IEEE AEROSPACE CONFERENCE

YELLOWSTONE CONFERENCE CENTER, BIG SKY, MONTANA, MAR 4 – 11, 2017

UNIVERSITY OF TRENTO - Italy

Information Engineering and Computer Science Department

An SDR-based Reconfigurable Multicarrier Transceiver for Terrestrial and Satellite Communications

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Outline

- *Introduction and motivations;*
- *Innovation with respect to the state-of-the-art;*
- *SC-OFDM vs. OFDM: similarities and differences;*
- *GNU Radio SDR tools;*
- *Implementation of the SDR-based reconfigurable multicarrier transceiver;*
- *Experimental results;*
- *Conclusion and future work.*

Introduction and motivations (1)

- **Orthogonal Frequency Division Multiplexing (OFDM)** and, more in general multicarrier modulations represent the cornerstone of modern mobile communication standards (4G LTE, IEEE 802.11n, DVB-T, etc.);

- OFDM is a viable transmission solution for broadband mobile transmissions (at least, since 1981, when digital I-FFT based implementation was discovered by B. Hirosaki) and provides flexible multi-user transmission thanks to OFDMA;

- Well known disadvantages are: power inefficiency due to nonlinear distortion vulnerability and low diversity gain when used over frequency-selective fading channels;

- To solve the aforesaid issues, **modifications of OFDM have been proposed in the literature** targeted at improving efficiency and resilience (sometimes the term *"OFDM-inspired waveforms"* is used[1]).

[1] B. Farhang-Boroujeny and H. Moradi, "OFDM-inspired waveforms for 5g," *IEEE Communications Surveys Tutorials*, vol. PP, no. 99, pp. 1–1, 2016.

Introduction and motivations (2)

- One of these improvement is the so-called **Single-Carrier OFDM** (SC-OFDM), known also as DFT-precoded OFDM or DFT-spread OFDM;
- SC-OFDM exhibits reduced peak-to-average power ratio (PAPR) and increased diversity gain in the frequency domain with respect to conventional OFDM;
- SC-OFDM (and the multi-user version known as SC-FDMA) is used in terrestrial LTE for the uplink, and in satellite DBV-NGH standard, despite its higher computational complexity;
- In this work, we propose **a reconfigurable transceiver** based on **Software Defined Radio (SDR) technology** enabling both OFDM and SC-OFDM transmission modes in uplink and downlink;
- The claimed objective is to seamlessly switch from OFDM to SC-OFDM (and vice-versa), when multi-mode transmission is required by link situation, power availability, computational resource constraints, etc.

Innovation with respect to state-of-the-art

- The underlying picture can highlight at a glance the step-ahead of this work with respect to the state-of-the-art framework:

SDR-based OFDM implementations

Implementation on WARP SDR open-source platform[2]

Direct implementation on FPGA[3]

SDR-based "OFDM-inspired" transceiver implementations

Implementation of filter-bank multicarrier (FBMC): test with Ettus USRP boards[4]

SDR-based SC-OFDM/ SC-FDMA transceiver implementations

Implementation of SC-FDMA-based LTE uplink: test with Ettus N210 boards[5]

ALL THESE IMPLEMENTATIONS ARE SINGLE-MODE, MULTI-MODE MULTI-CARRIER TRANSMISSION HAS NOT YET BEEN CONSIDERED

Possible applications of multi-mode reconfigurable OFDM/SC-OFDM transceiver:

- Emergency communications (SC-OFDM is more robust in safety-critical data exchange);
- Satellite mobile communications (higher power efficiency, less dBs of OBO).

[2]T. Suryani, Suwadi, Hasan, and S. W. Yoga, "Implementation and performance evaluation of orthogonal frequency division multiplexing (OFDM) using warp," in Intelligent Technology and Its Applications (ISITIA), 2015 International Seminar on , May 2015, pp. 451–456.

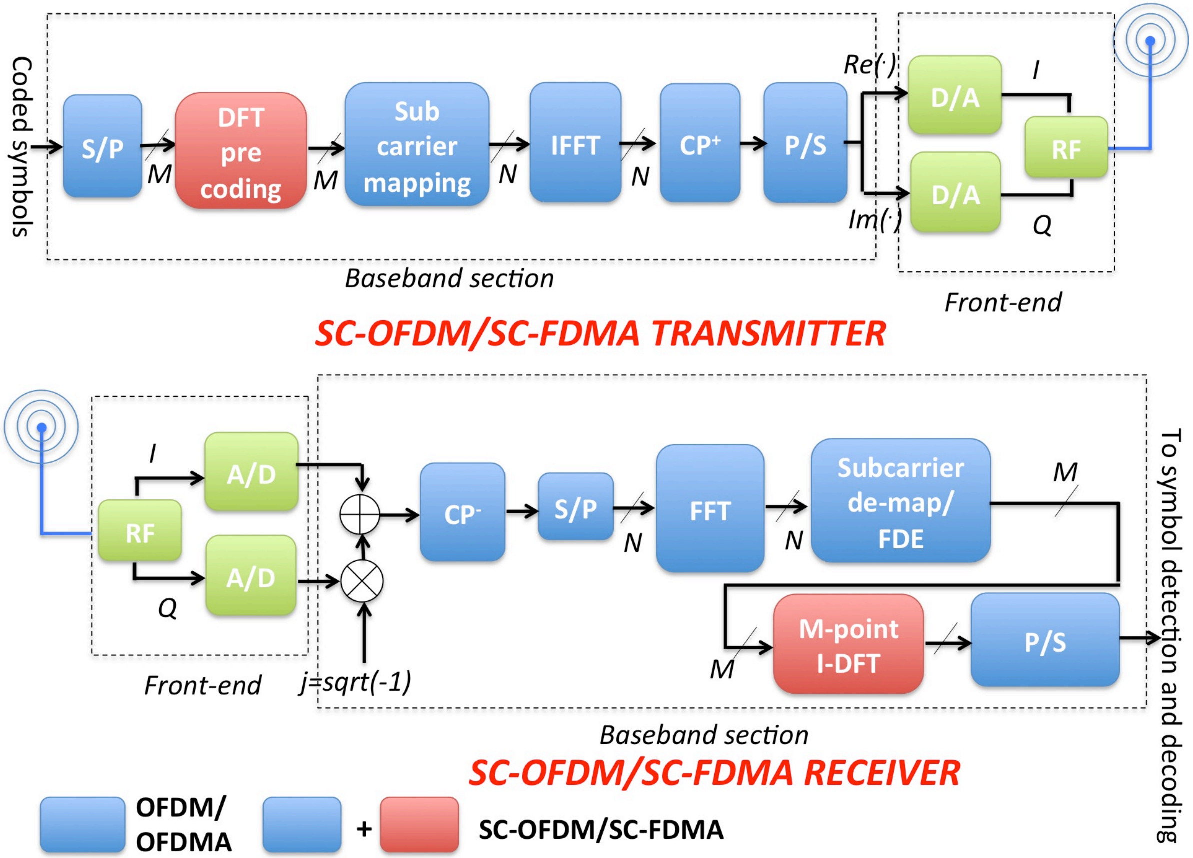
[3]J. Vasani, T. Kumar, R. Nagpal, M. Naik, and R. Malik, "Baseband OFDM physical layer implementation on FPGA using systemvue," in 2016 WiSPNET Conf., March 2016, pp. 967–972.

[4]B. Horvth and P. Bakki, "Implementation of FBMC transmission link using SDR," in RADIOELEKTRONIKA 2013 Conf., Apr. 2013, pp. 320–323.

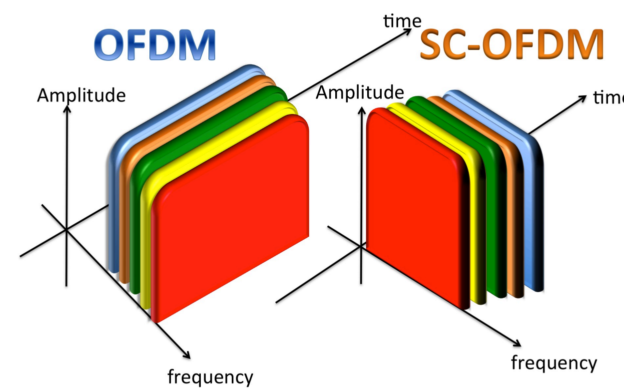
[5]P. B. Jłrgensen, T. L. Hansen, T. B. Słrensen, and G. Berardinelli, "Implementation of lte SC-FDMA on the USRP2 software defined radio platform," in Communication Technologies Workshop (Swe-CTW), 2011 IEEE Swedish , Oct. 2011, pp. 34–39.

SC-OFDM vs. OFDM: similarities and differences

- A block diagram of SC-OFDM is shown (the differences with respect to OFDM are highlighted in red):



SIGNAL REPRESENTATION IN TIME-FREQUENCY DOMAIN



- Frequency-domain equalization (FDE) is more effective with SC-OFDM, because is applied to the single-carrier received signal;
- Time synchronization of SC-OFDM signal is more critical (sampling time is reduced).

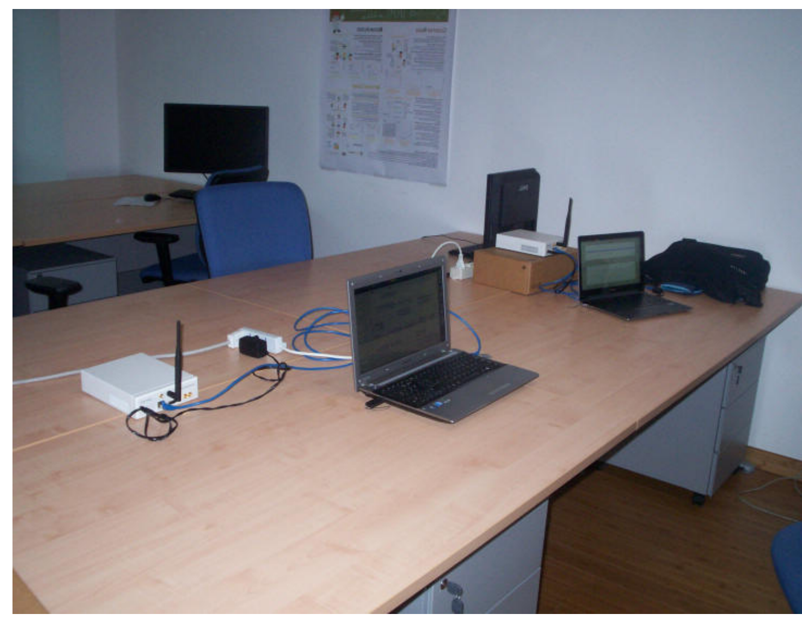
GNU-radio SDR tools

- The software implementation was done using the GNU Radio platform installed on commodity PCs running UBUNTU OS;

- The generation of the baseband waveform is full-software and performed by the PC. The Universal Software Radio Peripheral (**USRP) boards** (low-cost hardware components supplied by Ettus Research) transmit the RF signal onto the air;

- The **open-source GNU Radio platform** (www.gnuradio.org):
  - Incorporates software-implemented signal processing blocks.
  - For the software Implementation it uses:
    - C++ for the computationally intensive signal processing functions, e.g ., filters, mixers;
    - Python for the flow graphs connecting one block to another and other operations that aren't computationally intensive.

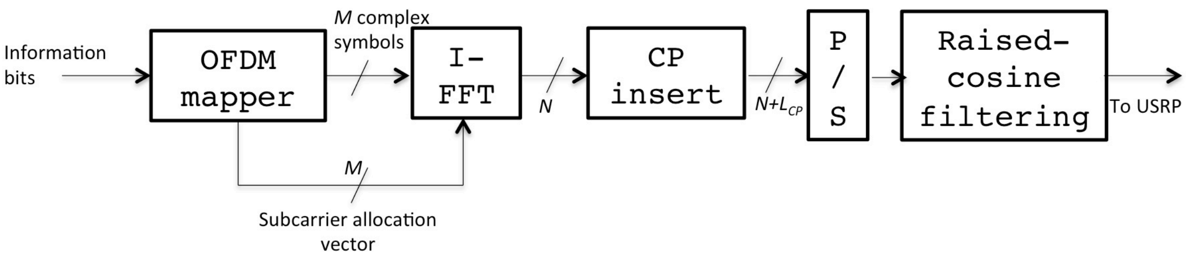
GNU Radio
THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM



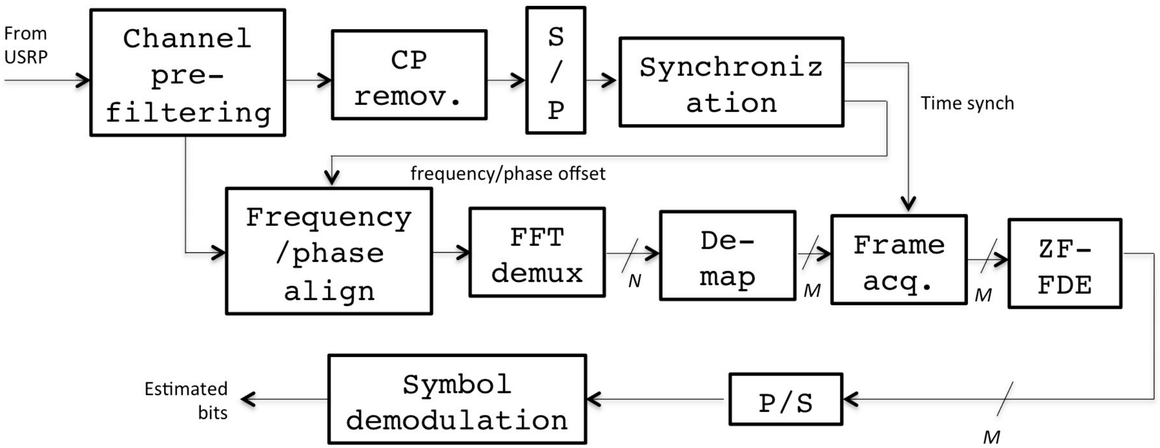
SDR implementation of the multicarrier transceiver (1)

- Let's start from the flowgraphs of baseline OFDM configuration:

OFDM transmitter flowgraph



OFDM receiver flowgraph



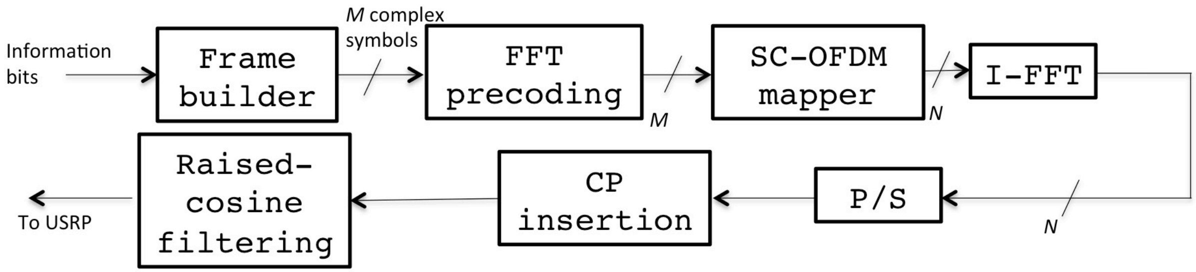
- Each block corresponds to a C++ function of the GNU Radio library;
- OFDM time/frequency synchronization is implemented by using the state-of-the-art algorithm of Schmidl and Cox shown in[6];
- Raised cosine filtering is used to reduce sidelobe power level (such a solution is also adopted by "4G and beyond" standard[7]).

[6]T. M. Schmidl and D. C. Cox, "Robust frequency and timing synchronization for OFDM," *IEEE Transactions on Communications*, vol. 45, no. 12, pp. 1613–1621, Dec 1997.
[7]X. Zhang,M. Jia, L. Chen, J. Ma, and J. Qiu, "Filtered OFDM - enabler for flexible waveform in the 5th generation cellular networks," *2015 IEEE Global Communications Conference (GLOBECOM),* Dec 2015, pp. 1–6.

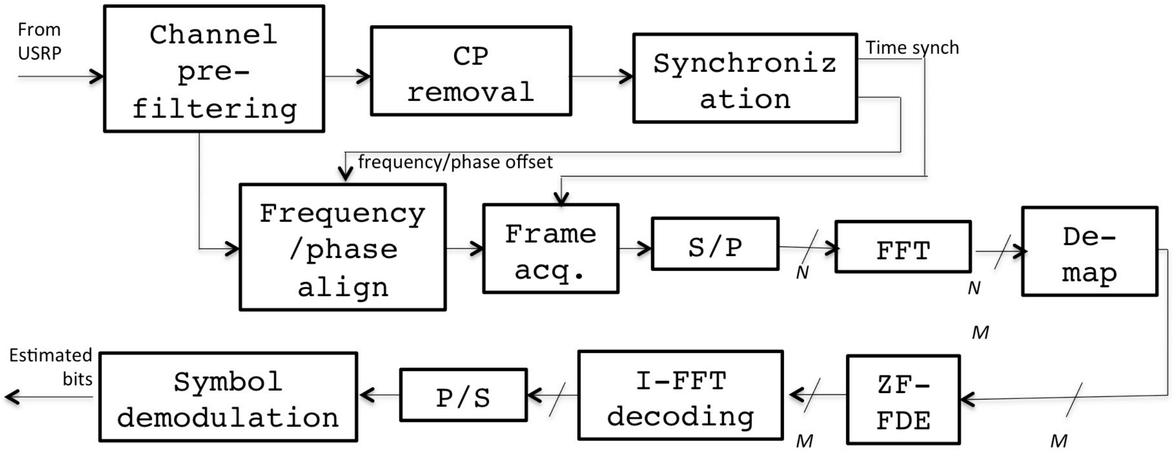
SDR implementation of the multicarrier transceiver (2)

- Now, let's focus on the SC-OFDM augmented flowgraph:

SC-OFDM transmitter flowgraph



SC-OFDM receiver flowgraph



- Apart from FFT precoding (and decoding) the flowgraph is the same of OFDM ;
- The same synchronization algorithm is used, BUT synchronization is performed before S/P conversion at higher sampling rate;
- Zero-Forcing FDE is performed on the single-carrier received signal converted in the frequency domain by the FFT and then reconverted in the time domain by the I-FFT.

Experimental results (1)

- HW/SW setup and open-field emulation scenarios:

COMPUTING MACHINES:

TRANSMITTER: ACER Aspire notebook, with two 1.33 GHz AMD C-70 CPUs, 3.6 GB of RAM and UBUNTU 14.04 OS,

RECEIVER: HP Beats Studio laptop with 4 2GHz Intel Core I7-4510U CPUs, 7.6 GB of RAM, and ARCHLINUX 2016 OS.

COMMUNICATION INTERFACES:

USRP N210 boards. All the boards use XCVR2450 half-duplex RF daughterboards.

Indoor LOS scenario

Outdoor LOS scenario

Outdoor with obstacle

Indoor with corner

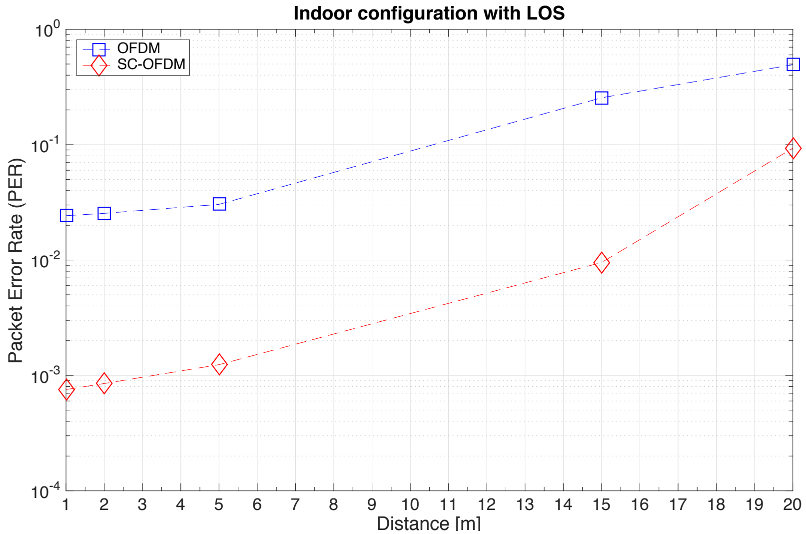
Experimental results (2)

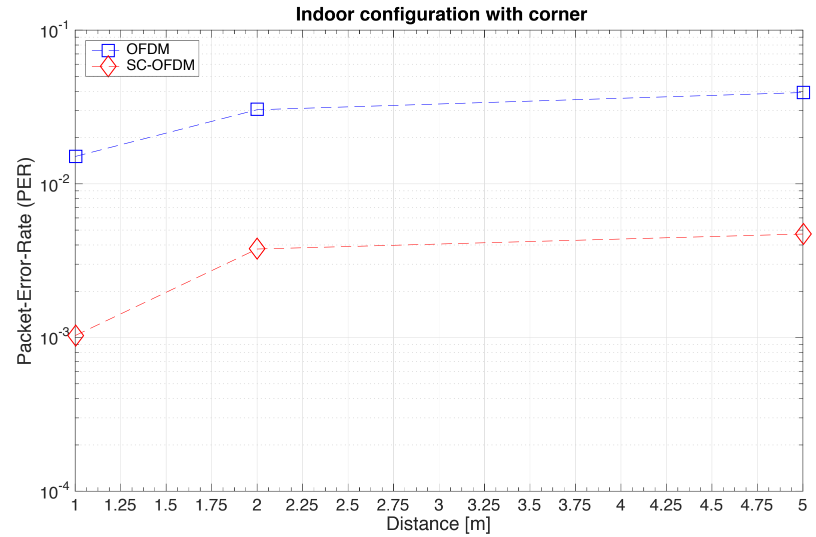
- Transceiver parameters setting:

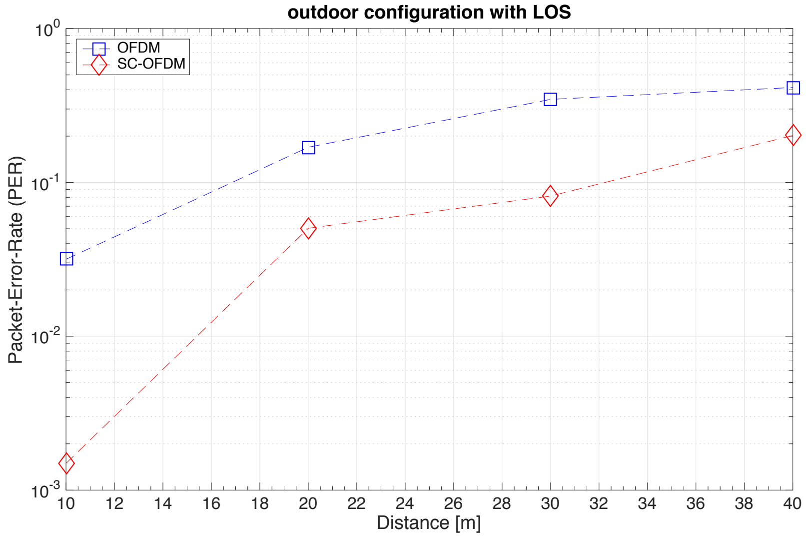
Parameter	Numerical value
Subcarrier number *(N)*	512
Subcarrier mapped per user *(M)*	256
Cyclic prefix length (symbols)	64
Frame length (Kbytes)	1.125
Size of trasmitted data per user (Kbytes)	125
Signal bandwidth (KHz)	500
Raised cosine filter roll-off	0.25
Modulation scheme	QPSK

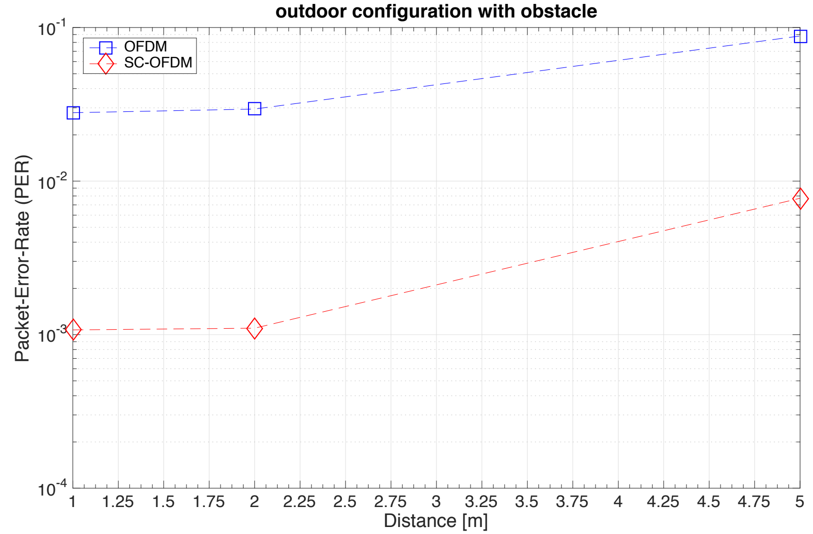
Experimental results (2)

- Packet-Error Rate results:



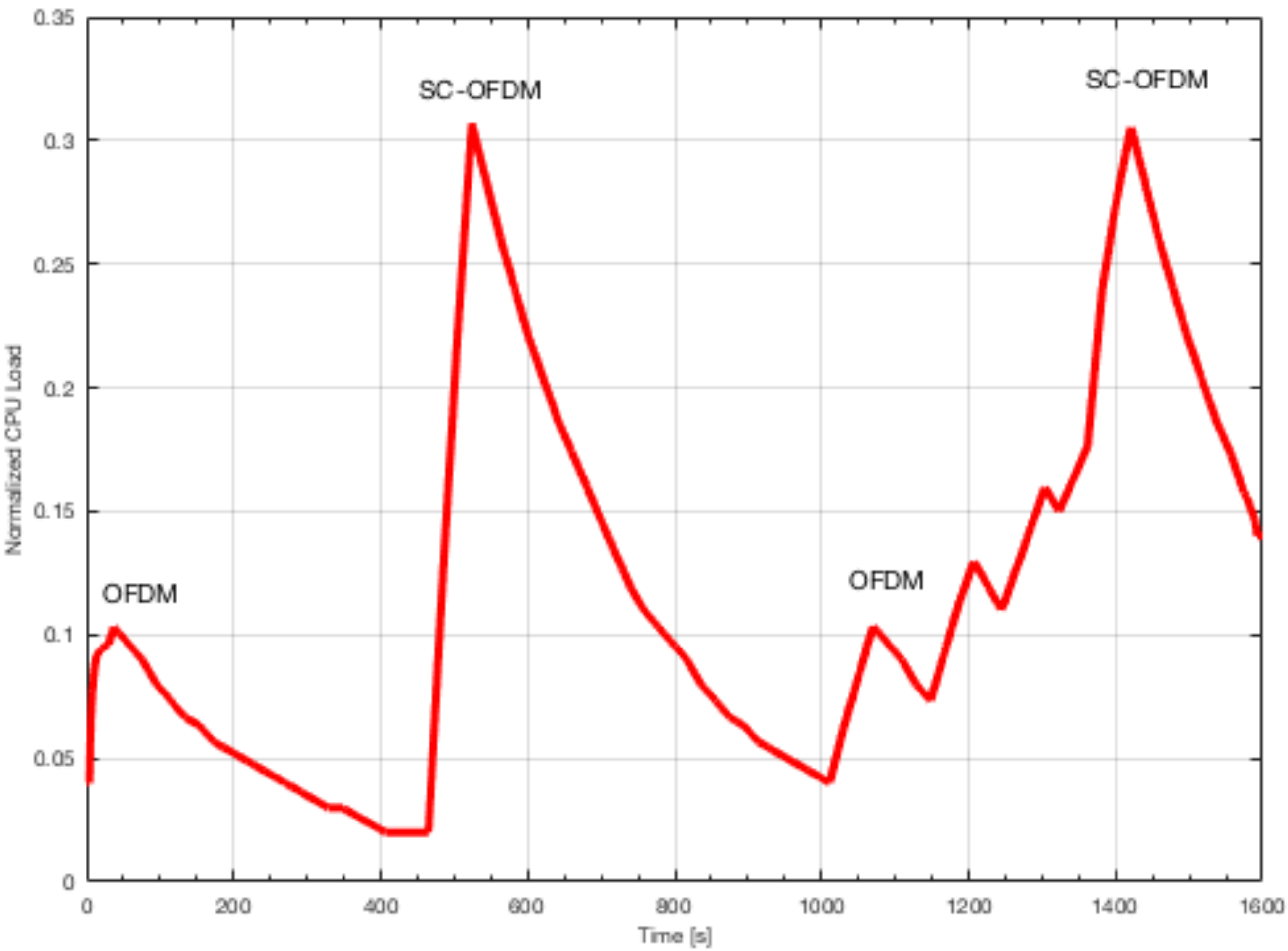






Experimental results (3)

- CPU load (measured at RX side):



COMMENT:

The dramatic link performance improvement yielded by SC-OFDM is paid by a noticeable increase of the computational complexity at the receiver side (<u>the CPU load is 3 times that of OFDM</u>)

Conclusion and future work

- This work has been focused on the implementation of a reconfigurable SDR-based dual-mode OFDM/SC-OFDM transceiver that can find applications both in terrestrial and satellite communications;

- The implementation has been carried out with GNU Radio tools and tested in open field by using Ettus USRP boards;

- The main achievement of the work is that OFDM and SC-OFDM can coexist in the same transceiver, provided that a computationally efficient hardware platform is employed, able at supporting SC-OFDM detection;

- Future work may concern with the introduction in the SDR chain of channel coding (turbo and/or LDPC coding, for instance) and the synthesis of further waveform formats like, e.g., constant-envelope OFDM (CE-OFDM) and CE-SCFDMA, already considered in literature, but not implemented with SDR and tested in open field.