Network Coding on the Physical-Layer

Presenter: Hongxing LI

October 8, 2010

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- Can be used to attain the maximum possible information flow in a network.

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Definition

Network coding is a technique where, instead of simply relaying the packets of information they receive, the nodes of a network will take several packets and combine them together for transmission.

Categorization of Network Coding

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2. By Mixing

Linear Random Codes: Mechanism

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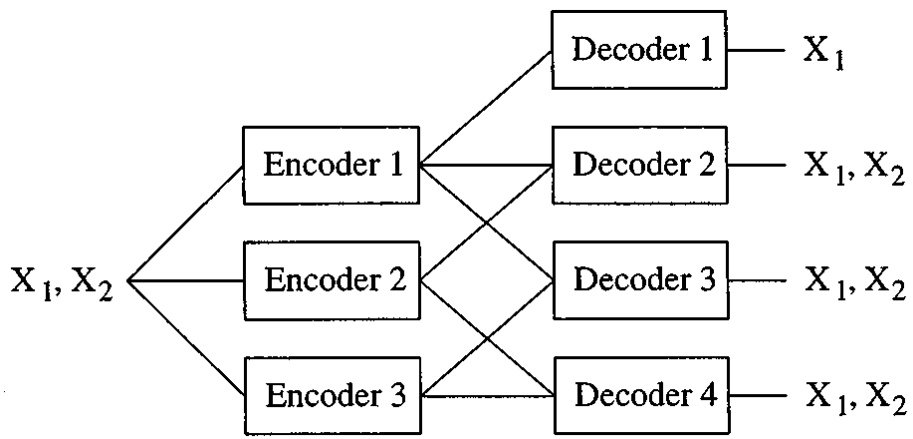

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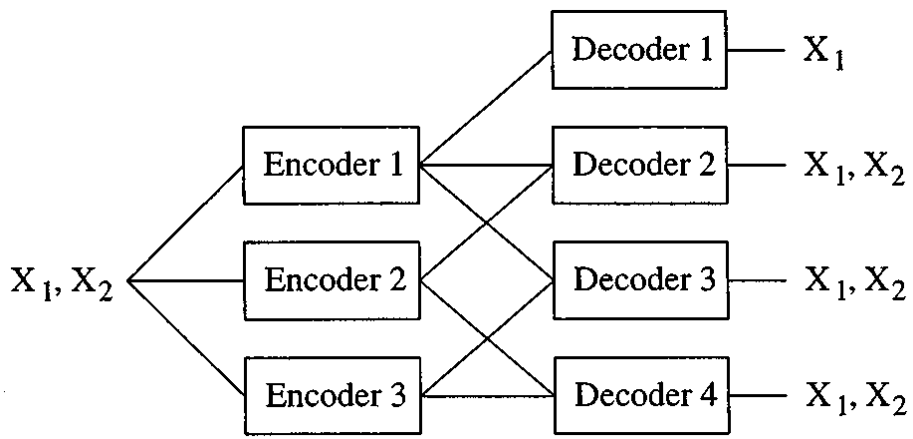

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Linear Network Coding: Merits

To recover source packets, instead of receiving the complete copies, we only need enough linear-independent code blocks. Each code block flows in the network as an equation of source packets.

- Delivery efficiency.
- Ease of management.
- Resilience to network dynamics: packet loss, node arrival and departure.

Linear Network Coding: Applications

- Live media broadcast.
- Media on demand.
- Stock quotes distribution.
- File sharing.
- Gaming.
- Conferencing.
- Distance learning.

Mixing

Instead of forwarding the data packets, we mix the packets, *i.e.* XOR operation, and send out the mixed packet.

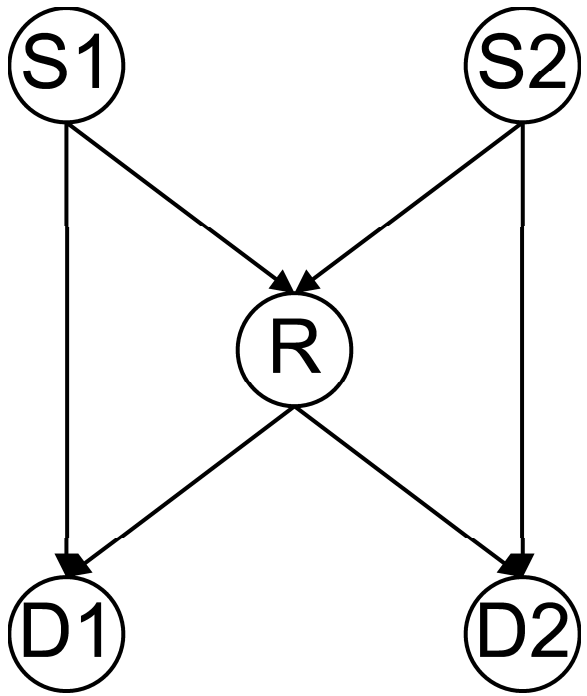


Figure: Butterfly topology.

Mixing

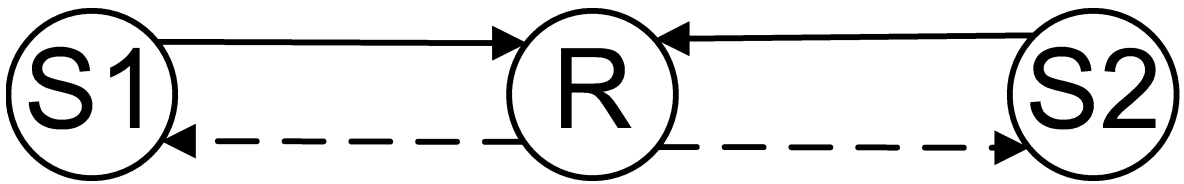


Figure: Two-way transmission.

Physical/Analog Network Coding

- Mixing at the signal level.
- Instead of decode-and-forward, the intermediate node only forwards the mixed signal.

Physical Network Coding

- Proposed by Zhang et al. (CUHK)
- Demodulate-and-forward.
- Bit-level synchronization.
- Power control.

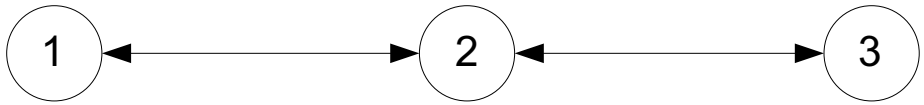


Figure: A three-node linear network.

Modulation mapping at N_1 and N_3,				Demodulation mapping at N_2		
				Input	Output	
Input		Output			Modulation mapping at N_2	
					Input	Output
$s_1^{(I)}$	$s_3^{(I)}$	a_1	a_3	$a_1 + a_3$	$s_2^{(I)}$	a_2
1	1	1	1	2	0	-1
0	1	-1	1	0	1	1
1	0	1	-1	0	1	1
0	0	-1	-1	-2	0	-1

Figure: PNC Mapping (QPSK): modulation mapping at 1, 2; demodulation and modulation mappings at 3.

Analog Network Coding

- Proposed by Katabi et al. (MIT)
- Amplify-and-forward.
- No synchronization.
- No Power control.

Modulation scheme: MSK. So received signal is in the form of $y[n] = Ae^{i\theta[n]} + Be^{i\delta[n]}$.

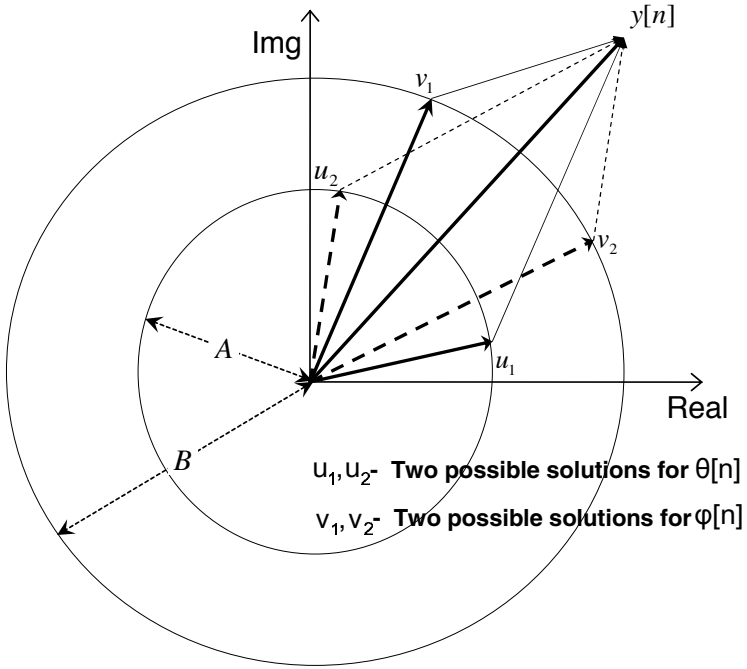
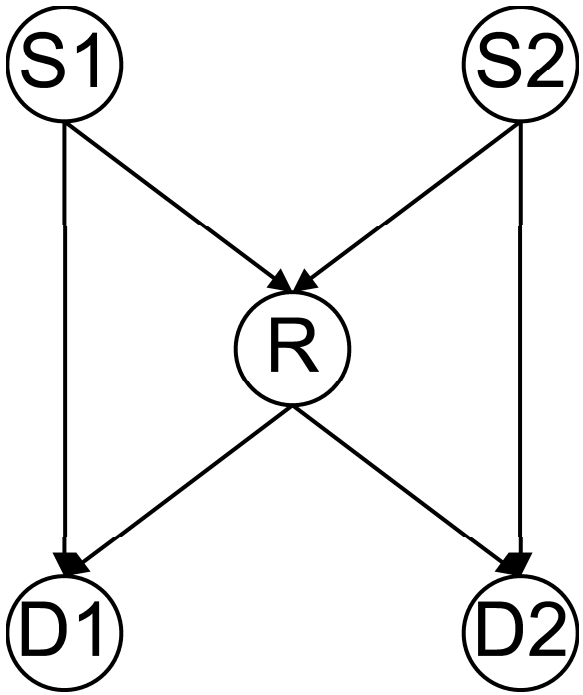


Figure: **Geometric representation of the phase computation**. the received complex sample $y[n]$ is the sum of two complex numbers u and v. The length of the first complex number is A and the length of second is B. There are exactly two pairs of such complex numbers (u, v) that sum up to $y[n]$. Thus, two solutions exist for the pair $(\theta[n], \delta[n])$.



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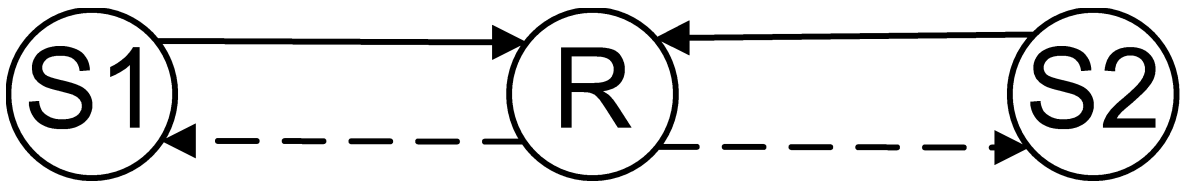

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- Explore the application of physical/analog network coding for **multi-hop** scenarios other than two-way Alice-Bob topology or its simple derivatives.
- Cooperation among relay nodes.
- Combination of linear random codes and physical/analog network coding.
  - Use the channel state, *i.e.* amplitude attenuation and phase drift, as the random codes.
  - Each path constitutes a linear equation of source packets.

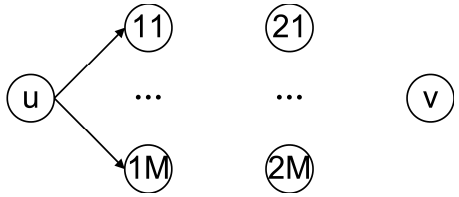
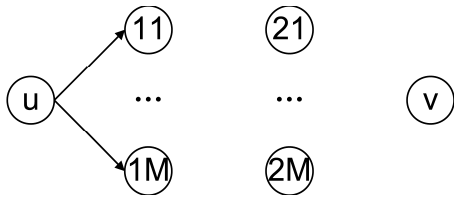


Figure: Step 1: Time slot 1 to M.



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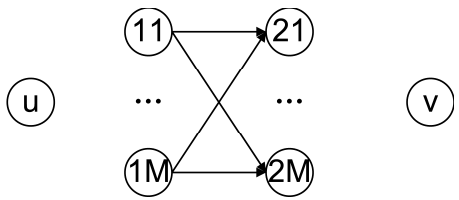
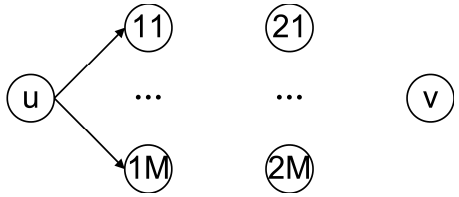


Figure: Step 2: Time slot $M + 1$.



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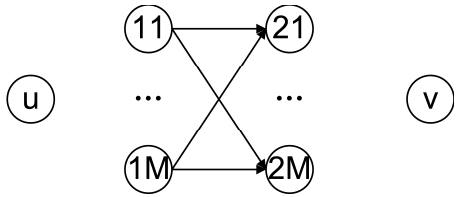

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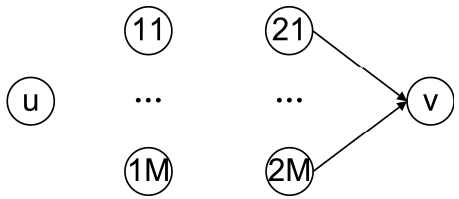


Figure: Step 3: Time slot $M + 2$ to $2M + 1$.

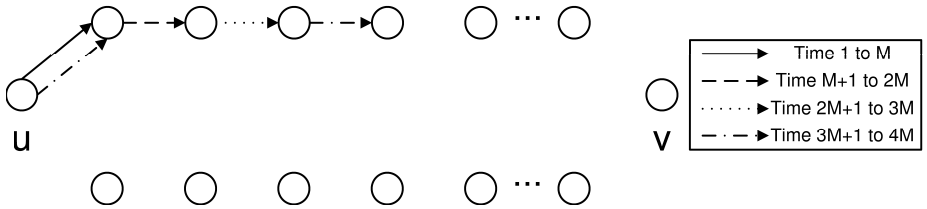
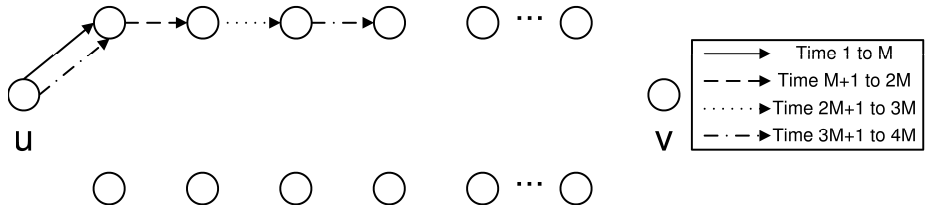


Figure: Scheduling of multi-hop unicast flow with traditional routing.



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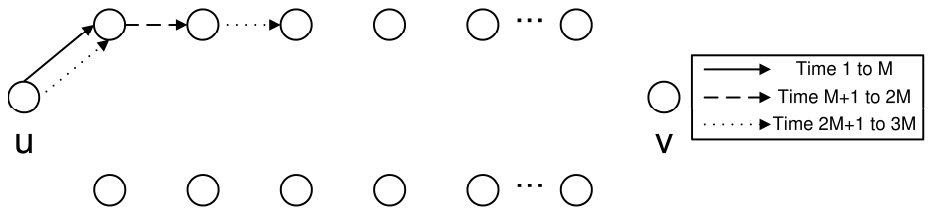

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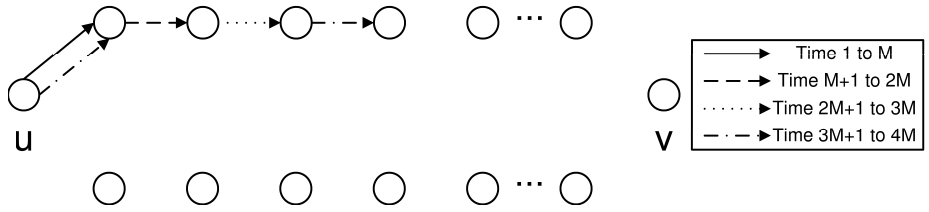

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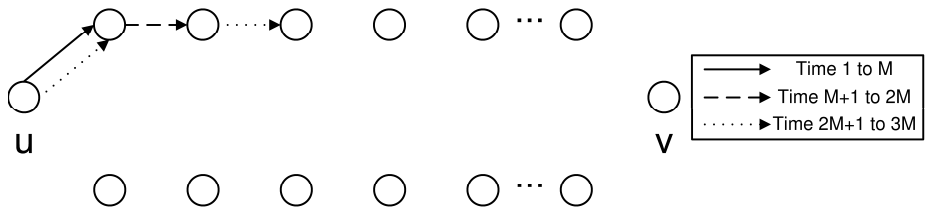

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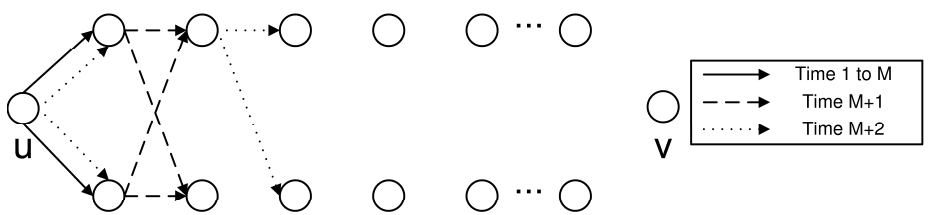
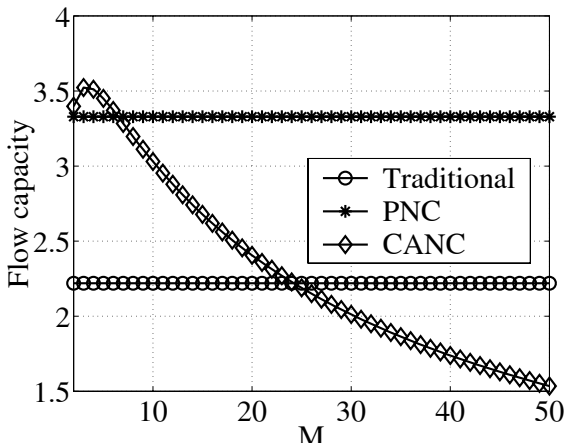
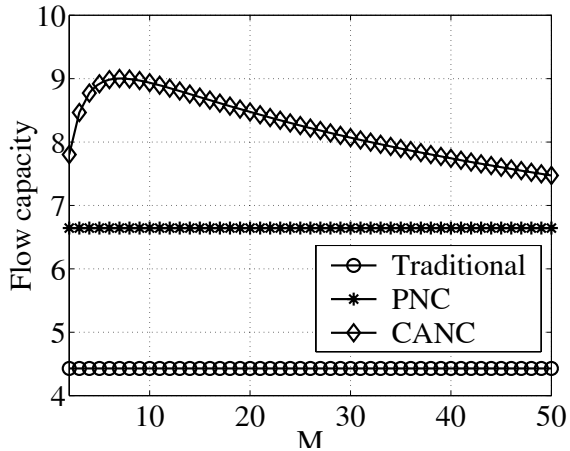


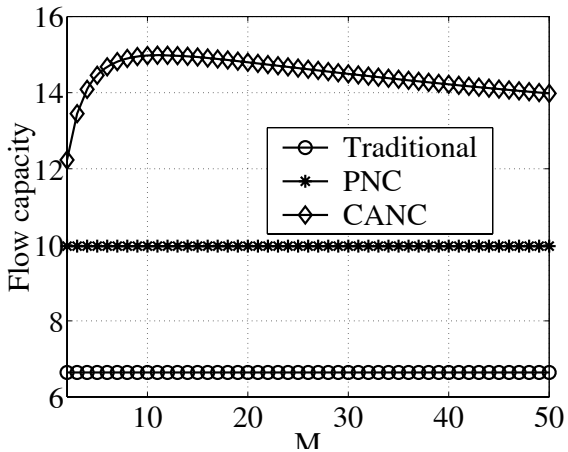
Figure: Scheduling of multi-hop unicast flow with *CANC*.



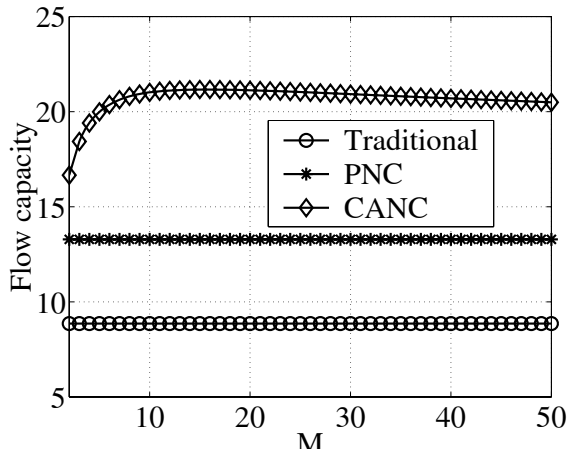
(a) $SINR = 20db$



(b) $SINR = 40db$



(c) $SINR = 60db$



(d) $SINR = 80db$

Figure: Unicast flow capacity: a comparison among three schemes.

Thank You!