



NETWORK CODING

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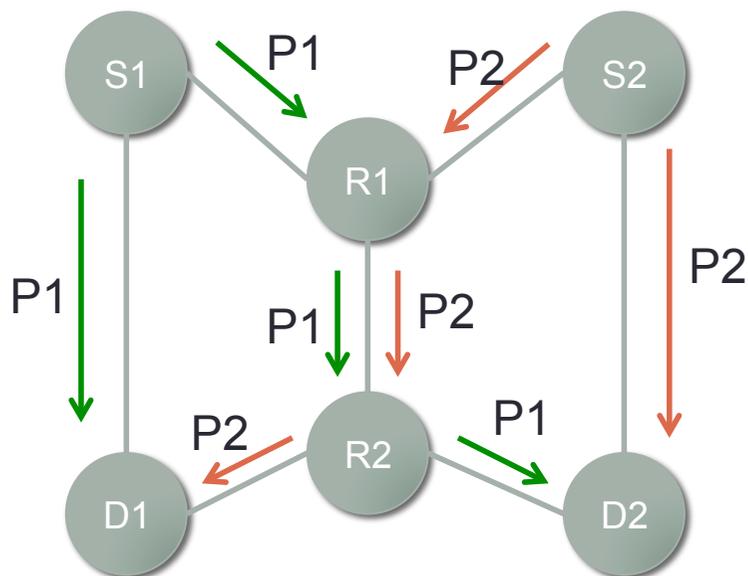
Outline

- Concept and application
- Inter-flow network coding
- Intra-flow network coding
- Conclusion

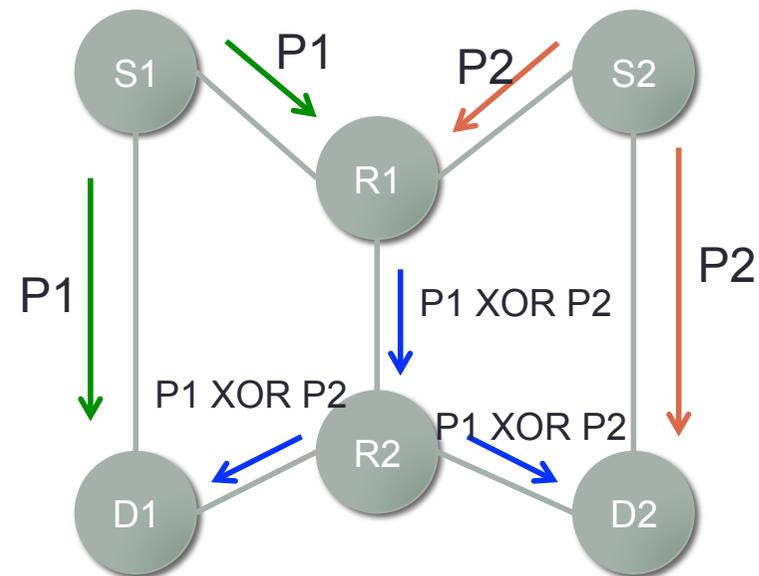
Network coding

- **Network coding** is a technique which allows network nodes to **combine** multiple native packets into one coded packet for transmission instead of simply forwarding packets **one by one**

Link capacity = 1 Mbps



Data rate = 0.5 Mbps



$$P2 = (P1 \text{ XOR } P2) \text{ XOR } (P1)$$

$$P1 = (P1 \text{ XOR } P2) \text{ XOR } (P2)$$

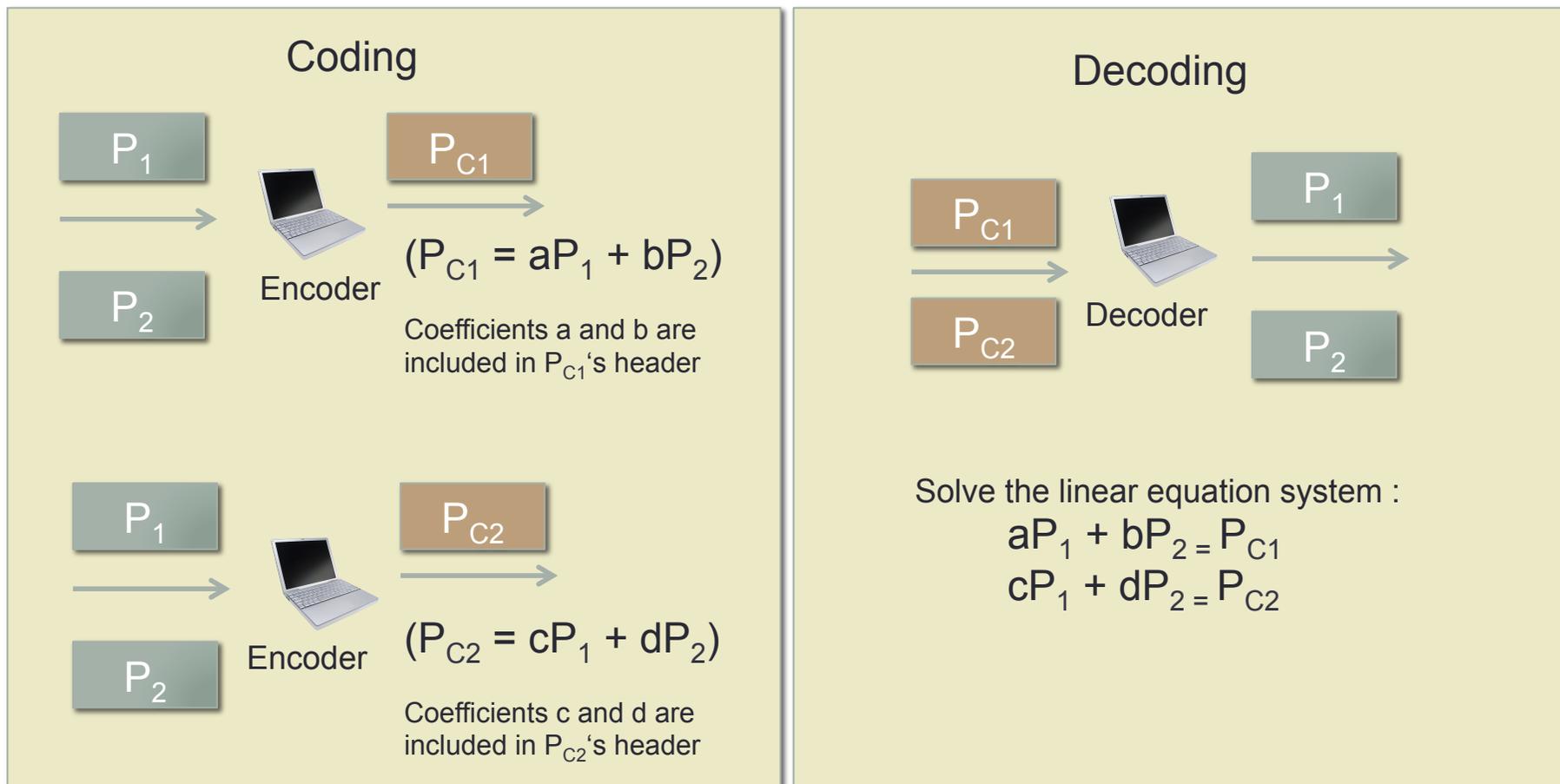
Data rate = 1 Mbps

Benefits and applications

- Benefits:
 - Improve network capacity
 - Provide transmission reliability
- Applications:
 - Multicast transmission
 - Peer-to-peer networks
 - Wireless mesh and ad-hoc networks
 - Transport protocol : Transmission Control Protocol (TCP)
 - Distributed storage

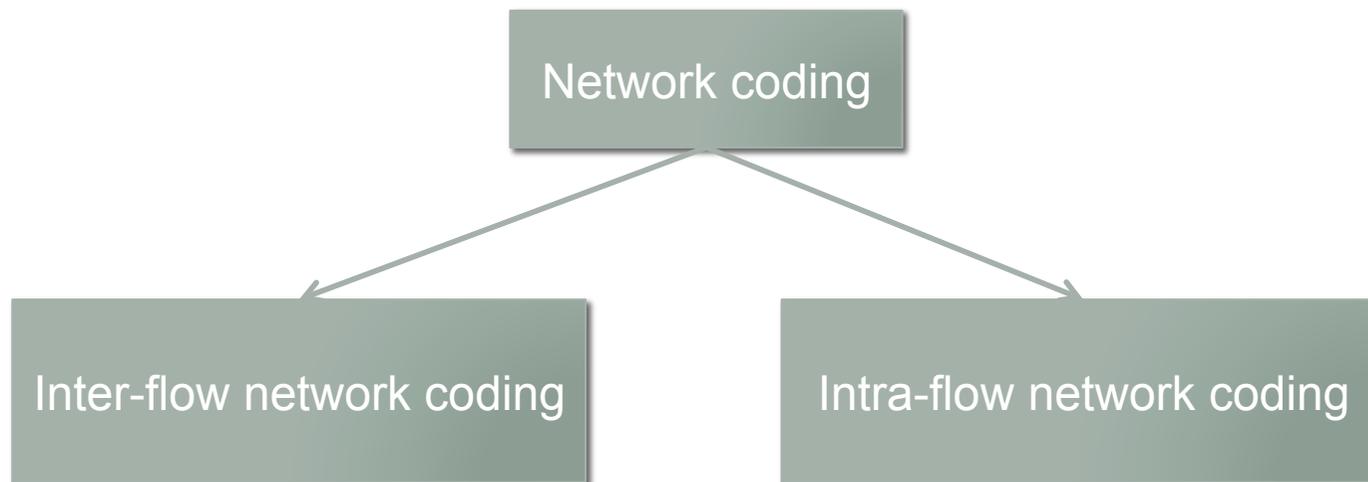
Linear network coding

- Encoding and decoding are based on a **system of linear equations**

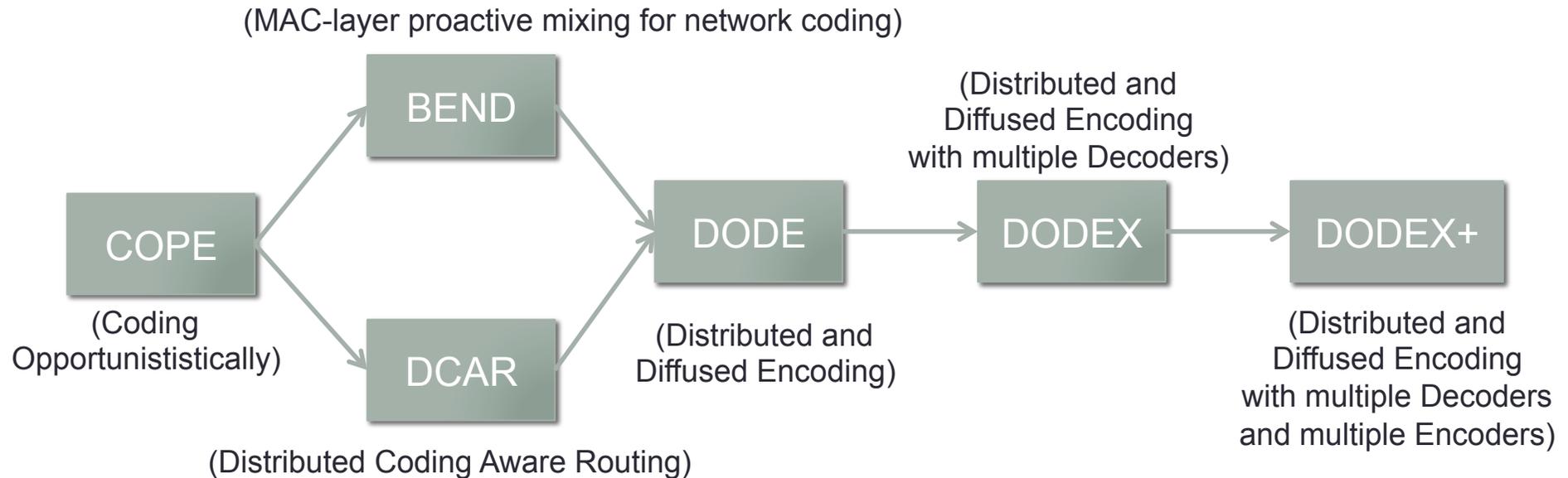


Classification

- Intra-flow network coding
 - Packets belonging to the same flow are mixed together
- Inter-flow network coding
 - Packets belonging to different flows are mixed together

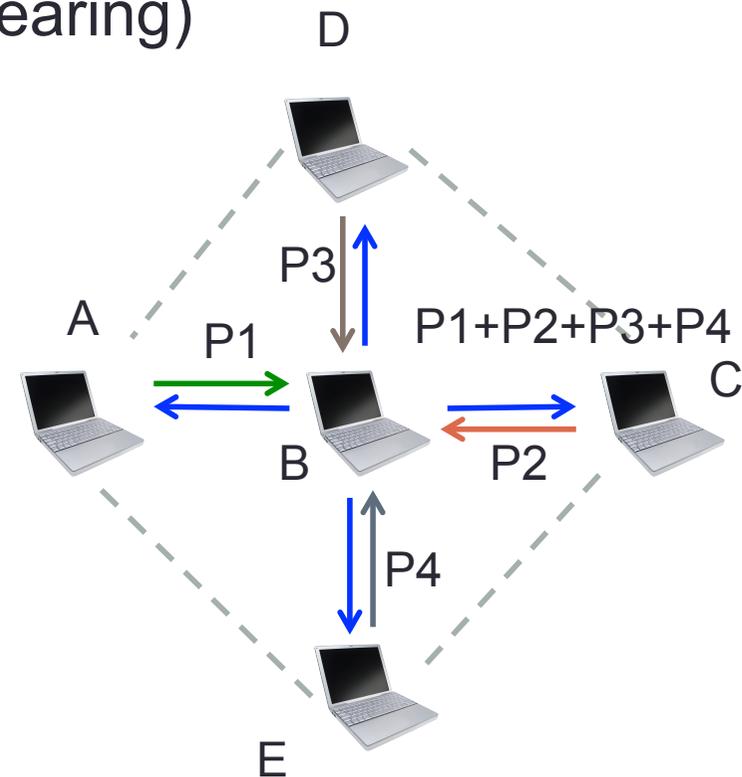
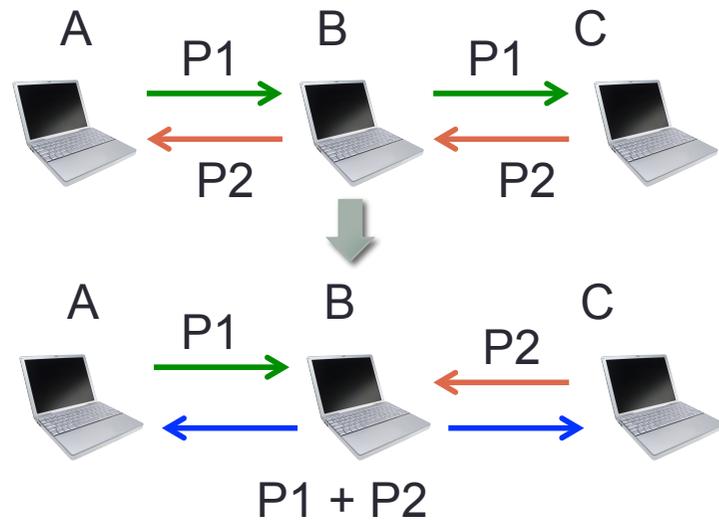


Inter-flow network coding

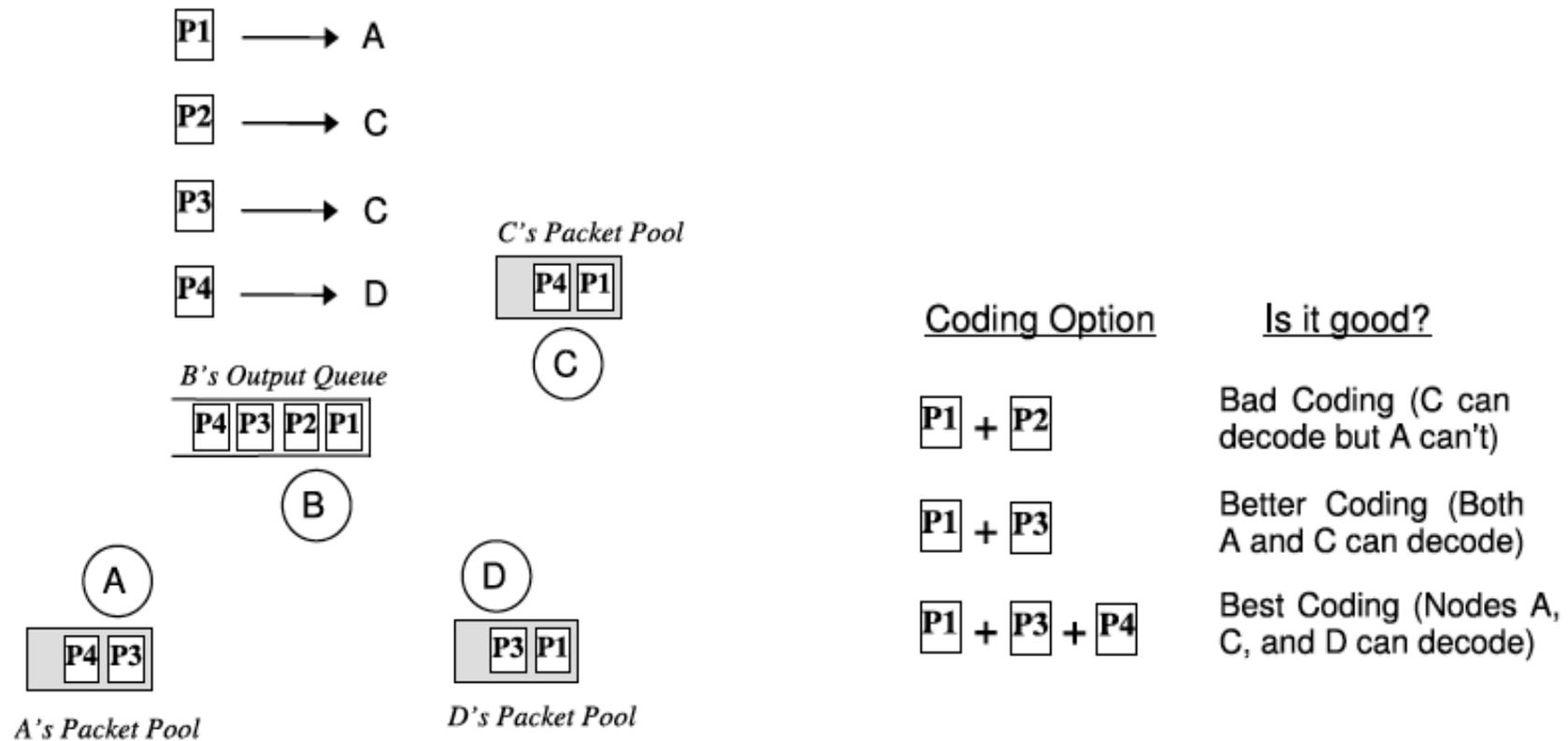


COPE

- Coding Opportunistically
- Two-hop coding pattern
- Different flows cross at a common intermediate node
- Opportunistic listening (Overhearing)



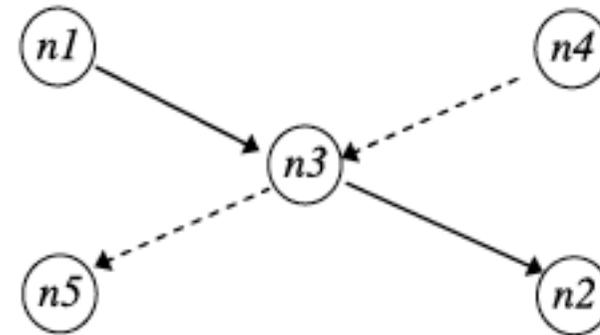
How to make coding decision?



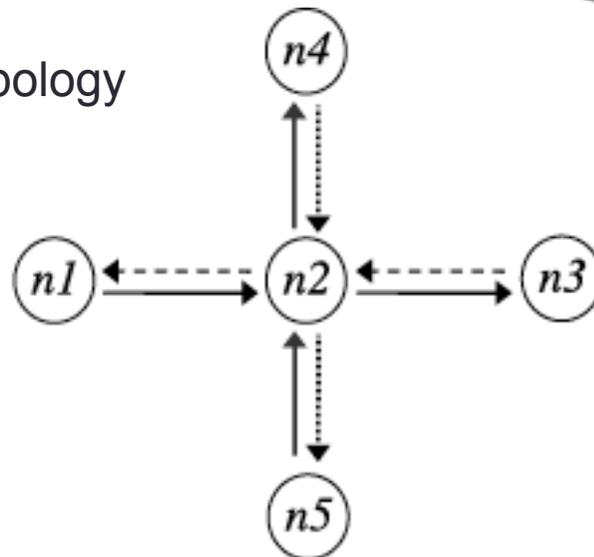
COPE topologies



(a) Alice-and-Bob topology

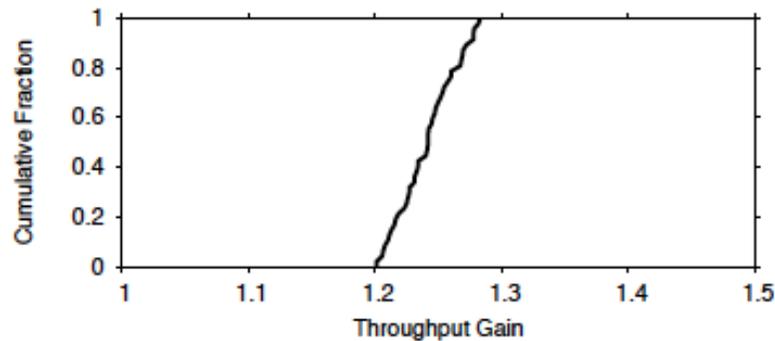


(b) "X" topology

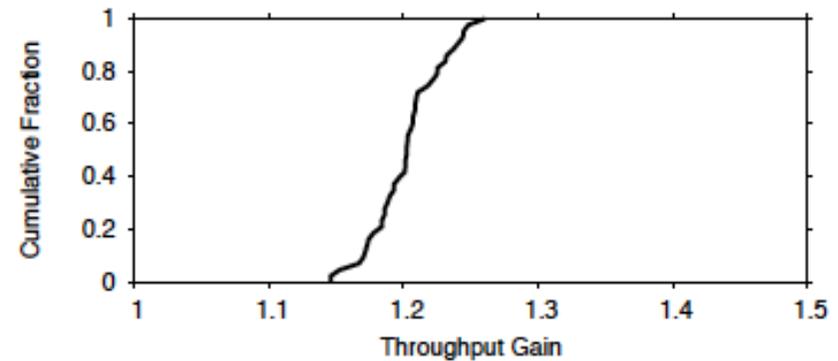


(c) Cross topology

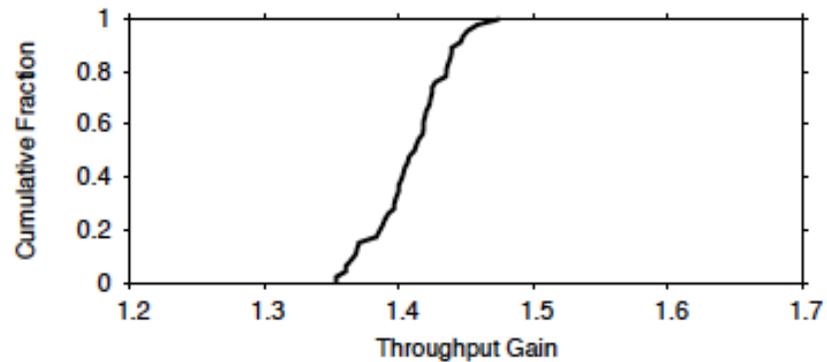
COPE performances - TCP



(a) TCP gain in the Alice-and-Bob topology

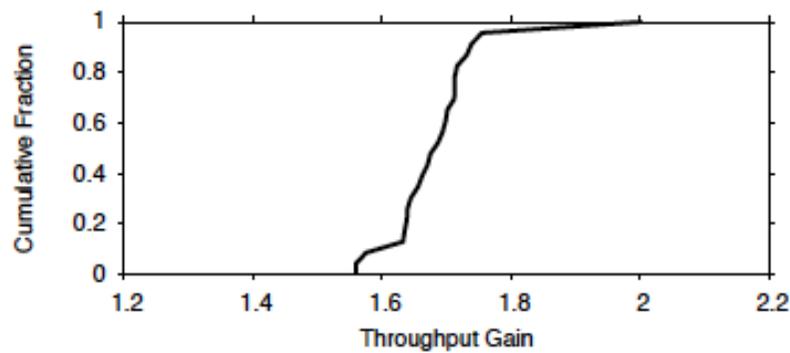


(b) TCP gain in the X-topology

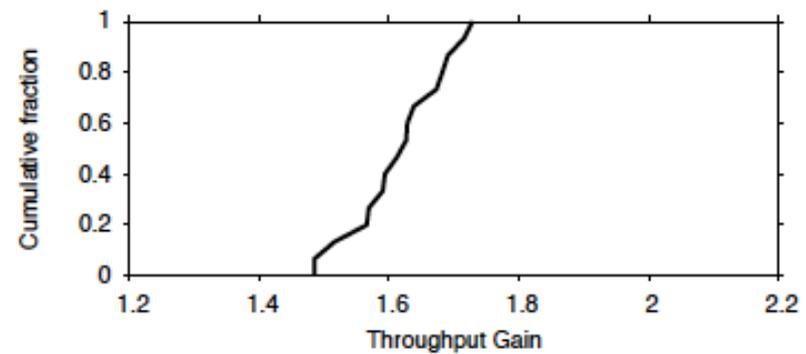


(c) TCP gain in the cross topology

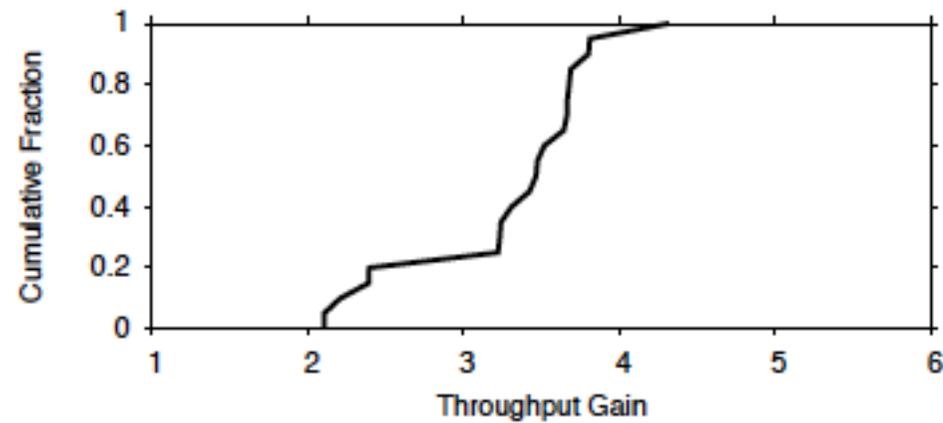
COPE performances - UDP



(a) UDP gain in the Alice-and-Bob topology



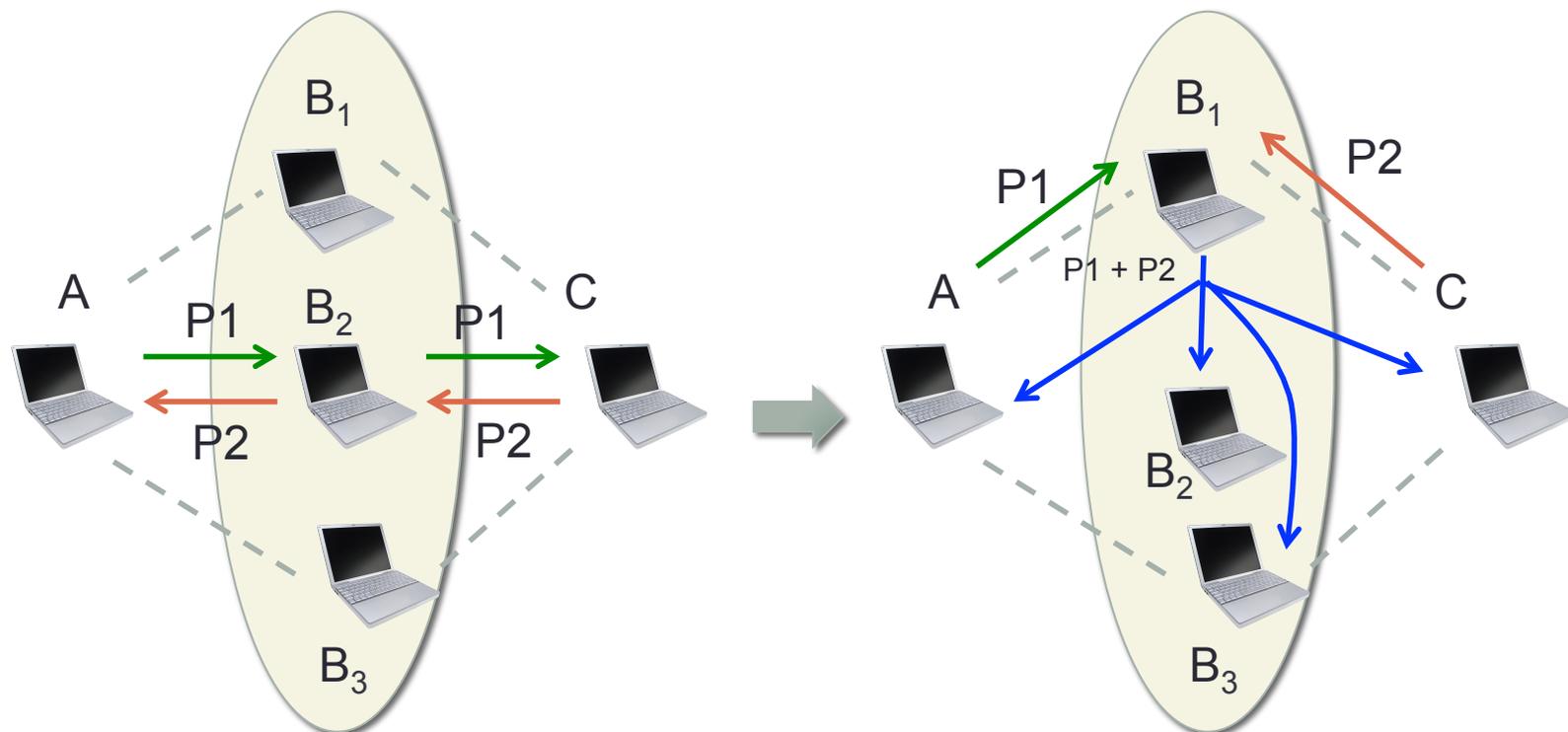
(b) UDP gain in the X-topology



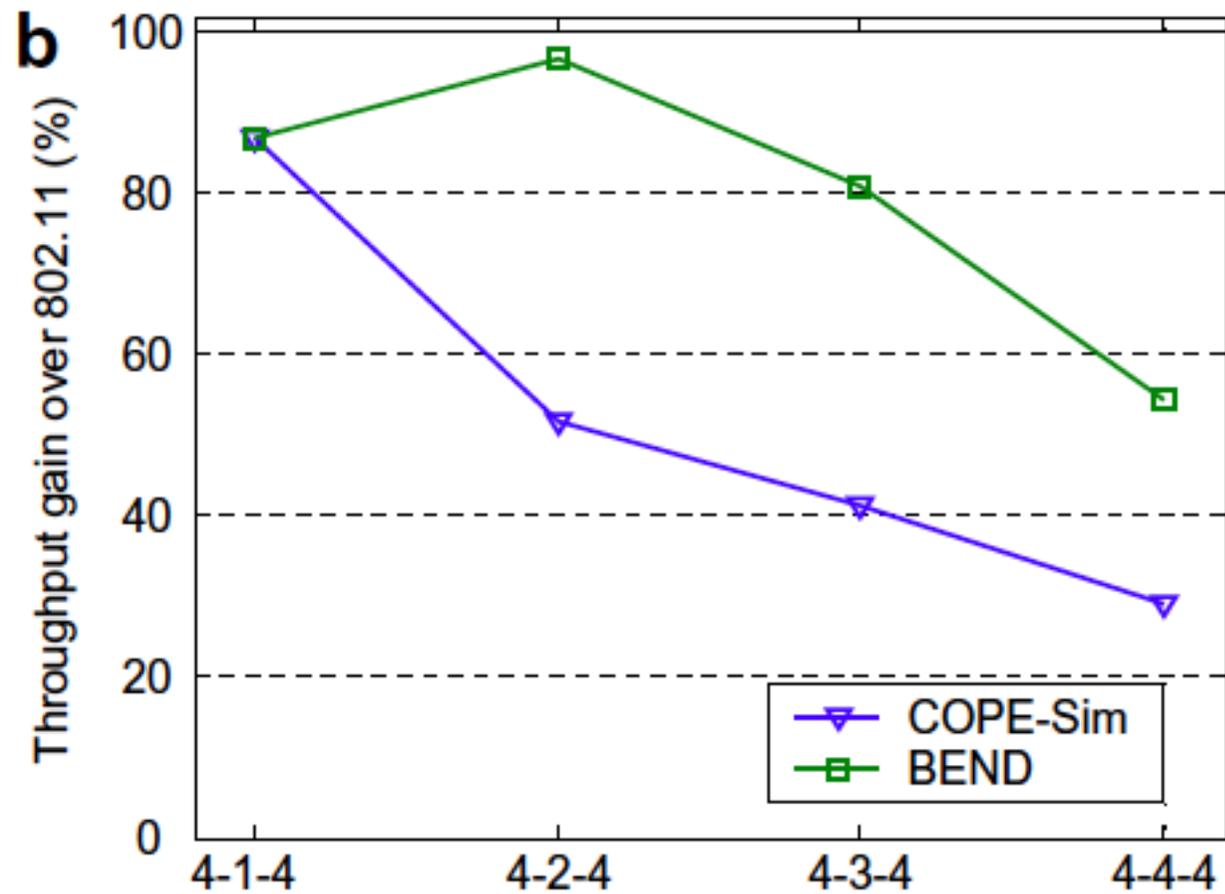
(c) UDP gain in the cross topology

BEND

- MAC-layer proactive mixing for Network Coding
- Extension of COPE
- 2-hop coding pattern for an encoder group

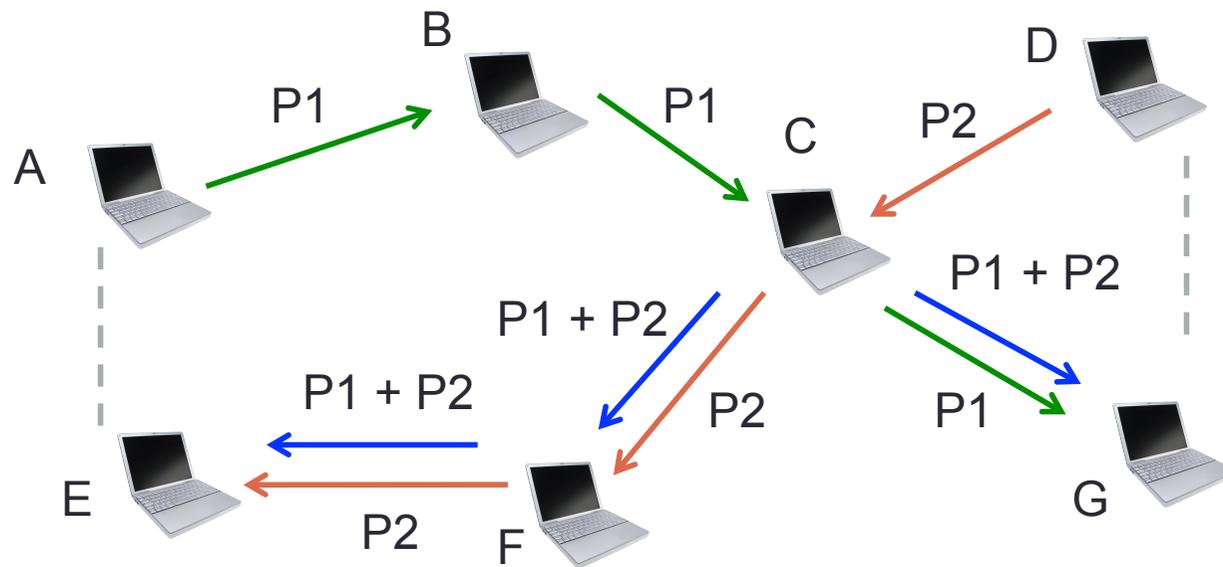


BEND performances

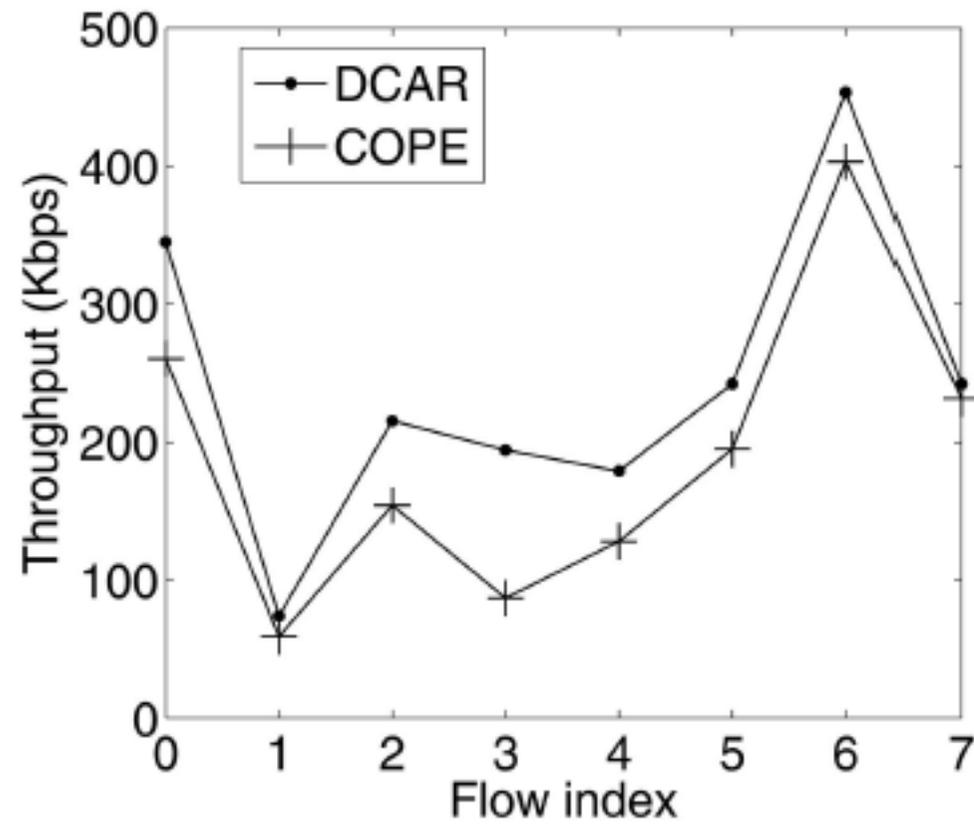


DCAR

- Distributed Coding-Aware Routing
- Extension of COPE
- More-than-2-hop coding pattern
- Flows cross at a common intermediate node

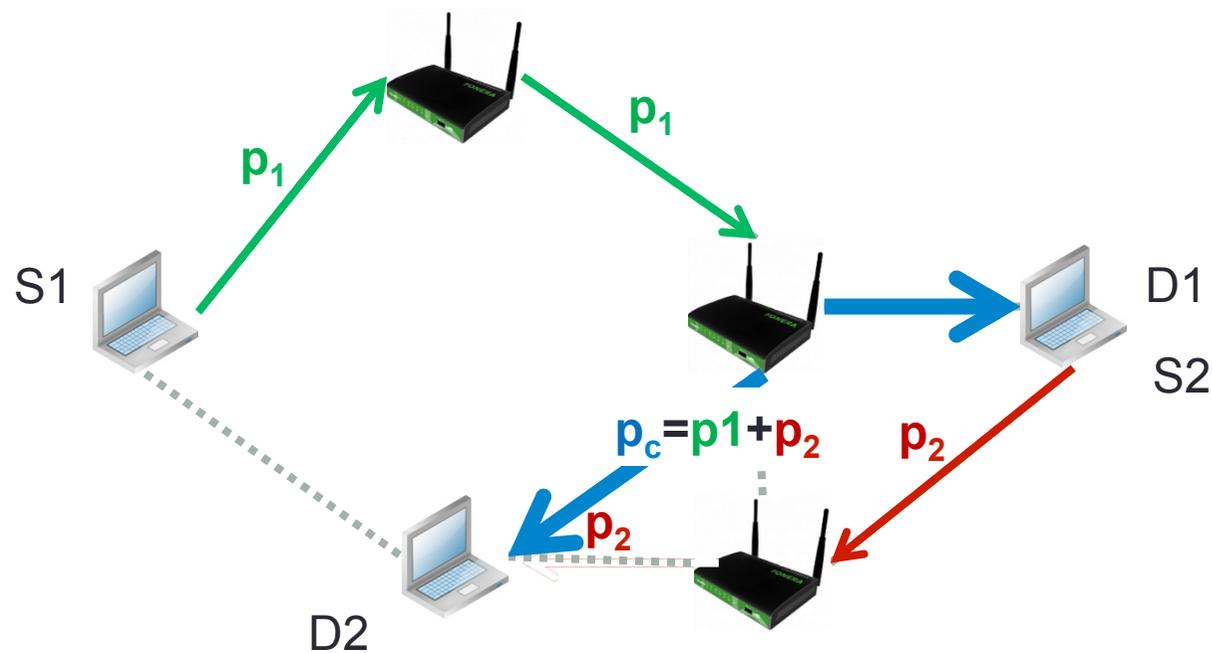


DCAR performances

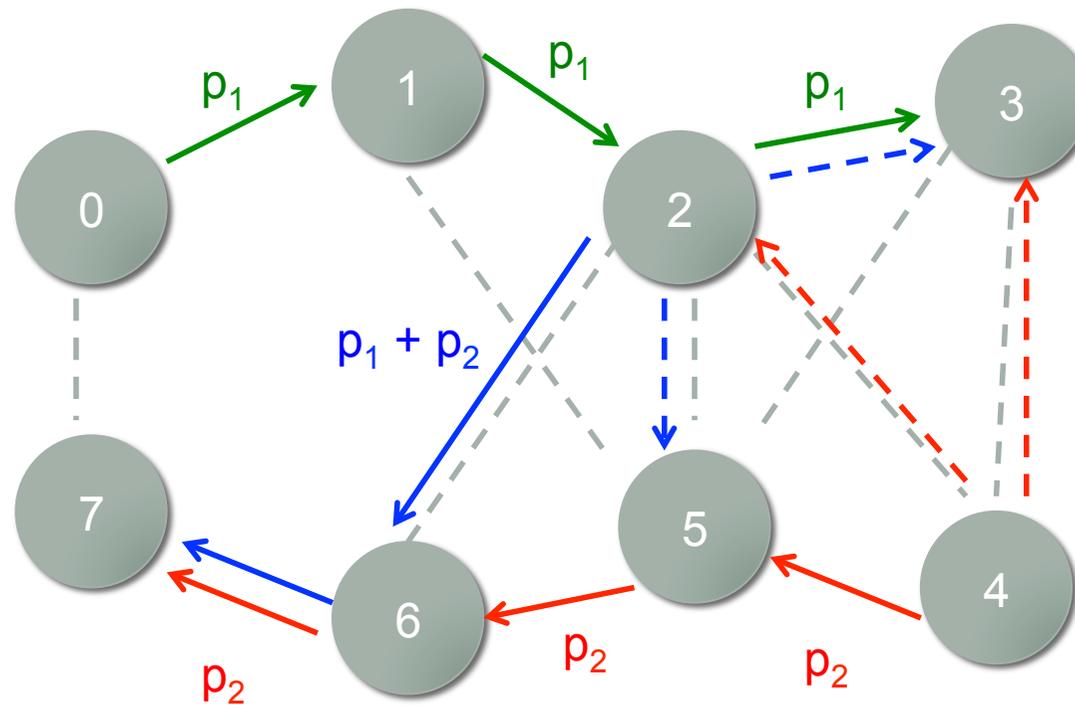


DODE

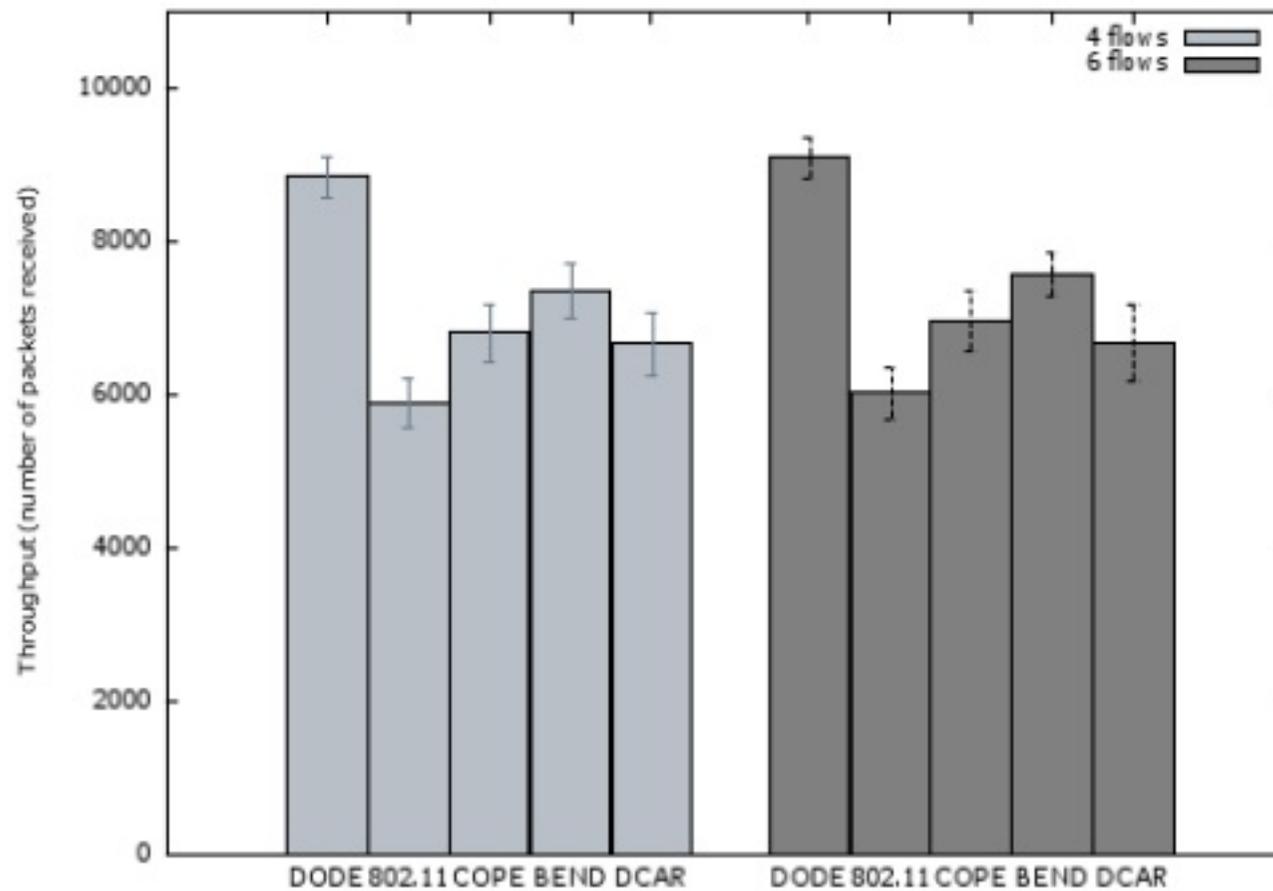
- Combination of BEND and DCAR
- Flows can be more than 2 hops
- Flows do not need to cross at a common intermediate node



Another topology for DODE

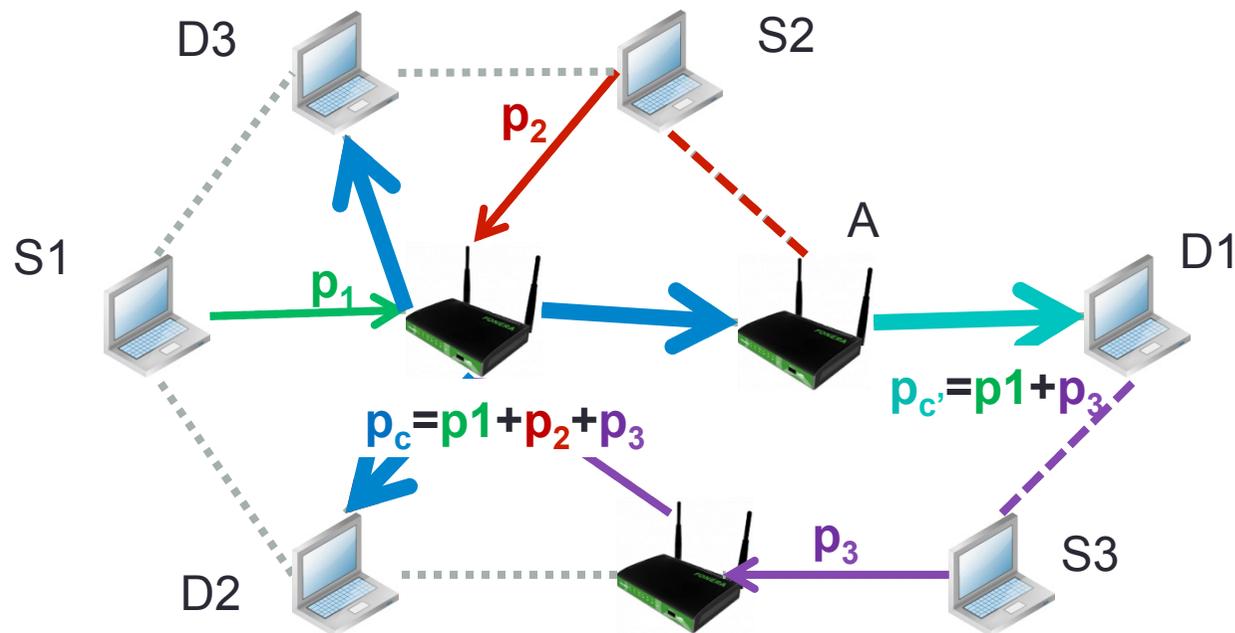


DODE performances

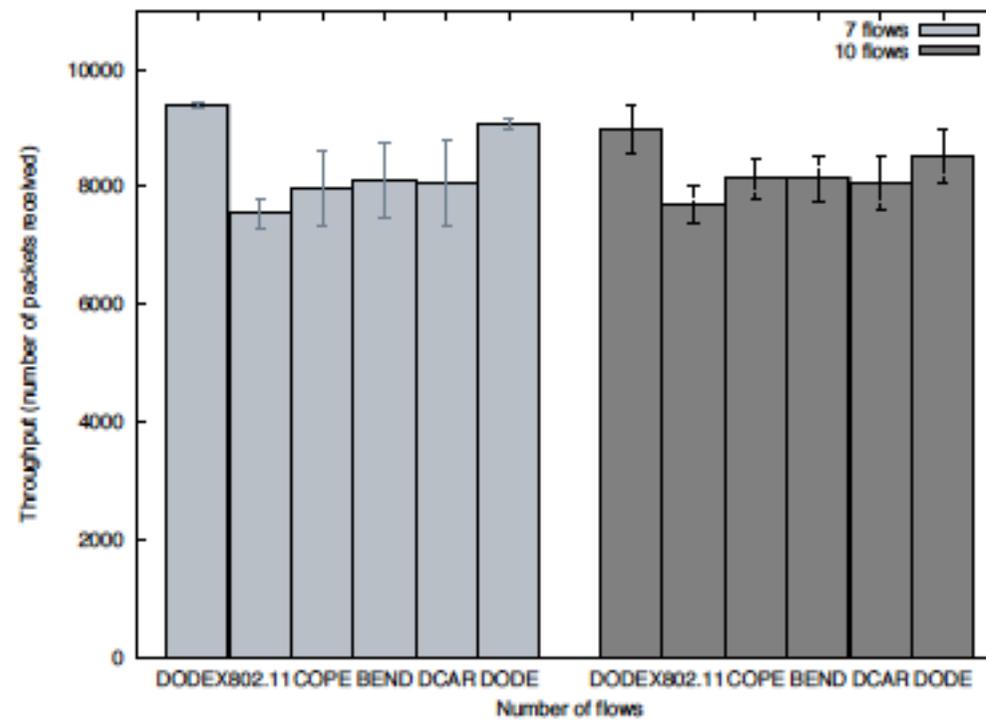


DODEX

- Extension of DODE
- Multiple decoders
- A decoder can partially decode an encoded packet

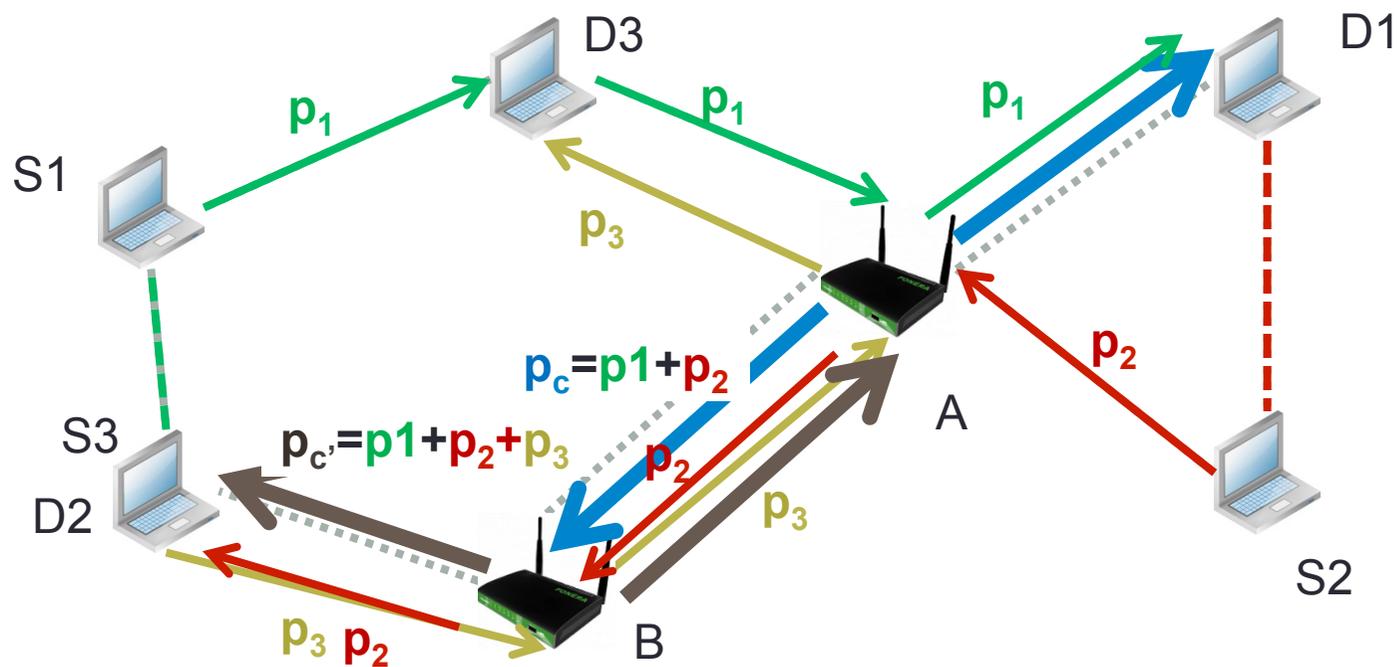


DODEX performances

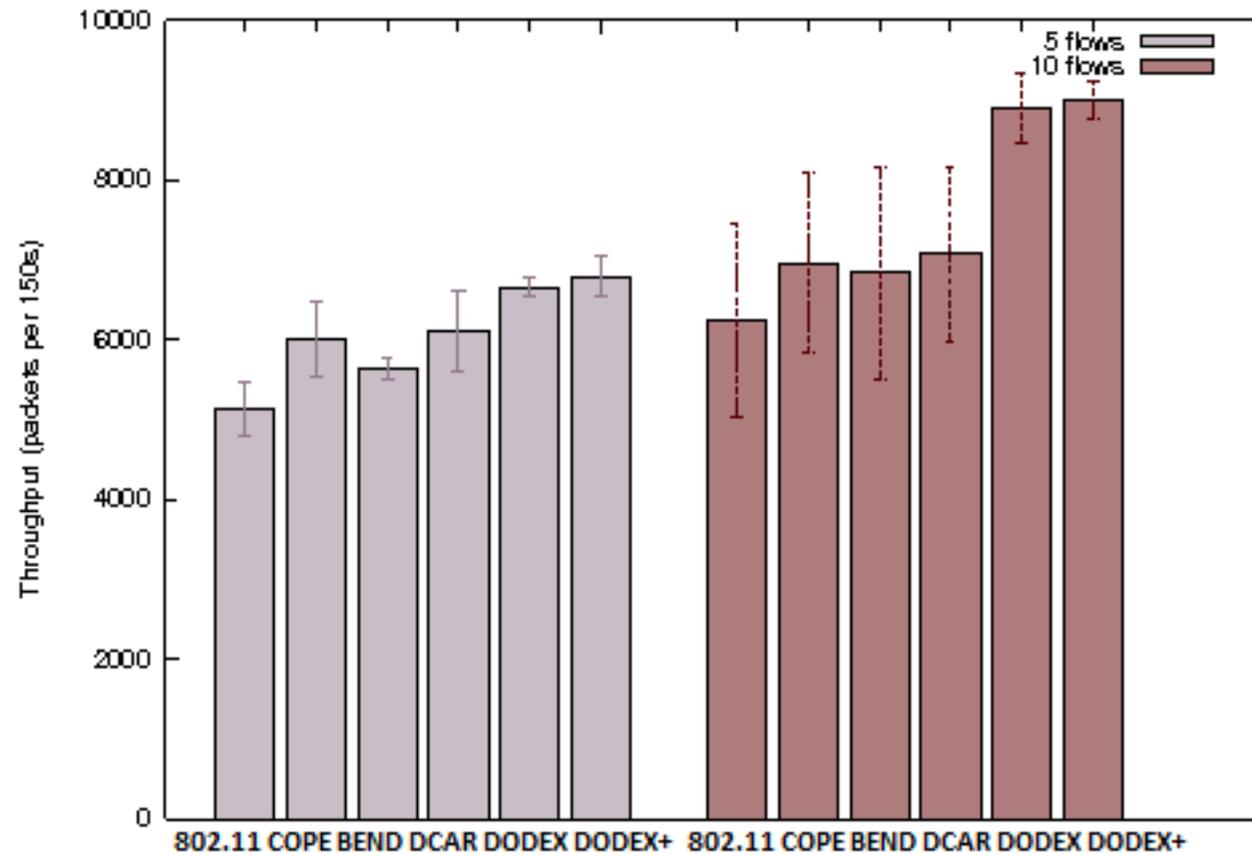


DODEX+

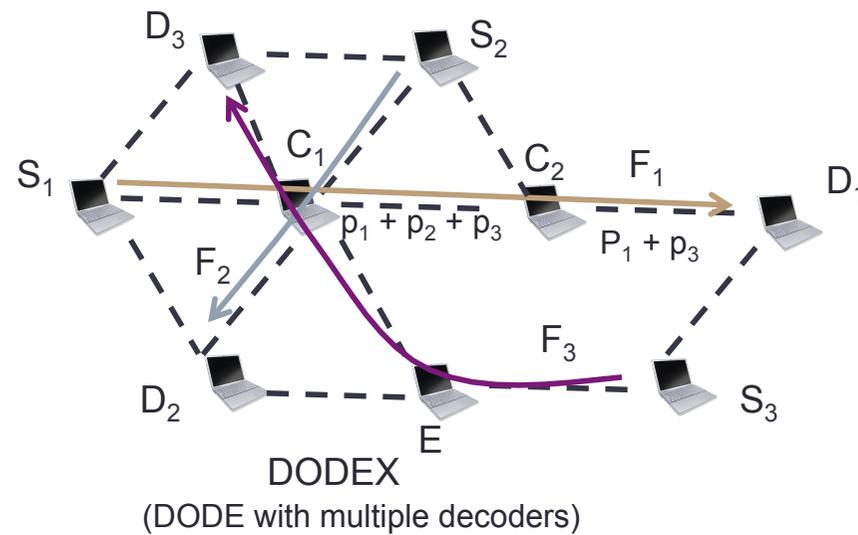
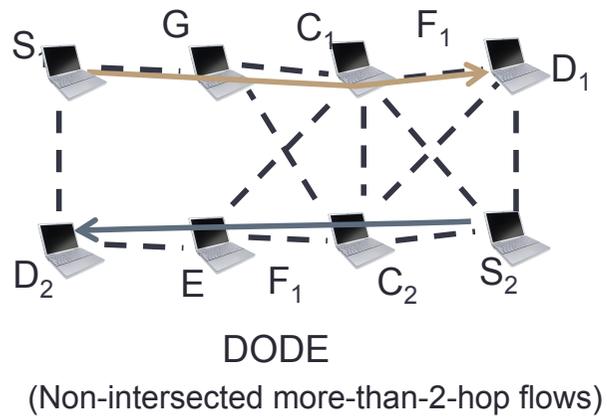
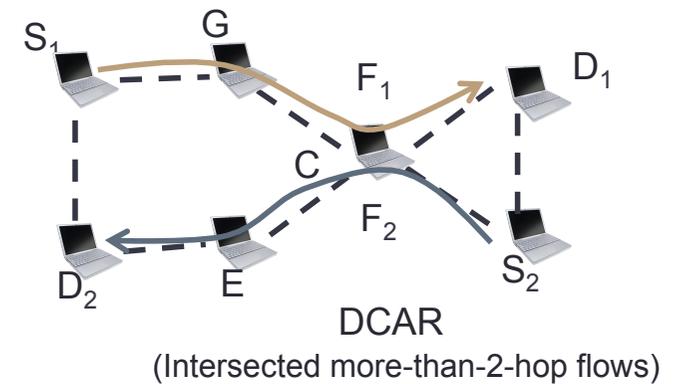
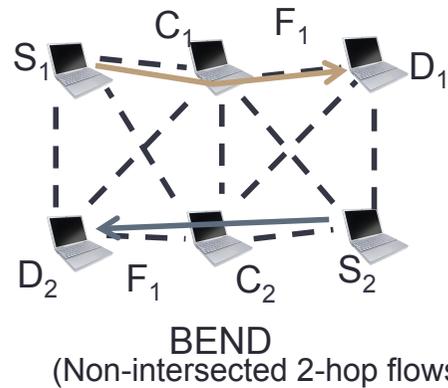
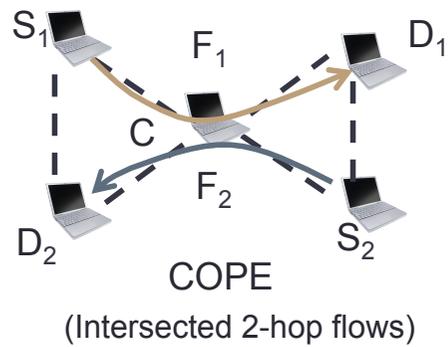
- Extension of DODEX
- Multiple encoders
- Allow re-encoding



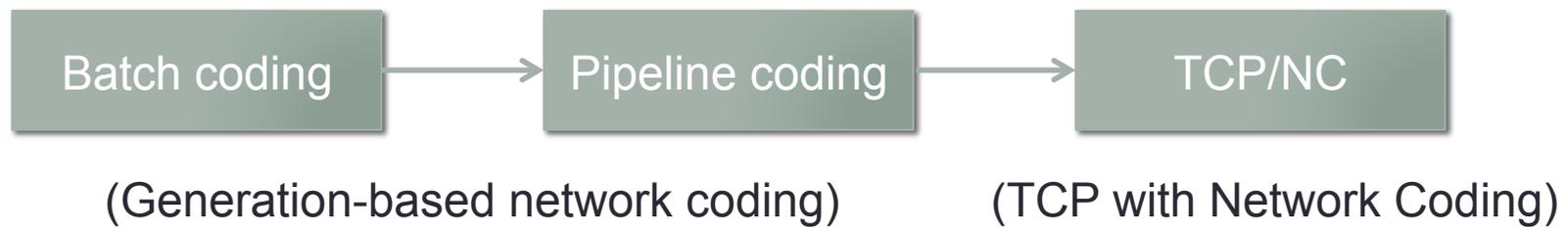
DODEX+ performances



CODING STRUCTURES

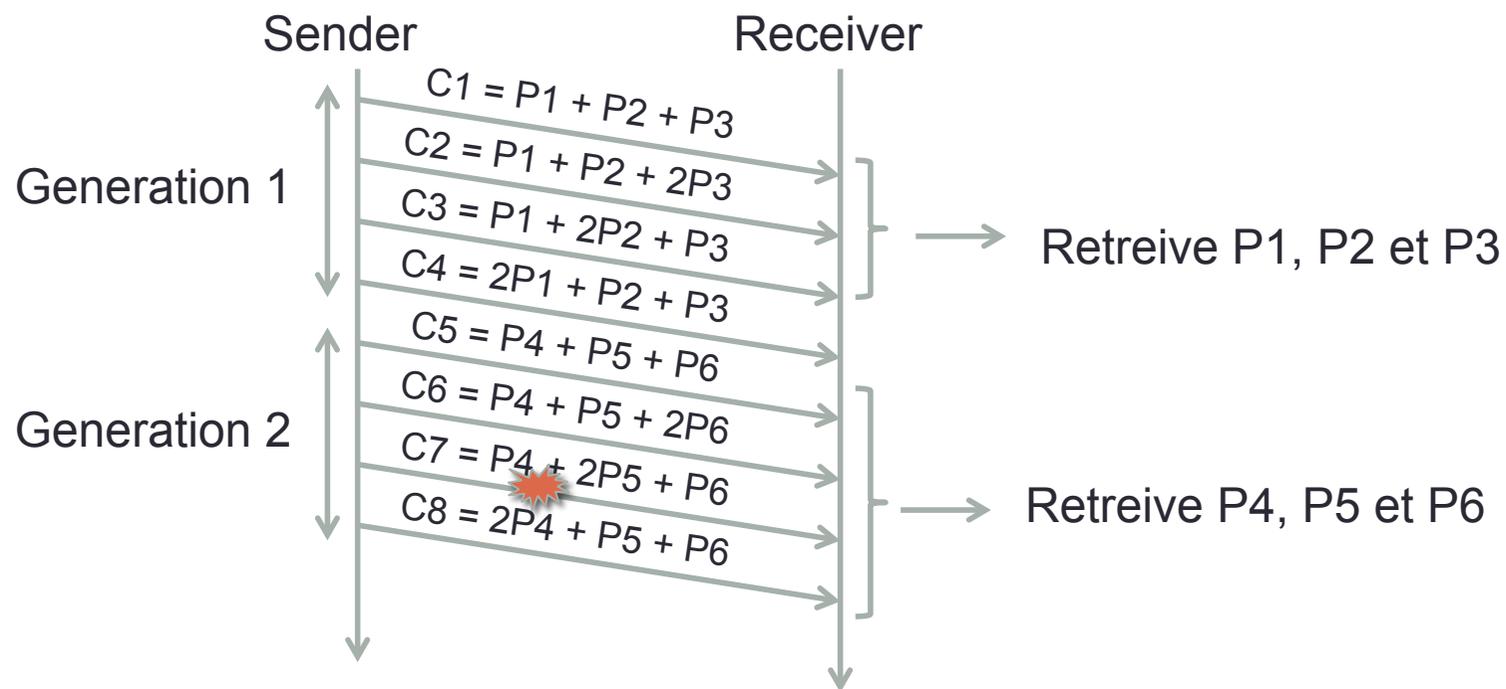


Intra-flow network coding



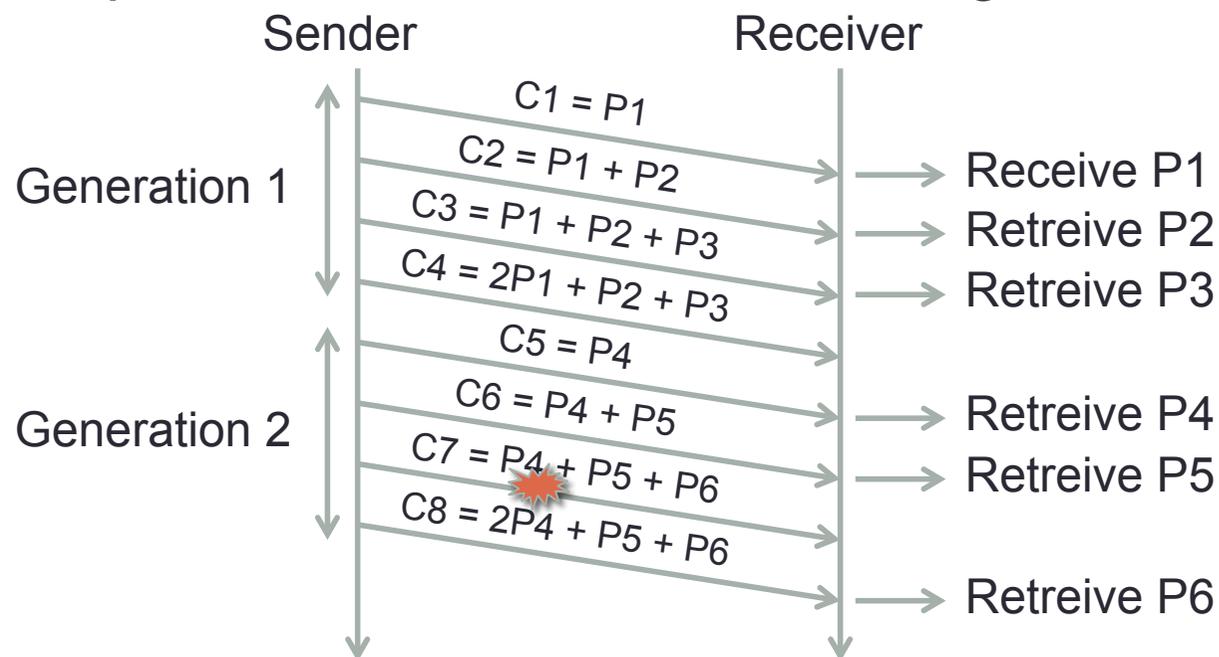
Batch coding

- Packets are grouped into **generation** of size n
- Fixe redundancy level
- Provide transmission reliability against packet loss



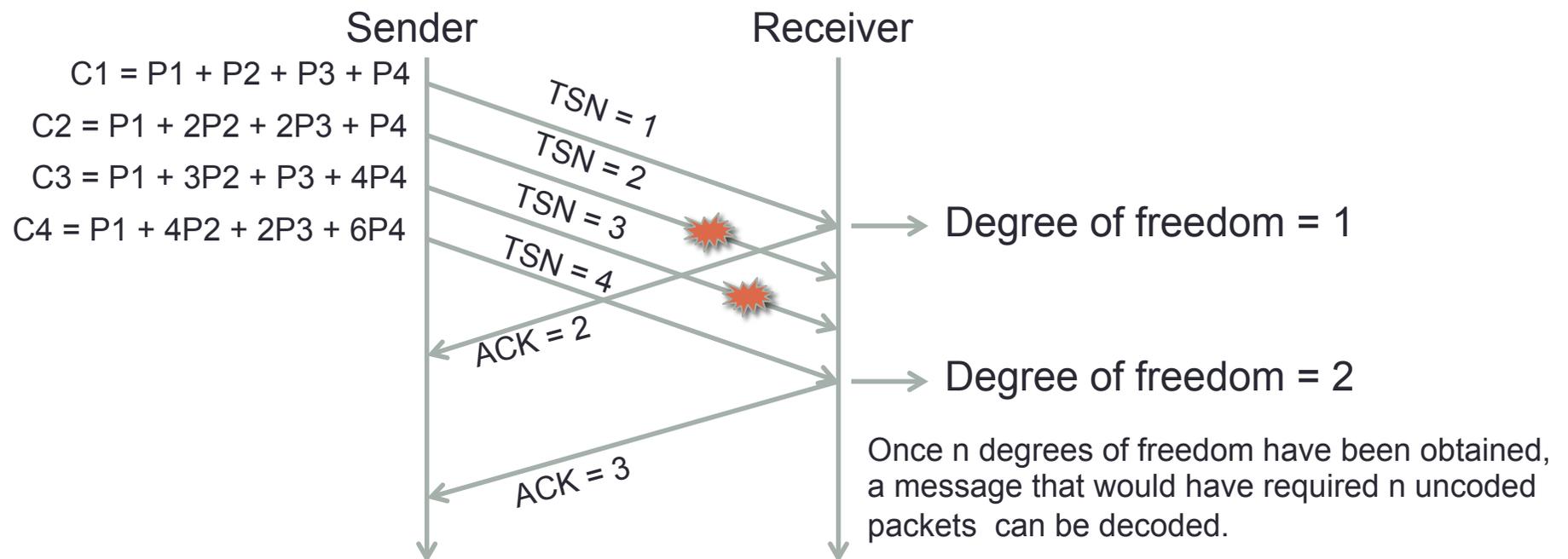
Pipeline coding

- Variation of batch coding
- Packets of a generation are added one by one into the encoding process
- The decoding does not need to wait for the arrivals of n coded packets \rightarrow reduce the decoding time

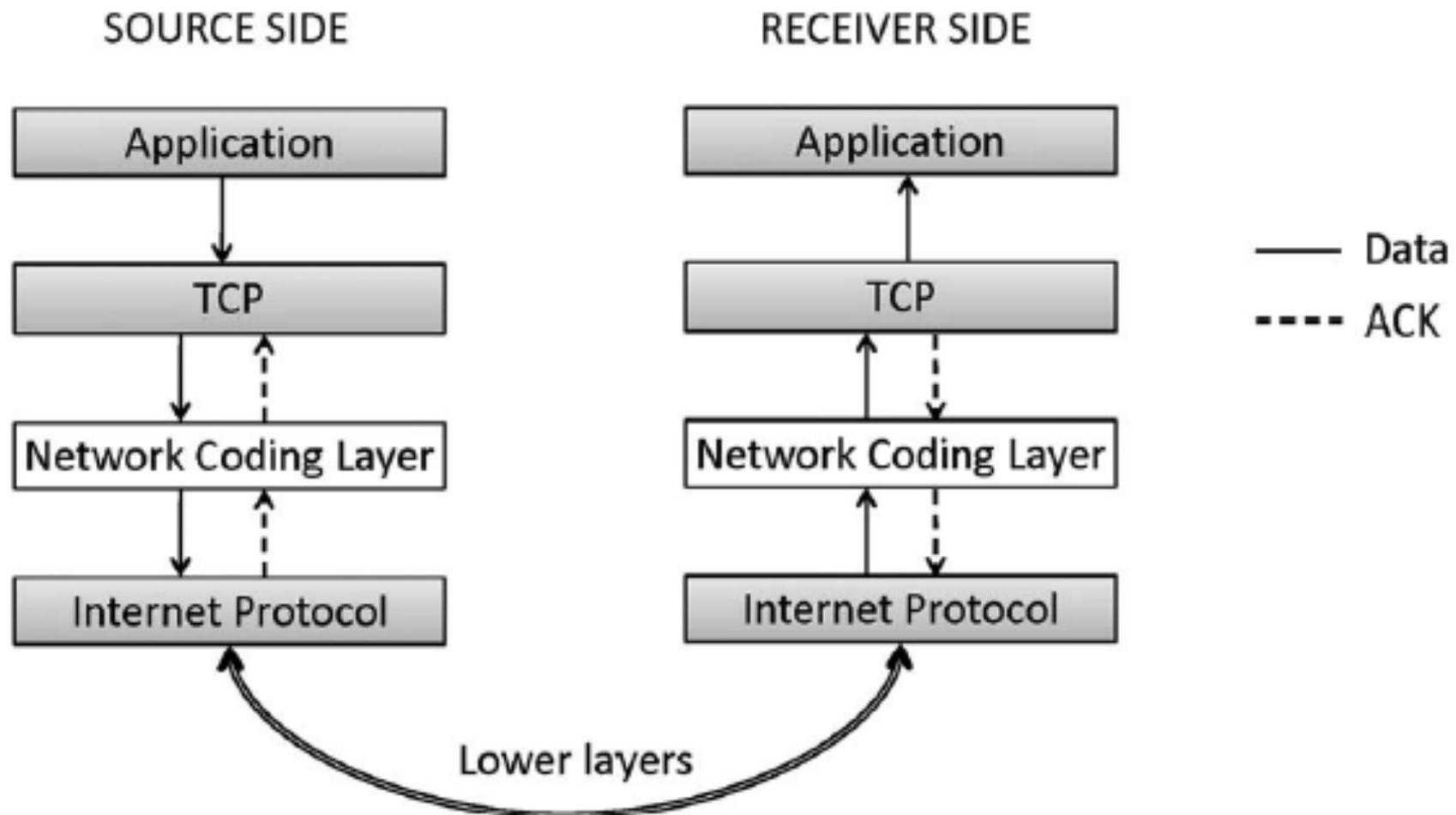


TCP/NC

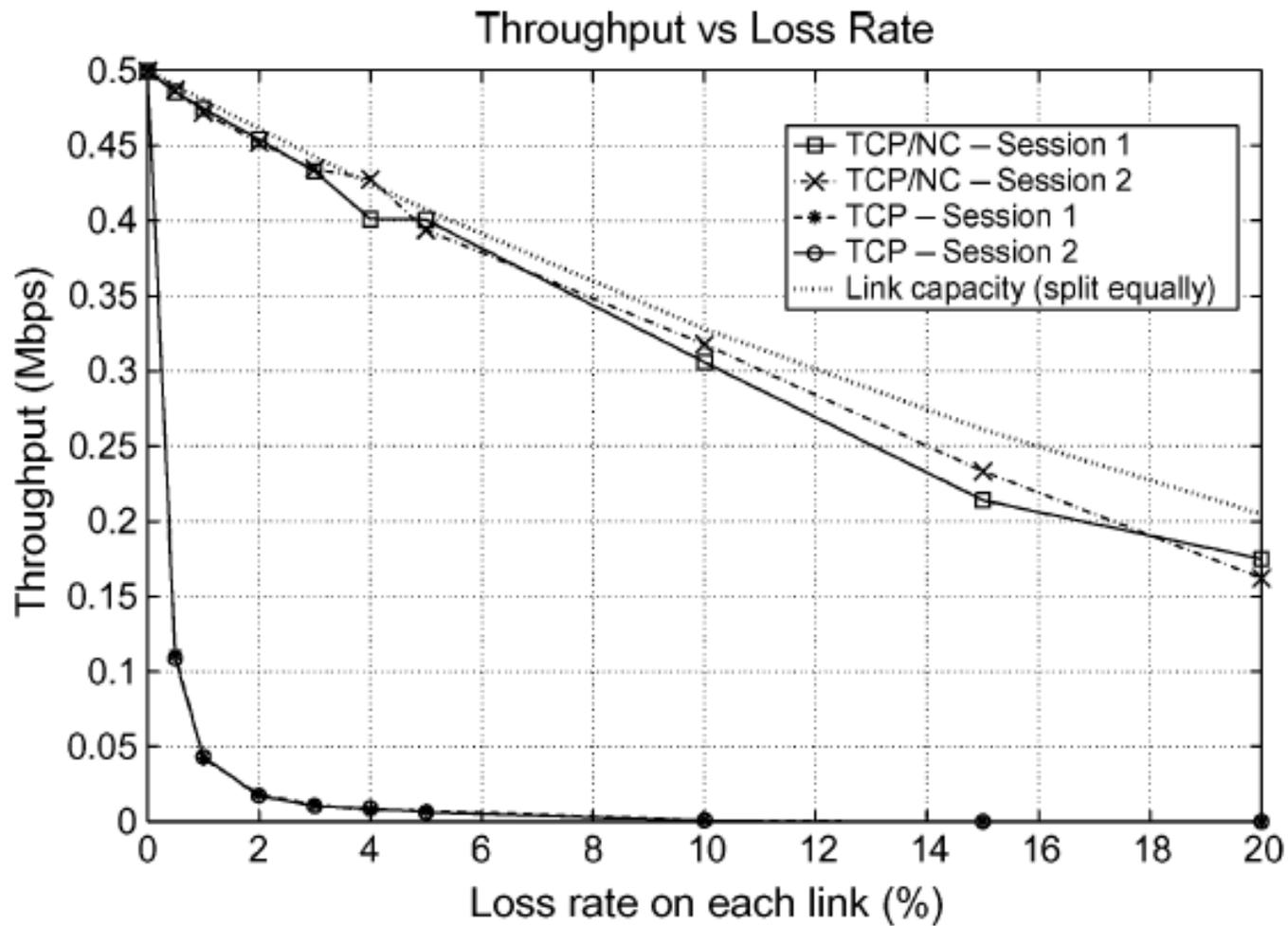
- Transmission Control Protocol with Network Coding
- No generation
- All packets in the congestion window are encoded together
- Acknowledge a degree of freedom (a linear combination that reveals one unit of new information)
- Mask packet loss from TCP congestion control → better throughput



TCP/NC implementation



TCP/NC throughput



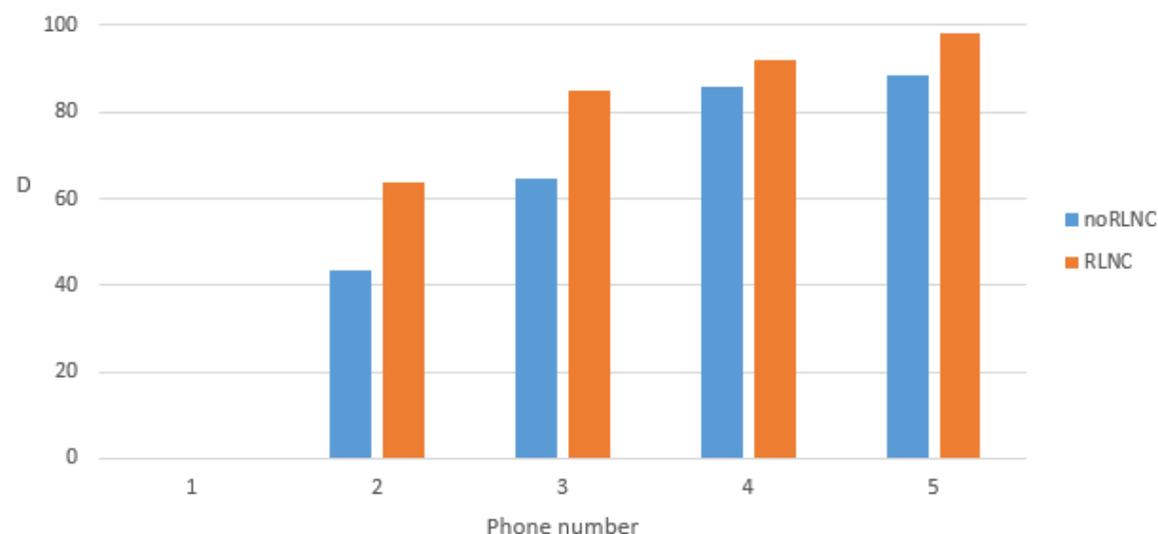
NETWORK CODING FOR D2D-BASED COOPERATIVE STREAMING

- ❖ A real test-bed of cooperative streaming with network coding at Nanjing University (NJU)
- ❖ The smart phones try to get video segments by D2D first
- ❖ The cellular interface is used when the waiting time is greater than a threshold
- ❖ Terminal 1 starts the video first
- ❖ Terminals 2-5 follow one after another every 20s



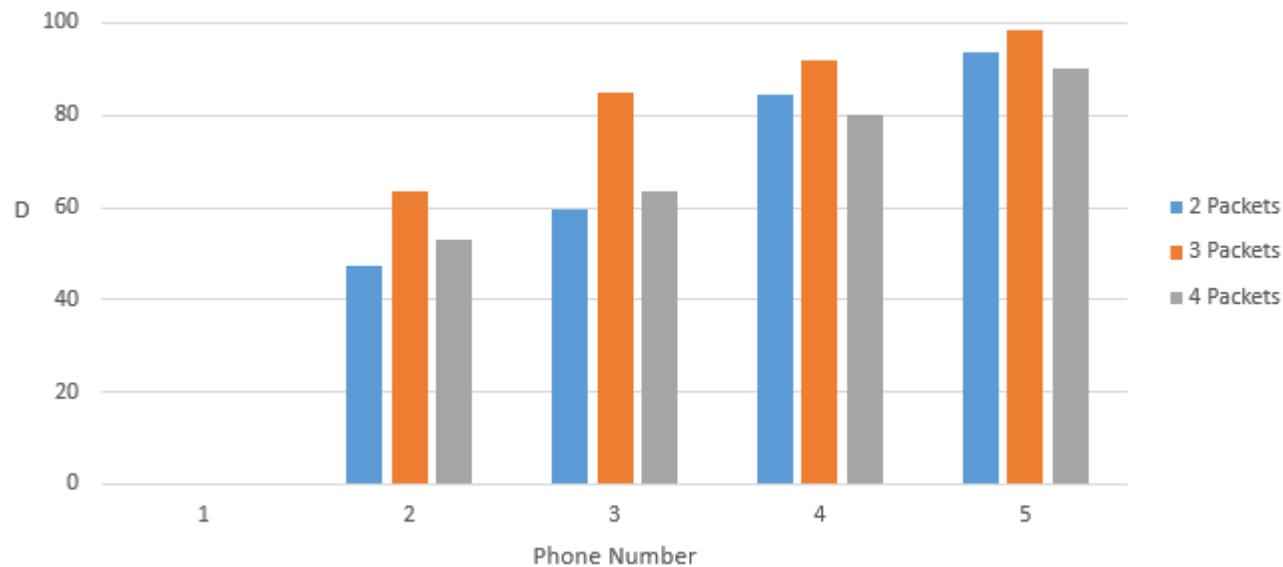
OFFLOADING GAIN WITH VS. WITHOUT USING NETWORK CODING

- ❖ Offloading gain $D = W/(W+C) * 100\%$
 - ❖ W : the amount of data obtained by video sharing using D2D communications
 - ❖ C : the amount of data obtained by directly downloading from the server using the cellular interface



OFFLOADING GAIN UNDER DIFFERENT GENERATION SIZES

- ❖ Generation sizes
 - ❖ 2 packets of 24 KB
 - ❖ 3 packets of 16 KB
 - ❖ 4 packets of 12 KB



Conclusion

- Network coding is a very promising solution to future networks
 - Increase network capacity by detecting coding opportunities and reduce the number of wireless transmissions
 - Provide transmission reliability by combining packets belonging to the same flow
- Changes in current network device behavior is needed to support network coding
 - Routers can combine incoming packets
 - Wireless interfaces need to enable overhearing
 - Transport protocols exchange packet combinations instead of native packets
- Network coding should be considered and integrated in the first step of future network architecture and protocol design