Two Applications of Physical Layer Network Coding in Multi-hop Wireless Networks

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Outline

PNC-SA in MIMO Wireless Networks

- 1. Introduction of PNC
- 2. PNC-SA Scheme
- 3. Precoding Design and BER Analysis
- 4. General Applications of PNC-SA and Throughput

Buddy Routing

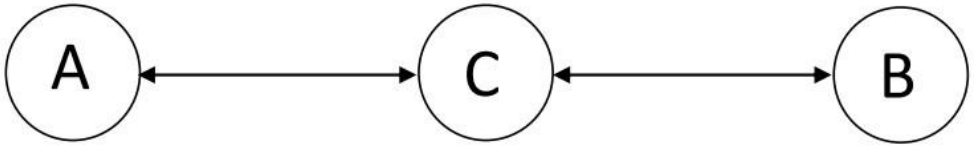
- 5. Introduction of Buddy Routing
- 6. Buddy Routing: Unicast
- 7. Buddy Routing: Multicast
- 8. Conclusion

PNC-SA in MIMO Wireless Networks

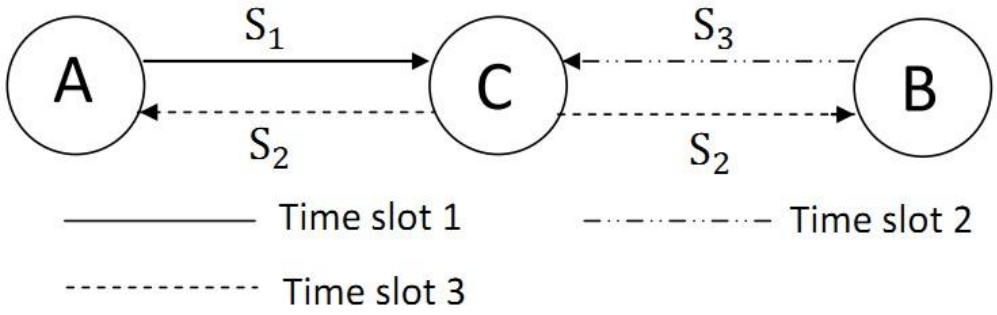
- **1. Introduction of PNC**
  - Digital Network Coding
  - Physical-Layer Network Coding

1.1 DNC

- Traditional Transmission Scheduling: 4 time slots.



- Digital Network Coding: 3 time slots
  - It is applied on digital bits that have been correctly received: $S_2 = S_1 \oplus S_3$

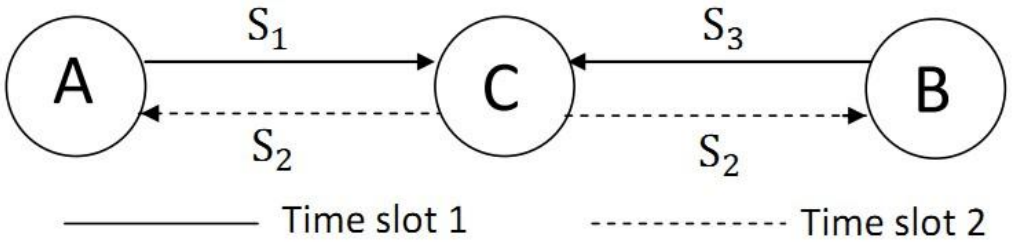


1.2 PNC

- **Physical-Layer Network Coding** (PNC):

  2 time slots

  - Additions of the EM signals are mapped to additions of digital bit streams

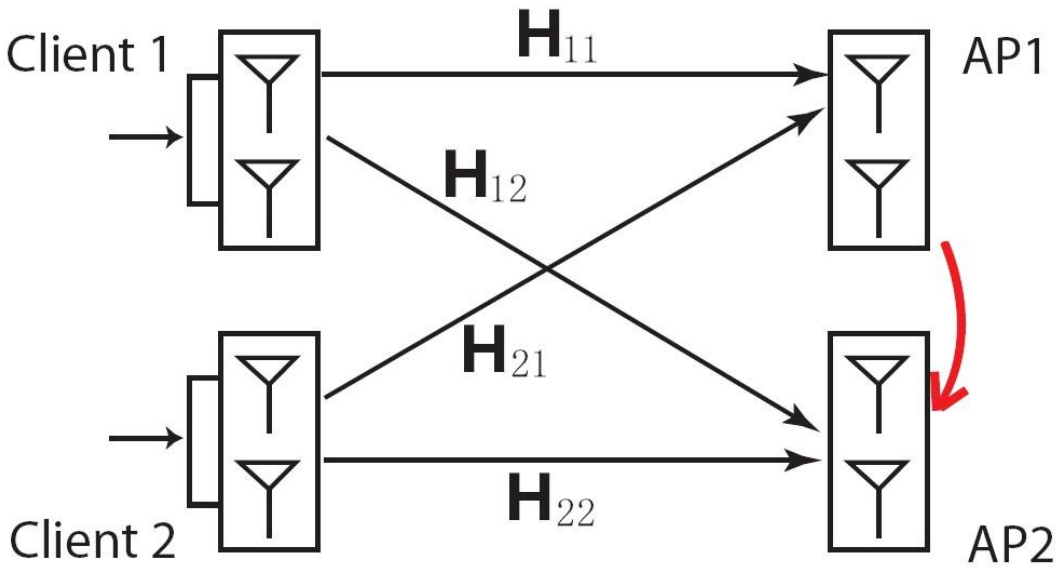


  - BPSK maps from{-1, 1} to {0, 1}
  - PNC demodulation maps from {+2, 0, -2} to {0, 1}

- **2. PNC-SA Scheme**
  - Uplink Communication Scenario
  - MIMO Link
  - Interference Alignment and Cancellation
  - PNC-SA Scheme

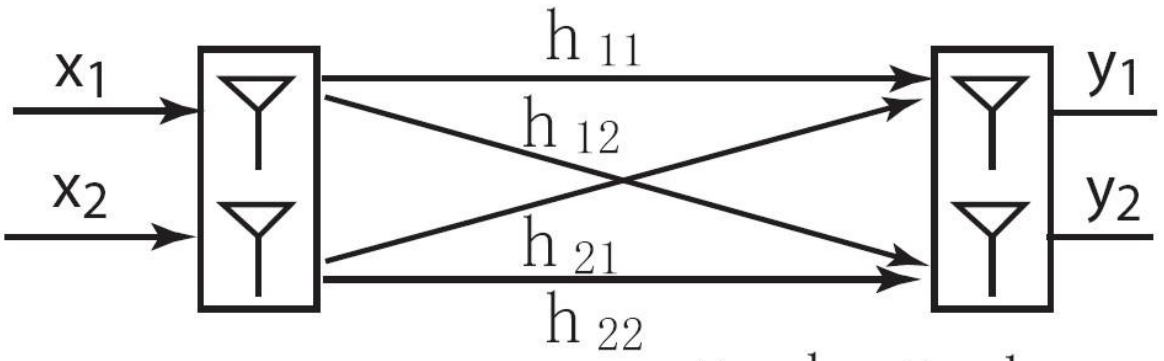
2.1 Uplink Scenario

- Each node: 2 antennas
- Ethernet link connects two APs
- **Goal: As fast as possible**



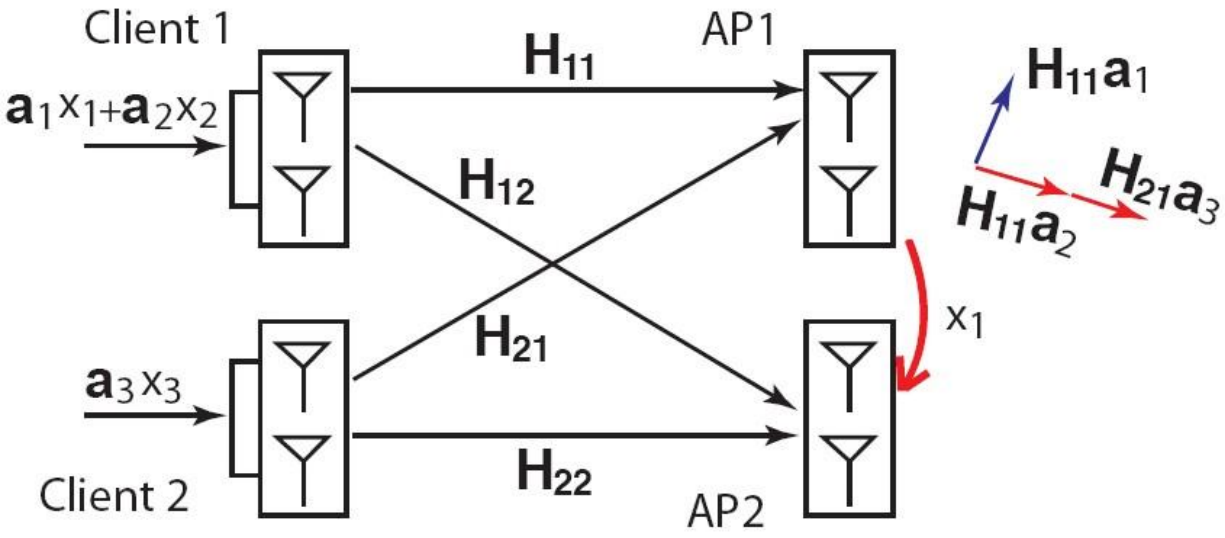
2.2 MIMO Link

- **One solution: 2×2 MIMO**
- Second 2×2 client-AP pair, transmit >2 packets? **No!**



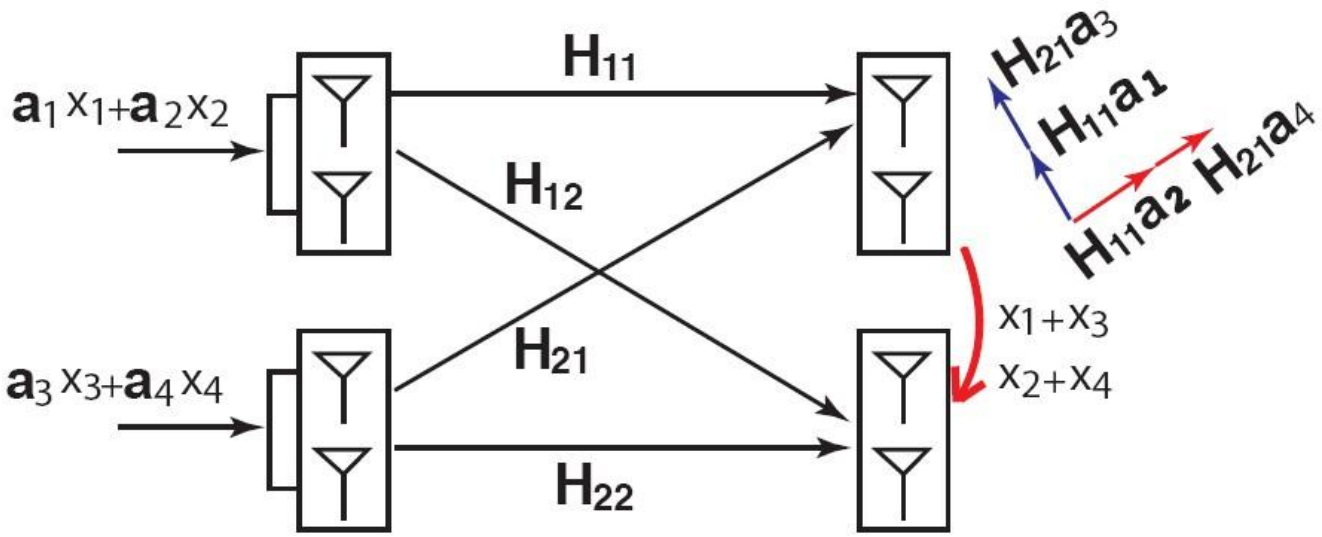
2.3 IAC

- **Interference Alignment and Cancellation** (IAC) breaks through this bottleneck
  - **IAC** treats the second and third packets as one unknown, AP1 sends x_1 on the Ethernet to AP2



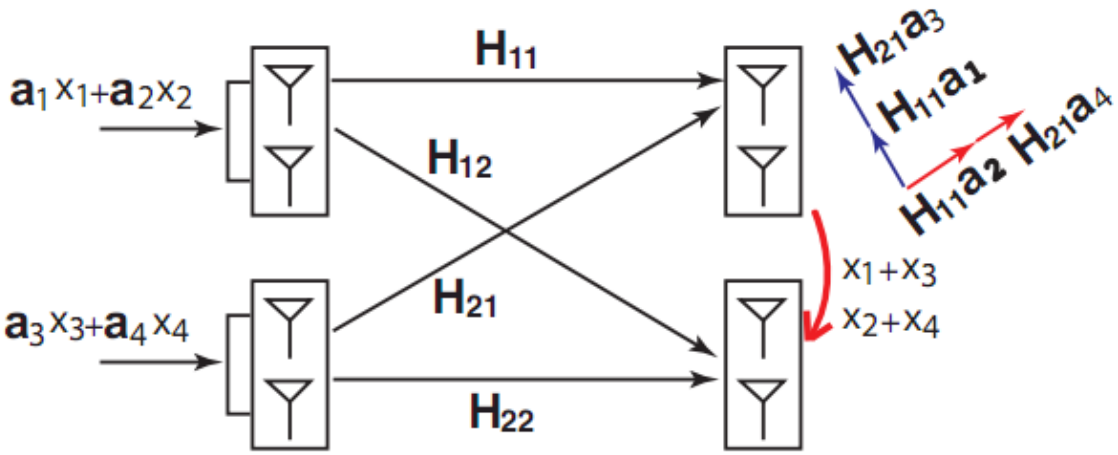
2.4 PNC-SA Scheme

- **Physical layer Network Coding with Signal Alignment** (PNC-SA)
- Align multiple **signals** to the same direction



- **3. Precoding and BER Analysis**
  - Precoding Constraint
  - Precoding Solution
  - BER Analysis

3.1 Precoding constraint



- **Alignment constraint:**

$$\mathbf{H}_{11}\mathbf{a}_1 = \mathbf{H}_{21}\mathbf{a}_3 = \mathbf{v}_1, \quad \mathbf{H}_{11}\mathbf{a}_2 = \mathbf{H}_{21}\mathbf{a}_4 = \mathbf{v}_2$$

- **Power constraint:** E_T
- Let $\mathbf{A}_1 = (\mathbf{a}_1, \mathbf{a}_2) \quad \mathbf{A}_2 = (\mathbf{a}_3, \mathbf{a}_4)$

3. 2 Precoding Solution

- **Precoding Formulation:**

Maximize $f(\mathbf{V}) = |\mathbf{v_1}^{\dagger} \cdot \mathbf{v_2}|$ (1)

Subject to:

$$\begin{cases} \mathbf{H_{11}A_1} = \mathbf{V} = \mathbf{H_{21}A_2} & (2) \\ \|\mathbf{A_1}\|_F^2 \leq E_T & (3) \\ \|\mathbf{A_2}\|_F^2 \leq E_T & (4) \end{cases}$$

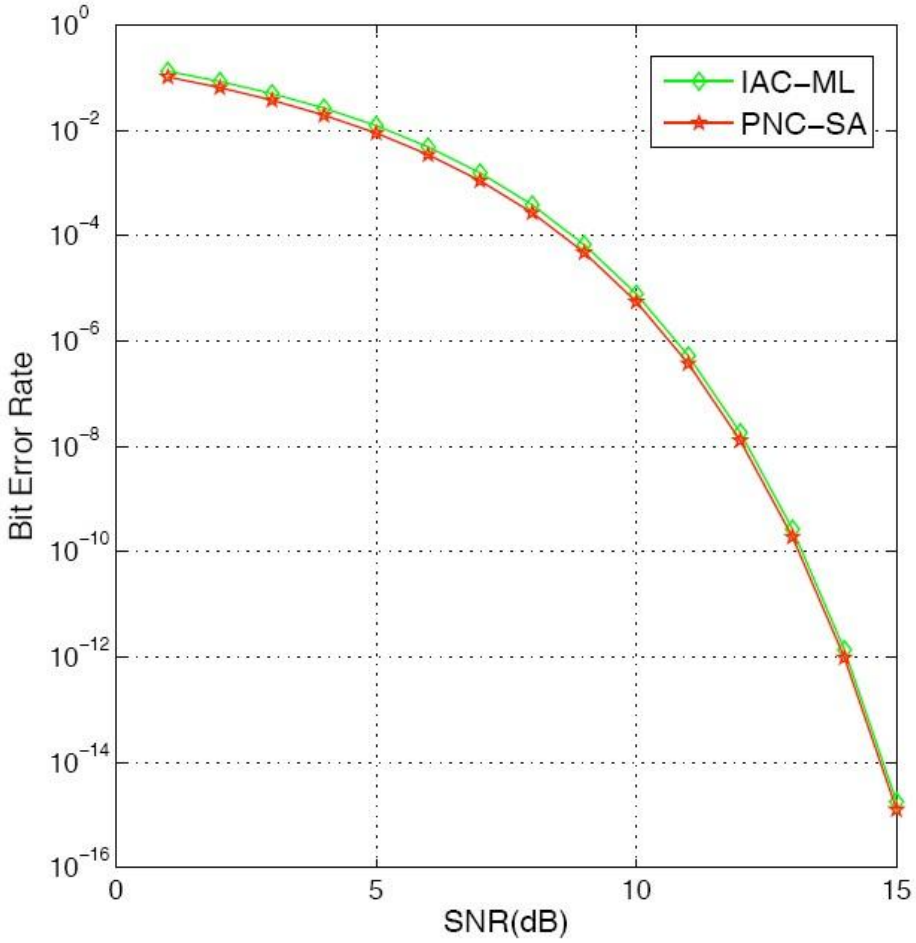
- **Solution:**

$$\mathbf{A_1} = \sqrt{\frac{E_T}{\xi}}\mathbf{H_{11}^{-1}V}, \mathbf{A_2} = \sqrt{\frac{E_T}{\xi}}\mathbf{H_{21}^{-1}V}.$$

$$\xi = \max(\|\mathbf{H_{11}^{-1}}\|_F^2), \|\mathbf{H_{21}^{-1}}\|_F^2)$$

3. 3 BER Analysis

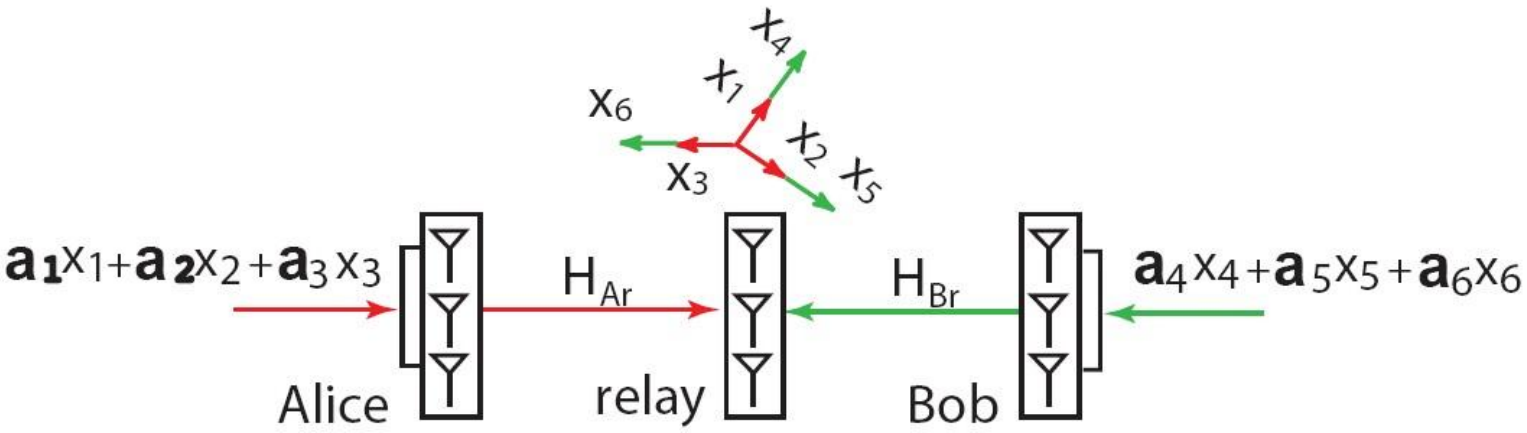
- Comparison of the BER performance of PNC-SA and IAC



- **4. General applications of PNC-SA and their throughput:**
  - PNC-SA for Info Exchange
  - PNC-SA for Unicast
  - PNC-SA for Multicast

4. 1 PNC-SA for Info Exchange

- PNC-SA for Info Exchange

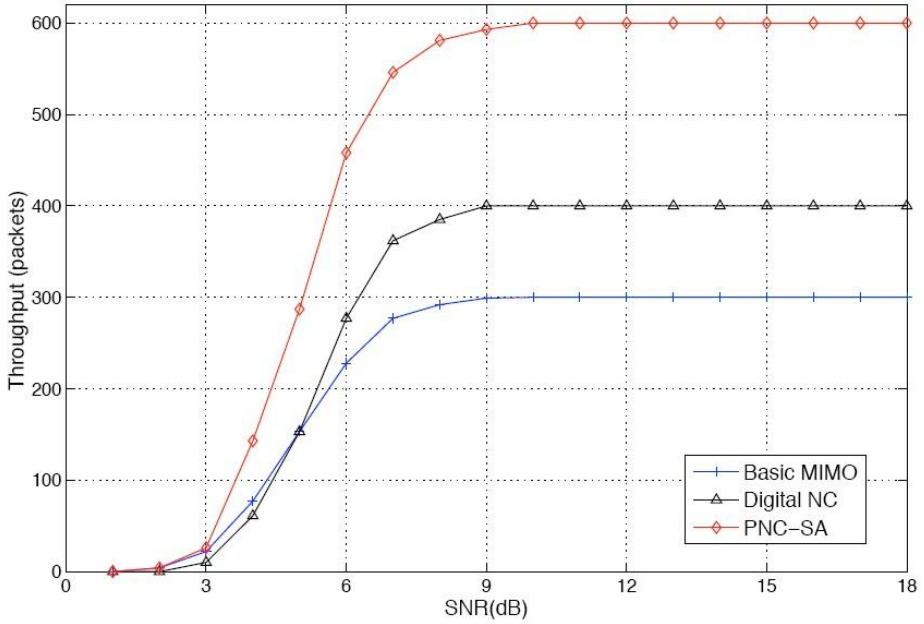


PNC-SA with three antennas per node

4. 1 Info Exchange-Throughput

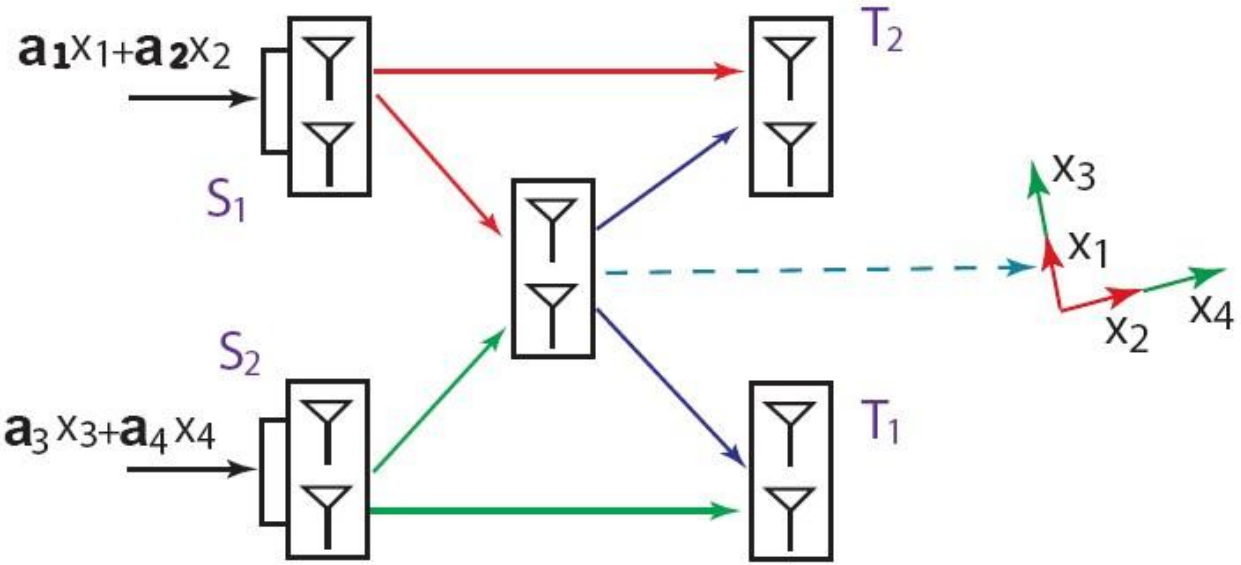
- PNC-SA: 6 packets in **2** time slots
- Digital network coding: 3 time slots, No coding: 4 time slots

Packet-level throughput for information exchange



4.2 PNC-SA for Unicast

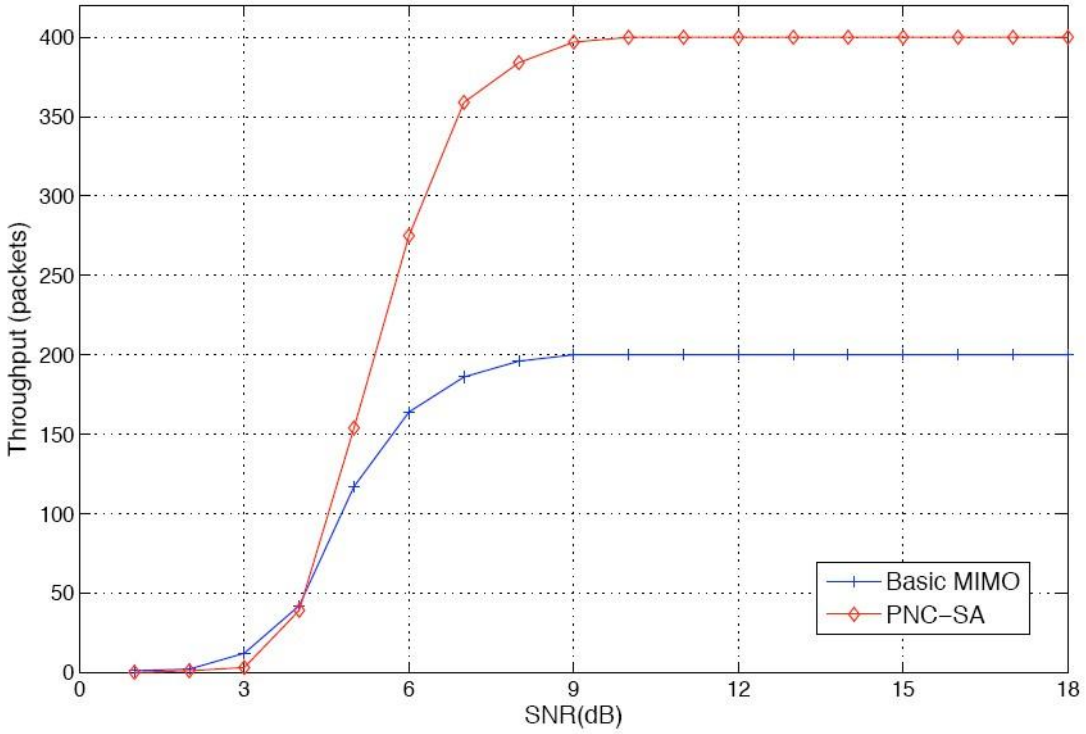
- PNC-SA for Unicast: Cross unicasts



PNC-SA performed at the relay node in the middle

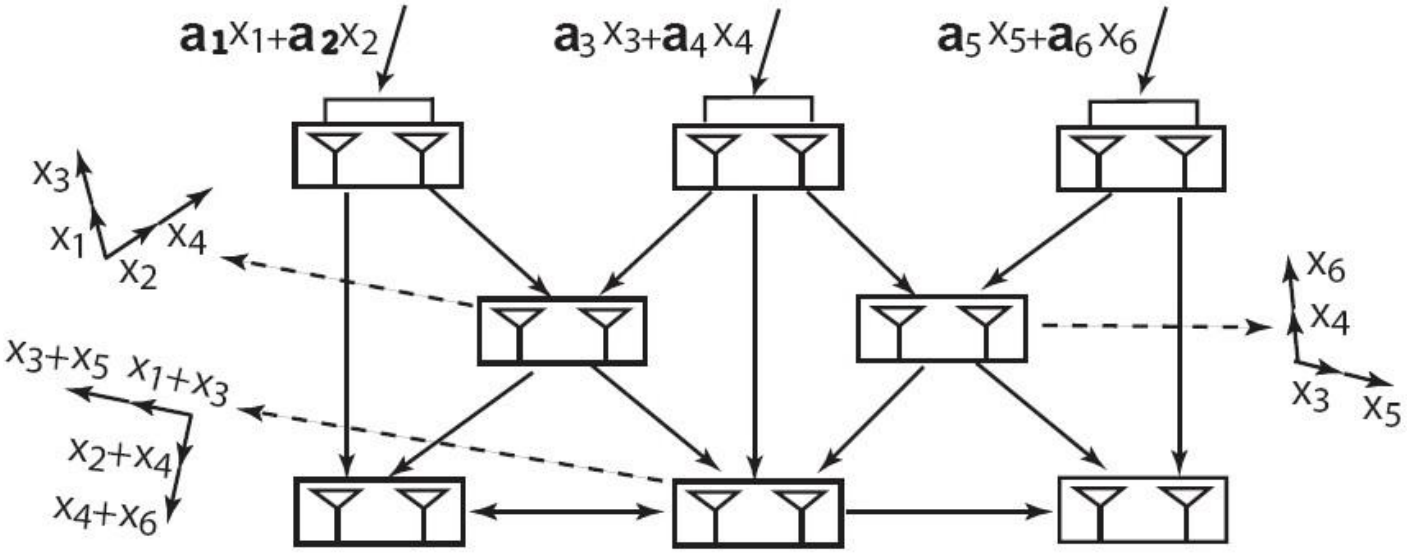
4.2 Unicast-Throughput

- PNC-SA: 4 packets in **2** time slots, without coding: 4 time slots



4.3 PNC-SA for Multicast

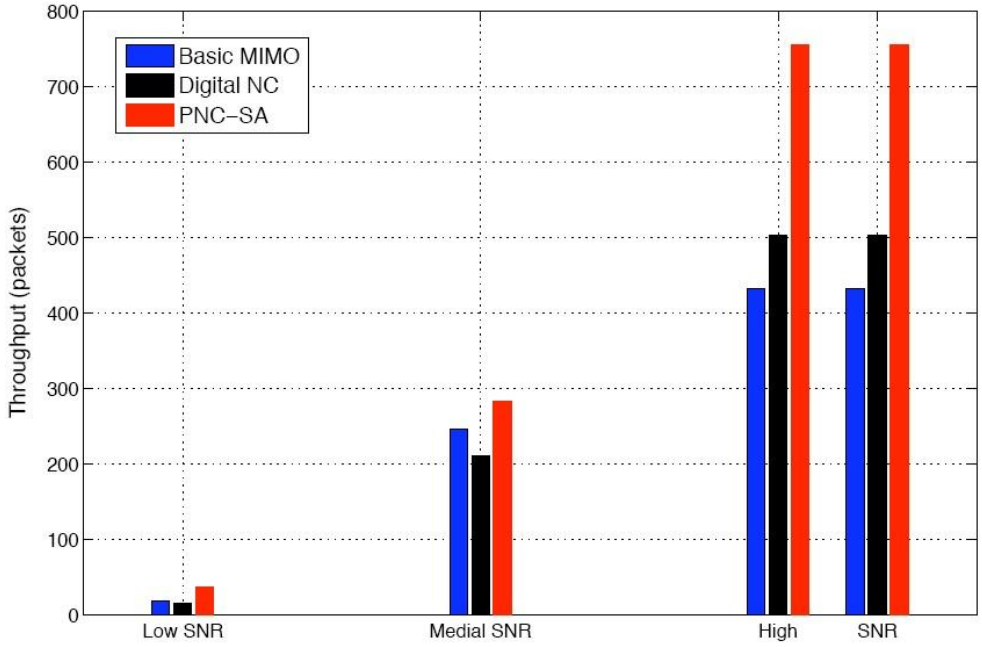
- PNC-SA for Multi-Sender Multicast
  - PNC-SA: 6 packets in **4** time slots



Multicast from top layer to bottom layer

4.3 Multicast-Throughput

- Digital network coding: 5 time slots
- Straightforward multicast scheme without coding: 7 time slots



Buddy Routing

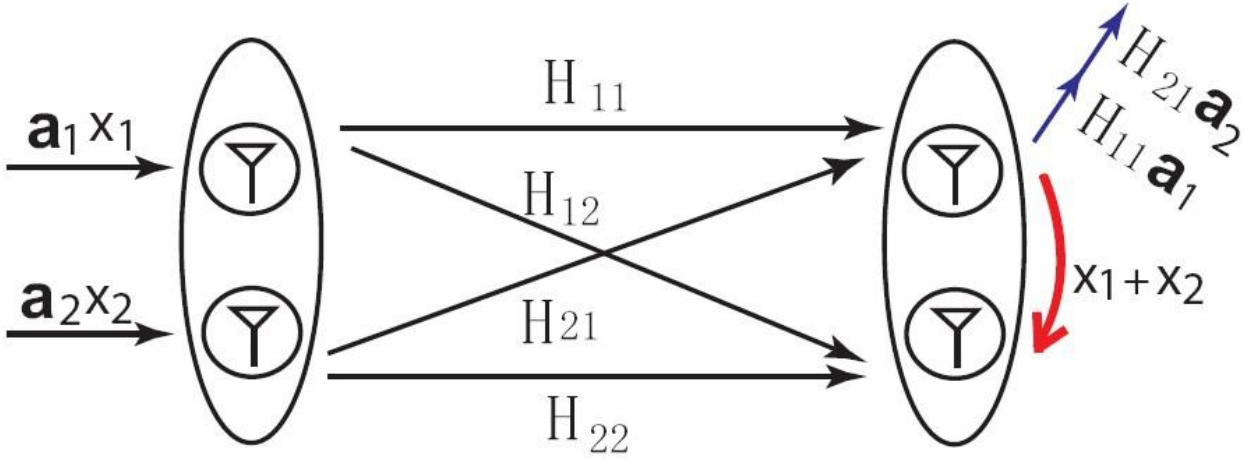
- **5. Introduction of Buddy Routing**
  - NanoNets
  - Main idea of Buddy Routing

5. 1 NanoNets

- **NanoNets**: a set of interconnected nano machines
  - Large network size and node density, low power
  - New applications: biomedical field, environmental research, military technology
- We focus on routing algorithm design, propose a new routing paradigm in NanoNets

5.2 Main idea of Buddy Routing

- Buddy Routing: Enabled by PNC, **pair-to-pair** data forwarding
- Three steps:



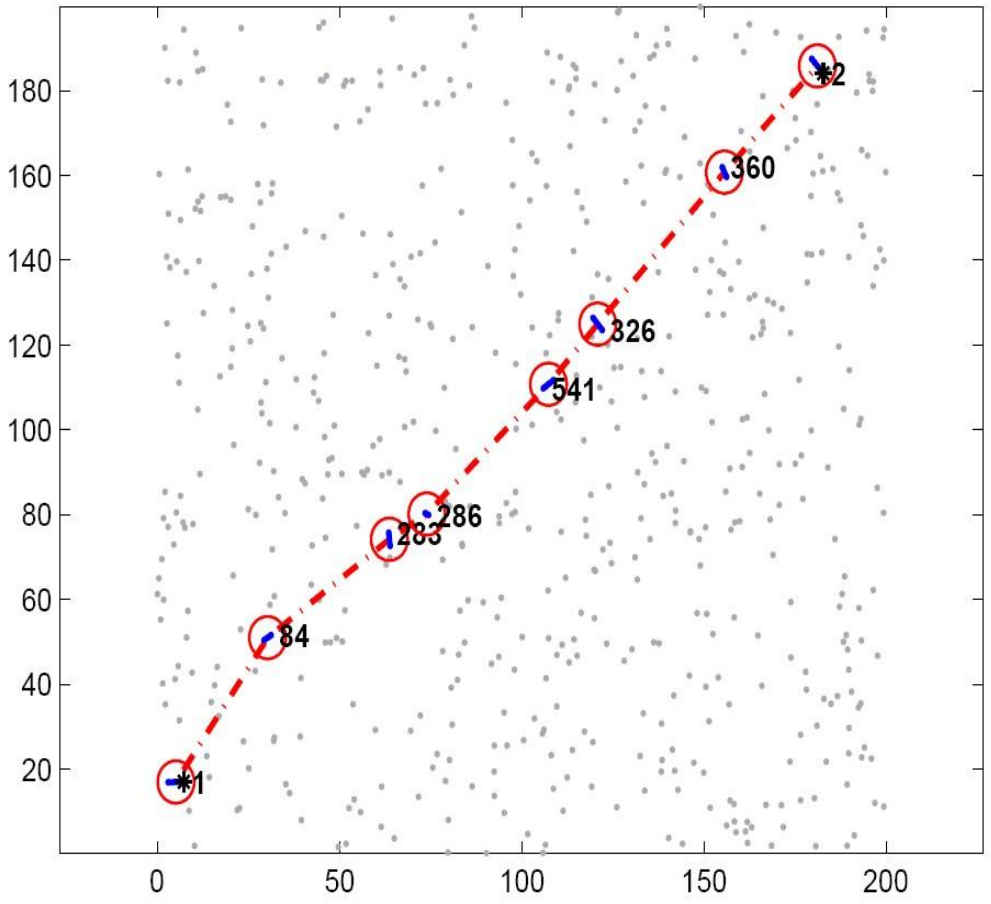
- **6. Buddy Routing: Unicast**
  - Two types of Time Slots
  - BR Unicast Routing Algorithm
  - Simulation

6. 1 Time Slots

- The PNC gadget can be used in multi-hop unicast routing
- Two types of time slots:
  - Long time slot : long-hop data transmission
  - Short time slot: local data transmission
- Relay node pair: no need to send a half packet, already has a digital version

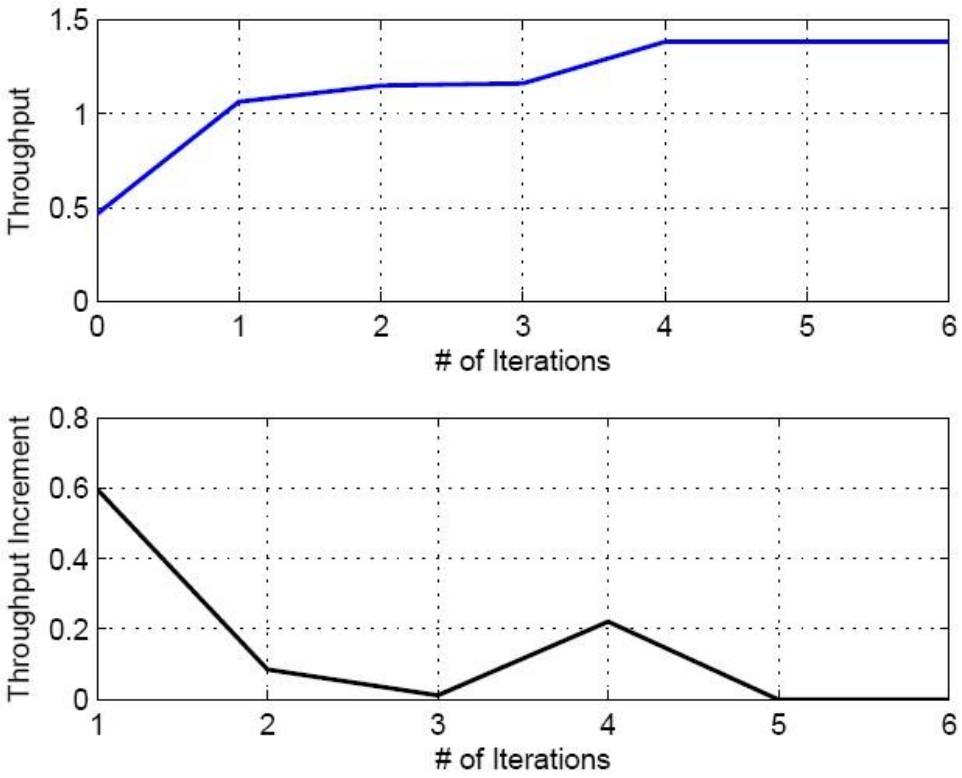
6.2 BR Unicast Algorithm

- 1.Construct the node connect-ivity graph and the pair connect-ivity graph
- 2. Run pair-to-pair **shortest path** routing from S to T



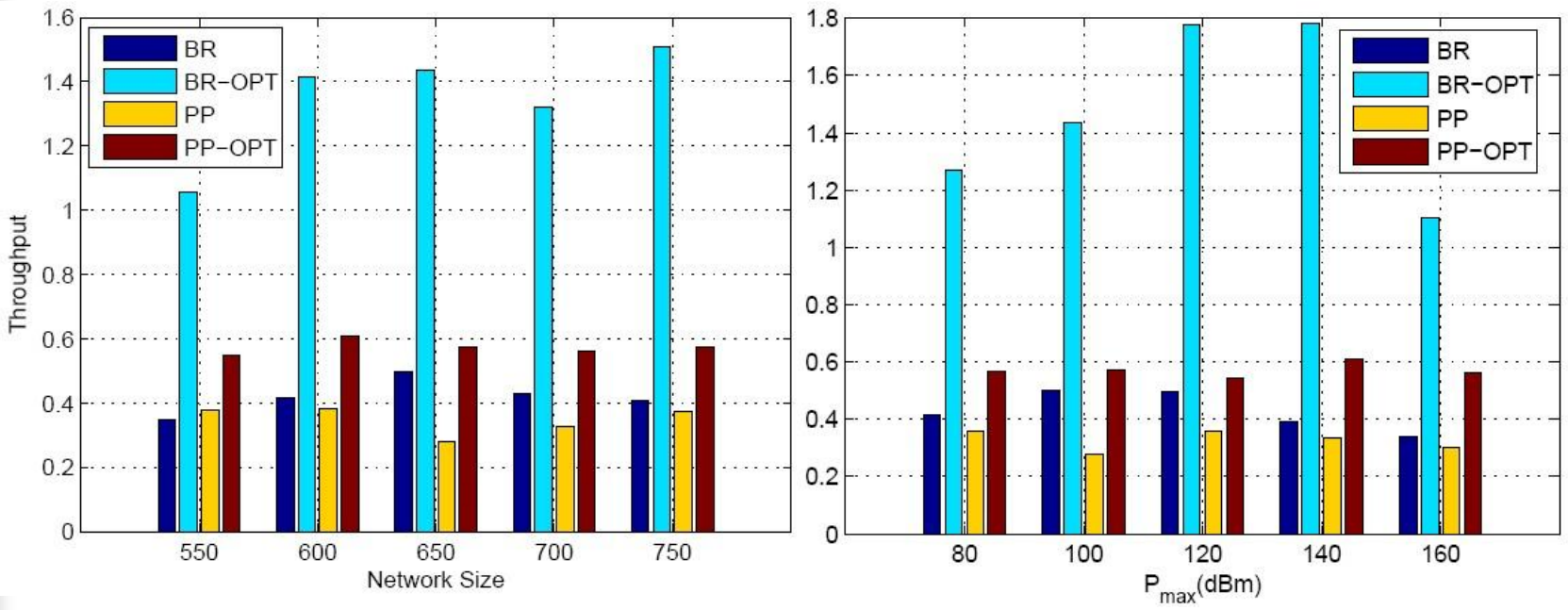
6.2 BR Unicast Algorithm

- 3. Perform iterative **power** (for both inter-pair, intra-pair transmissions) and **time slot** optimization for throughput



6.3 Simulation

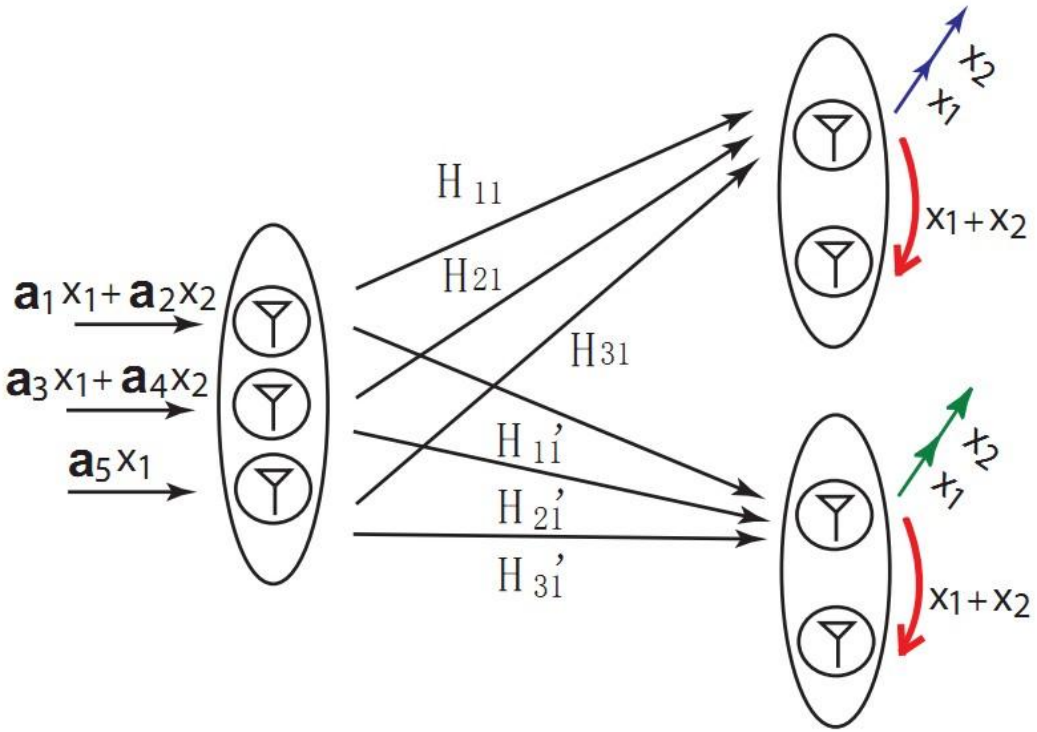
- BR Unicast, end-to-end throughput comparison, different x-axis



- **7. Buddy Routing: Multicast**
  - PNC Gadget for Multicast
  - BR Multicast Routing Algorithm
  - Simulation

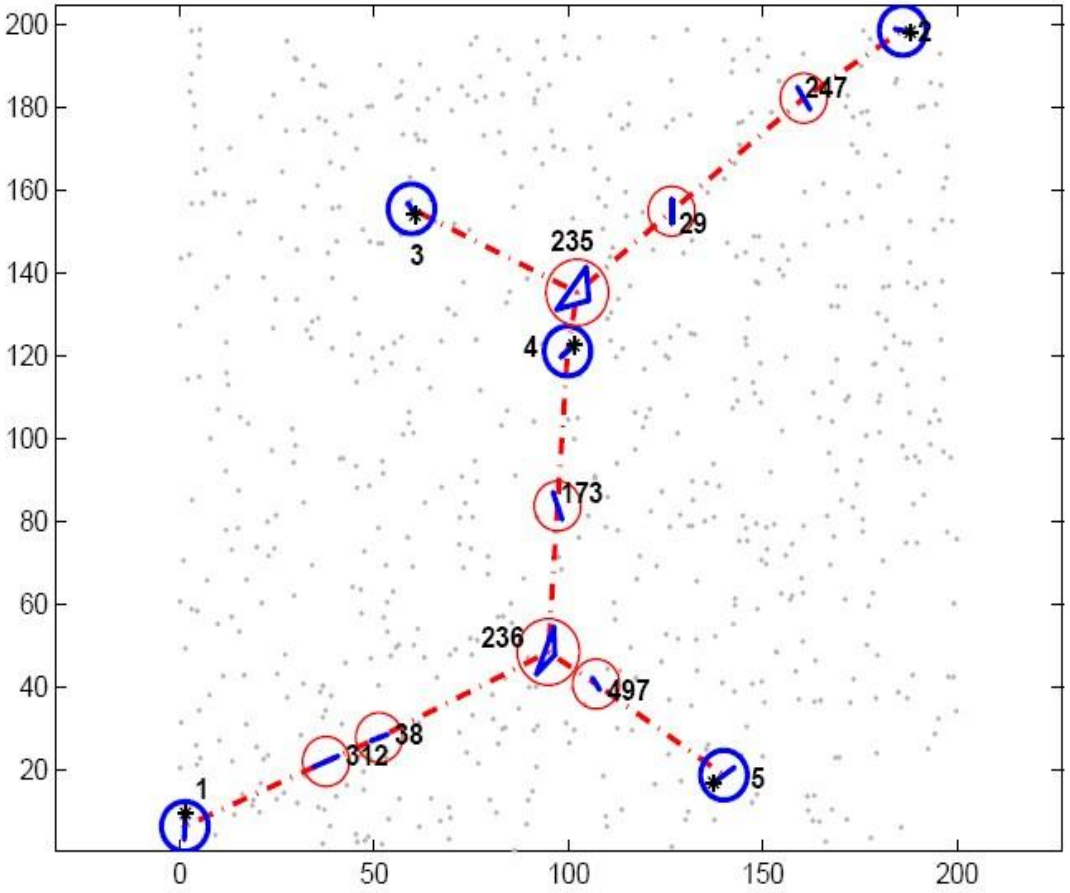
7.1 PNC Gadget for Multicast

- Multicast: **fork** in the transmission topology



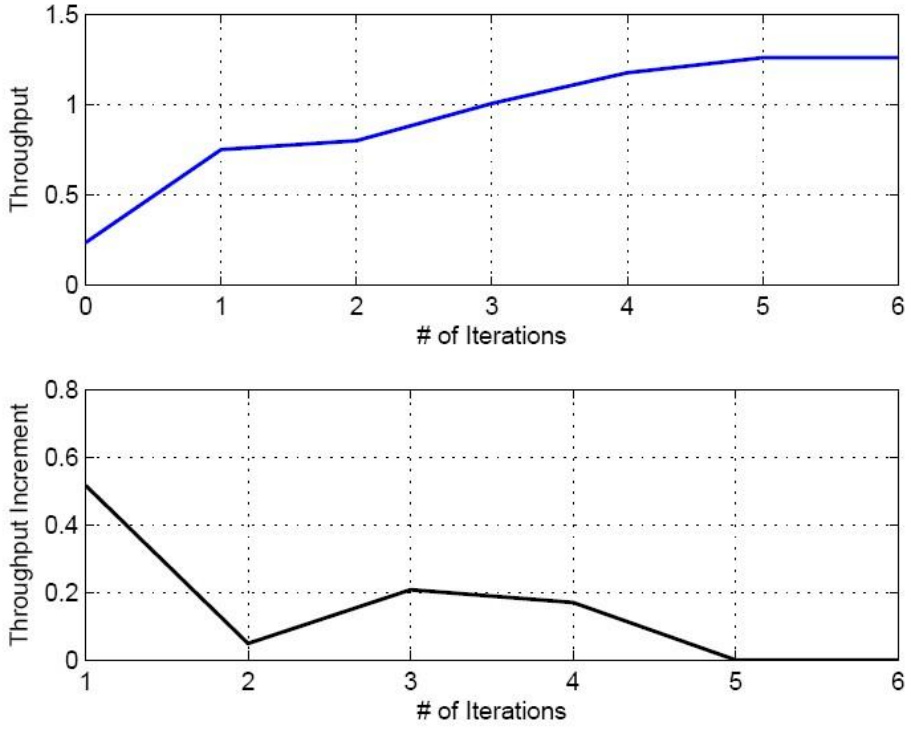
7.2 BR Multicast Algorithm

- 1. Apply a geometric **Steiner tree** algorithm
- 2. Run pair to pair shortest path algorithm between two end points



7.2 BR Multicast Algorithm

- 3. Iteratively **optimize** power and time slots



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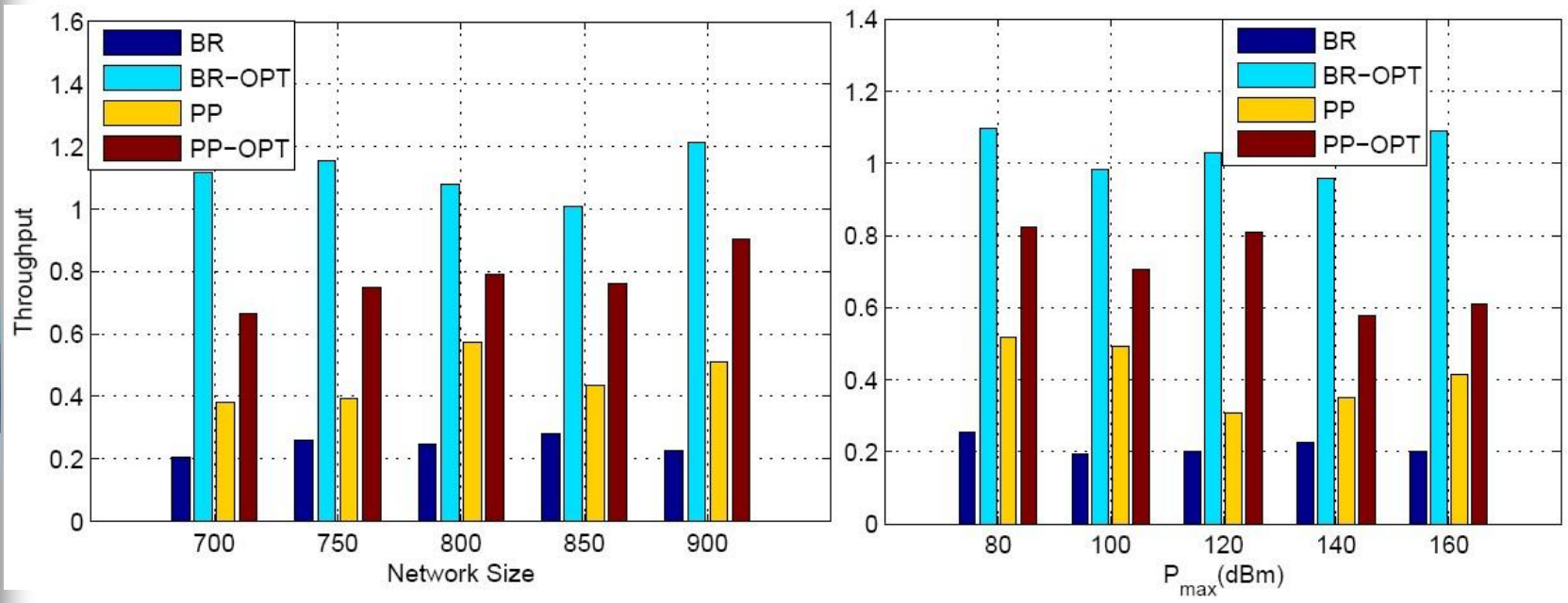
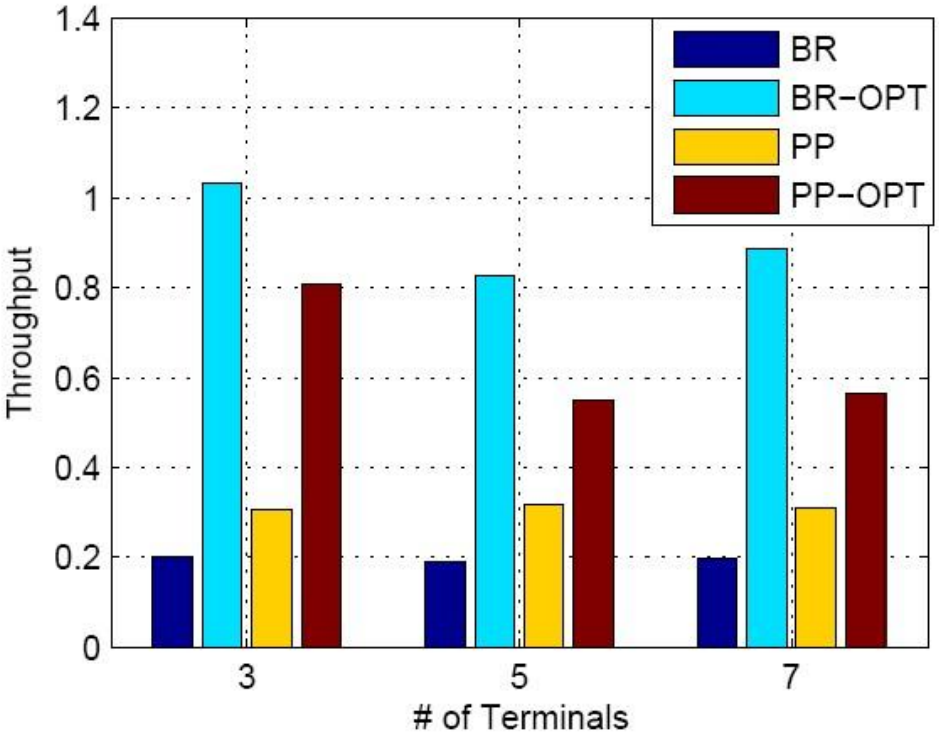


7. 3 Simulation

- BR Multicast, number of terminals =3,5,7



8. Conclusion

- **PNC-SA**, SA coupled with PNC, can open new design spaces for routing in MIMO wireless networks
- Study the optimal precoding and BER performance, demonstrate the general applications
- Propose and evaluate a **buddy routing** algorithm

- Thanks!
- Questions?