Hop-by-Hop Forwarding vs Immediate Forwarding for Two-Way Relaying: Stability Regions

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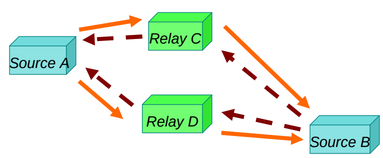
Motivation

•Two-way traffic: ad-hoc and peer-to-peer systems.
•Likely scenario: multiple intermediate relays cooperatively assisting end nodes.
•Impact of stochastic arrivals: how do we best communicate two-way stochastic traffic using the intermediate relays and how do the resulting stability regions compare?
•Policies with queues at relays (*hop-by-hop scheduling*) or without queues at relays (*immediate forwarding*)



Methodology

• Throughput optimal policy: All queues must be *bounded* for input rates in the stability region.
• Multiple relays, two-way stochastic traffic [Ciftcioglu-Yener-Berry 2008]
  •Rate allocation and relaying technique determined according to *channel* conditions and *queue* states *jointly*.
  •Models: (i) queues at relays (ii) no queuing at relays

•Objective: Compare the resulting *stability regions*
•Network flow problem

Transmission Policy Alternatives

Phase I: Information transmitted from sources to the relays
Phase II: Information transmitted from relays to end nodes
- Relays beam form to both directions → power splitting
- One relay transmits to both directions → power splitting
- One relay forwards data with XOR network coding

Hop-by-Hop scheduling with queues at relays
Schedule either Phase I or Phase II operation:
•Phase I- determine relay(s) to send, operating rate point
•Phase II- select relay(s) to be used and forwarding strategy with power splitting parameter if beamforming or superposition coding selected.

Immediate forwarding
Two phases scheduled jointly, time division determined

Throughput Optimal Hop-by-Hop Control Policy

•Cooperative and individual queues at relays for each direction
•Backpressure [Tassiulas-Ephremides 1992]: throughput optimality without apriori traffic statistics, operates with current channel and queue states
•CMDB policy - backpressure tailored to the model stabilizes the network

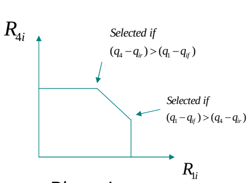
$$\max_{R\in C} \sum_{(i,j)\in L} w^*_{ij} R_{ij} + \sum_{(i,T)\in T} w^*_{iT} R_{iT} + \sum_{(S,i)\in S} w^*_{Si} R_{Si}$$

$$w^*_{ij} = \max_{k\in K} q_i^k - q_j^k$$
$$w^*_{iT} = \max_{k\in K} q_i^k - |T|\, q_T^k$$
$$w^*_{Si} = \max_{k\in K} |S|\, q_S^k - q_i^k$$

|T| : # receivers in source-to- multiple relay links (2)
|S| : # transmitters in multiple relay-to-destination links (2)
k=1,4 : Final destinations of data

Hop-by-Hop vs Immediate Forwarding

Hop-by-Hop:
- •In Phase I operation; operating point is one of the two MAC corner points of each mode.
- •Sources use one of a finite number of rates.
- •Queues at relays

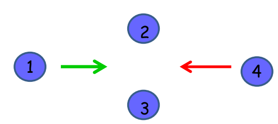


Phase I

Immediate Forwarding (IF):
- •Compute Phase I vs Phase II durations in each slot
- •Coding rates from a continuum

Stability Regions-Analysis

Set of arrival rate vectors (ρ_1^4, ρ_4^1) supported
Assume only cooperative traffic forwarded by both relays (S={2,3})



Hop-by-Hop scheduling

$$\rho_1^4 = f_{1S} = f_{S4}$$
$$\rho_4^1 = f_{4S} = f_{S1}$$
Flow conservation equations

$$(f_{1S}, f_{4S}, f_{S4}, f_{S1}) \in conv(C)$$

$$conv(C) = (\bigcup_{\Delta\in[0,1]} (\Delta R_{1S}, \Delta R_{4S}, (1-\Delta)R_{S4}, (1-\Delta)R_{S1}))$$

For any (R_{1S},R_{4S}) on the Phase I boundary, pairs of (R_{1S},R_{4S}, Δ,R_{S1},R_{S4}) supported which satisfy flow conservation equations such that

$$\Delta R_{1S} = (1-\Delta)R_{S4}$$
$$\Delta R_{4S} = (1-\Delta)R_{S1}$$
$$\Delta = R_{S4}/(R_{1S}+R_{S4}) = R_{S1}/(R_{4S}+R_{S1})$$

Resulting

$$(\rho_1^4, \rho_4^1) \quad \rho_1^4 = \Delta R_{1S} = R_{1S}R_{S4}/(R_{1S}+R_{S4})$$
$$\rho_4^1 = \Delta R_{4S} = R_{4S}R_{S1}/(R_{4S}+R_{S1})$$

Smaller arrival rate vectors also supported

Immediate forwarding

$$\rho_1^4 = f_{14} \qquad (f_{14}, f_{41}) \in conv(C)$$
$$\rho_4^1 = f_{41}$$

$$\Re_{e-e} = (\Delta_1 \Re_{Phase1}) \bigcap ((1-\Delta_1)\Re_{Phase2}) \qquad \Delta\in[0,1]$$

$$C_\Delta = (min(\Delta R_{1S}, (1-\Delta)R_{S4}), min(\Delta R_{4S}, (1-\Delta)R_{S1}))$$

$conv(C)$ *convex combinations between all* C_Δ

Phase Rates selected from

PhaseI

$$R_{1S} \le \min(\log(1+h_{12}P), \log(1+h_{13}P))$$
$$R_{4S} \le \min(\log(1+h_{24}P), \log(1+h_{34}P))$$
$$R_{1S} + R_{4S} \le \min(\log(1+(h_{12}+h_{24})P), \log(1+(h_{13}+h_{34})P))$$

P : Power constraint
$\sqrt{h_{ij}}$: Channel gain from node i to node j
$N_0W = 1$ (Noise variance and bandwith normalized)

Phase II

$$R_{S1} \le \log(1+\alpha(\sqrt{h_{12}}+\sqrt{h_{13}})^2 P)$$
$$R_{S4} \le \log(1+(1-\alpha)(\sqrt{h_{24}}+\sqrt{h_{34}})^2 P)$$

$\alpha \in [0,1]$
Power splitting parameter

•Every arrival rate pair in the region for hop-by-hop scheduling also supported by immediate forwarding
• Every arrival rate pair in the region for immediate forwarding also supported by hop-by-hop scheduling

⇨ *Stability regions are equivalent*

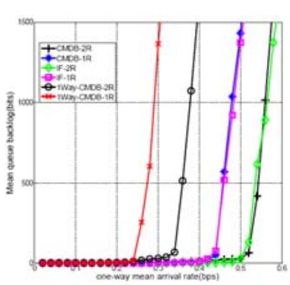
Simulation Results- Queue Backlogs

•Equal channel gains

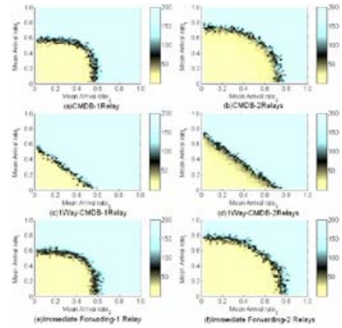
•Mean arrival rate from both sources identical.

•Higher load supported with multiple relays-beamforming

•2-hop operation outperforms 4-hop operation



•Equal channel gains



•4-Hop

Observations & Forward Look

•Queuing at the relays and immediate forwarding result identical stability regions for static channel gains with different design trade-offs for larger networks:
•Hop-by-hop: Better for >2 serial relays (line network)
•Immediate forwarding: Better for >2 parallel relays in two-hop scenario.
•Relative congestion levels and channel conditions determine the resource allocation policy.

•Future work: Exploit the time variations in the channel to find throughput optimal policies.

•Future work: Non-decode and forward relaying and throughput optimal strategies.

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