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Experimenting with Flexible D2D Communications in Current and Future LTE networks:

A D2D Radio Technology Primer & Software Modem Implementation

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Presented by:

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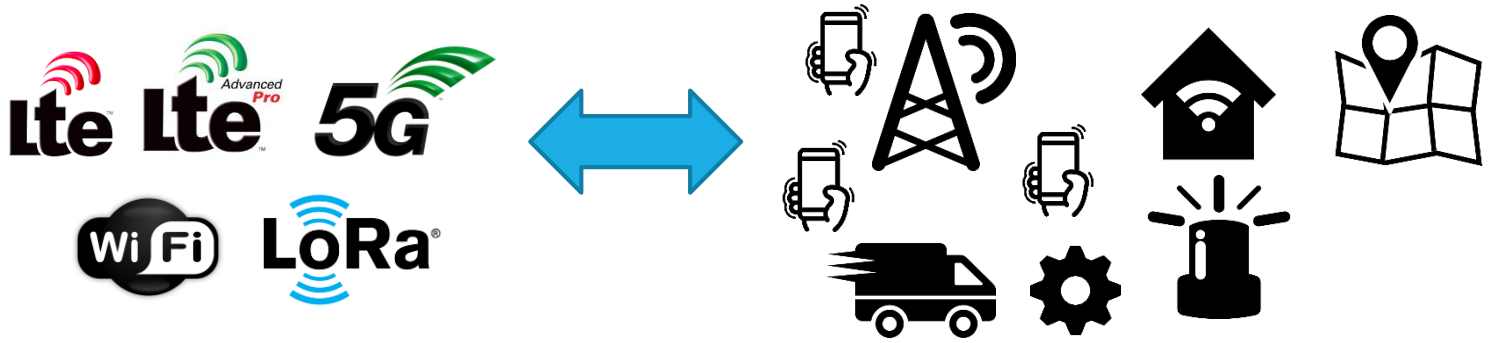
Part of the presented activities have received funding from the European Union's Seventh Framework Programme, under grant agreement no 612050 (FLEX Project), in particular, FLEX Open Call 2 Project "FLEX-D: Experimenting with Flexible D2D communications Over LTE".

Outline

- Background
  - Feron Technologies Profile
  - Involvement in FLEX Project
- Introduction in 3GPP D2D Radio
- *lte-sidelink*: An Open MATLAB Library for LTE-D2D Radio
  - Features, Status
  - D2D Radio assessment experiments
- D2D Software modem prototype
  - Challenges, Status
  - Runtime benchmarking results
- Roadmap

Background

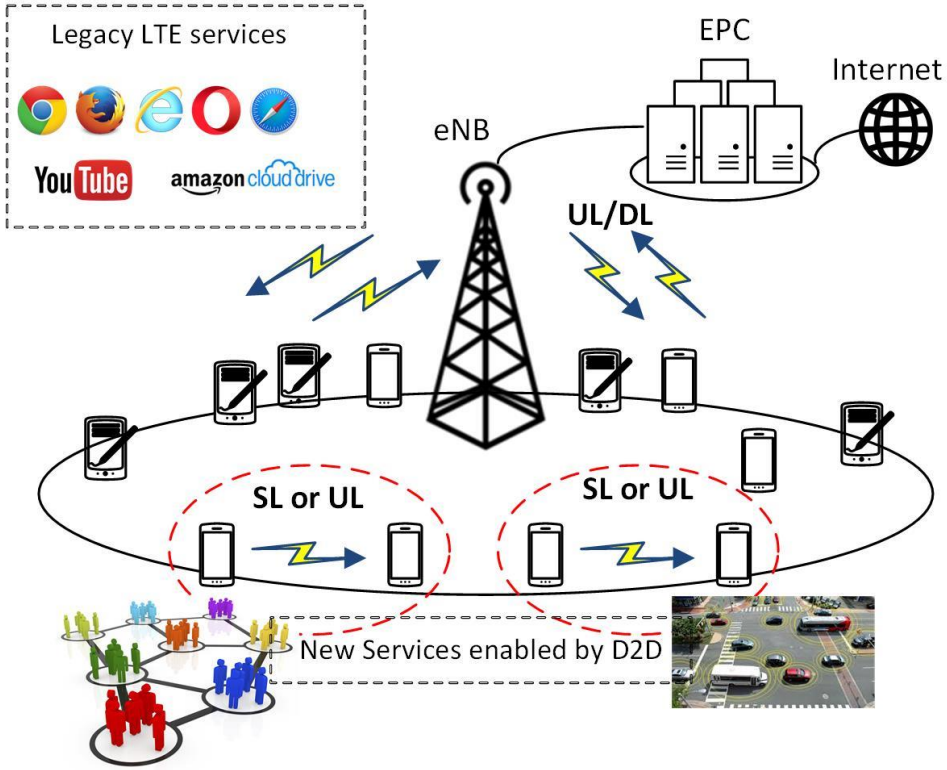
What We Do in Feron Technologies

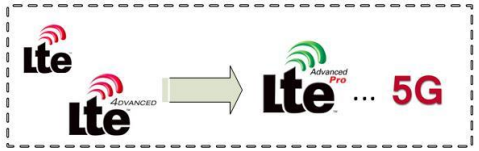


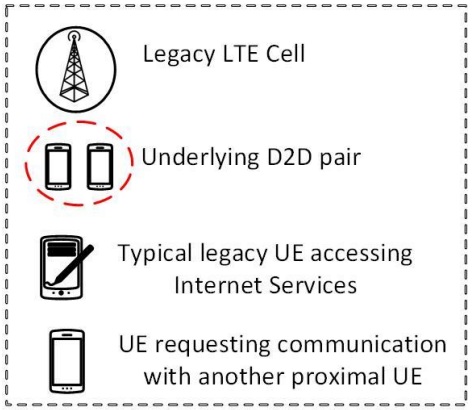
- **Software Libraries & Modems**
  - 3GPP LTE (Rel.8-10)
  - LTE D2D (Rel.12-13)
  - LTE V2V (Rel.14)
  - 802.11p/ITS-G5
  - Wi-MAX
  - ITU G.hn
  - NB-IOT (considered)
  - 5G/NR (considered)
- **Applications based on in-house software modems and SDR**
  - Passive Probe for Live 4G Mobile Data Networks Monitoring
  - ITS applications (e.g. platooning)
- **Applications based on COTS hw/sw**
  - Active Monitoring Probes for OTT services
  - IoT Platforms for Smart Sensing
  - First-Responder Systems

Involvement in FLEX

"FLEX-D" Open Call 2 Project







D2D introduction benefits

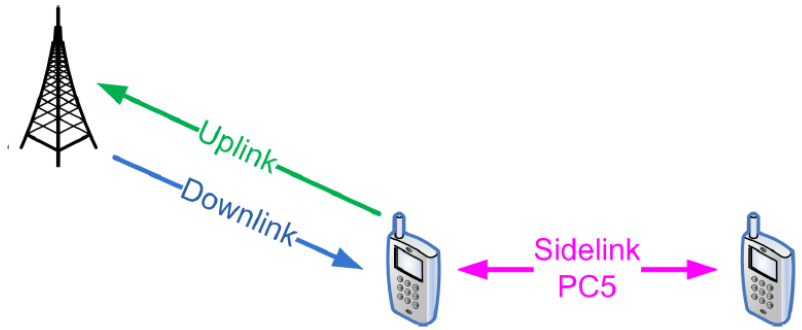
- UE experience (proximity)
- Latency (V2X)
- Legacy LTE offloading

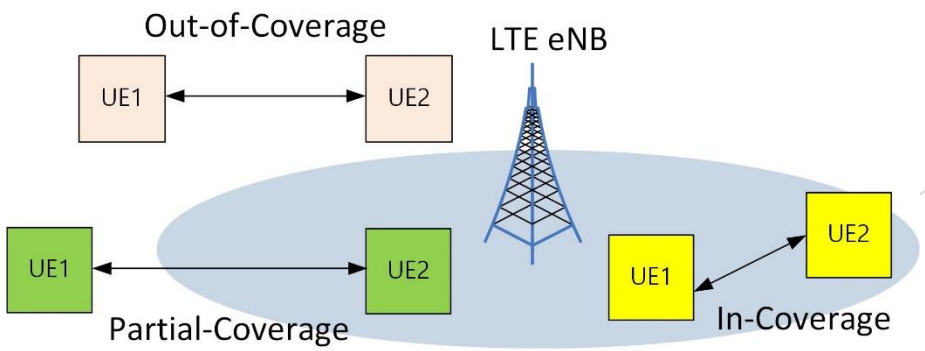
D2D Coexistence With Legacy LTE?

D2D Radio Introduction

History

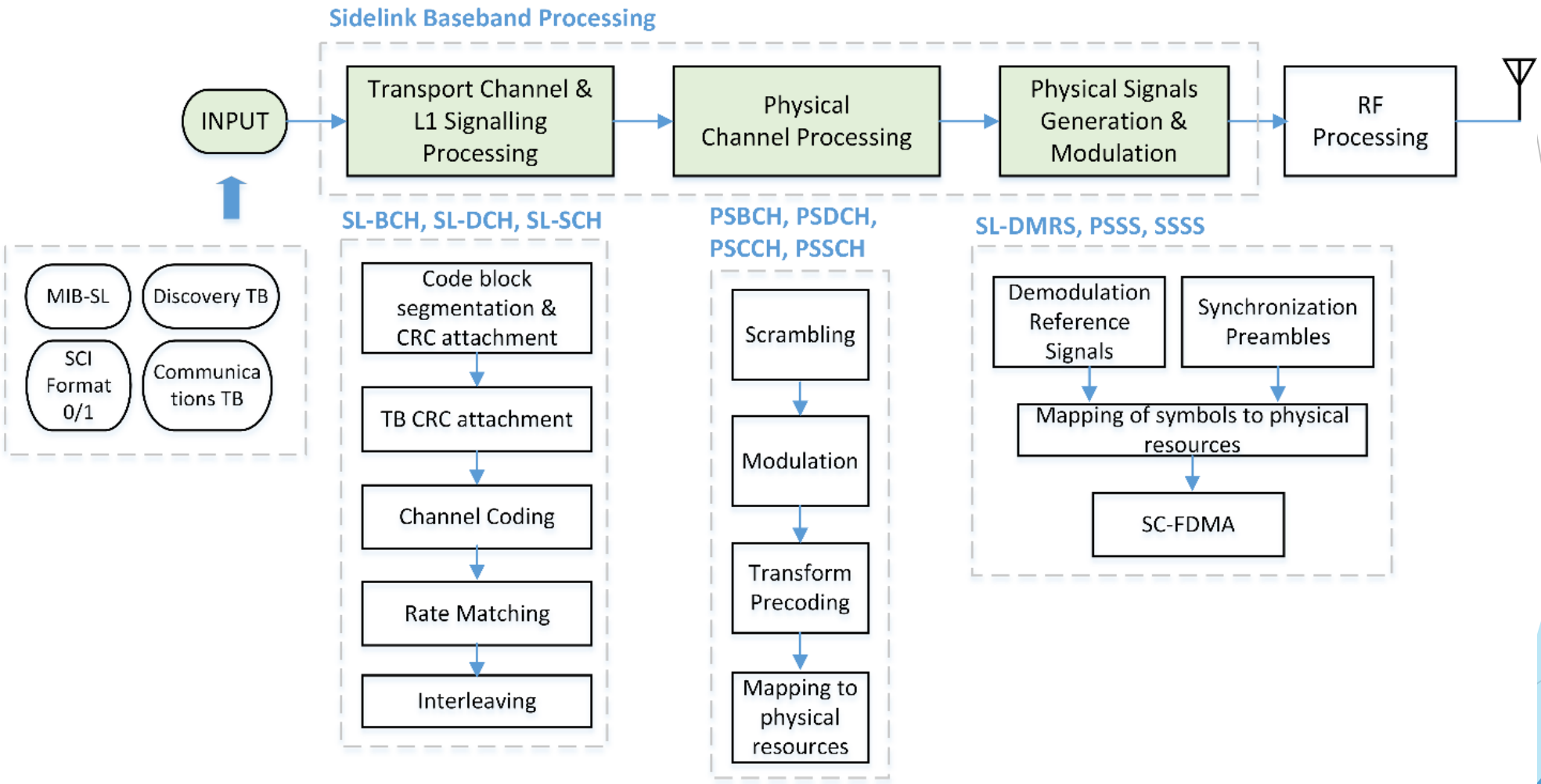
- Introduced in **LTE Rel.12** through the "ProSe" Work Item (majority of work done in RAN1 2013-14 meetings)
- Main Motivation behind D2D → **Public Safety** (primary) + **Consumer** (secondary)
- Operation Modes: **Discovery** & **Communication**
- eD2D in **LTE Rel.13** (advanced public safety)
- D2D enhancements for **V2X** in **LTE Rel.14** and **wearables** in **Rel.15**
- Sidelink is considered a critical mode for LTE-Evolution & 5G/NR (**Rel.15+**)





** Figures taken from Rohde & Schwarz White Paper "Device to Device Communication in 3GPP"*

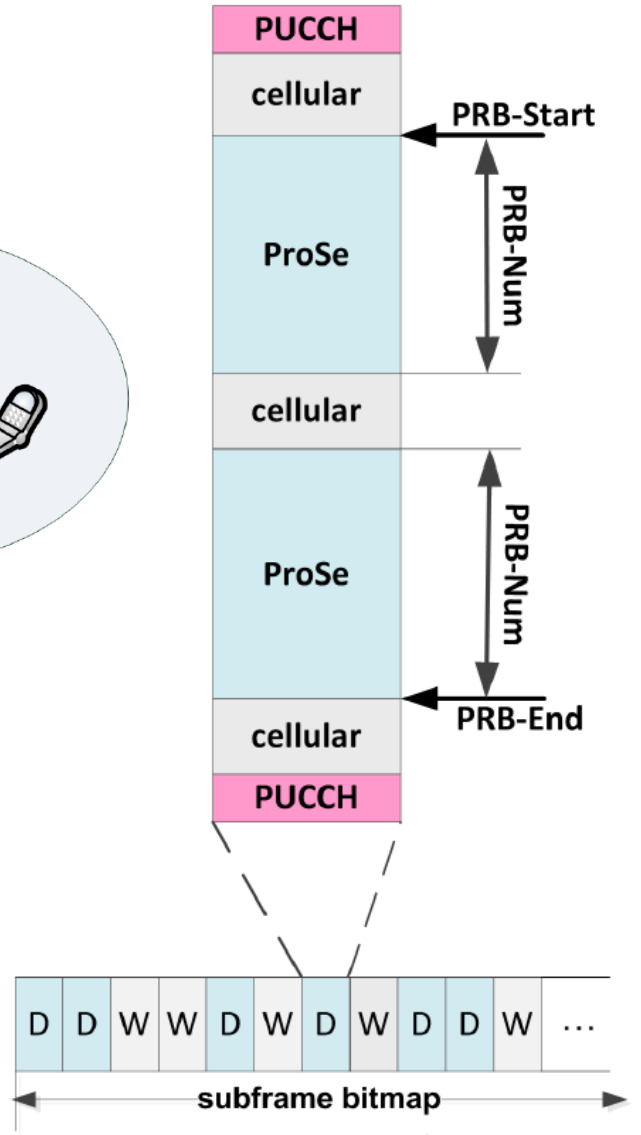
Sidelink L1 Design



Sidelink Resource Allocation

Sidelink-Uplink Coordination
- *Sidelink subframe pools*
- *Sidelink PRB pools*

Intra-Sidelink Resource Management
Time & Frequency Resources per sidelink UE



** Figures taken from Rohde & Schwarz White Paper "Device to Device Communication in 3GPP"*

Contributions (I):
An Open Software Library in MATLAB

“lte-sidelink”

- A software library developed in MATLAB, that implements the most important functionalities of the 3GPP LTE sidelink interface.
- Freely and openly available in : https://github.com/feron-tech/lte-sidelink
- Licensed under the GNU Affero General Public License v3.0.

Potential Usage Scenarios

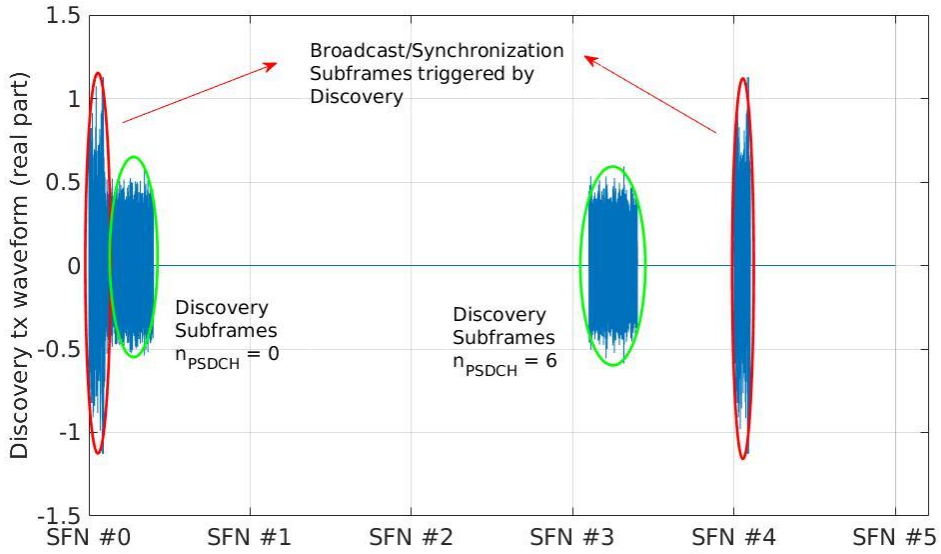
- An LTE sidelink waveform generator
- An end-to-end sidelink link-level simulator
- A core component of a sidelink system-level simulator
- A platform for testing new resource allocation/scheduling algorithms for D2D/V2V
- A tool to experiment with live sidelink signals with the help of SDR boards

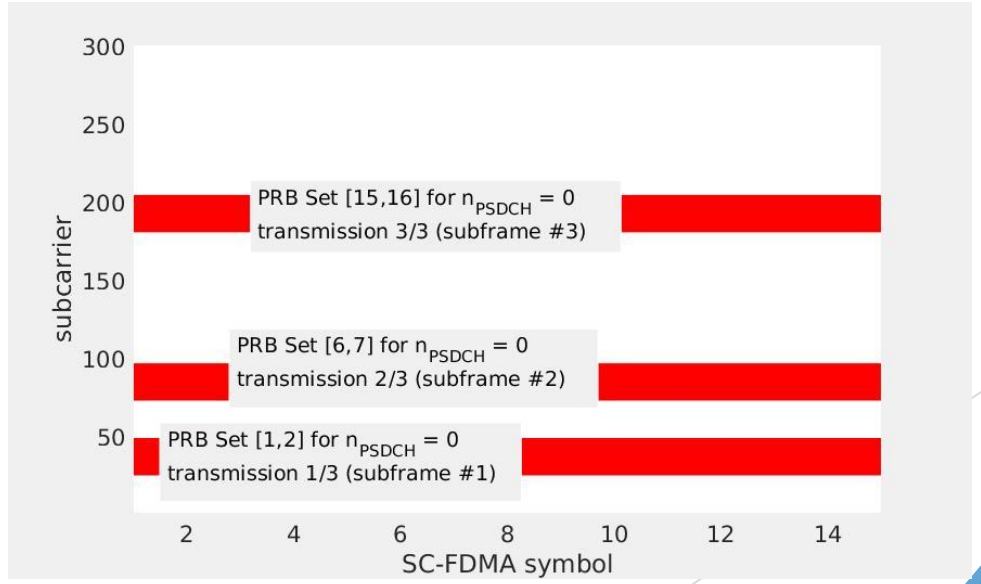
Main Features (v1.2.0)

- Sidelink air-interface compliant with
  - "Standard" D2D based on Rel.12 and Rel.13
  - D2D tweaks for V2V communications based on Rel.14
- Sidelink modes
  - Broadcast
  - Discovery
  - Communication
- Synchronization preambles & pilots (PSSS, SSSS, DMRSs) construction & recovery
- Subframe creation, loading and time-domain signal transformation
- Complete receiver processing functionality for sidelink-compliant waveforms
  - time-synchronization
  - frequency-offset estimation and compensation
  - channel estimation and equalization
  - signal demodulation/decoding
- Example scripts for configuring and running end-to-end broadcast, discovery, and D2D/V2X communication transceiver simulation scenarios.

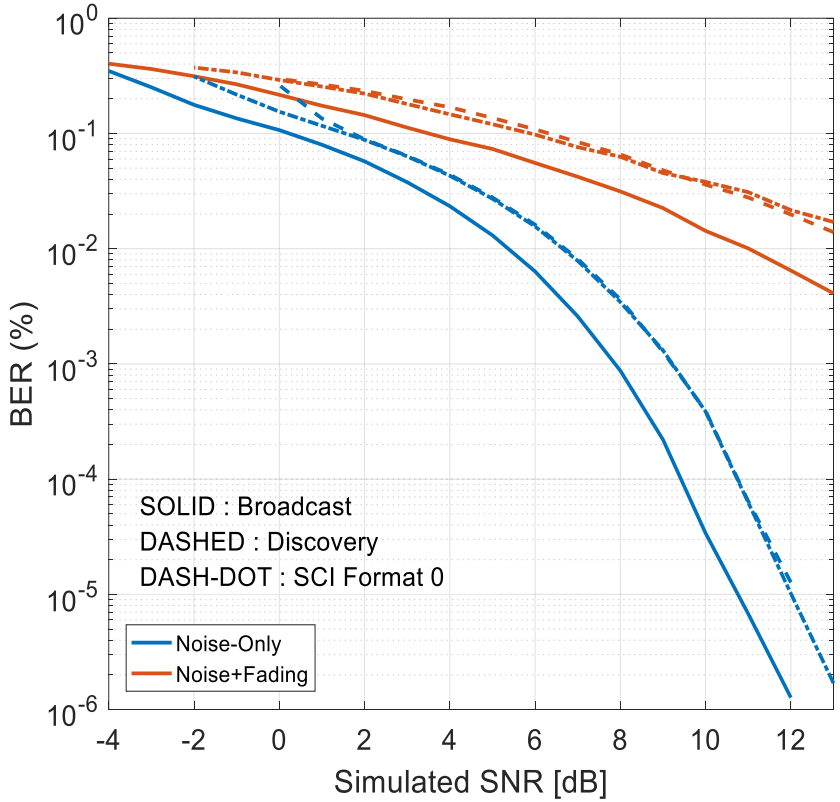
Example D2D Discovery Software Library Configuration

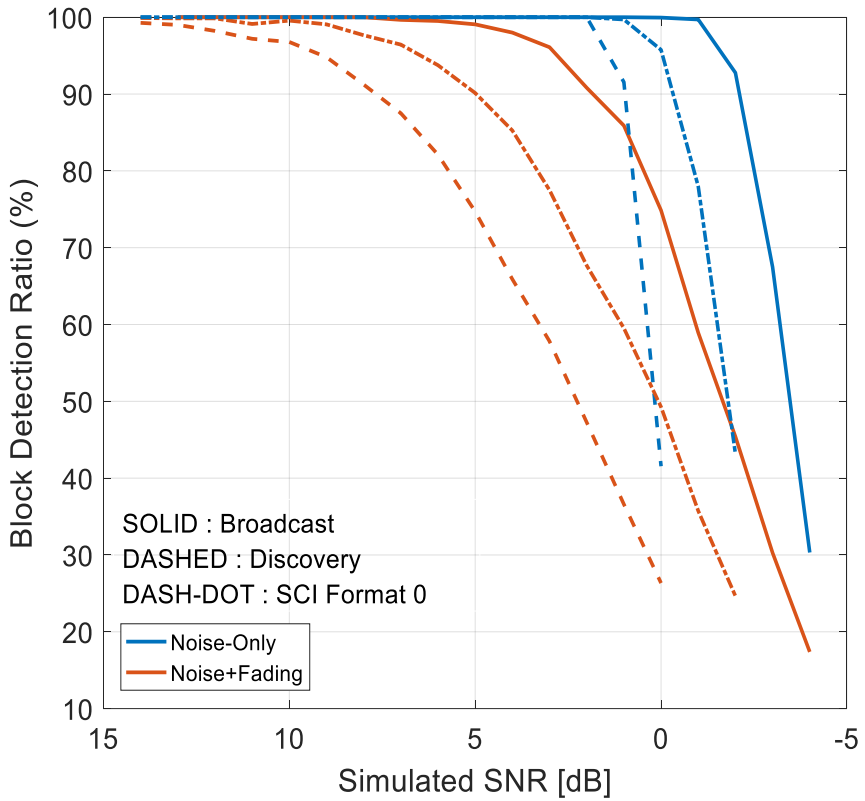
```
%% SL Basic Operation Parameters
slBaseConfig = struct;
slBaseConfig.NSLID = 301;
slBaseConfig.NSLRB = 25;
%% DISCOVERY Configuration
discConfig = struct;
discConfig.cp_Len_r12           = 'Normal';
discConfig.offsetIndicator_r12 = 40;
discConfig.discPeriod_r12       = 32;
discConfig.subframeBitmap_r12   = …
repmat([0;1;0;1;0],8,1);
discConfig.numRepetition_r12    = 5;
discConfig.prb_Start_r12        = 5;
discConfig.prb_End_r12          = 19;
discConfig.prb_Num_r12          = 4;
discConfig.numRetx_r12          = 3;
discConfig.discType             = 'Type1';
if isequal(discConfig.discType,'Type1')
    ueConfig.n_PSDCHs = [0; 19];
elseif isequal(discConfig.discType,'Type2B')
    ueConfig.discPRB_Index       = 1;
    ueConfig.discSF_Index        = 1;
    ueConfig.a_r12               = 1;
    ueConfig.b_r12               = 1;
    ueConfig.c_r12               = 1;
end
syncConfig = struct;
syncConfig.networkControlledSyncTx = 1;
syncConfig.syncTxPeriodic          = 1;
syncConfig.syncOffsetIndicator     = 0;
```





Simulation-based evaluation of Sidelink PHY Modes





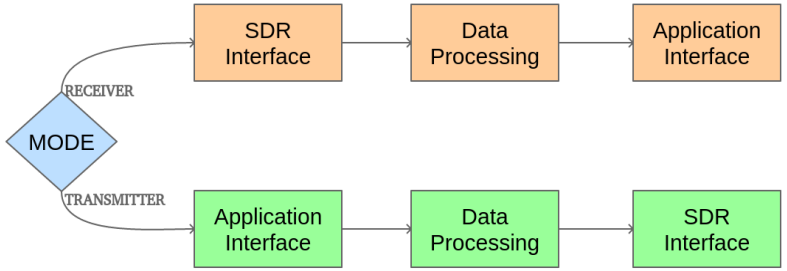
Contributions (II):
A real-time software modem prototype

Main Features

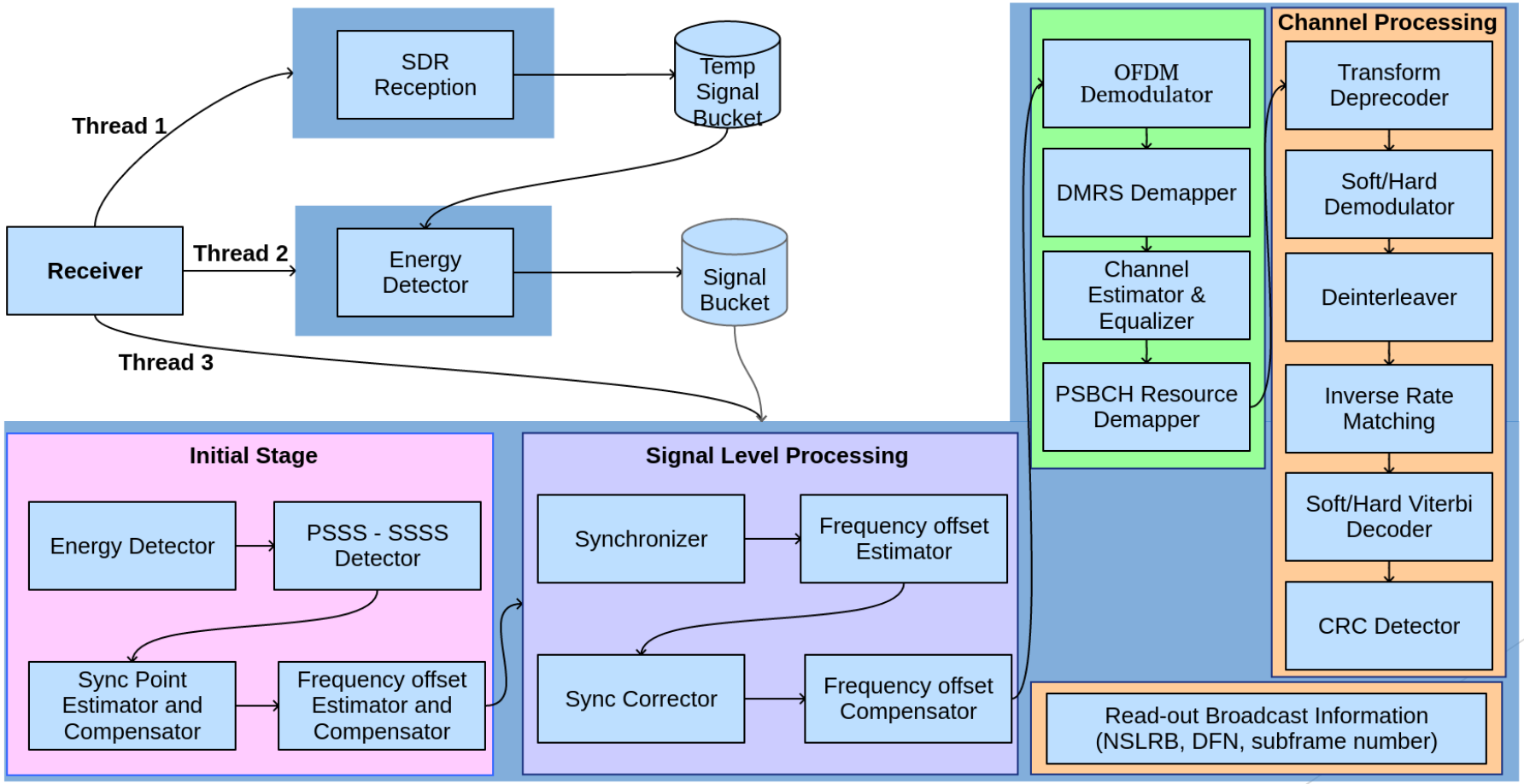



- Work in progress
- Implementation of a baseline D2D transceiver in C/C++
- Supports reference D2D channels/signals (broadcast/synchronization) and channels carrying information (discovery/communication)
- Fully configurable using configuration files
- Runs in Desktop and Single-board Hosts
- Interfaces with USRP boards for OTA transmission/reception
- Operates in real-time & offline modes
- Operation Demonstrated in the FIRE FLEX Platform
- Preparing a console application for announcing/monitoring messages using D2D

Modem Structure

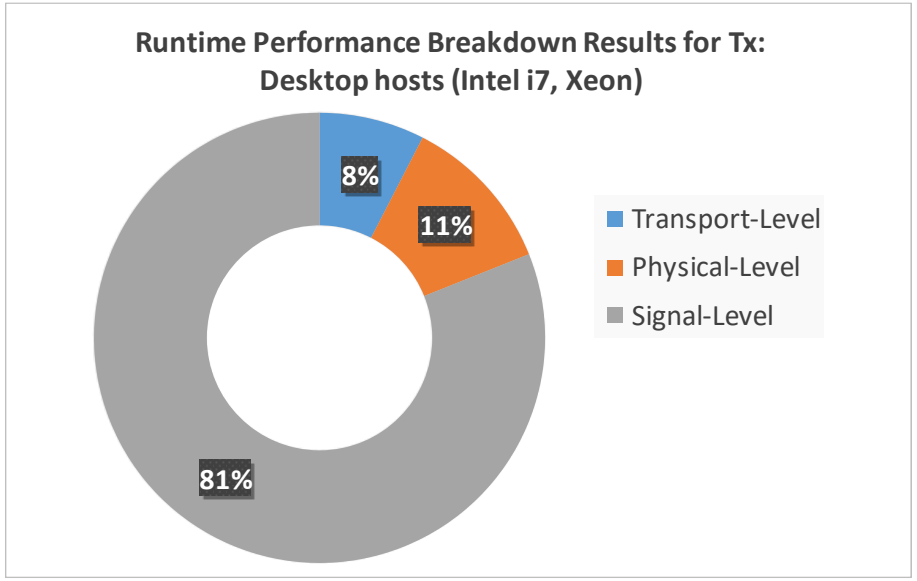


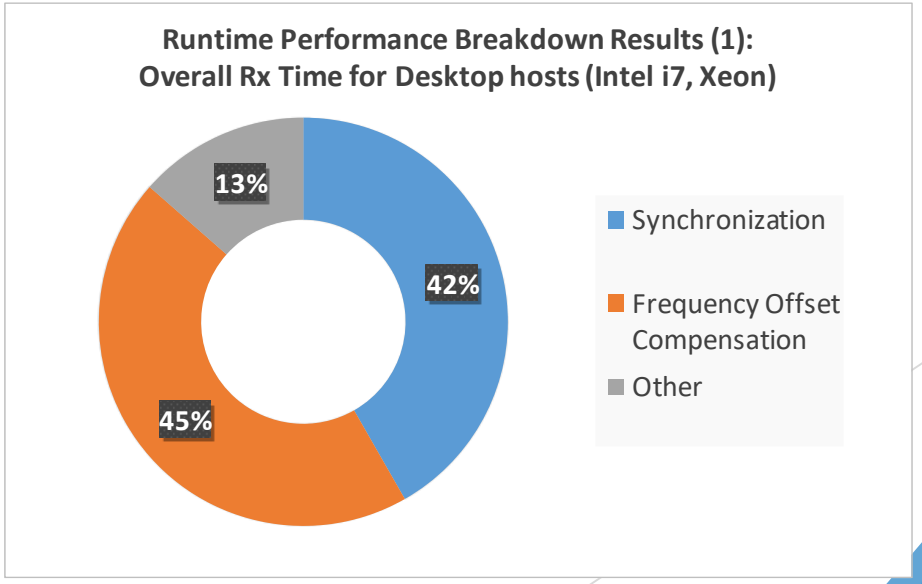
Sidelink Broadcast Receiver



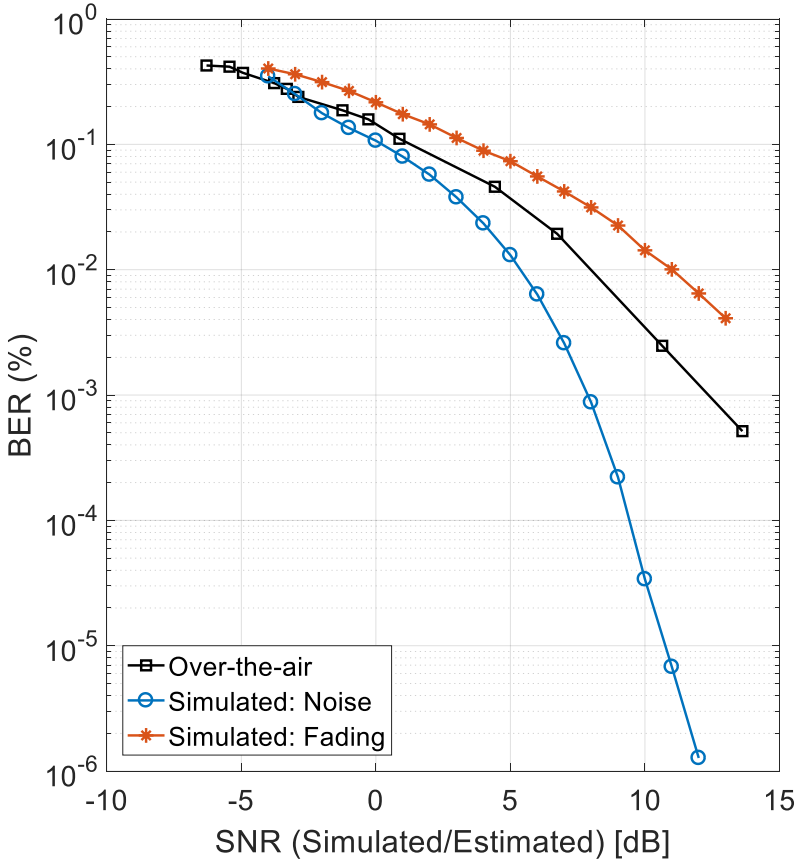
Runtime benchmarking initial results

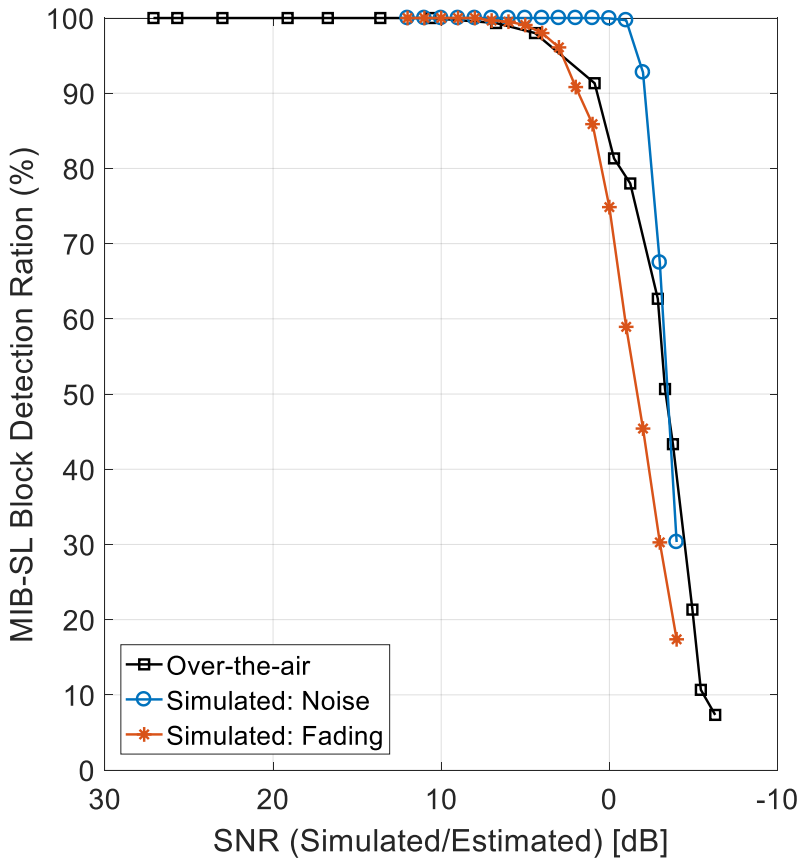
Platform Specifications					
Type	Desktop	Remote Node	Cloud VM	SBC	SBC
CPU model	Intel Core i7-4770K CPU	Intel Core i7-3770 CPU	Intel Xeon CPU E5-2673 v3	Intel Atom x5-Z8350	Intel Atom CPU E3826
CPU count/Cores/Threads Per Core	4/4/1	4/4/1	2/2/1	4/4/1	2/2/1
CPU frequency	3500 MHz	3400 MHz	2400 MHz	1440 MHz	1460 MHz
Cache	8 MB	8 MB	30 MB	1 MB	512k
RAM	16 GB	8 GB	4 GB	2 GB	2 GB
OS	Ubuntu Desktop 14.04	Ubuntu Server 14.04	Ubuntu Server 14.04	Ubuntu Server 14.04	Lubuntu
RECEIVER					
continuous operation stage (msec)	2.42	2.72	3.37	19.35	22.38
TRANSMITTER					
total time (msec)	0.14	0.14	0.19	1.15	1.49





Over-the-air Evaluation of Sidelink Broadcast Mode



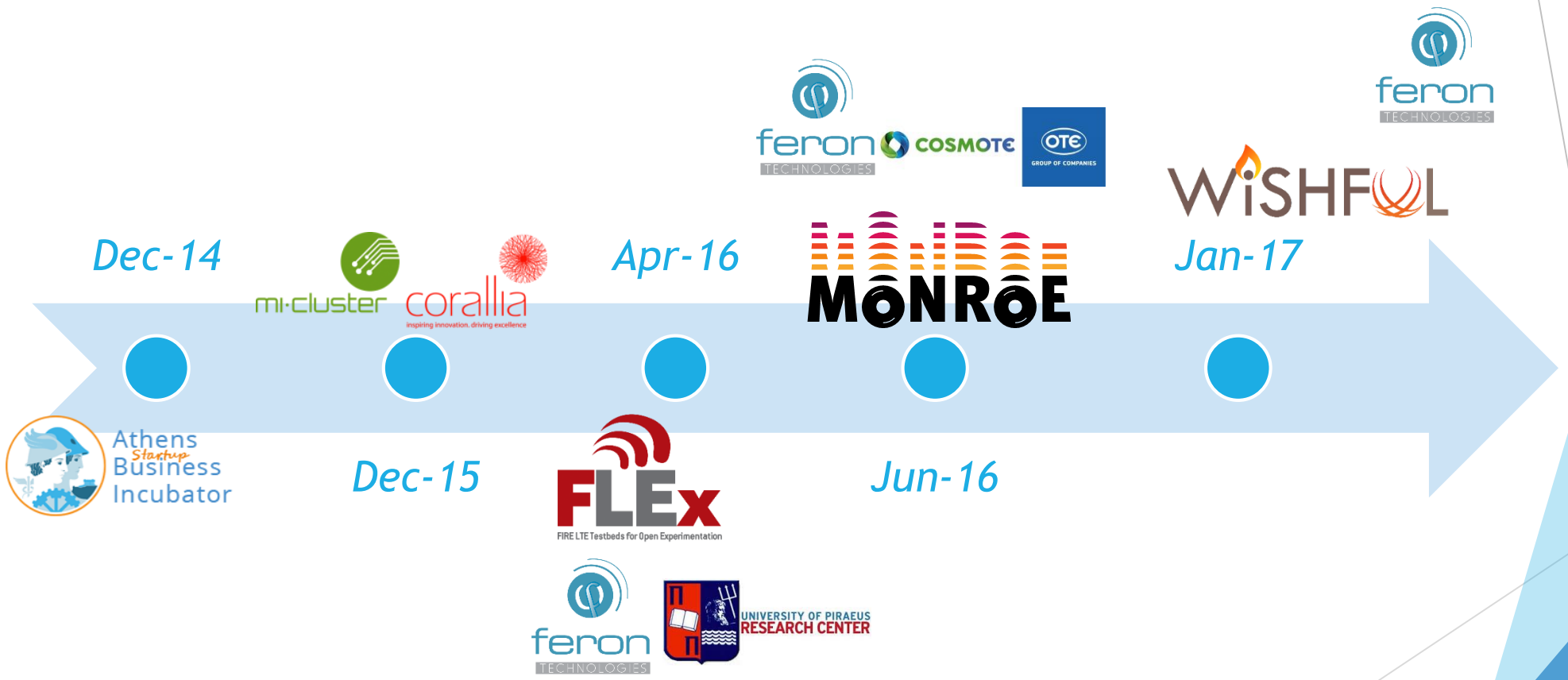


What's next

- Enhancements of **lte-sidelink library**
  - Incorporation of new features (Rel.14 and Rel.15)
  - Focus on emerging V2X use-case
- Extension of the **software modem prototype**
  - Runtime performance optimizations
  - Test in various host platforms and SDR boards
  - Full support of discovery & communication modes
- Build **applications**
  - Improve modem/application-layer interfacing
  - Real-world demonstration in vehicles, drones, etc.

Backup Slides

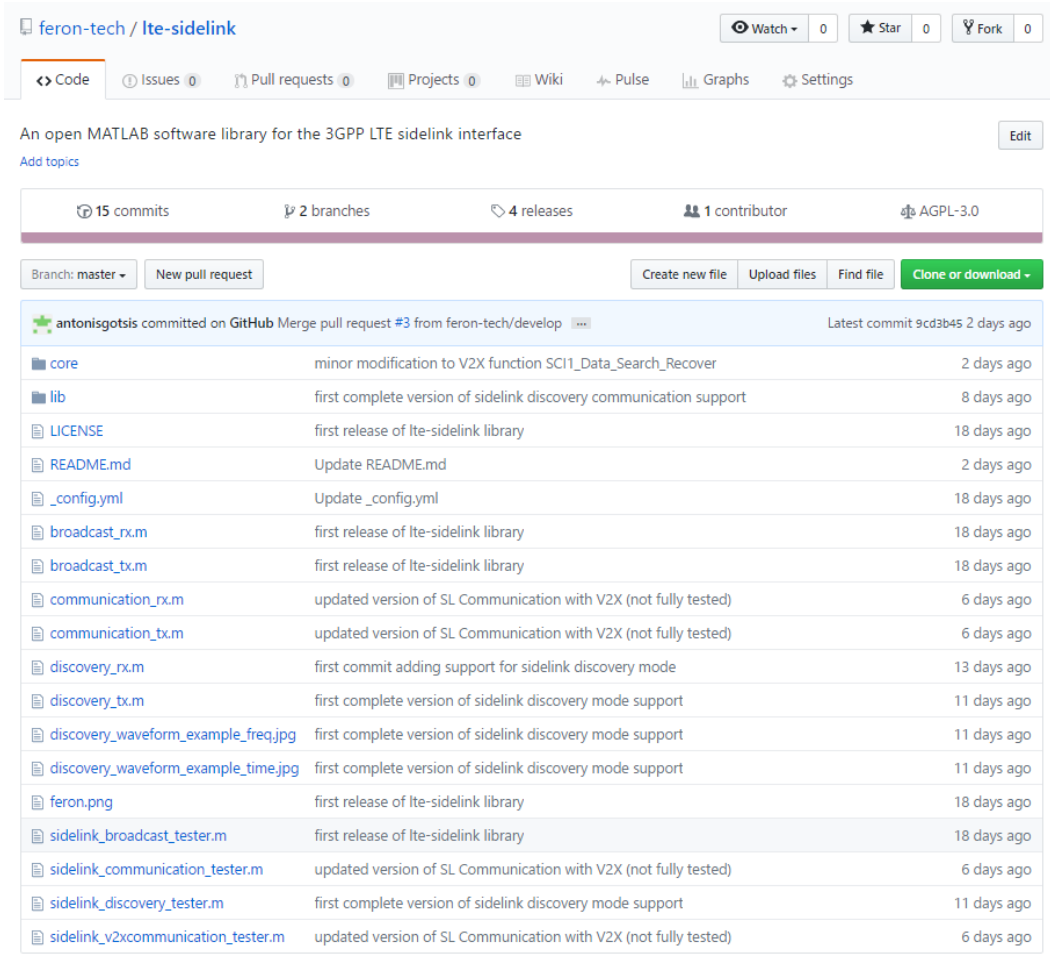
Feron Technologies Timeline



What is FLEX

- Extend FIRE facilities with LTE resources
- An open and highly configurable experimental facility that uses LTE resources
- Cost-effective experimentation with LTE resources
- Interaction of the user with real 4G networks
- Pave the way for 5G technologies
- Create the circumstances for innovation in the field of 4G network
- FLEX's experimentation environment features include both open source platforms and configurable commercial equipment that span macro-cell, pico-cell and small-cell setups.
- Attract research groups to conduct sophisticated experiments, test innovative usages or provide functional extensions of LTE testbeds.

lte-sidelink in Github



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An open MATLAB software library for the 3GPP LTE sidelink interface

Edit

Add topics

15 commits | 2 branches | 4 releases | 1 contributor | AGPL-3.0

Branch: master | New pull request | Create new file | Upload files | Find file | Clone or download

antonisgotsis committed on GitHub Merge pull request #3 from feron-tech/develop — Latest commit 9cd3b45 2 days ago

core	minor modification to V2X function SCI1_Data_Search_Recover	2 days ago
lib	first complete version of sidelink discovery communication support	8 days ago
LICENSE	first release of lte-sidelink library	18 days ago
README.md	Update README.md	2 days ago
_config.yml	Update _config.yml	18 days ago
broadcast_rx.m	first release of lte-sidelink library	18 days ago
broadcast_tx.m	first release of lte-sidelink library	18 days ago
communication_rx.m	updated version of SL Communication with V2X (not fully tested)	6 days ago
communication_tx.m	updated version of SL Communication with V2X (not fully tested)	6 days ago
discovery_rx.m	first commit adding support for sidelink discovery mode	13 days ago
discovery_tx.m	first complete version of sidelink discovery mode support	11 days ago
discovery_waveform_example_freq.jpg	first complete version of sidelink discovery mode support	11 days ago
discovery_waveform_example_time.jpg	first complete version of sidelink discovery mode support	11 days ago
feron.png	first release of lte-sidelink library	18 days ago
sidelink_broadcast_tester.m	first release of lte-sidelink library	18 days ago
sidelink_communication_tester.m	updated version of SL Communication with V2X (not fully tested)	6 days ago
sidelink_discovery_tester.m	first complete version of sidelink discovery mode support	11 days ago
sidelink_v2xcommunication_tester.m	updated version of SL Communication with V2X (not fully tested)	6 days ago

Acknowledgement

Part of the activities leading to this library received funding from the European Union's Seventh Framework Programme under grant agreement no 612050, "FLEX Project", and in particular FLEX Open Call 2 Project "FLEX-D: Experimenting with Flexible D2D communications Over LTE". FLEX-D is carried out by Feron Technologies and University of Piraeus Research Centre, Greece.

Welcome to the *lte-sidelink* project page

lte-sidelink is an open software library developed in MATLAB by Feron Technologies P.C., that implements the most important functionalities of the 3GPP LTE sidelink interface.

Introduction

Sidelink is a new LTE feature introduced in 3GPP Release 12 aiming at enabling device-to-device (**D2D**) communications within legacy cellular-based LTE radio access networks. Sidelink has been enriched in Releases 13 and 14 with various features. D2D is applicable to public safety and commercial communication use-cases, and recently (Rel.14) to vehicle-to-vehicle (**V2V**) scenarios. In legacy uplink/downlink, two UEs communicate through the Uu interface and data are always traversing the LTE eNB. Differently, sidelink enables the direct communication between proximal UEs using the newly defined PC5 interface, and data does not need to traverse the eNB. Services provided in this way are often called "Proximity Services" (or ProSe) and the UEs suppporting this feature "ProSe"-enabled UEs.

The library provides an (almost) complete implementation of the sidelink physical signals, physical channels and transport layer functionalities described in the 3GPP standard. In addition it provides the neccessary receiver processing functionalities for generating and/or recovering a real sidelink signal which is either simulated/emulated or sent over the air and captured from an SDR board. The code is highly-modular and documented in order to be easily understood and further extended.

The library has many usages. Typical use-case examples are the following:

- LTE sidelink waveform generator.
- End-to-end sidelink link-level simulator.
- Core component of a sidelink system-level simulator.
- Platform for testing new resource allocation/scheduling algorithms for D2D/V2V communications.
- Tool to experiment with live standard-compliant sidelink signals with the help of SDR boards.

The following 3GPP standard documents have been used and referenced through the code:

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