BBC: Wireless Interconnect Network on Chip for Broadcast-Based Parallel Computing

UBO/ Lab-STICC (Antennas – Channel propagation):

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UR1/INRIA-IRISA (Digital Coms. - Transceiver):

O. Sentieys, J. Ortiz (PhD INRIA/UBS), D. Chillet, C. Killian

UBS-CNRS/Lab-STICC (NOC – Routing/Mapping):

J-Ph.Diguet, C.Roland, H. Kumar Mondal (postdoc), N. Chatterjee (posdoc)

Motivation

1. Scaling up Manycore, so NoC size
   ➜ More hops = Increase of NoC Latency

2. Inefficient implementation of Multicast and Broadcast communications
   ➜ **Parallel computing** : Barrier synchronization, Mutex
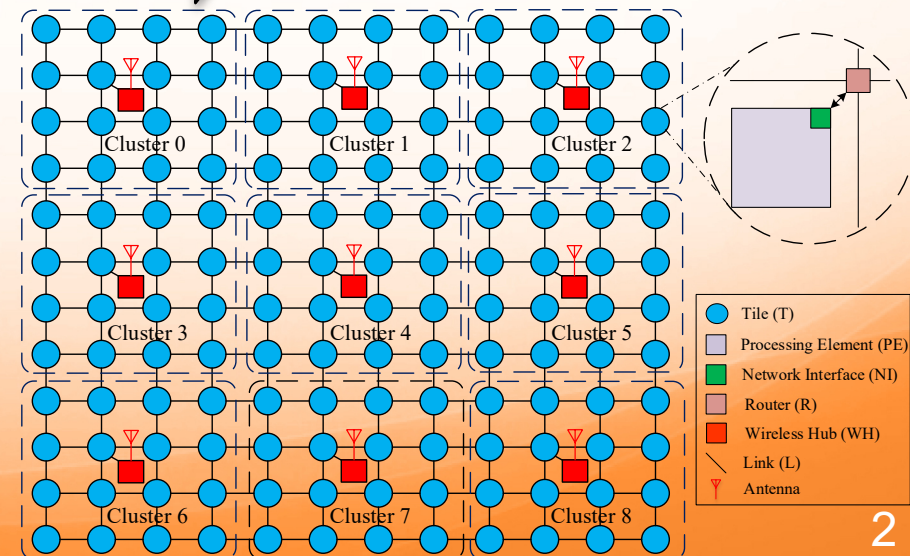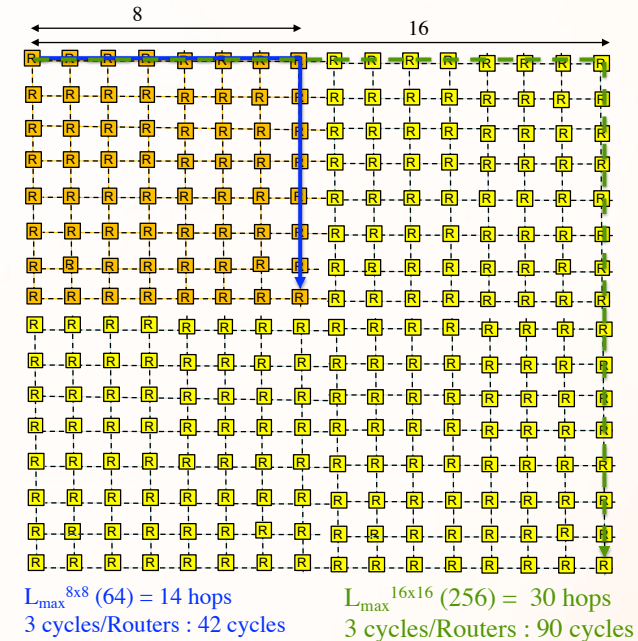   ➜ Cache Coherence protocol
   ➜ Applications such as DNN

3. Three types of Expertise
   ➜ Antenna & Channel Model (WP1)
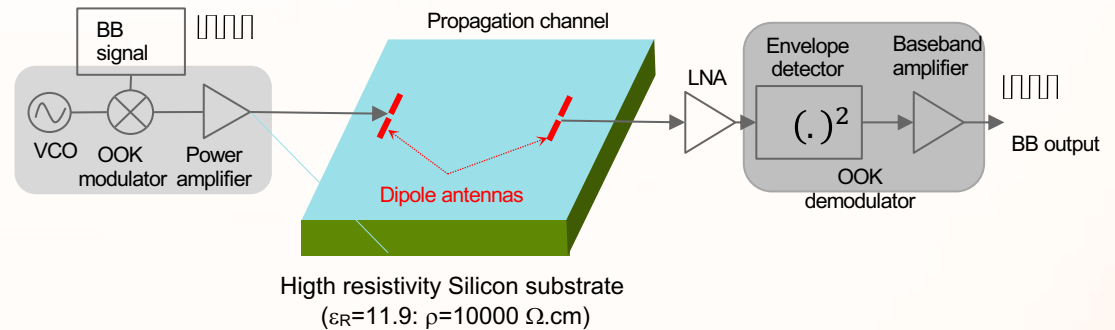   ➜ Digital Communications (WP2)
   ➜ NoC design & simulations (WP3)

L_{max}^{8x8} (64) = 14 hops
3 cycles/Routers : 42 cycles

L_{max}^{16x16} (256) = 30 hops
3 cycles/Routers : 90 cycles

Cluster 0   Cluster 1   Cluster 2
Cluster 3   Cluster 4   Cluster 5
Cluster 6   Cluster 7   Cluster 8

● Tile (T)
▢ Processing Element (PE)
▢ Network Interface (NI)
▢ Router (R)
■ Wireless Hub (WH)
＼ Link (L)
Ⴤ Antenna

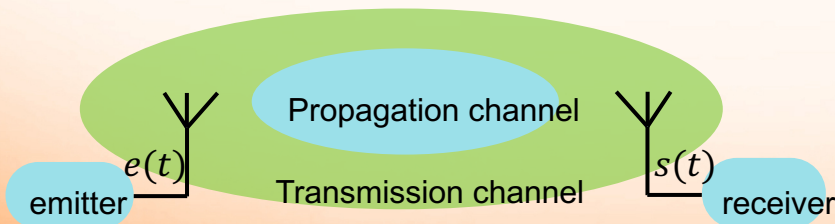# WP1: Study of physical layer

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- **Objectives**:
  - Physical layer analysis
  - Channel characterization (attenuation, multi-path, phase off-set,...)
  - Power consumption estimate for analogue-part .

- **Scheme for physical layer evaluation**

BB signal

VCO · OOK modulator · Power amplifier

Propagation channel

Dipole antennas

LNA · Envelope detector · $(.)^2$ · Baseband amplifier

OOK demodulator

BB output

Hight resistivity Silicon substrate
(ε_R=11.9: ρ=10000 Ω.cm)

- **Channel behaviour analysis**

emitter — $e(t)$ — Propagation channel — Transmission channel — $s(t)$ — receiver

- **Characterization**

Propagation channel :

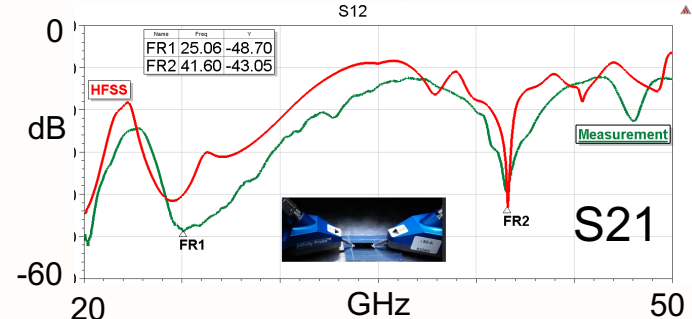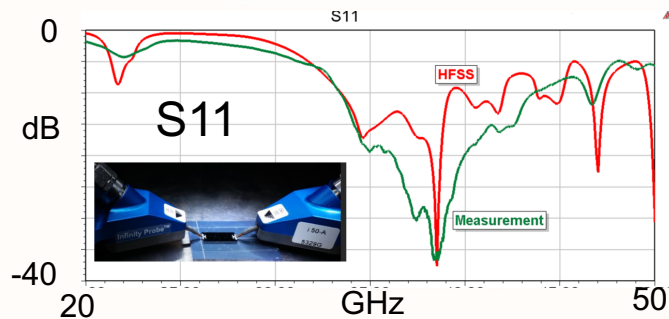$$G_a = \frac{|S_{ij}|^2}{(1 - |S_{ii}|^2)\left(1 - |S_{jj}|^2\right)}$$
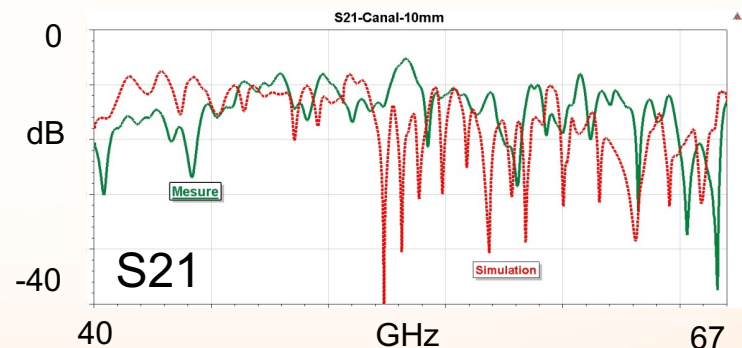
transmission channel :

$$S_{ij}$$
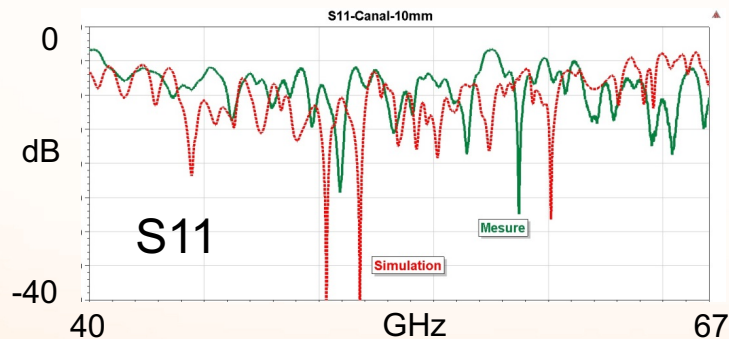
- **Measurement** in Q and V band (**30-67 GHz**)
- EM **simulations** (HFSS/CST) in sub terahertz band (around **200 GHz**)

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- **Ka band: measurement / EM simulation comparisons**

- **U-V band: measurement / EM simulation comparisons**


- **Conclusions**

  - Good matching between measurements and EM simulations
  - Responses with multiple resonances and transmission zeros => substrate act as a EM cavity with multiple stationary modes:
 - To be useful the cavity behavior must be avoided

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WP1: Proposed solution

- **Design of a solution to avoid substrate cavity behavior** : we propose to surround the Si HR with a Si-LR (Low Resistivity => high losses)

- Use of **doped Si around High Resistivity** Si substrate to act as **absorbing layer (Si-BR)**

- Limit effects of interface Silicon/Air: limit reflections and interferences.
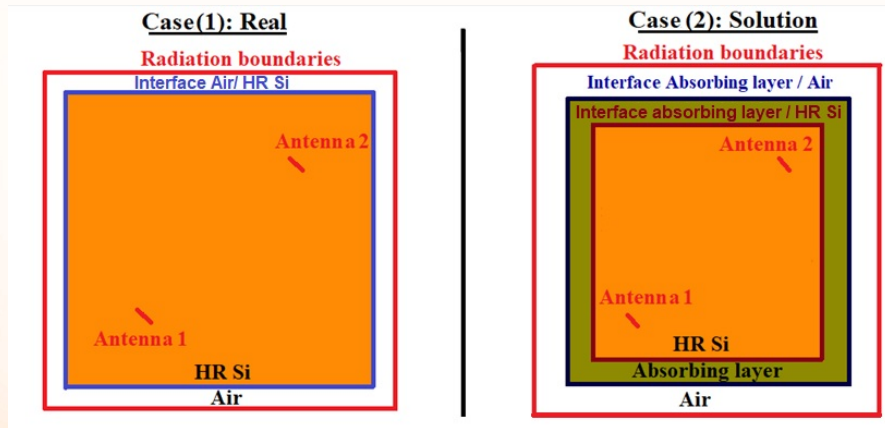
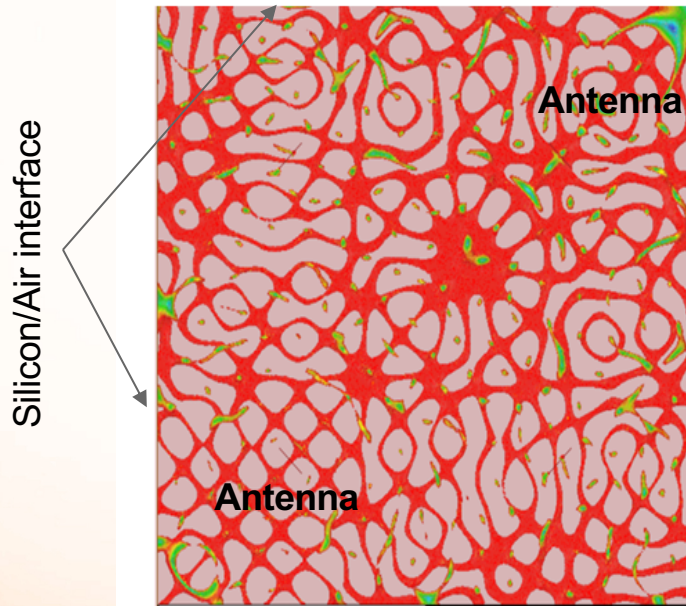Conductivity of Si-LR can be controlled using voltage polarization

Supply (V)	ρ (Ohm.cm)	σ (S/m)
0	2500	0,04
-0,6	**4**	**25**
-1	0,02	6667
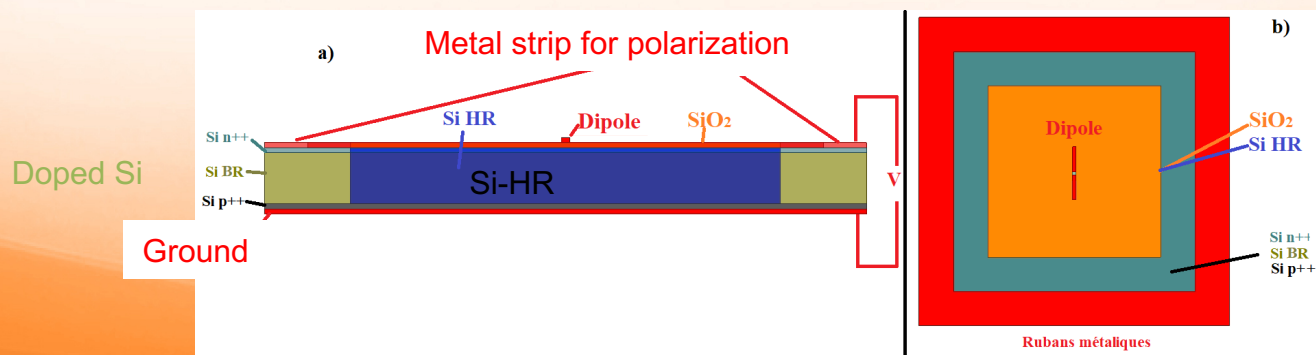
WP1: Absorbing layer assessment

- **E field distribution in the Si substrate**

Without absorbing layer

With a absorbing layer surrounding the Si-HR substrate

Silicon/Air interface

Antenna

Antenna

BR Silicon/Air interface

Absorbing layer

Antenna

Antenna

Cavity E field distribution
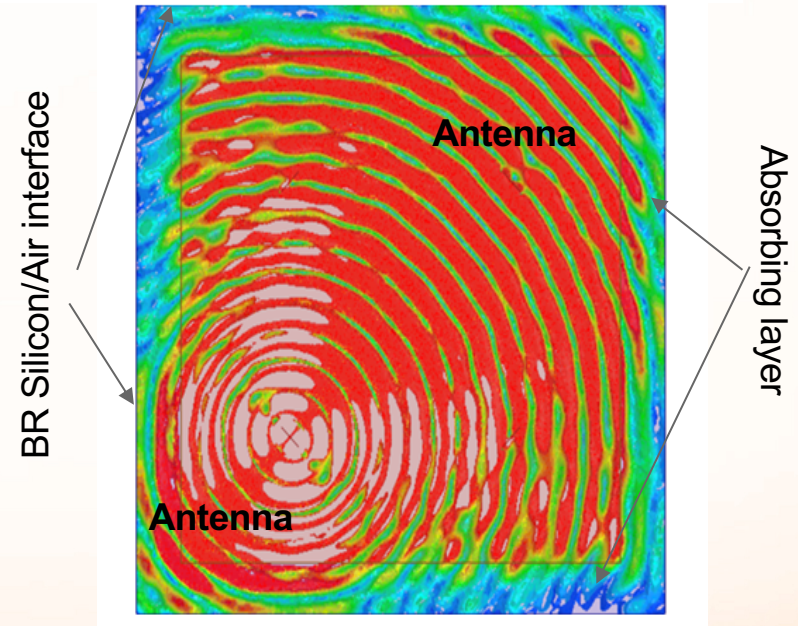
Propagating E field distribution

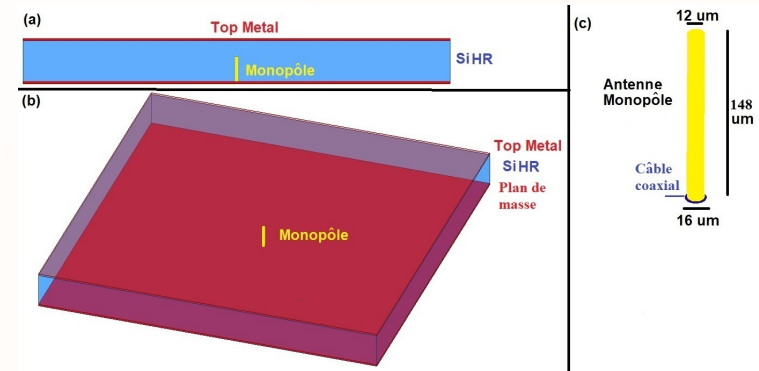Many transmission zeros

Few transmission zeros
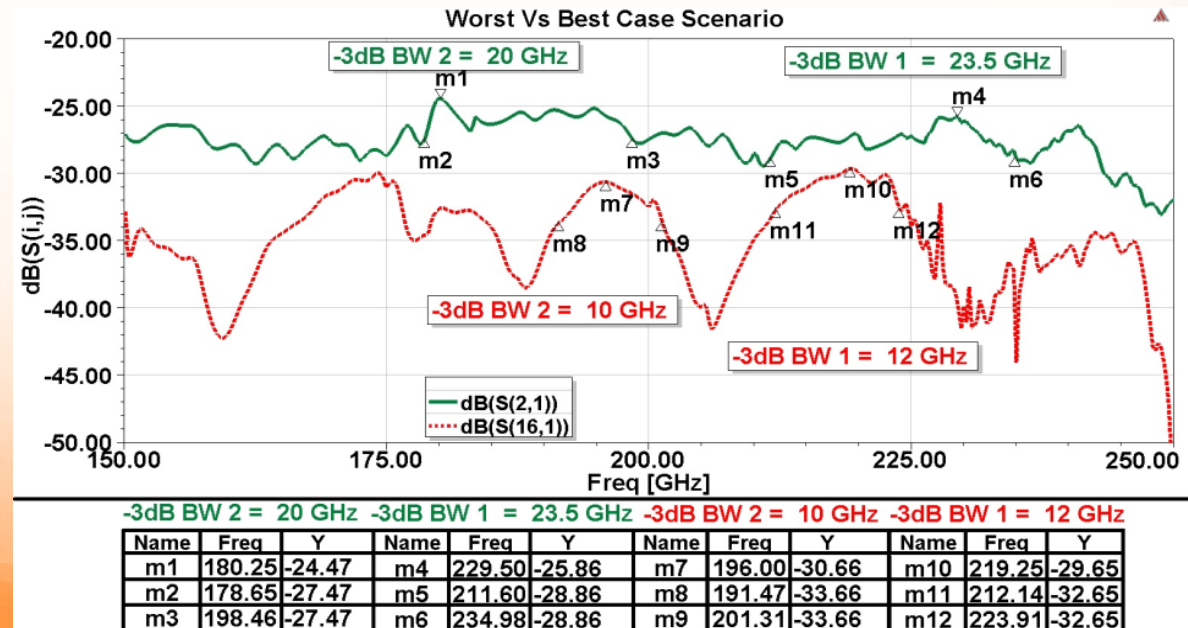
- **Measurement validation**
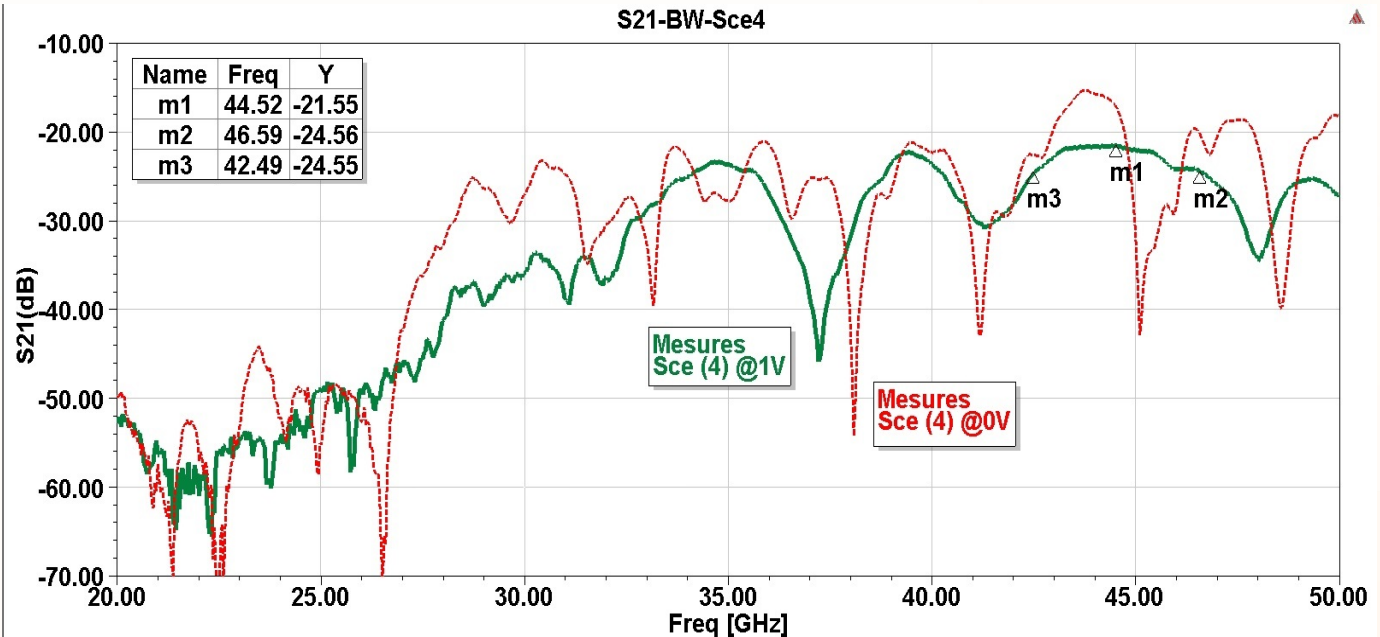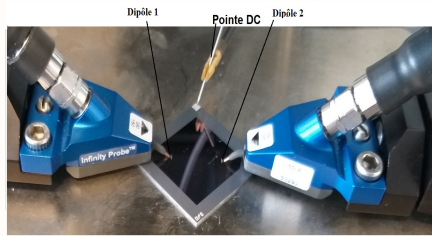
- **Solution evaluation**
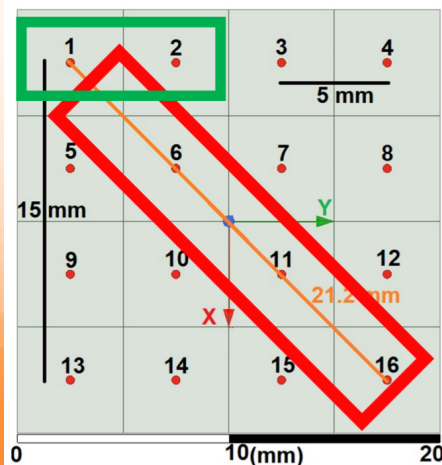 - Smoothly behaviour for the S21 parameter (transmission) using Si-LR
  - Available -3dB band (variation of S21) is Larger
  - The maximum of transmission parameter S21 is smaller
  - Additional surface of absorbing layer (around λ @ 40 GHz) is
  - Consumption due to polarization can be expensive (around 100 mW)

- **Control of Si/Air boundary have to be improved (consumption)**

- **Using a dedicated Si-HR substrate** (with surrounding absorbing layer) as propagation media and 2 metal plane at bottom and top of substrate

  - Radiation in the substrate
  - Monopole integrated in Si HR substrate with a coaxial access
 - 2 metal planes => good EM compatibility performances

- **EM simulation of 16 clusters**

			Name	Freq	Y	Name	Freq	Y	Name	Freq	Y	Name	Freq	Y
			m1	180.25	-24.47	m4	229.50	-25.86	m7	196.00	-30.66	m10	219.25	-29.65
			m2	178.65	-27.47	m5	211.60	-28.86	m8	191.47	-33.66	m11	212.14	-32.65
			m3	198.46	-27.47	m6	234.98	-28.86	m9	201.31	-33.66	m12	223.91	-32.65

WP2: Digital com. and Transceiver
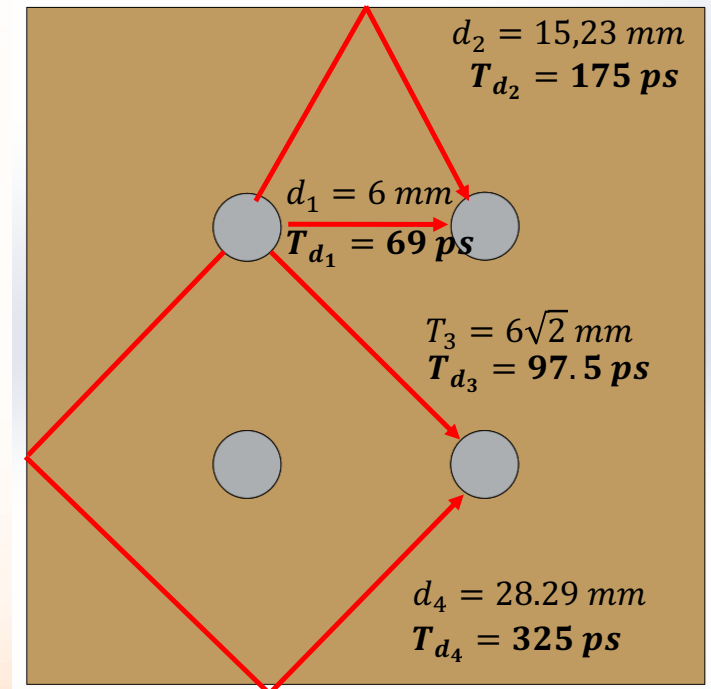
- **Problems**
  - **How to deal with WiNoC reliability in Multi-path Channel Environment**
  - **How to share bandwidth for concurrent communications**

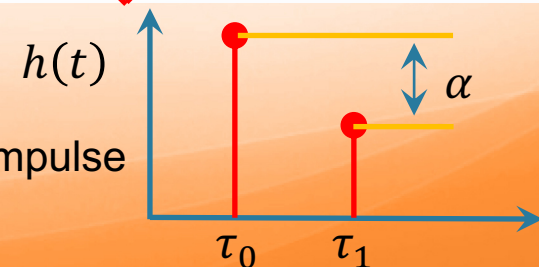- At least **three types of waves** are propagated over intra-chip channel
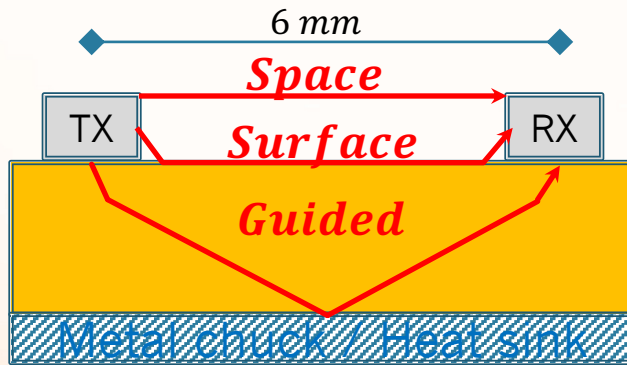
Attenuation: $A_{Si} \ll A_{Air}$
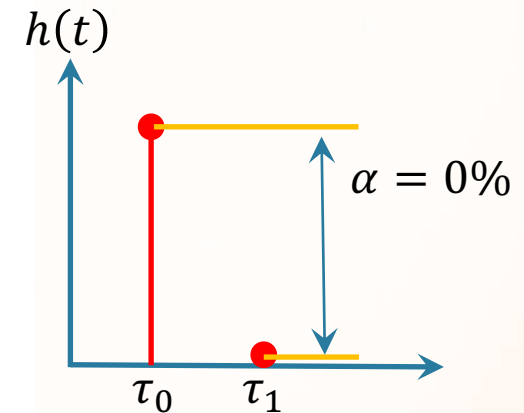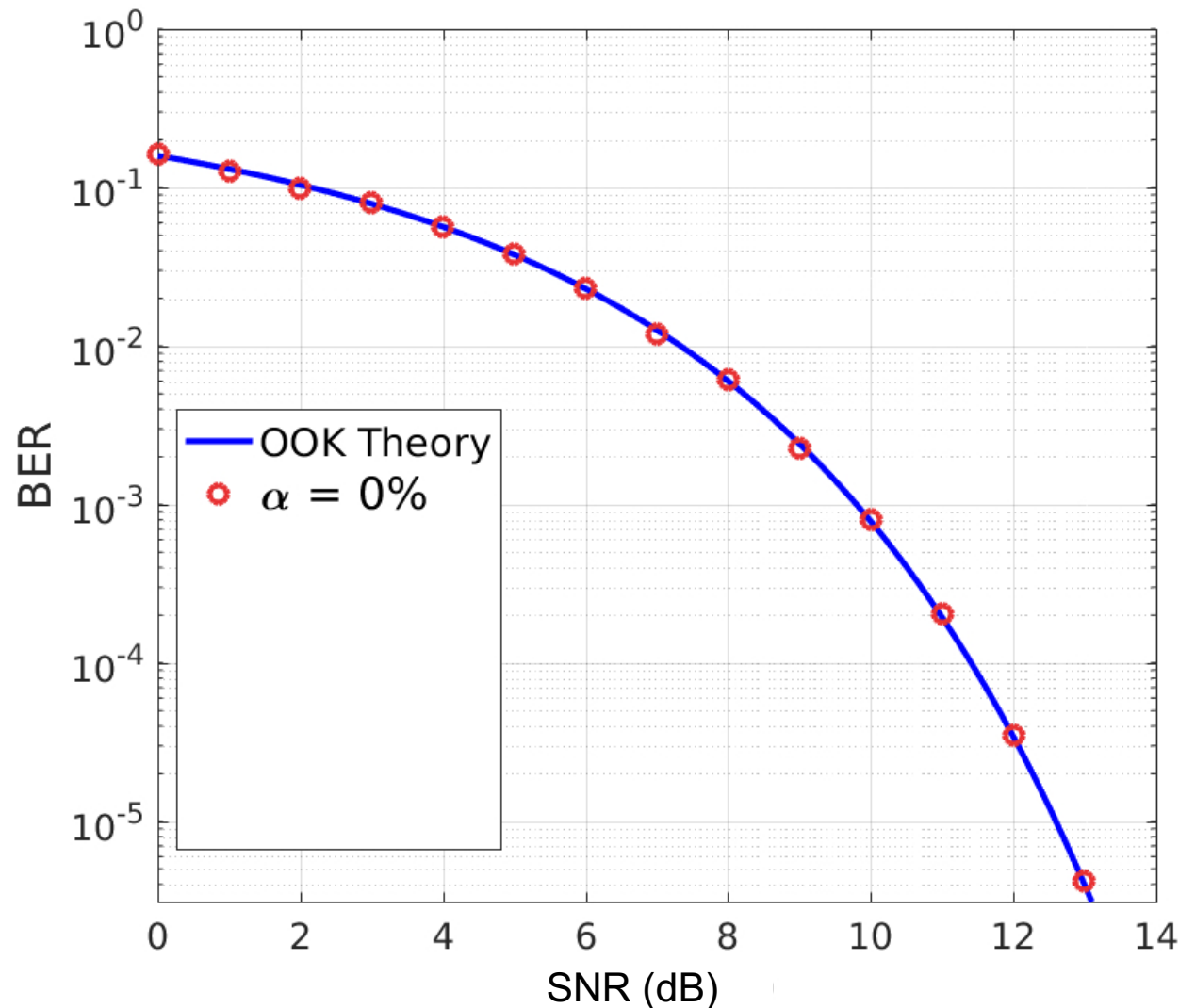
- **Dominant path is mainly surface wave**

- **Reflected Path due to chip edge**

$d_2 = 15{,}23 \; mm$
$T_{d_2} = 175 \; ps$

$d_1 = 6 \; mm$
$T_{d_1} = 69 \; ps$

$T_3 = 6\sqrt{2} \; mm$
$T_{d_3} = 97.5 \; ps$

$d_4 = 28.29 \; mm$
$T_{d_4} = 325 \; ps$

$h(t)$

CIR:
(Channel Impulse Response)

α

τ_0 τ_1

WP2: Digital com. and Transceiver

- **Multipath Effect in OOK**

Graph: BER vs SNR (dB), with legend "OOK Theory" (blue line) and "$\alpha = 0\%$" (red circles).

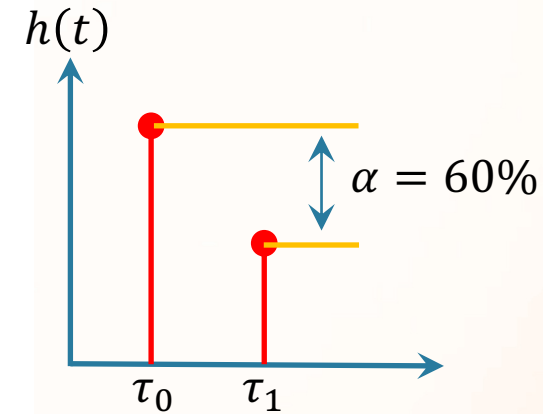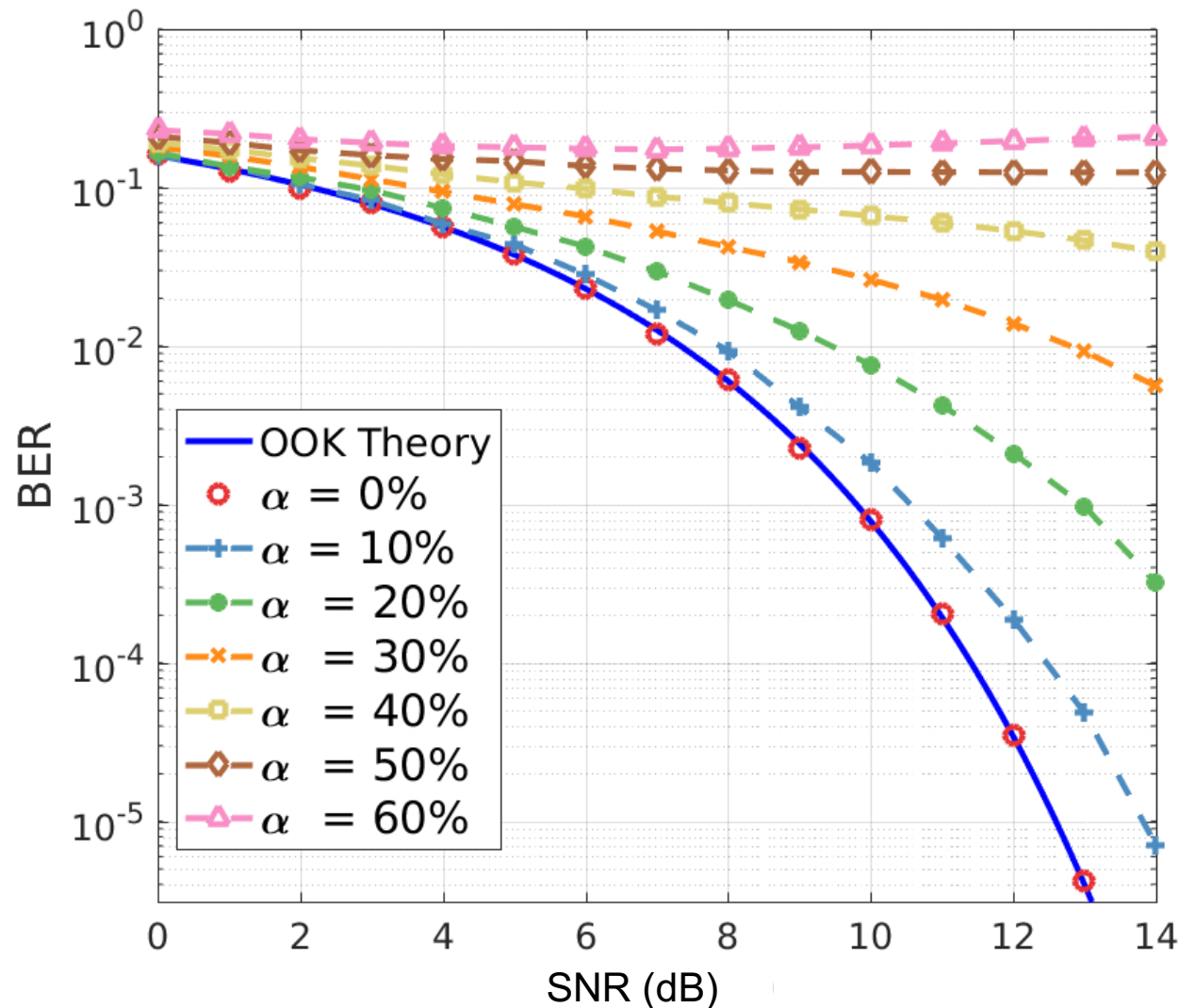Channel impulse response $h(t)$ with rays at τ_0 and τ_1, $\alpha = 0\%$.

- ❑ **Two-ray model**, time invariant and frequency selective channel

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- **Multipath Effect in OOK**

❑ **Two-ray model**, time invariant and frequency selective channel

❑ **Communication degrades rapidly**

WP2: Digital com. and Transceiver

- **Objectives**
  - Demonstrate significant degradation of WiNoC facing multi-path propagation
  - Propose **channel cancellation techniques** to improve reliability
  - **Design** and validate a **transceiver** architecture
  - Show **small overhead** and **significant improvement** of WiNoC reliability

WP2: Digital com. and Transceiver

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- **Channel compensation**

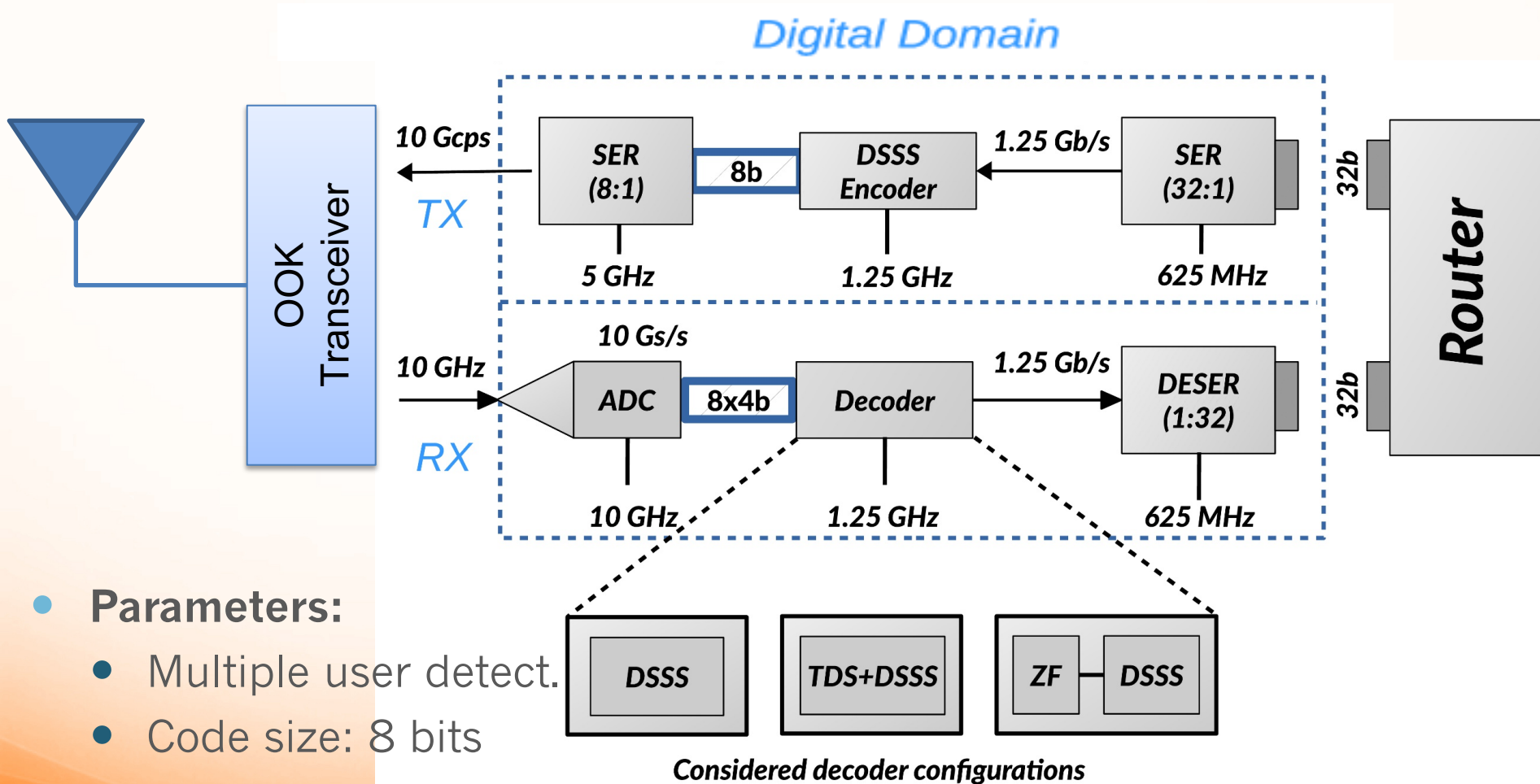| DS-Spread Spectrum (DSSS)	Time Diversity (TDS+DSSS)	Zero-Forcing Equalizer (ZF)

- ❑ Resistant to multi-path effects and interferences
- ❑ **Multiple users can share the channel**

- ❑ Multiple versions of the same signal are combined to increase SNR

- ❑ Applies the channel frequency inverse
- ❑ Increases noise power

DSSS Encoder

$C_{i,j} = 10011001$

data

1

0

XNOR

Coded data

10011001

01100110

TDS+DSSS

τ_0 $Corr_0$

τ_1 $Corr_1$

MRC

$h(t)$ α

τ_0 τ_1

ZF

$C(f) = \dfrac{1}{H(f)}$

$|H(f)|$

Frequency

$|Q(f)|$

Frequency

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WP2: Digital com. and Transceiver

- **Improving WiNoC Reliability**

Digital Domain

Considered decoder configurations
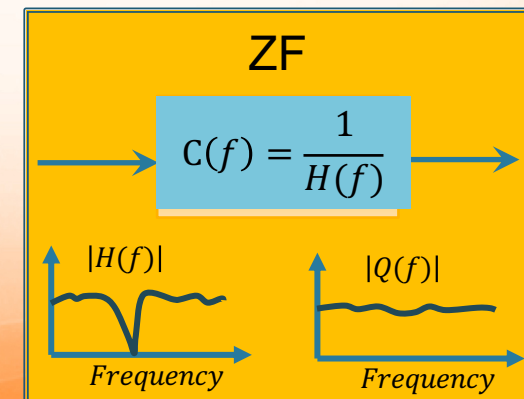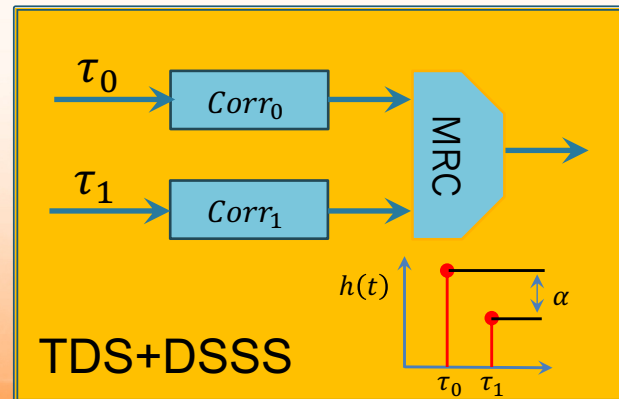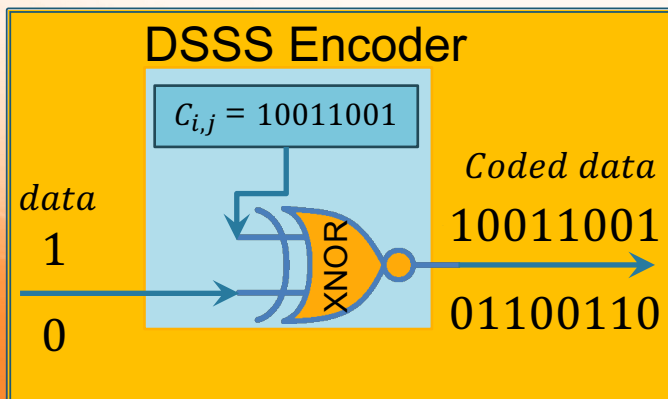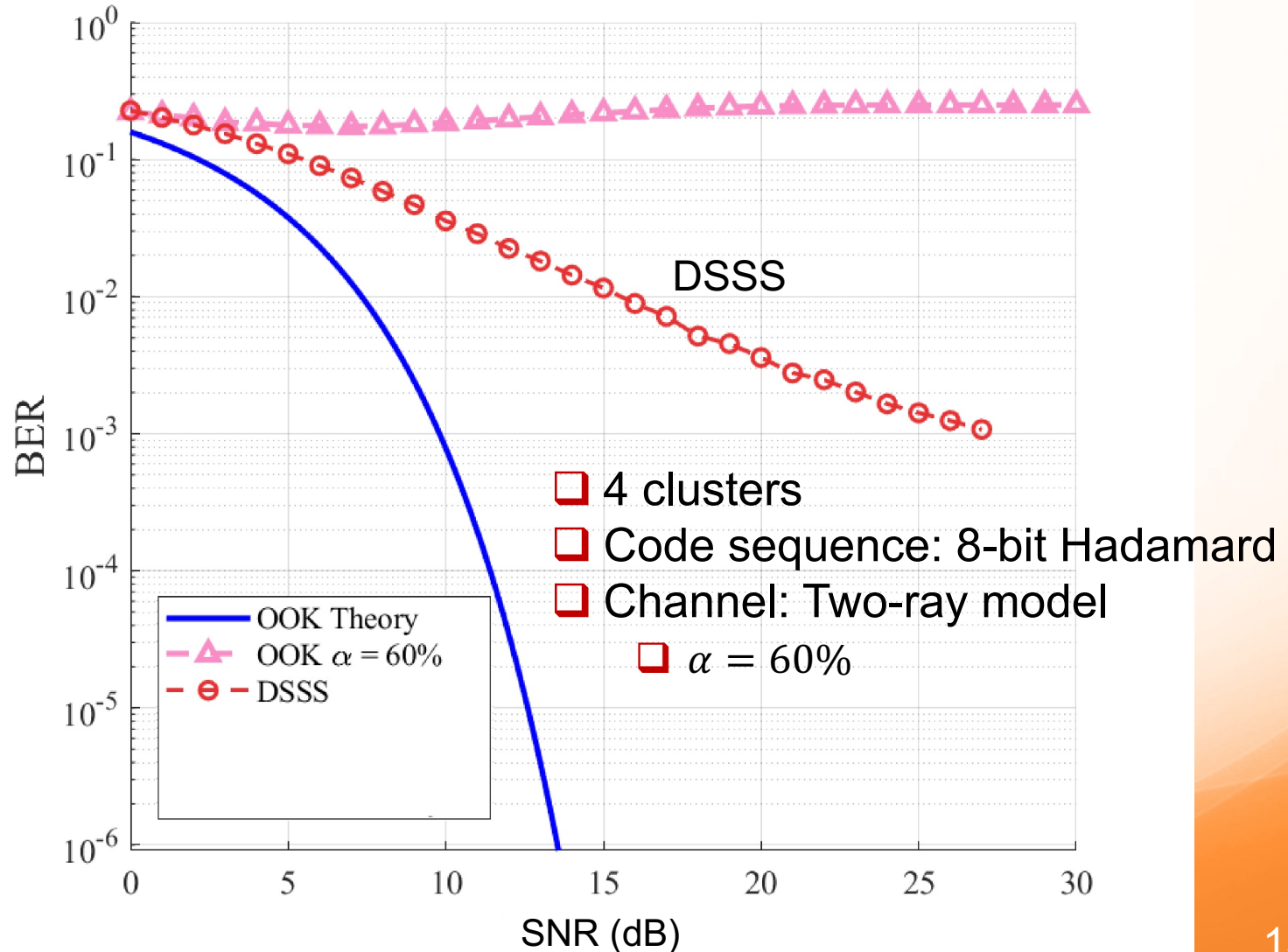
- **Parameters:**
  - Multiple user detect.
  - Code size: 8 bits
  - Data rate: 10 Gb/s
  - SAR ADC: ENOB=4 bits, time-interleaved

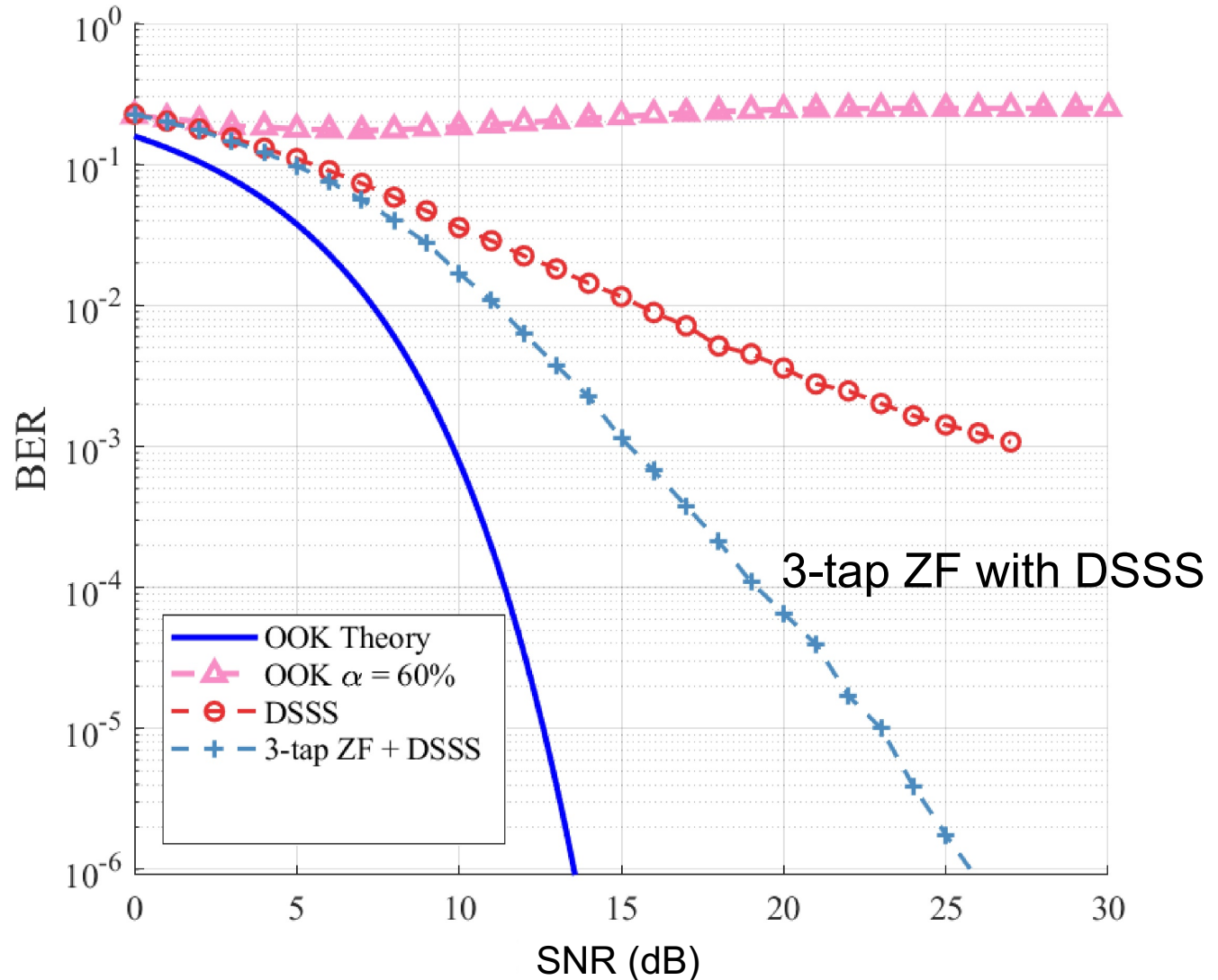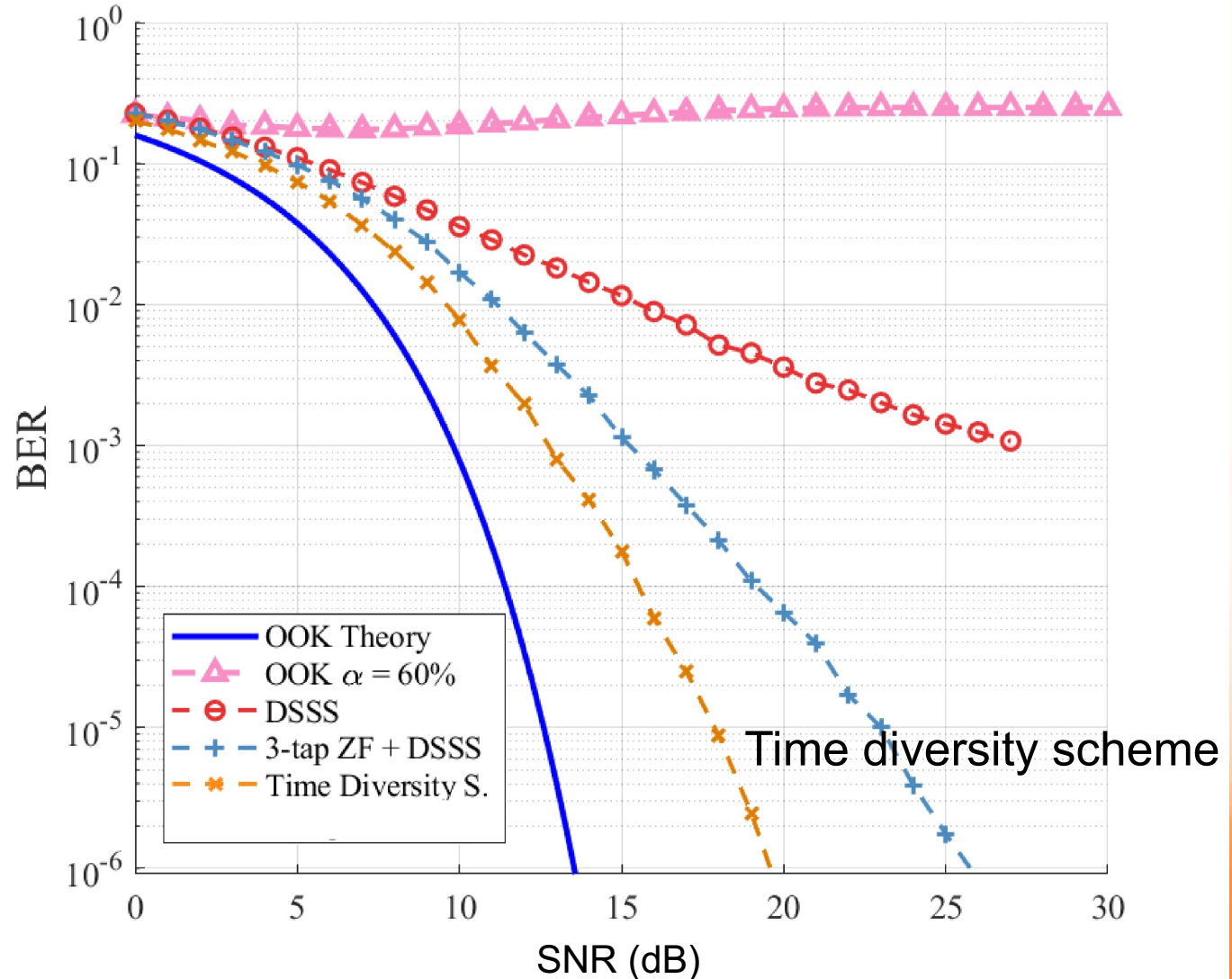- **Improving WiNoC Reliability**
  - Results:

DSSS

❑ 4 clusters
❑ Code sequence: 8-bit Hadamard
❑ Channel: Two-ray model
    ❑ $\alpha = 60\%$

Legend:
— OOK Theory
— △ — OOK $\alpha = 60\%$
— ⊖ — DSSS

WP2: Digital com. and Transceiver

- **Improving WiNoC Reliability**
  - Results:

3-tap ZF with DSSS

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- **Improving WiNoC Reliability**
  - Results:

Legend:
- OOK Theory
- OOK $\alpha = 60\%$
- DSSS
- 3-tap ZF + DSSS
- Time Diversity S.

Axis labels: BER (y-axis), SNR (dB) (x-axis)

Time diversity scheme

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- **Improving WiNoC Reliability**
  - Results:

WP2: Digital com. and Transceiver
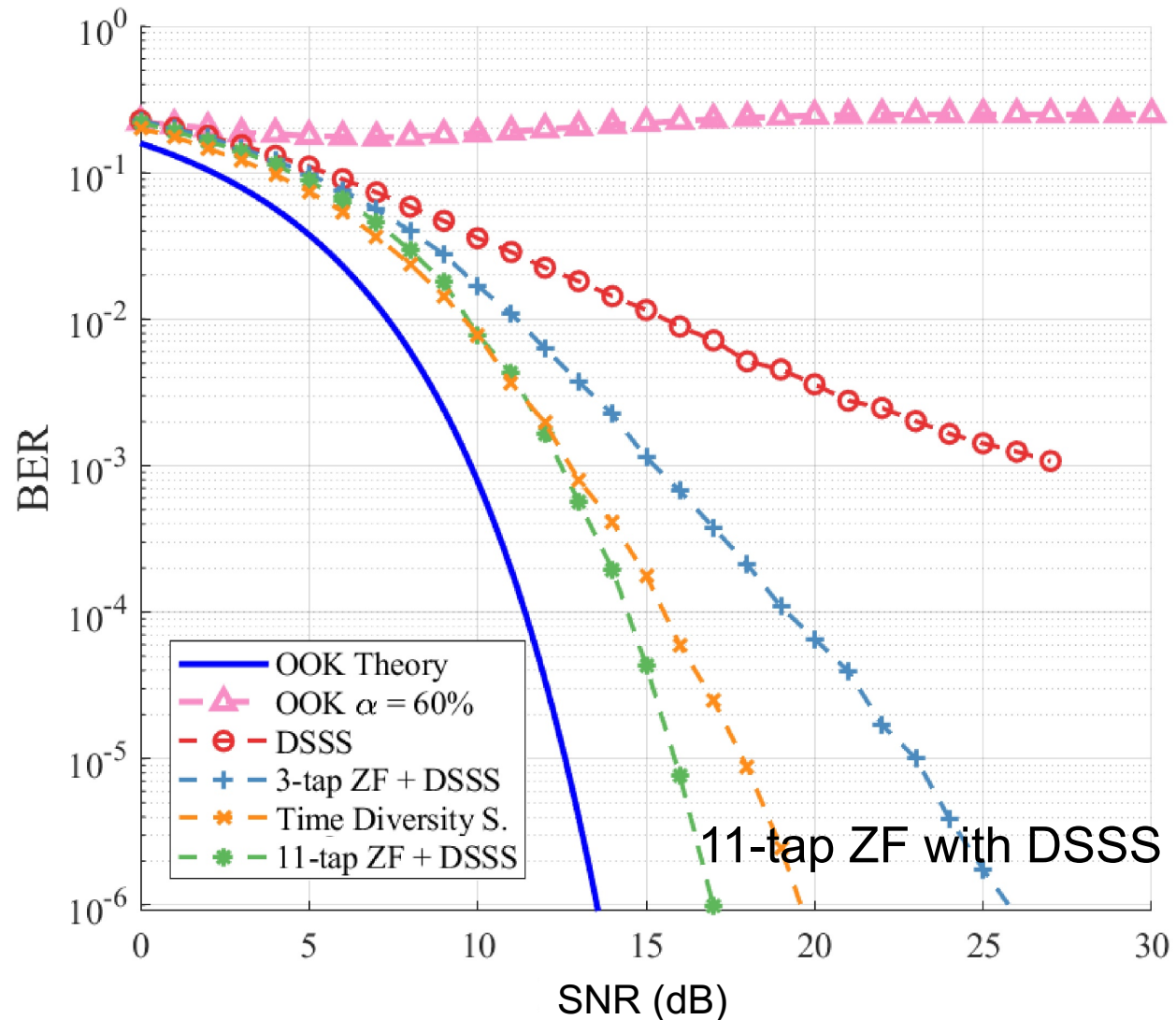
- **Area and power consumption**

Tech. 28-nm FDSOI	Area (μm^2)	Power (mW)
DSSS Codec	313,18	0,43
TDS Codec	401,63	0,82
Optimized TDS Codec	317,42	0,63
3-tap ZF with DSSS codec	490,41	0,98
11-tap ZF with DSSS codec	1967,37	4,04
8-bit Serializer (10 Gbps)	21,8	0,1741
32-bit Serializer (1,25Gbps)	49	0,04391
32-bit Deserializer (1,25Gbps)	50	0,044

Considered decoder configurations

Proposed TDS+DSSS codec

total area = 438 μm²

total power = 1,3 mW
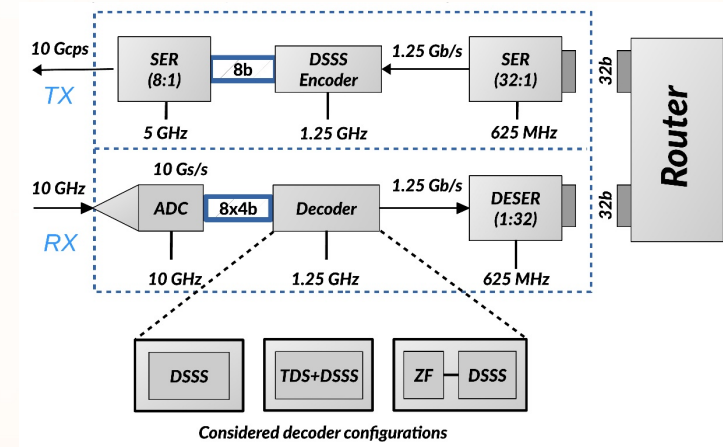
Tech. 28-nm FDSOI	Area (μm^2)	Power (mW)
OOK Analog Front-End	Not specified	20,8
ADC 4-bit	9200	15

WP2: Digital com. and Transceiver

- **Conclusions**
  - WiNoCs suffer from significant degradation due to multi-path interferences
  - Proposed **TDS+DSSS** transceiver provides the best trade-off between BER performance and area/power overhead
  - Other contributions:
    - Adaptive Transceiver for WiNoC to enhance Multicast/Unicast Communication Scenarios
    - Multi-Carrier Spread-Spectrum Transceiver for WiNoC
    - Unleash broadcast/multicast communications

WP3: CDMA-based NoC for parallel computing

- **Questions**
  - How to efficiently route Unicast/Multicast and Broadcast Messages using a hybrid Wired/Wireless NoC ?
  - How can a WiNOC improve Barrier Synchronization in Parallel computing ?
  - Which MAC protocol is better for parallel computing Token Passing or Collision Free ?
  - How to efficiently use CDMA techniques for parallel applications ?

CMDA utilization From WP2:
1 code: 16Gb/s
2 codes: 8Gb/s
4 codes: 4Gb/s

WP3: CDMA-based NoC for parallel computing

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- **Contribution 1 :** Broadcast Mechanism Based on Hybrid Wireless/Wired NoC for Efficient Barrier Synchronization in Parallel Computing.   E.g. 8x8 MESH case
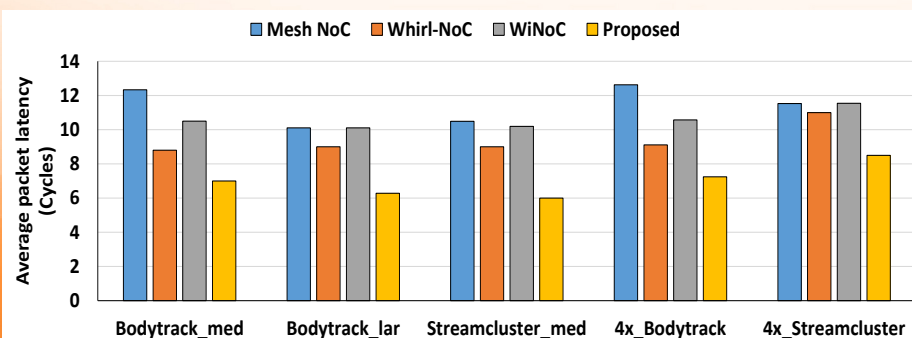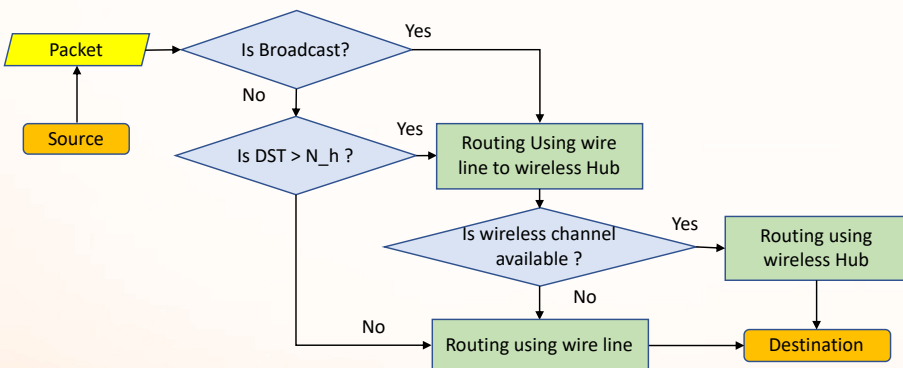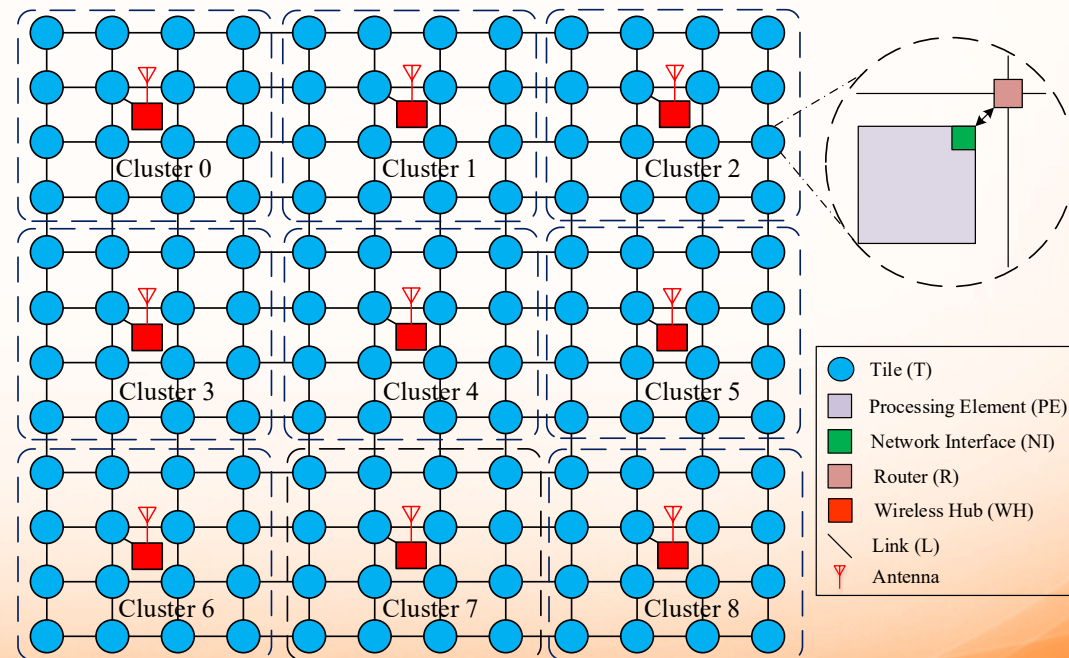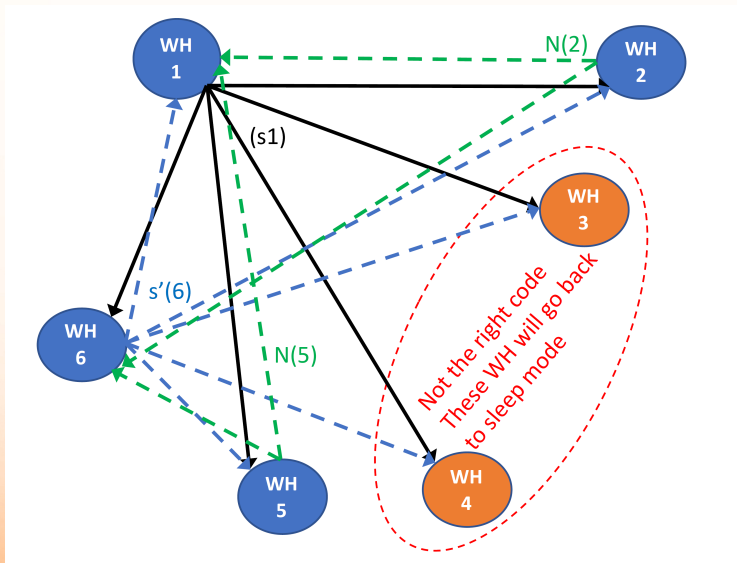

Average packet latency

| | Wireless Hub | Wired Node | Source router (WI_{SR}) |

Wireless Links   Wired Links
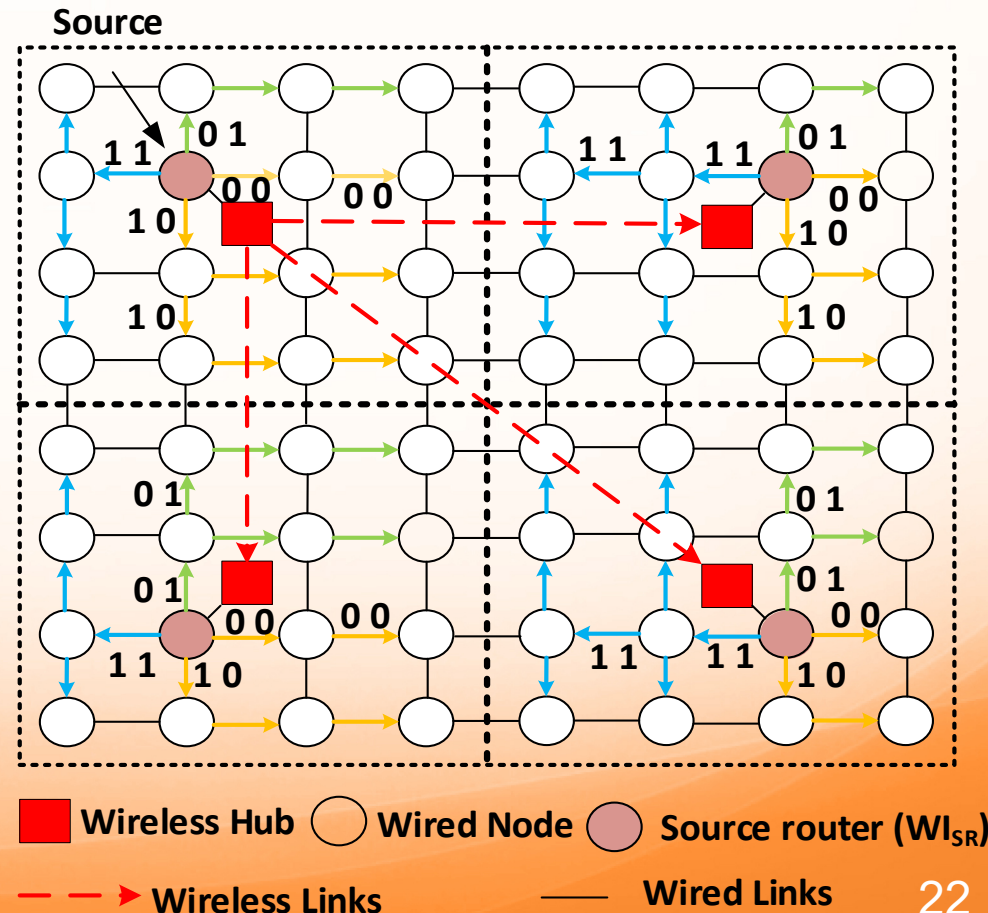
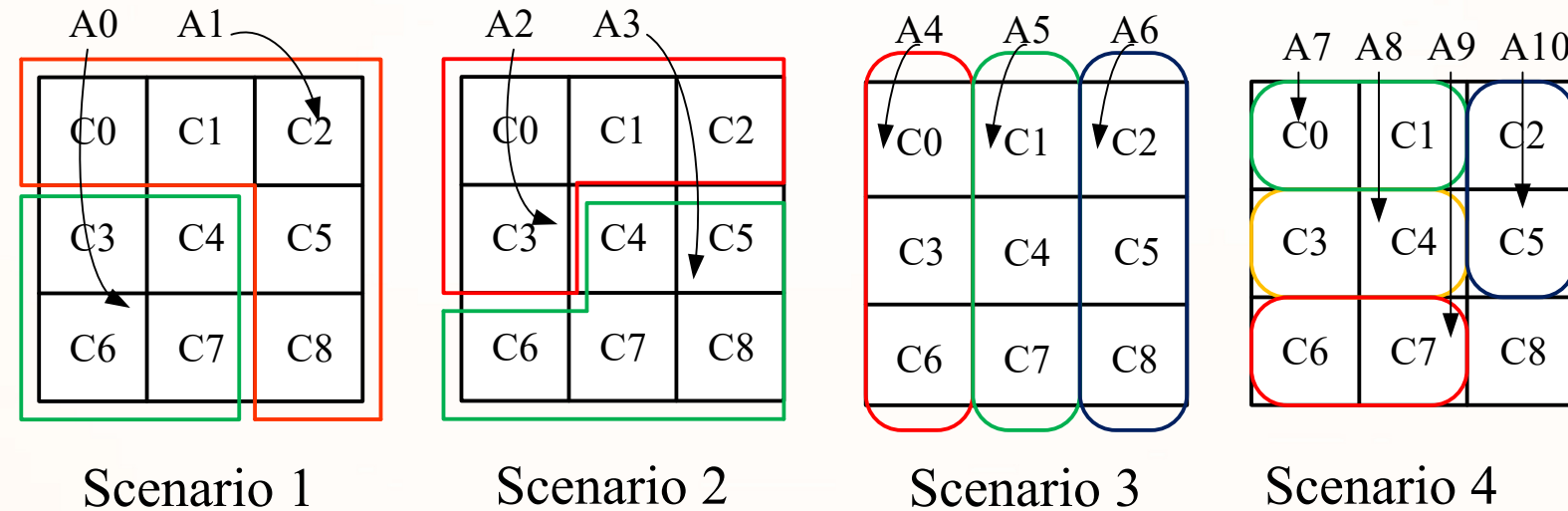# WP3: CDMA-based NoC for parallel computing

- **Contribution 2 :** CDMA-based Multiple Multicast communications on WiNOC for efficient parallel computing

E.g. 12x12 MESH case

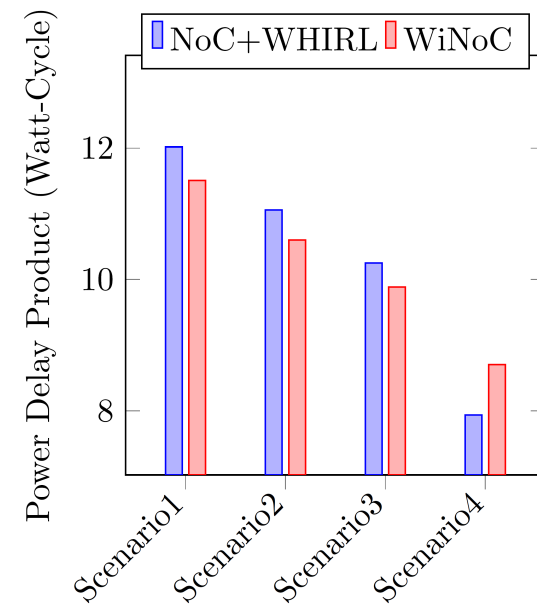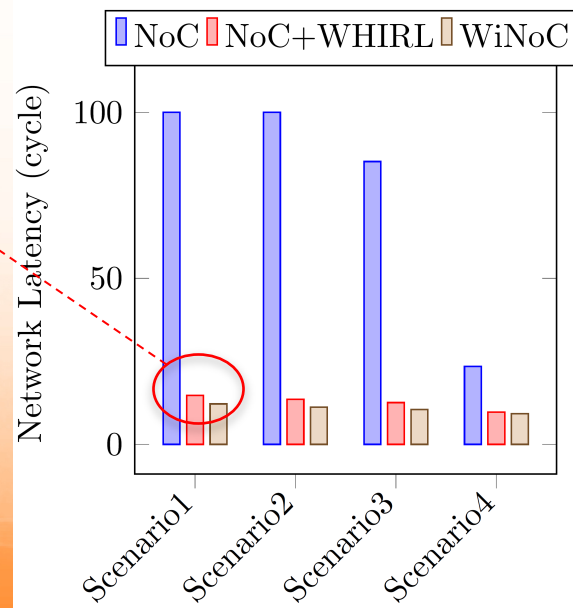**New MAC protocol: collision detection to replace token based method.**

WP3: CDMA-based NoC for parallel computing

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Scenario 1   Scenario 2   Scenario 3   Scenario 4

- **Latency** : 21%, 20%, 19% improvement over NoC+WHIRL for scenarios 1, 2, 3 and 5% for Scenario 4.

- **PDP** : 4.2%, 4.1%, 2.6T% improvement but degradation for Scenario 4.
- \# codes function of NoC Size.
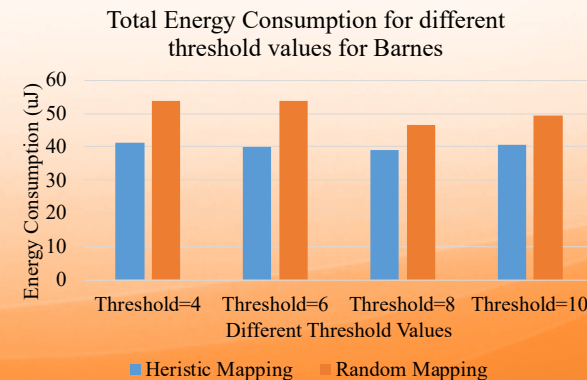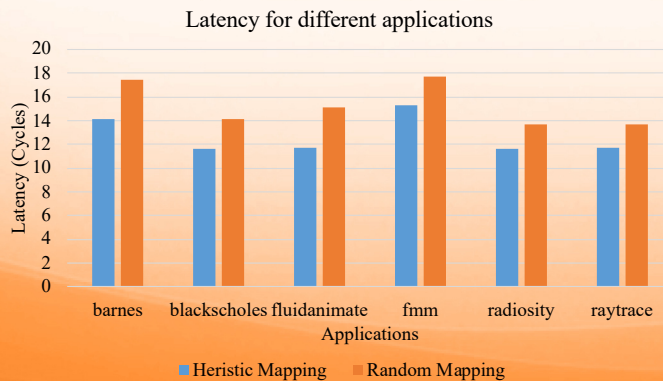- **Mapping is another key issue**

WP3: CDMA-based NoC for parallel computing

- **Contribution 3:** Mapping of broadcast and long-distance unicast nodes
  - *Significantly amplifies the gain of WiNOC with a smart mapping*

Latency for different applications

Energy Consumption for different applications
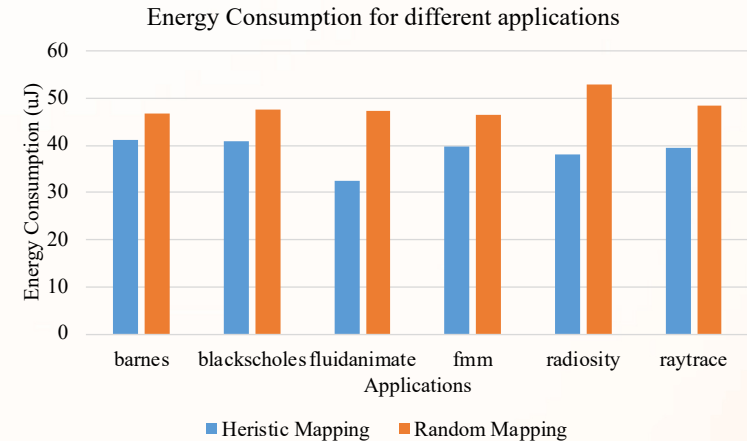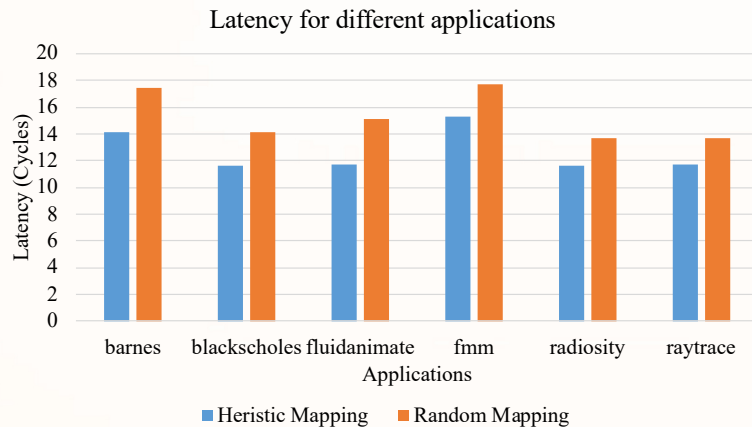
- **Others results:**
  - Our solution scale up, gains increase with NoC Size
  - Demonstrate possible runtime threshold adaptation according to traffic

Latency for different applications

Total Energy Consumption for different threshold values for Barnes

CONCLUSION

- **Demonstrate limits and opportunities of realistic WiNoC**
- **New contributions** in the WiNoC domain based on a realistic approach
  - Realistic channel modeling
  - Absorbing Layer to cope with cavity effects
  - TDS+DSSS transceiver design: best BER, Performance, area/power tradeoff
  - Multi-Carrier Spread-Spectrum Transceiver for WiNoC
  - Adaptive CDMA-based Multiple Multicast communications on WiNOC
  - Efficient Hybrid Wired/Wireless NoC for Broadcast/Multicast/Unicast Coms
  - Heuristic for Broadcast and Unicast Nodes Mapping
- **Publications** : 10 International Conferences SOCC'17, NOCS'18x2, NOCS'19x2, ISVLSI'19, ASP-DAC'20, SPI17,18,19 - 1 accepted journal IEEE Transactions on Components, 2 journals under review
- **2 PhD :** I. El Masri Oct. 19, J. Ortiz Feb. 20s
- **Next :** 2 ANR RAKES(2019), ANR JCJC SHNOC (2019)