Throughput Optimization for Multi-hop Wireless Networks with Asymmetric MIMO Links

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MIMO Fundamentals

Signaling Techniques Provided by MIMO:

- Spatial Multiplexing (SM)
  - Multiple independent data streams can be transmitted over the same link concurrently.
- Interference Cancellation (IC)
  - The antennas at the receiver can be used to suppress the interferences.

Our Work - SSPA

- Stream Scheduling Problem on Asymmetric MIMO links (SSPA)
- Given:
  - An existing network topology (multi-hop).
  - The traffic demand for every link.
- Objective:
  - Find out a MIMO link scheduling (SM & IC), that satisfies the traffic demands for all links by using smallest number of timeslots.

A Simplified Model for SM and IC

- Each Node:
  - has a number of Degree of Freedoms (DoFs) in terms of the number of antennas being equipped.
  - can simultaneously transmit at most K data streams if the node has K available DoFs.
  - can successfully decode the signal or suppress the interference of totally K data streams if the node has K available DoFs.

Assumptions

- Basic assumptions
  - TDMA environment
  - Directional links
  - Protocol interference model
  - Asymmetric MIMO links
- Assumptions in this presentation (for simplification)
  - Same data rate for all links
  - Normalized gain for each stream transmitted by SM is always 1

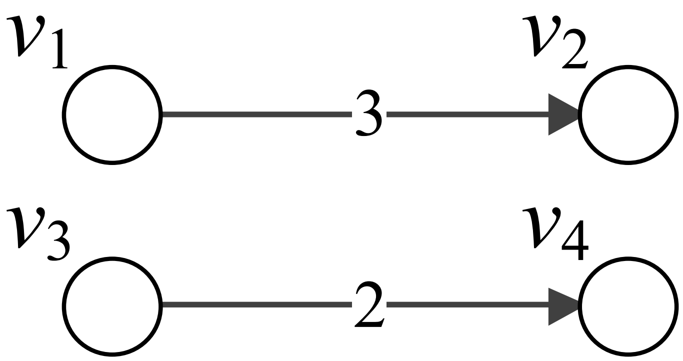
The Core Problem of SSPA

- SSPA
  - Find out a MIMO link scheduling (SM & IC), that satisfies the traffic demands for all links by using smallest number of timeslots.

- Maximum Scheduling Problem (MSP)
  - Schedule as many data streams as possible in one timeslot for the given set of unsatisfied links.

Traditional Solutions of MSP

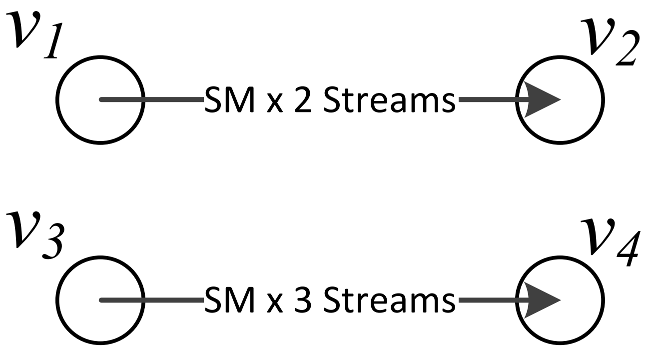
- Maximum Scheduling Problem (MSP)
  – Schedule as many data streams as possible in one timeslot for the given set of unsatisfied links.



A Graph Model for MIMO Transmissions

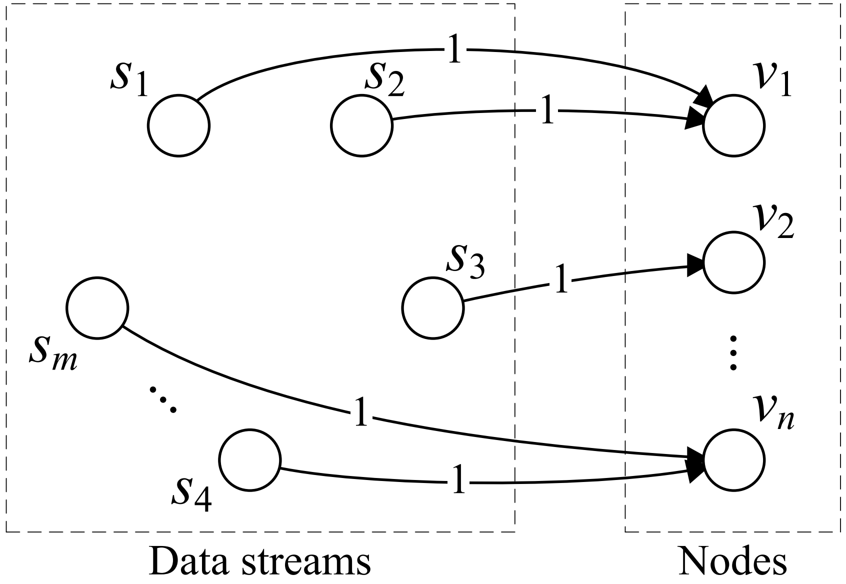
- This model describes the DoFs consumptions between different nodes and data streams for a given scheduling of one timeslot.

- The basic element in the graph G_T is data streams s and nodes v.



A Graph Model for MIMO Transmissions

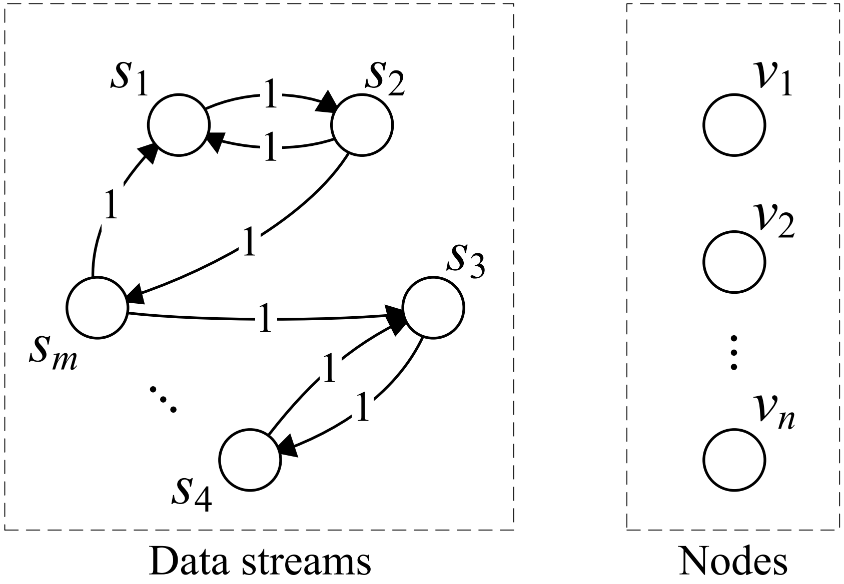
- TX DoFs consumption constraint:
  - For each scheduled stream s_i, one DoF is consumed at the transmitter node of s_i.
  - For each node v_i in TX mode, the DoFs consumption should not exceed the number of its antennas $d(v_i)$.



A Graph Model for MIMO Transmissions

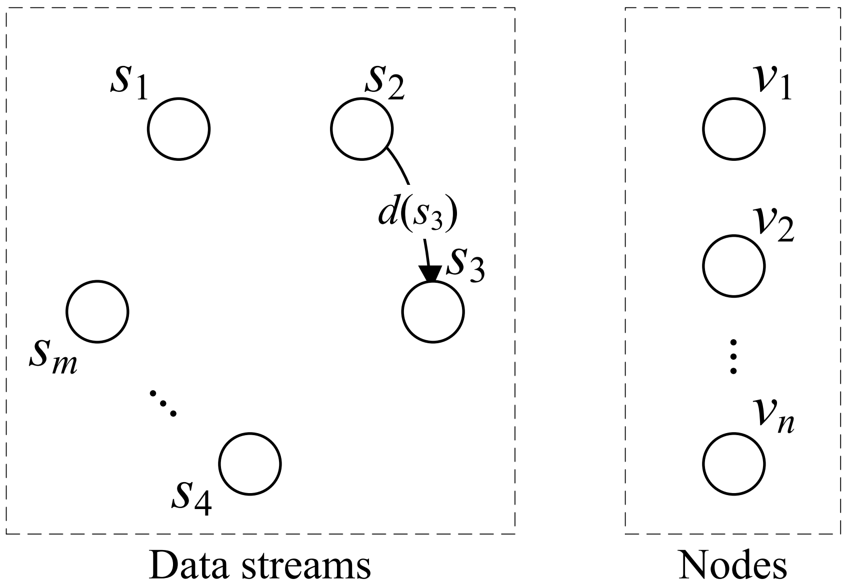
- RX DoFs consumption constraint :
  - If there exist interference from a scheduled stream s_j to the receiver node of s_i, one DoF is consumed at the receiver node of s_i.
  - For the receiving node of each scheduled stream s_i, the DoFs consumption should not exceed the number of its antennas $d(s_i)$.

Note: An extra DoF is consumed at the receiver node of each stream for decoding the data of the stream it self.



A Graph Model for MIMO Transmissions

- Half-duplex constraint :
  - If a node is the receiver node of one stream s_i, and the transmitter node of another stream s_j, the data of stream s_i cannot be successfully received.
  - In this case, we assume all DoFs will be consumed at s_i.



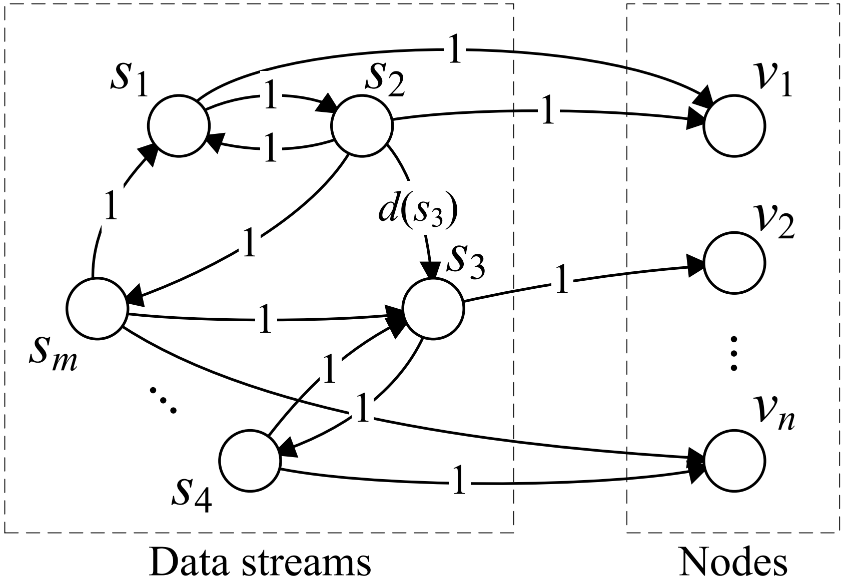
A Graph Model for MIMO Transmissions

The *verification constraint*:

$$\forall s_i, w(s_i) \leq d(s_i);\ \forall v_i, w(v_i) \leq d(v_i).$$

$w()$: *Total number of weights of incoming edges.*

$d()$: *DoFs consumption threshold.*



A Flow Graph for MSP

MSP: Schedule as many data streams as possible in one timeslot for the given set of unsatisfied links.

- Steps for graph transforming:
  - Schedule all unsatisfied links at max SM capacity.
  - Generate a graph G_T for MIMO transmissions.
  - Let $w^+(x)$ denote current $w(x)$ for each vertex x in the graph (i.e., weight for worst case).
  - We need to remove minimal number of streams, such that $w(x)$ for each vertex x do not exceed $d(x)$ (i.e., the reduction requirement for $w(x)$ is $w^+(x) - d(x)$).
  - The problem now becomes a Minimum Removal Problem for the streams.

A Flow Graph for MSP

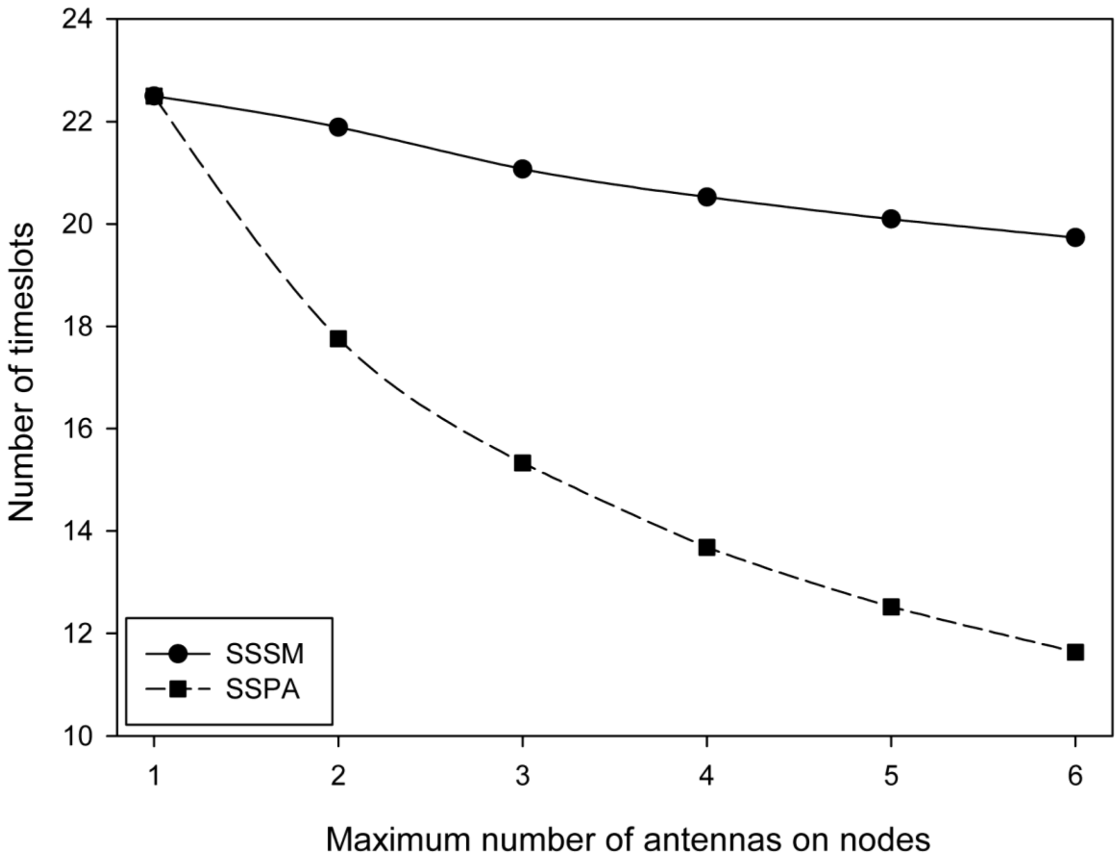
- The Minimum Removal Problem for streams:
  - Remove minimum number of streams, such that the deduction of $w(x)$ for each vertex x is above a threshold $w^+(x) - d(x)$ (and the verification constraint will be satisfied).

- The general Network Flow Problem:
  - Select the paths that have minimum total cost, such that the network flow requirement is satisfied.

The Minimum Removal Problem for streams can be transformed into a Fixed-charge Network Flow Problem. The MSP problem is solved. The SSPA problem can be also solved efficiently.

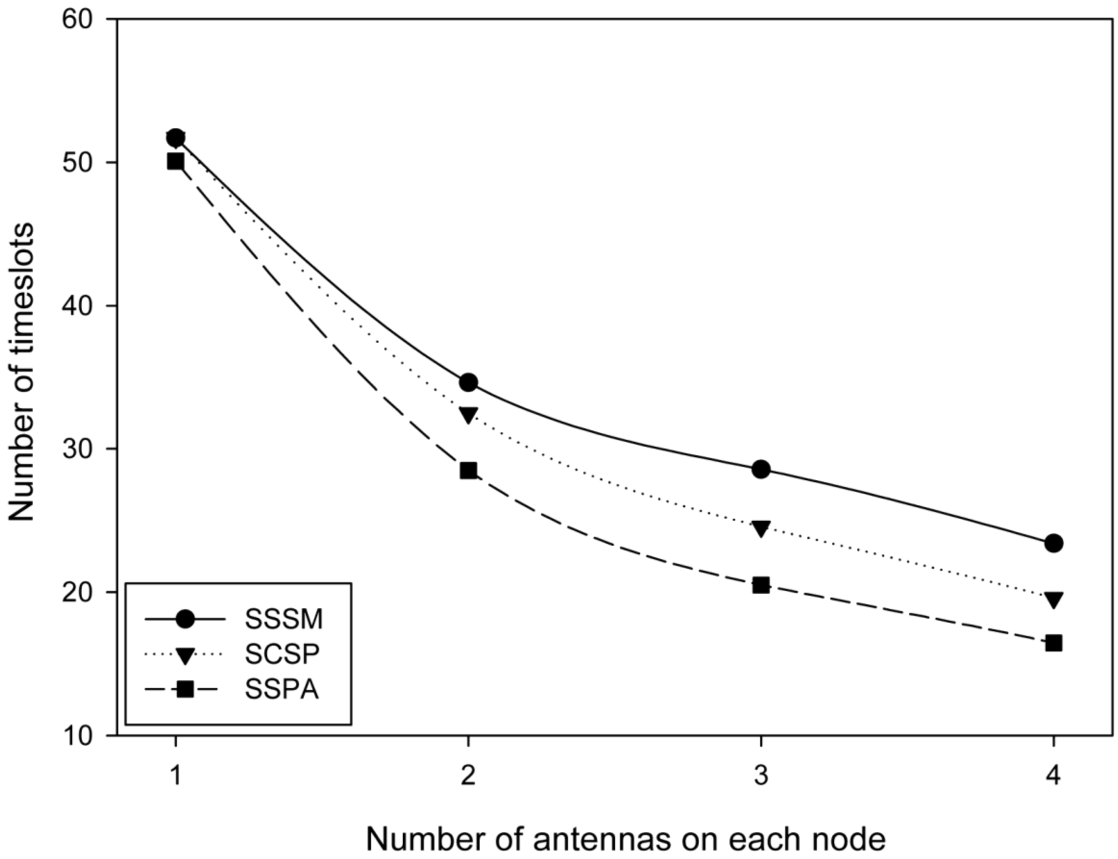
Simulation Results

- The cases of asymmetric MIMO links ($A_{min} = 1$)



Simulation Results

- The cases of symmetric MIMO links ($A_{min} = A_{max}$)



Thank You!