The Open-Source SDR LTE Platform for First Responders

Paul Sutton
Software Radio Systems
www.softwareradiosystems.com
Acronym Glossary

- 3GPP = 3rd Generation Partnership Project
- API = Application Program Interface
- CMS = Content Management System
- CSC = Computer Software Component
- D2D = Device-to-Device Communications
- DDPS = Device-to-Device Systems for Public Safety
- EK = Extended Kalman Filter
- EMS = Emergency Medical Services
- eMBMS = Evolved Multimedia Broadcast Multicast Services
- eNB = E-Ultran Node B
- EPC = Evolved Packet Core
- GMS = Global Macro Storage
- GUI = Graphical User Interface
- HARQ = High Availability Resolution Queue
- HSS = Home Subscriber Server
- HW = Handsets and Wearables
- IDMS = Intelligent Data Movement Service
- IMS = Information Management System
- KMS = Key Management Services
- LOS = Line-of-Sight
- LTE = Long Term Evolution
- MCPTT = Mission Critical Push-to-Talk
- MIMO = Multiple Input Multiple Output
- MME = Mobile Management Entity
- MUO = Micro Unit Operation
- NIST = National Institute of Standards and Technology
- NLOS = Non-Line-of-Sight
- NUC = Next Unit of Computing
- OAI = Open Air Interface
- OAM = Operations, Administration, and Maintenance
- OS = Operating System
- PGW = Packet Data Network Gateway
- ProSe = Proximity Services
- PSCCH = Physical Sidelink Control Channel
- PSCR = Public Safety Communications Research
- PSO = Public Safety Officers
- QoE = Quality of Experience
- QoS = Quality of Service
- QPP = Quality, Priority, and Preemption
- RB = Radio Band
- RX = Receive/ Reception
- SEC = Security
- SDK = Software Development Kit
- SDR = Software-Defined Radio
- SGW = Satellite Gateway
- SIM = Subscriber Identity Module
- SNR = Signal-to-Noise Ratio
- TX = Transmit/ Transmitter
- V2V = Vehicle to Vehicle
- VL = Vencore Labs
- VM = Virtual Machine
- UE = User Experience
Outline

• OpenFirst – Project Overview
  • Objectives
  • Approach
  • Technology

• srsLTE – The Open-Source LTE Software Suite
  • Baseline end-to-end system
  • MIMO
  • Ciphering
  • Mobility
  • Stability
  • Broadcast/Multicast
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Objectives

An open-source end-to-end LTE network for public safety research & development.

- A reference implementation of key LTE features for first responders.
- Enabling, supporting and growing the public safety broadband development ecosystem.
- Providing a commercialization path for public safety LTE using proven business models.
- Building upon the proven srsLTE suite of open-source libraries, tools and applications.
Technology – Software Radio

RF Front-End

Baseband Processor

- Snapdragon 8010 8010 8010 8010
- Qualcomm WTR1605L
- LTE/HEPA+CDMA2000/3G/CDMA/EDGE/GPS transceiver
- Qualcomm PM8841 power management IC
- Broadcom BCM4335 5G Wi-Fi combo chip with integrated power and low-noise amplifiers (the updated version of the BCM4335)
- Avago 11RF28
- InvenSense MPU-6515 9-axis (gyro + accelerometer) MEMS MotionTracking device
- Asahi Kasei AKIE63 3-axis electronic compass

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Requirements

1. Path towards operational implementation
2. Sufficient set of components
3. Sufficiently complete implementation / Interoperability
4. Clarity and completeness of documentation
5. Performance comparable to likely operational implementations
6. Network scale
7. Ease of use / Ease of programming new capabilities
8. Long-term sustainability / Development ecosystem
9. Availability for follow-on research / Potential for commercialization
Open Source

- GNU Affero General Public License (AGPLv3)
- Ensuring dissemination of the technology
- Maximizing usability
- Safeguarding availability
- Guaranteeing sustainability

www.github.com/srslte
Launchpad PPA

Software Radio Systems

PPA description

This is the Ubuntu PPA for snapshots of srsLTE, a free and open-source LTE software suite, along with some dependencies.

For more info, please visit https://github.com/srsLTE/srsLTE

Adding this PPA to your system

You can update your system with unsupported packages from this untrusted PPA by adding `ppa:srslte/snapshots` to your system's Software Sources. (Read about installing)

```
sudo add-apt-repository ppa:srslte/snapshots
sudo apt-get update
```

▶ Technical details about this PPA

For questions and bugs with software in this PPA please contact Software Radio Systems.

PPA statistics

Activity

2 updates added during the past month.

Overview of published packages

Published in: Any series • Filter

<table>
<thead>
<tr>
<th>Package</th>
<th>Version</th>
<th>Uploaded by</th>
</tr>
</thead>
<tbody>
<tr>
<td>srslte</td>
<td>18.05-SNAPSHOT-ubuntu2</td>
<td>Software Radio Systems (9 hours ago)</td>
</tr>
</tbody>
</table>

First • Previous • Next • Last
Clean Modular Architecture
Absolutely Community

Active Community

Open Source Software Radio Systems

Message sorted by: Date

Starting: Mon Apr 2 14:13:14 UTC 2012
Ending: Mon Apr 30 19:39:45 UTC 2012

Messages: 60

- [rw-announce] [2 images of config A] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
- [rw-announce] [2 images of config A] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
- [rw-announce] [2 images of config B] Giuseppe
Active Community

“OSMOSIS”
OPTIMISATION OF STREAMED MEDIA OVER SATELLITE INFRASTRUCTURES
Proven development models, languages, tools
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Roadmap

Phase 1 - Baseline end-to-end network
- Baseline srsEPC development
- Baseline srsENB optimization
- Baseline end-to-end IP test/optimization

Phase 2 - Rel 8/9 feature set
- Encryption - 128-EEA1, 128-EEA2
- End-to-end eMBMS support
- Measurements, X-2 handover support

Phase 3 - Advanced Features 1
- 2x2 MIMO - TM3, TM4 support
- CA support with cross-carrier scheduling
- Public Safety ProSe Basic

Phase 4 - Advanced Features 2
- Public Safety ProSe Advanced
- End-to-end QoS with priority and preemption
- IMS and VoLTE support

PSCR Public Safety Broadband Stakeholders Meetings
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.
Outline

• Motivations
• QPP Management in LTE Networks
• Impact of QPP policies
• Conclusion
Motivations

• First responders are expected to operate in any situation, including areas with low coverage and limited capacity

• A variety of applications are used to improve situational awareness and complete the mission

• The incident type, and events that occur throughout the incident, affect which user and application would bring more valuable information at any given time

LTE provides “knobs” to control the traffic but does not define the policies to control them.
**Quality of Service (QoS):** indication of the application performance requirements (e.g. delay, throughput, loss)

**Priority:** indication of relative importance of the user or application

**Pre-emption:** indication on how critical it is to setup and keep the user or application
QPP Policies During a Residential Fire Incident

1. Units arrive at the scene
   • Units are equipped with multiple applications (e.g. voice, location tracking, weather maps)

2. Firefighters enter the building
   • Start of biometrics and video applications

3. Intervention of additional firefighter units
   • Start of additional instances of voice and location applications

4. Second team enters the building to perform search and rescue
   • Start of biometrics and video applications

5. The injured responder is taken outside, the fire is controlled, and responders turn off applications

QPP Policy Functions
• Define user access levels (e.g. first responders over commercial)
• Define target network performance
• Define application access levels (e.g. voice vs video vs data)
• Reflect changes (e.g. local control)
• The LTE Network controls the traffic using Evolved Packet System (EPS) bearers
• Each bearer has the following QPP parameters
  • Data rate requirements (GBR, MBR)
  • ARP, consisting of pre-emption capability and vulnerability indicators (PCI and PVI), and access priority
  • Loss, delay, and scheduling priority (QCI)
• A device that connects to the network has a default (Non-GBR) and zero or more dedicated bearers (GBR or Non-GBR)
To reduce signaling overhead, 3GPP defines QCI profiles combining:
- Resource type
- Bearer priority
- Packet Delay Budget (PDB)
- Packet Error Loss Rate (PER)

Based on the requirements of the application(s) carried in the bearer, the network operator can assign a particular QCI:
- Voice (time sensitive, fixed rate)
- Email (not delay sensitive, variable rate)

To accommodate new application requirements (e.g. MCPTT, V2X), new QCI values have been introduced.

### Standardized QCI Characteristics (3GPP 23.203 v14.5)

<table>
<thead>
<tr>
<th>QCI</th>
<th>Resource Type</th>
<th>Priority</th>
<th>Packet Delay Budget</th>
<th>Packet Error Loss Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GBR</td>
<td>2</td>
<td>100ms</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>2</td>
<td>GBR</td>
<td>4</td>
<td>150ms</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>3</td>
<td>GBR</td>
<td>3</td>
<td>50ms</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>4</td>
<td>GBR</td>
<td>5</td>
<td>300ms</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>65</td>
<td>GBR</td>
<td>0.7</td>
<td>75ms</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>66</td>
<td>GBR</td>
<td>2</td>
<td>100ms</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>75</td>
<td>GBR</td>
<td>2.5</td>
<td>50ms</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>5</td>
<td>Non-GBR</td>
<td>1</td>
<td>100ms</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>6</td>
<td>Non-GBR</td>
<td>6</td>
<td>300ms</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>7</td>
<td>Non-GBR</td>
<td>7</td>
<td>100ms</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>8</td>
<td>Non-GBR</td>
<td>8</td>
<td>300ms</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>9</td>
<td>Non-GBR</td>
<td>9</td>
<td>300ms</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>69</td>
<td>Non-GBR</td>
<td>0.5</td>
<td>60ms</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>70</td>
<td>Non-GBR</td>
<td>5.5</td>
<td>200ms</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>79</td>
<td>Non-GBR</td>
<td>6.5</td>
<td>50ms</td>
<td>$10^{-2}$</td>
</tr>
</tbody>
</table>
Evaluating Impact of QPP Policies

- Use the residential fire scenario described previously
- Consider different sample policies
  - Example #1: First Responders First!
  - Example #2: Application Level Priority
  - Example #3: User Level Priority
  - Example #4: Adaptive Quality
- Evaluate impact of policies by looking at
  - Network performance (resource utilization, throughput)
  - User experience (R Factor, Structural Similarity)

<table>
<thead>
<tr>
<th>Users</th>
<th>Number of units</th>
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</thead>
<tbody>
<tr>
<td>Firefighters</td>
<td>18, 12 going inside the building</td>
</tr>
<tr>
<td>Incident Command</td>
<td>8</td>
</tr>
<tr>
<td>Staging Area</td>
<td>8</td>
</tr>
<tr>
<td>Perimeters</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applications</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>Voice communication between responders</td>
</tr>
<tr>
<td>Video</td>
<td>Helmet camera streaming from the responders going inside the building</td>
</tr>
<tr>
<td>GPS</td>
<td>Location tracking for all the responders</td>
</tr>
<tr>
<td>Biometrics</td>
<td>Vital signs monitors for the responders going inside the building</td>
</tr>
<tr>
<td>Maps</td>
<td>Download of building, utility, and area maps</td>
</tr>
<tr>
<td>Weather</td>
<td>Weather tracking</td>
</tr>
</tbody>
</table>
Example Policy #1: First Responders First!

- First responder applications have access priority over commercial user applications
- All first responders have the same access priority
- MCPTT/Voice has highest scheduling and retention priorities
- All other applications are served at the same priority levels
- Policy setup:

<table>
<thead>
<tr>
<th>User</th>
<th>Application</th>
<th>ARP</th>
<th>QCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Responders</td>
<td>Voice</td>
<td>Priority=1, PCI=true, PVI=false</td>
<td>1 (GBR, Priority=2)</td>
</tr>
<tr>
<td>All others (Default bearer)</td>
<td>Priority=9, PCI=true, PVI=true</td>
<td>9 (Non-GBR, Priority=9)</td>
<td></td>
</tr>
<tr>
<td>Commercial Users</td>
<td>Voice</td>
<td>Priority=10, PCI=false, PVI=true</td>
<td>1 (GBR, Priority=2)</td>
</tr>
<tr>
<td>All others (Default bearer)</td>
<td>Priority=11, PCI=false, PVI=true</td>
<td>9 (Non-GBR, Priority=9)</td>
<td></td>
</tr>
</tbody>
</table>
The results only show first responder traffic
  - Commercial users get pre-empted as needed

Uplink traffic consists mainly of video, biometrics, and location applications
  - Voice is not appearing due to low throughput

In the downlink, voice is taking more resources due to the fact that all responders receive the audio as part of the group communication

We also notice periodic spikes of data in the downlink for other data applications
• The network becomes congested in the uplink when the firefighters in Team 1 start additional applications (including video) and move inside the building

• Because all the data and video applications use default bearers, it is not possible to have detailed granularity during the allocation
  • Voice traffic is visible because it uses dedicated bearers
Example Policy #1: Qualifying User Experience

- Audio and video qualities are evaluated using widely-used metrics such as R Factor and Structural SIMilarity (SSIM).
- First responders have a stable audio quality throughout the incident
  - 90% of the time, first responders will experience very good audio quality
- Video applications deteriorate over time, as more traffic is injected in the network
  - 60% of the time the SSIM is less than 0.8 in stage 4, compared to 30% in stage 2

끼 But what does this actually mean in terms of the audio and video received?
Example Policy #1: User Experience

There is a need to differentiate traffic and ensure that application requirements are met.

Video Source:
**Example Policy #2: Application Level Priority**

- All first responders have the same access priority
- MCPTT/Voice has highest scheduling and retention priorities
- Video has second highest scheduling and retention priorities
- Data applications are grouped together and have the same priorities
- Policy setup:

<table>
<thead>
<tr>
<th>User</th>
<th>Application</th>
<th>ARP</th>
<th>QCI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First Responders</strong></td>
<td>Voice</td>
<td>Priority=1, PCI=true, PVI=false</td>
<td>1 (GBR, Priority=2)</td>
</tr>
<tr>
<td></td>
<td>Video</td>
<td>Priority=2, PCI=true, PVI=true</td>
<td>2 (GBR, Priority=4)</td>
</tr>
<tr>
<td>Other Applications</td>
<td>Priority=8, PCI=true, PVI=true</td>
<td>8 (Non-GBR, Priority=8)</td>
<td></td>
</tr>
<tr>
<td>Default bearer</td>
<td>Priority=9, PCI=true, PVI=false</td>
<td>9 (Non-GBR, Priority=9)</td>
<td></td>
</tr>
</tbody>
</table>
• Aggregate throughput is reduced due to the additional constraints imposed on the network
  • In example policy #1, maximum uplink was 7.8 Mb/s, while now it is 6 Mb/s; downlink was 10 Mb/s and now it is 8 Mb/s
• Voice traffic is still going through
• Data applications are suppressed once Team 2 starts the video applications and enters the building
Example Policy #2: Resource Allocation

- As with example policy #1, the network is congested in the uplink when the firefighters in Team 1 move inside the buildings.
- Video applications take up almost all resources once Team 2 activates and after that, 17% of the dedicated video bearers could not be set up.
- Data applications suffer from having the lowest priority, but bearers are not pre-empted because they are non-GBR.
- Once the firefighters exit the building and turn off their video, resources are allocated to the buffered data applications.
  - However, it is possible that the applications drop the packets because they arrive too late or the information is obsolete.
• Voice quality does not show changes compared to example policy #1, as voice still has highest priority
• Video quality has drastically improved (to the detriment of the data applications), except for Stage 4
• In Stage 4, we observe that 30% of the videos do not have any traffic
  • ARP prevented those dedicated bearers from being established in order to ensure the resources were available for those already accepted
Example Policy #2: User Experience

Those videos using dedicated bearers maintain better quality, even during congestion.

Video Source:
Example Policy #3: User Level Priority

- Firefighter applications have higher access and retention priority over other first responder applications
- MCPTT/Voice has highest scheduling priority
- Video has second highest scheduling priority
- Data applications are grouped together and have the same scheduling priority
- Policy setup:

<table>
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<th>QCI</th>
</tr>
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<tbody>
<tr>
<td><strong>Firefighters</strong></td>
<td>Voice</td>
<td>Priority=1, PCI=true, PVI=false</td>
<td>1 (GBR, Priority=2)</td>
</tr>
<tr>
<td></td>
<td>Video</td>
<td>Priority=2, PCI=true, PVI=true</td>
<td>2 (GBR, Priority=4)</td>
</tr>
<tr>
<td></td>
<td>Other Applications</td>
<td>Priority=3, PCI=true, PVI=true</td>
<td>8 (Non-GBR, Priority=8)</td>
</tr>
<tr>
<td></td>
<td>Default bearer</td>
<td>Priority=4, PCI=true, PVI=false</td>
<td>9 (Non-GBR, Priority=9)</td>
</tr>
<tr>
<td><strong>Non-Firefighters</strong></td>
<td>Voice</td>
<td>Priority=5, PCI=true, PVI=true</td>
<td>1 (GBR, Priority=2)</td>
</tr>
<tr>
<td></td>
<td>Video</td>
<td>Priority=6, PCI=true, PVI=true</td>
<td>2 (GBR, Priority=4)</td>
</tr>
<tr>
<td></td>
<td>Other Applications</td>
<td>Priority=7, PCI=true, PVI=true</td>
<td>8 (Non-GBR, Priority=8)</td>
</tr>
<tr>
<td></td>
<td>Default bearer</td>
<td>Priority=8, PCI=true, PVI=false</td>
<td>9 (Non-GBR, Priority=9)</td>
</tr>
</tbody>
</table>
• The maximum aggregate throughput is comparable to example policy #2
• In the downlink, the most significant differences occur in stage 4
  • Video traffic from firefighters has higher and more stable throughput
  • Voice traffic does not have as much throughput
Example Policy #3: Resource Allocation

- We can see significant amount of allocations to default bearers (shown as “Other” in the plots)
- In the downlink, we observe less resources allocated to voice in stage 4
  - Some voice bearers have been preempted to support video services
• Everything is similar until Team 2 enters the building (Stage 4)
• When Team 2 starts its video applications
  • Less video bearers were rejected compared to policy #2 (9 % vs 17 %)
  • However, 55 % of the voice bearers were preempted
• During congestion (as in Stage 4), if there are video applications sending data, voice communications are disrupted for non-firefighters

• As per this policy goals, we observe that firefighters are able to maintain audio good quality while supporting more videos

Audio Source:
Example Policy #3: Qualifying User Experience

- The quality of the videos that used dedicated bearers is high
- The number of videos that do not receive traffic is reduced to 20 %, instead of the 30 % we saw in example policy #2
Example Policy #4: Adaptive Quality

- All first responders have the same access priority
- MCPTT/Voice has highest scheduling and retention priorities
- Video has second highest scheduling and retention priorities
- Data applications are grouped together and have the same priorities
- Network is aware of the flexible application’s QoS requirements for video
- Policy setup:

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<td>Priority=9, PCI=true, PVI=false</td>
<td>9 (Non-GBR, Priority=9)</td>
</tr>
</tbody>
</table>
By adapting the quality of the videos, we can avoid having videos with no data received.

There is a tradeoff between the number of videos that need to be scaled and the quality of the videos.

- We can balance what is more acceptable: decreasing the quality of more videos, with each video taking a small rate reduction, or modifying a smaller amount of videos, with greater reductions on the data rate each time.
Example Policy #4: User Experience

Video with 25 % reduced rate

Video with 35 % reduced rate

Video Source:
• QPP policies have a big impact on both the network performance and service quality during congestion
• Dedicated bearers can be used to provide finer control and monitoring of resources
• Both user and application priorities need to be taken into account
• Assigning the highest priority to high throughput applications or users with bad connectivity may affect many other users
• With videos, it is important to evaluate what are the bandwidth requirements that allow them to be useful in each situation
• LTE provides mechanisms to manage priority of the users and services but does not define policies

• Policies already exist to manage co-existence between commercial and first responders, and give priority to the first responders

• Multiple policies may be needed to cover most situations and reduce user intervention but should allow for local control

• The results of our research can be used by operators and first responders to develop policy guidelines and best practices to avoid situations where the network is not able to meet the need of the first responders.

Conclusion
THANK YOU
• Use the residential fire scenario described previously

• Consider different sample policies
  • Example #1: First Responders First!
  • Example #2: Application Level Priority
  • Example #3: User Level Priority
  • Example #4: Adaptive Quality

• Evaluate impact of policies by looking at
  • Network performance (resource utilization, throughput)
  • User experience (R Factor, Structural Similarity)

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<td>Staging Area</td>
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<td>Perimeters</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applications</th>
<th>Type</th>
<th>Data Rate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>24 kb/s</td>
<td>Voice communication between responders</td>
<td></td>
</tr>
<tr>
<td>Video</td>
<td>1 Mb/s</td>
<td>Helmet camera streaming from the responders going inside the building</td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>0.5 kb/s</td>
<td>Location tracking for all the responders</td>
<td></td>
</tr>
<tr>
<td>Biometrics</td>
<td>2 kb/s</td>
<td>Vital signs monitors for the responders going inside the building</td>
<td></td>
</tr>
<tr>
<td>Maps</td>
<td>10 Mb (total transfer size)</td>
<td>Download of building, utility, and area maps. Once, at beginning of incident.</td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>200 kb (each update)</td>
<td>Weather tracking. Updates every 10 seconds</td>
<td></td>
</tr>
</tbody>
</table>
Propagation channel models and system performance for device-to-device communications for public safety application

Andreas F. Molisch (PI), Seun Sangodoyin
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Introduction

- Cellular (infrastructure-based) communications are not suitable for PSOs
  - Limited area coverage
  - Bad outdoor-to-indoor coverage
  - Device-to-device communication is needed

- D2D communication is being developed in 3GPP (LTE-Direct)
  - 3GPP channel models are not concerned with reliability

- Key scenario of interest:
  - V2V communication (between emergency vehicles)
  - O2I communication (outdoor command post to firefight in a building)
Project objectives and technical approach (1)

- Build/modify channel sounder for measuring D2D channels that is
  - Portable
  - Multi-antenna
  - Capable of dynamic measurements

State of the art: existing sounders either cannot do multi-antenna, or can only measure short burst
Project objectives and technical approach (2)

- Perform extensive measurement campaigns
  - V2V channels
  - I2O channels (outdoor to street level, indoor to ground or higher floor)

State of the art: only a few sample measurements exist at PSO frequencies

1 (http://www.wired.com/images_blogs/)

Fig 2. V2V Channels

Fig 3. I2O channel
Project objectives and technical approach (3)

- Evaluate measurement data with HRPE algorithm (4D RiMAX) and EKF
  - Extend 4D-RiMAX to handle the full-polarimetric case
  - Extend EKF algorithm to handle fast time-varying channels
  - Path tracking and clustering procedure

  State of the art: evaluation with Fourier resolution (order of magnitude worse than HRPE)

- Develop channel models for future system development

  State of the art: 3GPP channel models, which do not include non-stationarities, indoor-to-outdoor (high indoor to low outdoor) scenario, …
Project objectives and technical approach (4)

• Assess performance of LTE-Direct system
  - Use Matlab LTE-sidelink package to simulate D2D transceiver
  - Simulate with directly measured channels and developed GSCM model
  - Determine performance limitation (max. distance between devices)

  State of the art: no realistic performance assessment of LTE-Direct for PSO applications exists (as far as we know)

• Develop improvements for increasing reliability
  - Investigate antenna arrays applique as performance improvement
  - Modifications need to be standards compliant

  State of the art: LTE-Direct is mainly single-antenna system
Project Status
Measurement setup

- Re-configure existing measurement setup into a MIMO Channel Sounder
- Can measurement 3D i.e., Azimuth and elevation at TX and RX ends

Fig 4. V2V channel sounder setup

Fig 5. TX-RX system setup
Measurement setup

• Built a spherical uniform circular patch antenna array (SUCPA)
• 2- rings (8 elements per ring) cylindrical array that operates at 915 MHz
Measurement setup

- We calibrated the SUCPA in an anechoic chamber
- Radiation pattern of antenna array are shown below

Fig 8. SUCPA calibration setup

Fig 9. TX radiation pattern

Fig 10. RX radiation pattern
I2O Propagation Channel Measurement

- Two sets of I2O measurements on the campus of USC.
- Building has 5 floors and 28 rooms per floor.

Fig 11. Electrical Engineering Building

Fig 12. Indoor-to-outdoor scenario
I2O Propagation Channel Measurement

- First set of I2O measurements was conducted with 8–element circular array
I2O Propagation Channel Measurement

- Measurement setup with 8–element circular array
- Measurement data has been provided to NIST/PSCR

Fig 15. TX with antenna array indoor
Fig 16. RX antenna array outdoor
I2O Propagation Channel Measurement

- Second set of measurement with 16–element cylindrical array

Fig 17. TX measurement setup with antenna array indoor

Fig 18. RX measurement setup with antenna array outdoor
I2O Propagation Channel Measurement

- We conducted LOS and NLOS Measurements.

Fig 19. LOS measurement location

Fig 20. NLOS measurement location
Results

- Path gain results from different floors measured.

![Path gain results from different floors measured.](image)

**Table 1. Mean Path gain over antenna heights**

<table>
<thead>
<tr>
<th>Floor</th>
<th>Mean Path gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>-77.05</td>
</tr>
<tr>
<td>4</td>
<td>-80.29</td>
</tr>
<tr>
<td>3</td>
<td>-77.65</td>
</tr>
<tr>
<td>2</td>
<td>-78.89</td>
</tr>
</tbody>
</table>

**Fig 21. Scatterplot for Path gain**
Results

- Delay spread results from different floors measured.

![scatter plot](image)

**Fig 22. Scatterplot for delay spread**

<table>
<thead>
<tr>
<th>Floor</th>
<th>Delay spread (us)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>0.22</td>
</tr>
<tr>
<td>3</td>
<td>0.23</td>
</tr>
<tr>
<td>2</td>
<td>0.22</td>
</tr>
</tbody>
</table>

**Table 2. Delay spread over antenna heights**
V2V Measurements

- Plots and Videos (from on-going work).

Fig 23. TX-RX LOS Driving
V2V Measurements

- TX-RX V2V Obstructed LOS Driving

Fig 24. TX-RX OLOS Driving
Tracking Discrete Scatterers Contributions

- Parameter extraction algorithm provides path parameters such as delay ($\tau$), azimuth of arrival ($\vartheta_R$), azimuth of departure ($\vartheta_T$) and Doppler shift ($F$).

- These parameters can be tracked over measurement time using a tracking algorithm.

- The tracking is done jointly over multiple parameter dimension.

Fig 25. Path parameter over time
Tracking Discrete Scatterers Contributions

• Tracking mainly consists of three steps:

A. Estimation

Use parameters of the tracked path as “prior” for path parameter at next time constant.

Fig 26. Doppler tracking over snapshot
Tracking Discrete Scatterers Contributions

B. Judgment
Finding the “closest” component of the estimation at current time constant.
If fail, go to next time constant.

C. Deal with “gaps”
Continue to search along the estimation to overcome gaps.
Tracking Discrete Scatterers Contributions

Path 1 and Path 2: They are LOS and specular path.

Path 3:
AOA = 30 deg
AOD = -155 deg
Delay = 7.5 m in excess of LOS.

Path 3 experiences two reflections as shown in following picture.
Geometry-based stochastic channel Model (GSCM)

- The double-directional, time-varying propagation channel can be modeled as the superposition of paths from scatterers in a dynamic environment.

\[ h(t, \tau, \vartheta_T, \vartheta_R) = \sum_{i=1}^{N} a_i e^{j\nu_i t} \delta(\tau - \tau_i) \delta(\vartheta_R - \vartheta_{R,i}) \delta(\vartheta_T - \vartheta_{T,i}) g(\vartheta_{R,i}) g(\vartheta_{T,i}) \]

Fig 25. Path and scatterer distribution
Geometry-based stochastic channel Model (GSCM)

- Impulse can be divided into four distinct parts:
  1. the LOS component,
  2. discrete components stemming from static discrete scatters (SD)
  3. discrete components stemming from mobile discrete scatters (MD)
  4. diffuse components (DI).

\[
h(t, \tau) = h_{LOS}(t, \tau) + \sum_{p=1}^{P} h_{MD}(t, \tau_p) + \sum_{q=1}^{Q} h_{SD}(t, \tau_q) + \sum_{r=1}^{R} h_{DI}(t, \tau_r)
\]

Fig 26. Geometry of V2V channel model showing Path and scatterer distribution
Geometry-based stochastic channel Model (GSCM)

The basic procedures of constructing GSCMs is:

1. Scatters are placed in the environment according to statistic distributions.
2. Amplitude/Power contribution of scatterers are modeled (includes small- and large-scale).
3. Combine contributions from various scatterers at the receiver to form impulse response.
Geometry-based stochastic channel Model (GSCM)

- The discrete component amplitude can be modeled as

\[ a_p(d_p) = g_{S,p} e^{j\theta_p} G_p^2 \left( \frac{d_{\text{ref}}}{d_p} \right)^{n_p/2} \]

- \( d_p \) - the propagation distance of the \( p \)th component,
- \( G_p \) - the received power at a reference distance \( d_{\text{ref}} \),
- \( n_p \) - the path loss exponent
- \( g_{S,p} \) - the stochastic amplitude gain.

The deterministic pathloss can then be estimated from the low pass filtered signal using a classical power-law decay with propagation distance, such that

\[ G(d_p) = G_p - 10 n_p \log_{10} \left( \frac{d_{\text{ref}}}{d_p} \right) \]
Geometry-based stochastic channel Model (GSCM)

- The large-scale fading $G_{S,p} = 20 \log_{10} g_{S,p}$ is modeled as a correlated Gaussian random variable with zero mean and variance $\sigma_S^2$.
- The distance autocorrelation function is modeled by the Gaussian function

$$r_d(\Delta d) = \sigma_S^2 e^{-\frac{\ln 2}{d_c^2}(\Delta d)^2}$$

Where $d_c$ is its 0.5-coherence distance.
The diffuse component amplitude is modeled as

\[ a_r = G_r^{1/2} c_r \left( \frac{d_{ref}}{d_r} \right)^{n_{DL}/2} \]

Where \( c_r \) is zero-mean complex Gaussian variable.

The power of diffuse components has also been modeled as an exponential distribution in other works.
Expected Impact

• Provide realistic framework for testing D2D comm. for PSOs
• Allow benchmarking of standard and assess product offers to PSOs
• Suggestions for system improvements to meet reliability goals
• Develop channel models for future system development
• Provide channel measurement data that can be used by related projects
Device-to-Device System for Public Safety (DDPS)

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY PUBLIC SAFETY INNOVATION ACCELERATOR PROGRAM (PSIAP)

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Email: clau@vencorelabs.com

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• DDPS objectives
• Phase 1 achievements
• Test bed and DDPS demo
• DDPS/OAI ProSe software
• Resource allocation study
• Synchronization study
• Summary and DDPS Phase 2 preview
DDPS Objectives

• Build complete ProSe stack by extending current OpenAirInterfaceTM implementation to include D2D services based on 3GPP Rel-14 specifications
• Solve open issues related to resource allocation, time synchronization, and service continuity
  – Develop new scheduling algorithms for autonomous resource allocation to minimize collision probability.
  – Develop novel multi-antenna-based synchronization techniques to achieve significant improvement in UE autonomous synchronization
  – Solve complex service continuity challenges
• Demonstrate ProSe solution on software defined radio platform
• Help create an ecosystem that ultimately leads to a small form factor platform
Summary of DDPS Phase 1 Achievements

• ProSe software stack implementation. Completed a baseline version including:
  – Discovery, basic synchronization
  – D2D - 1:N multicast direct communication and 1:1 Direct communication
  – ProSe function (subset)
  – Group registration and authentication
  – Off-net, On-net (subset), UE-Network-Relay (Subset)
  – Applications include push-to-talk, image transfer, and text message

• Synchronization study
  – Simulated the VL “Array-Assisted Cross-Ambiguity Function (AACAF)” synchronization algorithm on MatLab for ProSe in-door and out-door environments
  – Compared the performance of multiple synchronization search algorithms including three variants of AACAF and four variants of direct correlation detector, under the variables of frequency offset, Gaussian noise, and pedestrian multipath channel conditions
  – Showed feasibility with respect to stringent SNR and frequency offset
Summary of DDPS Phase 1 Achievements - cont’d

- **Resource management study**
  - Investigated methods for reducing collision rates for off-net ProSe operations
  - Proposed new algorithms and compared performance with the baseline 3GPP ProSe resource assignment procedure.
  - Studied two variants of the resource assignment algorithm. Both achieved an improvement of ~25% reduction in collision rate. Further study will compare implementation complexity.

- **DDPS test bed demo**
  - Demo 3 UEs, connected in off-net mode
  - ProSe D2D, synchronization, discovery
  - Multiple sessions of 1:1, 1:N groups
  - Prototype with SDR, Intel NUC, laptops
DDPS Demo Plan

• Modes of operation
  – On-network
  – Off-network
  – Partial on-off network

• Proximity Service
  – Discover close-by mobiles
  – Enable D2D communications
  – Group (1: Many) communication
  – Direct (1:1) private communication

• Testbed supporting
  – Service continuity
  – Indoor and outdoor testing
  – Spectrum selection (Band 14 or others)
DDPS Demo - this week

• Demonstrate LTE D2D off-net autonomous group discovery and formation

• Include:
  ➢ ProSe stack
  ➢ Basic synchronization
  ➢ Discovery and Group authentication
  ➢ Simultaneous 1:N, 1:1 sessions
  ➢ Applications: Push-to-talk, send images, text messages

• Hardware platform:
  1. 3 UEs: Laptops, Intel NUC
  2. SDR: USRP (B210)
  3. Splitter/Combiner emulating RF environment
OpenAirInterface™ Software Alliance

- Vencore Labs has partnered with EURECOM to extend the capabilities of the OpenAirInterface™ to include ProSe capabilities.
- The mission of the OpenAirInterface™ Software Alliance (OSA) is to provide software and tools for 5G Wireless Research and Product Development.
- OSA currently provides a standard-compliant implementation of a subset of Release 10 LTE with extensions to Release 14 for UE, eNB, MME, HSS, SGW and PGW on standard Linux-based computing equipment (Intel x86 PC/ARM architectures).
- The OSA software can be used in conjunction with standard RF laboratory equipment available in many labs (i.e. National Instruments/Ettus USRP and PXIe platforms) in addition to custom RF hardware provided by EURECOM to implement these functions to a sufficient degree to allow for real-time interoperation with commercial devices.
Outline

• DDPS goals
• Phase 1 achievements
• Test bed and PSCR demo

➤ DDPS/OAI ProSe software - presented by Bill Johnson
• Resource allocation study
• Synchronization study
• Summary and DDPS Phase 2 preview
• Compared to the traditional LTE architecture, ProSe for Public Safety includes the following additional components and interfaces, the most significant addition being the PC5 (sidelink) interface between UEs.

• The PC5 interface has three major components:
  – PC5-U is used for communicating data between users. For example, voice traffic would be transported on PC5-U in a push-to-talk application.
  – PC5-S allows for signaling information to be communicated between devices. For example, PC5-S is used to negotiate secure direct communication links between individual devices.
  – PC5-D allows devices to discover nearby devices that belong to the same group(s). For example a public safety worker could learn of nearby colleagues via the PC5-D interface.
Implementation Details (High level UE SW Architecture)

- DDPS ProSe Application
- Direct Comm Agent
- PC5-D Discovery Agent
- OAI Interface Agent

Control Interface

Application Layer, e.g., Push-to-Talk applications and user interfaces

RRC eNodeB

PC5-S (Sidelink)
PC3
PC5-U (Sidelink)
PC5-D (Sidelink)

UEip ko kernel module

Control socket

PC5-C (MIB)

UE (out-of-coverage)

Configuration files

UE (connected to EUTRAN)

- PDCP
- RLC
- MAC

- rnti
- lcid

Default RB

sslrb

signaling

srfb1

srfb2

…

L1

Configuration files

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• In the on-network Case, UEs are connected to their respective eNBs (Cellular Base Stations). This is the typical state of a cellular network in a non-emergency situation.
• UEs synchronize to and attach to an eNB.
• UEs connect to the network ProSe Function to retrieve information related to ProSe communication, such as authorization and security parameters.
• Resource allocation is provided by the eNB instead of using preconfigured resource pools at the UEs as in the off-network case
• If authorized for ProSe communication, UEs can perform discovery and communicate with other UEs directly via the PC5 interface, which are both described in greater detail in upcoming slides.
• In an emergency such as a power failure, one or more eNBs may not be available for the public safety UEs to connect to. In this case, the UEs will be off network and can only communicate via the PC5 interface.

• A typical flow would require a UE to perform the following steps
  – Synchronize to a synchronization source
  – Check authorization via local stored parameters
  – Determine what other UEs are in close proximity via Discovery
  – Perform Group Communication – OR –
  – Establish a direct communication link with another UE and communicate with it.
• The LTE specifications provide a mechanism by which UEs can synchronize in an ad-hoc fashion without the need for a reference signal provided by an eNB.
• In the off-network scenario, one of the UEs will become the synchronization reference for nearby devices and will transmit a reference signal that can be used by in-range devices to synchronize subsequent communication.
• The UE will then determine whether it is authorized for ProSe communication based on stored parameters and information such as its location.
• The OAI LTE stack has been enhanced to include procedures to synchronize UEs when synchronization signals from an eNB are not available.
• When off network, public safety workers will wish to know which users are within communication range. This is especially true in an emergency situation when traditional network communication is suddenly lost.

• When UEs are not connected to the centralized LTE network, a mechanism called Discovery is provided by which UEs can securely announce their presence to other in range devices.

• UEs can be members of one or more Discovery Groups and will only be able to decode discovery announcements of UEs in the same group.
• If a UE is authorized for ProSe communication, it can use the PC5 interface (sidelink) to directly communicate with other UEs that belong to a common group in a 1:many fashion, i.e., transmissions are simultaneously received by all members in the group.

• The groups that a UE is a member of are either preconfigured in the device or can be queried from the network ProSe Function if the UE is connected to the LTE network.

• Users can be members of multiple groups and communication is secure within each group.
  – For example, if a user is a member of the FIRE group, but not a member of the EMS group, she can communicate with other fire fighters but not with members of the EMS group.
• A public safety worker may wish to have a direct private communication with another team member.

• A mechanism is provided to establish a secure direct communication links between two public safety workers via the PC5-S signaling link.

• Once established, any desired type of data can be privately shared on the PC5-U interface via the direct communication link, e.g., voice, text, or video.
• A UE can act as a network relay to extend network coverage to public safety workers who are in range of the relay UE but have limited or no connectivity with the eNB.

• This mechanism can be used to effectively extend the range of an eNB in an emergency situation where all eNBs are not functioning properly or if the public safety team is operating in an out of coverage area.

• The off-network user who is connected via a network relay can access network resources as if it was directly connected to an eNB.
Vencore Labs has created a simple messaging application that can be used to demonstrate the capabilities of the DDPS ProSe Application.

The messaging application provides the following features:
- The ability to monitor Discovery messages over the PC5-D interface
- Direct communication links can be established and terminated via the PC5-S interface.
- Text, image, and audio messages can be transmitted via the PC5-U interface either using group (1:_MANY) communication or a direct (1:1) communication link.

Extensive logging information is available such that the ProSe related procedures and data transmission can be examined at all levels of the LTE protocol stack for each type of communication.
Outline

- DDPS goals
- Phase 1 achievements
- Test bed and PSCR demo
- DDPS/OAI ProSe software
  ➢ Resource allocation study - presented by Heechang Kim
- Synchronization study
- DDPS Phase 2
• Mode 1 (Scheduled Mode)
  – eNB indicates the physical resources (via System Information Block) to be used on a UE-specific basis -> collision avoidance
  – A UE needs to be in the RRC_CONNECTED state (only in-network)

• Mode 2 (Autonomous Mode)
  – A UE on its own selects resources from a set of resource pools allocated on a non-UE specific basis
  – Works for a UE either in-network or out-of-network
    • In-network: UE is in the RRC_IDLE state. The resource pool configuration is indicated in SIB broadcast from the eNB
    • Out-of-network: The resource pool can be preconfigured in the mobile device.
Problem Statement in Resource Allocation

• Challenging Autonomous Mode Resource Allocation (Mode 2):
  – Resource selection is not coordinated. Each UE randomly selects RBs to transmit a Control message.
  – Collision will occur if more than two transmitting UEs happen to select the same RB to transmit a Control message.
  – Collisions unavoidably lead to data reception failure (due to lack of feedback mechanism).

• 3GPP Standard (Baseline) Approach
  – Control Channel pool is divided into two virtual partitions. The same Control message is sent two times on selected RBs in two virtual partitions for frequency hopping and diversity combining gain.
  – The first RB is randomly selected in the first partition. The second RB is selected in the second partition based on fixed frequency hopping pattern.
  – Collision in the first transmission leads to collision in the second transmission (not optimal in terms of collision minimization).
Example LTE Sidelink Resource Allocation (Mode 2)

- Transmitting UE selects RBs randomly in PSCCH pool to send a control message two times (for reliability). The control message has information on selected RBs (green boxes in the figure) where data will be sent in PSSCH.
- Receiving UE listens to the control message and knows how and where the data is transmitted by other UEs.

Control Channel resource pool
Shared Channel resource pool
Selected resource blocks (RB) to send Control Message
Selected resource blocks (RB) for data transmissions
Objective: To improve collision performance by optimally selecting an RB for the second transmission of Control Message

Approach: Optimize the schedule of a different frequency hopping pattern in the second transmission by using the knowledge of sensing when not transmitting

Proposed two schemes
- Adaptive Sensing scheme: Adaptively adjust the switching probability, $p$ based on $q$.
- Random Selection scheme: An RB is randomly selected in the 2nd partition.

$P$ (switching probability): UE switches to a different random hopping pattern with $p$. In other words, UE uses the same static (as in the 3GPP approach) frequency hopping pattern with $(1 - p)$.

$q$: (measured RB occupancy ratio)
Simulation results (1)

Objective: To find optimum switching probability $p$, by understanding the relationship between $p$ and $q$ via experimental simulation study.

$p$: Switching probability
$q$: \[ \frac{\text{occupied RBs}}{\text{total available RBs}} \]

$\text{Optimum Collision Performance Curve}$

$p$, $q$, $\text{occupied RBs}$, $\text{total available RBs}$
Simulation results (2)

Performance Comparison of Resource Allocation Schemes
(Num_RB_per_subframes = 16, Num_Subframes = 8)

\[ P_{collision}^{RS} = \left( 1 - \left( 1 - \left( \frac{1}{L_{PSCCH_{RB}}R_{RB_{PSCCH,RP}}} \right) \right)^{N_{UE}} \right)^2 \]

\[ P_{collision}^{3GPP} = 1 - \left( \frac{1}{L_{PSCCH_{RB}}R_{RB_{PSCCH,RP}}} \right)^{N_{UE}} \]

- Baseline 3GPP
- Random Selection (RS)
- Adaptive Sensing

25.1% gain
9.3% gain
Summary and Future Work

- Autonomous Mode Resource Allocation is challenging.
  - Resource selection is not coordinated (Collision will occur if more than two transmitting UEs select the same resource)
  - Collisions unavoidably lead to data reception failure (No HARQ feedback)
- Collision rate can be optimized by properly selecting a probability of staying in the same frequency hopping as 3GPP baseline approach (based on UE sensing the time-frequency resource blocks)
- Vencore Labs proposed two schemes
  - Adaptive Sensing scheme:
    - Achieves up to 25.1% gain over the baseline 3GPP approach.
    - Requires sensing feature (additional HW complexity).
  - Random selection
    - Performs similarly compared to Adaptive Sensing scheme in most traffic load conditions.
    - Does not require sensing
- Plan to conduct complexity analysis in resource allocation and refine the proposed schemes for implementation in Phase 2.
Outline

• DDPS goals
• Phase 1 achievements
• Test bed and PSCR demo
• DDPS/OAI ProSe software
• Resource allocation study

➤ Synchronization study - presented by Eric Beck
• Summary and DDPS Phase 2 preview
A Challenging Communication Environment

- Partial-in-network ProSe (PC5)
- Off-network ProSe (PC5)
- UE-Network Relay
- in-network ProSe (PC5)
- eNB
- S1
- U_u
- PC3
- PC4
- PC2
- EPC
- ProSe Appl Server
- ProSe Function

- Side link, SC-FMDA, FDD
- Cellular LTE
A Challenging Communication Environment

- Higher path loss – due to disadvantaged UE locations
- Rapid Synchronization time – due to dynamic ad-hoc networking
- Larger relative frequency offset – due to UE lower tolerance oscillators

Emergency Loss of Network Connectivity

- Higher path loss – due to disavantaged UE locations
- Rapid Synchronization time – due to dynamic ad-hoc networking
- Larger relative frequency offset – due to UE lower tolerance oscillators
High Level Synchronizer Requirements

• Reliable synchronization ( > 95%) in low SNR ( <= -4 dB) environments

• Rapid synchronization for ad hoc network reformation (single frame sync)

• Ability to acquire over twice the nominal UE frequency offset
  – (+/- 10 ppm -> +/- 20 ppm)
Synchronizers Evaluated

- Coherent correlation over entire PSSS synchronization pattern with 1 antenna
- Coherent detection over a single PSSS synchronization pattern with 2 antennas
- Coherent / Incoherent correlation over PSSS synchronization pattern with 1 antenna
- Coherent / Incoherent correlation over PSSS synchronization pattern with 2 antennas
- A proprietary Vencore Labs algorithm (AACAF) employing antenna array processing
Simulation Flow

For each file (above) compute the following:

1. For each file (above) compute the following:

   X.mat
   \[ \sum \]  X.mat
   \[ \times \]  PSSS Detector DUT
   \[ = \]  True sync location +/- tolerance
   \[ \uparrow \]  Estimated Sync location
   \[ \uparrow \]  Pass / Fail Counter
   \[ \uparrow \]  PSSS Detector DUT

   Noise Generator Sets Detector SNR
   \[ \uparrow \]  Local Oscillator UE "Frequency Offset"

1000 frames of sample data
40 mS each, 40 seconds of real time with 4 spatial receive paths

This set of files is used to stimulate each PSSS detector under test.
### Performance Plots

**One Antenna PSSS Synchronizers**

- 0 dB SNR
- -4 dB SNR

**Two Antenna PSSS Synchronizers**

- 0 dB SNR, Fully coherent correlator
- 0 dB SNR, Half coherent correlator
- -4 dB SNR, Fully coherent correlator
- -4 dB SNR, Half coherent correlator
- -4 dB SNR, Fully coherent AACAF
- -4 dB SNR, Half coherent AACAF

**Graph Details**

- X-axis: Frequency Offset, KHz
- Y-axis: Single Frame Synchronization Probability
Results

- Two antenna system vastly improves synchronizer performance
- Low SNR ( > -5 dB) and high probability of single frame synchronization (> 95%) is possible
- Half-length coherent combining is a good computation trade – fewer multiply adds, increased single sweep detector bandwidth
- Further study – algorithm performance in interferer environments. AACAF expected to provide advantages in this situation.
Summary and DDPS Phase 2 Preview

• Phase 1 summary:
  – Baseline implementation of 3GPP ProSe for direct communication
  – Encouraging result in resource allocation and synchronization
  – Demo of off-network ProSe on SDR platform

• Phase 2 Plan:
  – Update DDPS/OAI ProSe implementation for Service Continuity
  – Evaluate and implement resource allocation and selected synchronization scheme
  – Test bed readiness for support of:
    • Integrate legacy LTE and ProSe D2D
    • Radio frontend for range extension
    • SWAP consideration
    • Indoor and outdoor tests
Thank You
Questions?
Off-Network Mission Critical Push to Talk Evaluation: Factors Impacting Access Time

Yishen Sun and Wesley Garey
NIST/CTL/Wireless Networks Division
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.
OUTLINE

• Motivation
• MCPTT Access Time Definition
• Analysis
• Summary
Mission Critical Push-To-Talk (MCPTT) over LTE and Proximity Services (ProSe) provide first responders with the direct mode voice communication capabilities.

Time-to-connect is important to user experience:
- How long does it take for a user to connect?
- What are major factors that impact the time to connect?
• **3GPP** definition: “The **MCPTT access time** is defined as the time between when an MCPTT User requests to speak (normally by pressing the MCPTT control on the MCPTT UE) and when this user gets a signal to start speaking.”
WHAT DETERMINES MCPTT ACCESS TIME?

MCPTT ACCESS TIME IS DETERMINED BY...

- **MCPTT Parameters**
  - Timers;
  - Counters, etc.

- **ProSe Parameters**
  - Sidelink period;
  - Time resource pattern, etc.

- **System Conditions:**
  - Traffic load;
  - Channel, etc.

- **MCPTT Client**
  - PTT button push timing;
  - User Priority;
  - Human response time, etc.

- **Other Factors**
  - Hardware processing time;
  - Software processing time, etc.
ANALYSIS

• Baseline scenarios
• Impact of configuration
• Impact of additional users
• Impact of technology
BASELINE SCENARIOS

Press the PTT Button

1. Basic Group Call
2. Broadcast Group Call
3. Private Call
BASELINE SCENARIOS – LIST OF SCENARIOS

Access time is evaluated for:

- New Group Call
- New Private Call
- New Broadcast Call

- In Call – No one talking
- In Call – Someone talking
- Join Call – No one talking
- Join Call – Someone talking
ACCESS TIME FOR BASELINE SCENARIOS

- Given the access time above, does this meet the expectations of first responders in off-network environment?
- There are other metrics to evaluate in addition to access time.

* ProSe Sidelink period is set to 40 ms, and default 3GPP settings are used for MCPTT parameters.
** Assume zero software processing, hardware processing, or user interaction delays.
*** Assume half duplex effect collision is the only reason of transmission failures.
UNDESIRABLE OUTCOMES

• Multiple calls
  - Multiple group calls with the same group ID co-exist;
  - Should happen due to out of range UEs, but not due to premature call control timer expiration;
  - Can be resolved by call merge procedure.

• Simultaneous talkers
  - Simultaneous talkers (floor arbitrators) of the same group call co-exist;
  - May be due to UE out of range, hidden node, or premature floor control timer expiration;
  - The undesirable situation persists until one of the talkers finishes speaking.

Members of the same group are not in the same conversation. 😐
And they are not aware of that!!!
OCCURRENCE OF UNDESIRABLE OUTCOMES

Occurrence of Undesirable Outcomes in Baseline Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Undesirable Outcome Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Group Call</td>
<td>0%</td>
</tr>
<tr>
<td>New Private Call</td>
<td>0%</td>
</tr>
<tr>
<td>New Broadcast Call</td>
<td>0%</td>
</tr>
<tr>
<td>In Call - No One Talking</td>
<td>0%</td>
</tr>
<tr>
<td>In Call - Someone Talking</td>
<td>0%</td>
</tr>
<tr>
<td>Join Call - No One Talking</td>
<td>0%</td>
</tr>
<tr>
<td>Join Call - Someone Talking</td>
<td>0.0014%</td>
</tr>
</tbody>
</table>

- **Reasons of undesirable outcomes:**
  - Misalignment between MCPTT/ProSe parameter configurations and the potentially large variation in message exchange round-trip time and scenarios.
- **Mitigation of undesirable outcomes:**
  - Proper configuration of MCPTT and ProSe parameters to achieve better trade-offs.
ANALYSIS

• Baseline scenarios
• Impact of configuration
  • ProSe Sidelink Period
  • MCPTT Timers
• Impact of additional users
• Impact of technology
IMPACT OF ProSe SIDELINK PERIOD

Impact of ProSe Sidelink Period on Average Access Time

- New Group Call
- New Private Call
- New Broadcast Call
- In Call - No One Talking
- In Call - Someone Talking
- Join Call - No One Talking
- Join Call - Someone Talking

For ‘Join call – No One Talking’ scenario,
- The access time is eventually capped by the value of a timer (wait-for-call-announcement timer).
- When ProSe sidelink period is long, the average access time decreases, because the occurrence of multiple calls increases.

Impact of ProSe Sidelink Period on Undesirable Outcome Ratio

- Join Call - No One Talking
- Join Call - Someone Talking
- In Call - Someone Talking
IMPACT OF WAIT-FOR-CALL-ANNOUNCEMENT TIMER

- In order to prevent the multiple call situations, wait-for-call-announcement timer may take into account the duration of ProSe sidelink period.
- Scenario: Join Call – No One Talking; Undesirable Outcomes = Multiple Calls.
- Wait-for-Call-Announcement Timer = 150 ms (3GPP default setting) or 5 x sidelink period

- When increasing the wait-for-call-announcement timer, the occurrence of multiple calls can be reduced.

- How about access time?
The effective access time can be reduced by adjusting the wait-for-call-announcement timer properly.
IMPACT OF RETRANSMISSION TIMERS

Small Timer
• Faster Response;
• Timer expiration may be premature, which might lead to undesirable outcomes and/or overhead.

Large Timer
• Slower response;
• More reliable decisions are made.

The impact of floor request retransmission timer configuration will be further illustrated for scenarios when more MCPTT users are included.
ANALYSIS

• Baseline scenarios
• Impact of configuration
• Impact of additional users
  • One call
  • Separate calls
• Impact of technology
IMPACT OF ADDITIONAL USERS SCENARIOS

• One call

• Scenario: In Call – Someone Talking
• Undesirable Outcomes = Simultaneous Talkers
• Default 3GPP settings
• Sidelink period = 40 ms

• Separate calls
All additional UE’s make no PTT request – these are listening users

The total number of listening users on a call does not have much of an impact (if any) on access time

The same holds true for the number of undesirable outcomes

This is because overhead traffic generated by listening devices is light
IMPACT OF MORE USERS ON A SINGLE CALL

- All additional UEs make PTT requests within the same 320 ms – competing users
- The total number of competing users on a call has an impact on access time
- The same holds true for the number of undesirable outcomes
- This is because as more requests are made the messages are more likely to collide
- The likeliness of such competition is questionable
In all additional calls someone is talking.

At first glance, the impact of the total number of simultaneous calls is small.

But the ratio of undesirable outcomes increases significantly.

This is because talkers from different calls are competing for the same limited resources.

Adjusting the retransmission timer helps mitigate undesirable outcomes up to a certain point, but the tradeoff is a larger increase in access time.
ANALYSIS

- Baseline scenarios
- Impact of configuration
- Impact of additional users
- Impact of technology
MCPTT OVER Wi-Fi

• Why:
  • Wi-Fi is everywhere
  • Feedback from 2017 Stakeholder meeting

• Wi-Fi assumptions:
  • 802.11g (2.4 GHz)
  • Ad hoc mode

• Impact of separate calls
  • Scenario: In Call – Someone Talking
    • Two UEs in each call with one active talker
  • Undesirable Outcomes = Simultaneous Talkers
MCPTT OVER Wi-Fi – IMPACT OF SEPARATE CALLS

Observation:

- This is expected because:
  - Wi-Fi transmission is not restricted by sidelink period boundary
  - ProSe has no “back-off” mechanism, and thus no “back-off” delay
MCPTT OVER Wi-Fi – IMPACT OF RETRANSMISSION TIMER

• Wi-Fi still out-performs ProSe when the number of parallel calls is small
• By increasing the retransmission timer to reduce the undesirable outcomes:
  • The increase in access delay is much larger for Wi-Fi than ProSe
  • The reduction is more effective with ProSe than Wi-Fi
• Adjusting the configuration to reduce the number of unwanted outcomes is more effective for ProSe than for Wi-Fi when more traffic is introduced
MCPTT OVER Wi-Fi – OTHER ASPECTS

**ProSe**

- Coverage Range*
  - Outdoor: up to 225~549 m
  - Indoor: up to 83~115 m
- Interference from non-public safety users:
  - May be minimized by allocating higher priority to public safety users and/or utilizing dedicated frequency band.

**Wi-Fi**

- Coverage Range
  - To be investigated
- Interference from non-public safety users:
  - Cannot be avoided or reduced due to sharing the channel (the unlicensed frequency band that Wi-Fi devices are communicating over).

References:
MCPTT access time was analyzed under various off-network scenarios.

Results were presented for baseline scenarios with MCPTT parameters configured at 3GPP default setting.

To evaluate the ‘time-to-connect’ experience for an MCPTT user more comprehensively, new metrics are introduced in addition to 3GPP access time metric, such as the undesirable outcomes ratio and the effective access time.

MCPTT user access time is impacted by the configuration of MCPTT and/or ProSe parameters, the number and activities of other users sharing the system, and the medium access technology.
THANK YOU
Mission Critical Open Platform
Introduction
Demand for NG safety networks

Lack of enriched services

Interoperability problems

Different Standards
Different Vendors
Different Organizations

Financial crisis

Spectrum scarcity
Mission Critical Communications in 3GPP

Mission Critical Push to Talk in 3GPP Rel-13

3GPP entered the application domain by standardizing Mission Critical Push to Talk (MCPTT) in Rel-13, completed in 2016. To provide organisational support and focus a new working group - SAG - was established in order to complete the new application related work in concert with other 3GPP working groups in less than one and a half years - by March 2016.

By achieving this challenging goal, 3GPP not only honoured its commitment to the mission critical industries but also demonstrated its ability to take on new, application related work and to complete it within a set timeline.

Mission Critical Services in 3GPP Rel-14

MCPTT was the first major step in a series of MC Services and functionalities demanded by the market. In Rel-14, completed in 2017, 3GPP added additional MC Services and enhancements to its repertoire of standardized applications, specifically:

- Enhancements to MCPTT
- MCD atroc
- MC Video
- General framework which facilitates standardizing additional MC Services

Mission Critical Services and Industry Specific Requirements in 3GPP Rel-15 and beyond

All 3GPP working groups have already started work on Rel-15, the first release of the 5G system. In addition, 3GPP is also working on service requirements for Rel-16, the second release of the 5G system.

In Rel-15, the MC Services are further evolved. In addition to that, 3GPP is currently evaluating and studying further MC related topics for Rel-15 and beyond, in particular:

- Interconnection between 3GPP defined MC systems
- Interworking between the 3GPP defined MC system and legacy systems such as TETRA or P25, for voice and short data service
- MC Service requirements from railway industries
- MBMS APIs for MC Services
- MC Service requirements from maritime industries

From Rel12

To Rel15
Classical Entry Barriers in PMR

Proprietary Niche Technologies

Expensive HW platforms

Lack of interoperability
Challenge 1: complex ecosystem
Introduction

Monolithic proprietary apps

Proprietary APIs to MC capabilities

Dependence on internal OS APIs⇔ OEM only

Challenge 2: UE architecture

No access to user level apps to SIM/others

MCOP project
How can a Mission Critical Open Platform help?

- **Reduce Entry Barriers**
  - Open and standardized APIs in the UE
  - Overcome complex ecosystem issues

- **Avoid reinventing the wheel**
  - Share Lesson Learnt and MCPTT awareness.

- **Foster innovation ↔ democratization of MC communications**
  - Easy to use tools hiding technology complexity

- **Focus on each stakeholder’s needs**
The MCOP Approach

How to build a successful MCOP?
- Option 1) Start pushing APIs in standardization bodies
  - Time scale
  - Sustained and joint effort (several meetings)
- Option 2) Bring major vendors
  - Conflicting interests
  - Immature market: final business model still not clear
  - “We believe it’s important, but... I need to check with the managerial”
  - Already N different “vendor alliances”
    * Join one?

... the MCOP approach ref: “Field of Dreams” (1989) IMDB

“If you build it, they will come”
The MCOP approach

“If you build it, they will come”

- Foster INNOVATION
  - MCPTT Open Source SDK + clean APIs

- As possible
  - Technology neutral + flexible architecture
  - Multiple deployment models
    * From Private LTE to Hybrid

- Build and make available open testbeds
  - Online https://demo.mcopenplatform.org
  - MC-grade (live) e2e

- MC-Grade
  - Multicast (eMBMS)
  - High priority bearers (MC-QCIs)
  - Deployment/configuration/OAM
Monolithic MCPTT Application

Proprietary

Proprietary

No SIM access

No APN access

Clear single interface

Public API

OS vendor defined

Connection Manager

SIM vendor

LTE

Radio Layer Access

Vendor specific Radio Access

Proprietary

Proprietary

Proprietary

Proprietary

Proprietary

Proprietary

Proprietary

Operating System

MCOP OAM/OTA OPEN ACCESS

Hardened Platform

OAM (OTA)

IMSIM AUTH

Different OAM & OTA procedures

ProSE operations

eMBMS operations

MCOP project
How it works
**Technology neutral**
- API definition OPEN, for ANY platform

**De-coupling/isolation for different business models**
- Every component seamlessly provided by a different vendor

**Licensing and release cycles**
- No constraint

**Access to prioritized resources**
- OEM only if needed

**Alignment with Android and under-standardization APIs**
- Future-proof
MCOP APIs

- Open, free, publicly available
- Technology Neutral
- Limited dependencies
- Binder mechanism
- Multimedia
- Closer integration [optional]
  - Access to SIM card
  - Performance/UX
  - Power management
  - Dialer

Ref: https://developer.android.com/guide/platform/
MCOP architecture

- **Android implementation**
  - Independent nodes: bound services
    - MCPTT application (GUI), SDK, plugins...
    - No need to link together, merge licenses, coordinate release cycles
    - Synchronous operations + Asynchronous feedback
      - Messenger/AIDL callback

![Diagram showing MCOP architecture with User Space and Kernel Space]
MCOP architecture

Android implementation
Mutual Authentication framework

- Beyond play-store paradigm
- Restricted access to specific nodes
- Software based vs. Global Platform based

OAM Certificate Whitelist provisioning

SIM card / System level APP permissions
Current Status
MCOP roadmap

- Overall architecture
- API definition
- Testing system

MCOP project

- Sample APP
- MCOP SDK
- Plugins

Re-evaluation of MCPTT “compliance”/interop

DEMO1

DEMO2
Neutral APIs + Android implementation

https://www.mcopenplatform.org/resources

- Neutral definition published
- AIDL files to be released with the first version
  - CCW’18/PSCR’18
Current status

Features [June’18]

MCPTT Calls

Private Call
- On-network
  - Floor-control
    - With floor-control
    - Without floor-control (full duplex)
  - Commencement mode
  - Establishment
    - Automatic
    - Manual
    - Pre-established
    - On-demand

Group Call
- On-network
- Broadcast Group Call

Group Call
- Type
- Establishment

Broadcast Group Call
- Type
- Establishment

Emergency / Imminent Peril Calls
- On-network
- Type
- Establishment

Emergency Call
- Pre-established

Emergency Group Call
- On-demand

Imminent Peril Group Call
- Pre-established

Chat Group Calls
- On-demand

Emergency Private Call
- On-demand

Supported
Partly supported / under development
Not yet supported
Current status

Features

- IdMS/CMS/GMS
  - >Rel13 => Rel14
- Different user profiles
- No SEC/KMS yet
Current status

- MCOP approach already verified!!
  - “Hello World” MCOP sample app => MUOAPI
- Both APIs used
- Works with 3GPP Rel13/Rel14 MCPTT AS
- GUI interface only, developers do NOT need to know MCPTT
- <1000 lines of code (error/event handling)
Current Status: build your MCOP APP

✿ Step 1: Access to MCOP development VM or repo
  – Android studio
  – Clone GUI (and SDK) projects
Step 2: Code your own GUI based on MCOP examples/build from scratch/evolve your existing APP

– Remember 1000 lines
How it works: build your MCOP APP

🔹 Step 3: Build, deploy and test it on the online/live lab
How it works: build your MCOP APP

**Step 4:** Deploy it in a MC device supporting MCOP integration API

– + MC QCI
– + Access to SIM card
– + eMBMS
Benefits for different stakeholders
Eco-system Benefits

- Easier Product Integration
  - MCOP APIs will pave the way towards simpler MC-PTT integration mechanisms.

- Decrease the Single Vendor dependence
  - MCOP open approach and the OAM management platform will allow vendor-agnostic deployment.

- Increase MC-PTT Awareness
  - Open Source demo apps and whitepapers will enable stakeholders to get an unbiased view of current capabilities and status of the MC-PTT technology.

- Hands-on Trials and Training
  - Best method for fostering new technology acceptance and provide early training.
Device Vendor and App Developer Benefits

- Reduce Development Cost
  - Common MCOP APIs allow Device Vendors to easily integrate different MC-PTT solutions and alternative chipset hardware platforms.

- Faster Time-to-Market
  - MCOP SDK will isolate App Developers from the complexity of the MC-PTT communication primitives.

- Untie Application Layer to specific Hardware platform
  - Well defined MCOP APIs will allow different MC-PTT clients and applications be deployed over different chipsets, eMBMS middleware and hardware platform.
LTE Broadcast in Mission Critical Open Platform
PSCR June 2018
Need: Critical Communications Pain Points

• First responders need to save lives! Community lives and their own.

• Agencies need to coordinate their efforts and communicate with each other:
  – Firemen, Police, Medical, Environmental, Local
  – Using the same standards. Private radio networks often do not use the same standards

• First responders need to share valuable live information, including videos, voice, maps, pictures, …

• Agencies want to avoid congestions with dedicated bandwidth.

• Agencies want to use secure networks.
Need: Crisis in crowded events

B-C use-case

LTE Network operators become congested in populated areas during popular events
Analysis: Unicast

• In Unicast every user device is asynchronous to others
• Signals coming from secondary antennas can act as an interference, reducing signal efficiency
• Users have different signal quality resulting in inconsistent QoE
• Users receive information at different times – saturated cells
Analysis: LTE Broadcast Efficiency

- LTE Broadcast uses SFN and single cell point to multipoint technologies in a single cell.
- Data is transmitted in a synchronized manner using the same channel across all eNodeBs in service area.
- Devices can add up contributions from secondary antennas, improving the actual information signal.
- All users have the same guaranteed bit rate with a consistent QoS across the service area.
- Starting with 1.5 user per cell LTE Broadcast makes sense.
Analysis: on demand LTE Broadcast activation

- **Based on consumption:**
  - Activation of multicast stream can be based on the number of users on the network

- **Based on policy:**
  - Mission-critical content can be given multicast priority
  - The MC application servers send expected QoS to BMSC server
  - QoS parameters contain ARP (Allocation and Retention Priority) which tells the network which communications have priority

- The switching from unicast to multicast and back is automatic
Why is LTE Broadcast even more important for Mission-Critical Communications?

- LTE provides:
  - Proven carrier-grade network
  - Broad interoperability
  - 1-1 and small group voice calls

- LTE Broadcast delivers in addition:
  - Strictly committed bandwidth
  - Prioritized bandwidth
  - Consistent QoS and QoE
  - Resilience to congestion
  - Large group voice calls
  - Group video and data distribution
Why is LTE Broadcast even more important for Mission-Critical Communications?

- Only LTE Broadcast, on 4G and future 5G networks, meets these requirements.
- Governments WW are mandating the use of LTE and LTE Broadcast for mission critical applications.
- ¾ bids mandate LTE Broadcast.
- Video, need information in real time, simultaneous distribution for all receptors, avoid congestion.
Several LTE Broadcast components present in multiple places
How to integrate them into your mission-critical applications?
MCOP: Simplifies The Integration of LTE Broadcast Functionality

Mission Critical Applications
MUOAPI
Open Source SDK
Integration API
SIM
LTE Broadcast Middleware Component
Connectivity
OAM
LTE Broadcast Network Components
Integrating eMBMS in MCOP

- Simple architecture with neutral open APIs and open source SDK
- Easily build applications for first responders
  - With real mission-critical features
  - With insured interoperability
  - That follow 3GPP standards
- Reduce integration burden
  - Different mission-critical applications
  - Different LTE/eMBMS chipsets
  - Different and changing intermediate Android layers and APIs
- Uncouple your business model as UE vendor from every specific MCPTT app
- Simply migrate your applications to MC UEs supporting MCOP integration API => off-the-shelf eMBMS capabilities
Get involved
Get involved

Demo APP  3\textsuperscript{rd} Party App

MCOP Unified Open Application API

MCOP Open Source SDK

MCOP Integration API

OS + HARDWARE PLATFORM

Live Testing Platform
Come to our DEMO!!

Wanna know more?

- Whole ecosystem (on site testbed)
  - LTE + IMS + MCPTT AS Rel13/Rel14 + MCOP UEs
- e2e MC grade
  - eMBMS
  - MC-QCIs
  - SIM based authentication
- Real time traces 3GPP Rel13+ compliant
  - Rel12, Aligned, Ready

MCOP project
Are you a developer?

★ Hands on training with MCOP core developers and MCPTT experts

★ Hackathon
  – Build your MCPTT app during PSCR’18

★ Full MC eMBMS+IMS+LTE+MCPTT in a box live testbed available

★ MC devices available

MCOP project
Are you a PSO member?

- Check Technology
- Design your own GUI
  - User experience + tailored design
- ASK us for a mockup-> real APP!!!!
**Fully 3GPP compliant**

**Ask us to show the traces!!!**

– Including eMBMS/MC-QCIs/CSC operations!!!
Mission
Critical
Open
Platform

WE WANT YOUR FEEDBACK

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