Joint Optimization of HD Video Coding Rates and Unicast Flow Control for IEEE 802.11ad Relaying

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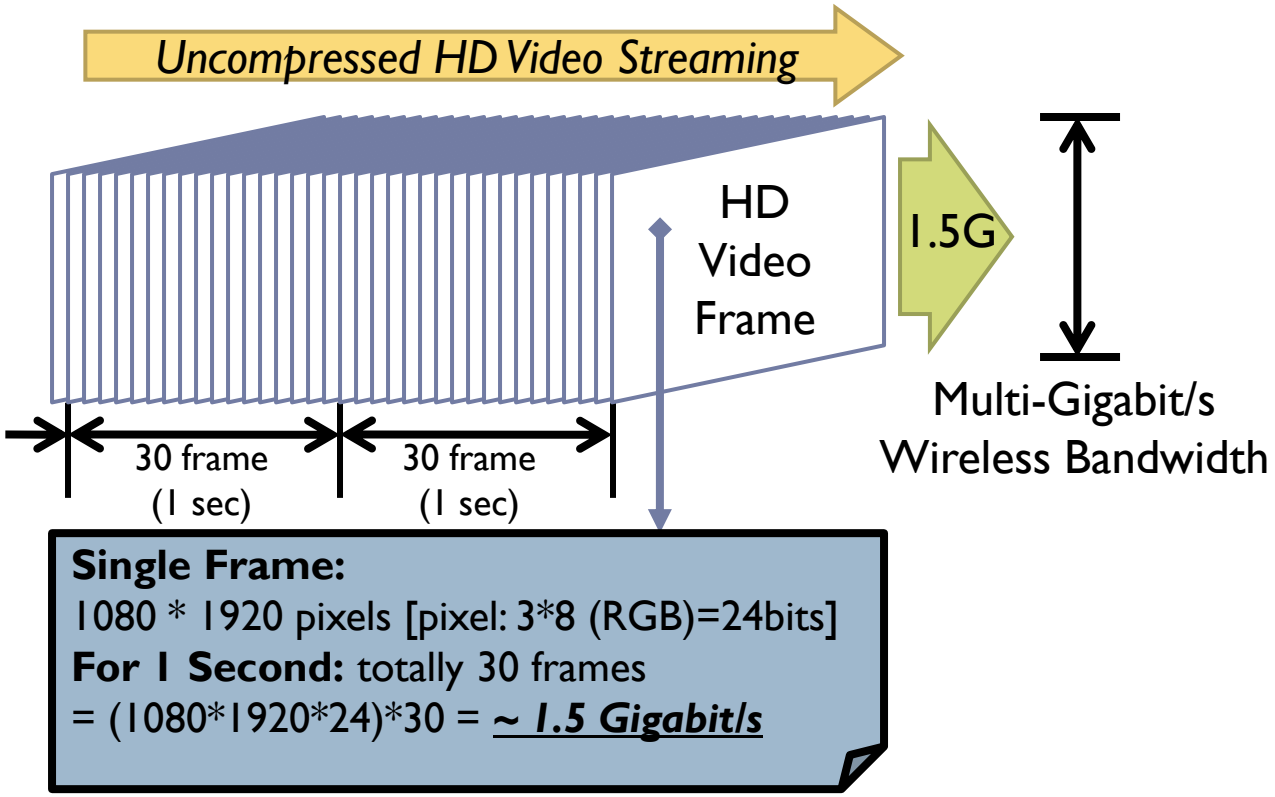
Outline

- Introduction
- Preliminaries
- Problem Formulation
- Performance Evaluation
- Conclusion and Future Work

Prologue

- Uncompressed HD Video Streaming requires 1.5 Gbps.



- By transmitting video signals in 60 GHz mmWave band, up to 7 GHz is available.

Introduction

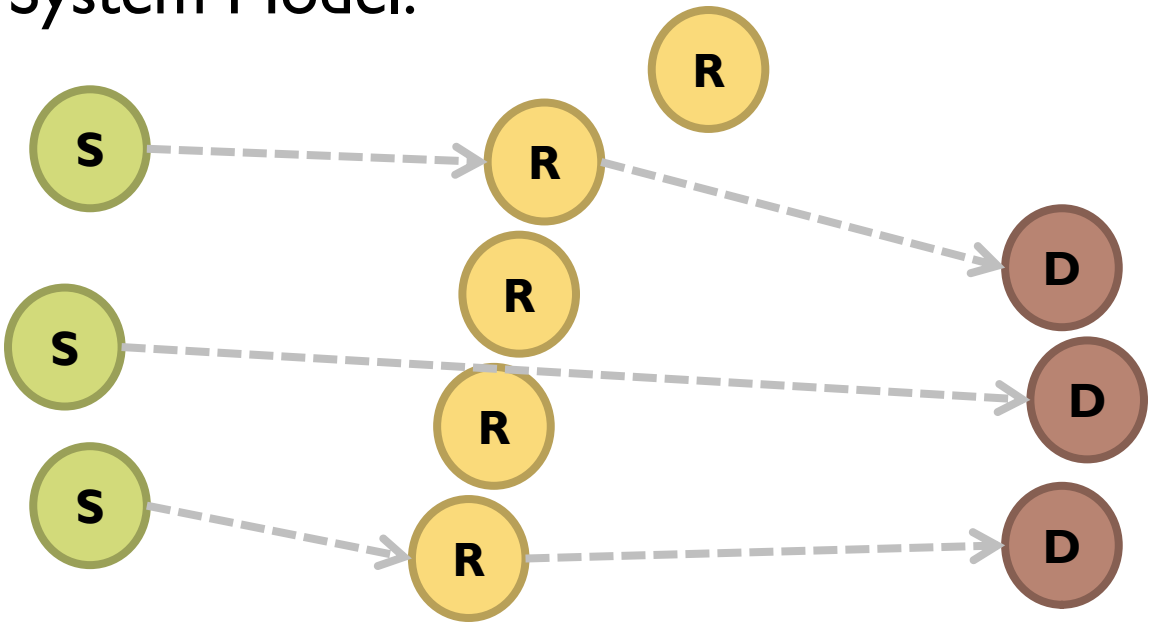
- Main Challenge for 60 GHz Streaming:
  - The short transmission range due to the high path-loss
    → Using ***relays*** is one promising way.

- IEEE 802.11adVHT (TGad draft 3.0):
  - This mmWave standard is designed for *HD video streaming* and supports *relaying operation* (the other mmWave standards can NOT support relaying operation)
    - *WirelessHD:* TX-RX pair for wireless TV, i.e., no relaying operation
    - *Wireless Gigabit Alliance (WiGig):* no relaying in usage scenarios
    - *IEEE 802.15.3c:* relaying operation is not defined
    - *IEEE 802.11adVHT:* **only this spec. defines relaying operation.**

Introduction (Cont'd)

- Main Contribution:
  - In IEEE 802.11ad VHT, determination of relay assignment for the optimization of video quality in polynomial-time.

- Logical System Model:



Preliminaries

- Related Work
- Cooperative Relaying
- Penalty Function Design

Preliminaries: Related Work

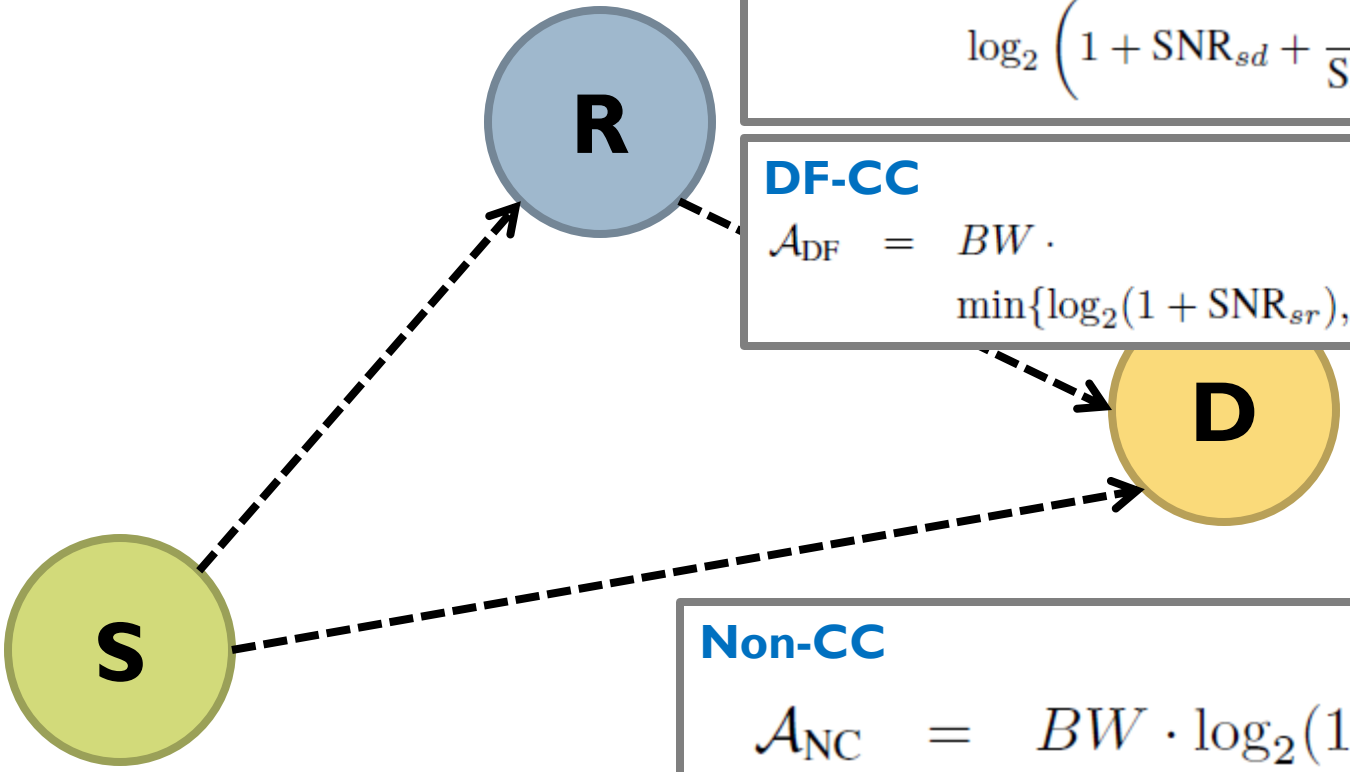
- Relaying for 60 GHz Wireless Networks
  - [Su-GLOBECOM2009]
    - Only one relaying scheme for 60 GHz wireless networks up to now.
    - Contribution
      - Describing the general feature of 60 GHz relaying with multiple flows and hops.
    - However,
      - It considers only general multi-hop relaying (NO consideration for videos).
      - It does NOT consider cooperative relaying with AF-CC and DF-CC.
    - [Su-GLOBECOM2009] H. Su and X. Zhang, "**Joint Link Scheduling and Routing for Directional-Antenna Based 60 GHz Wireless Mesh Networks**," in *Proceedings of IEEE GLOBECOM*, HI, Dec. 2009.

Preliminaries: Related Work (Cont'd)

- Wireless Video Transmission
  - Mainly, video coding to transmit multimedia data over bandwidth-limited wireless links.
    - Uncompressed video streaming is NOT possible in 2.4 or 5 GHz, yet.
  - 60 GHz mmWave enables uncompressed video streaming!
    - Current research results:
      - Error correction
      - MAC-layer design
      - Hardware implementation
    - However,
      - The specific consideration for video quality is not studied yet.

Preliminaries: Cooperative Relaying

- An adaptive cooperative mode selection is required.



AF-CC

$$\mathcal{A}_{\mathrm{AF}} = BW \cdot \log_2\left(1 + \mathrm{SNR}_{sd} + \frac{\mathrm{SNR}_{sr} \cdot \mathrm{SNR}_{rd}}{\mathrm{SNR}_{sr} + \mathrm{SNR}_{rd} + 1}\right)$$

DF-CC

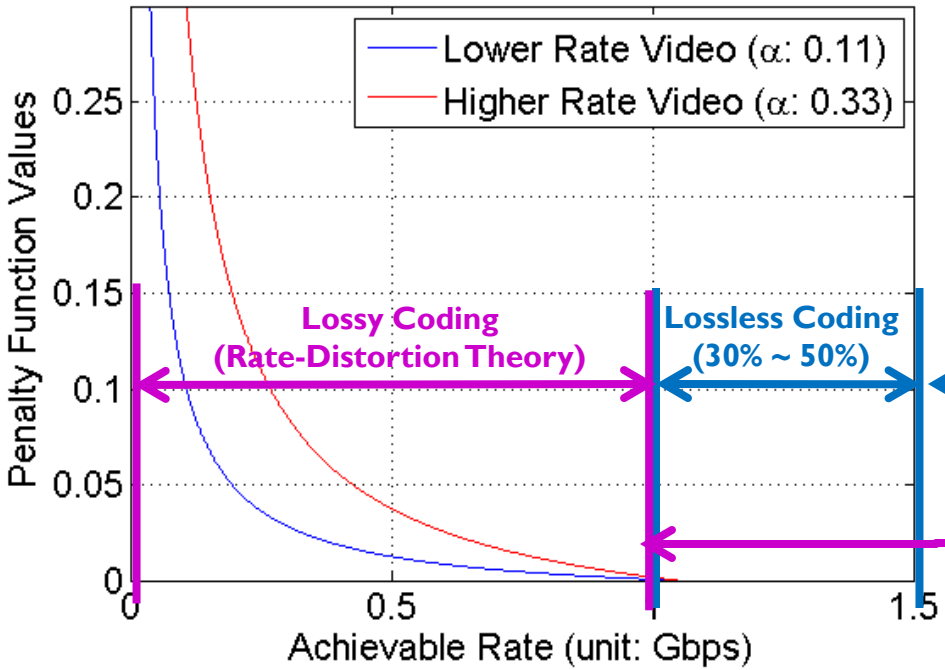
$$\mathcal{A}_{\mathrm{DF}} = BW \cdot \min\{\log_2(1 + \mathrm{SNR}_{sr}), \log_2(1 + \mathrm{SNR}_{sd} + \mathrm{SNR}_{rd})\}$$

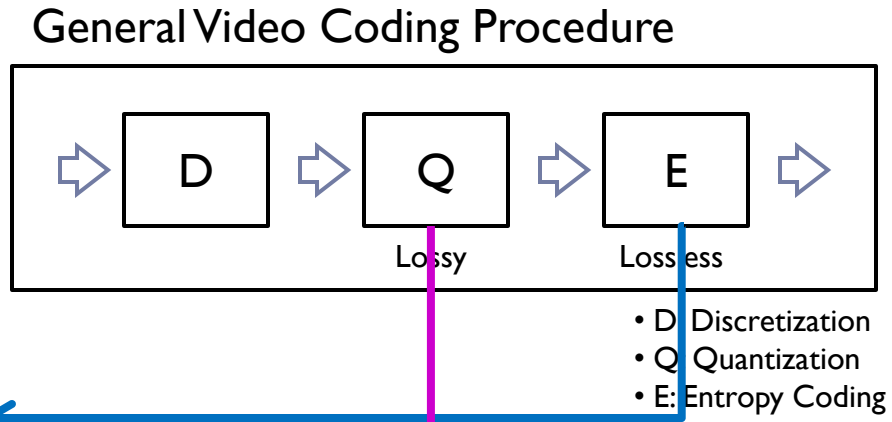
Non-CC

$$\mathcal{A}_{\mathrm{NC}} = BW \cdot \log_2(1 + \mathrm{SNR}_{sd})$$

Preliminaries: Penalty Function Design

- The penalty function is designed based on the general video coding procedure.





Penalty Function Design

Problem Formulation

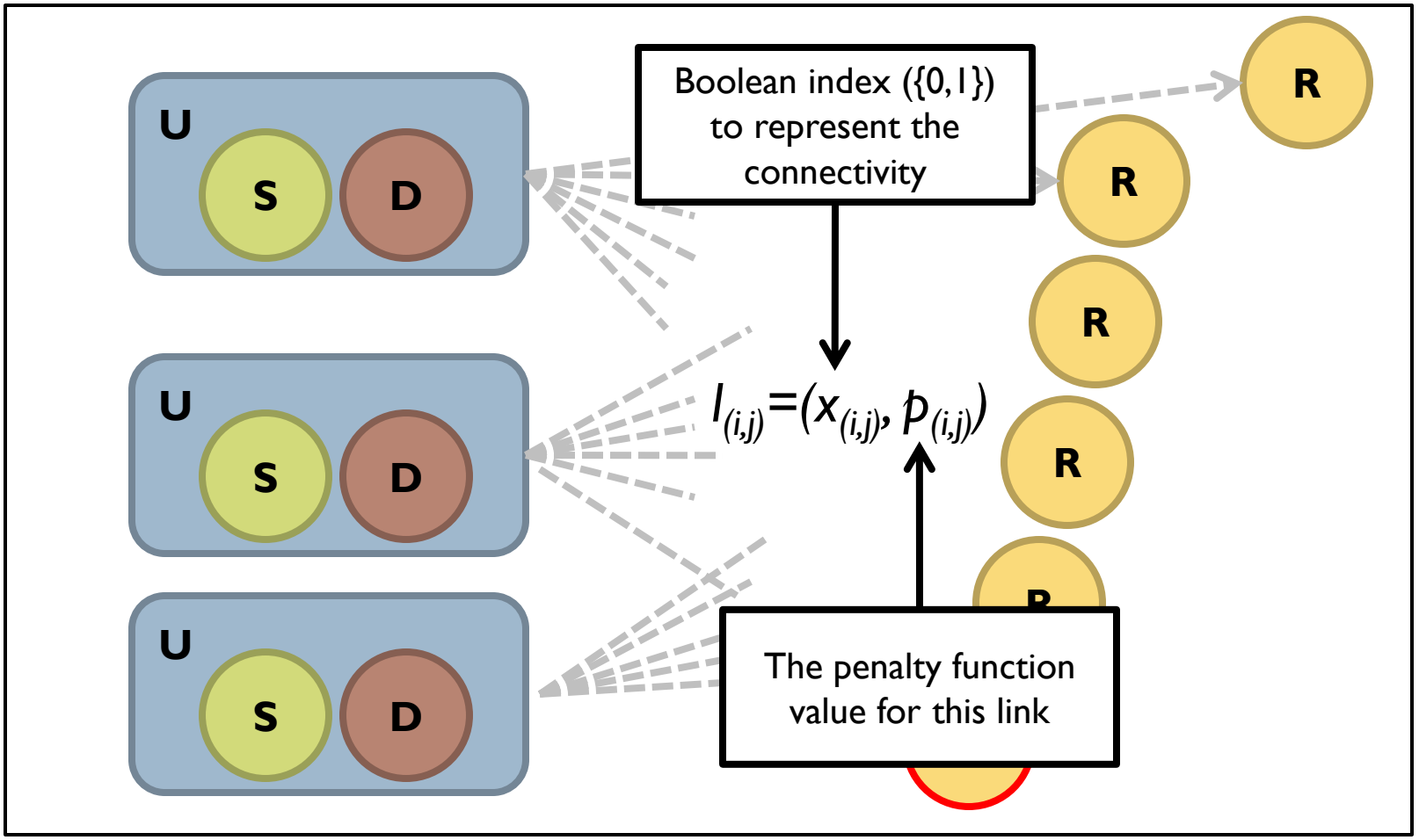
- Assumptions
- Formulation
- Computational Complexity

Problem Formulation

- Assumptions
  - Multiple unicast links can operate without mutual interference.
    - Due to high directionality
  - Sufficient number of relays
    - The number of relays is larger than the number of unicast flows.
  - Static nodes and line-of-sight (LOS) wireless channels

Problem Formulation

- Formulation



Problem Formulation

- Formulation (Cont'd)
  - Objective Function

$$\min \sum_{k=1}^{N_u} \left(\mathbf{P}_k \mathbf{x}_k^T \right)$$

where

Constraints

[#1] Each unicast pair selects exactly one relay unit. $x_{(i,1)} + x_{(i,2)} + \cdots + x_{(i,N_r')} = 1$

[#2] Each relay serves at most one unicast pair. $x_{(1,r_r)} + x_{(2,r_r)} + \cdots + x_{(N_u,r_r)} \leq 1$

$$\mathbf{P} \triangleq \begin{bmatrix} p_{(1,1)} & \cdots & p_{(1,N_r')} \\ \vdots & \ddots & \vdots \\ p_{(N_u,1)} & \cdots & p_{(N_u,N_r')} \end{bmatrix} = \begin{bmatrix} \mathbf{P}_1 \\ \vdots \\ \mathbf{P}_{N_u} \end{bmatrix}$$

Matrix of Penalty Function Values

$$\mathbf{x} \triangleq \begin{bmatrix} x_{(1,1)} & \cdots & x_{(1,N_r')} \\ \vdots & \ddots & \vdots \\ x_{(N_u,1)} & \cdots & x_{(N_u,N_r')} \end{bmatrix} = \begin{bmatrix} \mathbf{x}_1 \\ \vdots \\ \mathbf{x}_{N_u} \end{bmatrix}$$

Matrix of the Boolean Index of Relay Selection

Problem Formulation

- Computational Complexity
  - Combinatorics problem generally goes to NP-hard.
  - In our modeling, the constraints are formulated in matrix forms where the elements are 0 or 1. **(Totally unimodular matrix form)**
  - According to the following well-known Theorem,

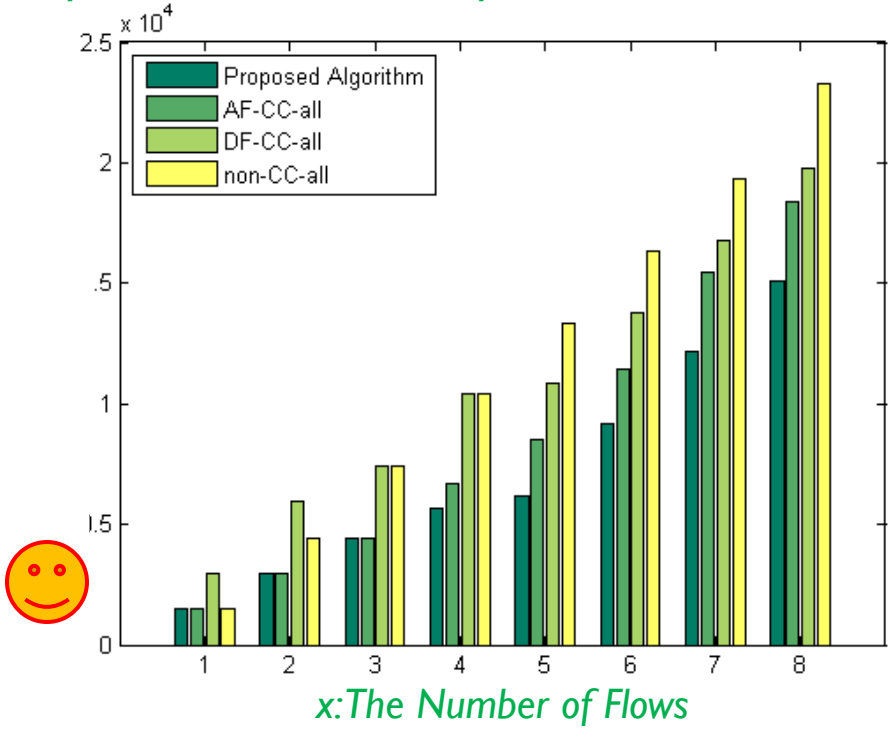
Theorem 1. *If the constraint matrix M_c in linear programming formulation is totally unimodular, then there exists an optimal solution as an integer .*

    - Ref: R.K. Ahuja, T.L. Magnanti, and J.B. Orlin, ***Network Flows: Theory, Algorithms, and Applications,*** Prentice Hall, 1993.,
  - the optimal solution can be obtained by general LP solving algorithm. → polynomial-time solution!

Performance Evaluation

- Simulation Results

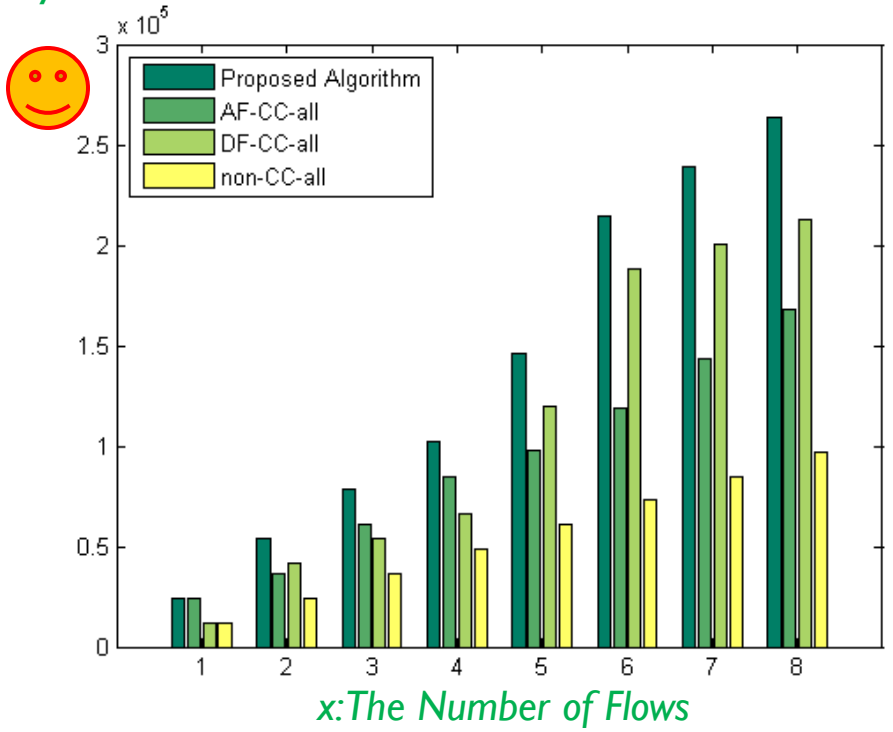
y: Summation of Penalty Function Values



x:The Number of Flows

Penalty Function Values
(vs. the number of flows)

y:Total Achievable Rates



x:The Number of Flows

Total Achievable Rates
(vs. the number of flows)

Conclusion and Future Work

- Aim:
  - Selecting relays and their cooperation modes that can maximize the total achievable video quality for multiple unicast flows in IEEE 802.11ad VHT relaying systems.
- Achievement:
  - Polynomial-time solution for relay selection scheme
  - Optimized video quality (NOT just data rate)
- Future Work Direction:
  - What if the number of relays is not sufficient?

Q&A

- Any Questions?
  - For additional questions and feedback,
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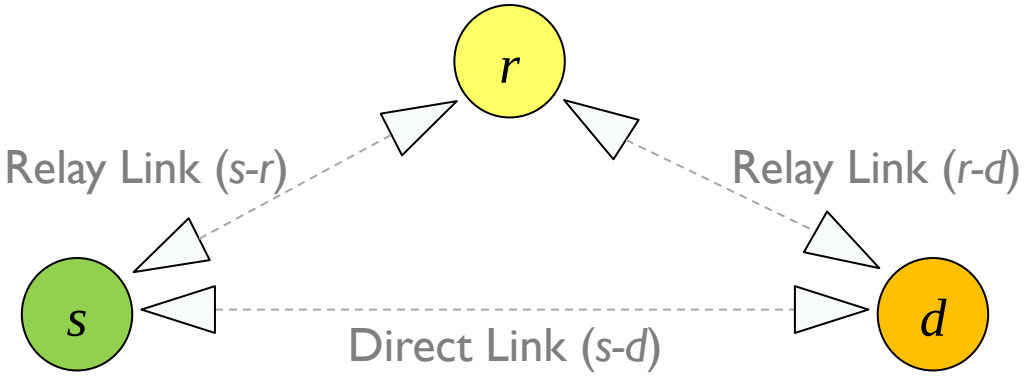
Appendix A. IEEE 802.11ad VHT Relaying



Link Switching Type

If the *s-d* direct PHY link is disrupted, the source (*s*) redirects the transmission of frames addressed to the destination (*d*) via the relay (*r*).

Direct link between the source (*s*) and destination (*d*) can resume after the direct link between them is recovered.

Link Cooperating Type

The relay (*r*) is actively involved in the direct link communication between *s-d*.

At the same time, a frame transmission from the source (*s*) to the destination (*d*) is repeated by the relay (*r*).

It can possibly increase the signal quality received at the destination (*d*). [cooperative diversity]