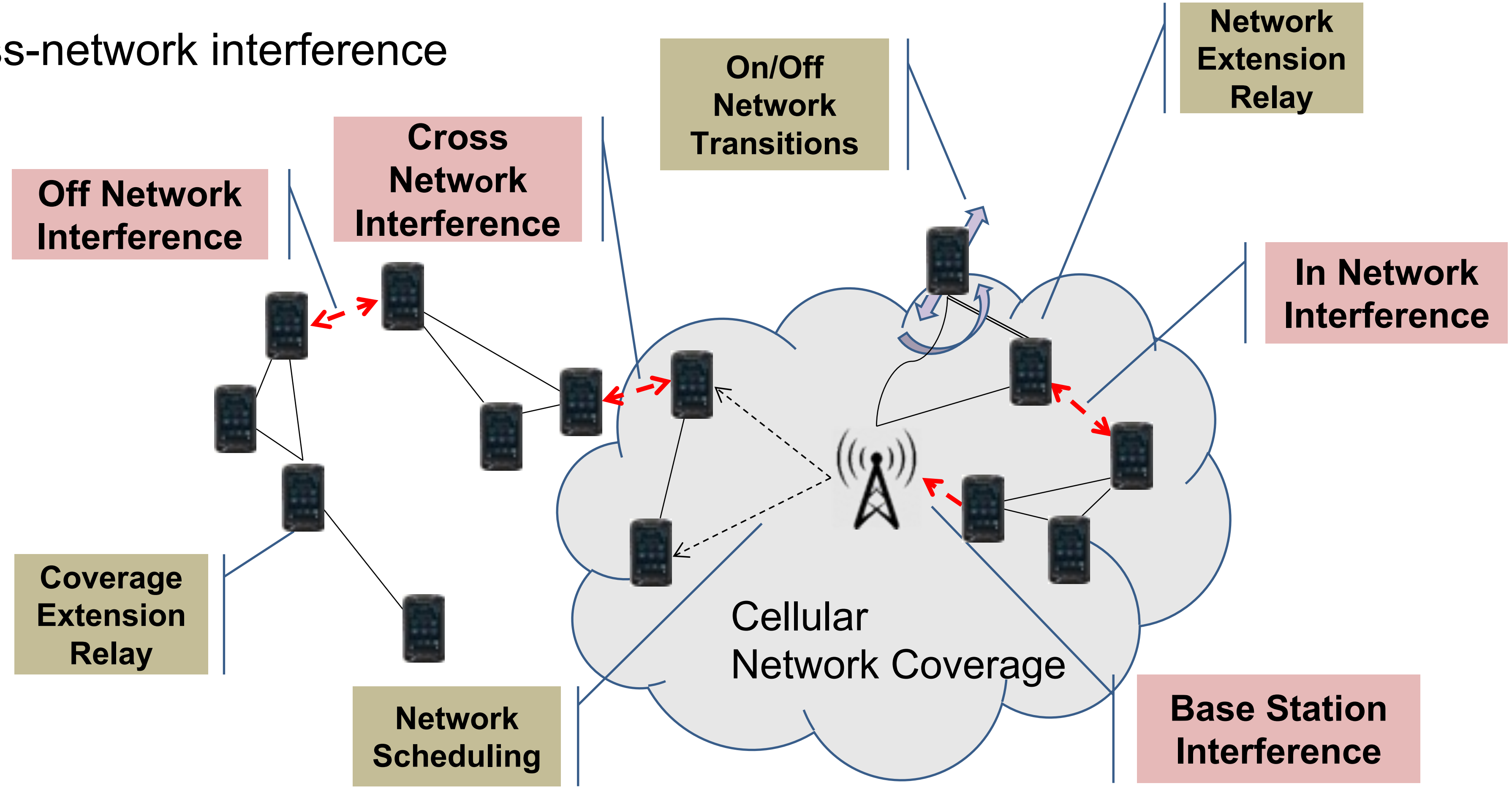
Cellular & off-network overlay

MANET Management

- Link life cycle, relays, network transitions, resource allocation

Interference Control

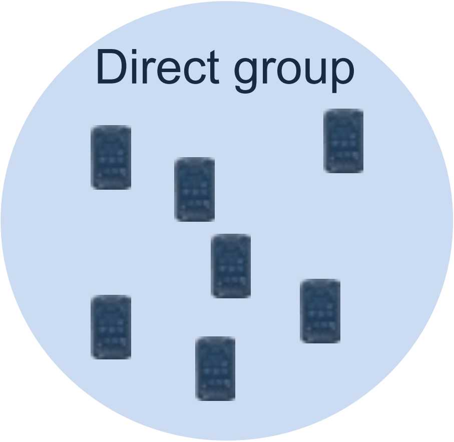
- Intra-MANET & cross-network interference



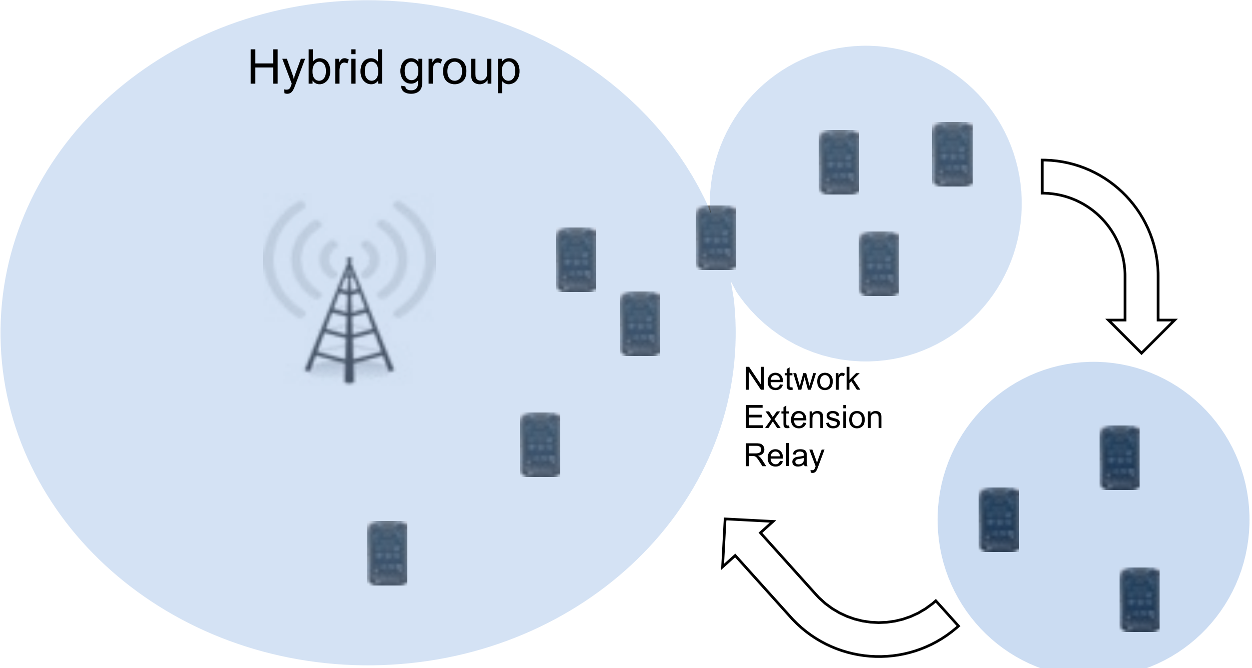
Group domains

Network communications provides:

- Greater efficiency
- Less congestion limitations
- Connections for
  - Reporting chain monitoring
  - Evidentiary recording

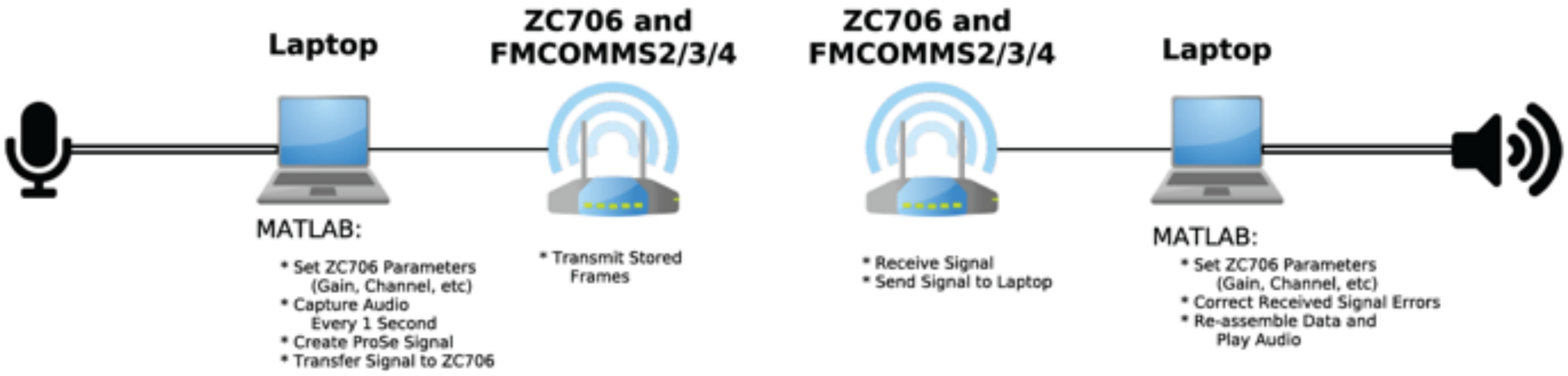


Not efficient in good network coverage



Groups can fragment and reconnect

Development platform for evaluating new capabilities



Modeling, Simulation and Performance Evaluation for Future Public Safety Networks

Sumit Roy, Thomas R. Henderson, Collin Brady

University of Washington

Lorenza Giupponi, Zoraze Ali, Manuel Requena

CTTC

June 2018 Public Safety Broadband Stakeholders Meeting

Contact: tomhend@u.washington.edu

Program overview

- R&D proposal responding to topics A (**Mission Critical Voice**), D (**PSC Demand Models**), and E (**Research and Prototyping Platforms**) of the 2017 NIST-PSIAP-01 NOFO
- Two year program conducted by **University of Washington** and **Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)** investigators

Presentation outline

- Topic A (20 minutes): **Advances in ns-3 simulation support for LTE-based public safety networks**
- Topic B (20 minutes): **Advances in modeling device discovery in LTE D2D mode 2 operation**
- 10 minutes for Q&A

ns-3 Models and Scenarios for PSCR

Tom Henderson (presenting) and CTTC team (L. Giupponi, Z. Ali, and M. Requena)

UNIVERSITY of WASHINGTON

ns-3 Models and Scenarios for PSCR

- **Need:** Create PSCR-focused research and prototyping platforms (topic E)
  - **Packet-level network simulators** simulate the end-to-end flow of application data through model network scenarios
- **Project goal:** Enhance the ns-3 discrete-event network simulator to become a preferred simulation framework for public safety communications research
- **Technical leads**: Tom Henderson (Univ. of Washington) and Lorenza Giupponi (CTTC)

Why simulate networks?

> Study aspects of technology not yet implemented or specified

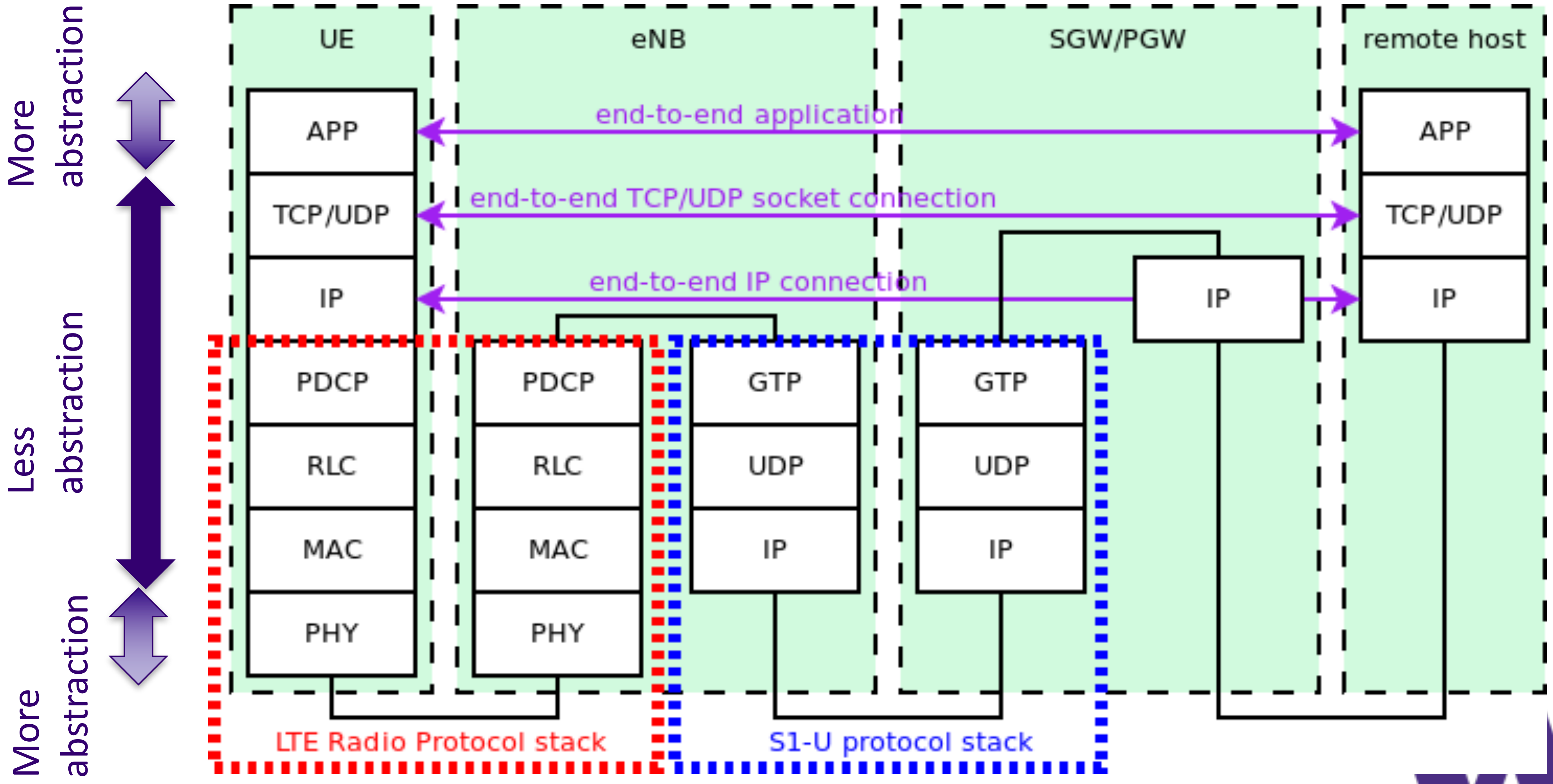
> Repeatable, scalable, cost-effective experiments

Analysis | Pure simulation | Simulation "cradles" | Virtual/Physical test beds | Field experiments | Live networks

Increasing realism →

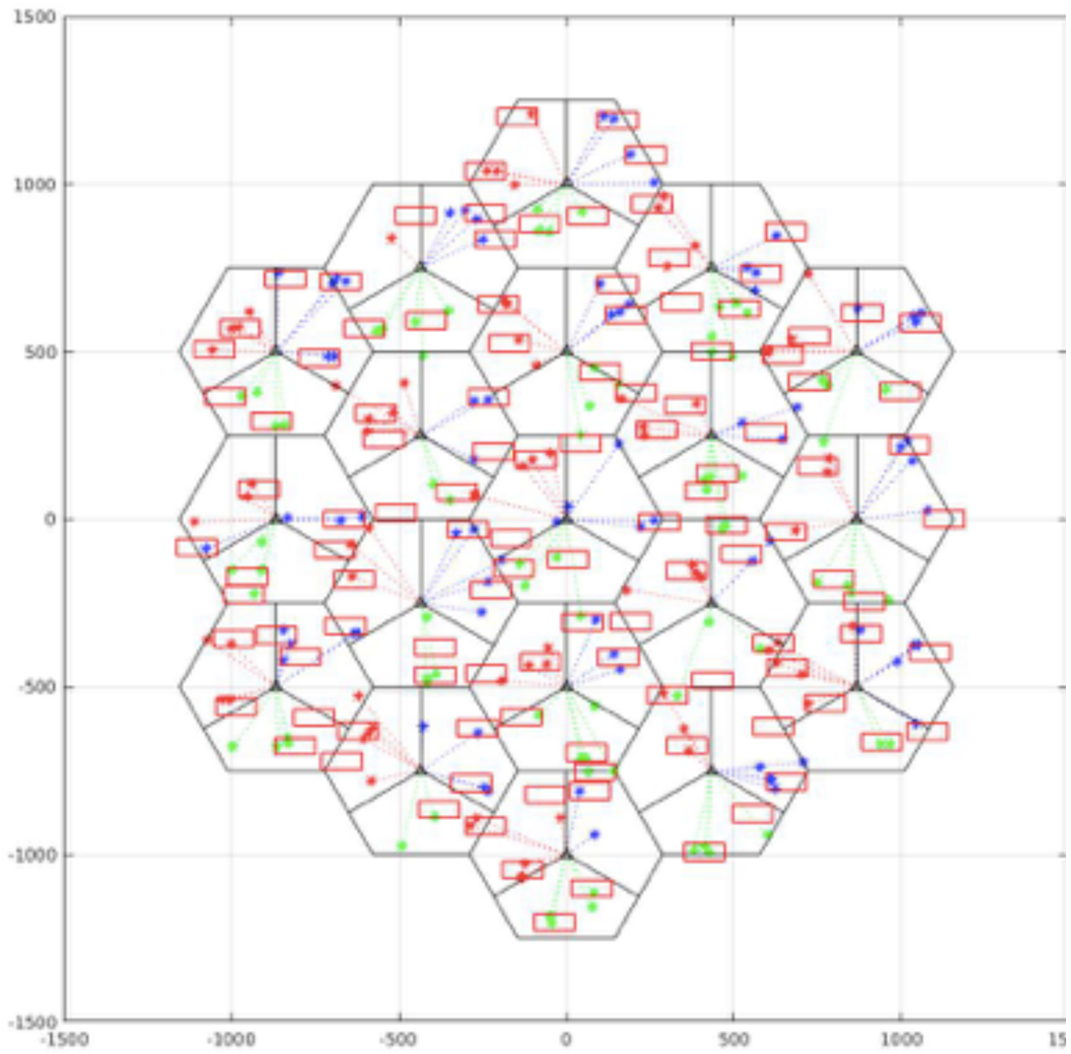
Increasing cost and complexity →

Packet-level simulation overview

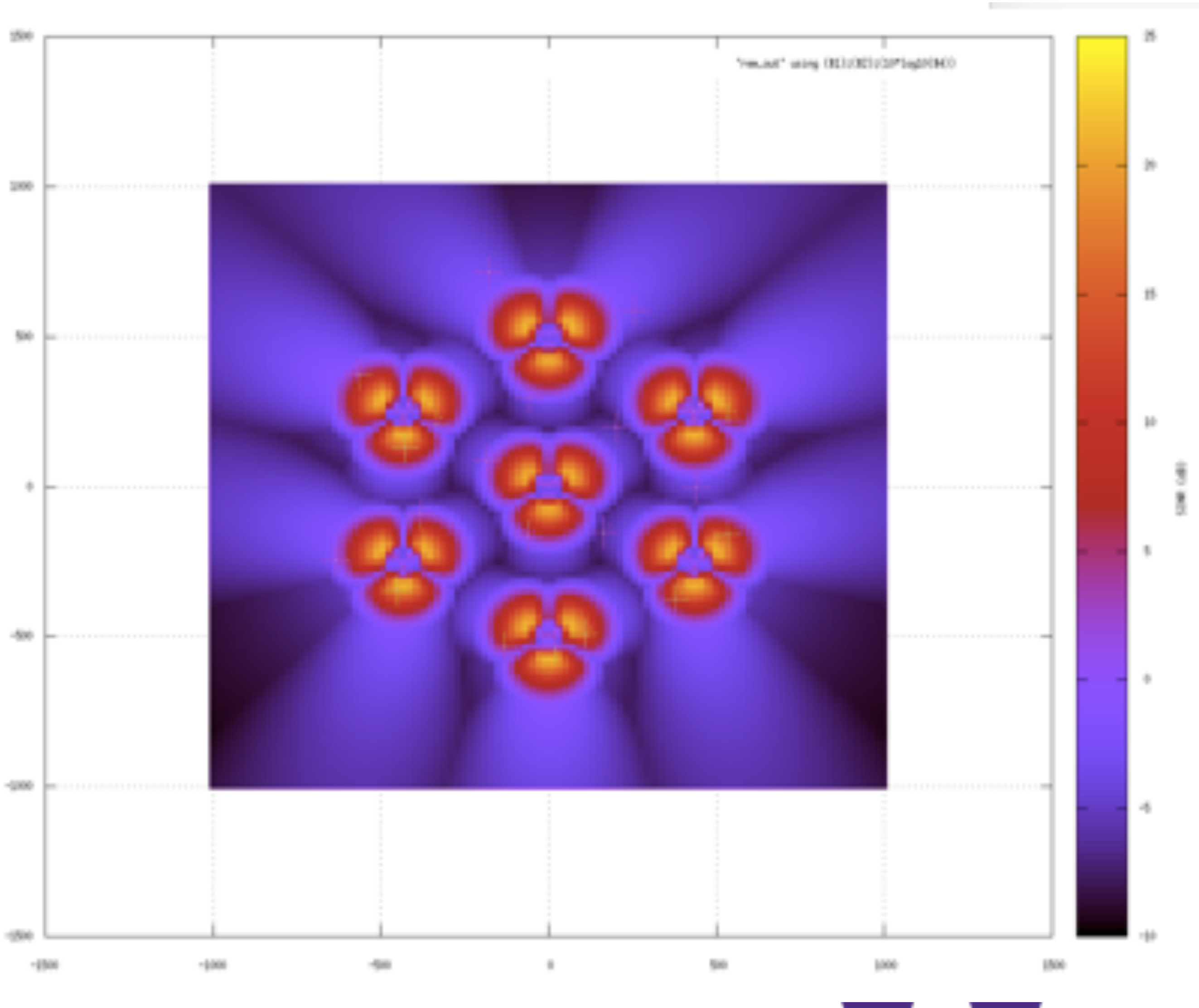


Network-level views

Network cell structure showing eNBs, UEs, and buildings



Radio environment map showing signal strength from eNBs



Sample questions for packet-level simulation study

Topics sampled from the literature, found on Google Scholar

- > Performance analysis of hybrid aerial-terrestrial 4G LTE/Wi-Fi multimode base stations deployed on airborne platforms
- > Rate allocation algorithms to optimally allocate resources while delivering minimum QoS guarantees
- > Performance of priority access alternatives on shared commercial LTE networks
- > Performance of distributed base stations in LTE public safety networks

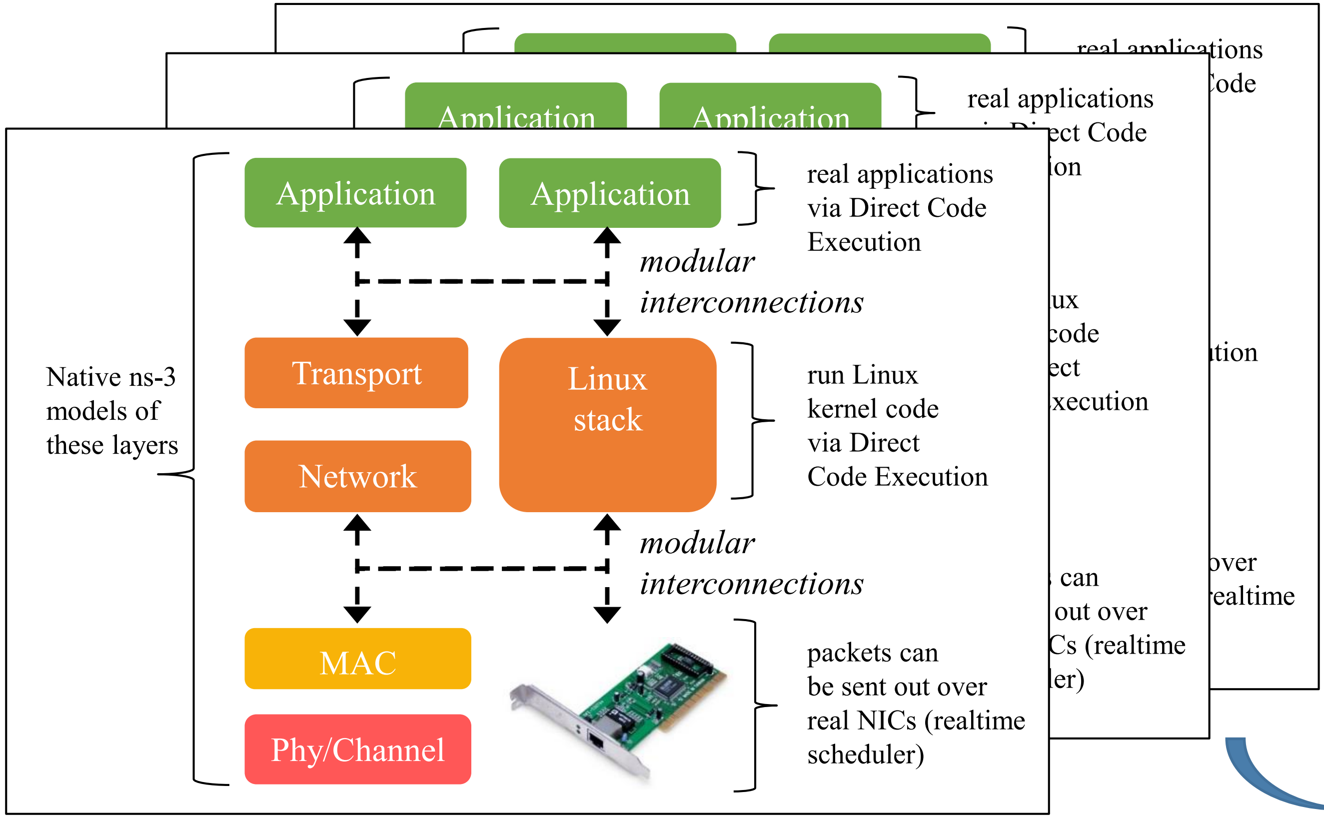

FSR: Formal Analysis and Implementation Toolkit for Safe Interdomain Routing


Augmenting Data Center Networks with Multi-Gigabit Wireless Links

Why ns-3?

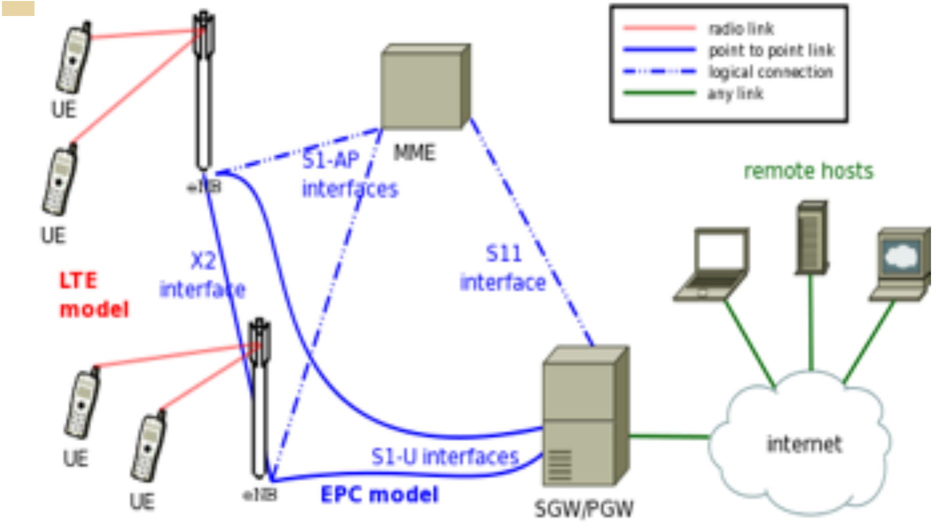
- Common, open source tool to advance the research and leverage the work of others
- NIST PSCR group has already made significant developments

A single simulation instance can run on a workstation or laptop



Alternatively, scenarios can be parallelized across a cluster

Development plans for ns-3's PSCR module

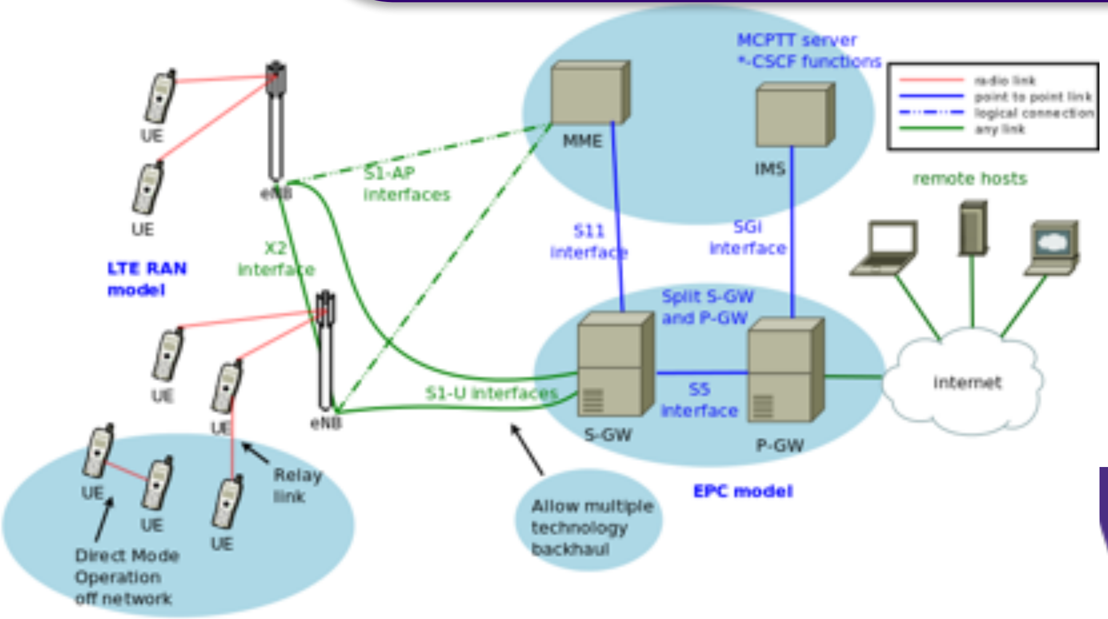


Extend ns-3's existing LTE module to incorporate the public safety extensions

- off-network modes, MCPTT, enhanced backhaul models

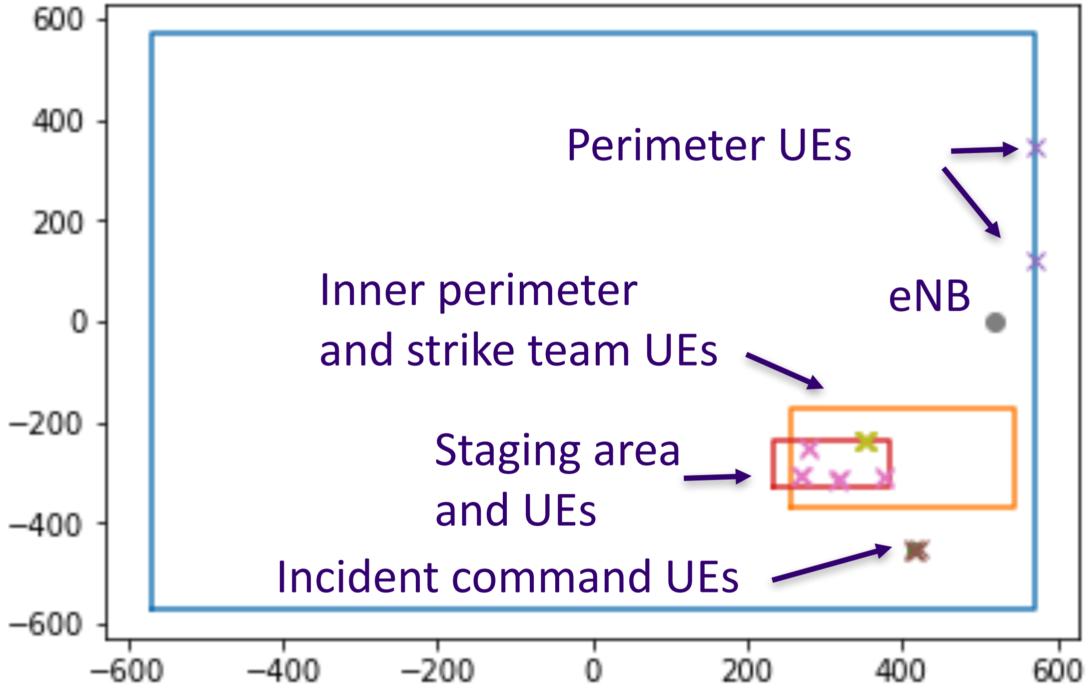
Create sample public safety network scenarios (templates)

Existing ns-3 LTE support



Modeling a first responder scenario in ns-3

NIST PSCR has created a ns-3 scenario based on the **Televate Report**[1] describing a hypothetical (urban or rural) hostage incident



Python Matplotlib rendering of scenario nodes

[1]https://dps.mn.gov/divisions/ecn/programs/armer/Documents/Minnesota_Needs_Assessment_Report_FINAL.pdf

Televate applications

- A number of notional applications are configured to generate and consume traffic bursts

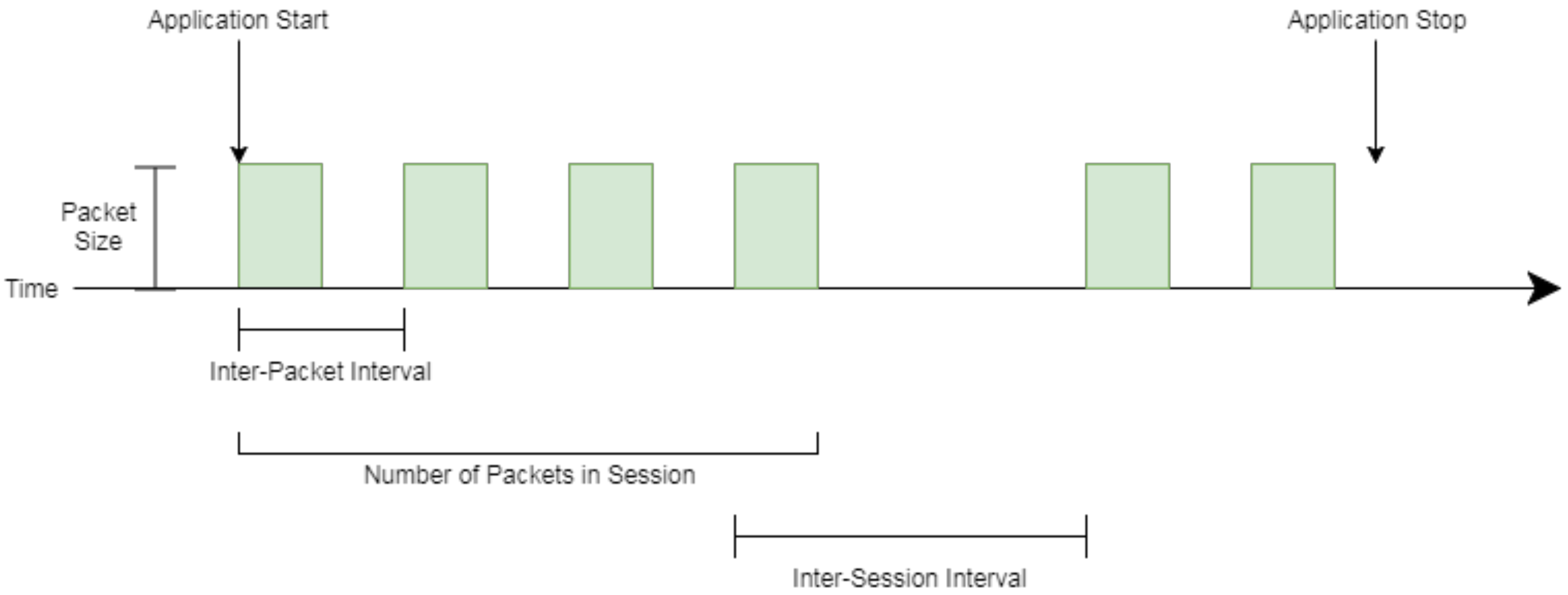


Figure source: Incident Helpers Description, NIST/CTL/WND - 2017/10/25

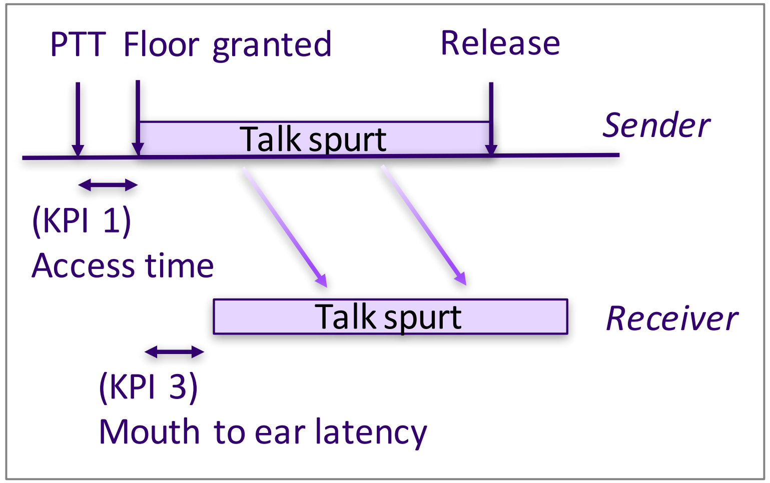
- Supplementing with higher fidelity application models as appropriate; e.g. on-network MCPTT

Incident scenario example

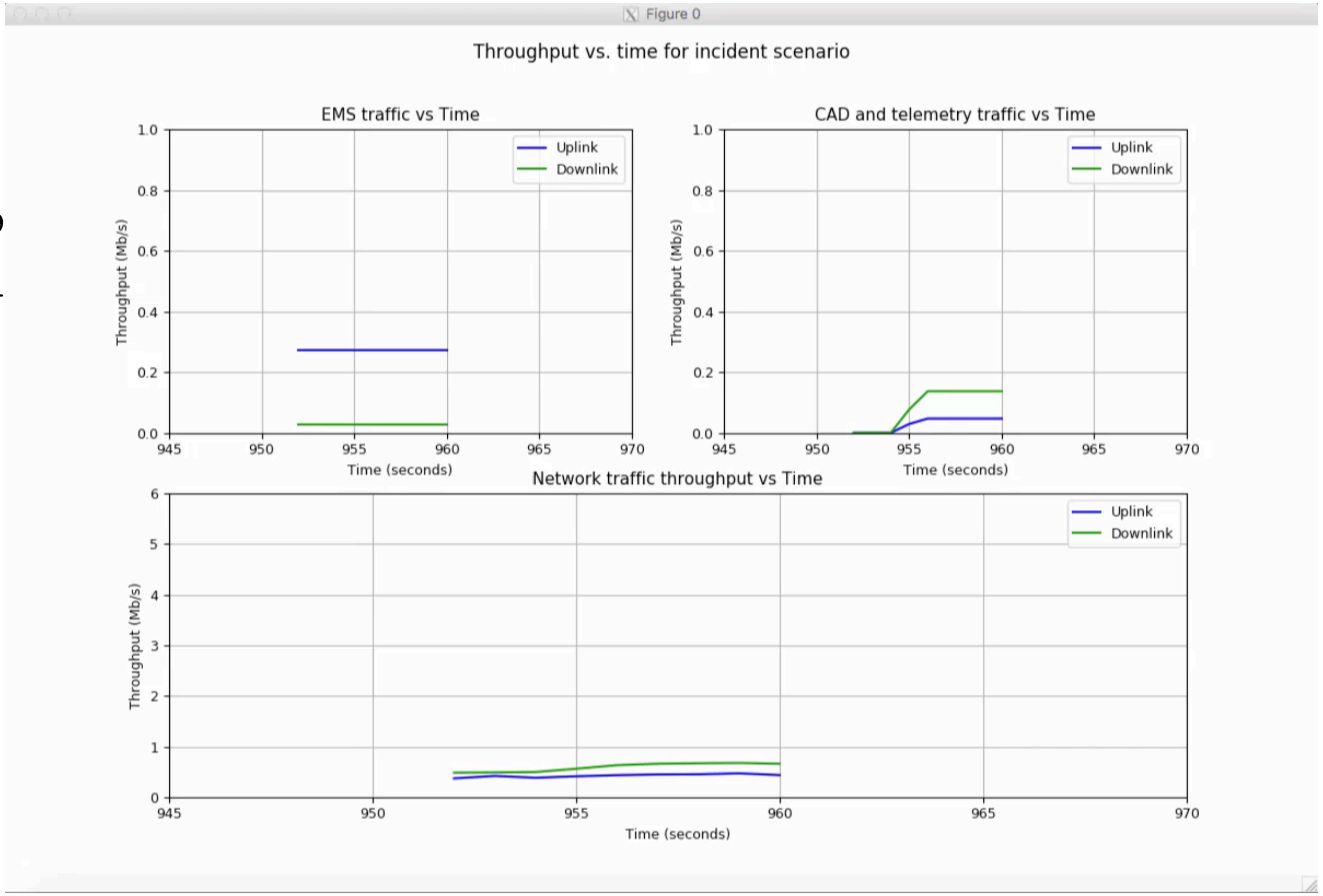
Raw trace data generated by ns-3

```
EmsVideo_1_Server 942.363929 RX 1012 1061 U 2395
EmsVideo_1_Client 942.373177 TX 1012 1061 U 2398
EmsVideo_1_Client 942.377 RX 64 113 U 2397
WebBrowsingGraphics_0_Server 942.380928 TX 1024 1073 U 2399
WebBrowsingGraphics_0_Client 942.394 RX 1024 1073 U 2399
AvlAssetPerimeter_1_Server 942.42492988 RX 1408 1457 U 2401
```

Used to measure KPIs



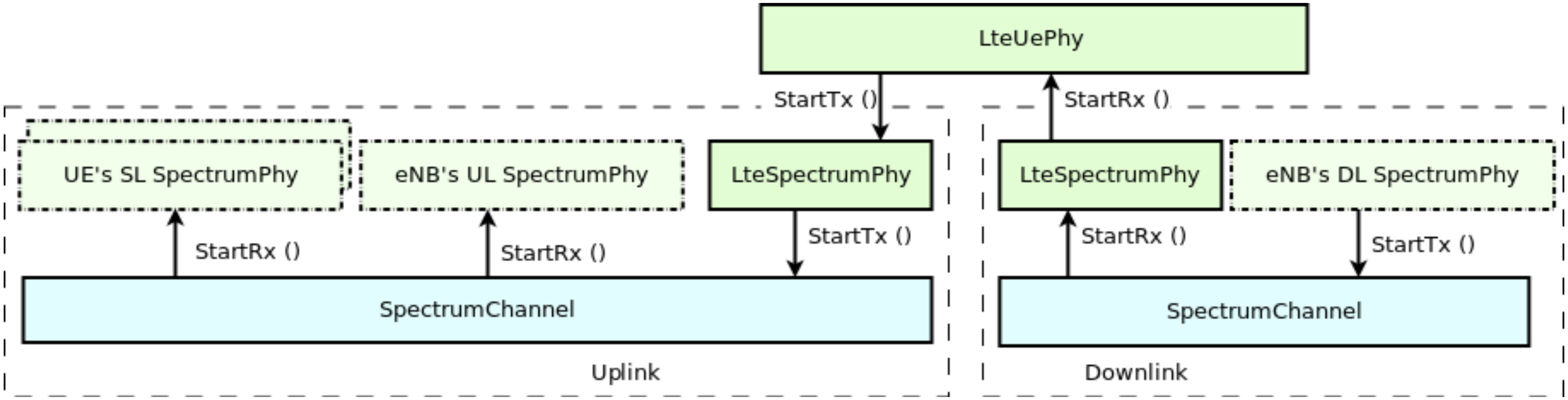
Animated



Summary of year-1 progress

1) Software integration and availability

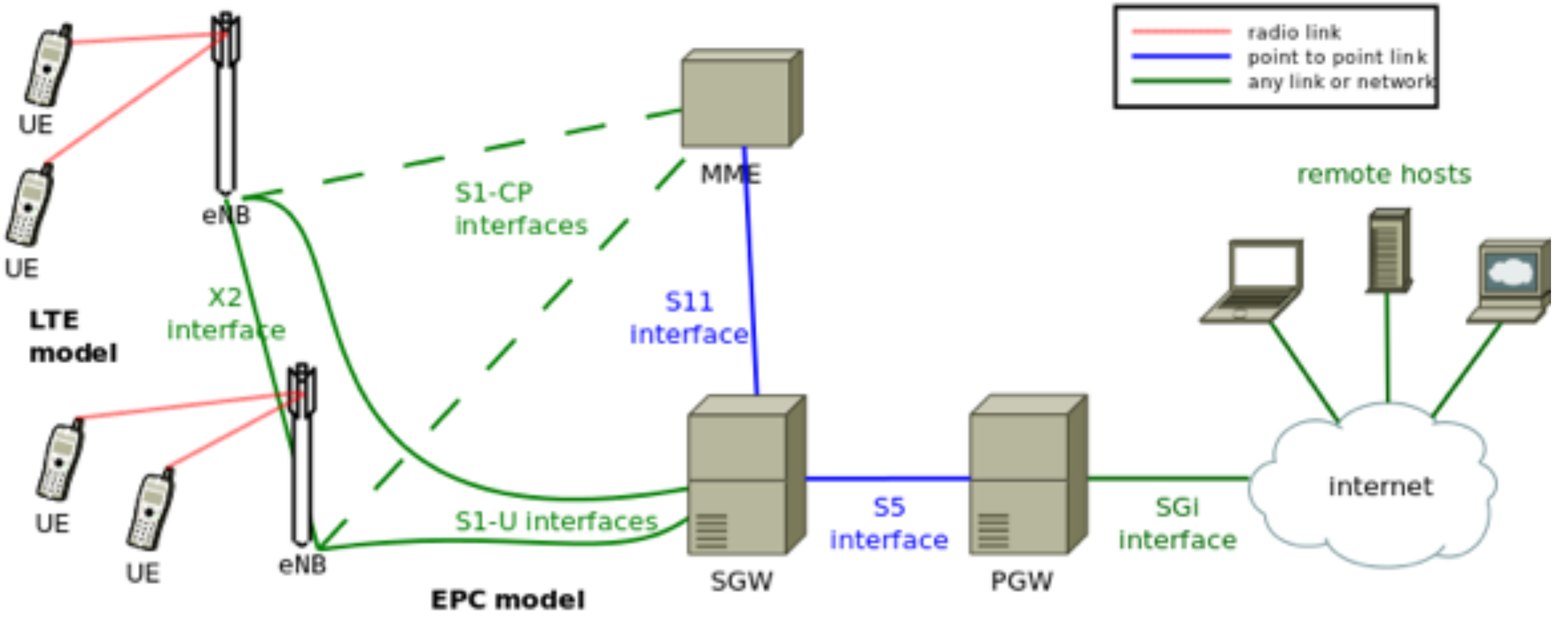
– Make NIST D2D and ProSe models compatible with the mainline ns-3 release



Summary of year-1 progress (cont.)

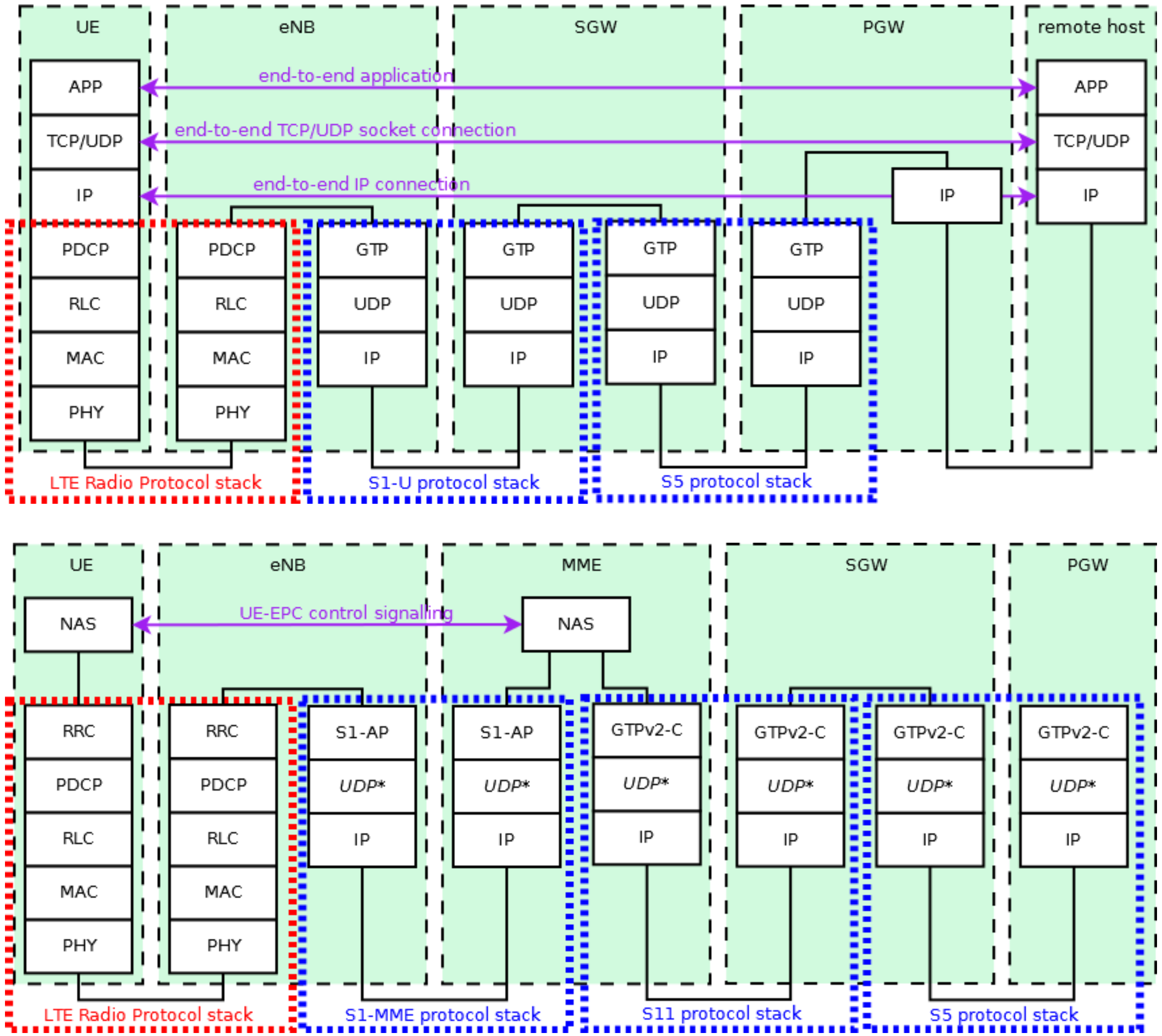
2) Improved model fidelity for public safety scenarios

- Improvements to the LTE EPC model (for more flexible network configurations)
- Start to support on-network modes of MCPTT



Summary of year-1 progress (cont.)

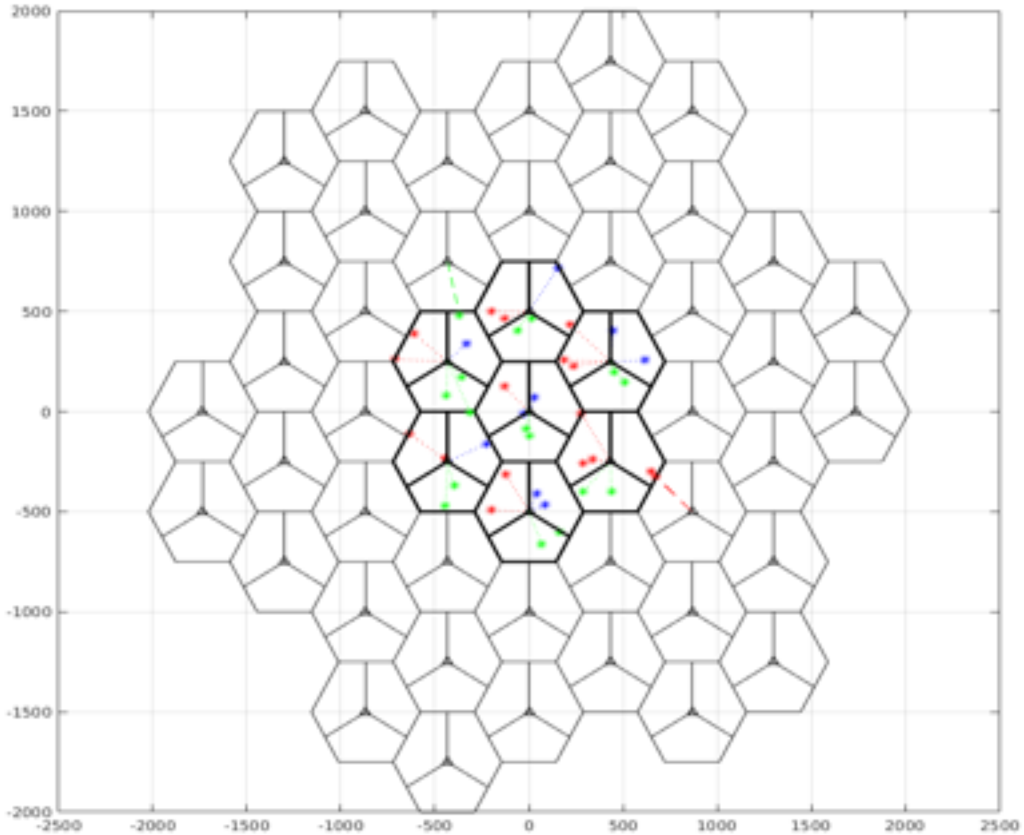
Improvements to the LTE / EPC model



- New SGW, PGW and MME nodes
- New S5 interface
  - GTPv2-C protocol
- Management of data/control TEIDs in core network entities

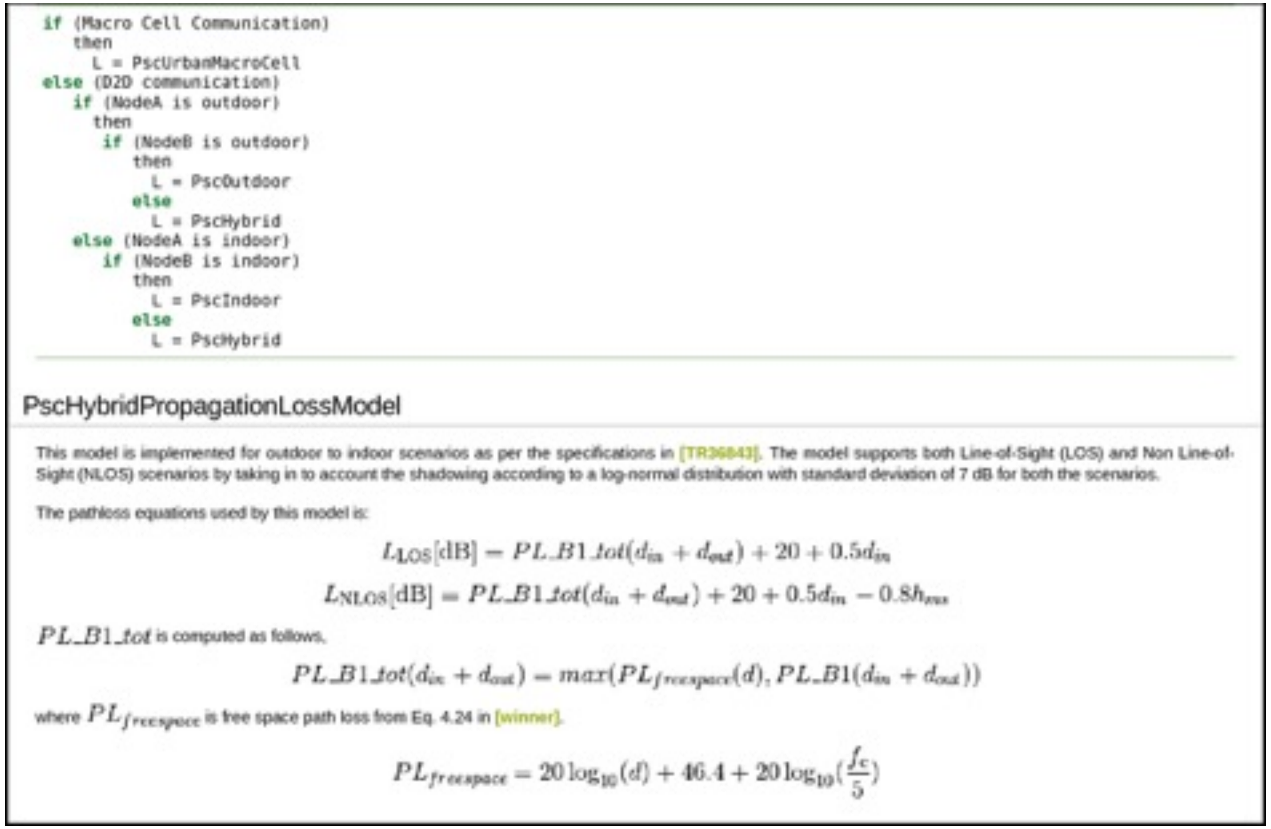
Example of software testing and integration

> Testing of wraparound methods to simulate multi-cell edge effects



Sample documentation

> Extend PSC module documentation (e.g. pathloss models, sidelink bearer activation, tests to validate code)



```
if (Macro Cell Communication)
  then
    L = PscUrbanMacroCell
else (D2D communication)
  if (NodeA is outdoor)
    then
      if (NodeB is outdoor)
        then
          L = PscOutdoor
        else
          L = PscHybrid
  else (NodeA is indoor)
      if (NodeB is indoor)
        then
          L = PscIndoor
        else
          L = PscHybrid
```

PscHybridPropagationLossModel

This model is implemented for outdoor to indoor scenarios as per the specifications in [TR36843]. The model supports both Line-of-Sight (LOS) and Non Line-of-Sight (NLOS) scenarios by taking in to account the shadowing according to a log-normal distribution with standard deviation of 7 dB for both the scenarios.

The pathloss equations used by this model is:

$$L_{\mathrm{LOS}}[\mathrm{dB}] = PL\_B1\_tot(d_{in} + d_{out}) + 20 + 0.5d_{in}$$

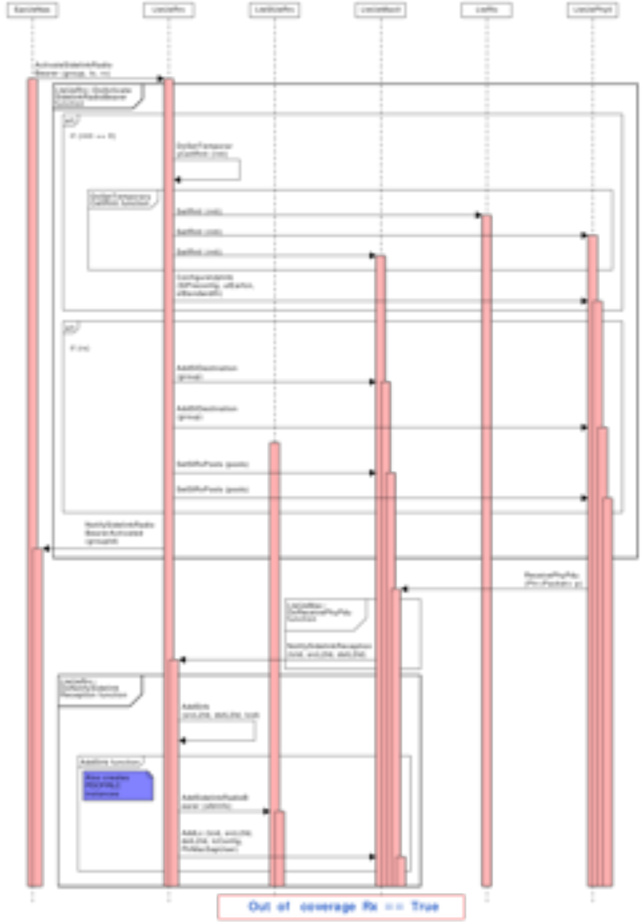
$$L_{\mathrm{NLOS}}[\mathrm{dB}] = PL\_B1\_tot(d_{in} + d_{out}) + 20 + 0.5d_{in} - 0.8h_{ms}$$

PL_B1_tot is computed as follows,

$$PL\_B1\_tot(d_{in} + d_{out}) = max(PL_{freespace}(d), PL\_B1(d_{in} + d_{out}))$$

where $PL_{freespace}$ is free space path loss from Eq. 4.24 in [winner].

$$PL_{freespace} = 20\log_{10}(d) + 46.4 + 20\log_{10}(\frac{f_c}{5})$$



Future plans

- Finish **EPC model upgrades** and **in-network MCPTT** support
- Additional features:
  - Support of **LTE IDLE** mode and **radio link failures (RLF)** as nodes transition in and out of coverage
  - Scalability and system level support for more **real code integration** and for **simulation checkpointing**
  - Support **evolution of D2D/ProSe** to later 3GPP release features (more in-network support and prioritization)
- Continued **scenario development**, and start to **enable new users** to conduct interesting research on PSC-based LTE networks

Modeling Device to Device Discovery in LTE Mode 2

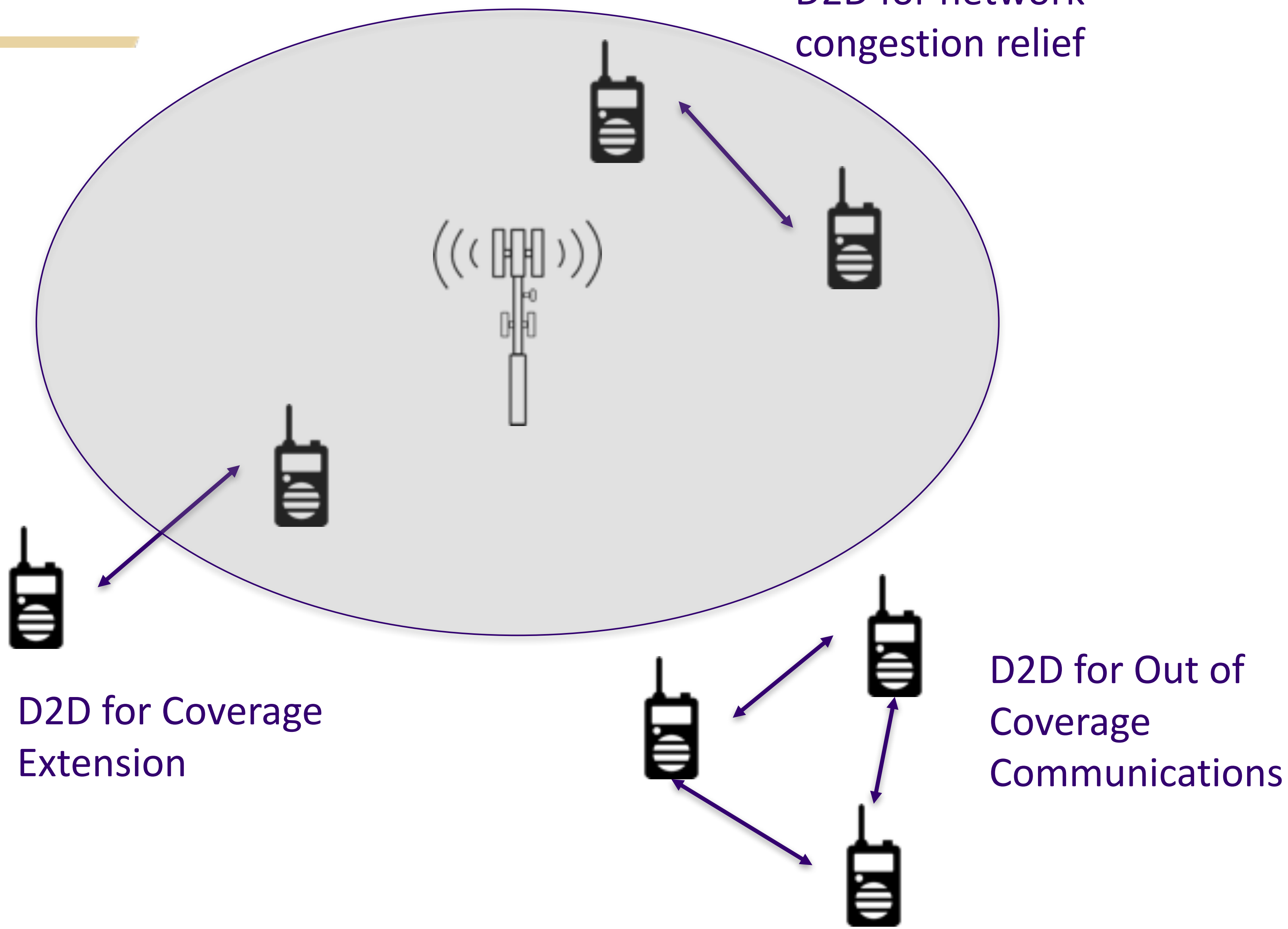
Collin Brady (presenting) and Sumit Roy

UNIVERSITY *of* WASHINGTON

Overview

- **Motivation:** Current LTE specifications lack a robust D2D discovery process. As more public safety users adopt LTE, D2D discovery must be optimized for time critical situations.
- **Operational Benefit**: First responders in off-network situations can discover each other and communicate more quickly.
- **Approach:** Modeling each discovery round as an ALOHA like process allows for mathematical analysis complemented by MATLAB simulations.
- **Future Work:**
  - Extension of first round results to subsequent rounds
  - Algorithmic adaptation of transmission probability

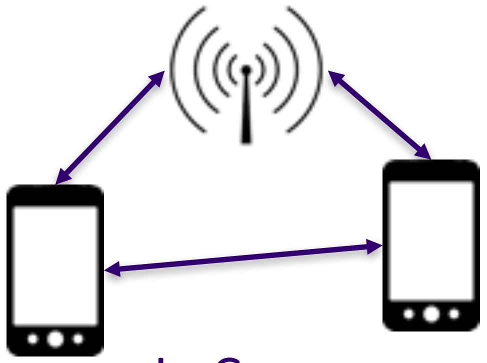
D2D in LTE



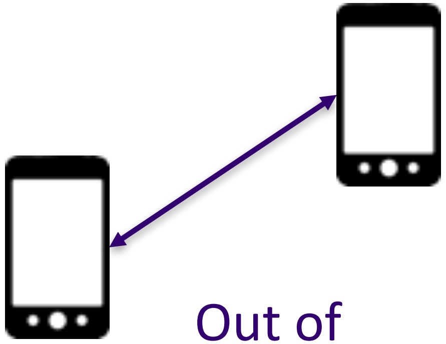
D2D for network congestion relief
D2D for Coverage Extension
D2D for Out of Coverage Communications

D2D Discovery

- "Discovery" is a function that allows UE to learn about other UE in their vicinity
- Two discovery modes are defined in the standards:
  - Mode 1: In network
  - Mode 2: out of network
- Discovery messages advertise what each UE is capable of

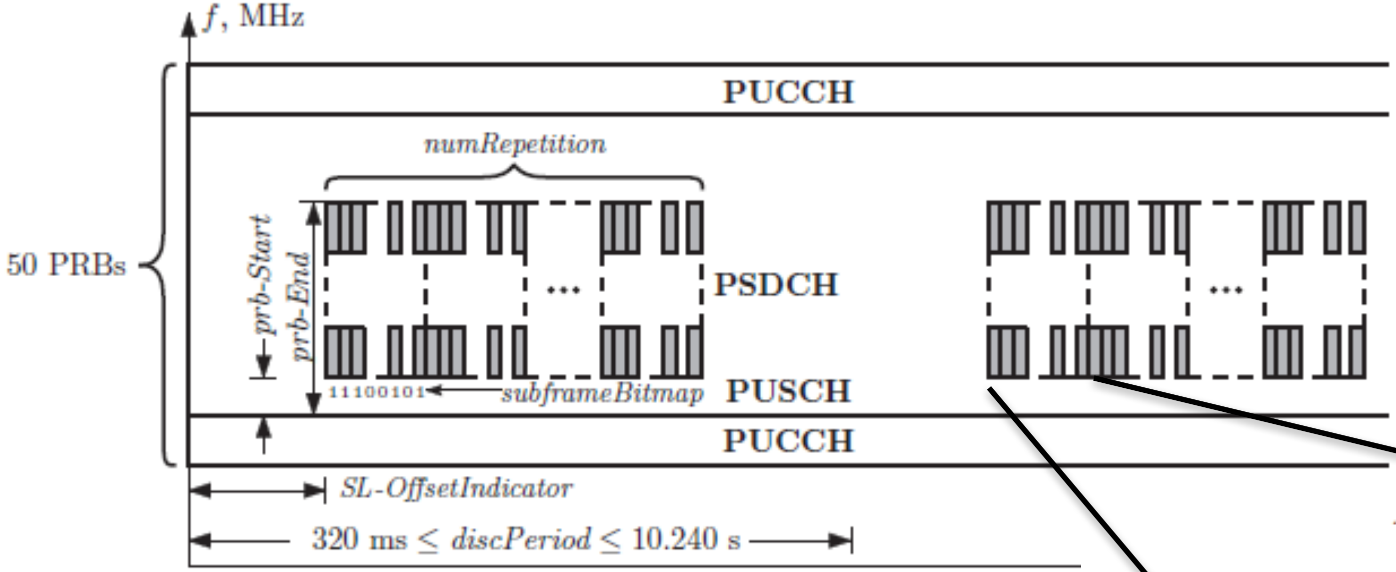


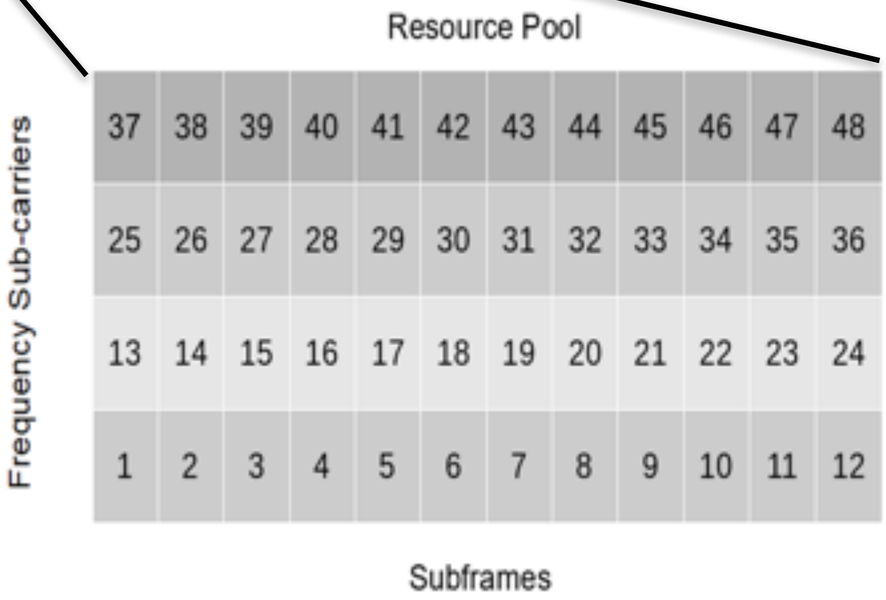
In Coverage



Out of Coverage

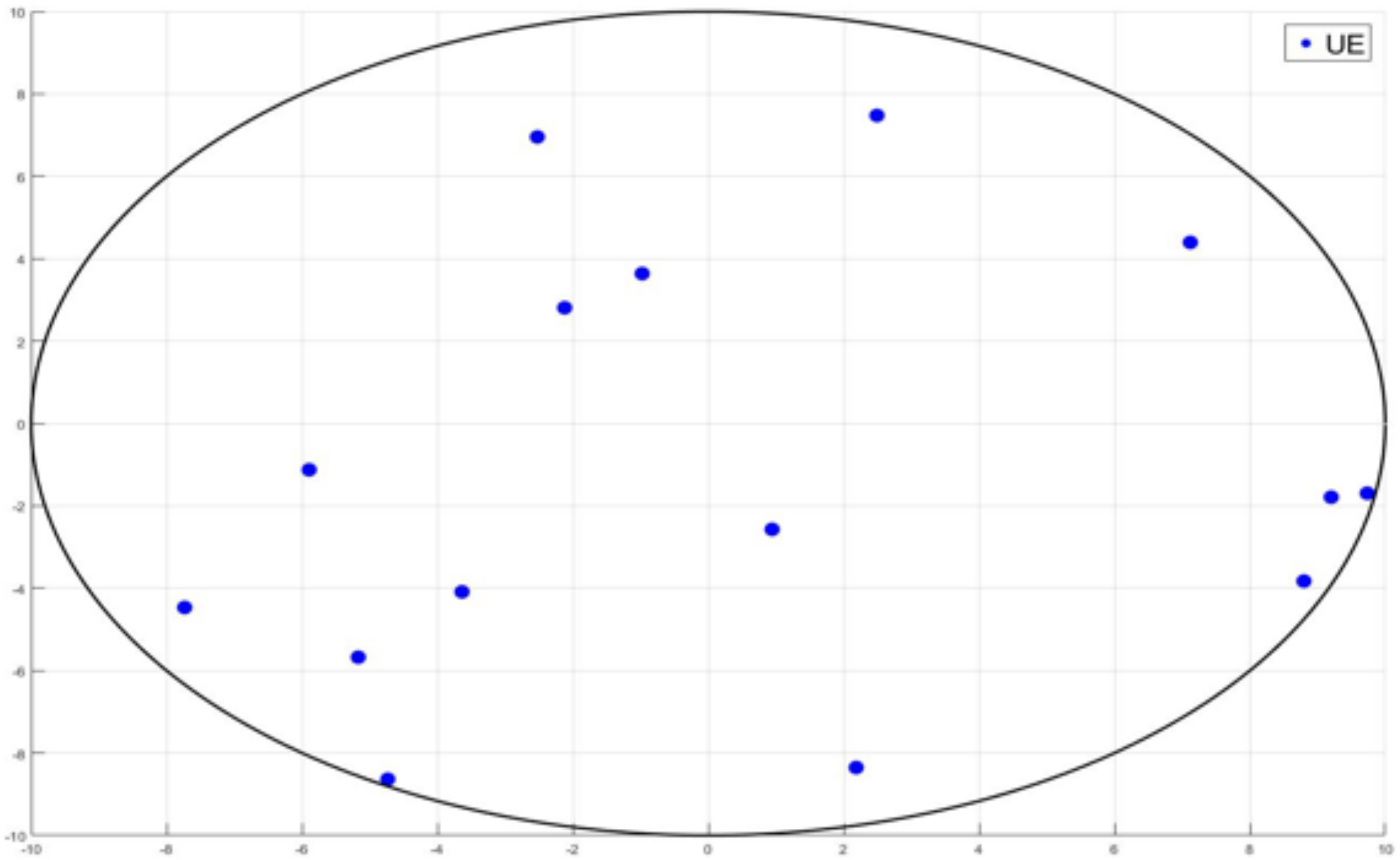
LTE Physical Sidelink Discovery Channel(PSDCH)



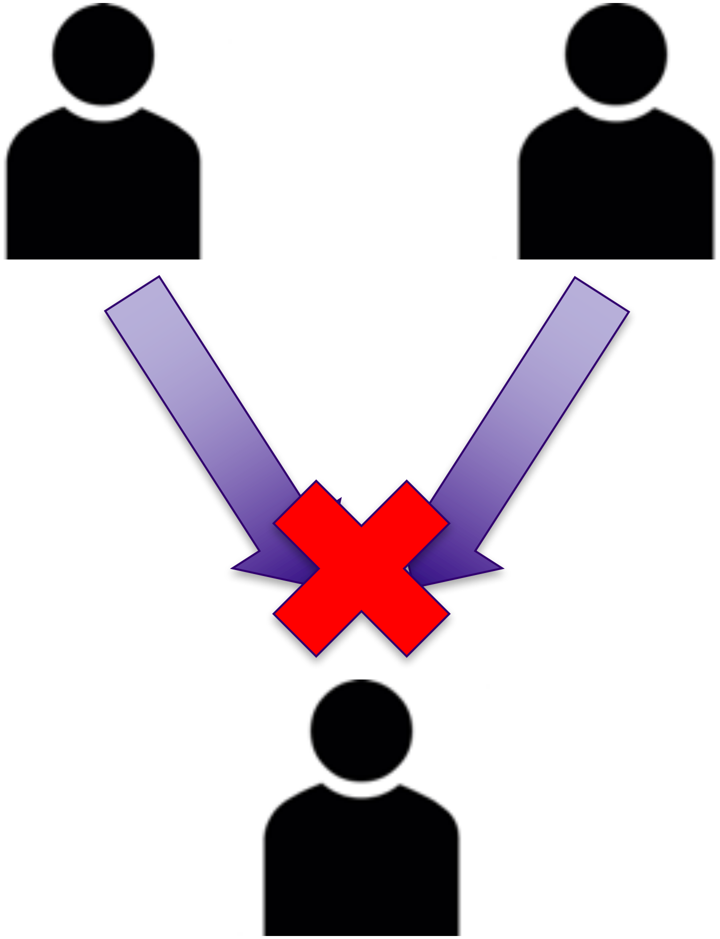


Griffith, David. [Figure]. Retrieved from https://www.nist.gov/publications/optimizing-ue-transmission-probability-d2d-direct-discovery

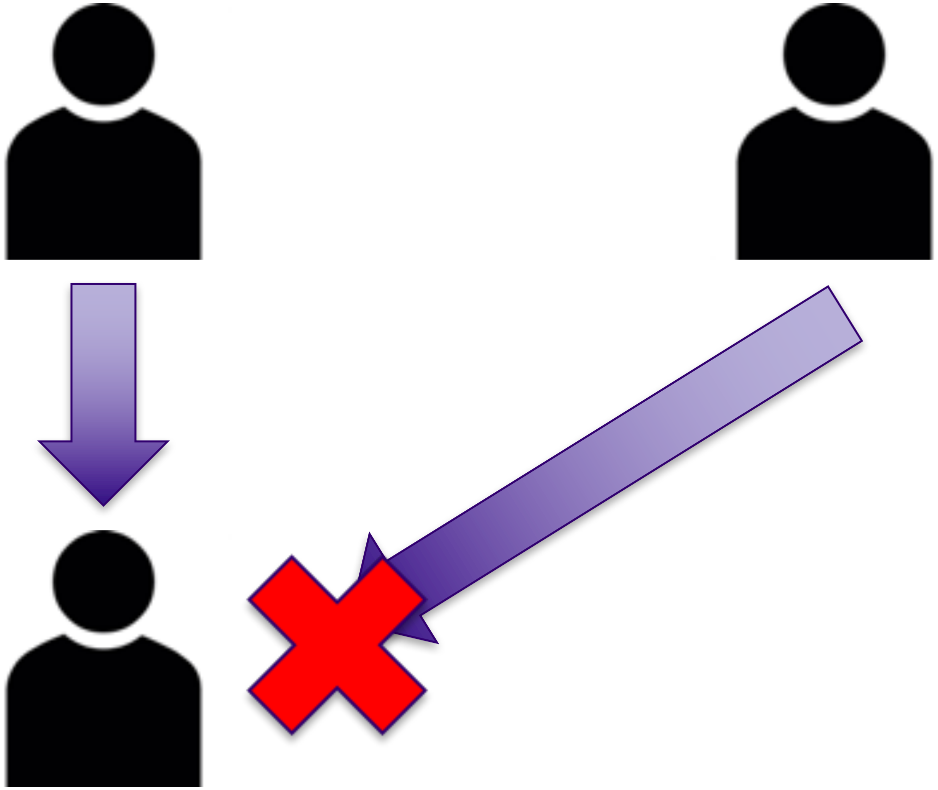
Spatial Distribution of UE



Collisions and Capture

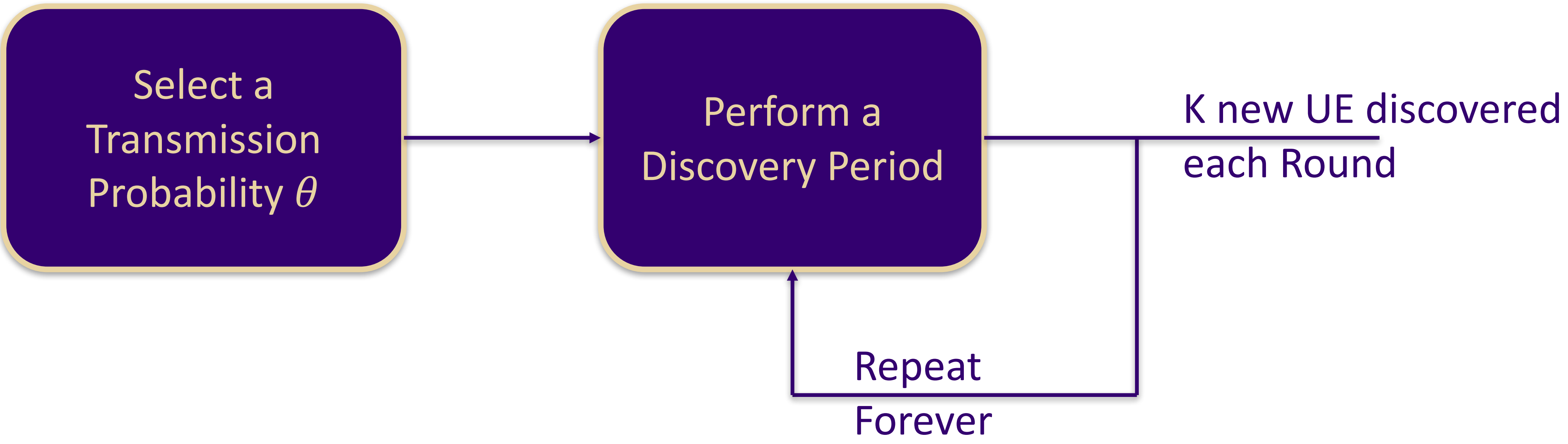


Collision



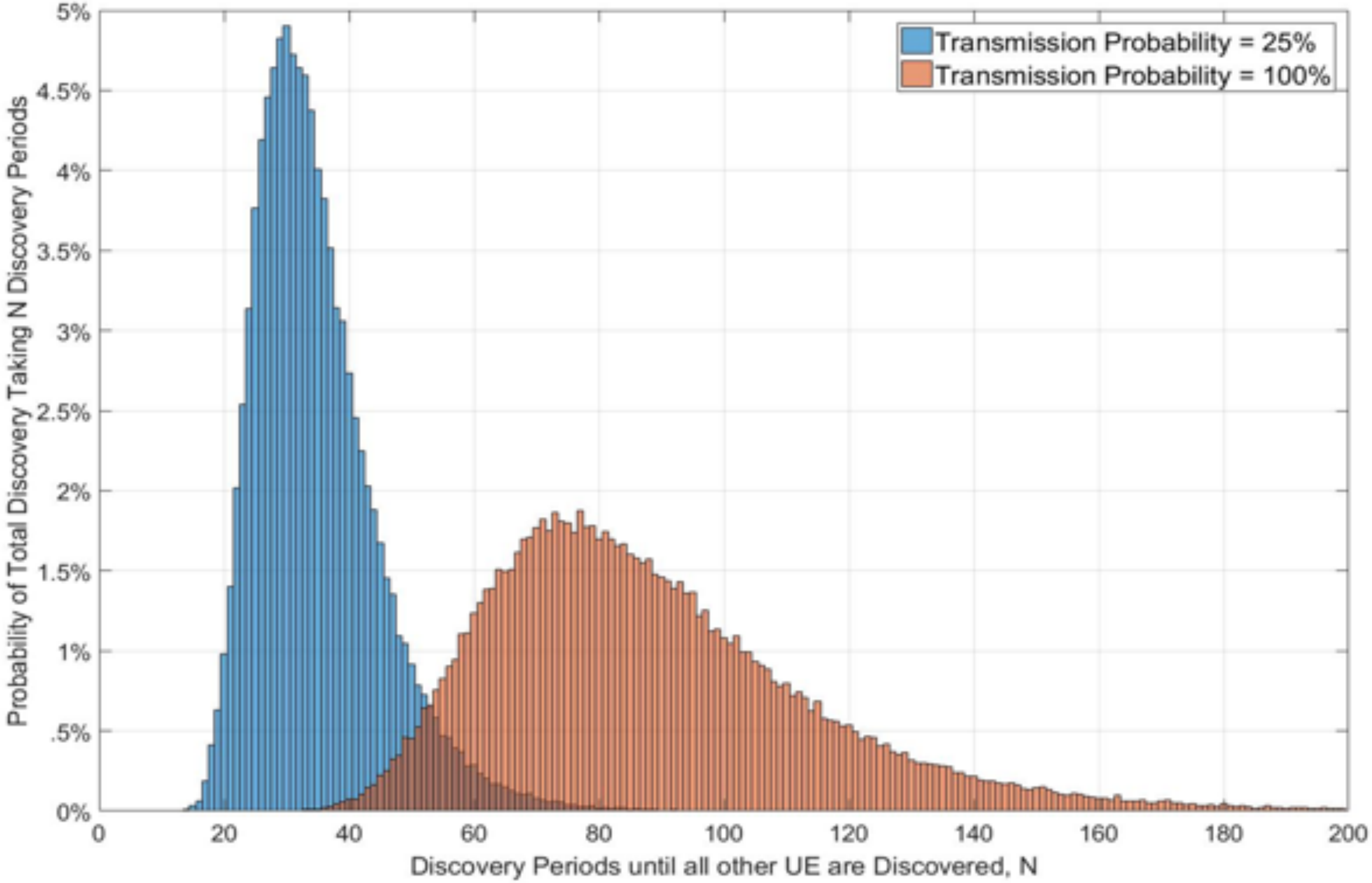
Capture

Current Discovery Algorithm



- θ never changes

Effects of suboptimal transmission probability choice on rounds until total discovery



Goal

Using a Markov chain model of the discovery process, minimize the time it takes for one UE to discover all other users

Phase 1: Model the first discovery period and determine a probability distribution for K discoveries

Phase 2: Extend the first round results to rounds beyond the first, and develop an estimator for the number of UE in the group

Phase 1: Single Round Model

- Define $P_{disc}(K)$
- Conditioning on events:
  - Whether or not a reference UE transmits
    - If it does: The number of transmitting UE who select the same PRB as the reference UE
  - The number of other UE that choose to transmit aside from the reference UE, N_{ac}

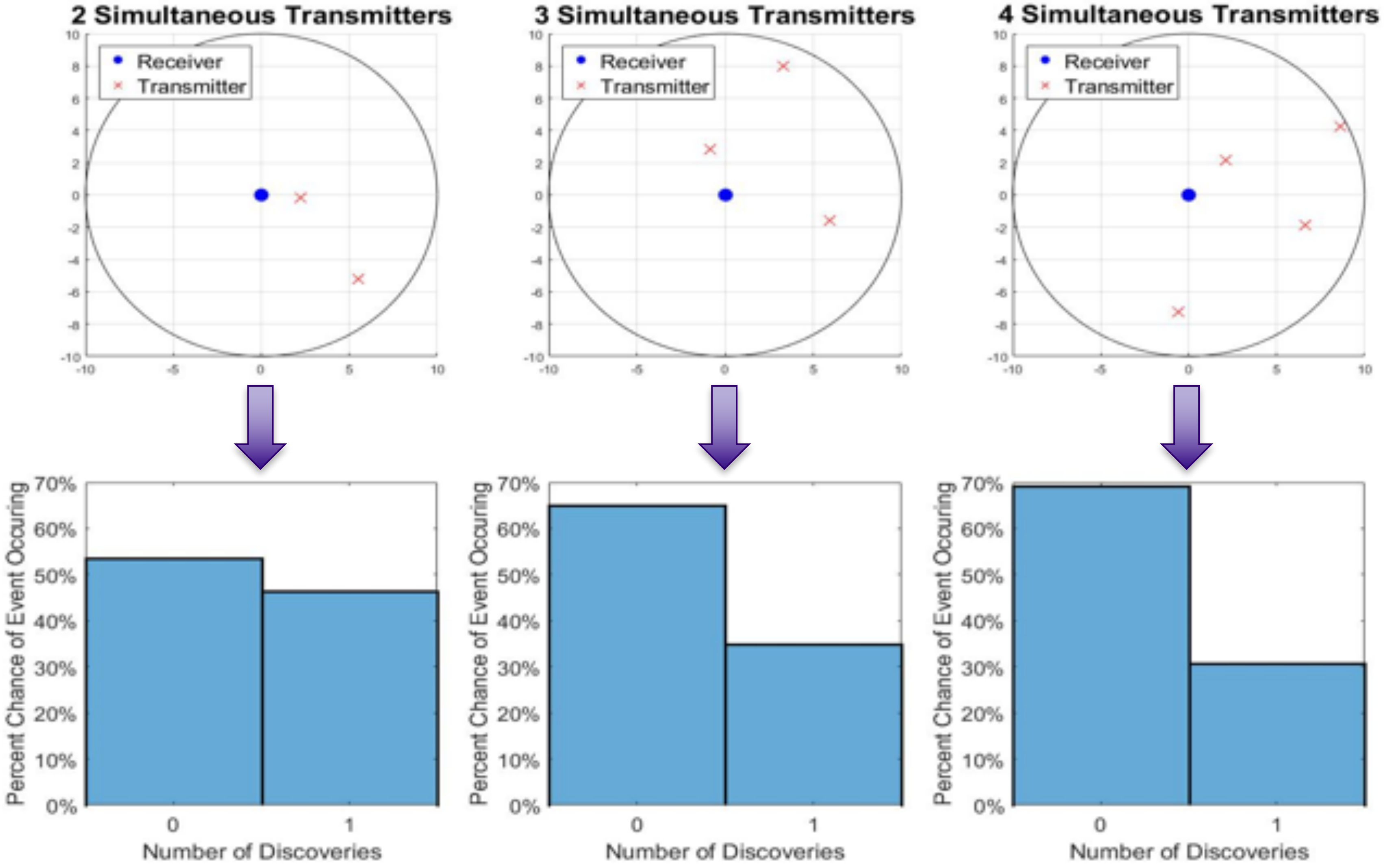
Phase 1: UE PRB Choices

	Resource selected																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
UE 1			X																	
UE 2							X													
UE 3																			X	
UE 4			X																	
UE 5														X						
UE 6									X											
UE 7																			X	
UE 8								X												
UE 9							X													
UE 10			X																	

	Number of users in each PRB																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
X	0	0	3	0	0	0	2	1	1	0	0	0	0	1	0	0	0	0	2	0

	Number of UE in each occupied PRB					
A	3	2	2	1	1	1

Phase 1: Collision and Capture Probabilities

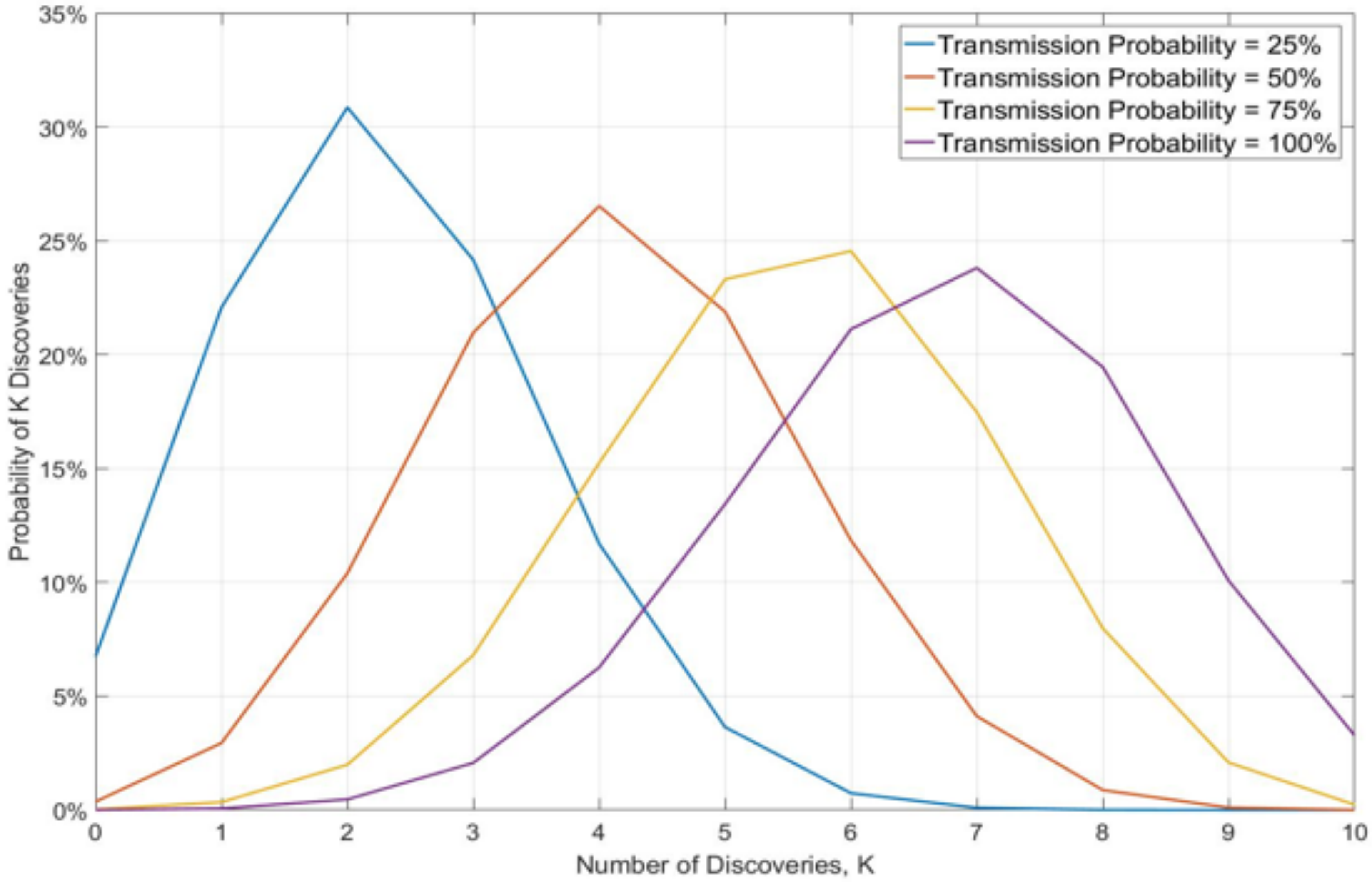


Phase 1: Collision and Capture

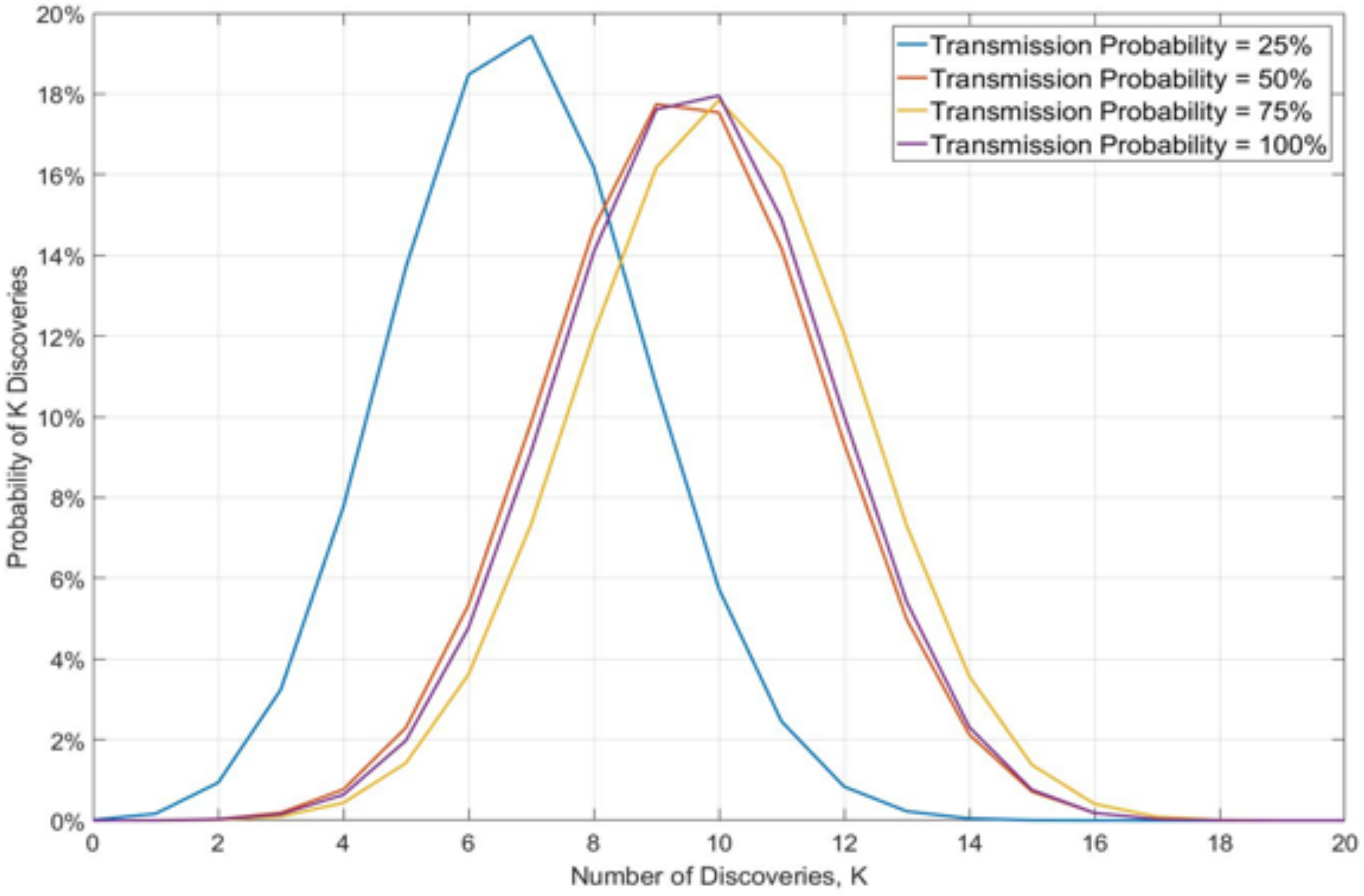
PRB Occupancies						
	3	2	2	1	1	1
Event 1	Capture	Collision	Collision	Capture	Capture	Capture
Event 2	Collision	Capture	Collision	Capture	Capture	Capture
Event 3	Collision	Collision	Capture	Capture	Capture	Capture

- Single occupancy PRBs are guaranteed to be decoded
- Remaining discoveries must come from multiple occupied PRBs
- Total probability is the sum of all event probabilities

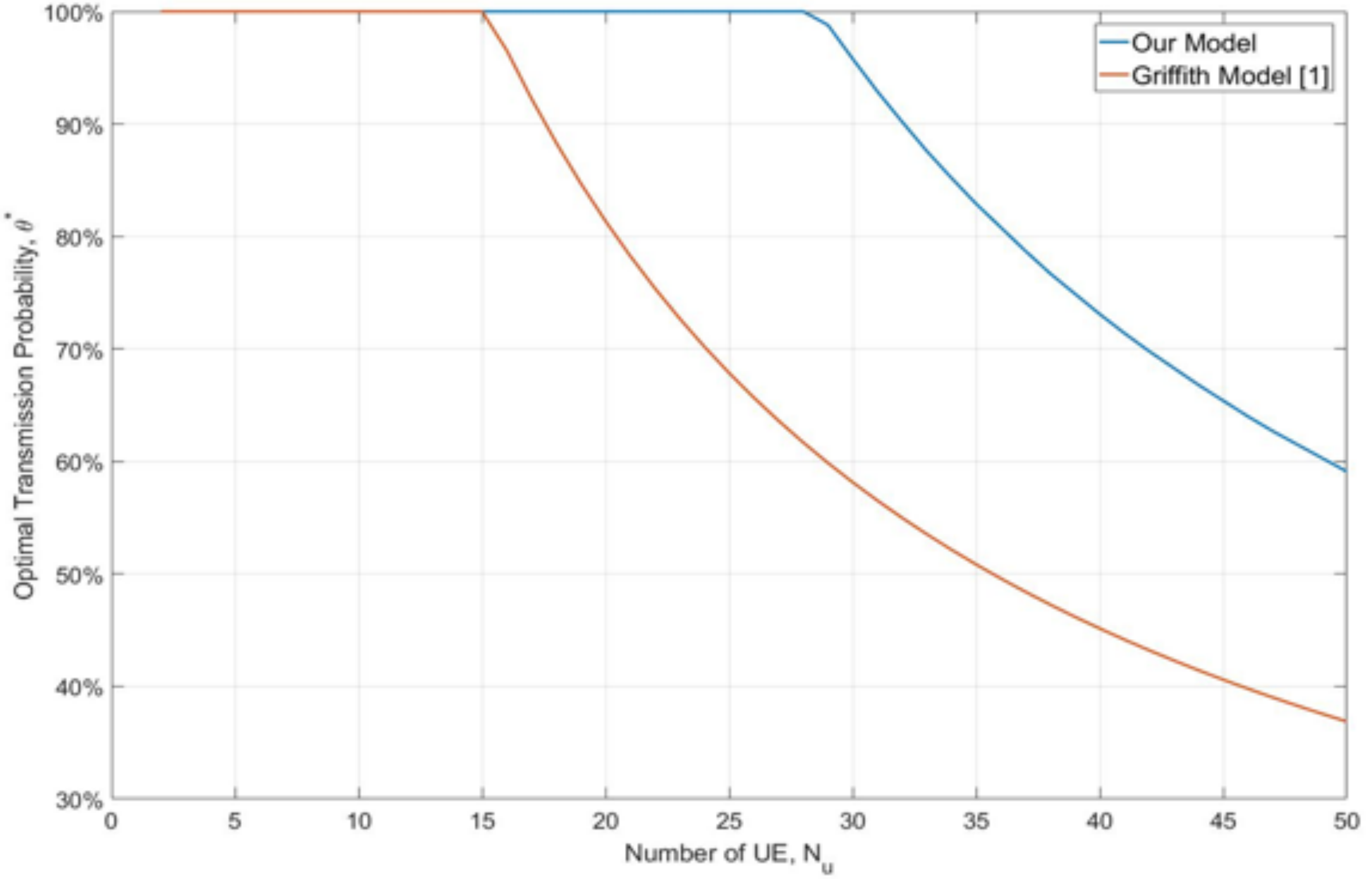
Effects of Transmission Probability on Discovery Probability with few UE



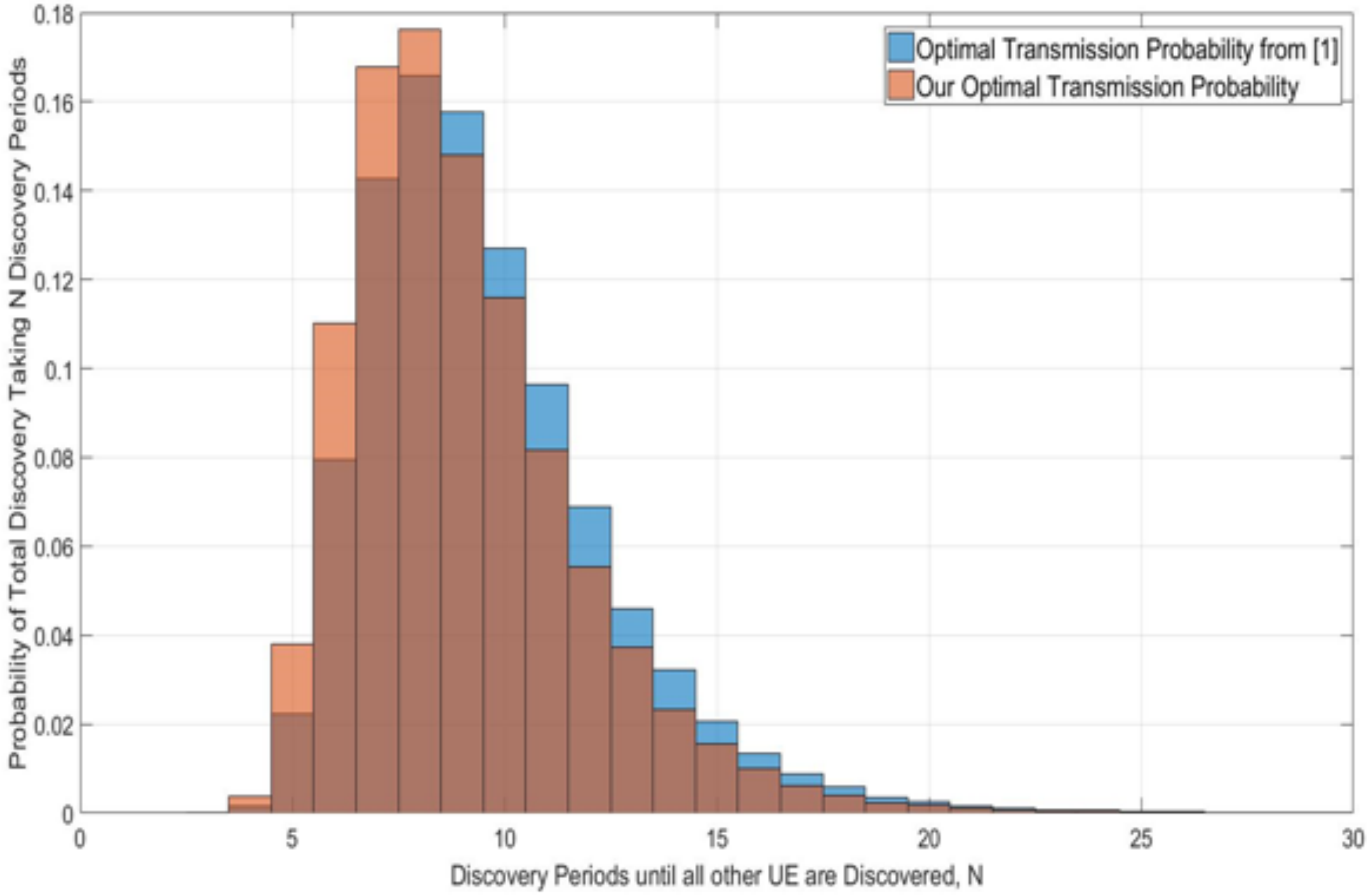
Effects of Transmission Probability on Discovery Probability with many UE



Optimal Transmission Probability, Our Model vs [1]

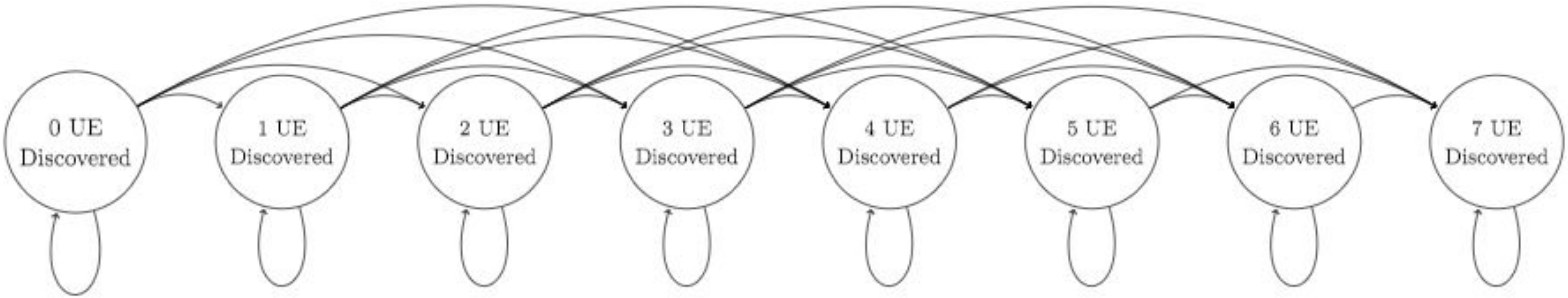


Effects of our Optimal Transmission Probability



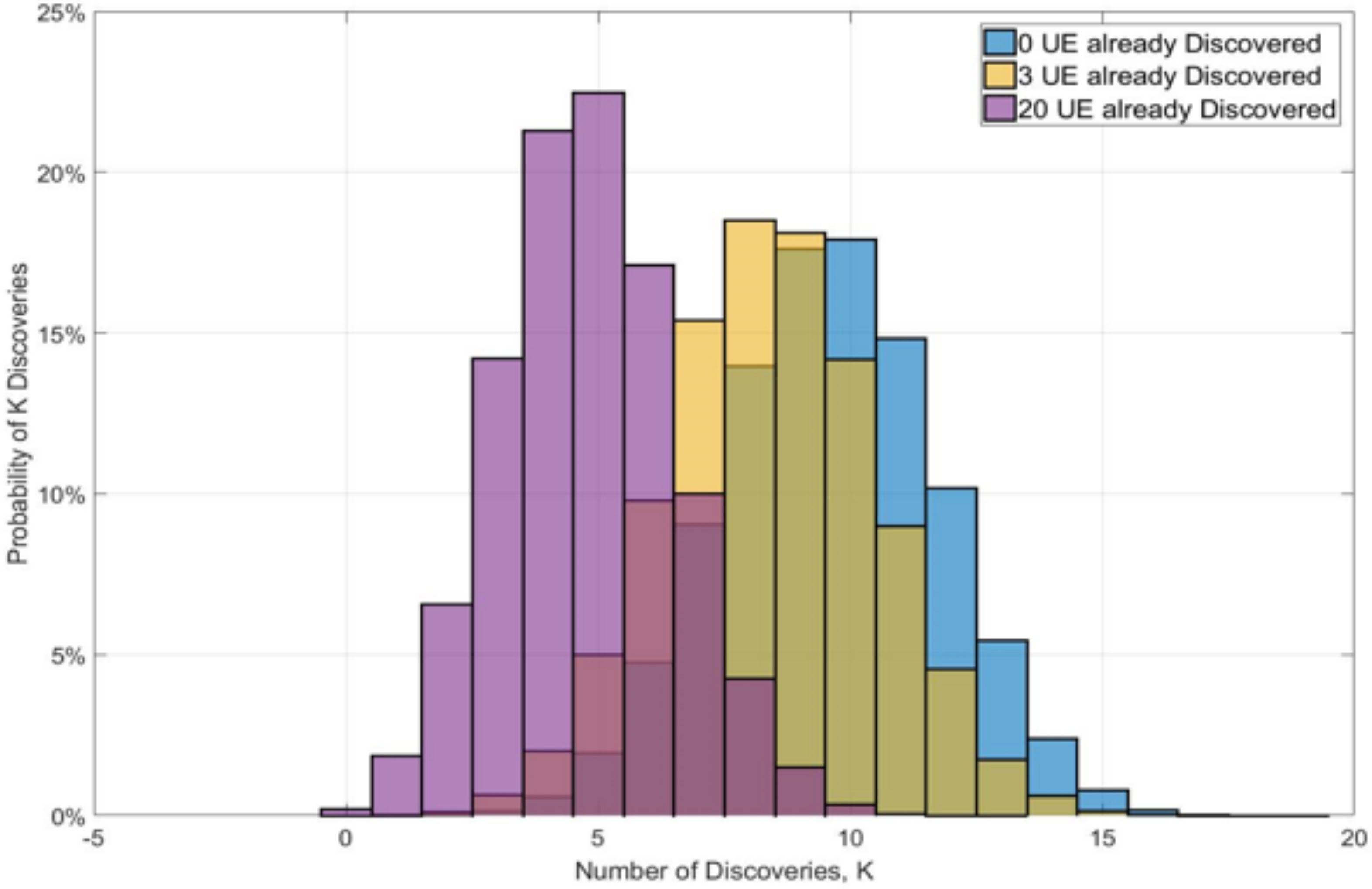
Phase 2: Multiple Round Theory

- Use modified coupon collector's problem as a framework

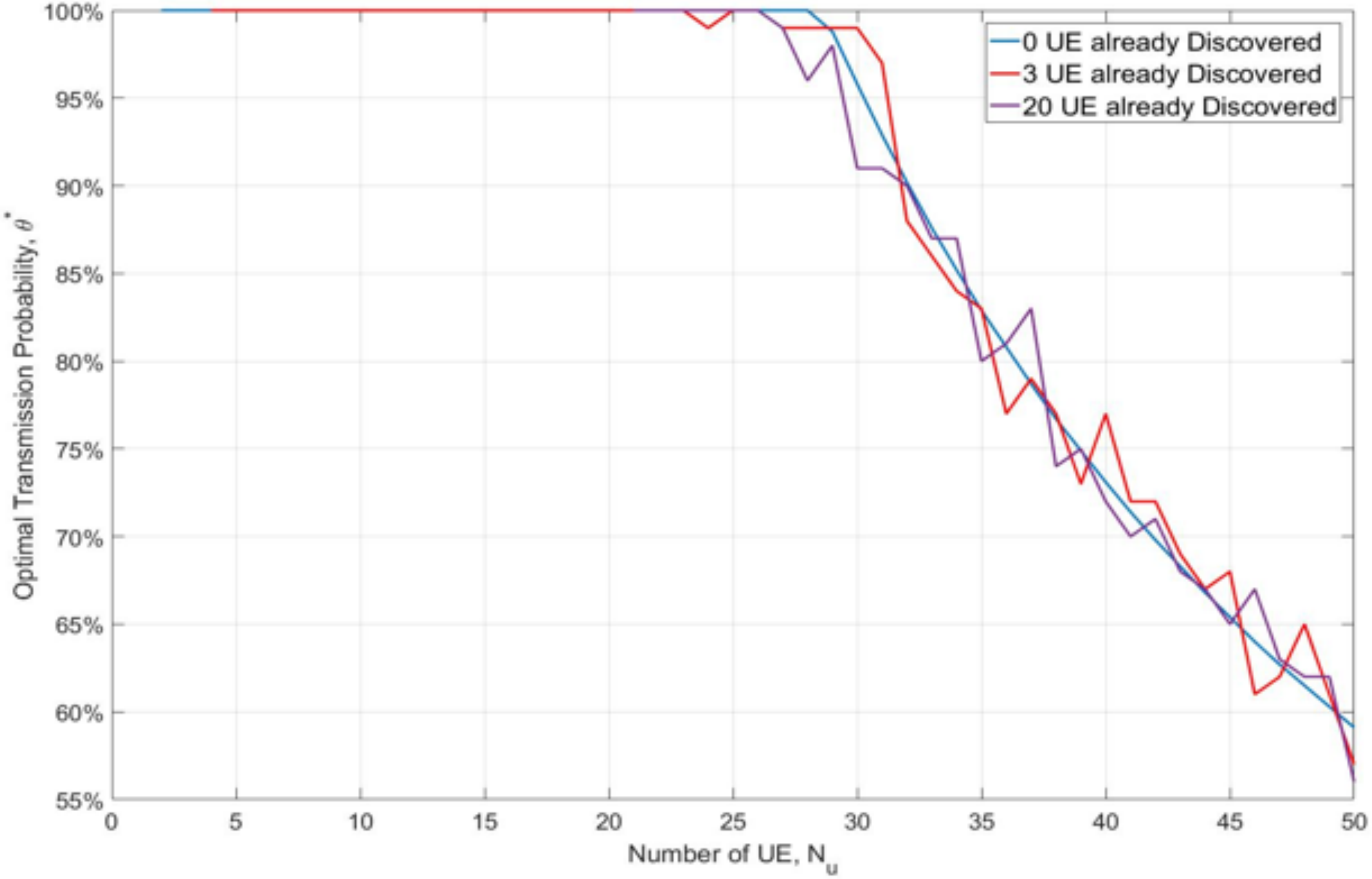


- Define: $P_{disc}(K, N_{disc})$

Effects of Previously Discovered UE on Discovery Probability



Effects of Previously Discovered UE on Optimal Transmission Probability



Future Work

- Using:
  - Current number of UE discovered
  - Previous number of UE discovered
- Find: Estimate of total number of UE
- Use estimate to select θ

Key Takeaways

- In a wireless scenario only one UE can be discovered per PRB unless other methods, successive cancelation or others, are implemented.
- By taking into account the spatial distribution of UE the transmission probability can be set higher than previously thought.
- The optimal transmission probability is not dependent on how many UE have already been discovered and so the best way to improve discovery performance is to estimate the number of UE as quickly as possible.

Sources and Acknowledgements

[1]: D. Griffith and F. Lyons, "Optimizing the UE Transmission Probability for D2D Direct Discovery," *2016 IEEE Global Communications Conference (GLOBECOM)*, Washington, DC, 2016, pp. 1-6.

[2]: A. Ben Mosbah, D. Griffith and R. Rouil, "A novel adaptive transmission algorithm for Device-to-Device Direct Discovery," *2017 13th International Wireless Communications and Mobile Computing Conference (IWCMC)*, Valencia, 2017, pp. 177-182.

[3]: D. Griffith, A. Ben Mosbah and R. Rouil, "Group discovery time in device-to-device (D2D) proximity services (ProSe) networks," *IEEE INFOCOM 2017,* 2017.

This work was supported in part under NIST PSIAP Program via Coop. Agreement # 70NANB17H170.

Question and Answer Session

Related Work

- Griffith et al. [1] derived analytical expressions for modeling the distribution of time required for a UE to discover all other UEs within a single group. These analytical expressions can be used to guide the selection of transmission probabilities.
- Our results extend those of [1] by accounting for the possibility that not all discovery collisions are destructive. Our more optimistic model provides modified analytical expressions for time distributions and optimal transmission probabilities.

Phase 1: Results

- Final results for $P_{disc}(K)$:

$$P_{disc}(K) = \sum_{n_{ac}=0}^{N_u-1} P(N_{ac}=n_{ac}) \Big[\theta \sum_{n_d=0}^{n_{ac}} P(N_d=n_d) \sum_{A \in A_{N_{prb}-1, N_{ac}-N_d}} P(A) P_{disc}(K|A, N_{ac}=n_{ac}-n_d)$$

$$+ (1-\theta) \sum_{A \in A_{N_{prb}, N_{ac}}} P(A) P_{disc}(K|A, N_{ac}=n_{ac}) \Big]$$

Mission Critical Voice: Quality of Experience and Key Performance Indicators

PSCR

Disclaimer

Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately.

Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

*Please note, all information and data presented is preliminary/in-progress and subject to change.

AGENDA

- Quality of Experience (QoE)
- Existing LMR/LTE Key Performance Indicators (KPIs)
- New MCV QoE Federal Funding Opportunity (FFO)
- QoE KPIs for Mission Critical Voice (MCV)
- PSCR Projects on QoE KPIs

PSCR

Quality of Experience (QoE)

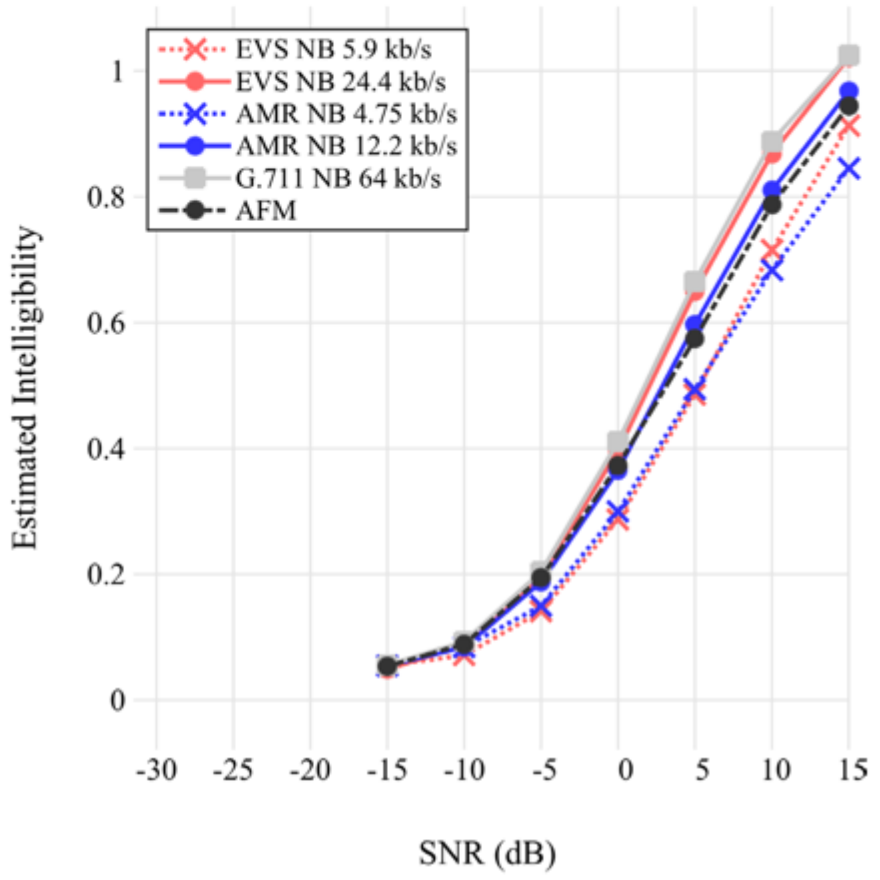
- LMR/LTE Industry
  - Ensure that Their Devices/Systems Function
  - Primarily Concerned with Compliance
    - Technology specific
  - Performance Measurements are Quality of Service (QoS) Based
- Public Safety Users
  - Need Their Devices to Work with Other Devices
  - Primarily Concerned with Operational Success
    - Not concerned with the technology itself
  - Do Not Often Relate to QoS Metrics

Quality of Experience (QoE)

- Public Safety/Industry
  - Need Open Capabilities/Methods to Compare and Fairly Evaluate Technologies
- NIST
  - Tasked with Measurement Science and Standards
- PSCR
  - Customers are Public Safety Users
  - Measurement Science and Standards for Public Safety Communications

Quality of Experience (QoE)

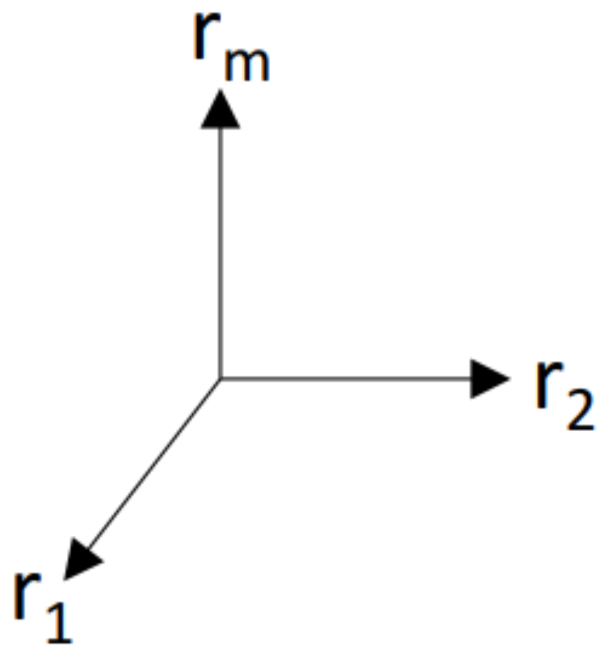
- QoE Definition
  - Quantity that Numerically Describes User Experience
  - Consists of Other Measurable Quantities
  - Could Be Both Objective and Subjective
- Example
  - Voice Quality/Intelligibility
    - POLQA Scores
      - How good does it sound?
    - ABC-MRT Scores
      - How well can it be understood?



PSCR

Quality of Experience (QoE)

- PSCR Internal Focus
  - MCV (MCPTT, Direct Mode, Group Communications)
  - Measure Component Quantities (KPIs)
    - Apply generically as possible to any technology
    - Same test for systems with networks, direct mode, and group communications
  - System Level Measurements
    - Heavily audio-based
- PSCR External Focus – New FFO
  - Measure How KPIs Impact Public Safety Users' Job Performance



Existing LMR/LTE KPIs

- QoS Based
- Compliance Based
- Technology Specific
- Depend on Complicated/Proprietary/Internal Measurements
- Example: PTT Access Time - Standards
  - TIA Definition: Time Between Button Press and Traffic Channel Transmit
  - 3GPP Definition: Time Between Button Press and Acknowledgement from System (KPI 1/2)
- QoE Definition
  - Time Between Button Press and Receiving User Hearing Transmitting User (End-to-End Access Time)

PSCR

QoE KPIs for MCV

- 2017 PSCR MCV Roundtable
  - Basis for MCV KPI Development
- All User Experience Based
- Simple and Inexpensive (Where Possible)
- Distilled Down to Four Primary KPIs

PSCR

QoE KPIs for MCV

- Access/Retention Probability
  - Ability to Establish Call
  - Ability to Retain Call
  - Coverage
- Mouth-to-Ear Latency
  - Time it Takes Audio to Get from Transmitting User to Receiving User
- End-to-End Access Time
  - Time Between Button Press and Receiving User Hearing Voice
  - Access Delay + Mouth-to-Ear Latency
- Audio Quality/Intelligibility
  - Public Safety Cares Most About Intelligibility

PSCR

QoE KPIs for MCV

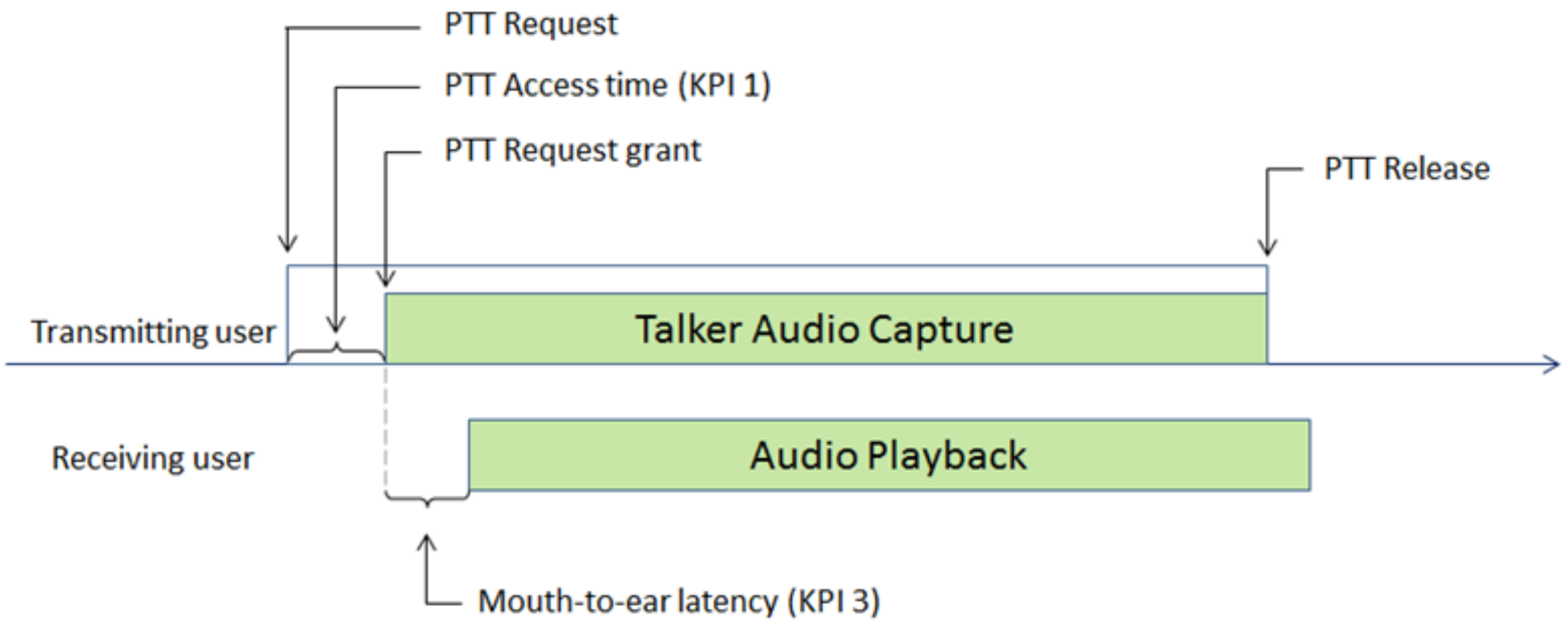
- Why Do All This?
  - Understand How Existing LMR Systems Affect Users
  - Apply to New/Different MCV Technologies
  - Compare LMR to LTE

PSCR Projects on QoE KPIs

- Mouth-To-Ear (M2E) Latency Measurement Method
  - Develop a method to measure & quantify M2E latency of any voice communications system
  - Method is based on audio in/audio out and is technology agnostic
  - Very challenging to develop this measurement methodology
    - Component to system level testing complexities with uncertainties
  - First step in establishing QoE-based Key Performance Indicators (KPI)

PSCR Projects on QoE KPIs

- 3GPP M2E Latency and Access Time

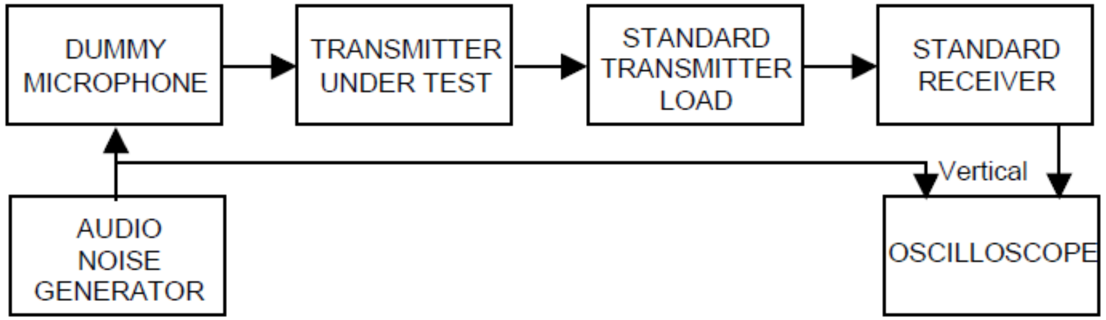


3GPP (2017) Mission Critical Push to Talk (MCPTT). 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 22.179. Version 16.0.0 URL: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=623

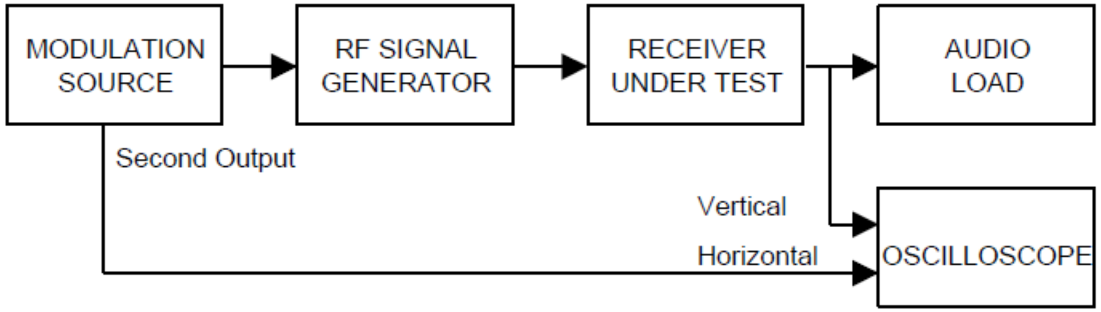
PSCR

PSCR Projects on QoE KPIs

- TIA 102 P25 M2E Latency Measurement Method
  - Transmitter Throughput Delay



  - Receiver Throughput Delay



PSCR

ANSI/TIA-102.CAAA-E-2016 TIA Standard Project 25 Digital C4FM/CQPSK Transceiver Measurement Methods

PSCR Projects on QoE KPIs

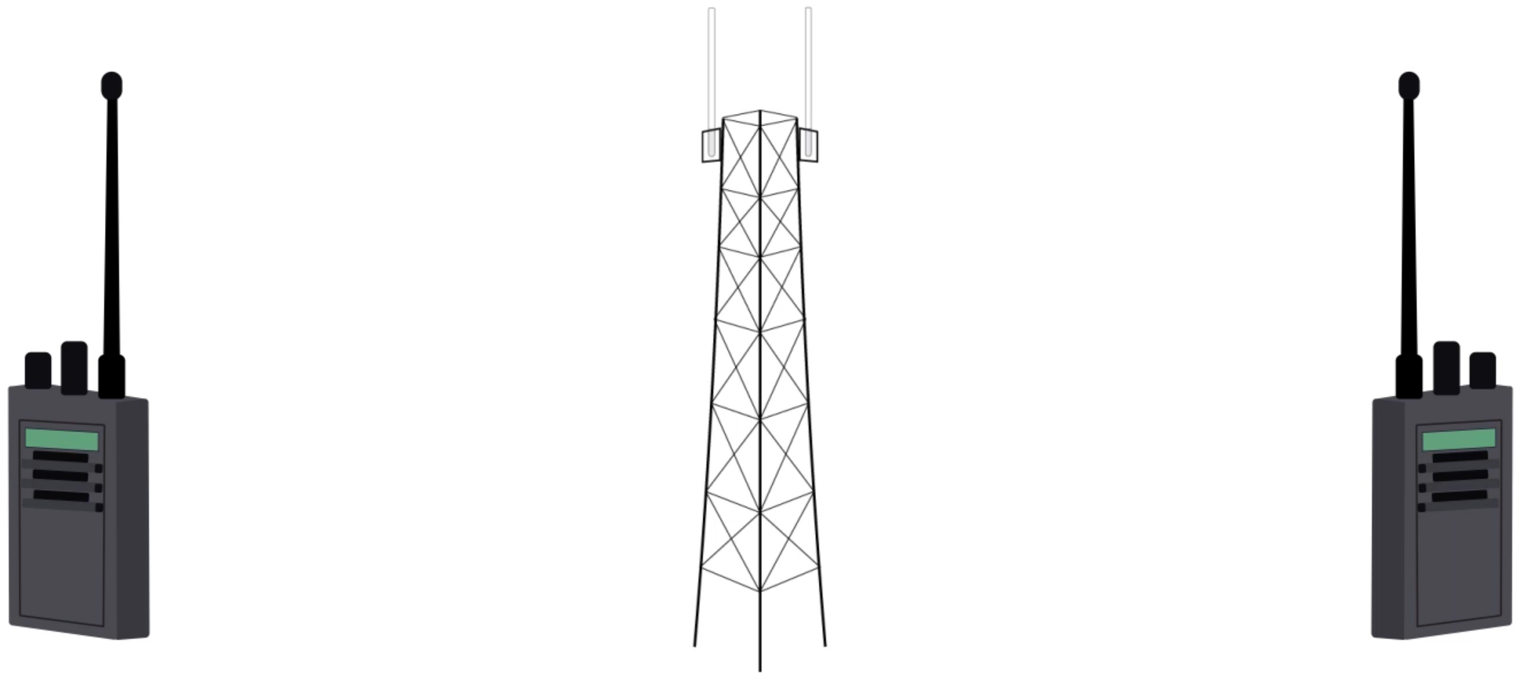
Direct Mode

Talker Audio Capture

PSCR

PSCR Projects on QoE KPIs

Trunked Mode



Talker Audio Capture

PSCR

PSCR Projects on QoE KPIs

- Standards Definitions and Measurement Methods are QoS-Based
- TIA 102 does not actually define M2E latency
- 3GPP defines M2E latency but does not specify a measurement method
- NIST/PSCR establishes a method to measure and quantify M2E latency
    - Addresses the end goal of the talker and listener

PSCR

PSCR Projects on QoE KPIs

- M2E Latency Measurement Method
  - LMR Direct Mode (VHF/UHF)
    - One Location - Lab
    - Two Location - Lab & Field
  - LMR Trunked Mode (VHF/UHF)
    - One Location - Lab
    - Two Location - Lab & Field

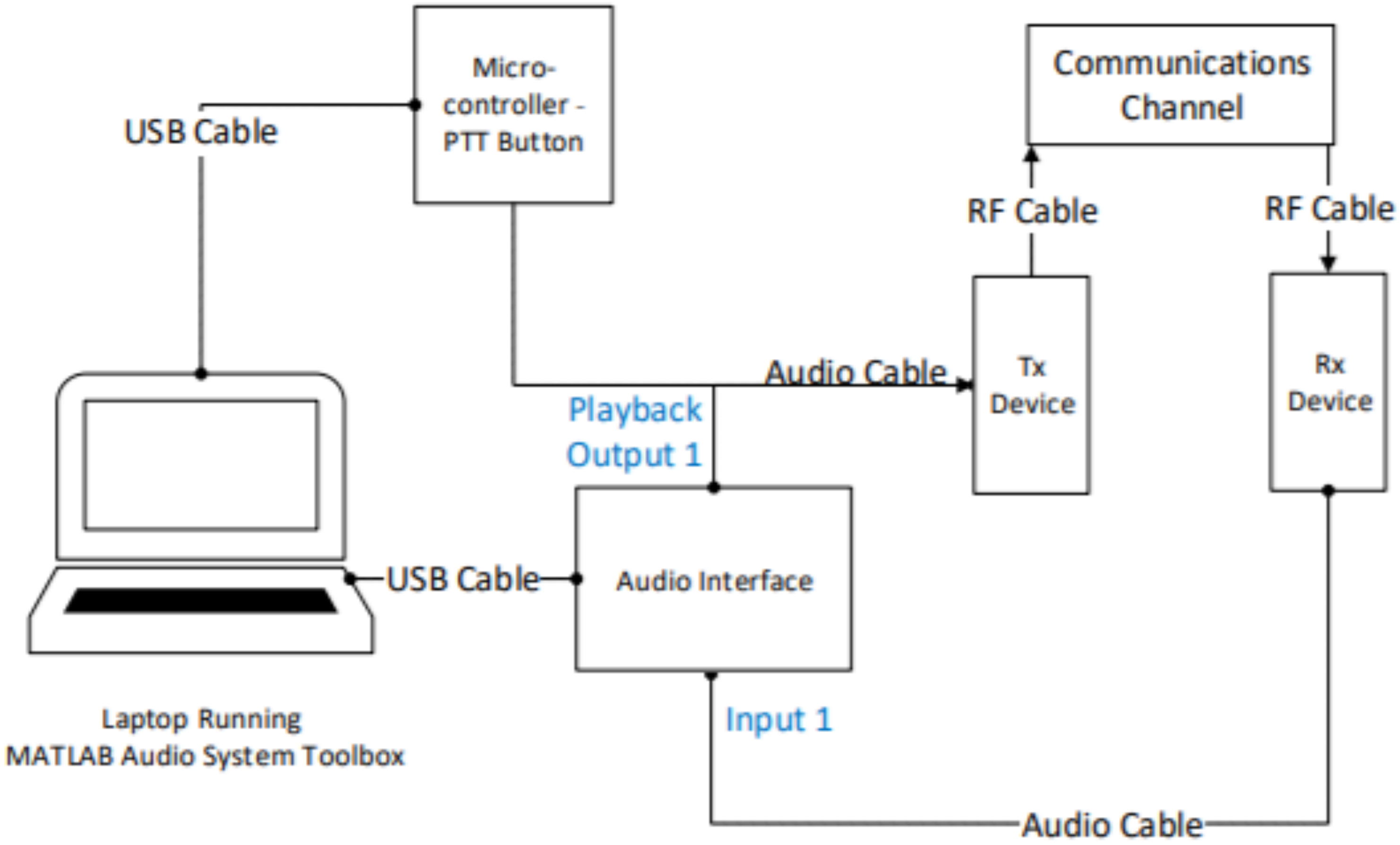
PSCR

PSCR Projects on QoE KPIs

- Behringer UMC 204HD Audio Interface
- Audio Interface Settings
  - Sampling rate, buffer size, and USB Streaming Mode values chosen to prevent data over/under runs and audio glitches
- Audio Interface Device Characterization
  - Latency: 21.85 ms (± 0.07 ms measurement uncertainty)
    - Time offset between play and record
- ESE ES-185E GPS Master Clock Timecode Generators
  - Provide synchronization for two location tests
  - Output IRIG-B format signals
- MATLAB
  - Audio System Toolbox
    - Used to play and record audio samples and quantify latency
    - Used to automatically key the PTT button via the microcontroller

PSCR Projects on QoE KPIs

- One Location Test Setup Diagram



Site 1 – TX/RX

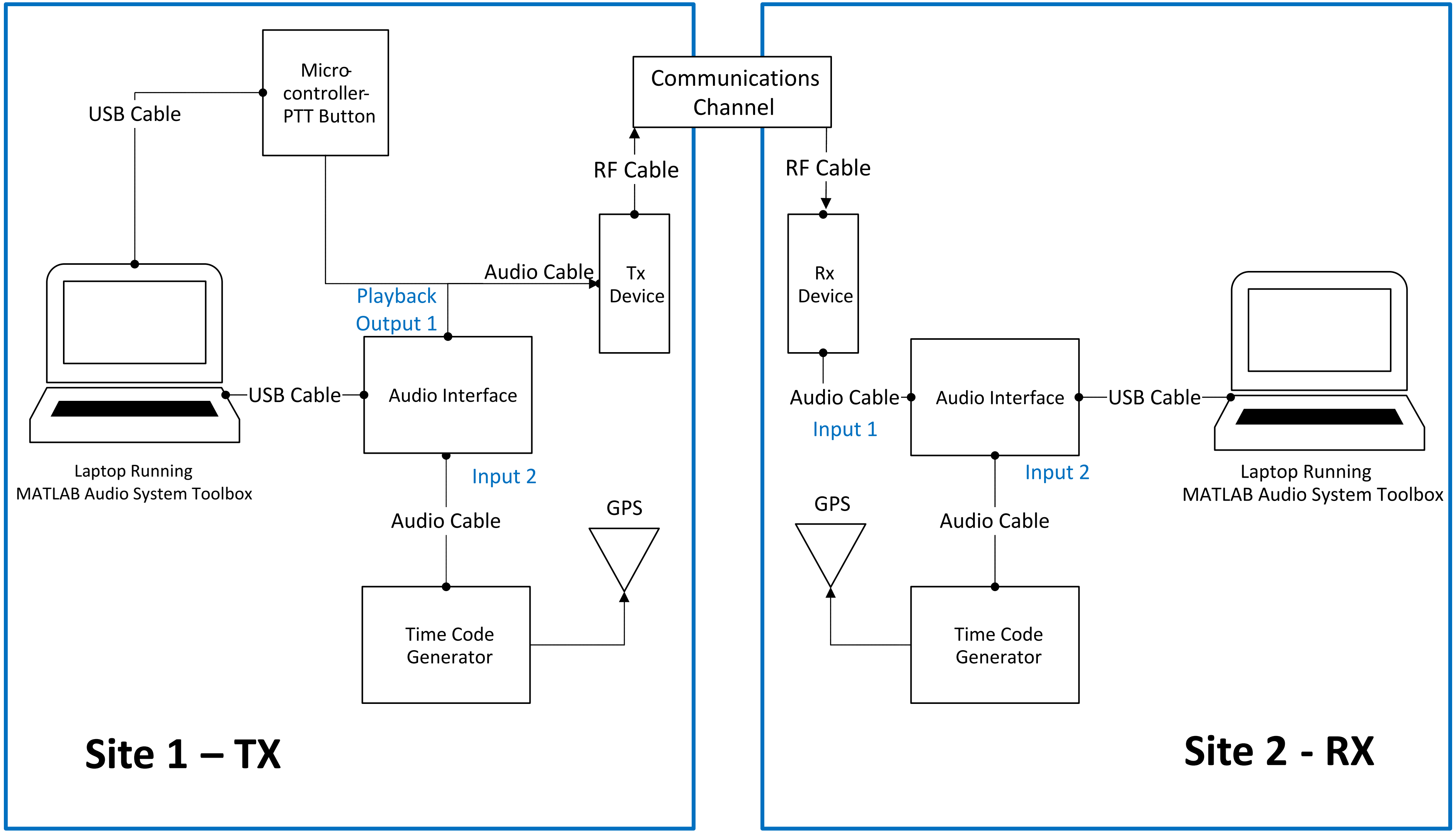
PSCR

PSCR Projects on QoE KPIs

- UHF Direct Mode One Location Setup (Over the Air)

PSCR Projects on QoE KPIs

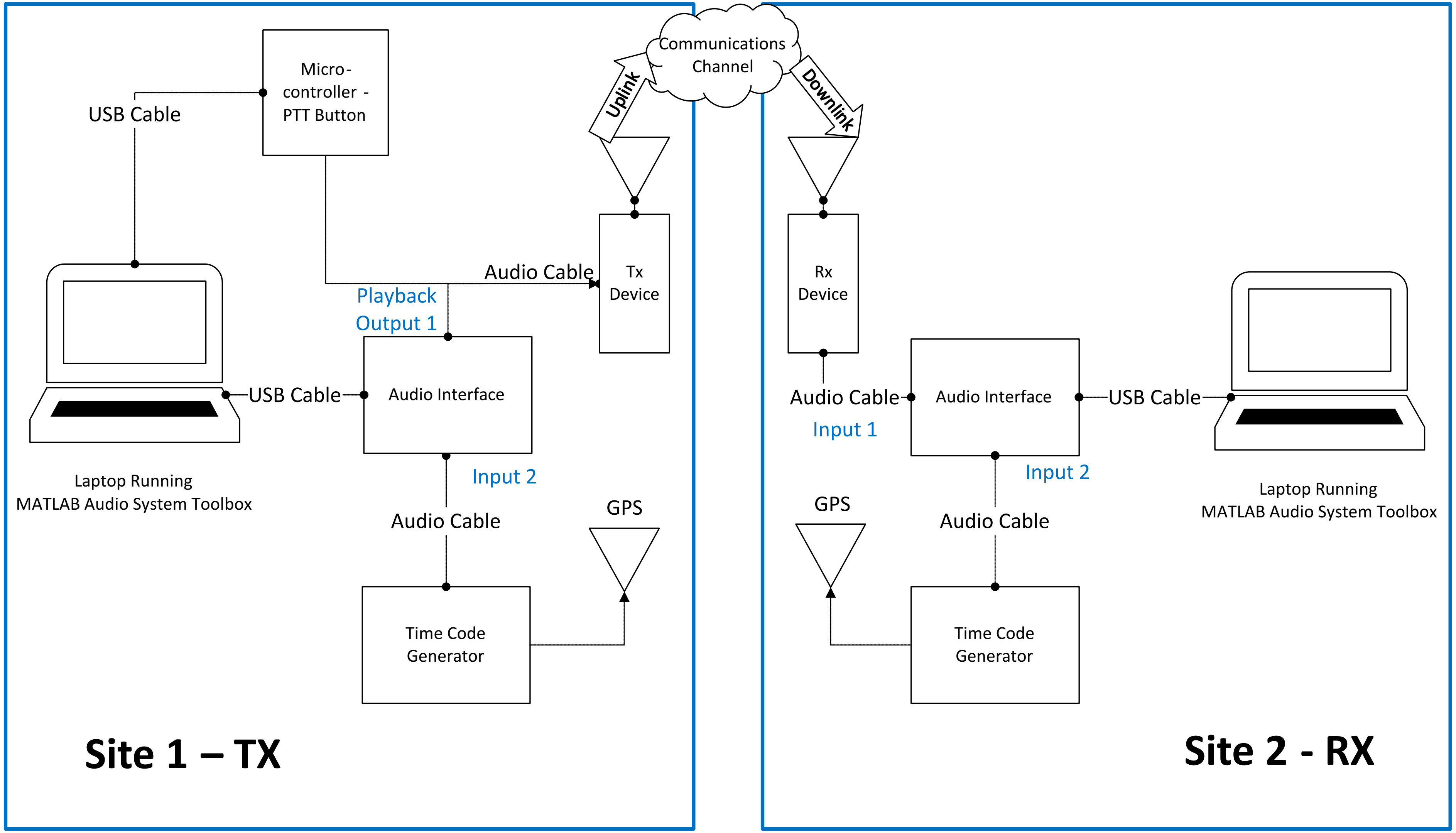
- Two Location Lab Test Setup Diagram



PSCR

PSCR Projects on QoE KPIs

- Two Location Field Test Setup Diagram



PSCR

PSCR Projects on QoE KPIs

- M2E Latency Measurement Results

	Single Location Lab (ms)	Two Location Lab (ms)	Two Location Field (ms)
Audio Device Characterization	21.85 ± 0.07	21.85 ± 0.07	21.85 ± 0.07
UHF-Direct	201.4 ± 0.4	201.2 ± 0.3	201.8 ± 0.4
UHF-Trunked	415.8 ± 2.8	413.1 ± 3.3	417.0 ± 2.9
VHF-Direct	201.7 ± 0.5	201.6 ± 0.4	202.4 ± 0.4
VHF-Trunked	403.9 ± 1.8	403.3 ± 2.8	405.3 ± 1.2

- 7 km distance between TX and RX radios for two location field tests
  - 23 µs (microsecond) propagation delay (negligible)
- Untuned prototype MCPTT system - one location field measurements
  - Not optimized for performance, tested to verify measurement method works on LTE

PSCR

PSCR Projects on QoE KPIs

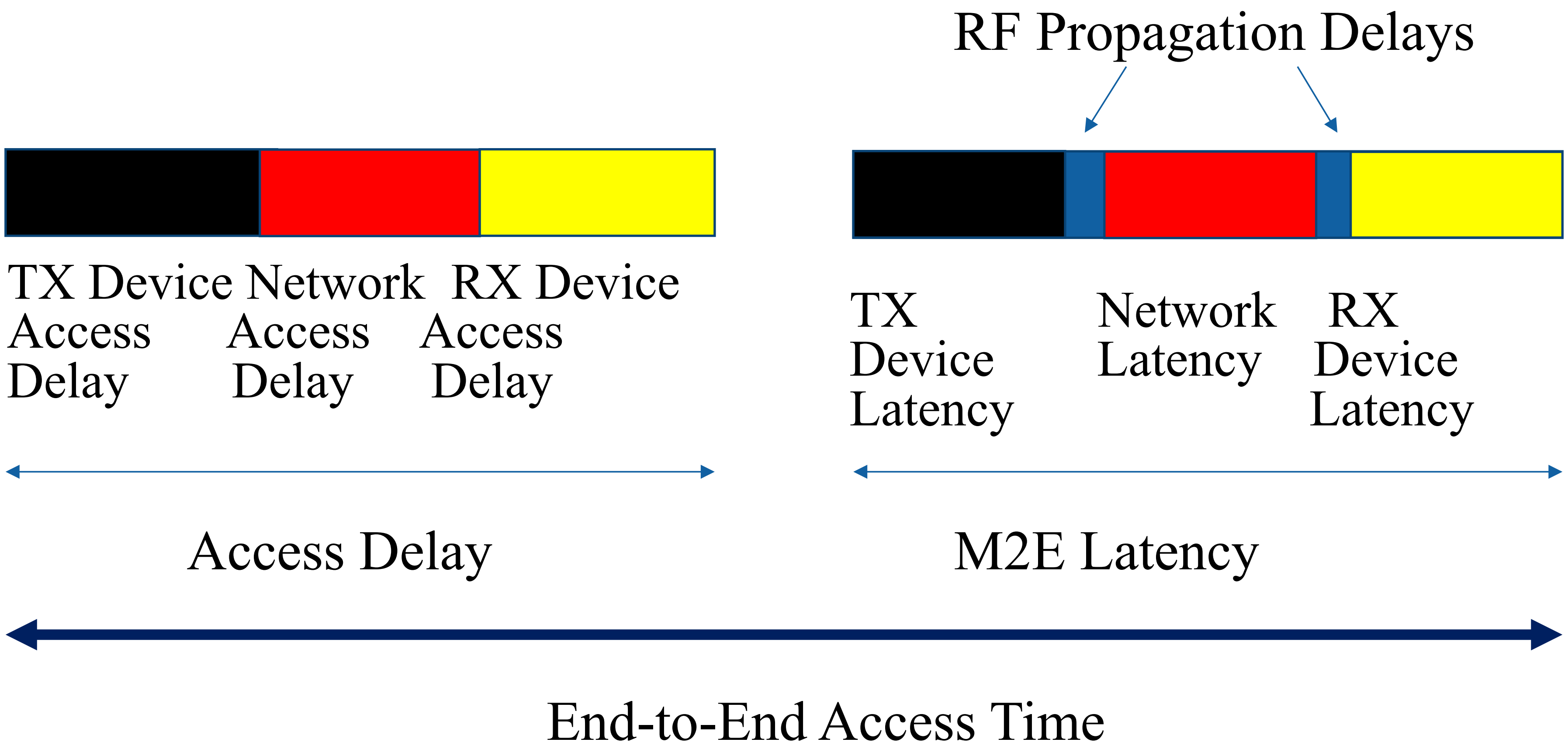
- PSCR MCV QoE M2E Latency Measurement Methods
- Paper is available on the mobile app
- Demo at 1PM Friday
- Webpage
  - https://www.nist.gov/ctl/pscr/mission-critical-voice-qoe-mouth-ear-latency-measurement-methods
- Paper
  - https://doi.org/10.6028/NIST.IR.8206
- MATLAB Code
  - https://github.com/usnistgov/mouth2ear
- Test Data
  - Delay Values: https://s3.amazonaws.com/nistmidas/1865/Delay_Values.zip.sha256
  - Processed Audio Files: https://s3.amazonaws.com/nist-midas/1865/Processed-Audio.zip.sha256
  - Raw Data: https://s3.amazonaws.com/nist-midas/1865/Raw%20Data.zip.sha256

PSCR Projects on QoE KPIs

- Access Time
  - Trunked Mode/MCPTT
  - Measurement Methods/Definitions
    - TIA-102 P25 - Voice Access Time
    - 3GPP Definition - PTT Access Time (KPI 1)
    - NIST/PSCR Definition
      - End-to-End Access Time
  - Very challenging to develop this measurement methodology
    - Component to system level testing complexities with uncertainties

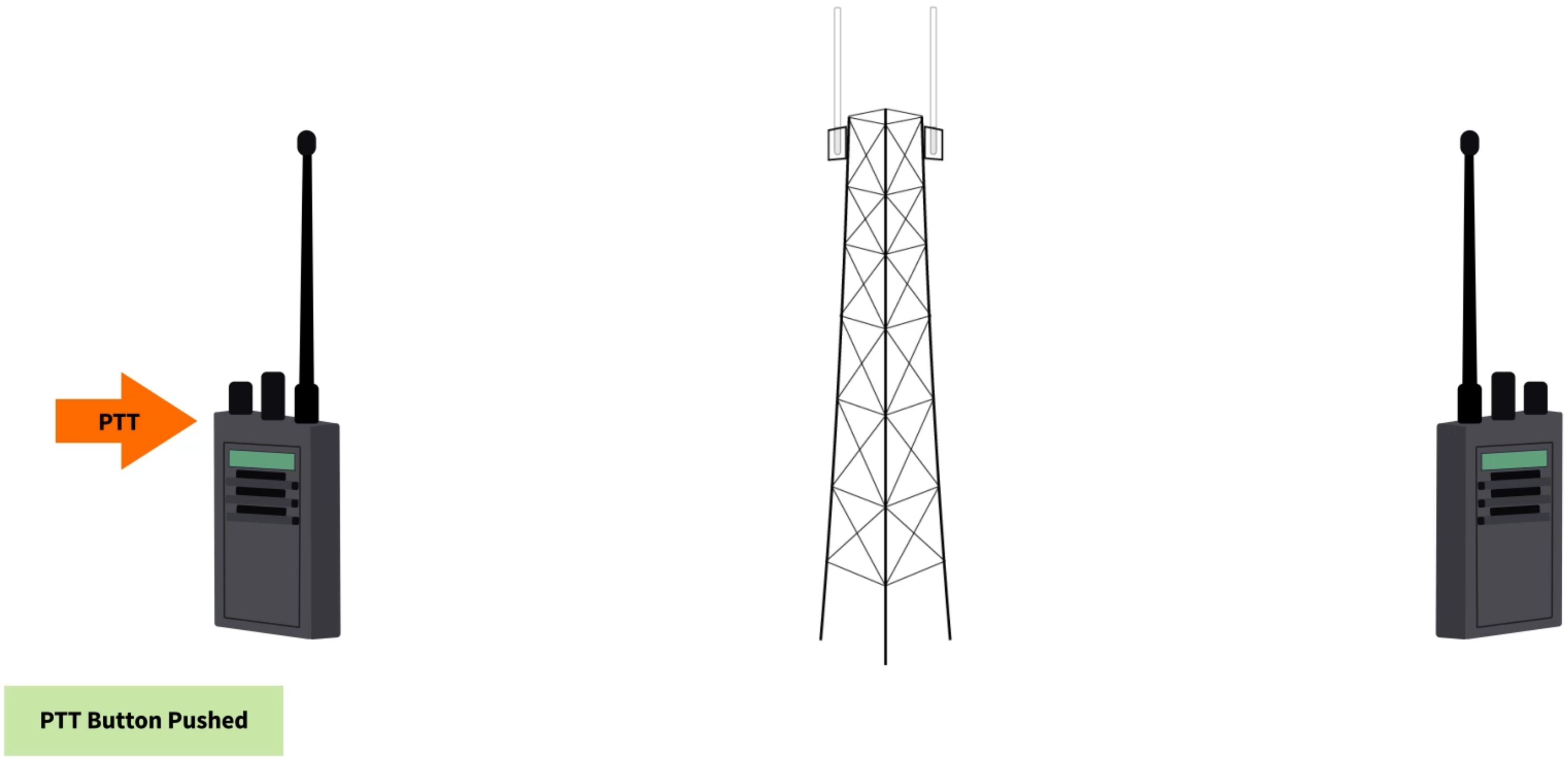
PSCR Projects on QoE KPIs

- End-to-end Access Time: Access Delay + M2E Latency



PSCR Projects on QoE KPIs

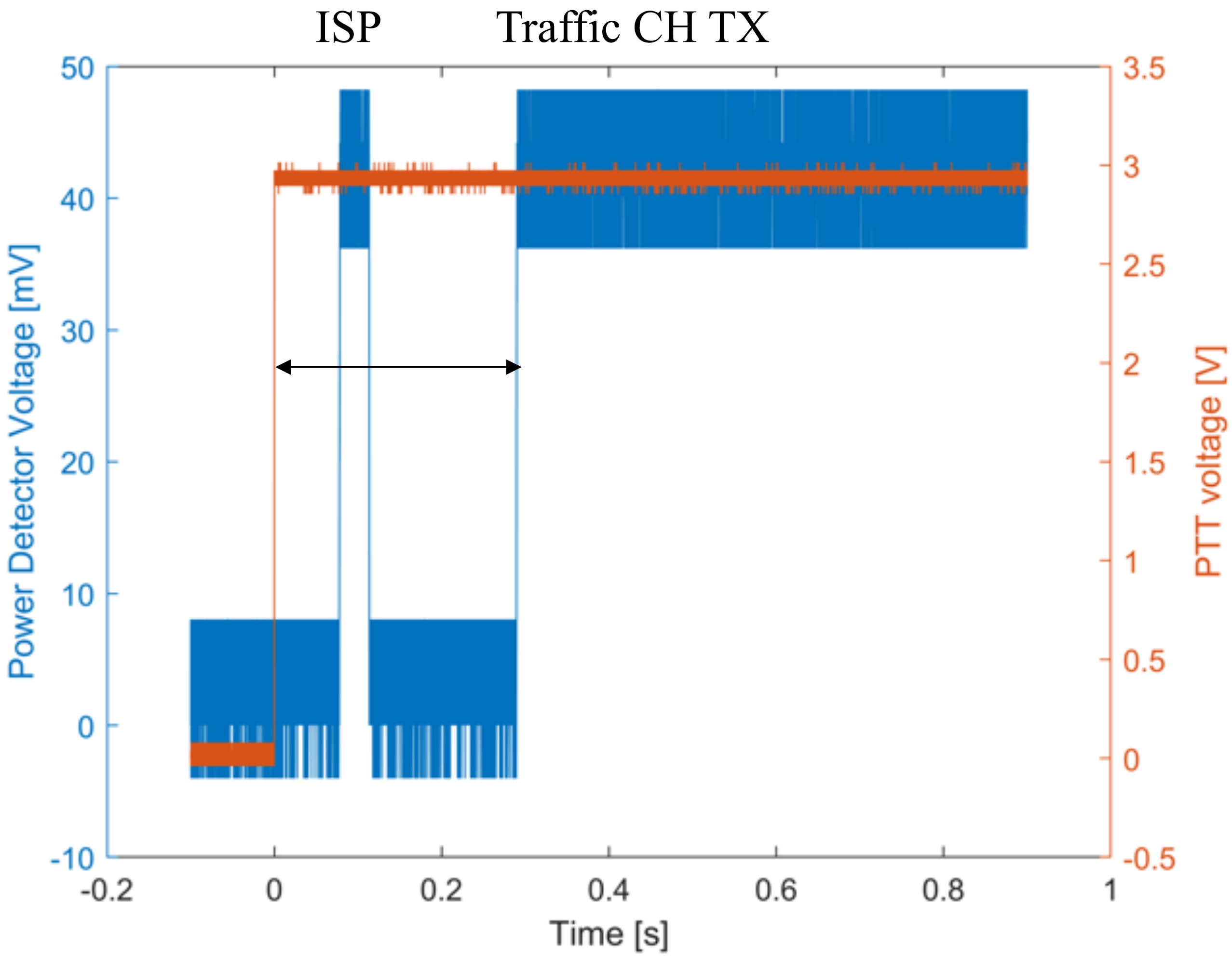
TIA 102 (P25) Access Time



PTT

PSCR Projects on QoE KPIs

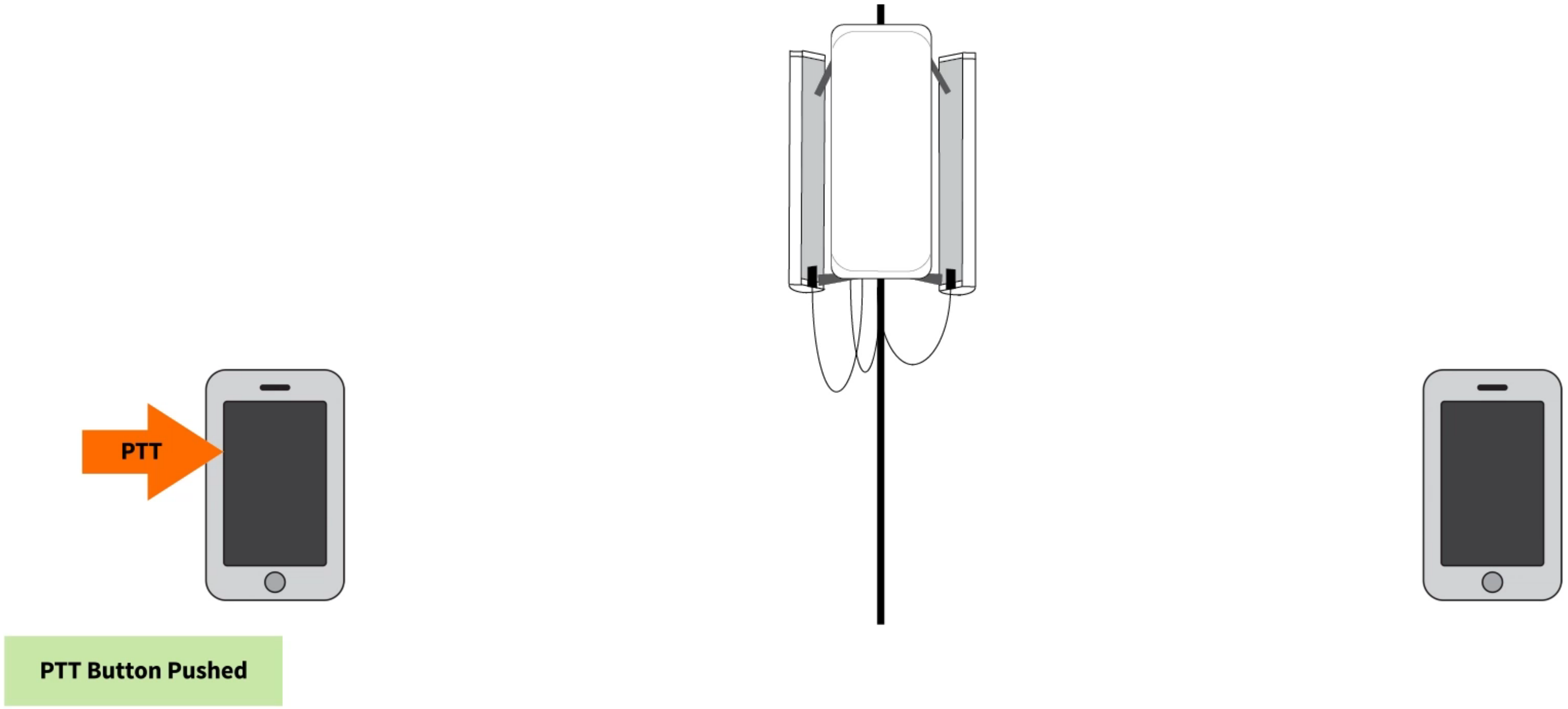
- TIA 102 P25 Access Time
  - A power detector and directional coupler are used to measure the power coming from the TX radio
  - TIA102 defines access time as the time between the PTT signal and the last rising edge of the power detector
  - Only works for P25 systems
  - The TX radio will transmit an Inbound Signaling Packet (ISP) on the control channel to request the channel
  - Once access is granted, the TX radio transmits the encoded audio



PSCR

PSCR Projects on QoE KPIs

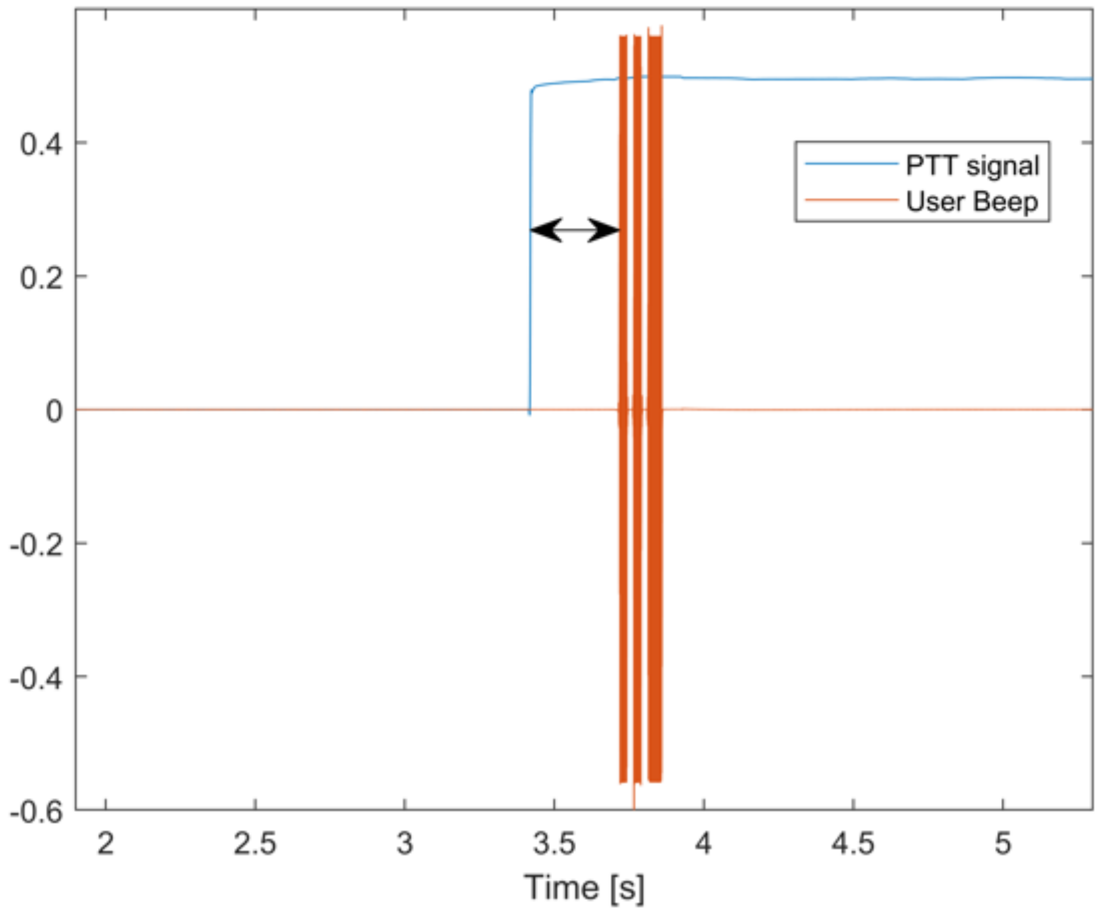
3GPP Access Time



PTT

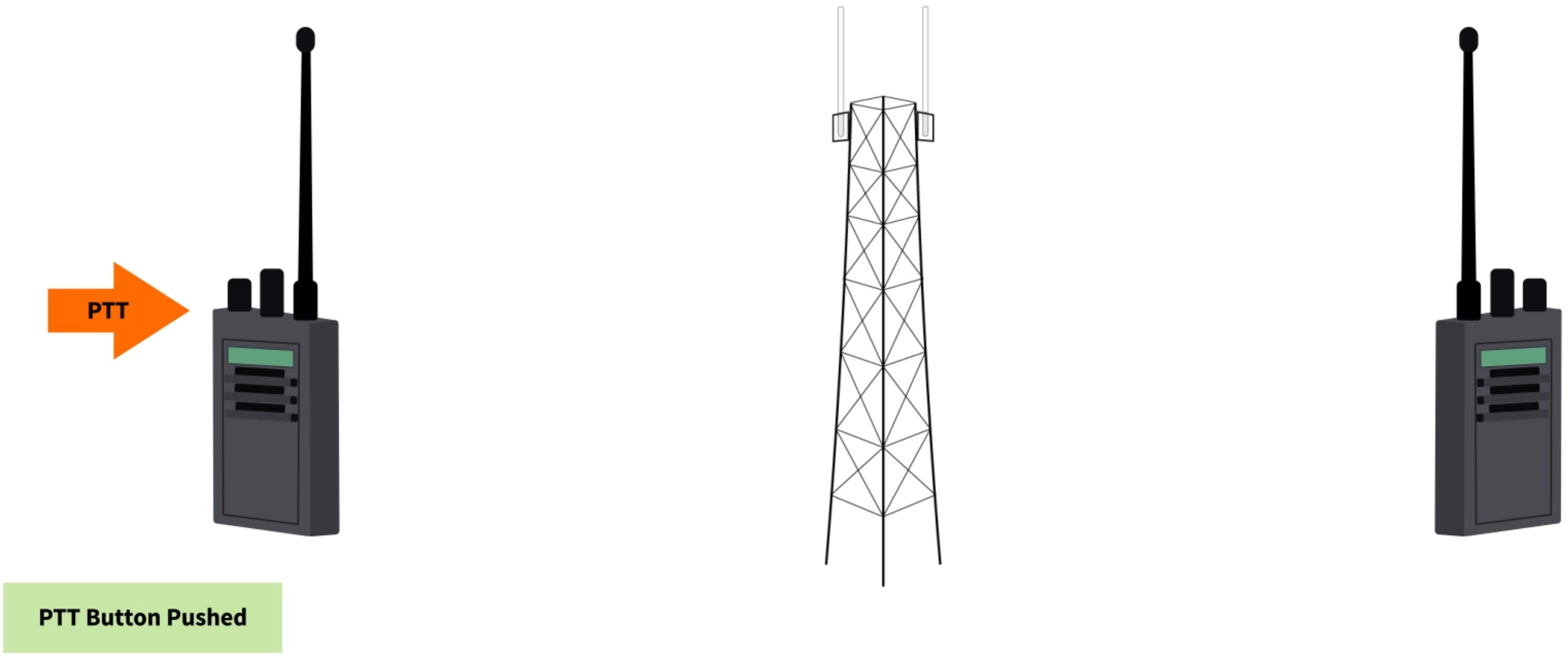
PSCR Projects on QoE KPIs

- 3GPP Defined PTT User Access Time (KPI 1)
  - Measures the time between the PTT signal and the signal (or beep) from the TX radio
  - Transportable to other technologies



PSCR Projects on QoE KPIs

PSCR/NIST Access Time



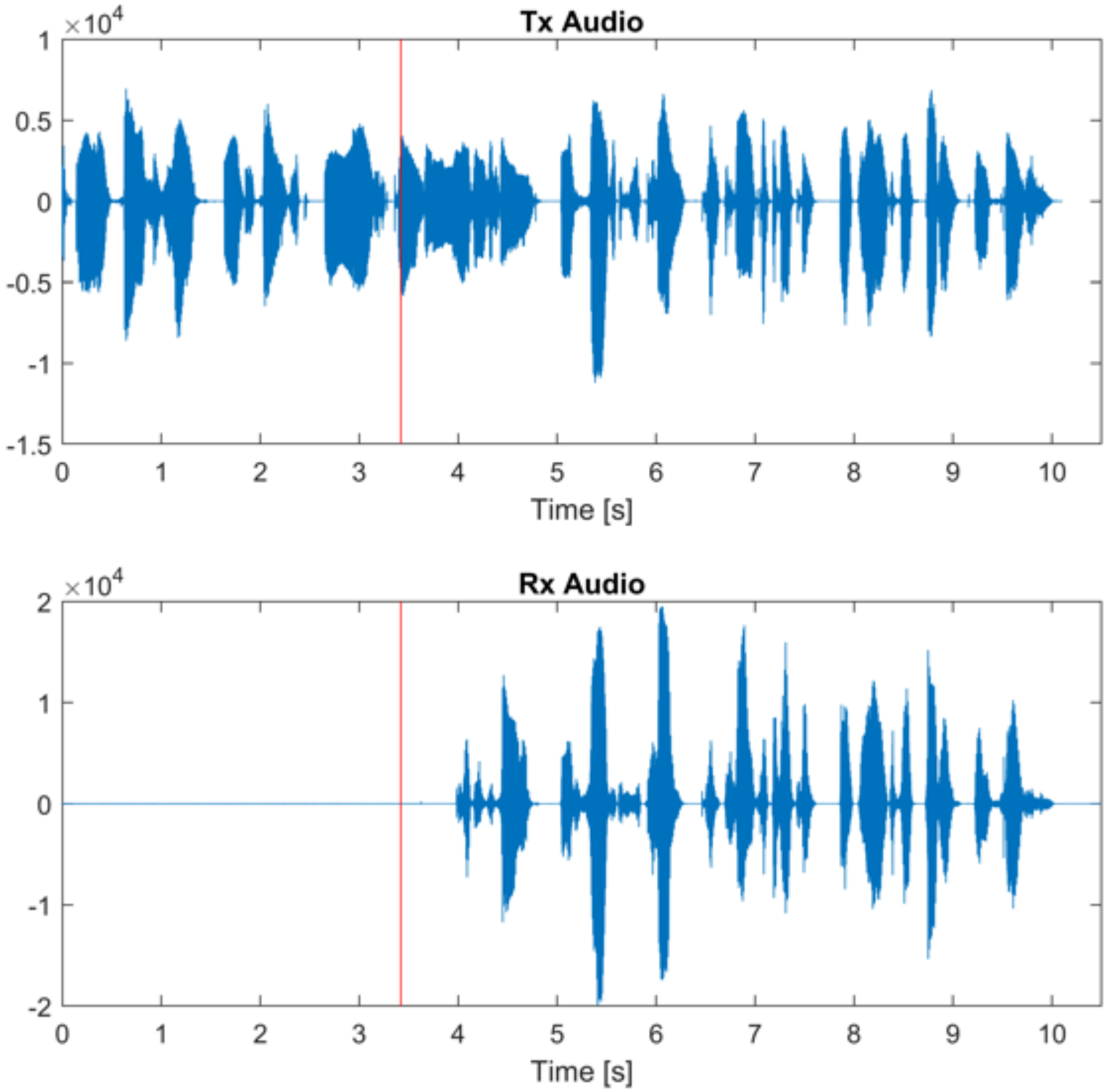
PTT

PSCR Projects on QoE KPIs

- NIST/PSCR Definition of Access Time
- Focuses on Access Delay
- Transportable to other Technologies
- More user centric (QoE) measurement than TIA-102 and 3GPP

PSCR Projects on QoE KPIs

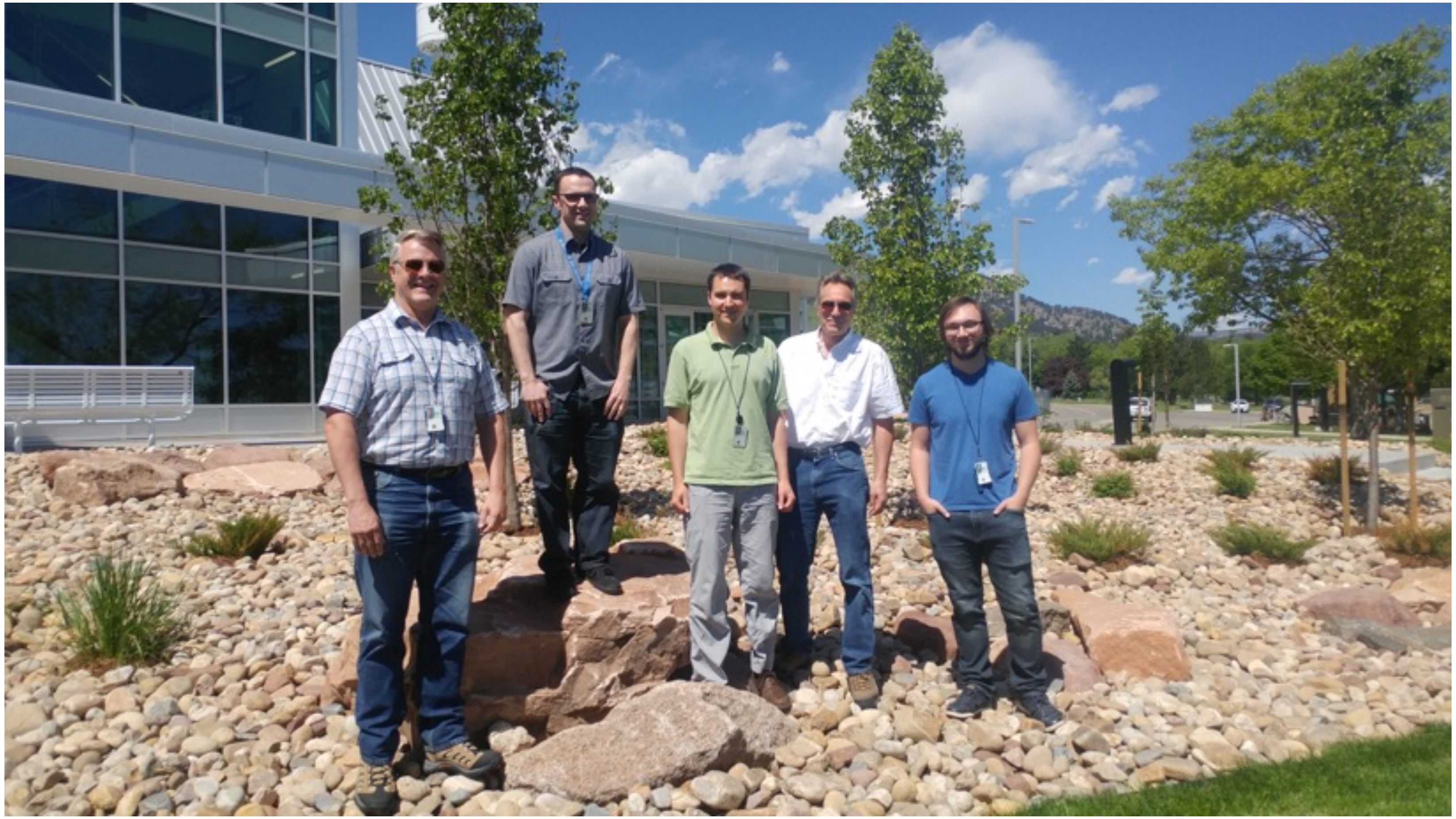
- Measurement Method based on NIST/PSCR definition
- Audio in/audio out method
- Audio is started before PTT button is activated
- Access delay is determined by the first speech played back by the receiver device



PSCR

PSCR Projects on QoE KPIs

- Team
  - Jesse Frey
  - Jaden Pieper
  - Don Bradshaw
  - Steve Voran (ITS)
  - Tim Thompson



PSCR

THANK YOU

End-to-End Research Platform for Public Safety Millimeter Wave Communications

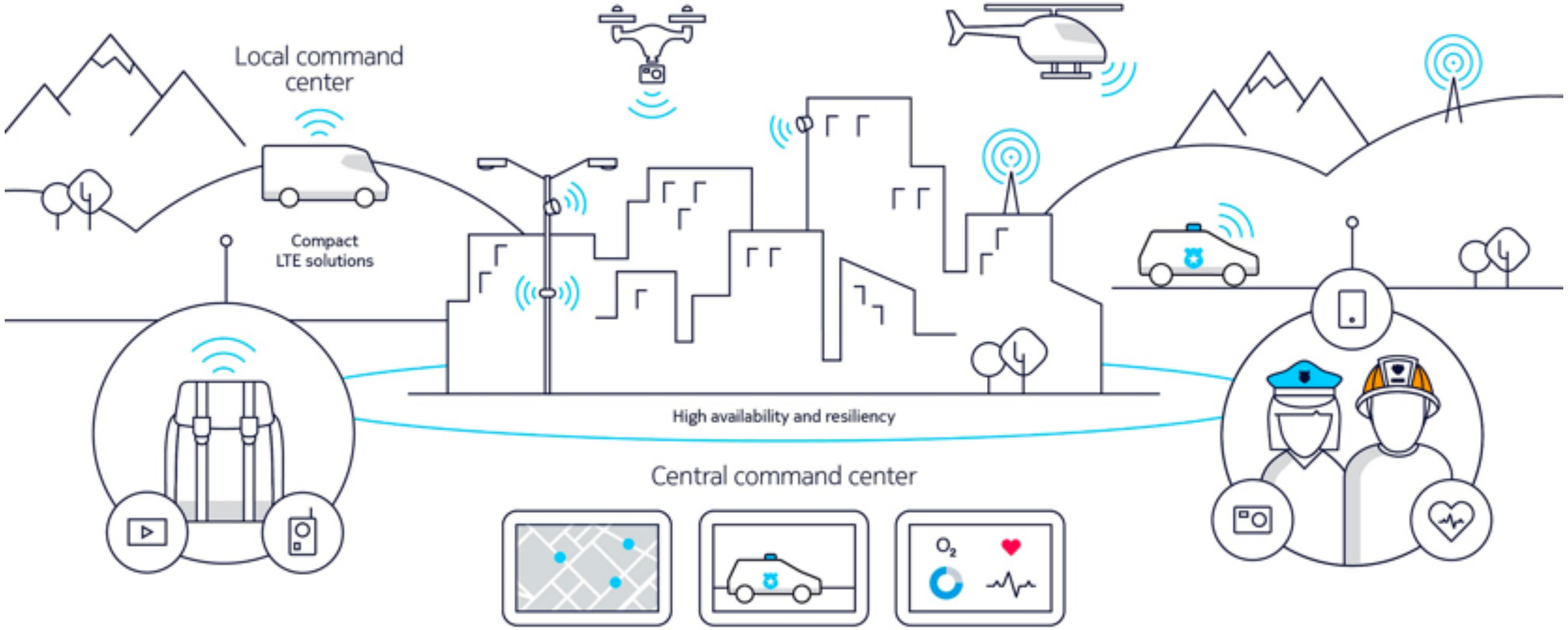
PSIAP STAKEHOLDER MEETING, SAN DIEGO

JUNE 6TH 2018

Outline

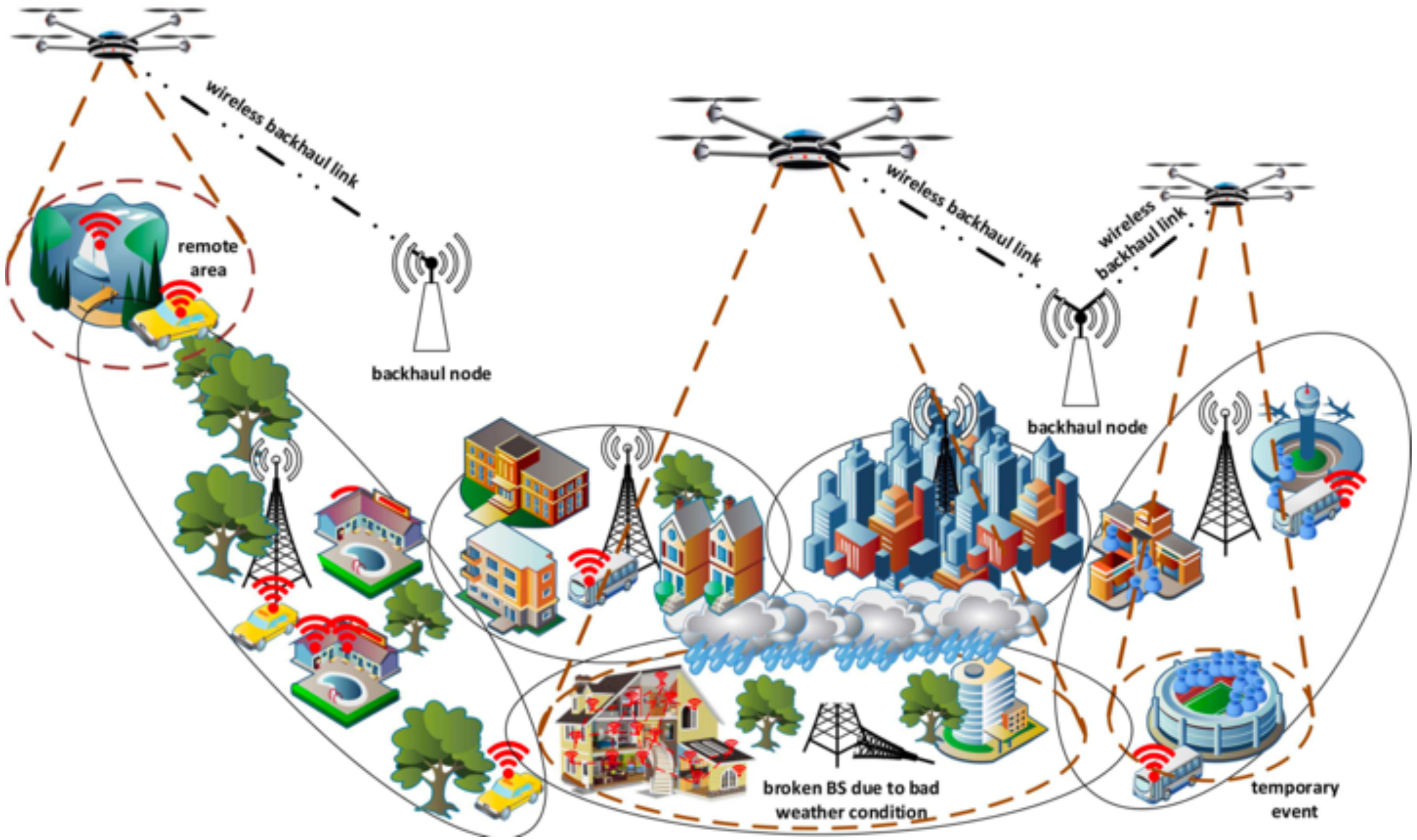
- Introduction
  - Motivation
  - mmWave Communications
- mmWave Research platform
  - Thrust 1: Dynamic Channel Sounding
  - Thrust 2: Software Defined Radio
  - Thrust 3: Channel Emulation
  - Thrust 4: End-to-End Network Simulation

4G LTE Public Safety



From Nokia, "ViTrust - End-to-end solution for mission-critical mobile broadband".

5G NR Public Safety



From E. Kalantari et al., "Backhaul-aware robust 3D drone placement in 5G+ wireless networks".


AT&T CEO highlights FirstNet role as 'foundation' to carrier's 5G plans

Donny Jackson | Urgent Communications Feb 1, 2018

http://urgentcomm.com/public-safety-broadbandfirstnet/att-ceo-highlights-firstnet-role-foundation-carrier-s-5g-plans


AT&T says 6 GHz band key for FirstNet, 5G

by Monica Alleven | Mar 21, 2018 8:54am

https://www.fiercewireless.com/wireless/at-t-says-6-ghz-band-key-for-firstnet-5g

below 6 GHz

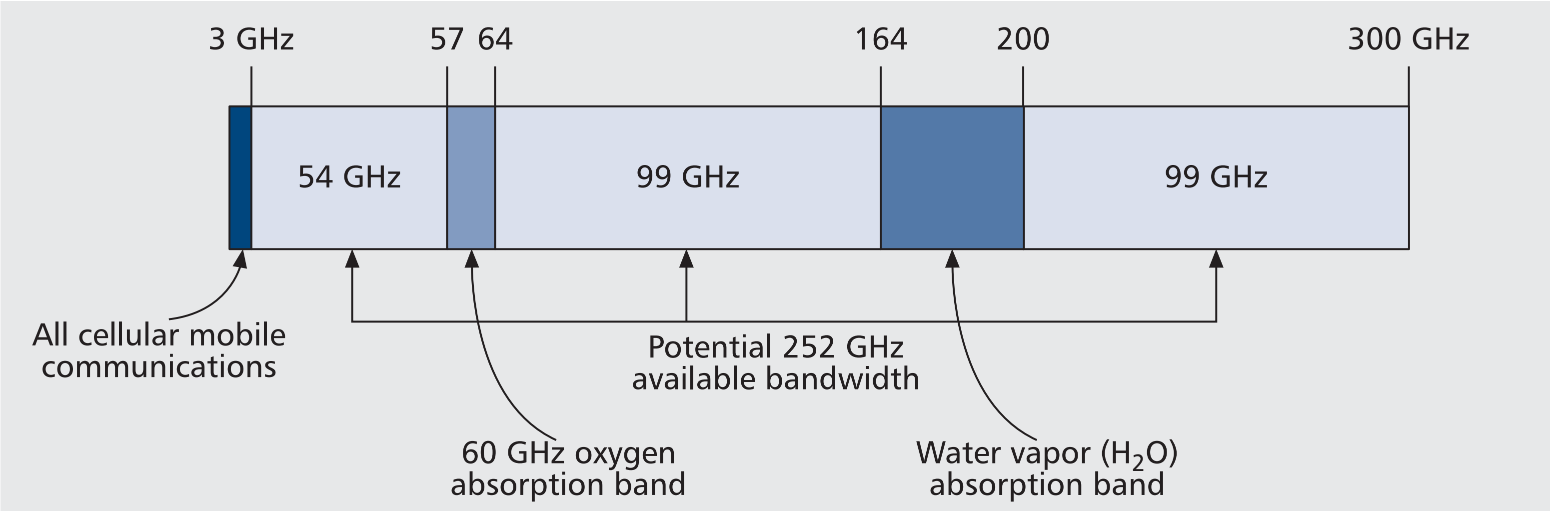
traditional frequencies

above 6 GHz

towards the mmWave band…

A Key 5G Enabler: the Millimeter Waves

- Vast untapped spectrum
  - Up to 100x bandwidth than current allocations



From Khan, Pi “Millimeter Wave Mobile Broadband: Unleashing 3-300 GHz spectrum”

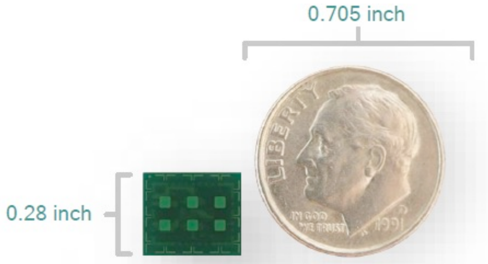
The Main Challenges

❑ Pathloss

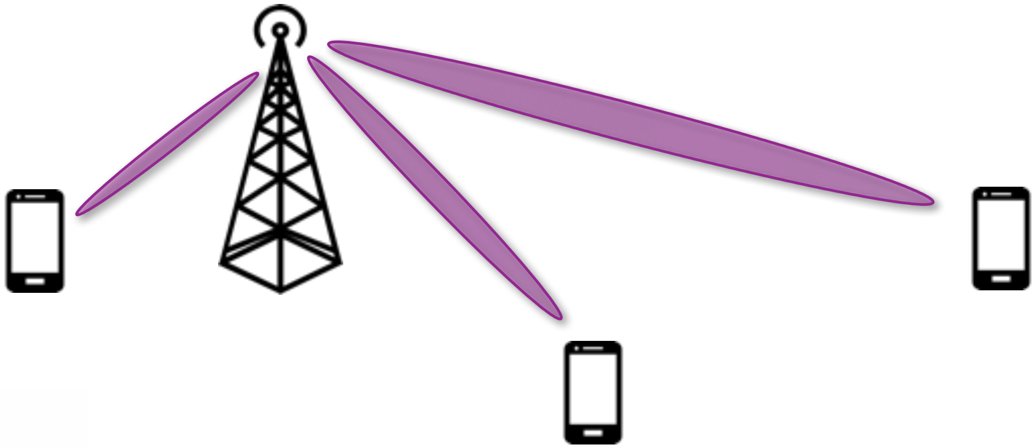
high isotropic loss

SOLUTION (and challenge)

- MIMO beamforming, resulting in directional transmissions



Qualcomm® VIVE™ 802.11ad technology with a 32-antenna array element



❑ Blockage

very sensitive waves

SOLUTION (and challenge)

- Beam-tracking/switching

Initial NYU mmWave Measurements

- Millimeter wave: It can work!
  - First measurements in urban canyon environment
  - Distances up to 200m
  - Propagation via reflections
- Proved feasibility of cellular systems
  - Measurements made urban macro-cell type deployment
  - Rooftops 2-5 stories to street-level

Rappaport, Theodore S., et al. "Millimeter wave mobile communications for 5G cellular: It will work!." *IEEE access* 1 (2013): 335-349.

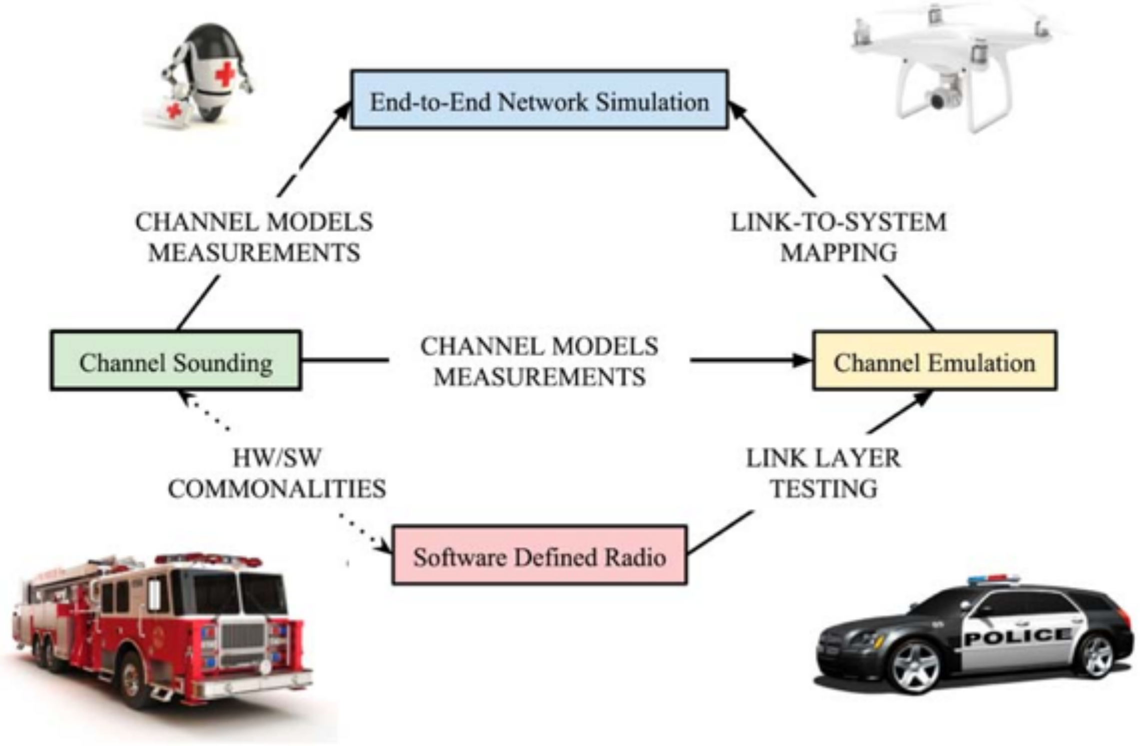
Winner of Donald Fink award: Best paper across all IEEE

Industrial Affiliates

at&t
CableLabs
CROWN CASTLE
ERICSSON
HUAWEI
INTERDIGITAL
KEYSIGHT TECHNOLOGIES
NATIONAL INSTRUMENTS
NOKIA
oppo
QUALCOMM
SiBEAM
SONY
Sprint
UMC
verizon

An end-to-end research platform for Public Safety Communications over mmWave

- Measure dynamic directional channels in Public Safety (PS) scenarios.
- Prototyping new ultra-low latency MAC and synchronization algorithms likely to be used in the PS links.
- Provide the first scalable real-time emulation of complex mmWave channels in PS settings.
- Development and integration of PS specific scenarios in end-to-end mmWave network simulator.



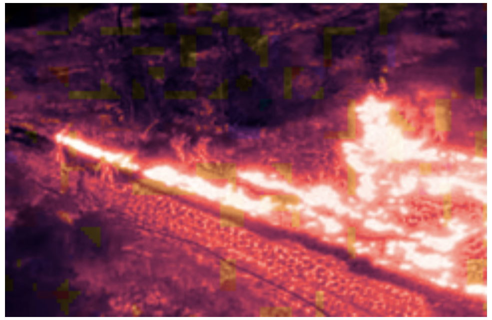
Austin Fire Department

Robotics Emergency Deployment Team

AIR

LAND

WATER

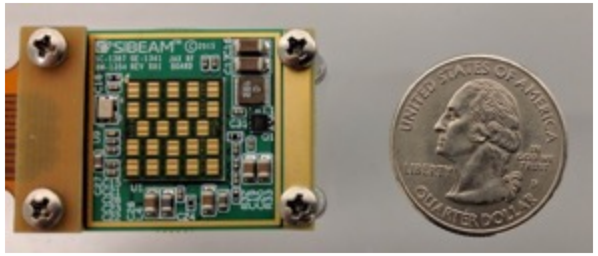


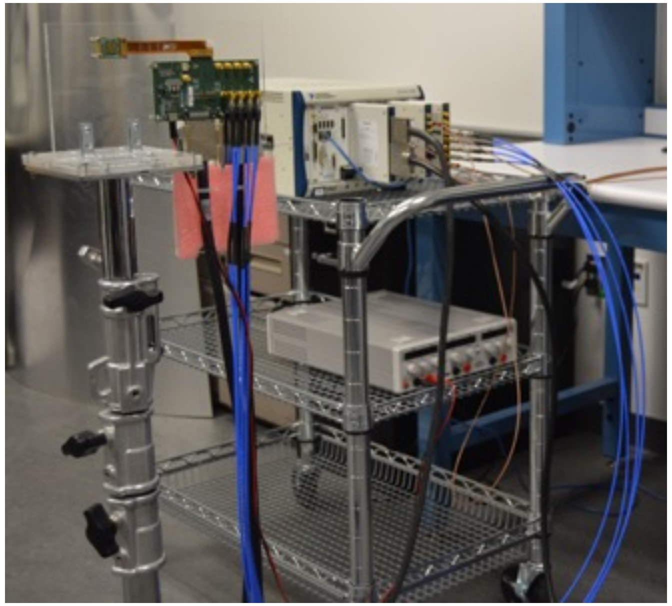
- The **mission** of the RED Team is to mitigate real-world problems through the deployment of air, ground, and maritime remotely operated resources
- The **vision** of the RED Team is to enhance firefighter safety and improve emergency response through the use of emerging technologies such as robotics.

Thrust 1: Dynamic Channel Sounding

60 GHz Measurements

- Measurements performed at 60 GHz using a custom channel sounder with phased arrays
  - SiBeam Phased Array with 12 steerable antenna elements and 45 degree steerable range.
- Rapid steering ability and wide bandwidth
  - Scans over 144 TX/RX pointing angles repeated every 3 ms
  - The phased array is mounted on steerable gimbal to simulate orientation motion
- Primarily investigated human blockage
- Collaboration with Sony





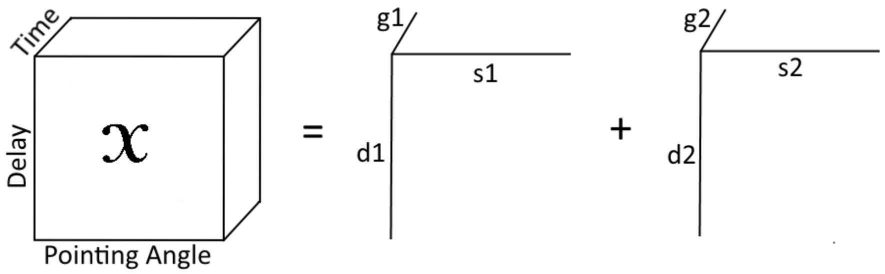
NYU TANDON SCHOOL OF ENGINEERING

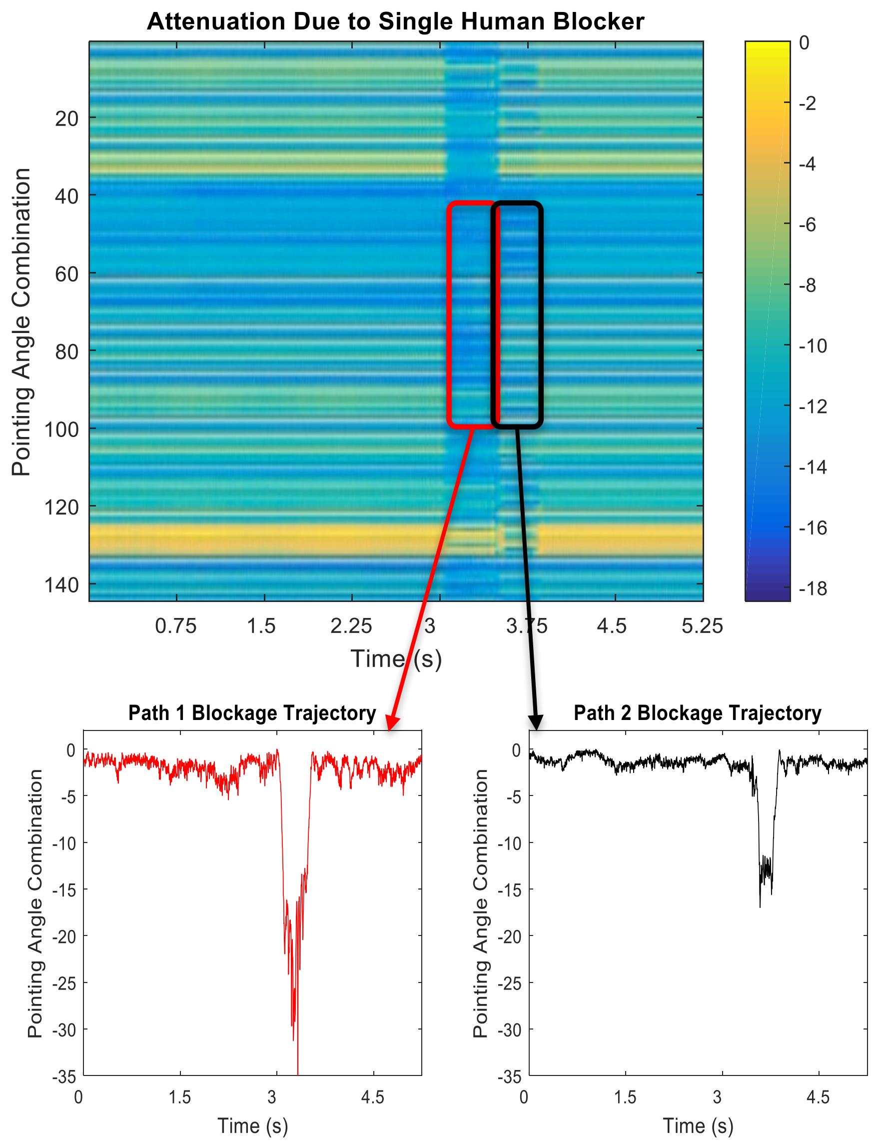
NYU WIRELESS

PARAFAC

- Tensor decomposition technique to aid in extracting blockage trajectories for each path
- Novel model for wireless channel
  - Useful technique for modeling

$$x_{ijk} = \sum_{\ell=1}^{L} d_{i\ell}\, s_{j\ell} b_{k\ell}$$





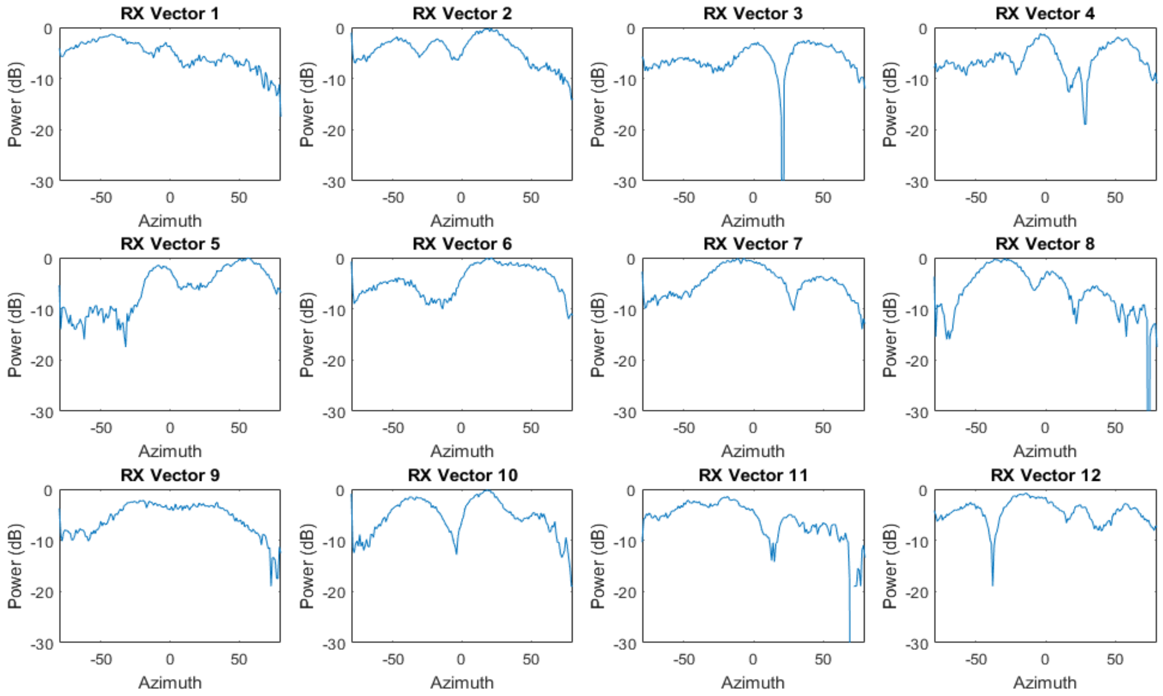
Next Steps

- New measurement campaigns planned
  - Ceiling mounted AP
  - Large, open venue
  - 3+ nodes, relaying
- New hardware
  - Additional later generation phased array hardware donated by NI
- Can implement data link to implement proof-of-concept system instead of measurement system

Thrust 2: Software Defined Radio

Limitations of Current System

- Limitations / issues in current 60 GHz systems
  - SiBeam phased arrays appear to have poor antenna patterns
  - Limited directional gain
  - Desired system at 28 GHz
- Significant delay in receiving OFDM NR code
- Considering developing alternate system
- Leverage other SDR developments
  - Platforms for Advanced Wireless Research

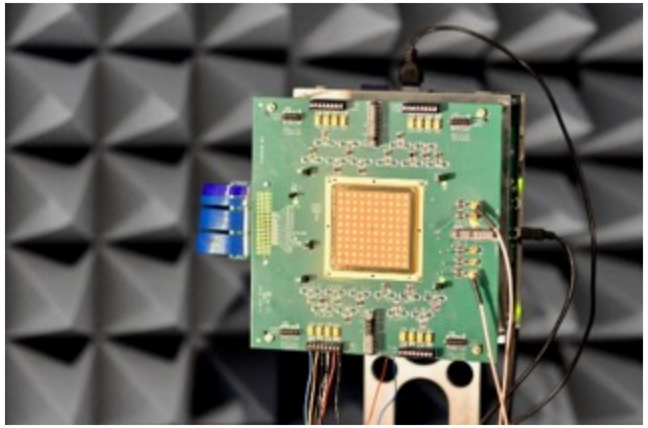


Platforms for Advanced Wireless (PAWR)

- ❑ NYU, Columbia and Rutgers to lead testbed
  - Rutgers overall lead. NYU leads mmWave
- ❑ One of two awarded in US
  - $10 million funding per testbed
- ❑ 20 block testbed in Upper Manhattan
- ❑ Showcases several advanced technologies
  - Cloud RAN, NFV, MmWave, Massive MIMO
  - Applications include VR/AR and autonomous driving
  - Can be used to test first responder scenarios
- ❑ Seeks strong industry collaboration.
  - Provide testbed for developing new wireless technologies and applications

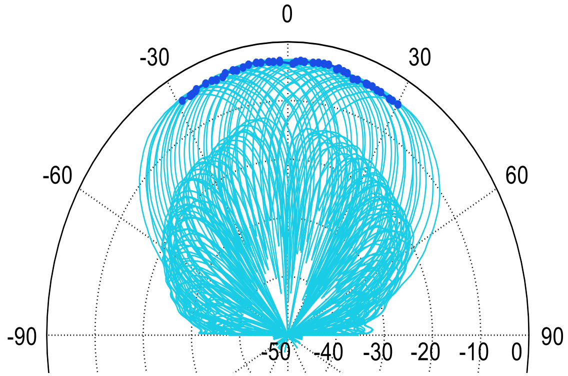
PAWR 28 GHz IBM Phased Array System

Module features:
- 64-dual polarized antennas and 4 ICs each with 32 TRX elements
- 128 TRX elements in total
- 8 independent 16-element beamformers, each supporting 1 polarization of 16 ant.
- RF true time delay based architecture
- 28GHz RF, 5GHz ext. LO, 3GHz input/output IF
- 54dBm saturated EIRP on each polarization



28GHz phased array eval. board

Example outdoor link experiment at IBM



Measured Precise
1.4°/step beam steering

- Plan to migrate development to PAWR system
  - Leverage 28 GHz IBM/Ericsson phased array
- Baseband will be co-developed
- Consider various options for FPGA

Next Steps

- Finalize architecture choice for 28 GHz SDR system
  - IBM phased array has already been selected for 28 GHz
  - Currently evaluating Sivers 60 GHz module
  - Currently in discussion with vendors and other SDR teams on FPGA platform
- Begin development of 5G NR code
  - Cannot be done by single university
  - In discussion with Open Air Interface to use their stack (designed for sub 6 GHz)
  - Will need to port to higher bandwidths and latest FPGA platforms

Thrust 3: Channel Emulation

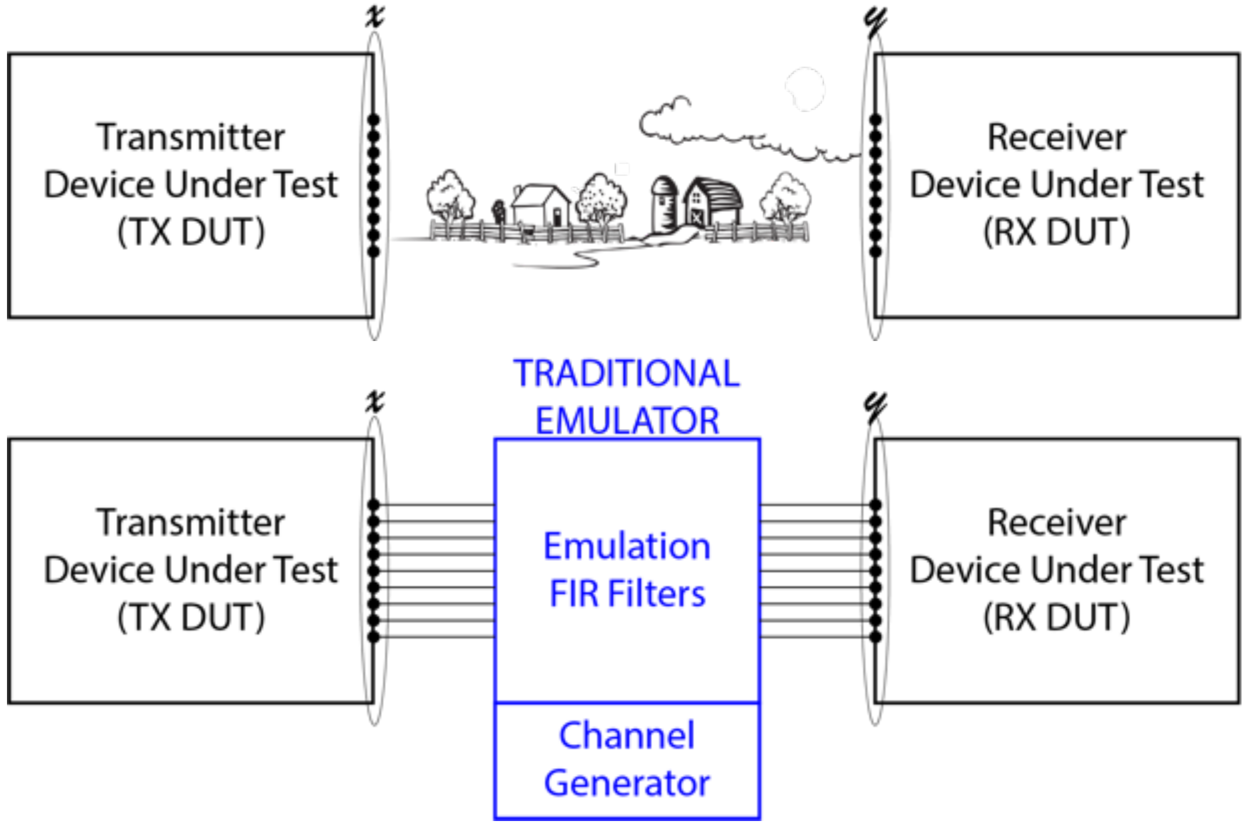
Background: The need for Emulation

Over-the-air: $x \rightarrow y$

+ Realistic scenarios
- Time consuming and expensive
- Labor intensive
- Non-reproducible

Channel Emulator: $x \rightarrow y$

+ No need to leave the lab
+ Easy to replicate and reproduce
+ Standard channel models (i.e. 3GPP, …)
+ Worst-case scenario testing

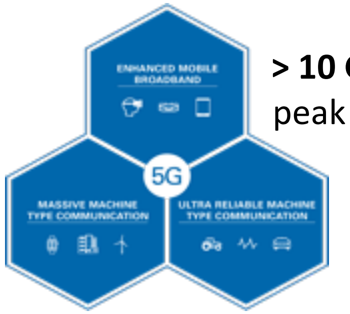


Emulators are a critical tool in the design and test of wireless systems. They are therefore a staple of any lab bench.

Challenges with Emulation for mmWave 5G

5G mmWave Mobile Broadband

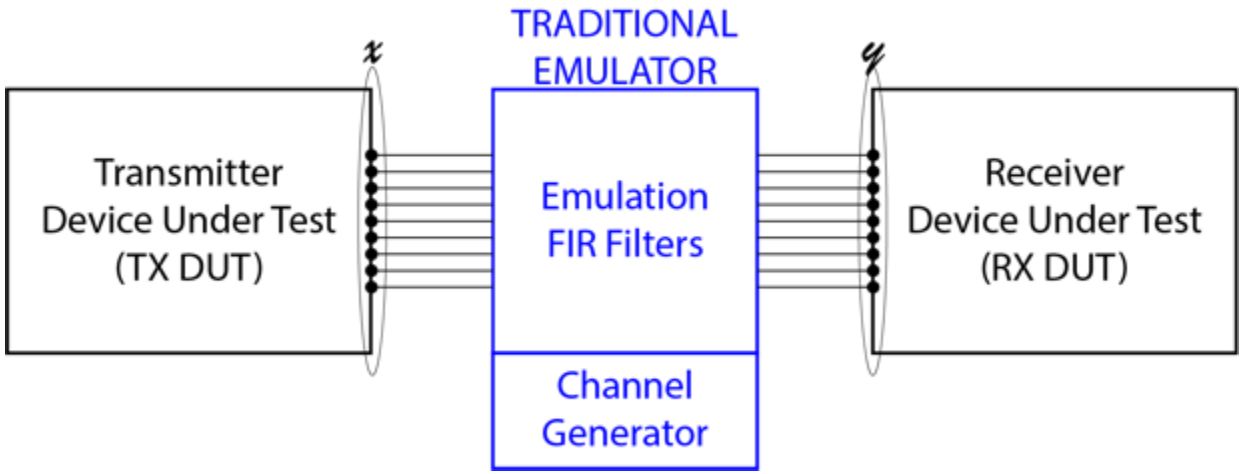
- Large number of antenna elements (N=10x)
- Massive bandwidth (B=10-100x)
- Fast beam-steering



> 10 Gbps peak rates

Emulation Challenges

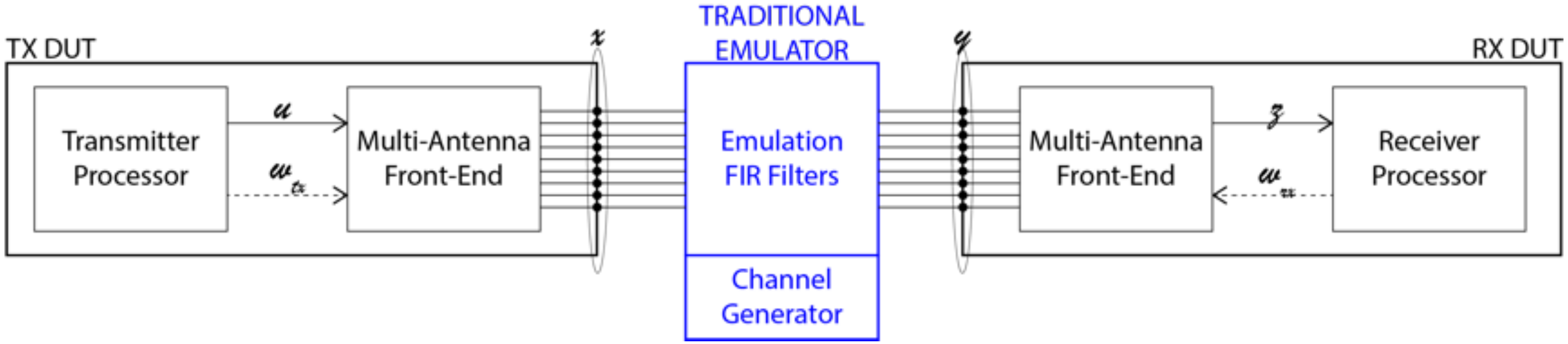
- Prohibitive number of cables (large N)
  - Emulator does $x \rightarrow y$, where signals x and y are RF
  - Connecting a phased array to cables is itself impossible!
- Emulator becomes very expensive to build (large N)
  - Large number of RF up/down-converters
  - Large number of DAC/ADCs
  - Data marshalling (movement) becomes hard to do
- Computational infeasibility (large N,B)
  - Massive number of FPGAs will be needed



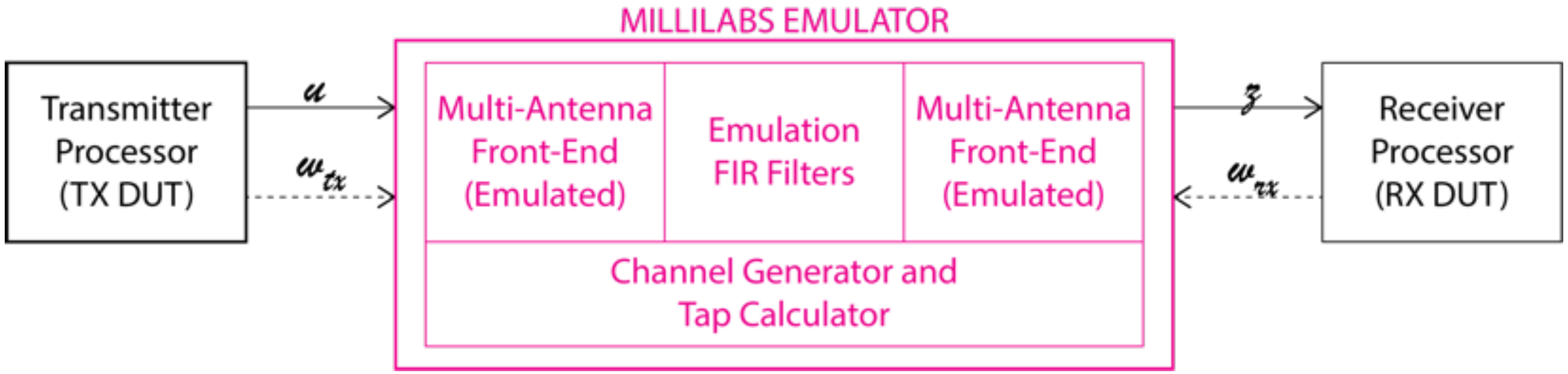
The existing emulation paradigm is unsuitable for 5G mmWave mobile broadband.

A new emulation paradigm is needed!

NYU Emulator: A New Paradigm



- BF is done on the DUTs
  - TX: $u \rightarrow \boldsymbol{x}$
  - RX: $\boldsymbol{y} \rightarrow z$
- Basic operation: $x \rightarrow y$
  - x, y are N-ary
  - x, y are in RF

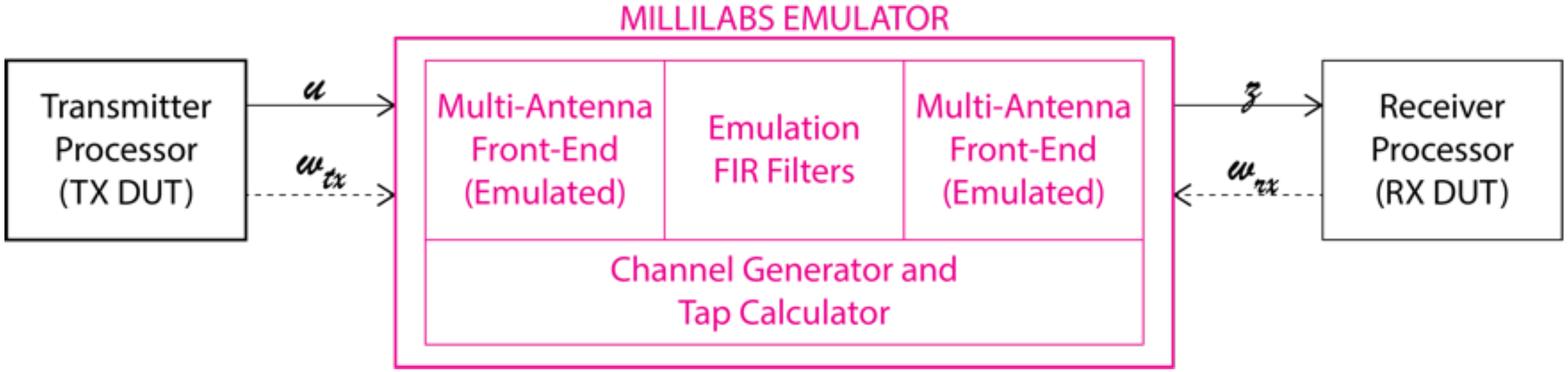


- Basic operation: $u \rightarrow z$
  - u, z are m-ary, where $m \ll N$
  - u, z can be baseband, IF, or RF
- BF is done on the Emulator
  - Very efficient implementations
- Highly modular and adaptable architecture

There is a reason why 5G mmWave Emulators aren't available today.

The NYU Emulator is specially designed for large N and B.

NYU Emulator: Key Features and Specs



- Implementation on OTS components
  - NI's PXIe Software-defined radio platform
  - PXIe chassis, FPGAs, DAC/ADCs, IF modules, mmWave heads, …
- Data signals u and z
  - Analog/digital baseband
  - Easy upgrade path to IF/RF
- Control signals w_{tx} and w_{rx}
  - Serial, generic DIO
  - Custom interfaces upon request

- Number of antennas, N
  - Up to 1024
  - Linear/rectangular arrays
  - Easy (and cheap) upgrade path to N=1024
  - Custom array topologies upon request
- Front-end Modeling
  - Steering errors/noise
  - Phase noise, frequency offset modeling
- Bandwidth: > 2GHz

- Channel Models and Features
  - 3GPP, Channel sounding, ray-tracing, …
  - Multipath, doppler, mobility, blockage, …
- Beamforming Architectures
  - Analog beamforming
  - Upgrade path to hybrid beamforming
- TX/RX Reference Implementations
  - Available upon request
  - TX/RX can operate in the same chassis

The NYU Emulator is highly modular, flexible, and customizable.

NYU Emulator: Summary

Feature	Traditional Emulators	NYU Emulator
Millimeter Wave Support	No	Yes
Computational Complexity	Prohibitively High	Efficient
Hardware Cost	Expensive	Low-cost
Reusable Hardware	No	Yes
Channel Emulation	Yes	Yes
RF Front-end Emulation	No	Yes
Bandwidth Supported	Less than 200 MHz	More than 2 GHz

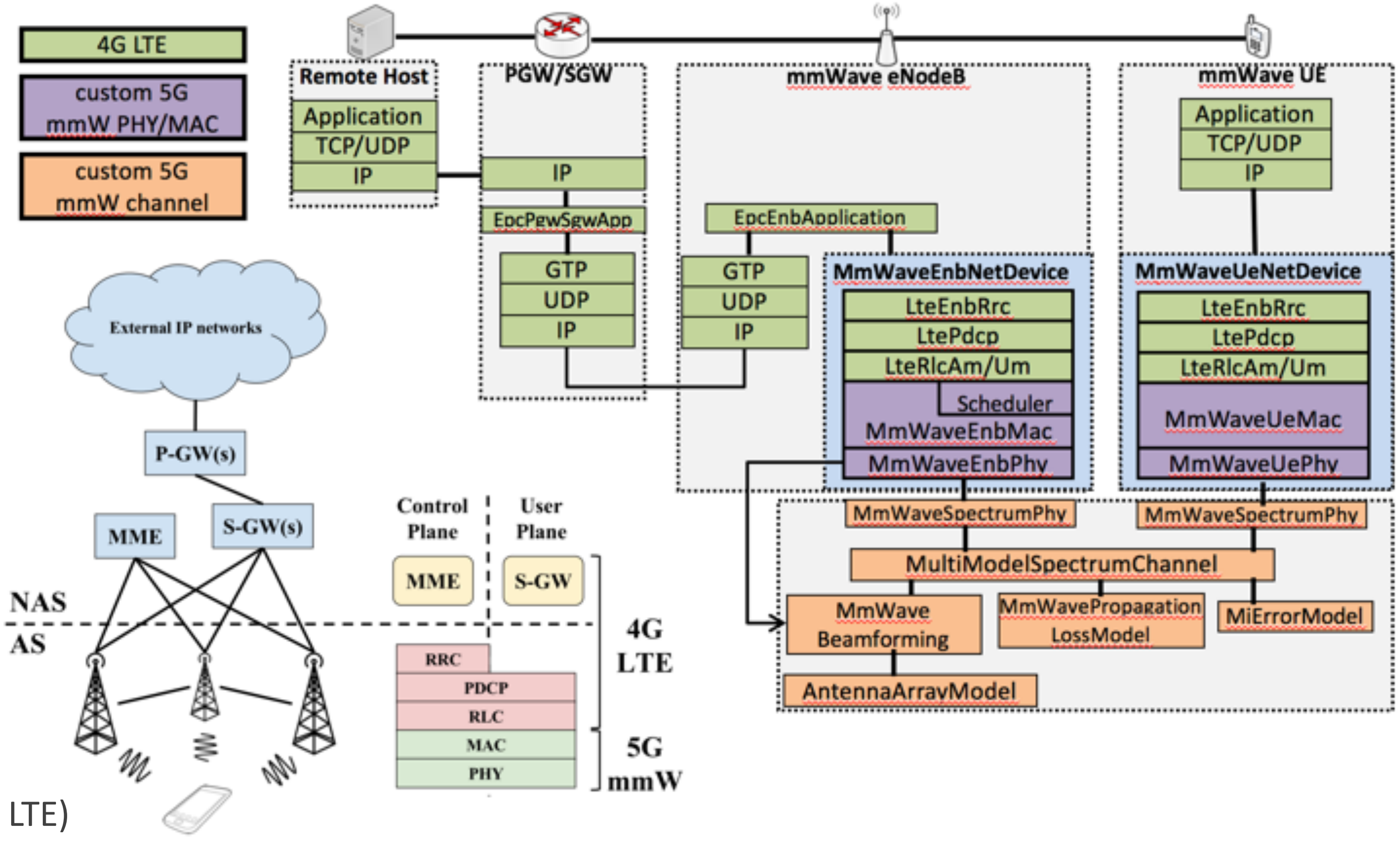
Next steps

- Implementation of the new peer-to-peer public safety channel models.
- Interface with the SDR platform for the synchronization and control design. This may include emulation of fully digital transceivers.
- Addition of interference sources and multiple synchronization signals.

Thrust 4: End-to-End Network Simulation

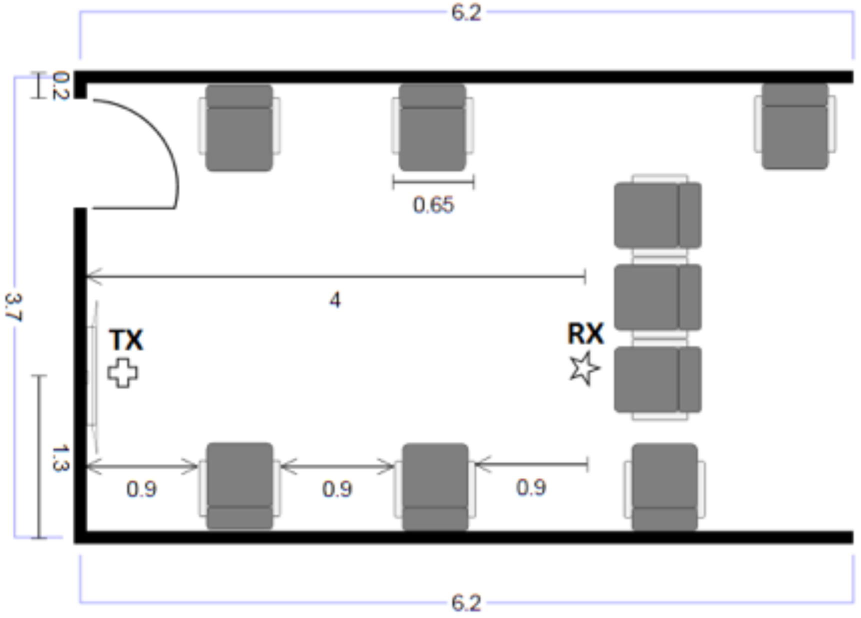
End-to-end mmWave Network Simulator

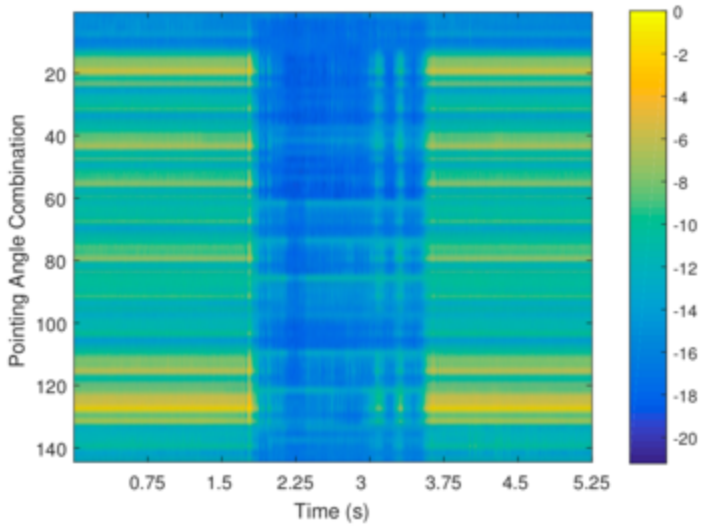
- Open source
- 3GPP channel models / scenarios
- Mobility (including vehicular / hi-speed transportation / drones)
- Customizable 3GPP NR frame structures, frequency bands, OFDM numerologies, schedulers
- 3GPP NR beam management
- E2E performance evaluation including:
  - TCP/IP, S2/X1, PDCP, RLC, MAC/PHY metrics
  - RRC signaling, RLC buffers, HARQ procedures
  - Coexistence with other radio technologies (e.g., IEEE 802.11, LTE)
- Dual connectivity, carrier aggregation, IAB, etc.

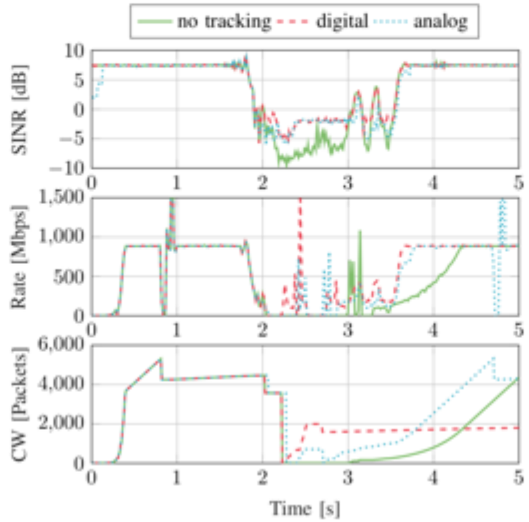


Measured channel dynamics

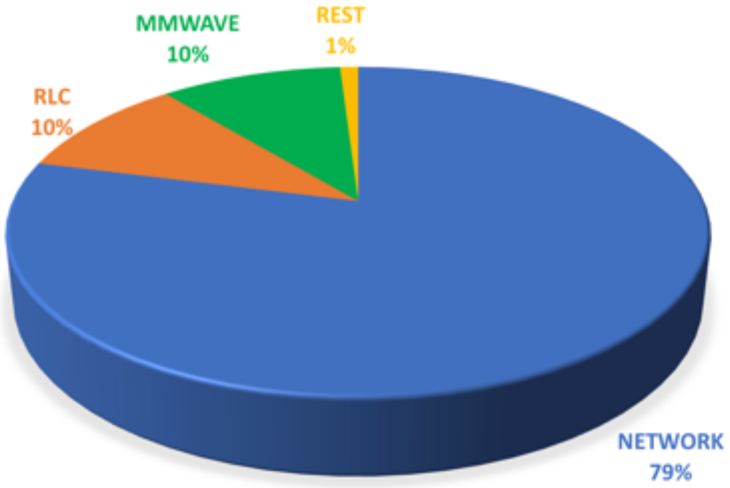
- C. Sleizak, M. Zhang, M. Mezzavilla, S. Rangan, *Understanding End-to-End Effects of Channel Dynamics in Millimeter Wave Cellular*, IEEE SPAWC 18
- Phased-array indoor measurements integrated in ns-3
- End-to-end network performance evaluation with different beamforming architectures



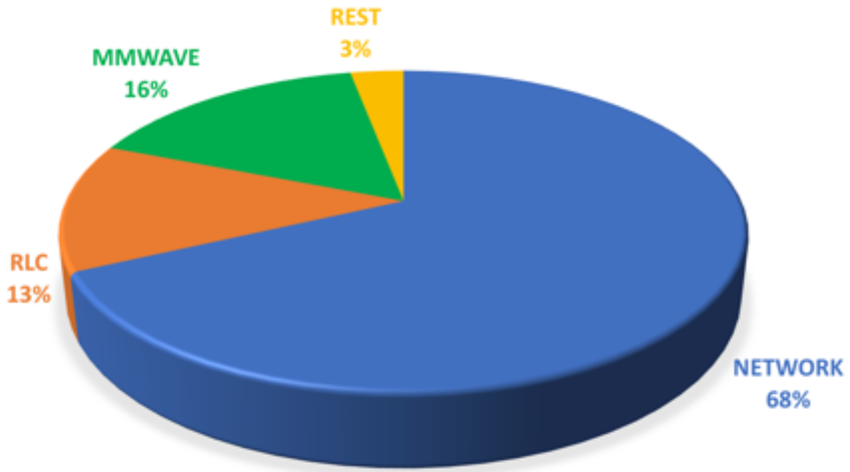




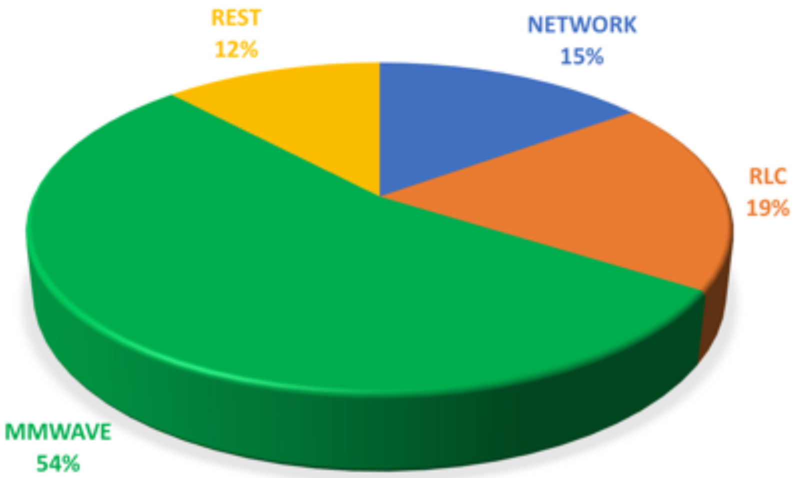
ns-3 profiling



TCP TRAFFIC, 1 BASE STATION AND 1 USER



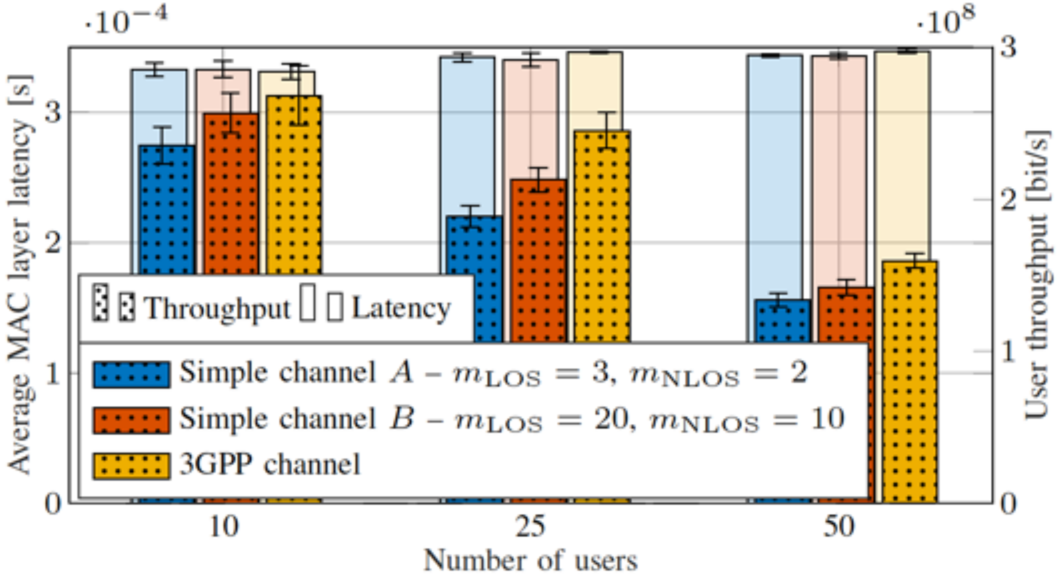
UDP TRAFFIC, 1 BASE STATION AND 1 USER



TCP TRAFFIC, 2 BASE STATIONS AND 10 USERS

Simulation scalability

- M. Polese, M. Zorzi, *Impact of Channel Models on the End-to-End Performance of mmWave Cellular Networks,* IEEE SPAWC'18.



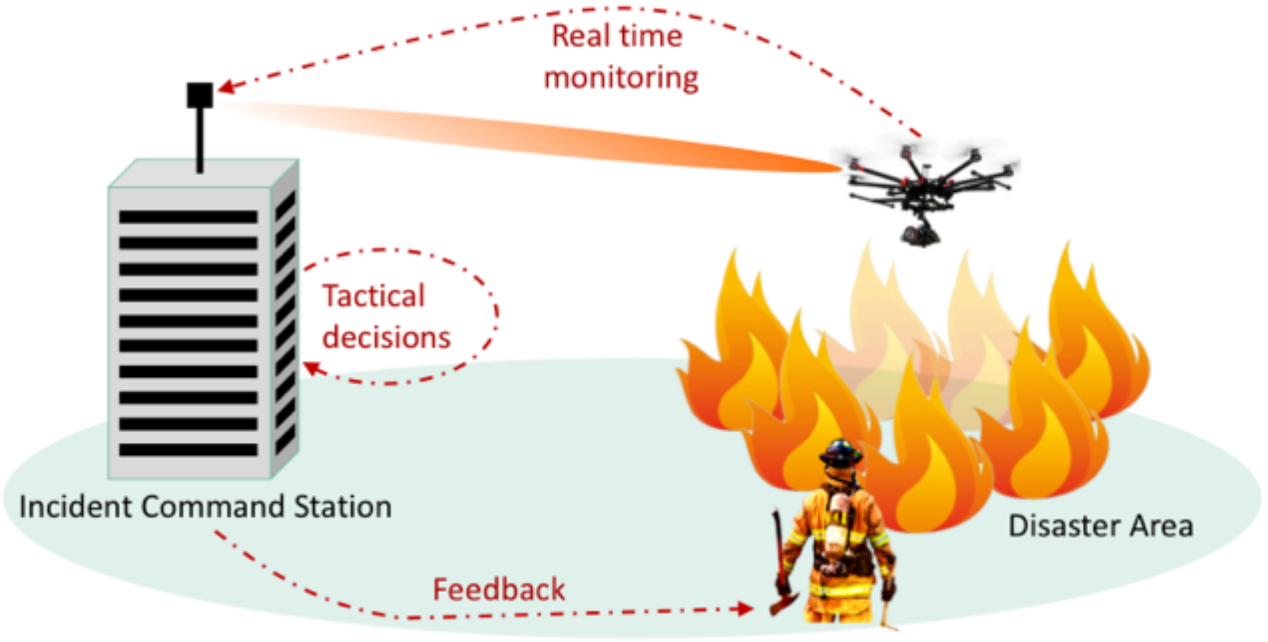
- NYU is working on a new statistical model to abstract the behavior of 3GPP channels [TR 38.900]
- NSF-RCN effort led by NYU and UW (CSP/NET interface for mmWave – with particular focus on link abstraction)
  - Industry participation (Intel, Nokia)

NYU TANDON SCHOOL OF ENGINEERING

NYU WIRELESS

Use case: wildfire

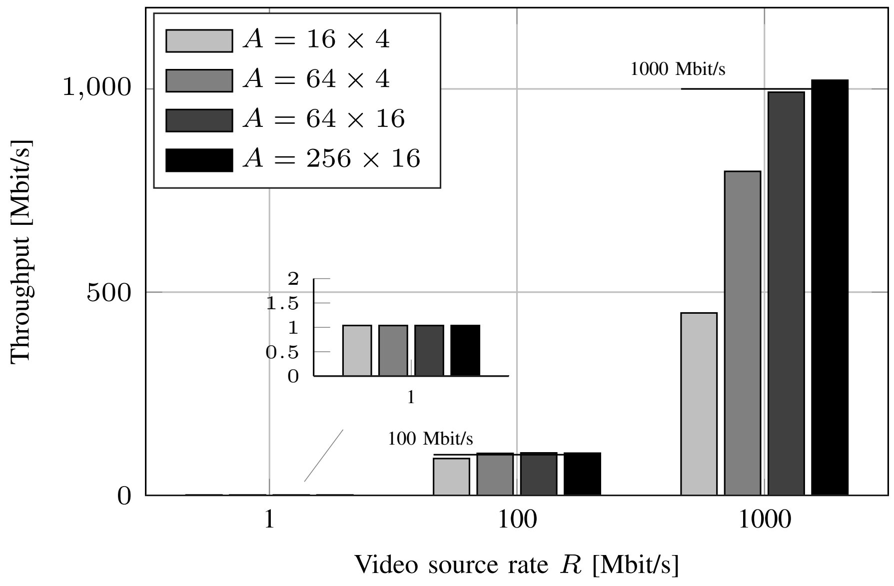
- Rapid response and coordination need real-time data
- Fixed infrastructure is not available
- UAV can be deployed with mmWave links for high quality video streaming and aerial multi-hop

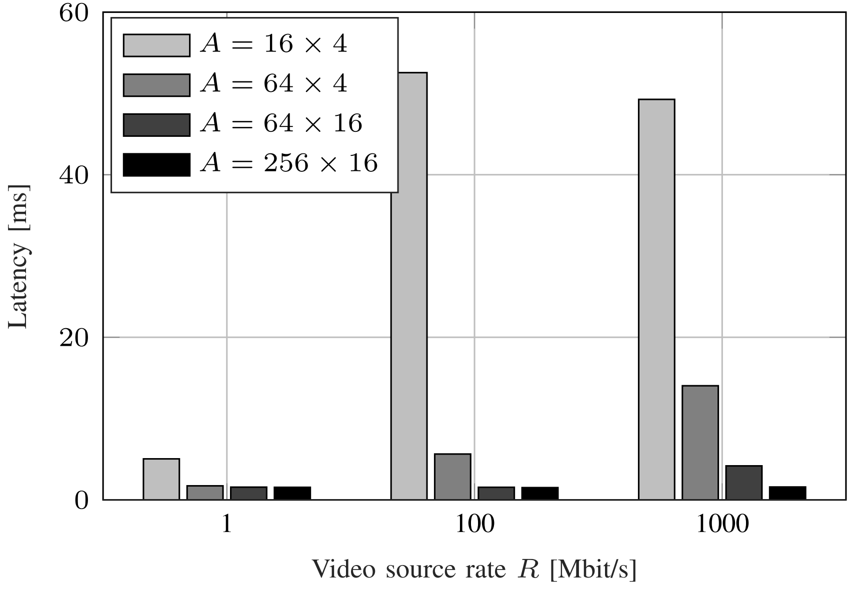


Use case: wildfire

- End-to-end performance evaluation with network simulator ns-3
  - 3GPP-inspired protocol stack, channel models, beam tracking

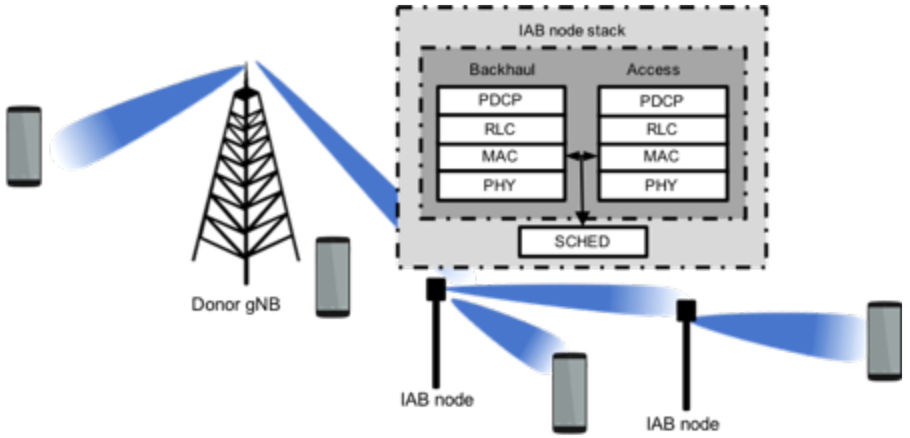
A := TX antennas x RX antennas

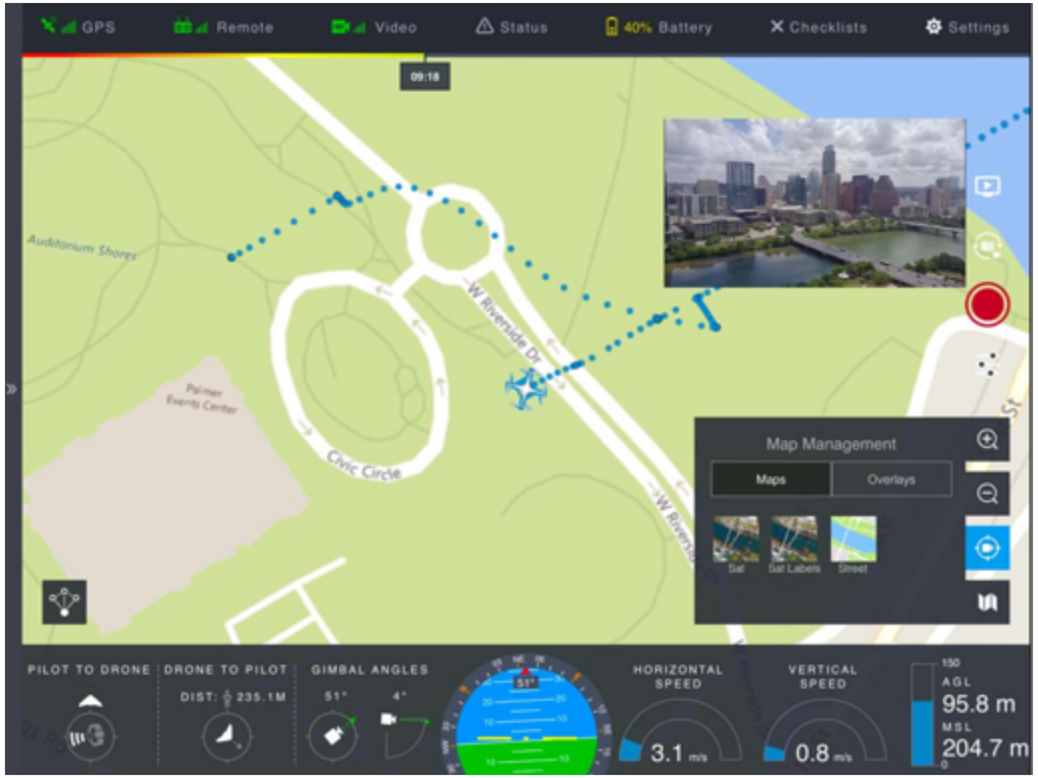




Next steps

- Integration of flight-traces from disaster response missions (collaboration with Dronesense)
- Vehicular mmWave
- Relaying/Multi-hop (fixed or mobile – drones/cars)





References

- Rappaport, Theodore S., et al. "Millimeter wave mobile communications for 5G cellular: It will work!." IEEE ACCESS 1 (2013): 335-349.
- Mustafa Riza Akdeniz, Yuanpeng Liu, Mathew K. Samimi, Shu Sun, Sundeep Rangan, Theodore S. Rappaport, Elza Erkip, *Millimeter Wave Channel Modeling and Cellular Capacity Evaluation*, IEEE Journal on Selected Areas in Communications (Volume: 32, Issue: 6, June 2014)
- Marco Mezzavilla, Sourjya Dutta, Menglei Zhang, Mustafa Riza Akdeniz, Sundeep Rangan, *5G mmWave Module for ns-3 Network Simulator*, MSWiM '15 Proceedings of the 18th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems 2015
- Russell Ford, Menglei Zhang, Sourjya Dutta, Marco Mezzavilla, Sundeep Rangan, Michele Zorzi, *A Framework for End-to-End Evaluation of 5G mmWave Cellular Networks in ns-3*, in Proceedings of the Workshop ns-3 (WNS3) 2016
- M. Zhang, M. Polese, M. Mezzavilla, S. Rangan, M. Zorzi, "*ns-3 Implementation of the 3GPP MIMO Channel Model for Frequency Spectrum above 6 GHz*", ACM Proceedings of the Workshop on ns-3 (WNS3) 2017
- Marco Mezzavilla, Menglei Zhang, Michele Polese, Russell Ford, Sourjya Dutta, Sundeep Rangan, Michele Zorzi, *End-to-End Simulation of 5G mmWave Networks*, IEEE Communications Surveys and Tutorials 2018
- ns-3 mmWave module: https://github.com/nyuwireless/ns3-mmwave
- Sourjya Dutta, Marco Mezzavilla, Russell Ford, Menglei Zhang, Sundeep Rangan, Michele Zorzi, *Frame Structure Design and Analysis for Millimeter Wave Cellular Systems*, IEEE Transactions for Wireless Communications 2017
- Sourjya Dutta, Marco Mezzavilla, Russell Ford, Menglei Zhang, Sundeep Rangan, Michele Zorzi, *MAC Layer Frame Design for Millimeter Wave Cellular System*, 2016 European Conference on Networks and Communications (EuCNC) 2016
- Russell Ford, Felipe Gomez-Cuba, Marco Mezzavilla, Sundeep Rangan *Dynamic Time-domain Duplexing for Self-backhauled Millimeter Wave Cellular Networks*, IEEE ICC 2015 - Workshop on Next Generation Backhaul/Fronthaul Networks (BackNets 2015)

References

- Russell Ford, Menglei Zhang, Marco Mezzavilla, Sourjya Dutta, Sundeep Rangan, Michele Zorzi, *Achieving Ultra-Low Latency in 5G Millimeter Wave Cellular Networks*, IEEE COMMAG 2017
- N. Barati, A. Hosseini, M. Mezzavilla, S. Rangan, T. Korakis, S. Panwar, M. Zorzi, "*Initial Access in Millimeter Wave Cellular Systems*", IEEE Transaction on Wireless Communications 2016.
- M. Giordani, M. Mezzavilla, M. Zorzi, "*Initial Access in 5G mm-Wave Cellular Networks*", IEEE Communications Magazine 2016
- M. Giordani, M. Mezzavilla, C. Barati, S. Rangan, M. Zorzi, "*Comparative Analysis of Initial Access Techniques in 5G mmWave Cellular Networks*", CISS 2016
- M. Giordani, M. Mezzavilla, A. Dhananjay, S. Rangan, M. Zorzi, "*Channel Dynamics and SNR Tracking in Millimeter Wave Cellular Systems*", European Wireless 2016
- Menglei Zhang, Marco Mezzavilla, Russell Ford, Sundeep Rangan, Shivendra Panwar, Evangelos Mellios, Di Kong, Andrew Nix, Michele Zorzi, *Transport Layer Performance in 5G mmWave Cellular*, IEEE INFOCOM mmWave Networking Workshop, April 2016, San Francisco
- M. Zhang, M. Mezzavilla, S. Rangan, S. Panwar, "TCP dynamics over mmwave links", IEEE SPAWC 2017.
- M. Polese, M. Zhang, M. Mezzavilla, J. Zhu, S. Rangan, S. Panwar, M. Zorzi, "milliProxy: a TCP Proxy Architecture for 5G mmWave Cellular Systems", Asilomar 2017.
- M. Polese, M. Mezzavilla, S. Rangan, M. Zorzi, "*Mobility Management for TCP on mmWave Networks*", to appear in proceedings at mmNets17.
- M. Polese, R. Jana, M. Zorzi, *TCP in 5G mmWave Networks: Link Level Retransmissions and MP-TCP*, IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS) 2017

References

- M. Polese, R. Jana, M. Zorzi, *TCP and MP-TCP in mmWave Mobile Networks*, IEEE Internet Computing magazine, special issue on 5G 2017
- Marco Giordani, Marco Mezzavilla, Sundeep Rangan, Michele Zorzi, *Multi-Connectivity in 5G mmWave Cellular Networks*, in Ad Hoc Networking Workshop (Med-Hoc-Net), 2016
- Marco Giordani, Marco Mezzavilla, Sundeep Rangan, Michele Zorzi, *An Efficient Uplink Multi-Connectivity Scheme for 5G mmWave Control Plane Applications*, submitted to IEEE Transaction on Wireless Communications 2017
- Michele Polese, Marco Mezzavilla, Michele Zorzi, *Performance Comparison of Dual Connectivity and Hard Handover for LTE-5G Tight Integration*, ACM SIMUtools 2016 conference, August 22 - 23, 2016, Prague, Czech Republic
- Michele Polese, Marco Giordani, Marco Mezzavilla, Sundeep Rangan, Michele Zorzi, *Improved Handover Through Dual Connectivity in 5G mmWave Mobile Networks*, JSAC Special Issue on Millimeter Wave Communications for Future Mobile Networks 2017
- M. Mezzavilla, M. Polese, A. Zanella, A. Dhananjay, S. Rangan, C. Kessler, T. Rappaport, M. Zorzi, *Public Safety Communications above 6 GHz: Challenges and Opportunities*, to appear in IEEE ACCESS on Mission Critical Public-Safety Communications: Architectures, Enabling Technologies, and Future Applications 2017
- T. Zugno, M. Polese, M. Zorzi, *Integration of Carrier Aggregation and Dual Connectivity for the ns-3 mmWave Module*, WNS3 2018
- M. Polese, M. Mezzavilla, S. Rangan, C. Kessler, M. Zorzi, *mmWave for future public safety communications*, i-TENDER 2017
- M. Polese, M. Zorzi, *Impact of Channel Models on the End-to-End Performance of mmWave Cellular Networks*, SPAWC 2018
- M. Drago, T. Azzino, M. Polese, C. Stefanovic, M. Zorzi, *Reliable Video Streaming over mmWave with Multi Connectivity and Network Coding*, ICNC 2018
- T. Azzino, M. Drago, M. Polese, A. Zanella, M. Zorzi, *X-TCP: a cross layer approach for TCP uplink flows in mmwave networks*, MedHocNet17

References

- M. Zhang, M. Polese, M. Mezzavilla, J. Zhu, S. Rangan, S. Panwar, M. Zorzi, *Will TCP work in 5G mmWave Cellular Networks?*, major revision for IEEE Communication Magazine, 2018
- M. Rebato, M. Polese, M. Zorzi, *Multi-Sector and Multi-Panel Performance in 5G mmWave Cellular Networks*, submitted to Globecom 2018
- C. Slezak, M. Zhang, M. Mezzavilla, and S. Rangan, *Understanding End-to-End Effects of Channel Dynamics in Millimeter Wave Cellular*, IEEE SPAWC (2018)
- C. Herranz, M. Zhang, M. Mezzavilla, D. Martín-Sacristán, S. Rangan, J. Monserrat, *A Lightweight mmWave Beam-Tracking Approach to Improve the End-to-End Performance of 5G NR*, submitted to IEEE Communication Magazine
- C. Herranz, M. Zhang, M. Mezzavilla, D. Martín-Sacristán, S. Rangan, J. Monserrat, *End-to-end Performance of mmWave Directional Synchronization*, submitted to ACM MSWiM (2018).

End-to-End Research Platform for Public Safety Millimeter Wave Communications

PSIAP STAKEHOLDER MEETING, SAN DIEGO

JUNE 6TH 2018