A random network coding testbed: Implementation And Performance Results

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Outline

- Main Concepts
  - Network Coding
  - Cooperative Networking
  - Cooperative Network Coding
- Wireless Network Coded Systems
  - System Model
  - Random Network Coding
- Testbed Studies
  - Testbed Deployment-Details
  - Image Transmission Example
  - Test Results
- Conclusions

An Option: Network Coding (1/2)

- Conventional communication systems:
  - Network nodes function independently
    - Routing, error control coding and data storage have been designed in accordance with this independency principle
- Data flow rates from source nodes to destination nodes in a network can be increased by transmitting combinations of data [1]
- Stemming from the early works of in the form of multi-level diversity [2]

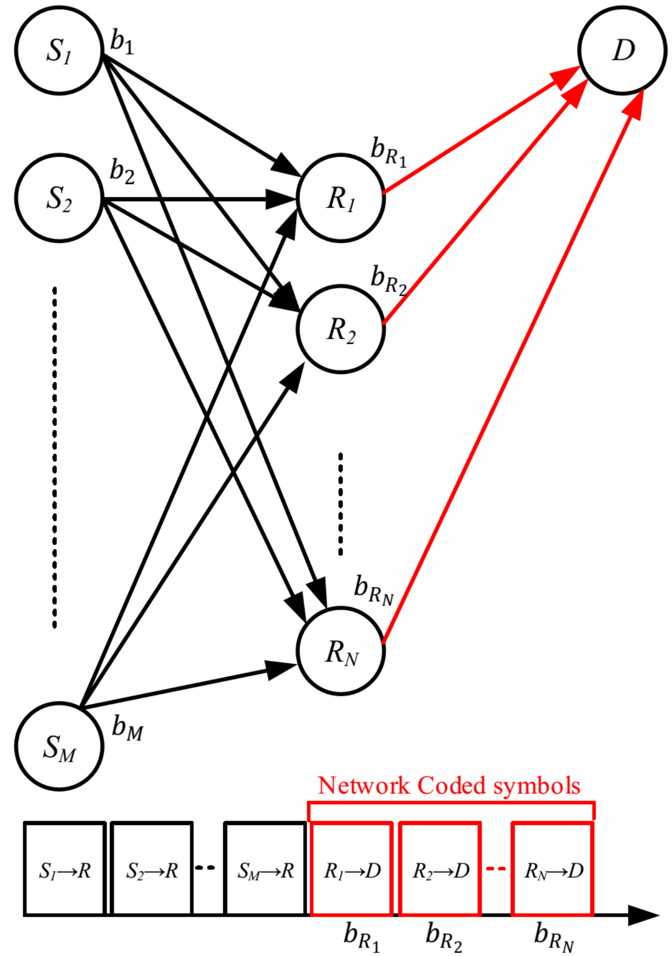
[1] R. Ahlswede, N. Cai, S.-Y. Li, and R. Yeung, “Network information flow,” IEEE Trans. Inf. Theory, vol. 46, no. 4, pp. 1204–1216, July 2000.
[2] R. Yeung, “Multilevel diversity coding with distortion,” Information Theory, IEEE Transactions on, vol. 41, no. 2, pp. 412–422, Mar 1995.

An Option: Network Coding (2/2)

- Generalized set-up:
  1. BROADCAST PHASE

     Source nodes transmit information symbols in N orthogonal resource block (time slots or frequency channels) during the multiple access phase (solid black lines) to relay nodes.
  2. RELAYING PHASE

     N relay nodes perform network coding on the M estimated symbols and transmit in N resource blocks in the to destination



The majority of the literature on network coding targets wired networks
(or application layer deployments)

Assumption: no erroneous transmissions

What about error propagation?

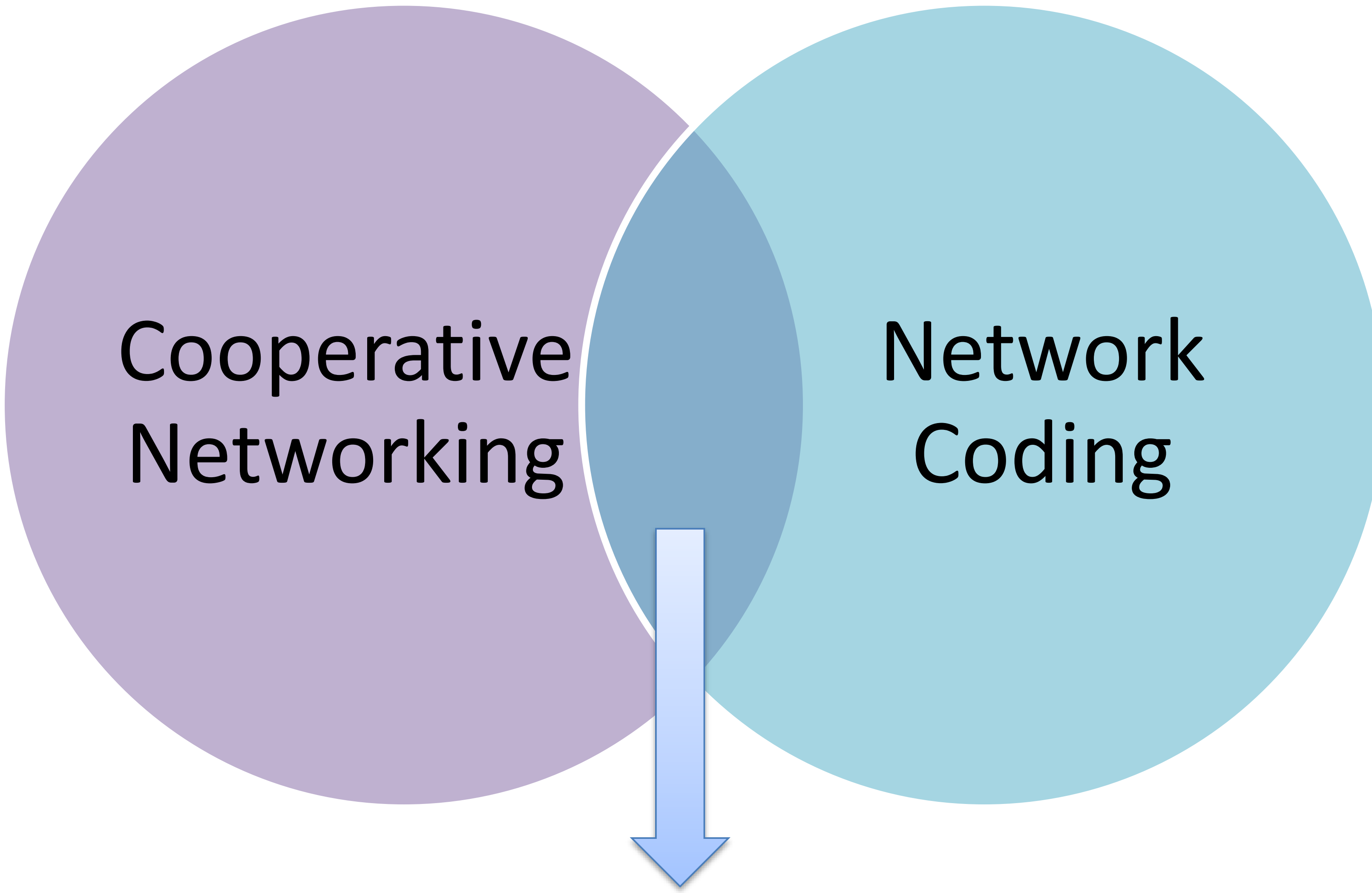
Main Idea

Wired Network Coding ≠ Wireless Network Coding

1. Fading channels
2. Direct source-destination links
   - Cooperative Diversity
   - Detector Design

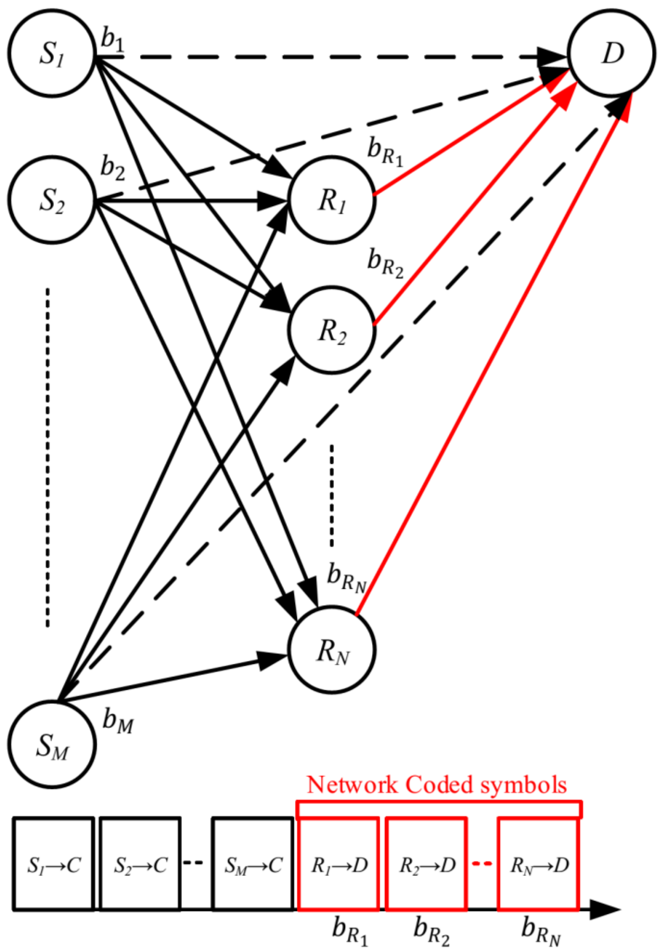
with test results !

+ Wireless Channels



Network Coded Cooperation

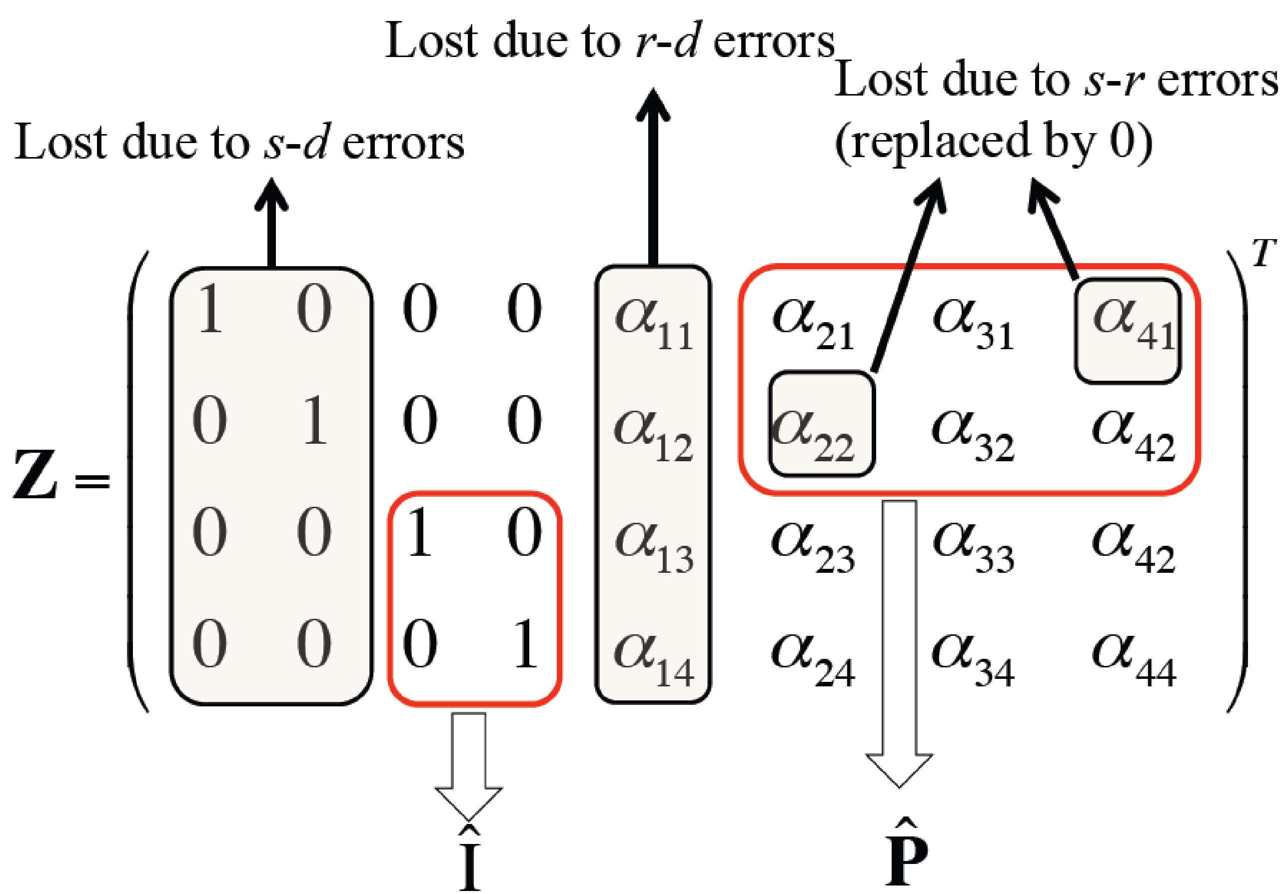
Network Coded Cooperation



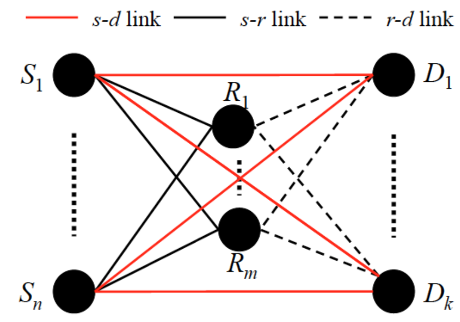
- Combining network coding and cooperative networking
- Can exploit the intrinsic characteristics of wireless networks to improve
  - Throughput
  - Robustness.
- Based on the preliminary works of Chen, Kishore and Li in [4].

[4] Y. Chen, S. Kishore, and J. Li, "Wireless diversity through network coding," WCNC 2006

Example: 4 source nodes, 4 relay nodes, broadcast transmission



Random Network Coding



- Random network coding at relay nodes
- In presence of direct communication links decoding probability becomes

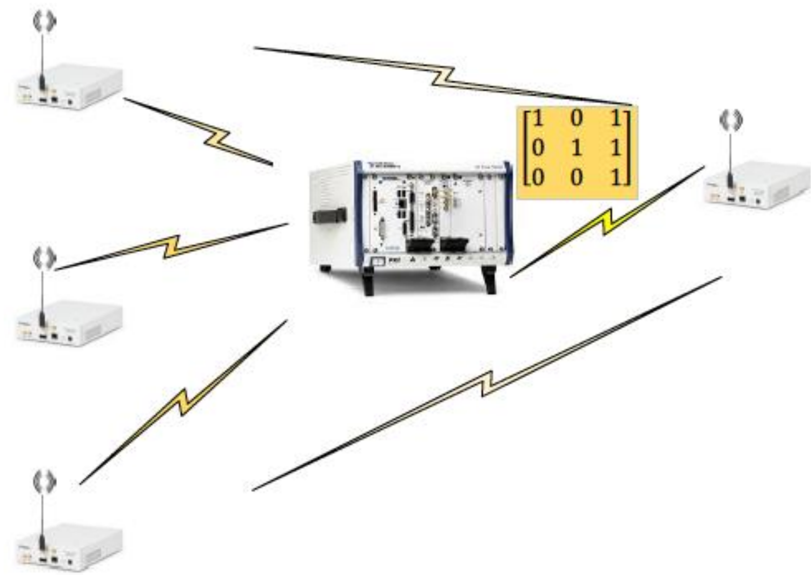
$$P_d = \sum_{k=0}^{n}\sum_{l=0}^{m-k}\sum_{t=0}^{m-l}\left[\binom{n}{k}\phi_{sd}^{k}(1-\phi_{sd})^{n-k}\binom{m}{l}\phi_{rd}^{l}(1-\phi_{rd})^{m-l}\binom{m-l}{t}\left(\frac{k\phi_{sr}}{n}\right)^{t}\left(1-\left(\frac{k\phi_{sr}}{n}\right)\right)^{m-l-t}\right]$$
$$\times\left[\sum_{p\in\wp_n(t)}\frac{\frac{n!}{x(p)}C(p)}{\sum_{p'\in\wp_n(t)}\frac{n!}{x(p')}C(p')}\frac{\left(\mathrm{mat}_q(k,m-l,\hat{S}_{p,1},k)\right)}{\sum_{r=0}^{k}\mathrm{mat}_q(k,m-l,\hat{S}_p,r)}\right]$$

$$\phi_u = 1-\exp\left(\left(-2^{R_u}-1\right)/\gamma_u\right) \qquad \text{where } u = sd, sr, rd$$

[6] S.Tedik Başaran, S. Gökceli, G.Karabulut Kurt, Enver Özdemir, Ergün Yaraneri, "Error Performance Analysis Random Network Coded Cooperative Systems in Wireless Channels," in preparation

Testbed Studies

- Implemented a cooperative network coded system using software defined radios
- 3 source nodes,
- 1 relay node
- 1 destination node



[10] S. Gökceli, H. Alakoca, S.Tedik Başaran, G.Karabulut Kurt, "OFDMA-based Network Coded Cooperation: Design and Implementation Using Software Defined Radio Nodes", EURASIP Journal on Advances in Signal Processing, EURASIP, 2016, November.

Hardware Details (1/2)

- Hardware Components:

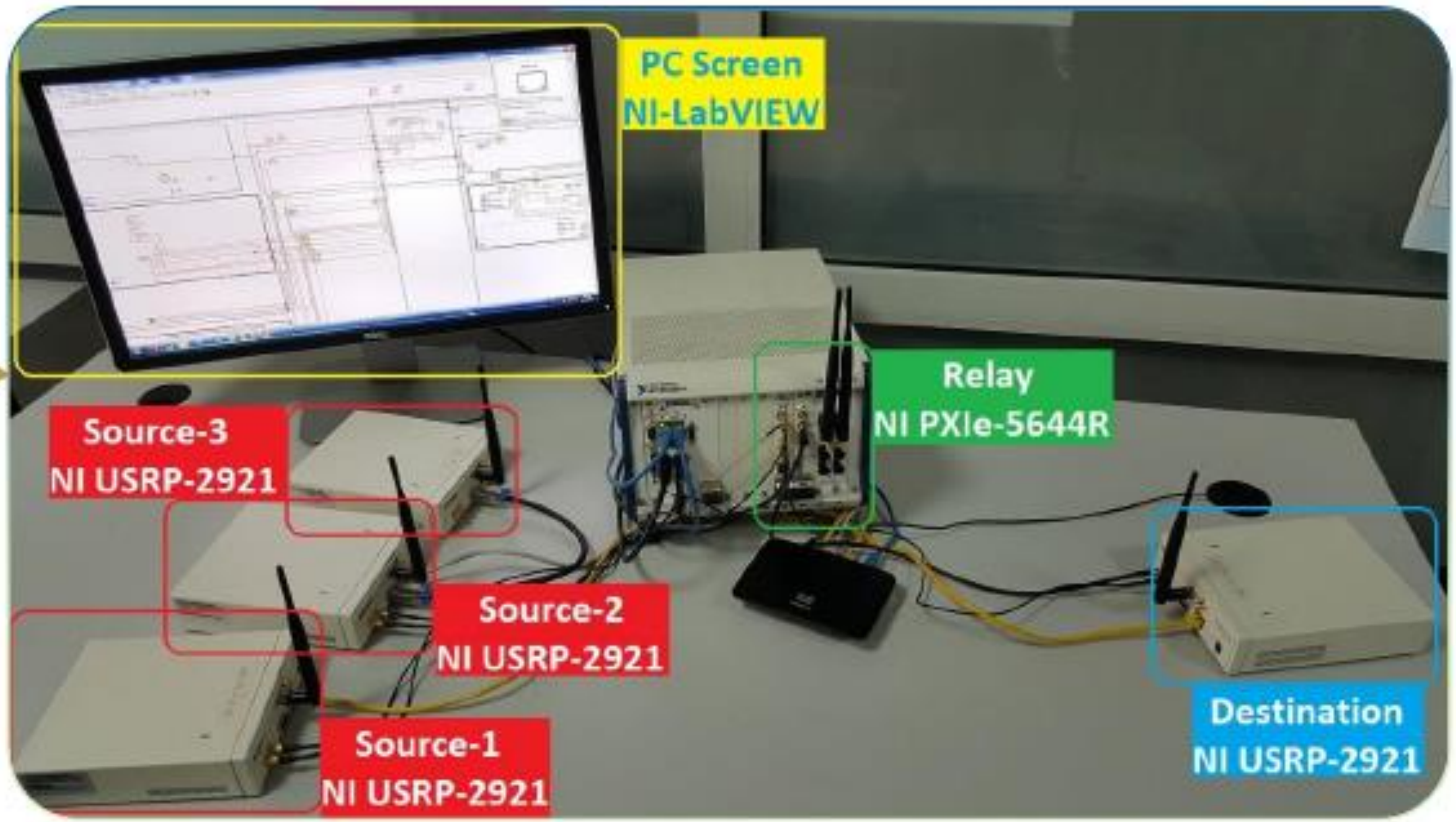
  - NI USRP-2921: Source and Destination Nodes, Instantaneous bandwidth up to 20 MHz
  - NI PXIe-1082 Chassis:
    - NI PXIe-5644R VST: Relay Node, Instantaneous bandwidth up to 80 MHz
    - NI PXI-6683: Clock Signal Source

Hardware Details (2/2)

- Synchronization Solution:

  - Three external 10 MHz signals are provided by NI PXI-6683 Timing and Synchronization Module
  - These signals are transmitted to two source nodes and destination node via cables
  - Remaining source node receives synchronization signal through MIMO cable
  - Synchronization configuration in code

Physical Set-up



Testbed Details (1/8)

- Software Component:

  -LabVIEW Software: Visual Programming Language, Programming with Virtual Instruments (VI)

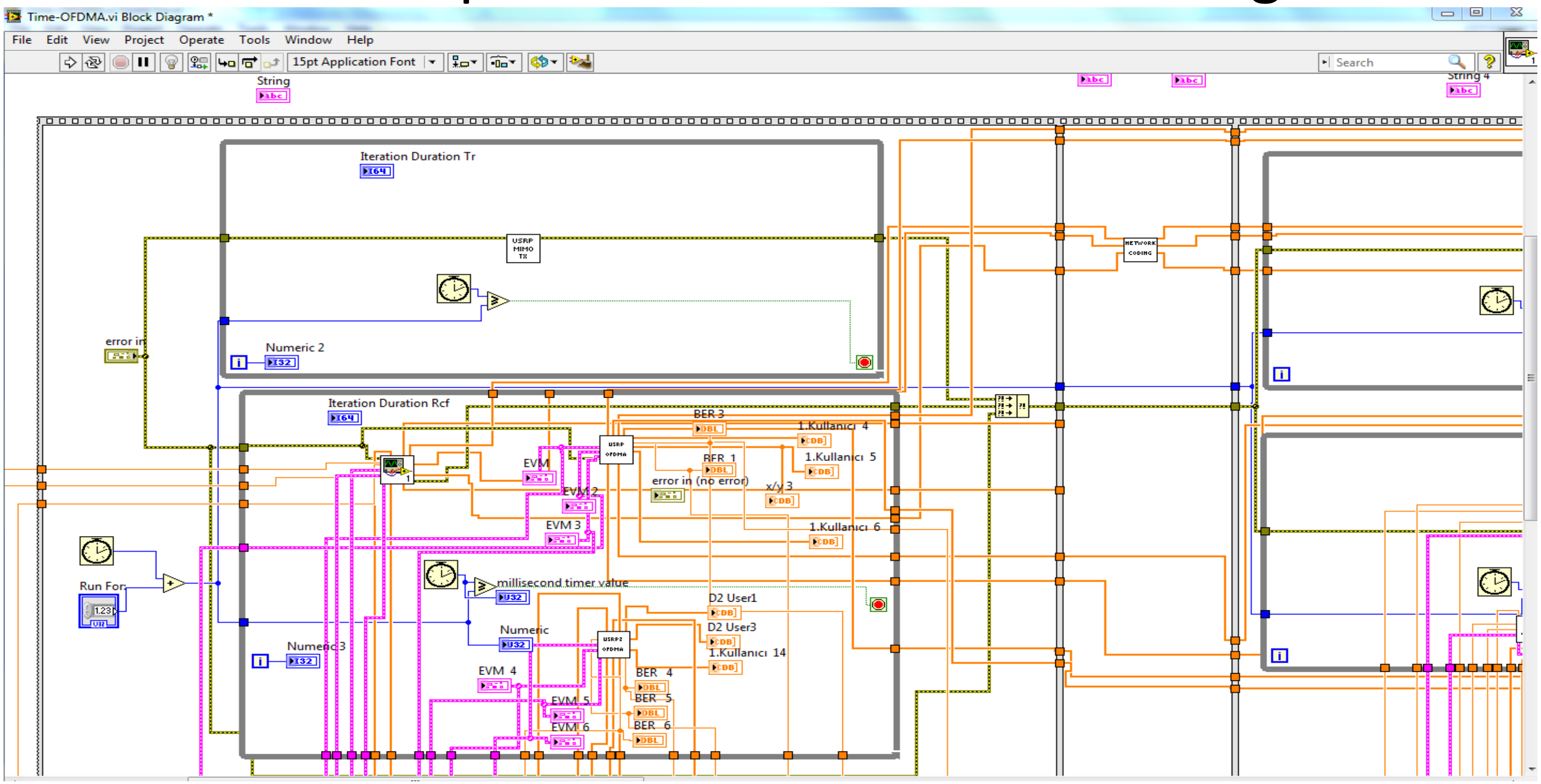
  -Timed Flat Sequence Structure: Main VI of the code, consists of:

    -Source, relay and destination node SubVI

    -Network coding and decoding SubVI

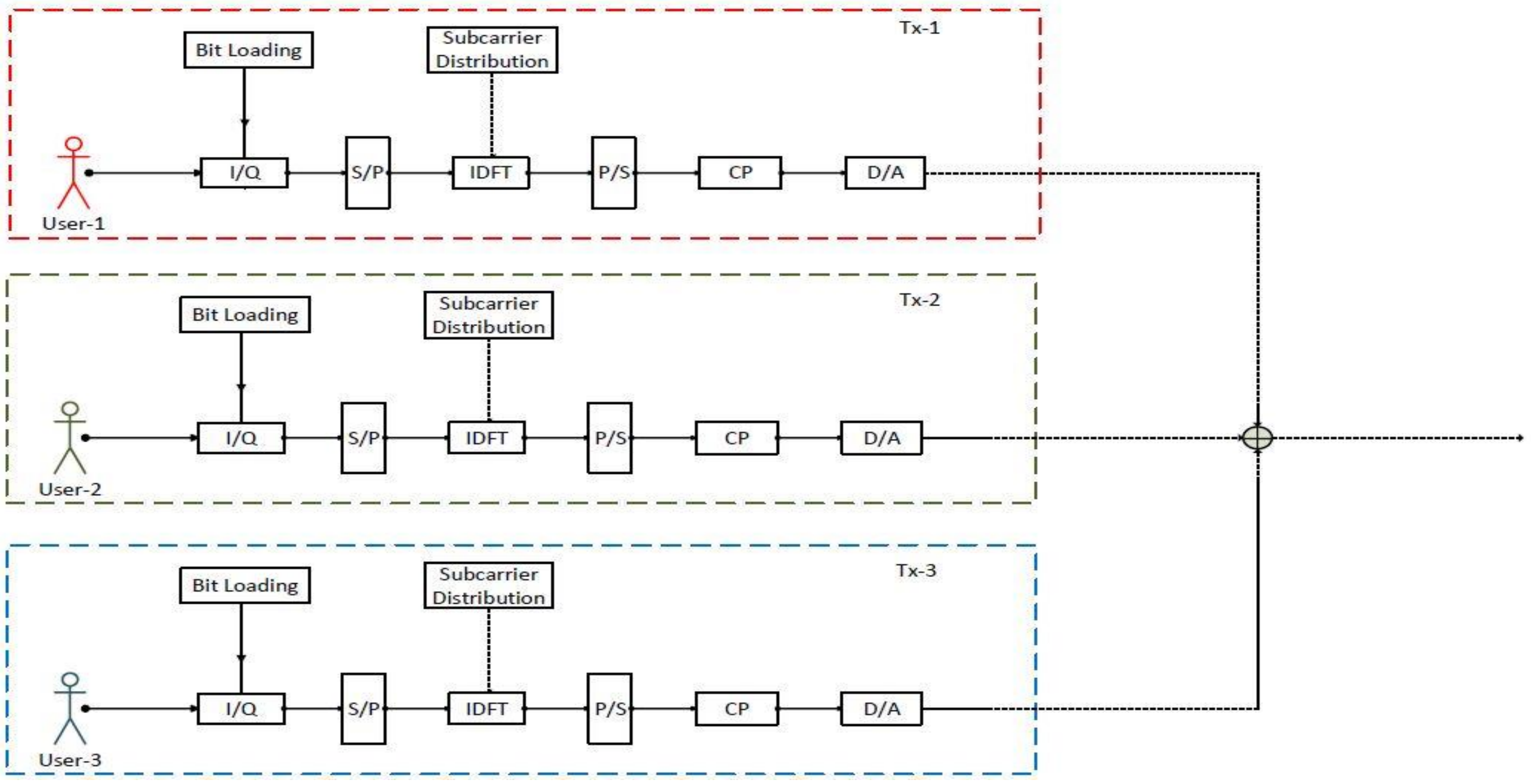
Testbed Details (2/8)

- Timed Flat Sequence Structure VI Block Diagram:



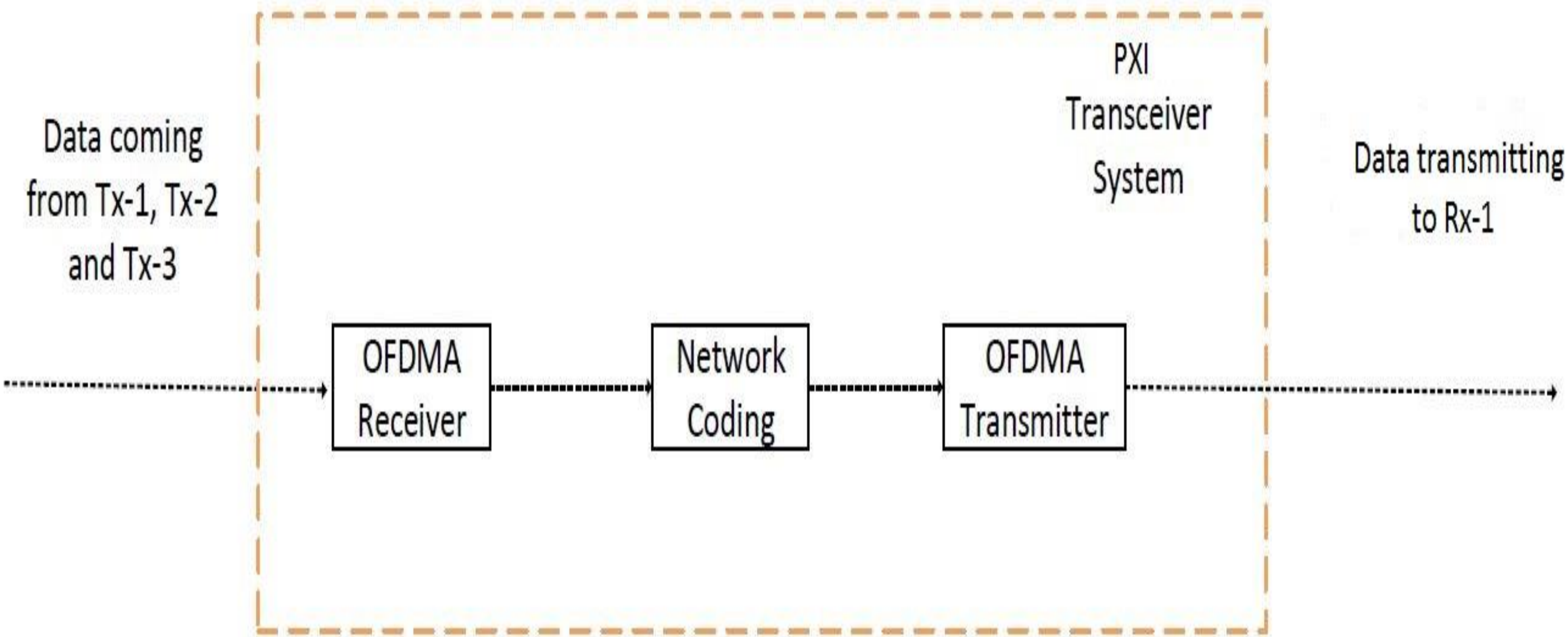
Testbed Details (3/8)

- Source node SubVI implementation structure:



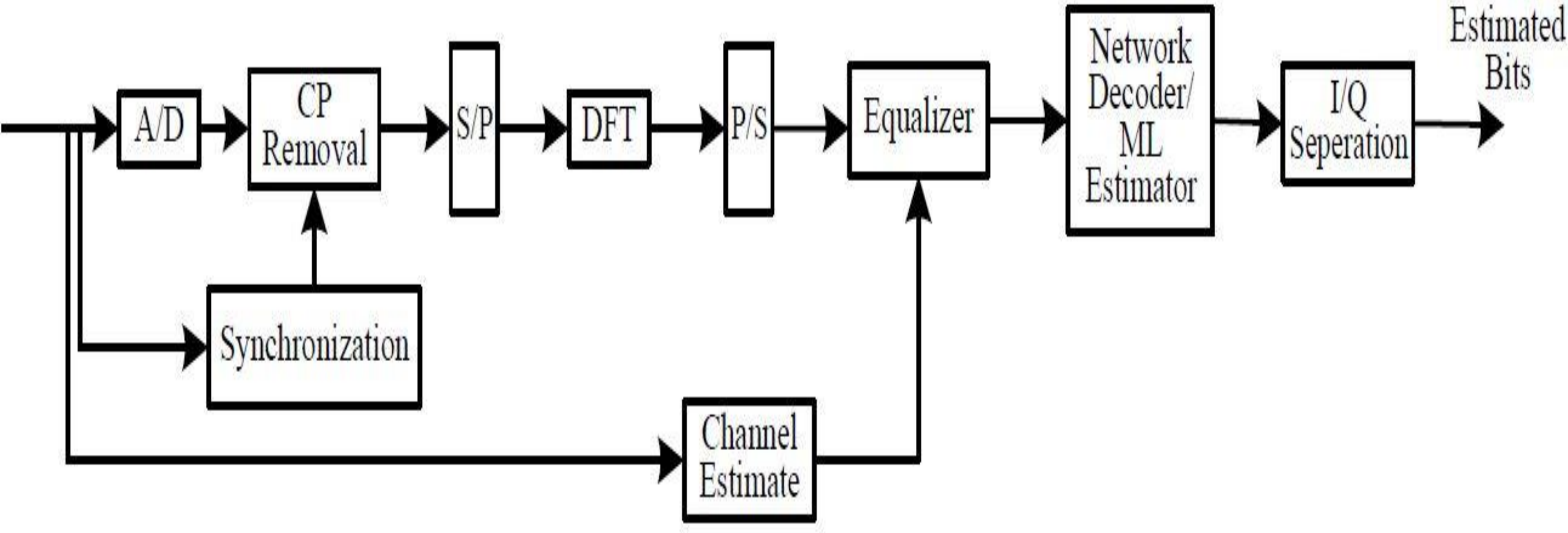
Testbed Details (4/8)

- Relay node SubVI implementation structure:



Testbed Details (5/8)

- Destination node SubVI implementation structure:

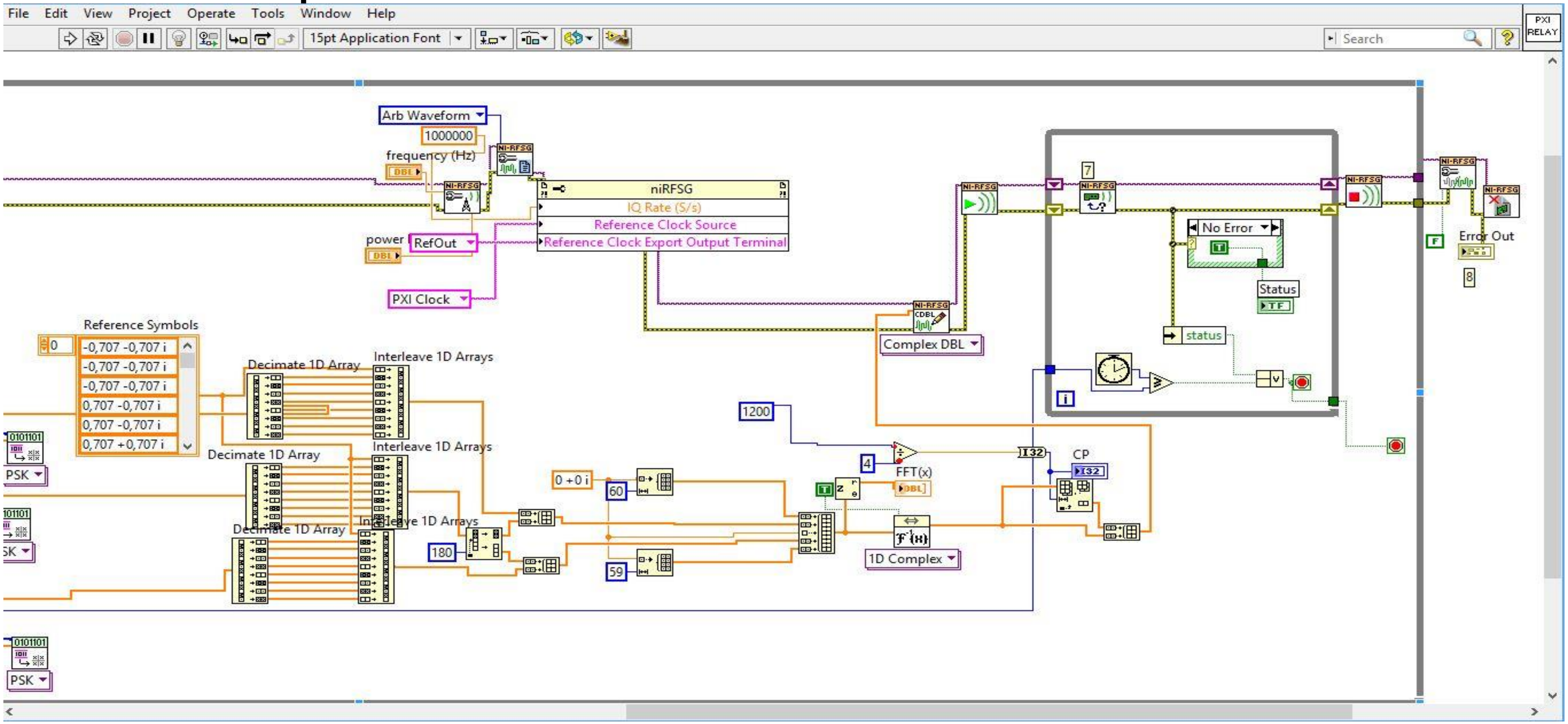


Testbed Details (6/8)

- Example of LabVIEW implementation:
  - -Relay SubVI's transmitter code:
    - -RFSG VI
    - -Modulation Toolkit VI
    - -Signal Processing Library VI
    - -Array functions

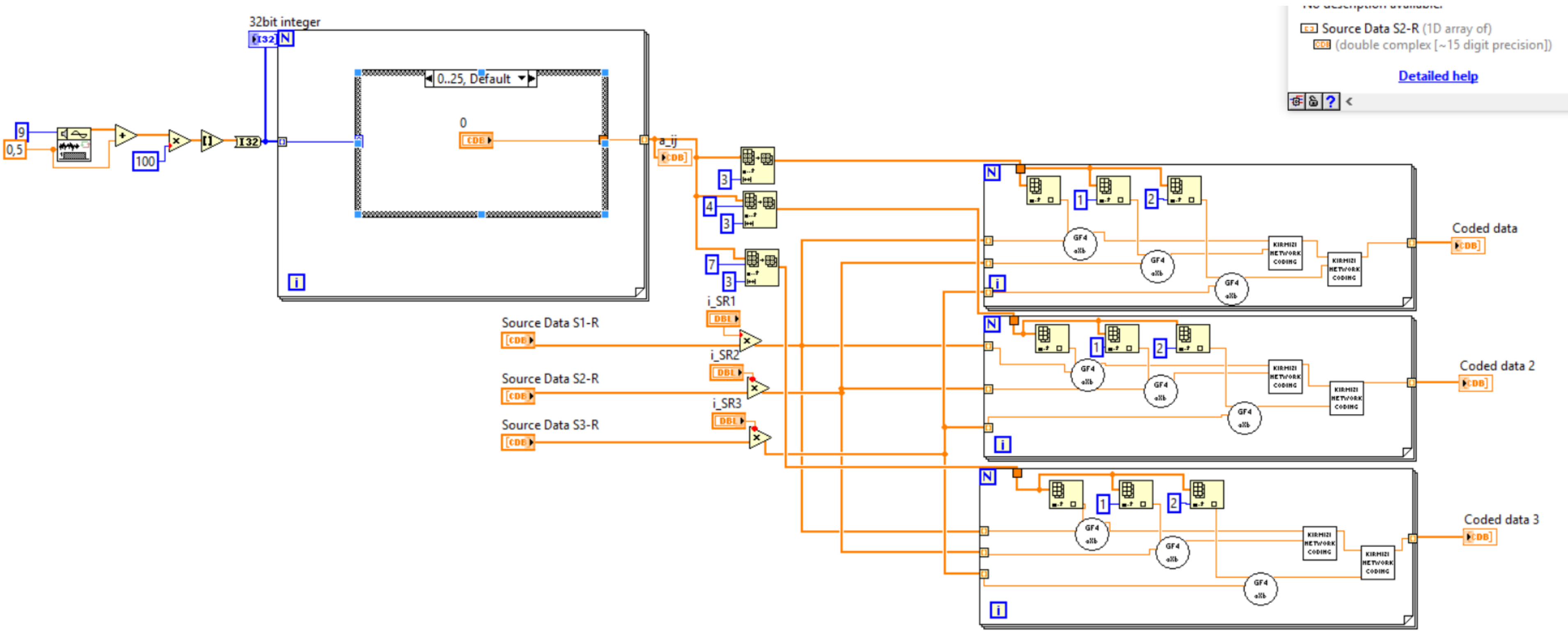
Testbed Details (7/8)

- Correspondent SubVI:



Testbed Details (8/8)

- Block diagram of relay network coding SubVI.

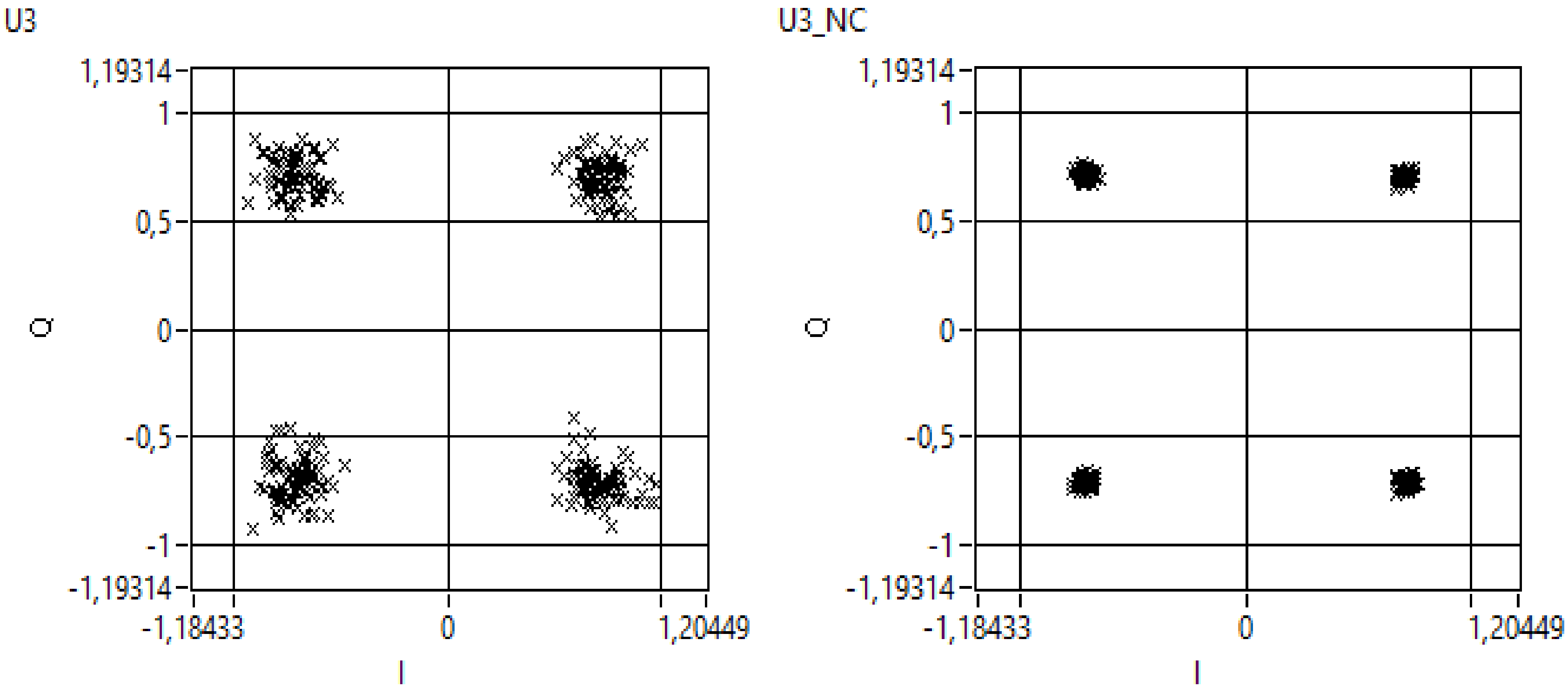


Test Parameters

Carrier frequency	2.45 GHz
I/Q data rate	1 MS/sec
Number of bits used in one frame	2080 bits
Number of 4-QAM symbols	1040 samples
Number of subcarriers of the one user data portion	320 samples
Number of reference subcarriers	40 samples
Number of source/relay/destination node	3/1/1
Zero padding/DFT/CP length	120/1200/300 samples
Distance between sources and destination	50 cm

Test Results (1/2)

- Exemplary received 4-QAM constellation diagrams:



Test Results – Image Transmission

- Image Transmission Implementation:

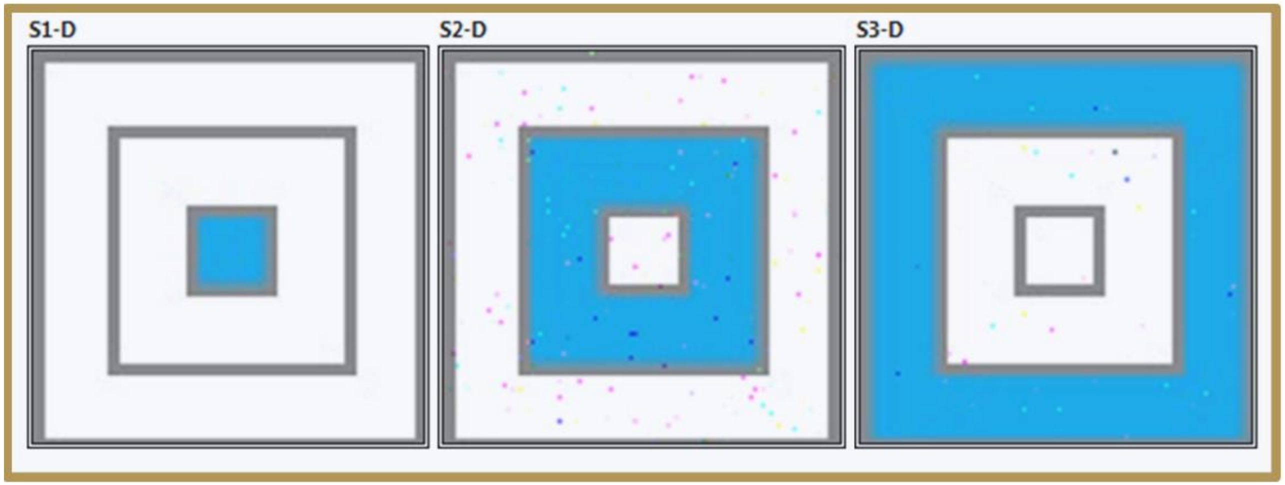
  -Packet Transmission Algorithm:

    -Dividing 100x100 pixel images to packets

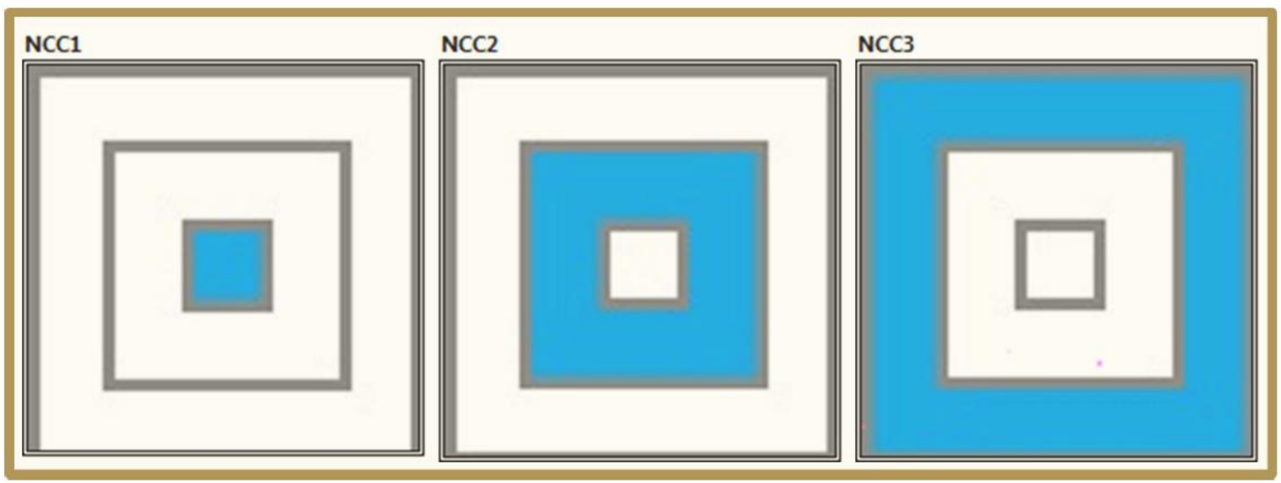
    -Index Portion: Shows packet's index number, %5 of the frame length

    -At Rx, by using index portion, packets are determined and put in right order to form image

Test Results – Image Transmission



without direct link



with direct link (NCC)

[11] S. Gökceli, S.Tedik Başaran, G.Karabulut Kurt, 'A Testbed for Image Transmission over a Network Coded Cooperation System', under review, *VTC Fall 2016*

Test Results (2/2)

- Decoding performances:

	EVM		
	SD	SR	RD
S1	0,62125	0,98375	0,870625
S2	0,657188	1	0,864063
S3	0,591563	1	0,870625

	Successful Decoding Probability	
2^q	Simulation Results	Test Results
2	0.091	0.091
4	0.112	0.111
8	0.123	0.124
16	0.127	0.129
32	0.131	0.128
64	0.133	0.134
128	0.132	0.133
256	0.133	0.133

Conclusions

- For practical applicability the impact of the wireless channel needs to be considered ➔Cooperative network coding systems
  - Non-zero error/erasure rates
  - Direct source destination links

Thank you!

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