Aalto University
School of Electrical Engineering

USRP-based resource management research platform

EECRT Project

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End-to-end Cognitive Radio Testbed (EECRT)

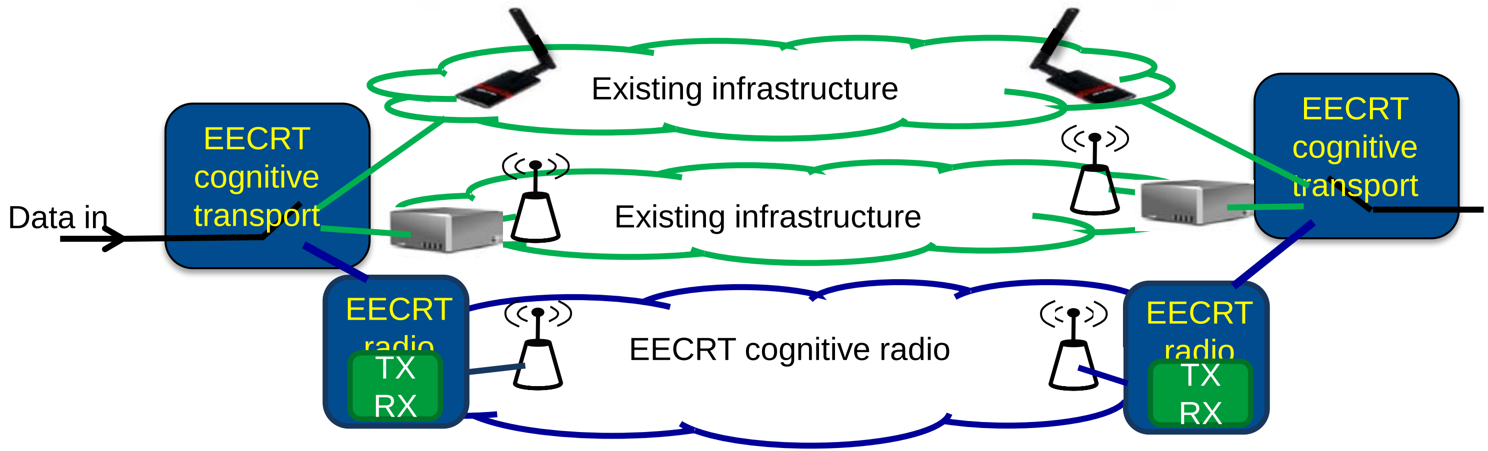
- Project creates a “living lab” cognitive radio testbed
  - Living lab: Transmission of the real application data over the air interface
  - Testbed for a large network
- The testbed is intended for investigating
  - Dynamic Spectrum & Bandwidth Management (DSM) and Cognitive Radio Resource Management (CRRM) algorithms
  - Radio usage business models
  - Radio interface selection algorithms with the focus on end-to-end performance
  - Cognitive radio algorithms for physical layer usage

EECRT project structure

- Network techno economics
  - Evaluation of configurations of plausible value networks
  - Provides the cognitive transport layer with parameters that have to be controlled
- Cognitive transport
  - Control of data transport route selection
  - Optimizing the end-to-end performance
    - Client driven radio interface selection, algorithms implementation
- Cognitive radio physical layer
  - Provides access to the physical layer parameters that can be controlled
  - Physical layer algorithms selection
  - Algorithms implementation in USRP hardware platform
    - Provides the reconfigurable platform for data transmission over physical interface

EECRT testbed

- Cognitive transport engine selects among different radio access networks
  - Selection is based on the end to end performance
  - Radio access is selected (for instance) from different mobile operations WLAN or EECRT cognitive radio.
- EECRT radio provide software defined radio that can be tuned to frequencies: 0.4 – 2.2 GHz.



Rationale for the RRM testbed

- The need of testbeds in network level research
  - In academy no easy access to large scale system test data
  - The system level studies mostly analytical
    - Model based
  - Theoretical analysis and the ”real needs” are diverging
    - Most analysis are not concerned with ”real” problems in large networks
- Testbed in RRM research
  - Radio control can use very many parameters
    - Which ones are best to control?
  - Extremely many proposed algorithms
    - Most studies contain simplifications, are they reasonable?
  - Practical implementation helps to identify most relevant approaches

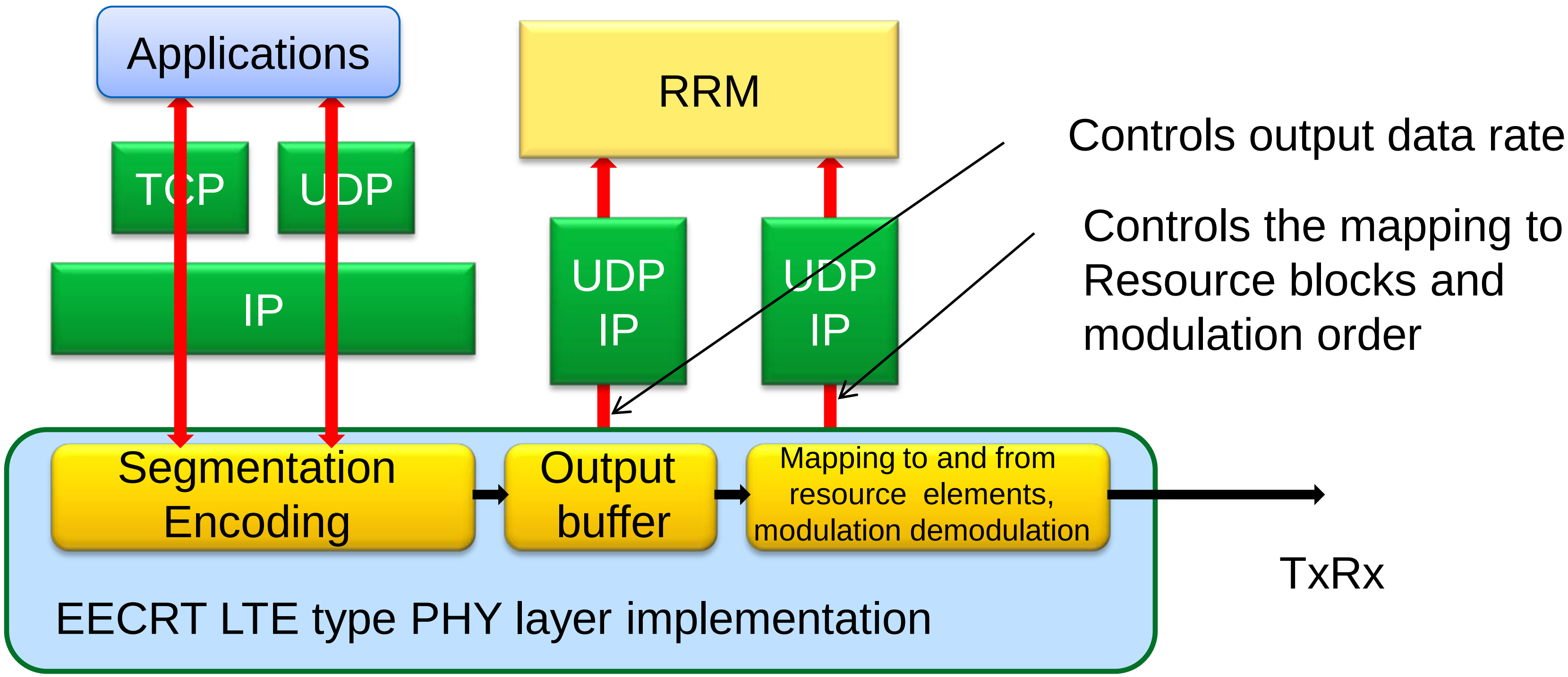
Properties of the RRM testbed

- RRM controls the interference
  - Multi-user, multi-network control
- Comapred to TxRx processing the RRM algorithms run at relatively low speed
  - The RRM only controls transmission parameters
    - Tx power, resource blocks (channel) allocation, data rates, …
- Split the control function and TxRx chain
  - The testbed provides physical layer that can be configured by the RRM algorithms

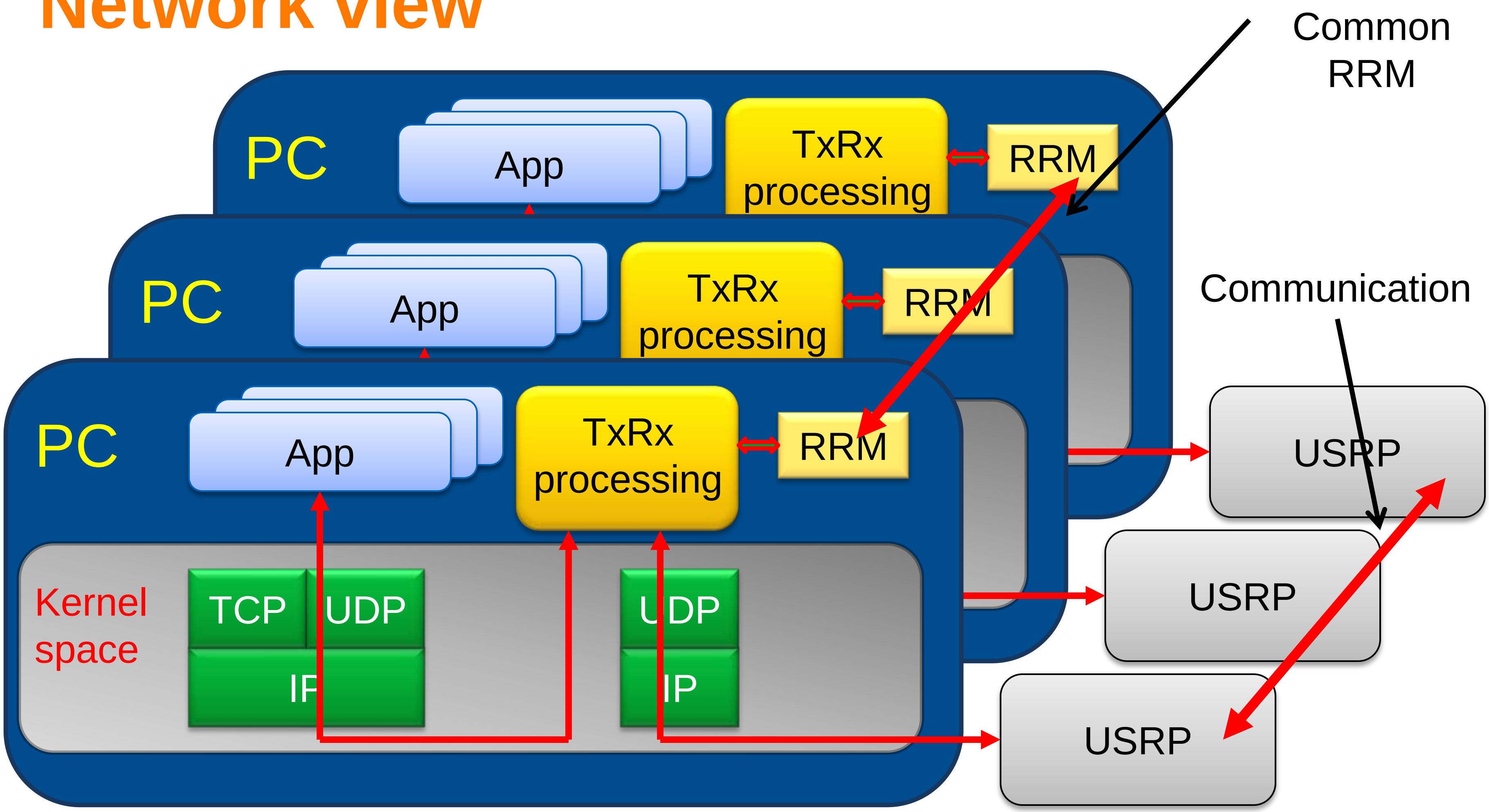
System design decisions

- TxRx is able transmit “real” application data over radio interface
  - Receives IP traffic and sends it over air
  - To be similar to LTE as possible
  - By removing USRP it can operate as the system simulator
- Separation of the resource management and TxRx chain
  - RRM does not updated in every frame
- RRM controls the TxRx chain over UDP socket
  - TxRx chain is seen by RRM as the monolithic module which parameters can be controlled
- Distributed RRM
  - Each entity has its own RRM
  - RRM operations can be coordinated over network

Platform view



Network view



EECRT radio development platform

- 18 USRP boxes
  - 4 *   (USRP 2 + xcvr2450)
  - 12 * (N200 + SBX daughter boards)
  - 2 * (N210 + SBX daughter boards)
- Programming platform
  - GNU radio
    - Copies data between the modules
  - Matlab
    - The UHD interface is not well supported
  - OpenBTS
    - GSM specific
  - …
- C++ based implementation of TxRx module
  - LTE frame type PHY layer implementation
  - The module is seen by RRM as one controllable block
  - The TxRx is split into multiple threads
- RRM is currently implemented in Matlab

PHY level

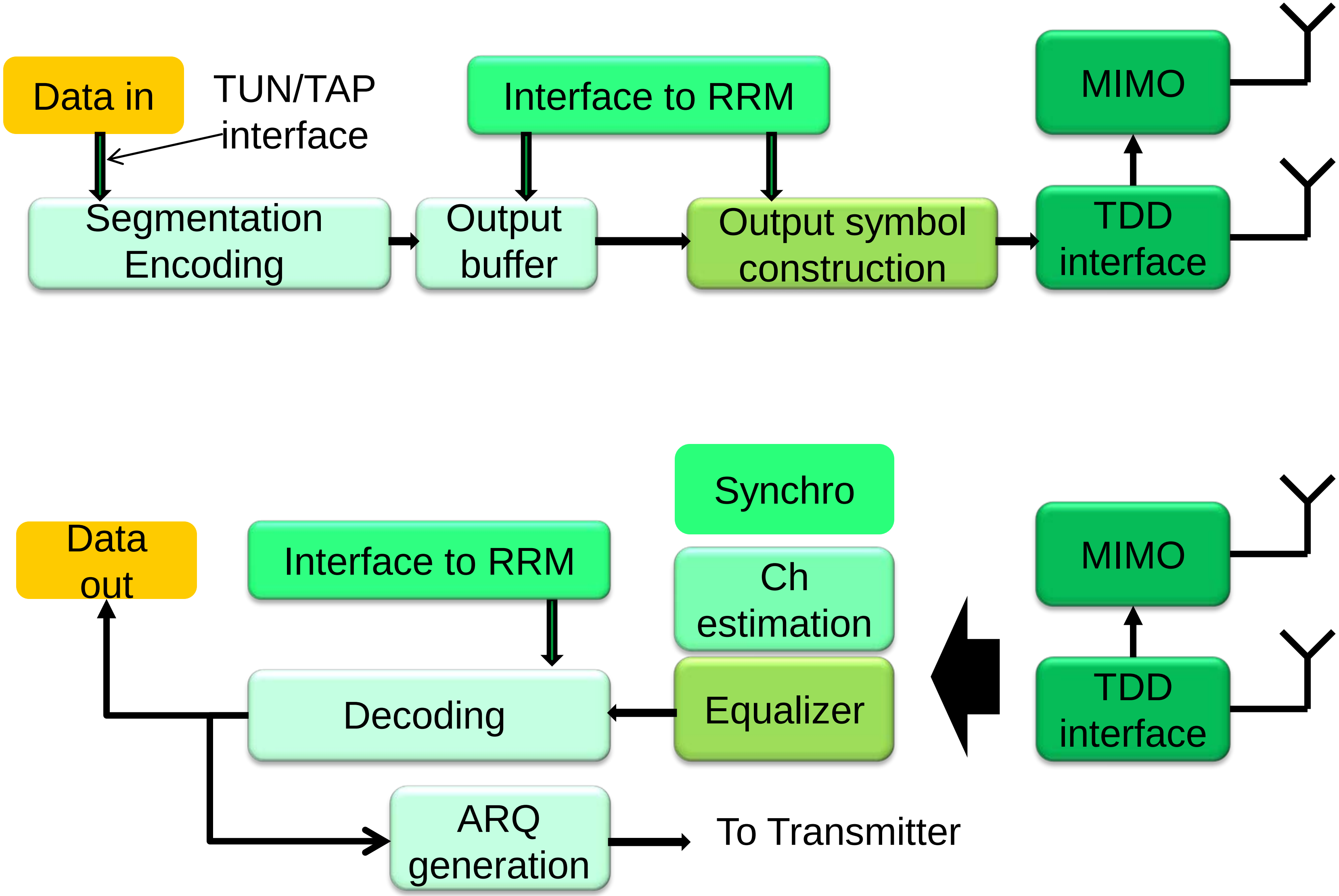
- LTE type frame structure
  - Bit exact LTE synchronization and pilot allocation
- TDD type transmission
- 2 antennas MIMO
- LTE bit exact segmentation and encoding
  - Turbo coding
- Modules implemented in C++
  - For testing purposes all modules first implemented in Matlab
    - Implement algorithm in C++ and make MEX file that is called from Matlab
  - Testing: comparison of the Matlab and C++ implementations

The PHY level, current state

– Individual modules implemeted

– Each module is used also for independent research
  - MIMO – polarization based transmission
  - TDD – self organizing network synchronization
  - Transmitter/Receiver – interference cancellation in overlay transmission

– Target to integrate the whole TxRx chain for September 2012


Data in
TUN/TAP interface
Interface to RRM
MIMO
Segmentation Encoding
Output buffer
Output symbol construction
TDD interface
Synchro
Data out
Interface to RRM
Ch estimation
MIMO
Decoding
Equalizer
TDD interface
ARQ generation
To Transmitter

Performance of USRP

RF daughterboards

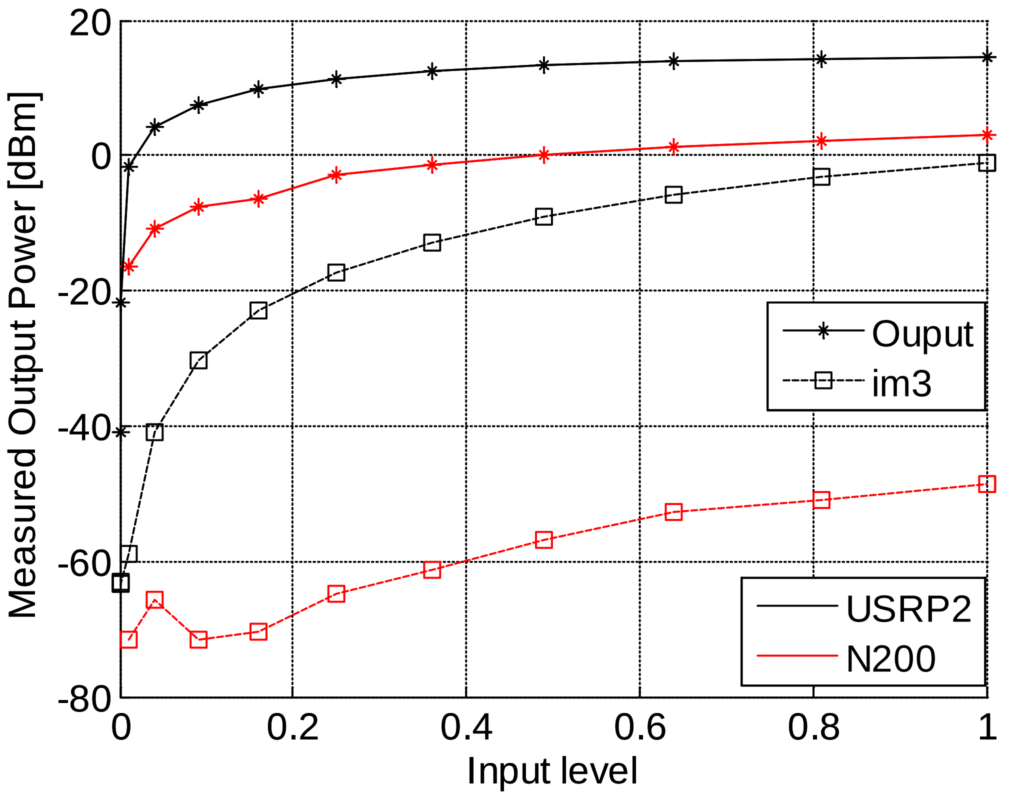
xcvr2450

- 2.4-2.5 GHz and 4.9-5.9 GHz
  - Half Duplex Only
- TX output power
  - 100 mW
- Single synthesizer shared between Rx and Tx
- RSSI measurement that can be read from software

SBX

- 400 MHz to 4.4 GHz
- TX output power
  - 16 to 20 dBm,
  - with 32dB of power control range
- Dual synthesizers for independent Tx and Rx
- NF
  - < 3GHz: 5-7 dB
  - 3 – 4 GHz: 7 -10 dB
  - 4 – 4.4 GHz: 10 – 13 dB

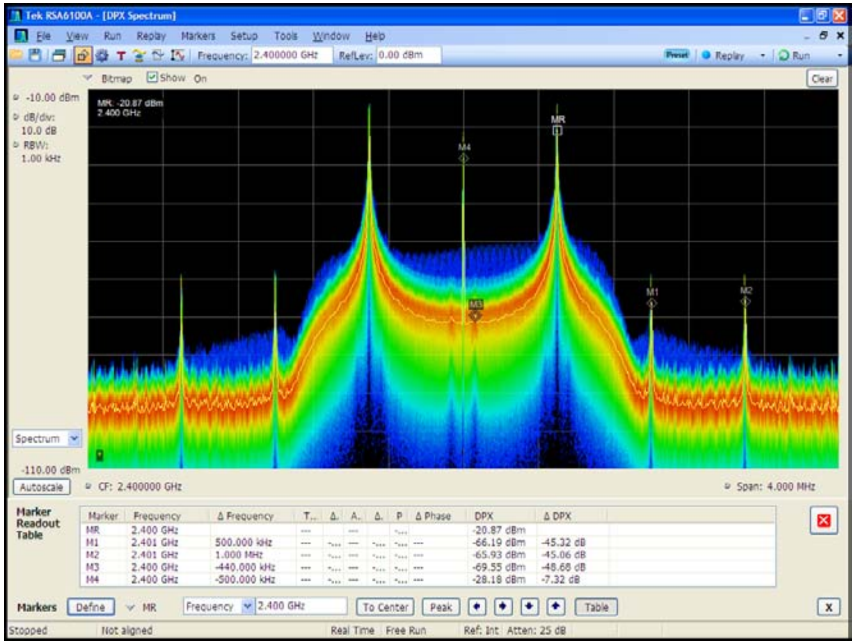
Devices linearity

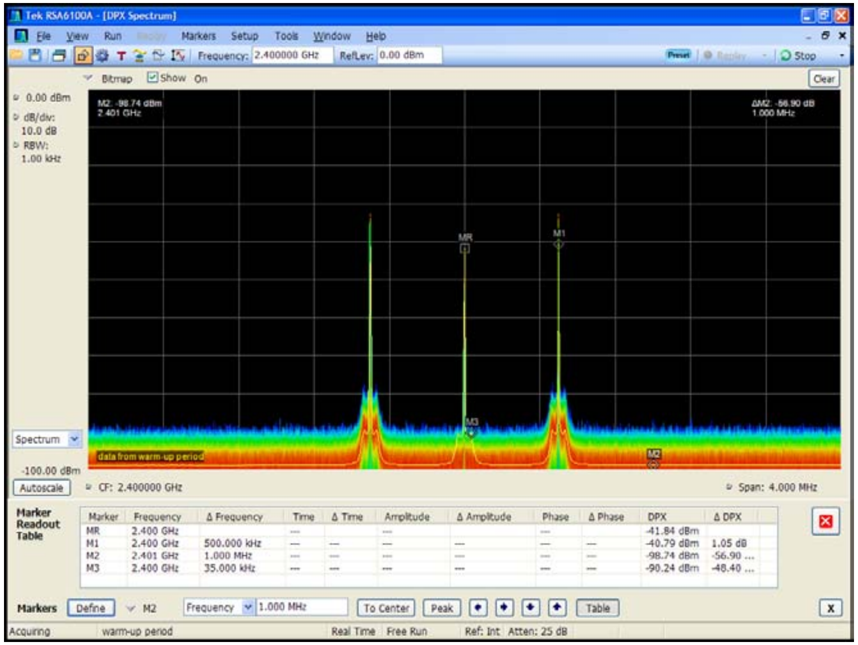


Linearity II input 0.1

USRP2

N200





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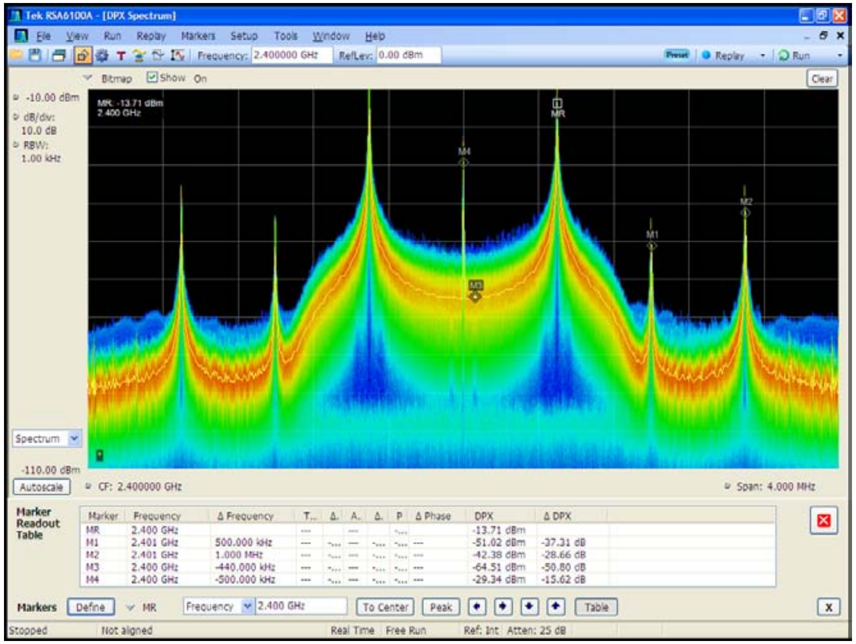
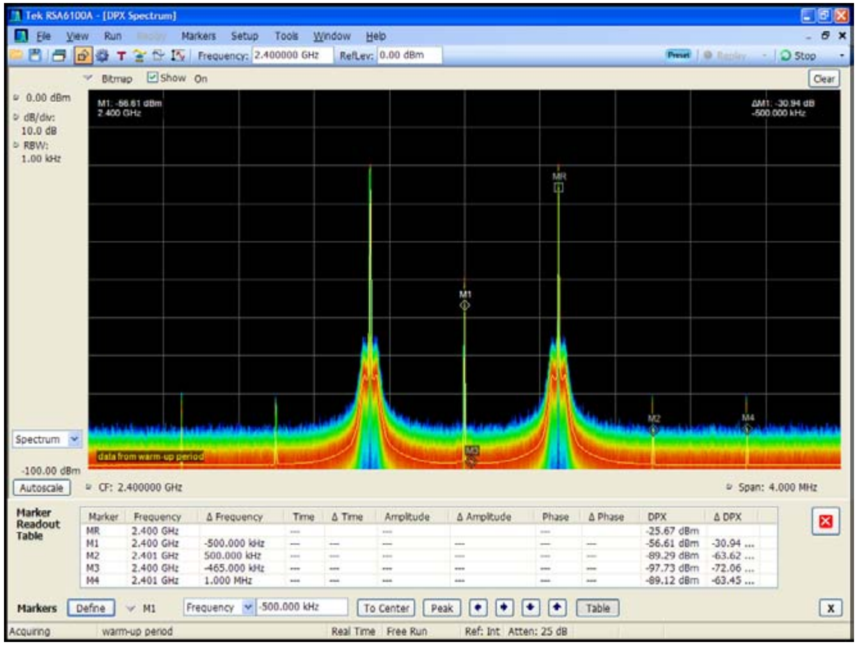
Linearity II input 0.5

USRP2



N200



TDD transmission

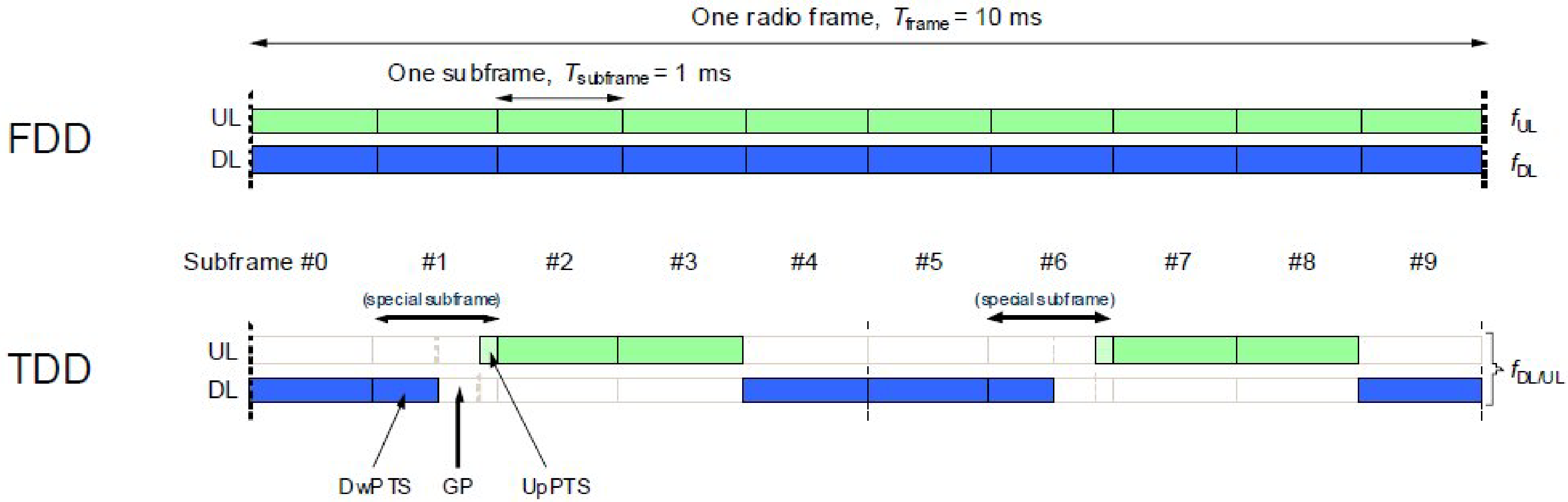
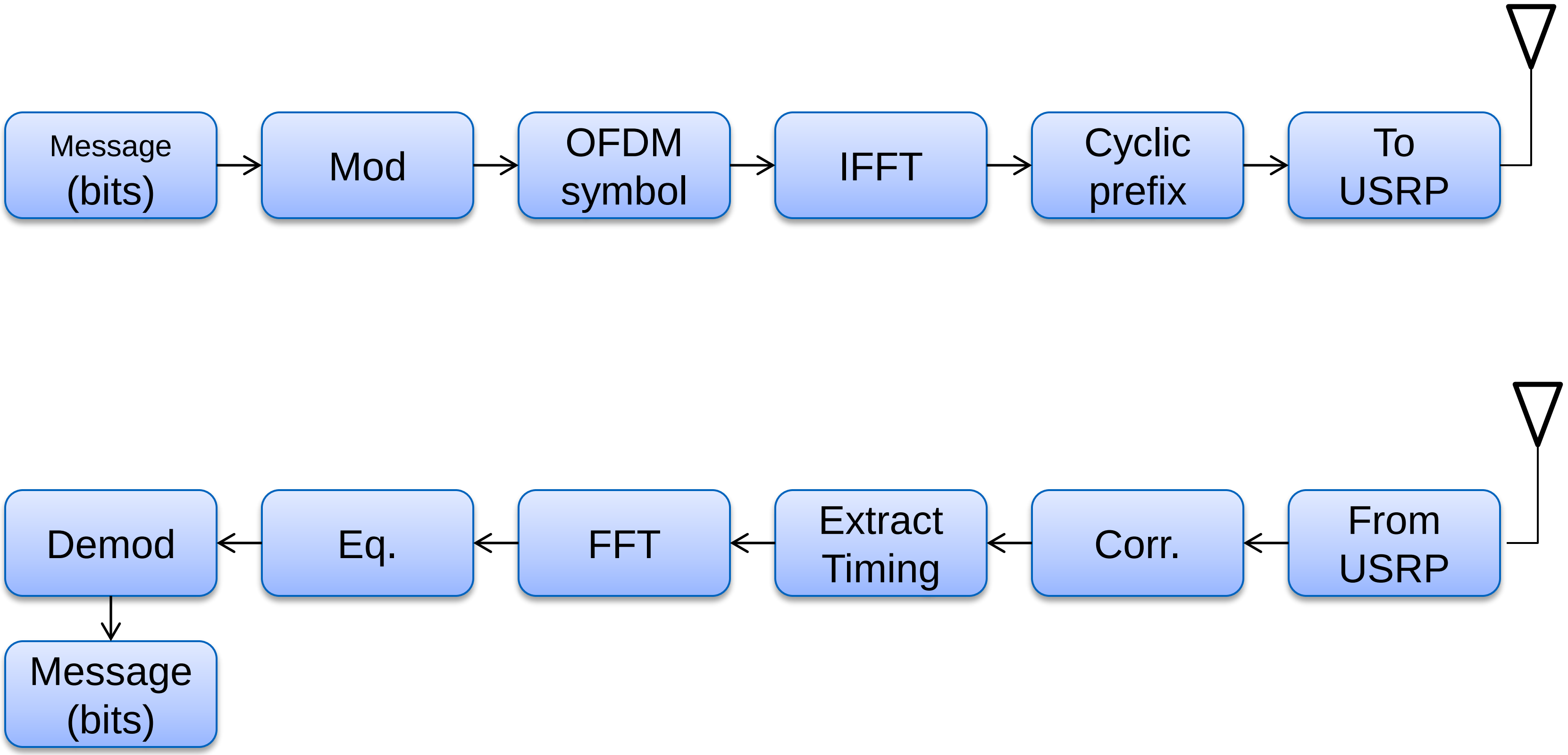


Figure 3. LTE Frame Structure

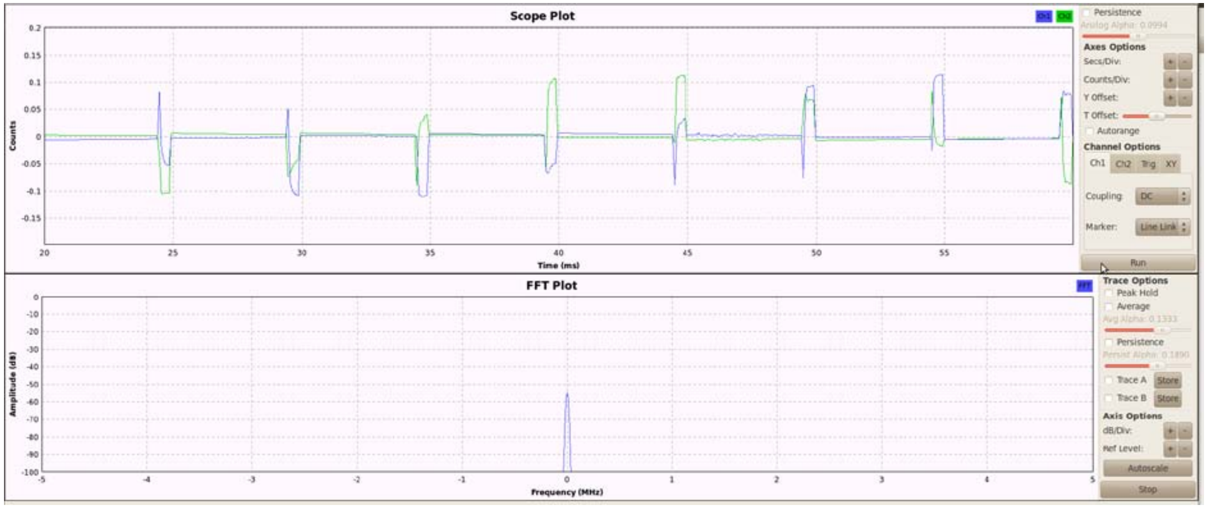
TDD TxRx



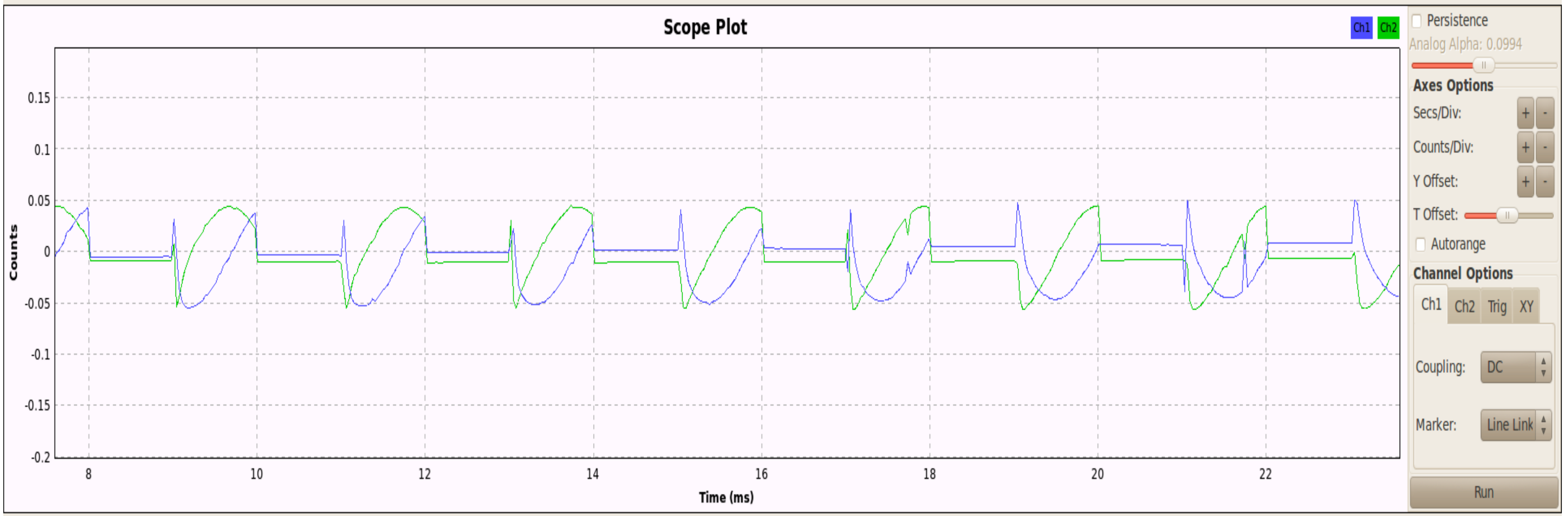
Message
(bits)
Mod
OFDM
symbol
IFFT
Cyclic
prefix
To
USRP
Demod
Eq.
FFT
Extract
Timing
Corr.
From
USRP
Message
(bits)

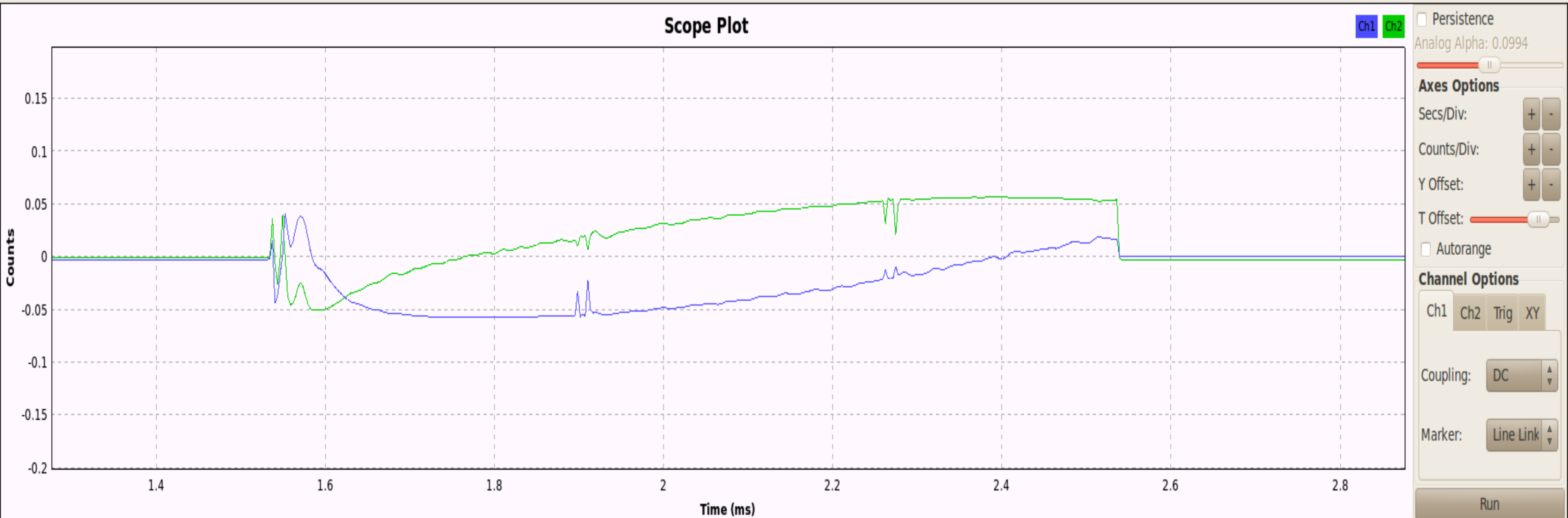
Tx Bursts Demo

- Constant complex data is transmitted as bursts of 0.5 ms duration with 5ms sec delay between the bursts
- Currently state
  - Implementation of the transmission synchronization between two transmitters
  - Control of the timing meta parameters

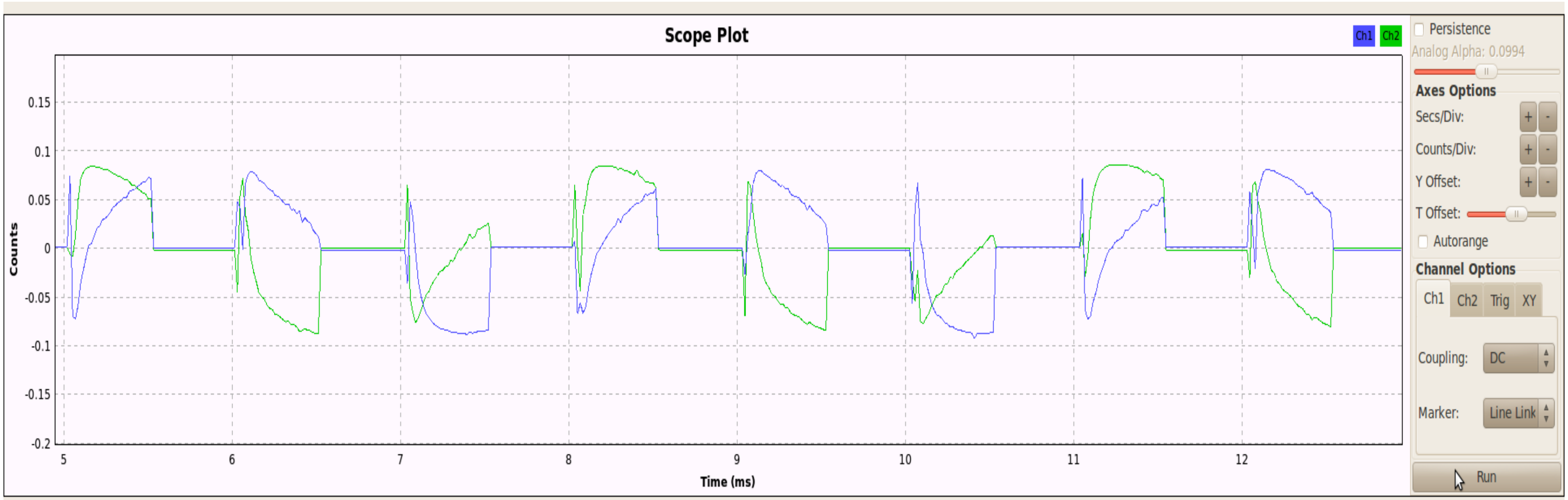


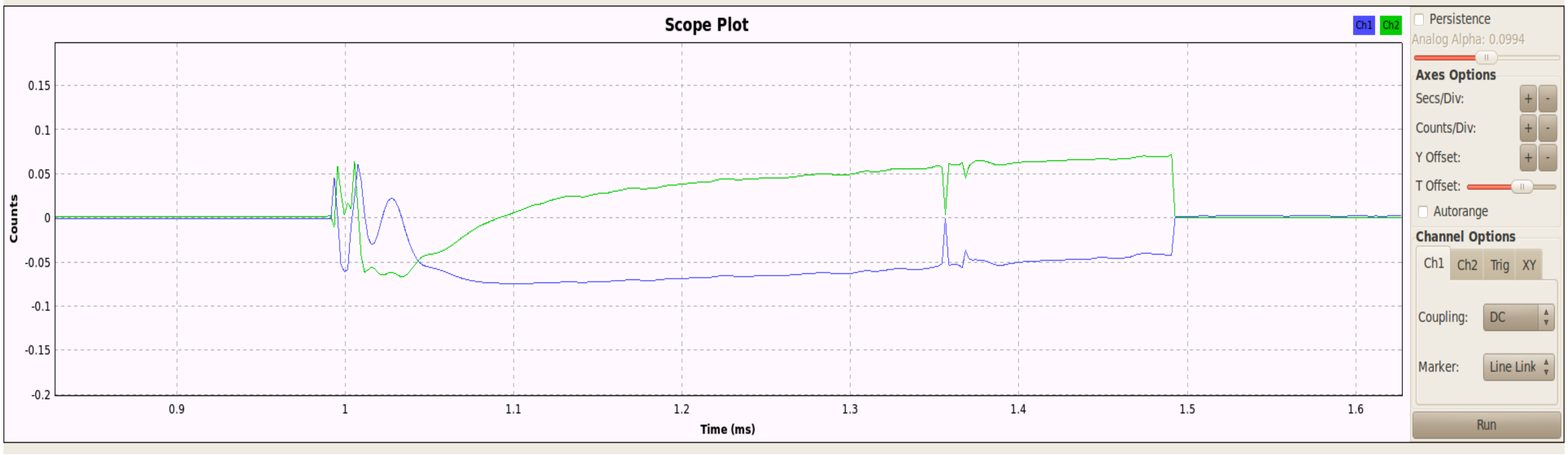
Burst of duration 1 ms . Delay between bursts 1





Burst duration 0.5 ms. Delay between bursts 0.5 ms





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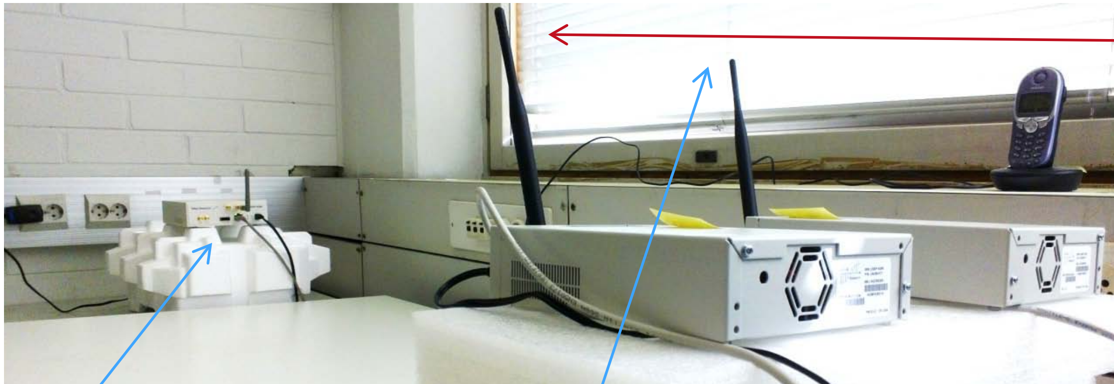
MIMO Test Setup

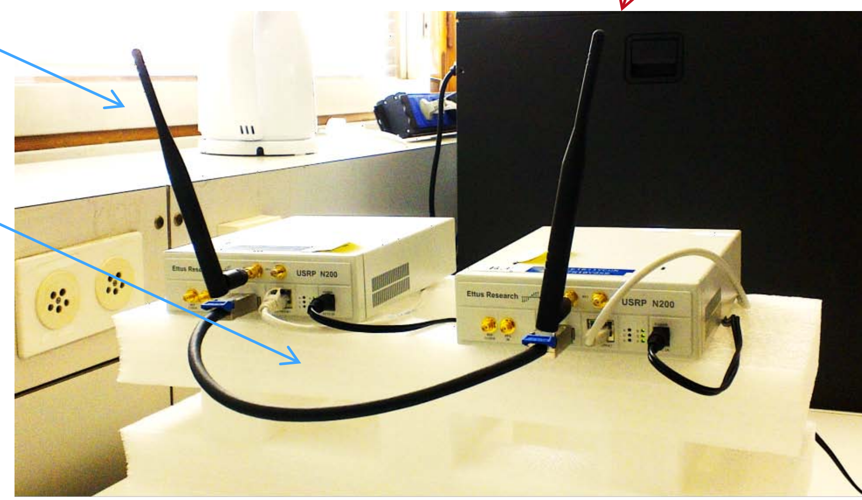


Tx antenna 2

Tx antenna 1

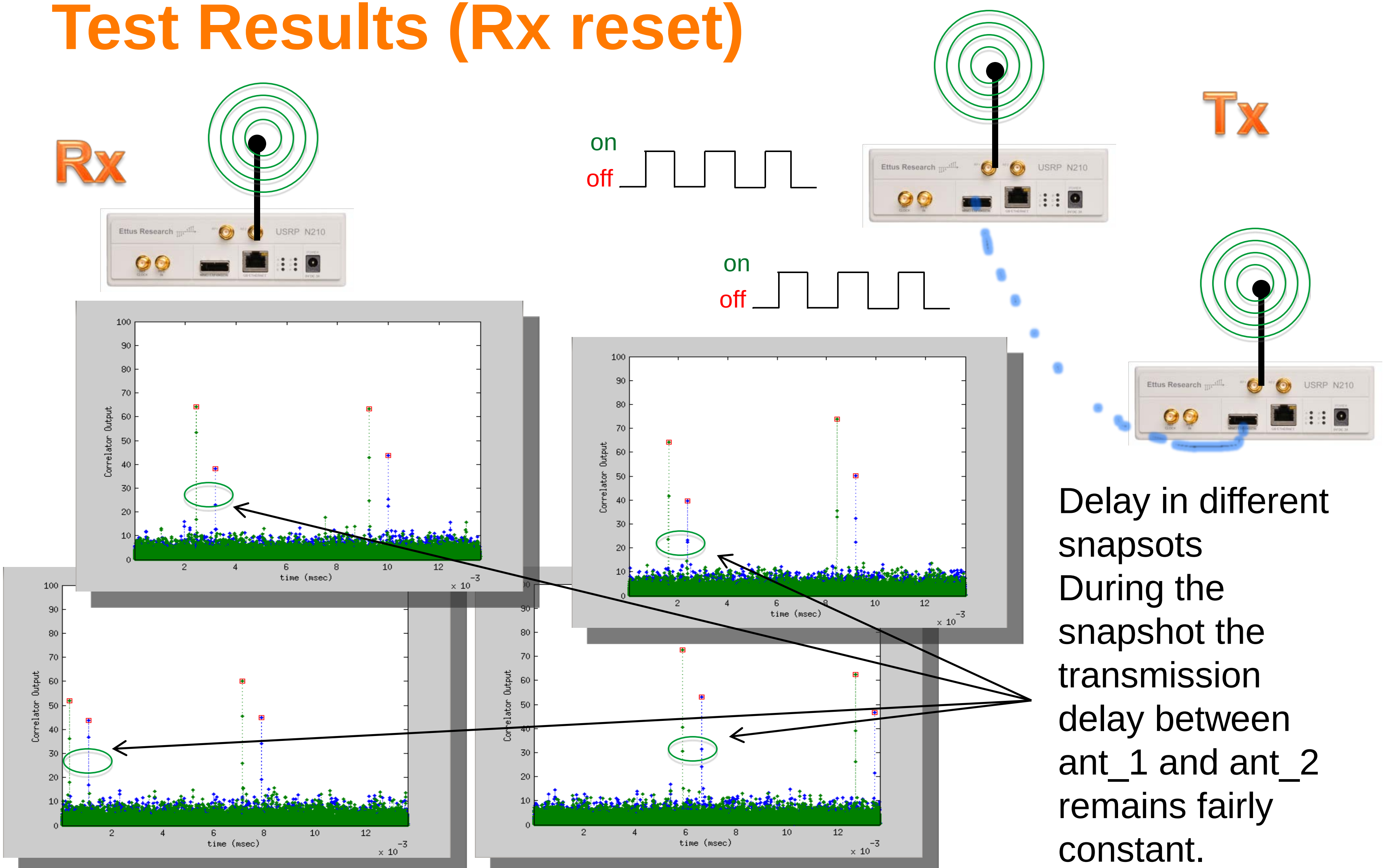
Receiver

MIMO sync cable



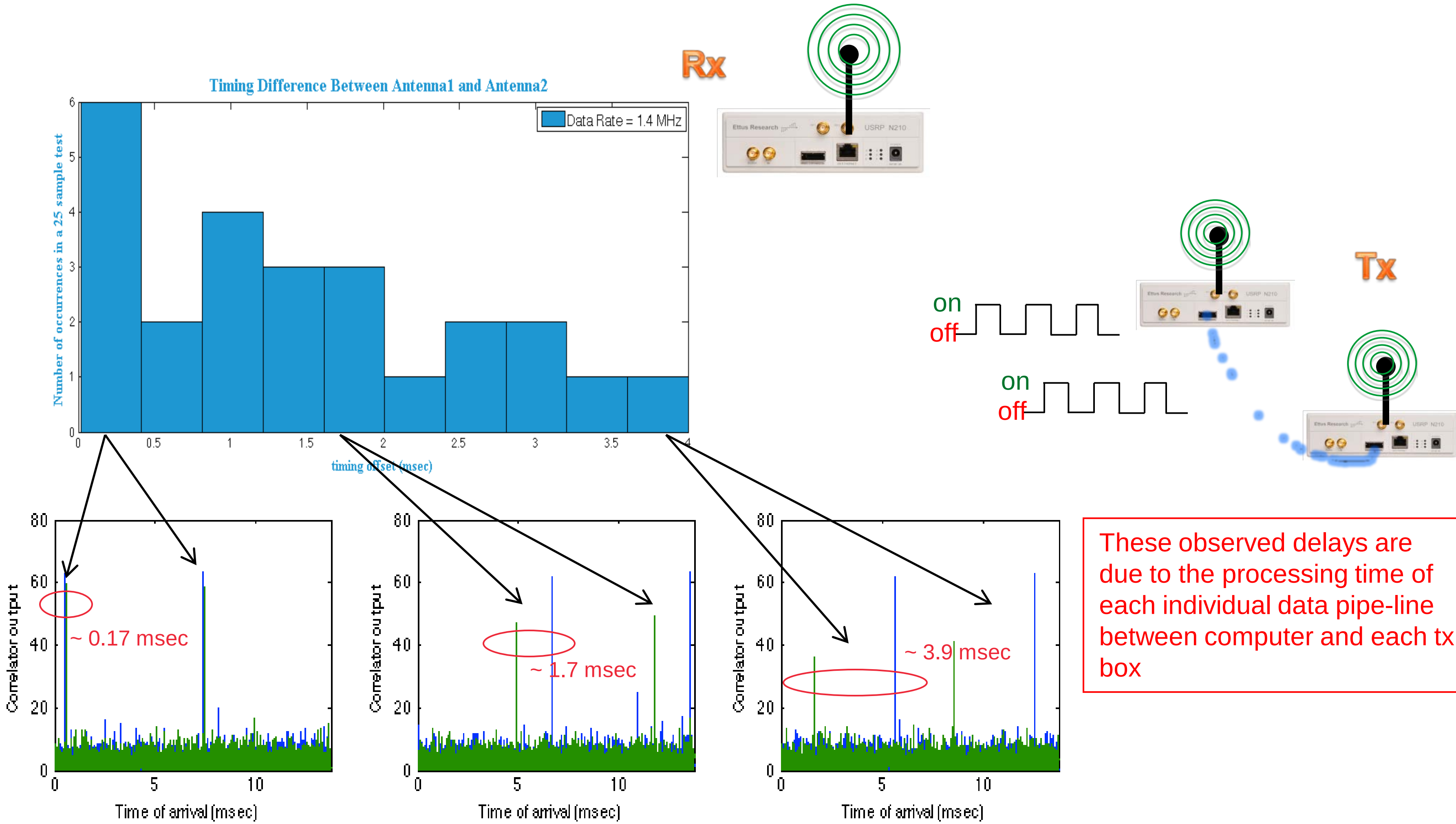
- Data collected by the receiver is process and analyzed by a dedicated computer.
- The two transmitters are controlled by a single computer and synchronized by a MIMO sync cable (shown in the bottom-left image)

Test Results (Rx reset)



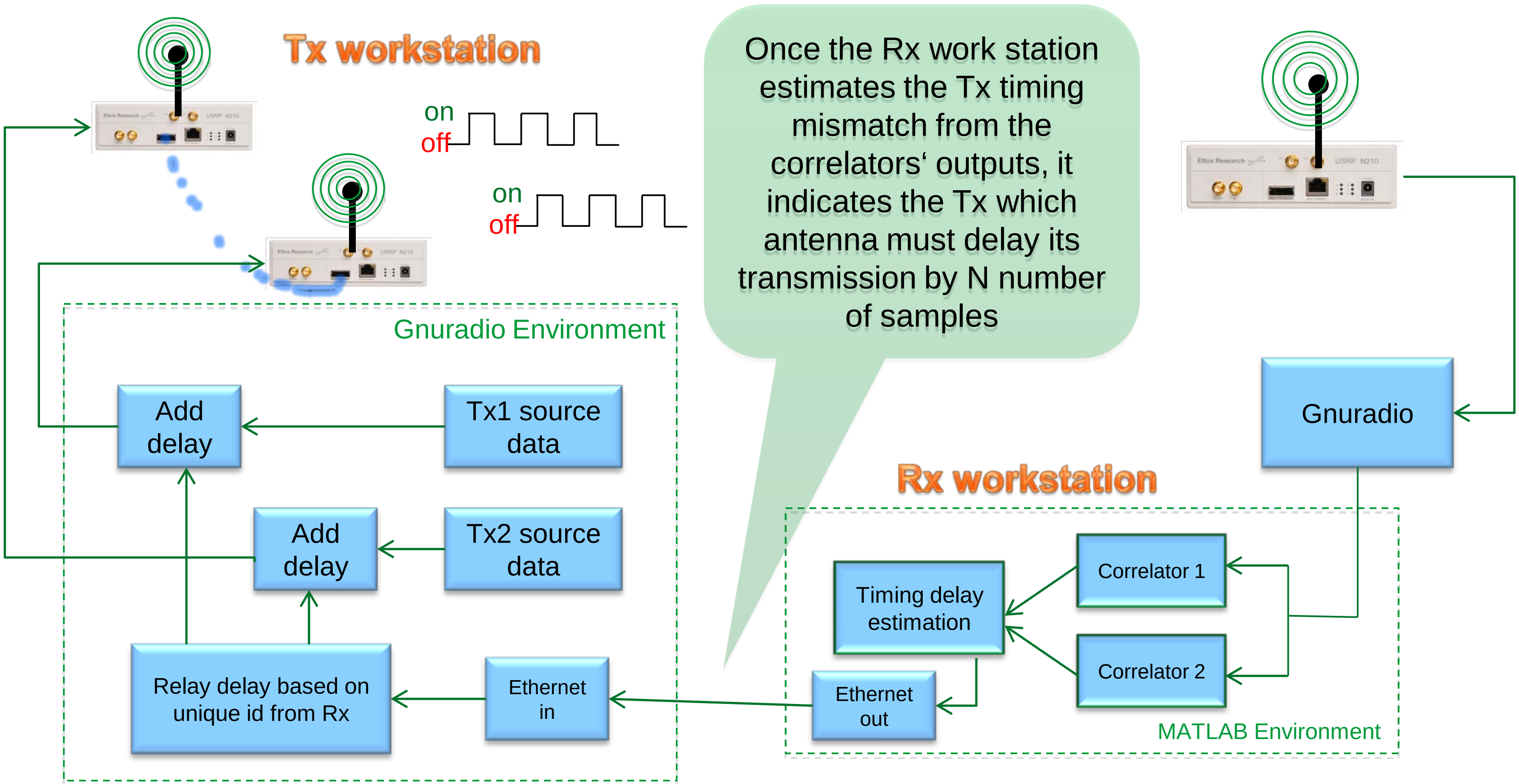
Delay in different snapsots During the snapshot the transmission delay between ant_1 and ant_2 remains fairly constant.

Test Results (Tx reset)



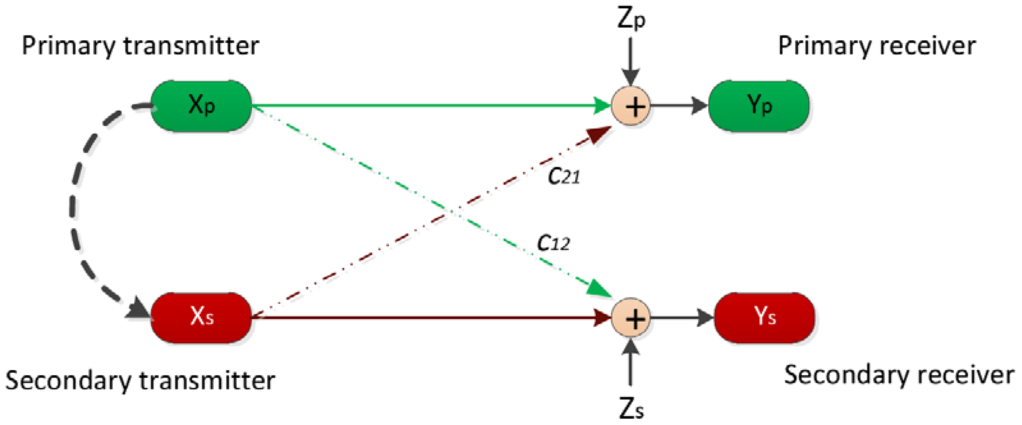
These observed delays are due to the processing time of each individual data pipe-line between computer and each tx box

Tx Timing Mismatch Calibration



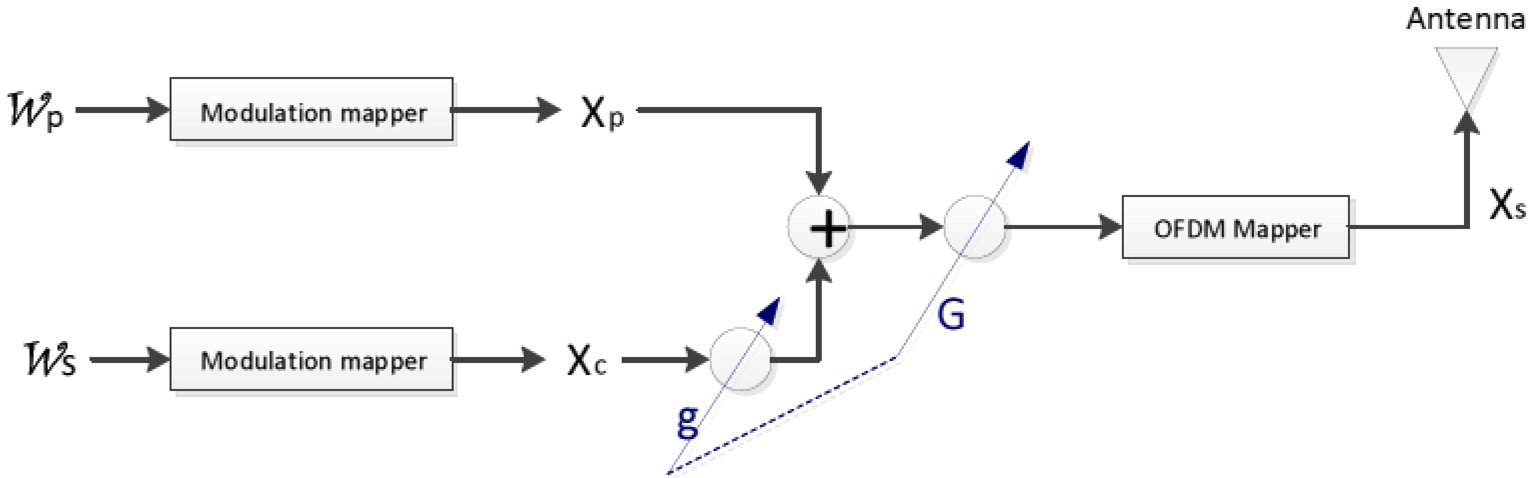
Receiver performance: Overlay cognitive radio

- The secondary transmitter overlays its signal on top of primary signal at relatively low power which the primary receiver can tolerate.
- The secondary transmitter is assumed to know codebooks and signal transmitted by primary transmitter and relays the primary signal in order to compensate for interference.
- The channel is a modeled as interference channel with asymmetric side information at the secondary transmitter.



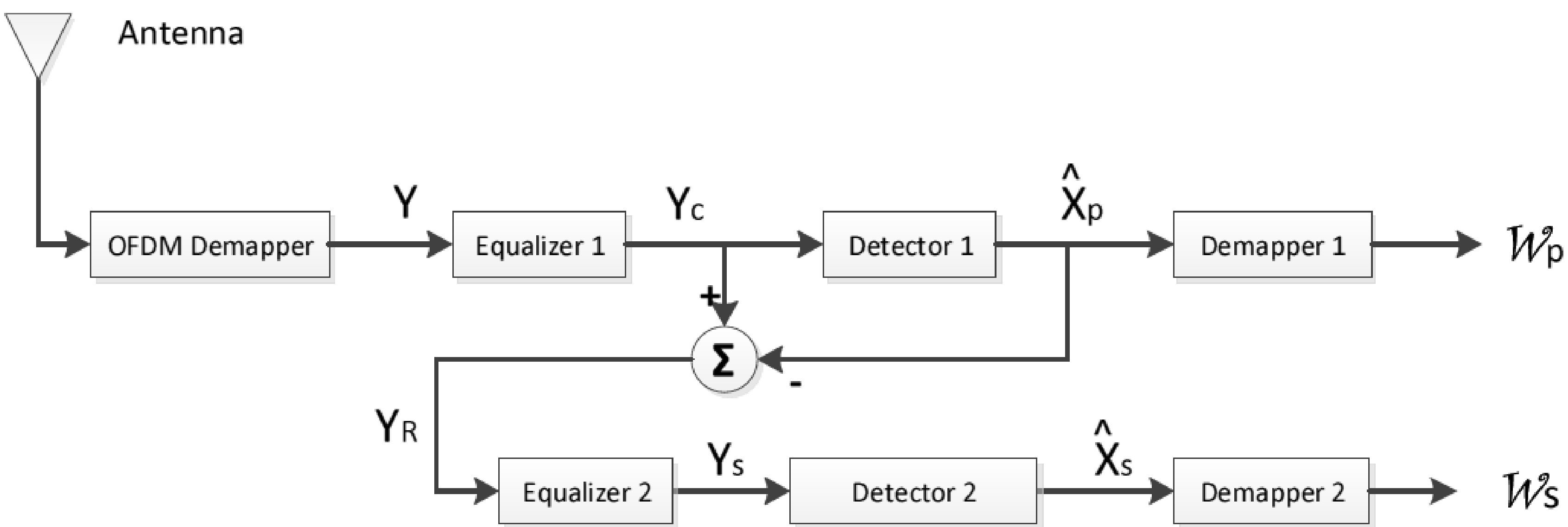
Design and implementation

- Transmitter design
  - The transmitter allocates fraction, **α**, of its power, **P_s**, for relaying primary signal, **X_p**.



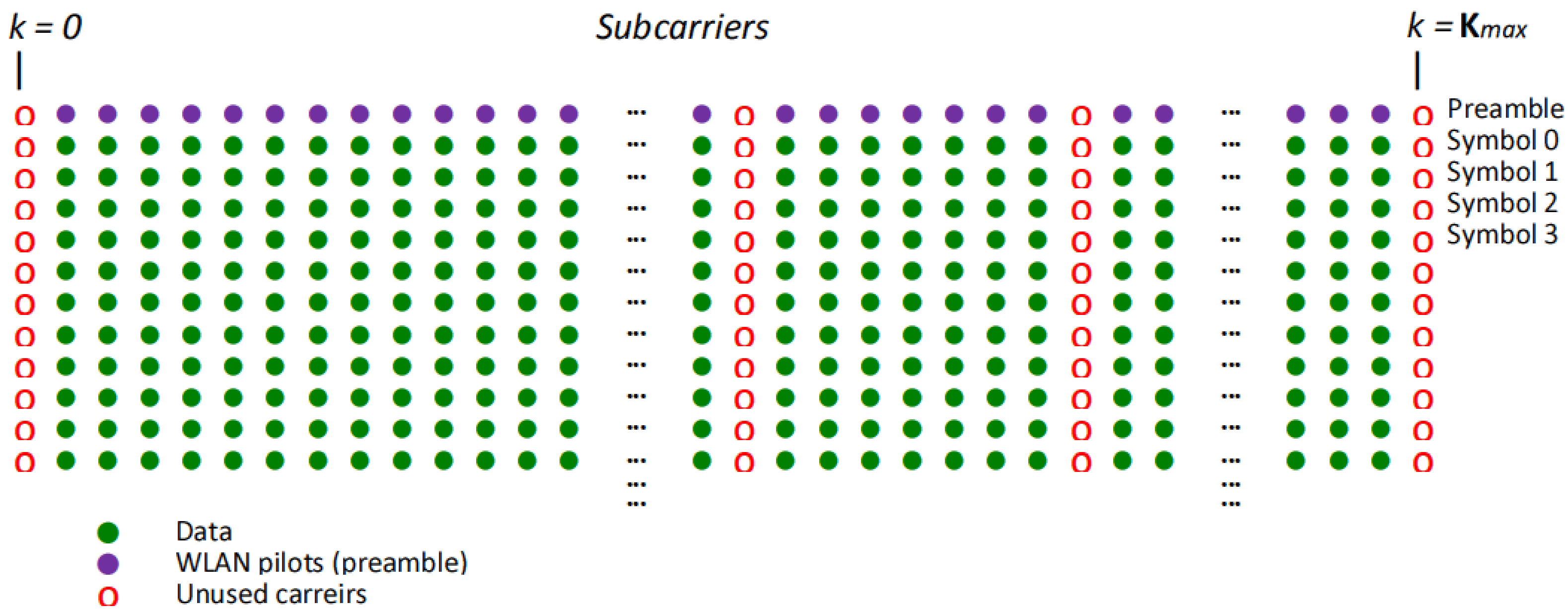
Design and implementation

- Receiver design
  - The receiver first decodes the primary signal.
  - Estimate of primary signal is subtracted from received signal.
  - The secondary signal is decoded from the residual signal. x



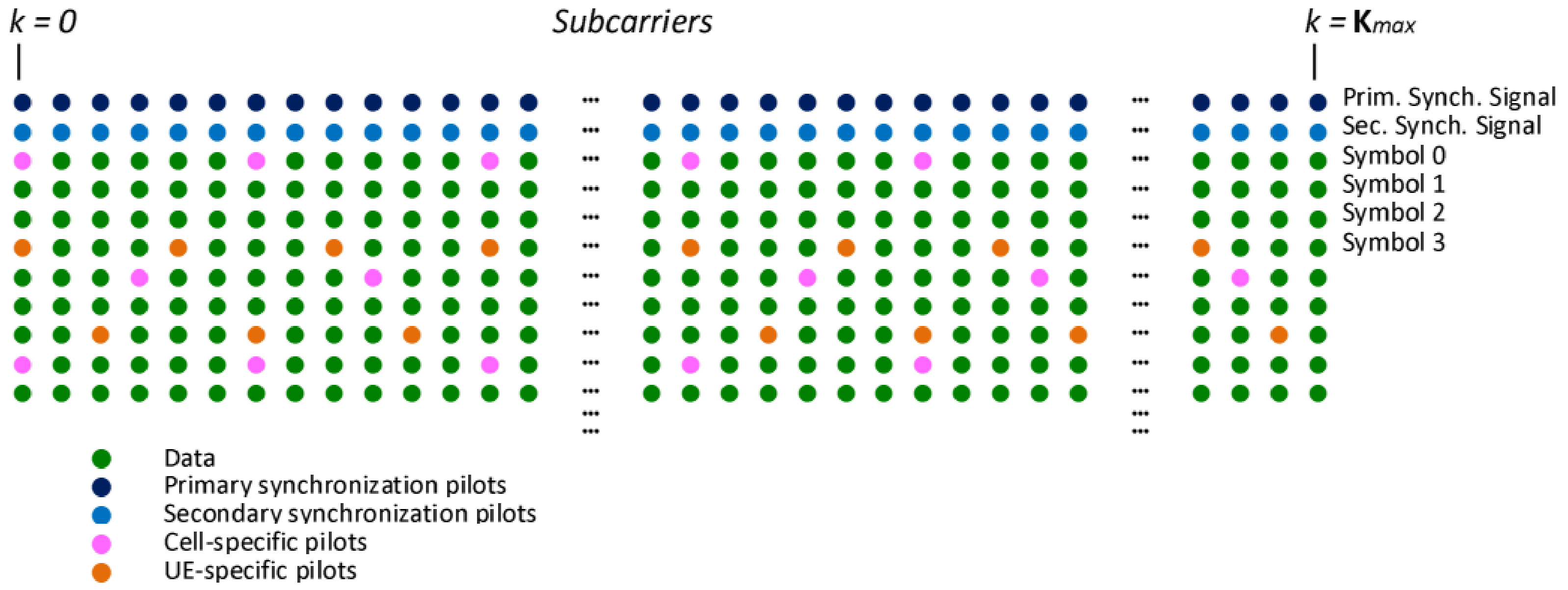
Practical considerations

- **Orthogonal pilot**: secondary system transmits orthogonally to DVB pilot carriers
- WLAN-type transmitter with modified preamble sequence is considered for *orthogonal pilot* overlay transmission.



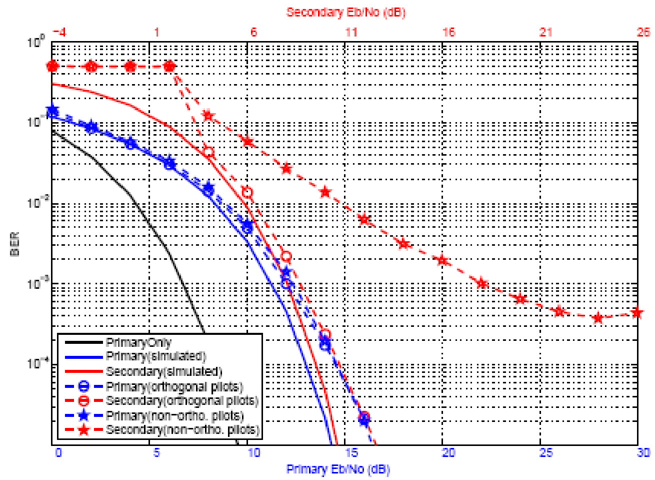
Practical considerations …continued

- **Non-orthogonal pilot**: secondary system transmits on all DVB carriers
- LTE-type transmitter is considered for *non-orthogonal pilot* overlay transmission.

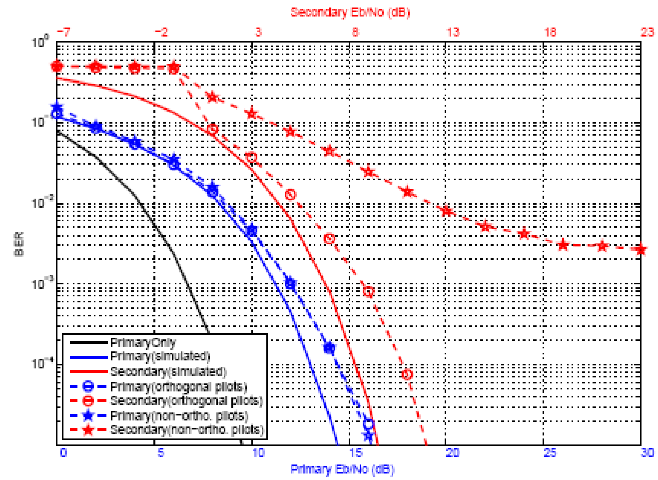


Test results:

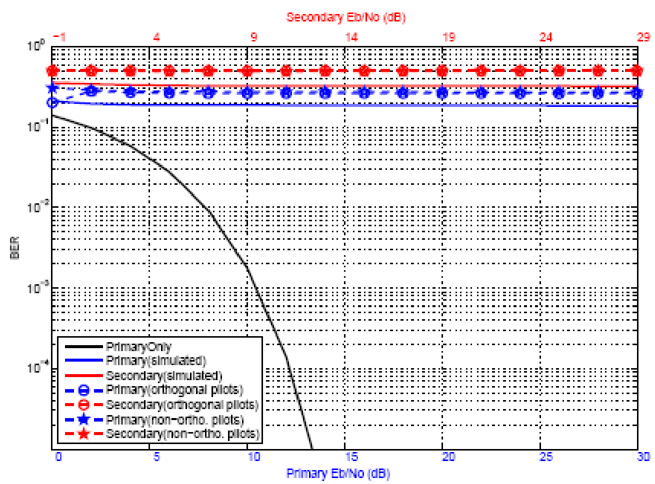
$$\gamma_p = 7dB$$



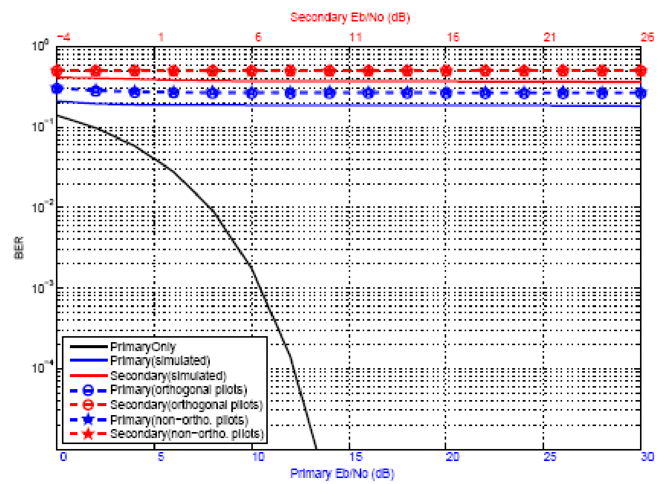
(a) Primary: 4QAM, Secondary: BPSK



(b) Primary: 4QAM, Secondary: 4QAM



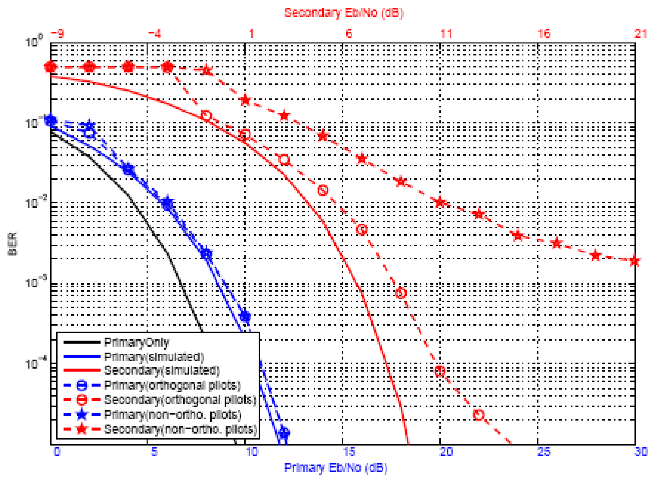
(c) Primary: 16QAM, Secondary: BPSK



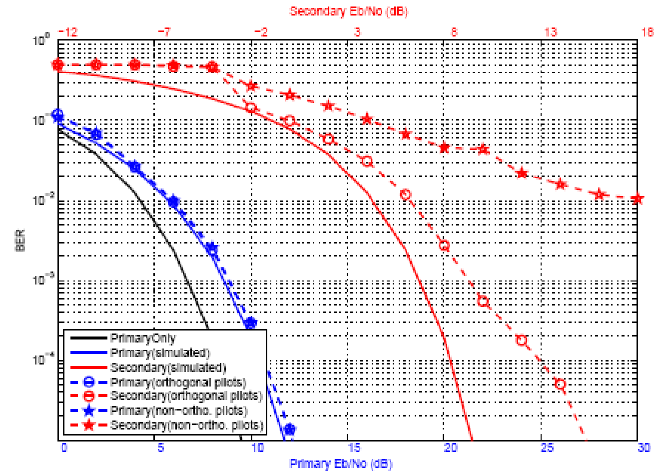
(d) Primary 16QAM, Secondary: 4QAM

Test results:

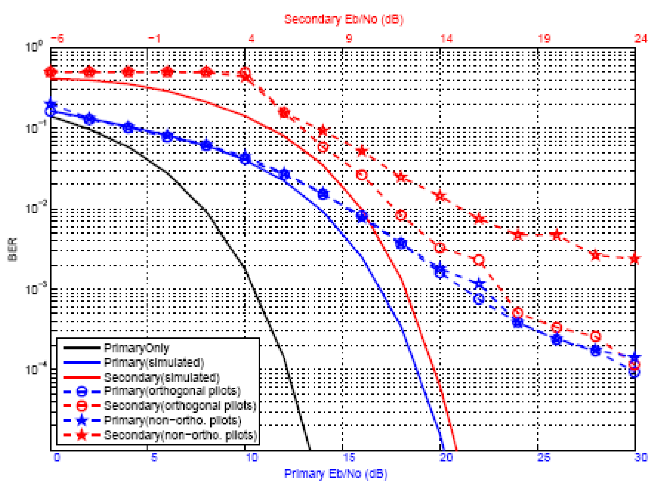
$$\gamma_p = 12dB$$



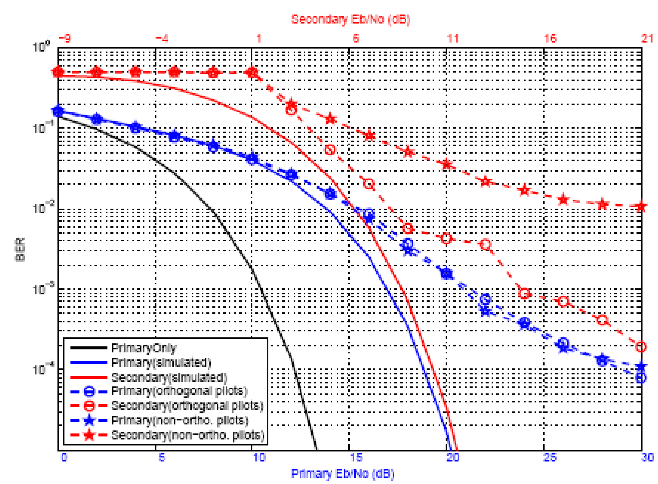
(a) Primary: 4QAM, Secondary: BPSK



(b) Primary: 4QAM, Secondary: 4QAM



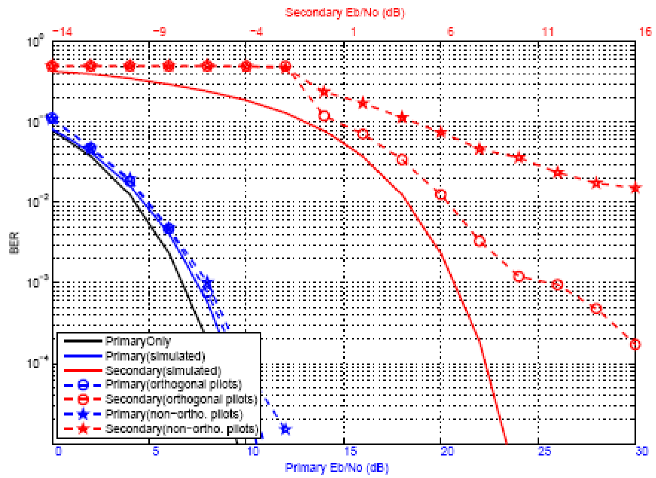
(c) Primary: 16QAM, Secondary: BPSK



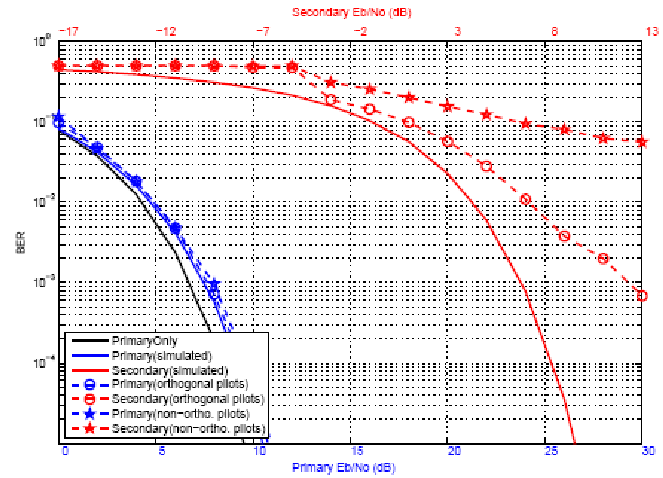
(d) Primary 16QAM, Secondary: 4QAM

Test results:

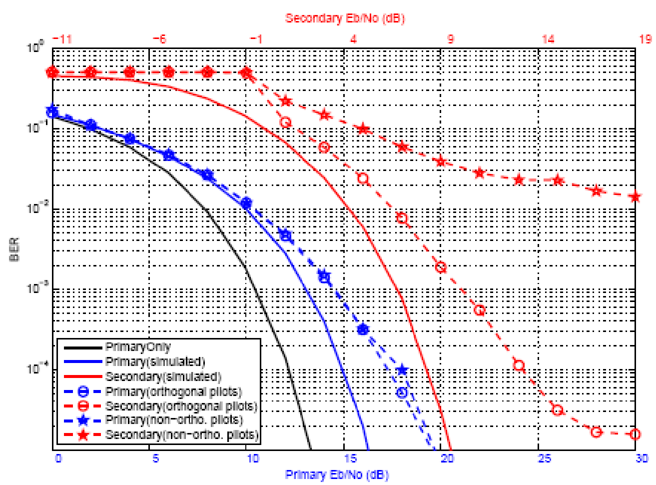
$$\gamma_p = 17dB$$



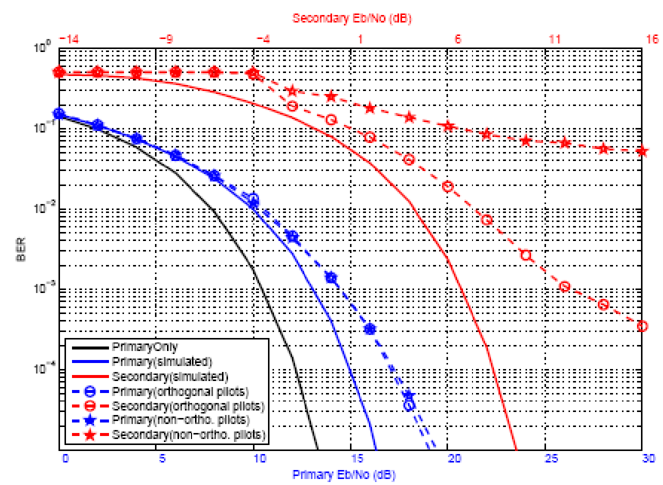
(a) Primary: 4QAM, Secondary: BPSK



(b) Primary: 4QAM, Secondary: 4QAM



(c) Primary: 16QAM, Secondary: BPSK



(d) Primary 16QAM, Secondary: 4QAM

Radio Resource management

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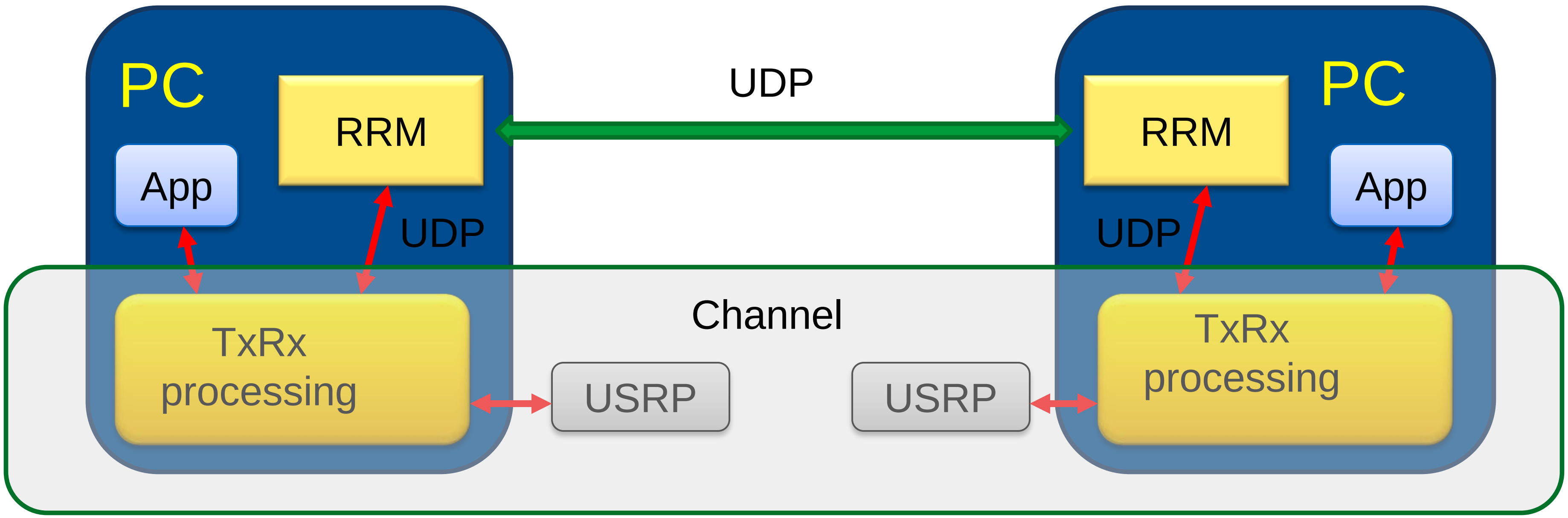
RRM studies

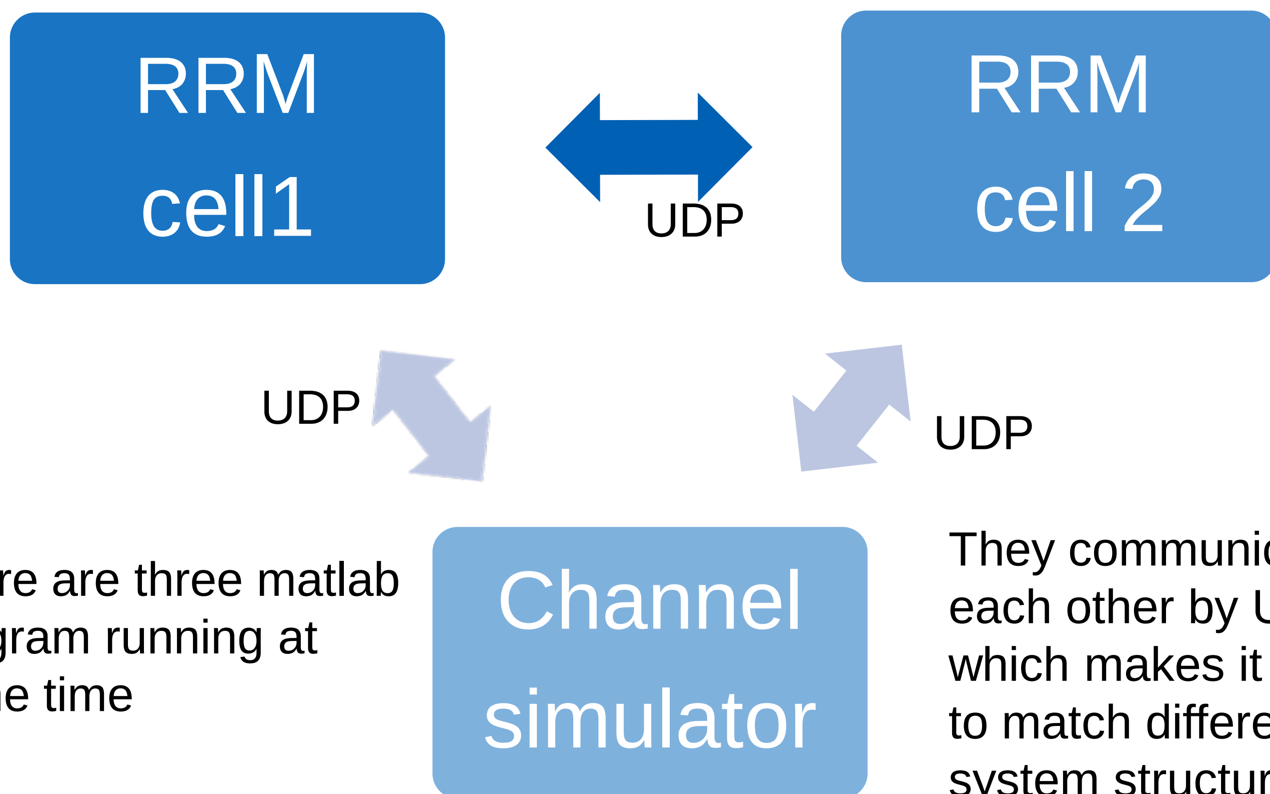
- Modular struture
  - Can start to study the RRM algorithms in parallel with PHY development
  - Use the same code base for simulations and for testbed

- Distributed RRM algorithms
  - Self orginizing interference control
  - Communication between RRM instances
- Co-oexiste manager assisted interference control
  - RRM instances communicate with the manatger

Network view



Matlab simulation structure



There are three matlab program running at same time

They communicate with each other by UDP, which makes it flexible to match different system structure.

Example of RRM algorithm

- Self organizing RRM algorithm:

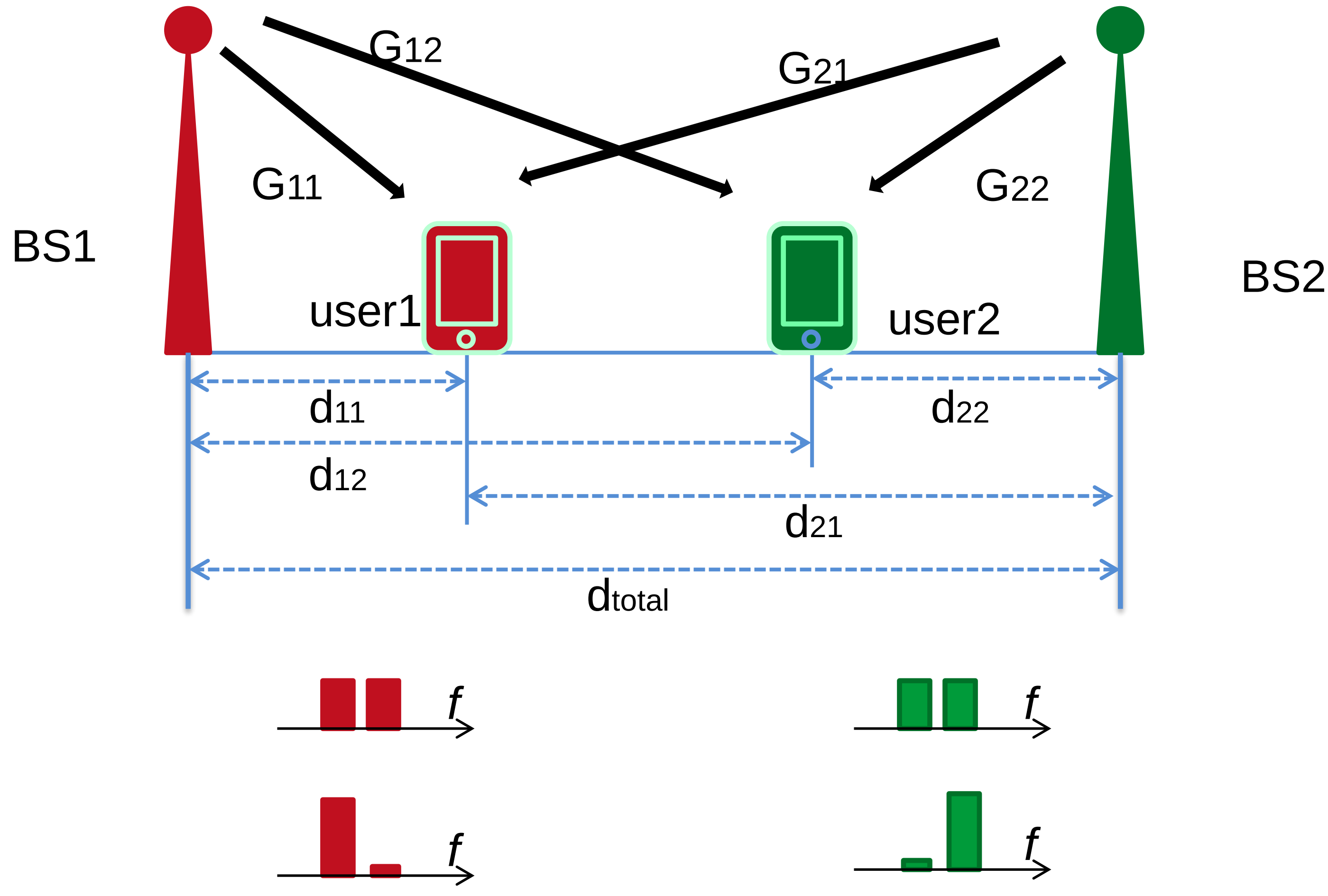
  Stolyar, A.L.; Viswanathan, H.; , "Self-Organizing Dynamic Fractional Frequency Reuse for Best-Effort Traffic through Distributed Inter-Cell Coordination," *INFOCOM 2009, IEEE* , vol., no., pp.1287-1295, 19-25 April 2009

- Optimization of the network utility $U = \sum_i \log X_i$

$$X_i = \sum_j \phi_{ij} R_{ij}$$

- *i* is the index of the spectrum area
- ϕ_{ij} fraction of channel usage for user *j*
- R_{ij} datarate of user j

Simulation model



Simulation parameter (1)

- Initial power matrix is

$$P = \begin{bmatrix} 0.5 & 0.3 \\ 0.6 & 0.4 \end{bmatrix}$$

- The distance matrix is

$$d_1 = \begin{bmatrix} 1000 & 1000 \\ 1000 & 1000 \end{bmatrix}$$

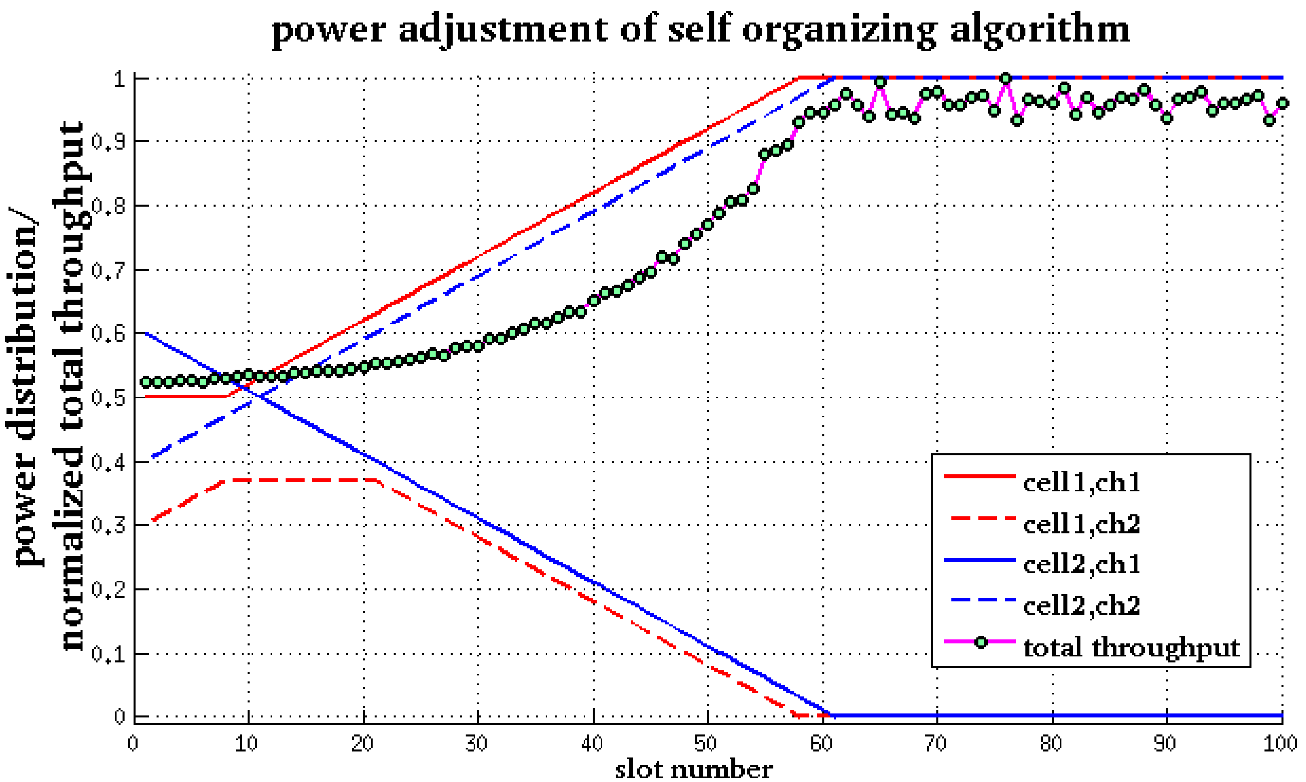
- The passloss is calculated by

$$G_{pathloss}(dB) = -33.6 - 35 \log d$$

- The signal interference noise ratio is calculated as

$$SINR_{cell=1,user=1} = \frac{G_{11}P(1,:)}{N_0 + G_{21}P(2,:)}$$

Result of simulation (1)



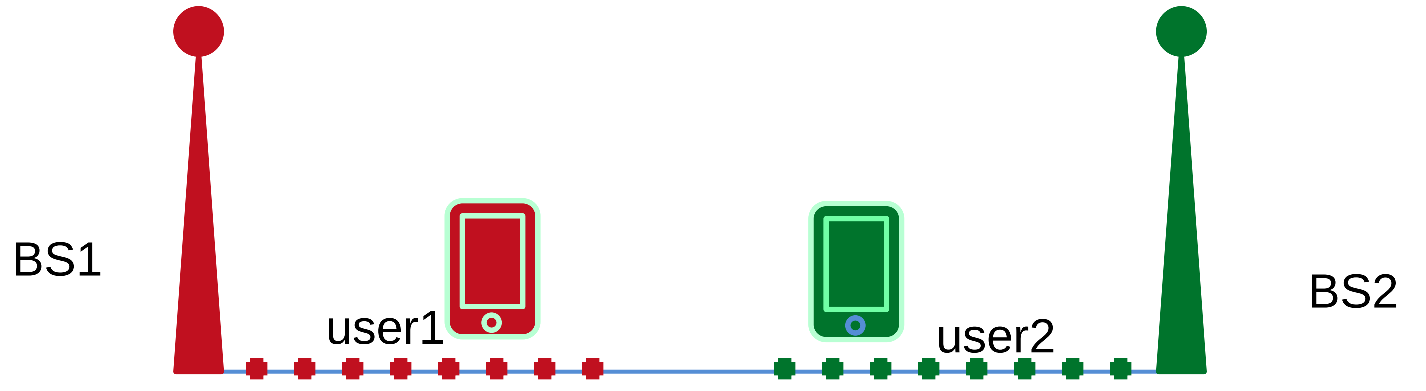
When both users locate at same place at cell edge, fractional frequency reuse is automatically generated.

Simulation parameters (2)

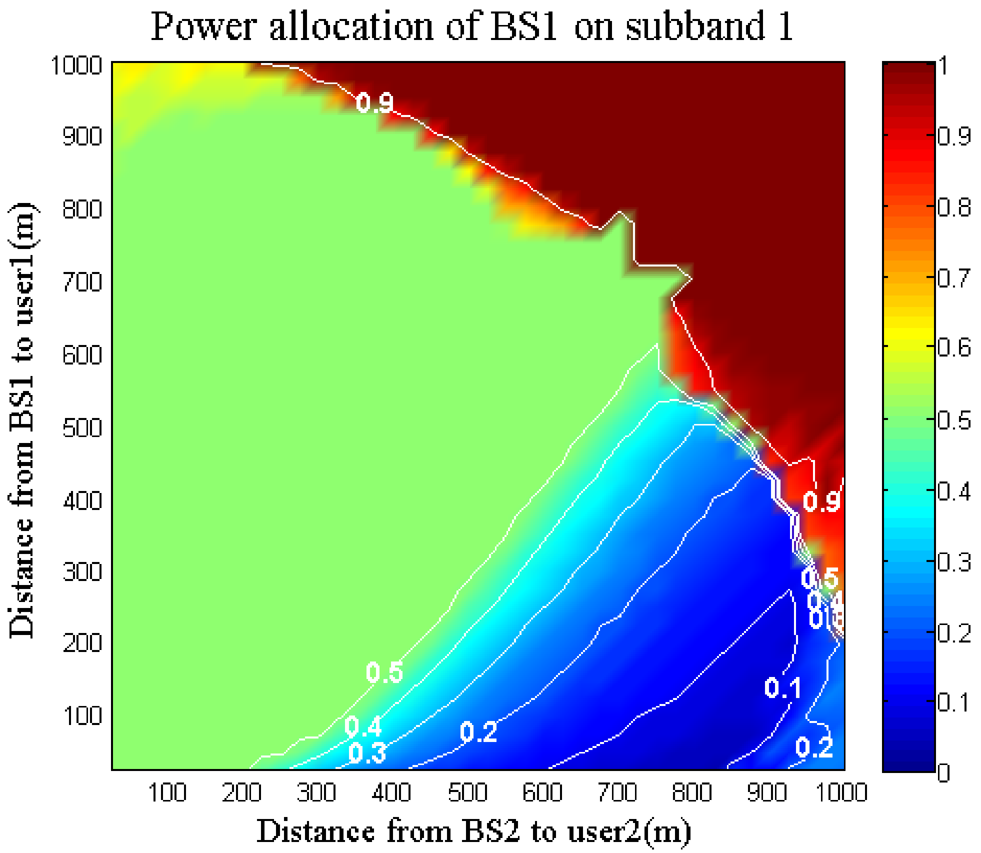
- Initial power matrix is

$$P = \begin{bmatrix} 0.5 & 0.5 \\ 0.5 & 0.5 \end{bmatrix}$$

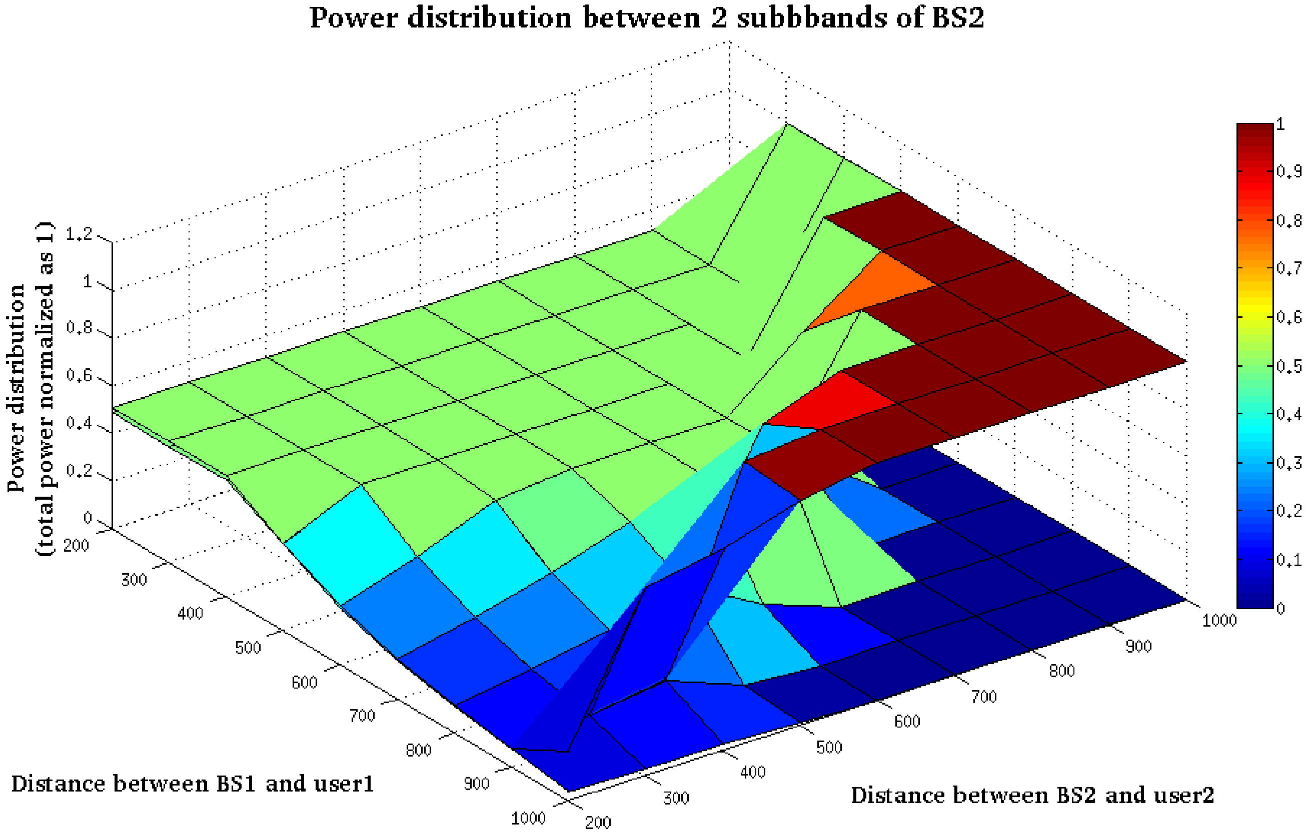
- The distance from each user to his own base station is varying from 200m to 1000m. Suppose 2 users are located on straight line between base stations.

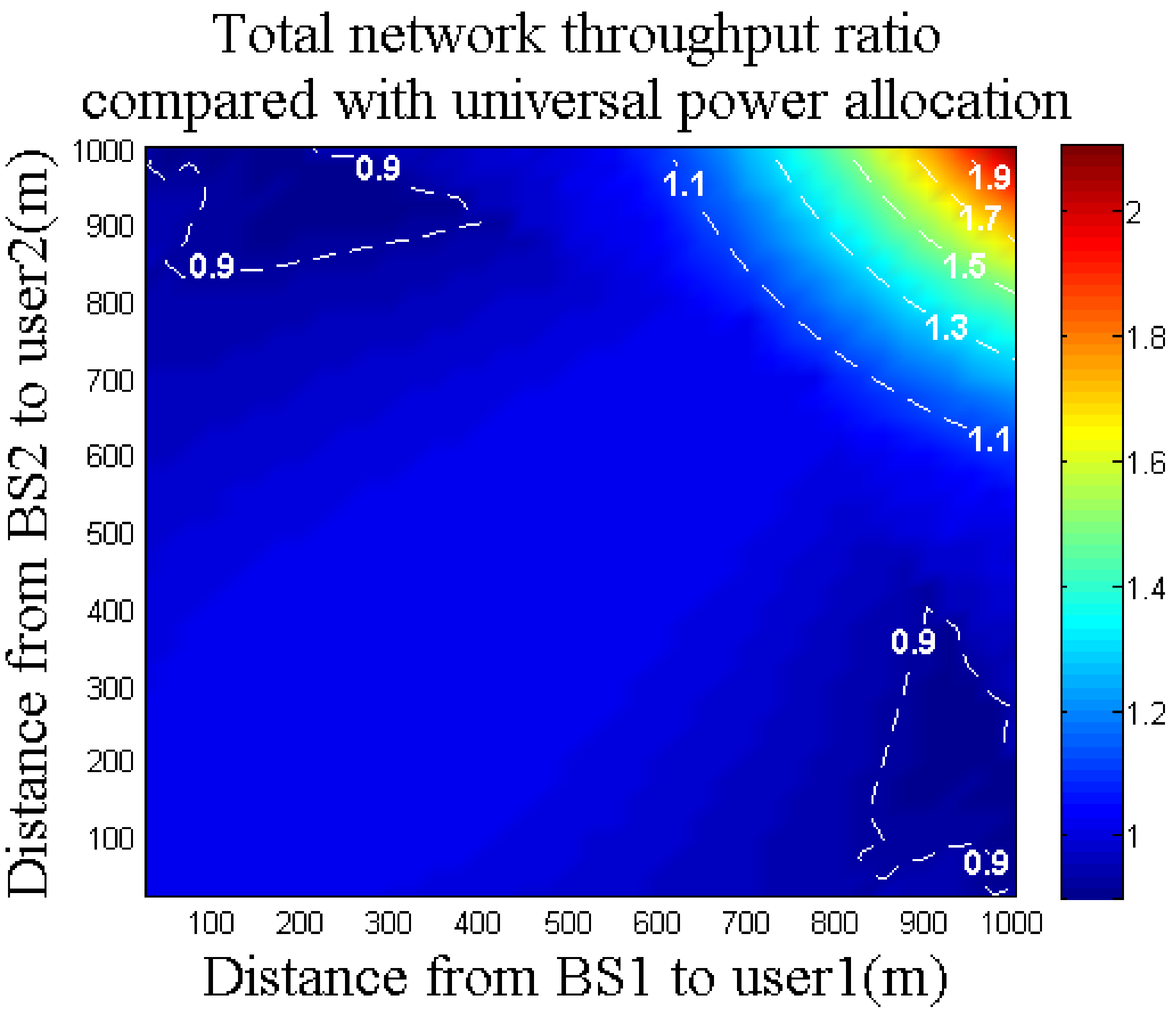


Result of simulation (2)
Power allocation in different subbands BS2

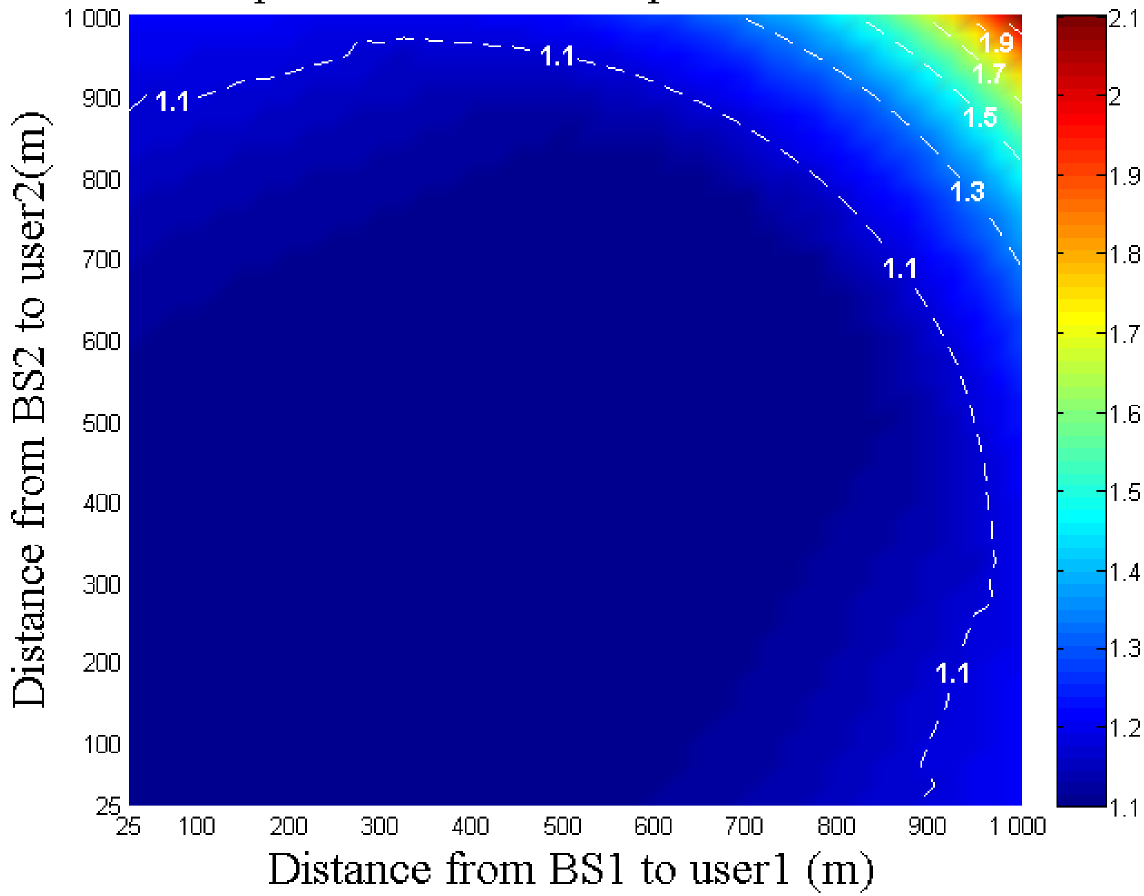


Result of simulation (2)
Power allocation in different subbands BS2



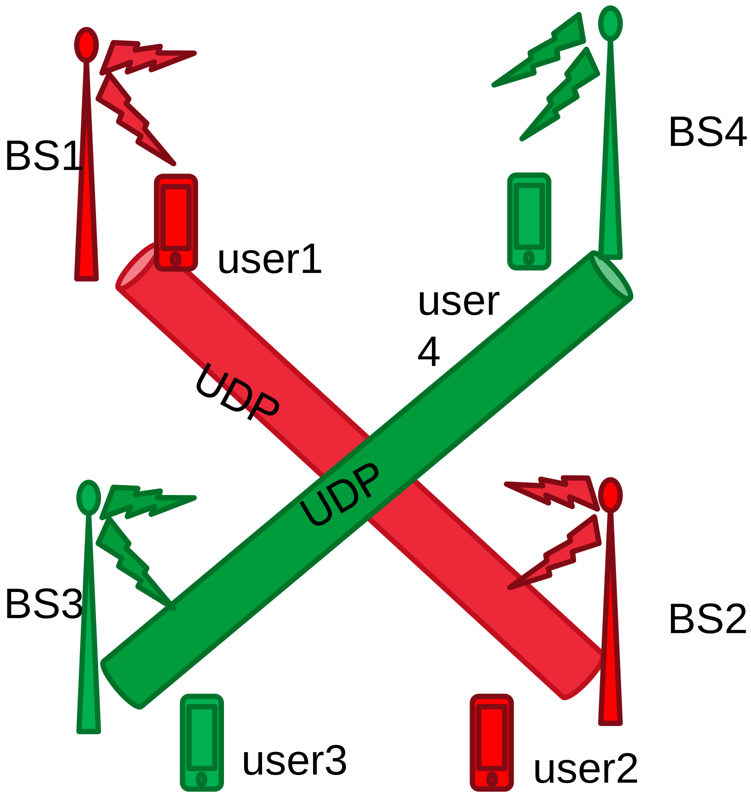

Total network throughput ratio
compared with universal power allocation
Distance from BS2 to user2(m)
Distance from BS1 to user1(m)
100
200
300
400
500
600
700
800
900
1000
0.9
0.9
1.1
1.9
1.7
1.5
1.3
1.1
0.9
0.9
2
1.8
1.6
1.4
1.2
1

Network Utility improvement ratio
compared with universal power allocation.

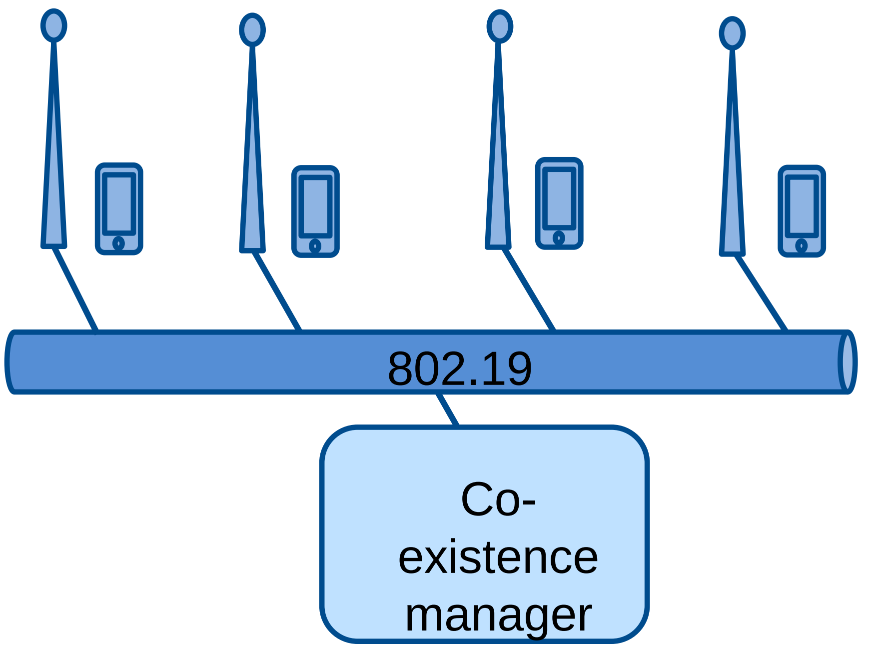


Future plans for RRM modeling

RRM among different networks



802.19 type coexistence manager



Thank you.