Joint Relaying and Network Coding in Wireless Networks

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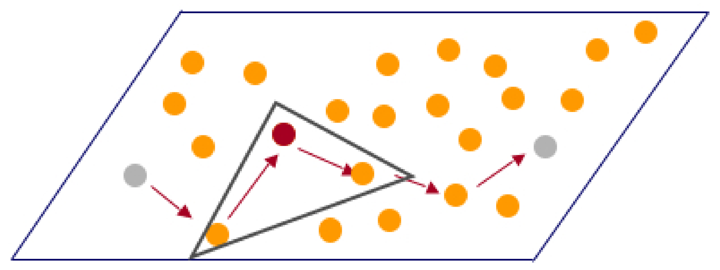
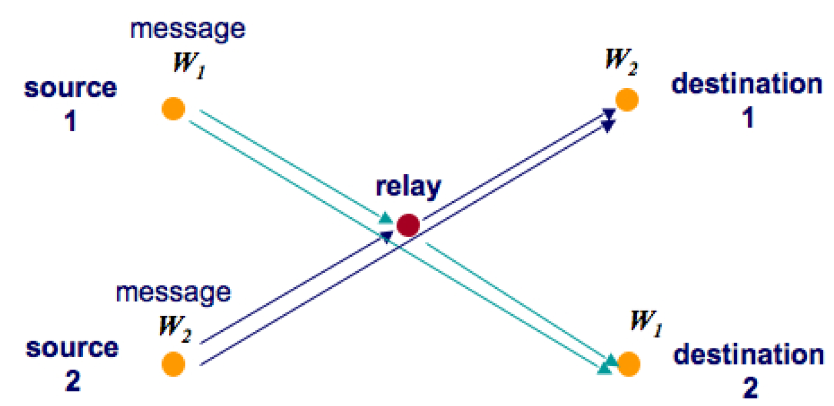
Relaying



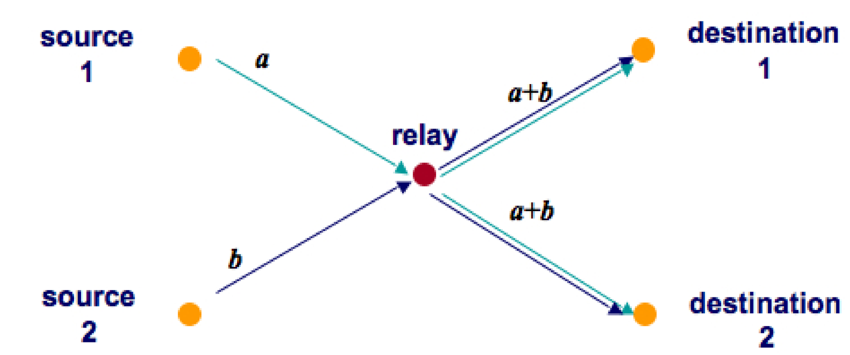


- Traditional communication in wireless networks: multihop through logical point-to-point links
  - Other signals treated as interference
- Cooperative strategies developed for the relay channel are known to improve the performance
  - Nodes do not discard interfering signals
  - Nodes cooperatively encode

- Relaying still implies routing on the network layer

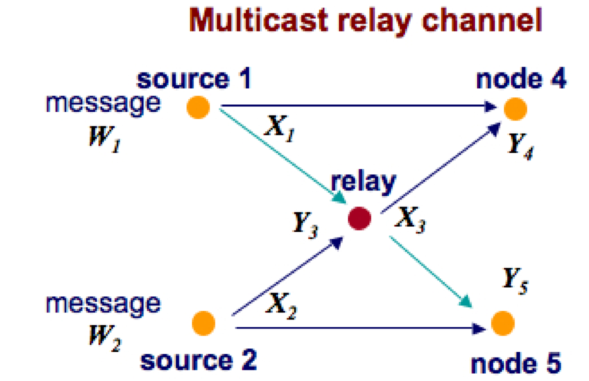
- Relay switches between forwarding two streams

Network Coding in Wireless Settings



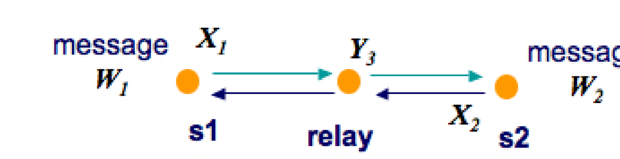
- Combining data streams at the relay is crucial
- Assumptions: non-wireless setting
  - No interference
  - No broadcasting

Multicast relay channel



Smallest relevant multicast network

Two-way relay channel



Smallest relevant unicast network

- We consider broadcasting and interference

$$Y_3=X_1+X_2+Z_3$$
$$Y_4=X_1+X_2+X_3+Z_4$$
$$Y_5=X_1+X_2+X_3+Z_5$$

Approach

1) Consider routing

Relay time shares between relaying two data streams

⇒ signal at the relay:

$X_3=f(X_1)$ for $t=[0,\tau]$ relaying for source 1

$X_3=f(X_2)$ for $t=[\tau,T]$ relaying for source 2

- Determine outer bounds
  - Employ cut-set bounds for the relay channel

2) Consider simple *analog* network coding scheme

$X_3=\alpha Y_3$

- This combines two data streams since:

$X_3=\alpha Y_3=\alpha(X_1+X_2+Z_3)$

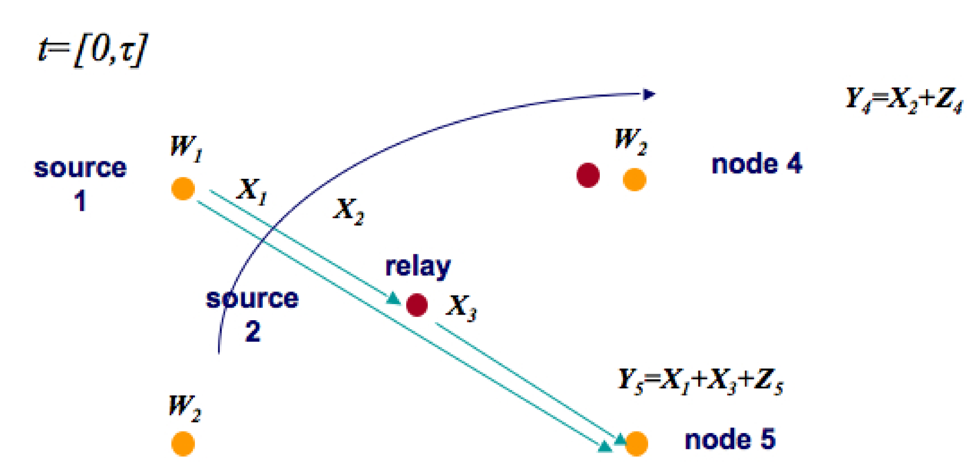
- Evaluate the achievable rates for multicast and unicast in two considered networks

compare

- Showing that rates achievable with analog network coding can outperform the outer bounds of relaying will demonstrate the benefits of joint relaying and network coding

Outer Bound to any Routing Scheme

$t=[0,\tau]$



- "Genie" gives W_2 to node 5 and the relay ⇒ no interference X_2
  - Outer bounds for the relay channel apply:

$$R_{15}^{\tau}\leq\tau\max_{p(x_1,x_3)}\min\{I(X_1;Y_3,Y_5\mid X_3)I(X_1,X_3;Y_5)\}$$

$$R_{15}^{\tau}\leq\tau\min\left\{\frac{1}{2}\log\left(1+P_1(1-\rho^2)\left(\frac{1}{N_3}+\frac{1}{N_5}\right)\right),\frac{1}{2}\log\left(1+\frac{P_1+P_3+2\rho\sqrt{P_1P_3}}{N_5}\right)\right\}$$

- Direct transmission of message W_2
  - Genie" gives W_1 to node 4 ⇒ no interference X_1, X_3

$$R_{24}^{\tau}\leq\tau\max_{p(x_2)}I(X_2;Y_4)\quad R_{24}^{\tau}\leq\tau\frac{1}{2}\log\left(1+\frac{P_2}{N_4}\right)$$

$t=[\tau,1]$: Symmetric scenario *except* for an upper bound we assume that relay decoded W_2 in $t=[0,\tau]$

Outer bound:

$$R_{15}\leq\tau R_{15}^{\tau}+(T-\tau)R_{15}^{T-\tau}$$
$$R_{24}\leq\tau R_{24}^{\tau}+(T-\tau)R_{24}^{T-\tau}$$

Achievable Rates with Simple Analog Network Coding

- Transmitted at the relay: $X_3=\alpha Y_3$
- Received at the destination t:

$$Y_4=(1+\alpha)X_1+(1+\alpha)X_2+\alpha Z_3+Z_4$$
$$Y_5=(1+\alpha)X_1+(1+\alpha)X_2+\alpha Z_3+Z_5$$

Compound MAC

- Capacity region of compound MAC is known *[Ahslwede, 1974]*

⇒ an achievable rate region in the considered channel

- More realistic model: delay at the relay
- Received at the destination t

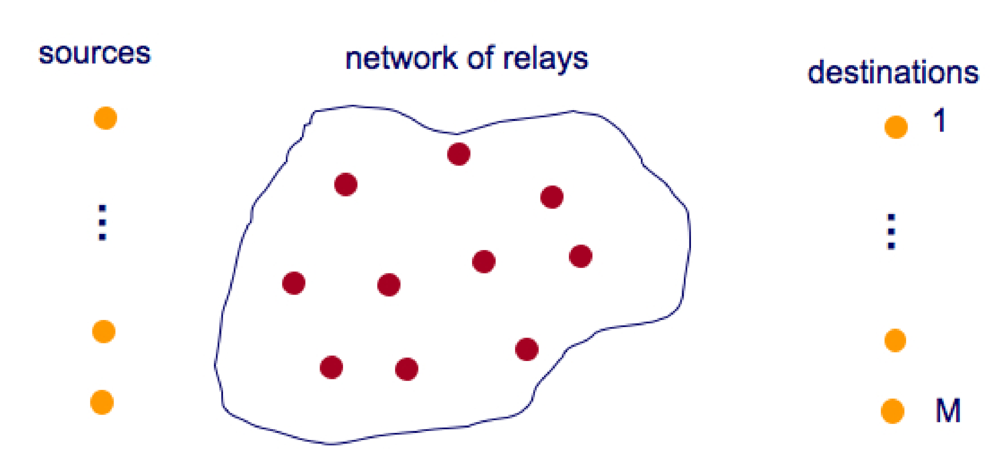
$$Y_4[i]=X_1[i]+\alpha X_1[i-1]+X_2[i]+\alpha X_2[i-1]+\alpha Z_3[i-1]+Z_4[i]$$
$$Y_5[i]=X_1[i]+\alpha X_1[i-1]+X_2[i]+\alpha X_2[i-1]+\alpha Z_3[i-1]+Z_5[i]$$

Compound MAC with ISI

- Capacity region of MAC with ISI is known *[Cheng& Verdu, 1993]*
- Again, it constitutes an achievable rate region for the considered channel

Future Work

- **Generalize to Large Networks:**



- Relay strategies such as Block Markov encoding, sliding-window decoding, backward decoding become very involved in larger networks
  - Proposed joint encoding scheme is simple ⇒
  - The achievable rates of the same coding scheme can be evaluated in a large network with M>2 destinations

Further work on small networks:

- Obtain tighter bounds on the performance of the relaying and routing scheme
- Further explore and propose cooperative schemes that incorporate joint relaying and network coding and result in improved or optimal performance
- Determine scenarios in which the separation between relaying and network coding does not result in the loss of performance