MULTI-LAYER VIDEO STREAMING WITH HELPER NODES USING NETWORK CODING

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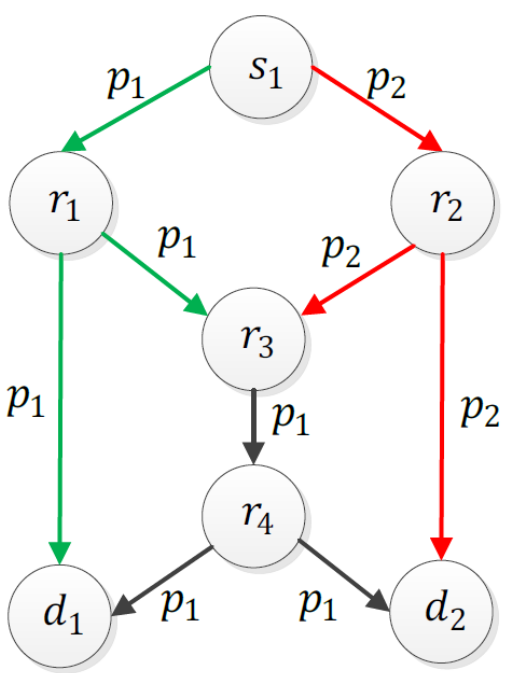
Agenda

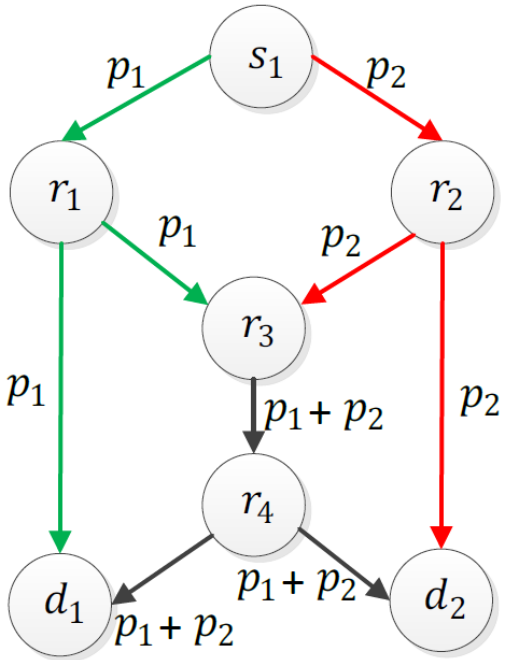
- Introduction
  - Network Coding Background
  - Priority-Based Network Coding
- Layered Video Streaming
  - Linear Programming
  - Distributed Solution
- Conclusions and Future Work

Network Coding in Wired Networks

- Single multicast session
  - Bottleneck problem (Ahlswede'00)



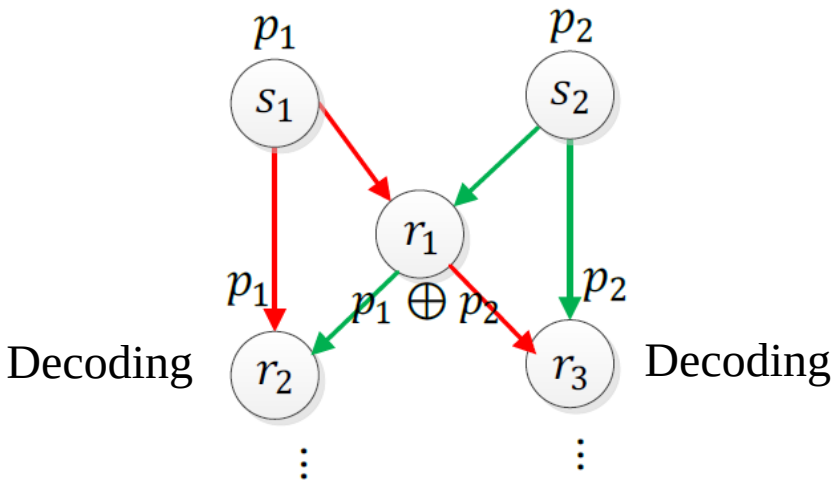
No coding



Coding

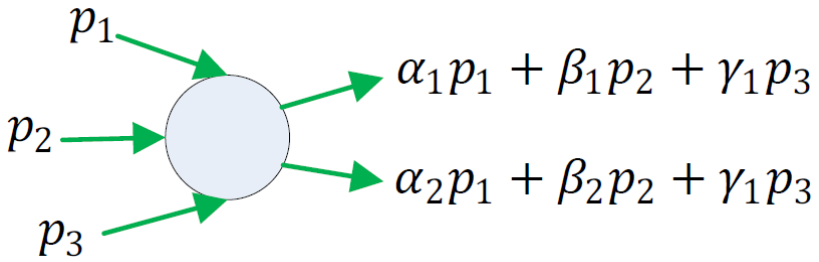
Network Coding Classification

- Local
  - Hop-by-hop decoding
  - XOR operation



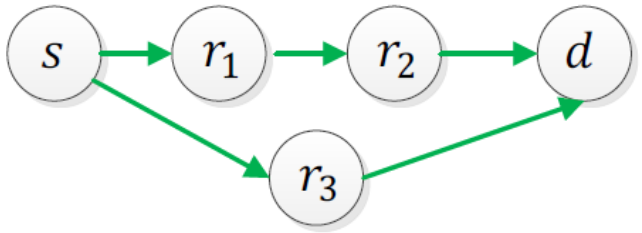
- Global
  - Decoding at the destination
  - Linear network coding

    (on a finite field)

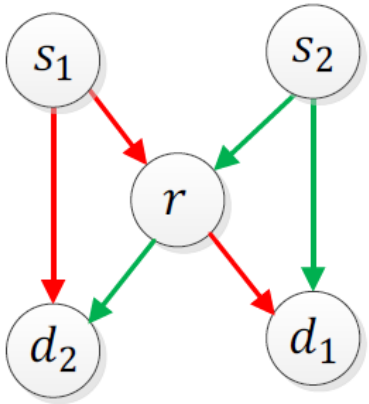


Network Coding Classification

- Intra-flow
  - Within a flow
  - Robustness enhancement



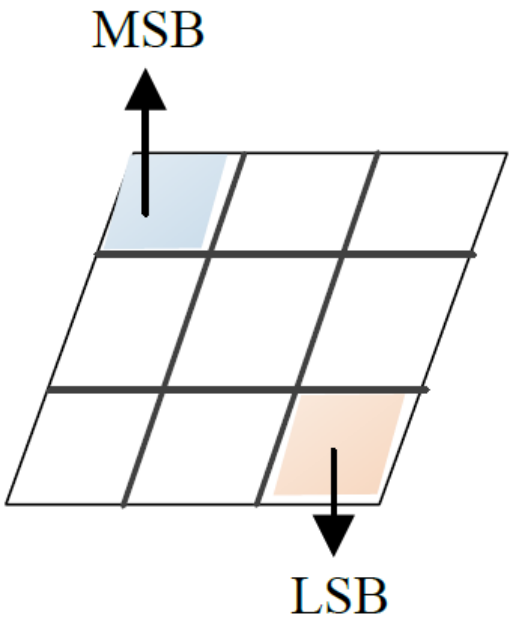
- Inter-flow
  - Between different flows
  - Throughput/capacity enhancement



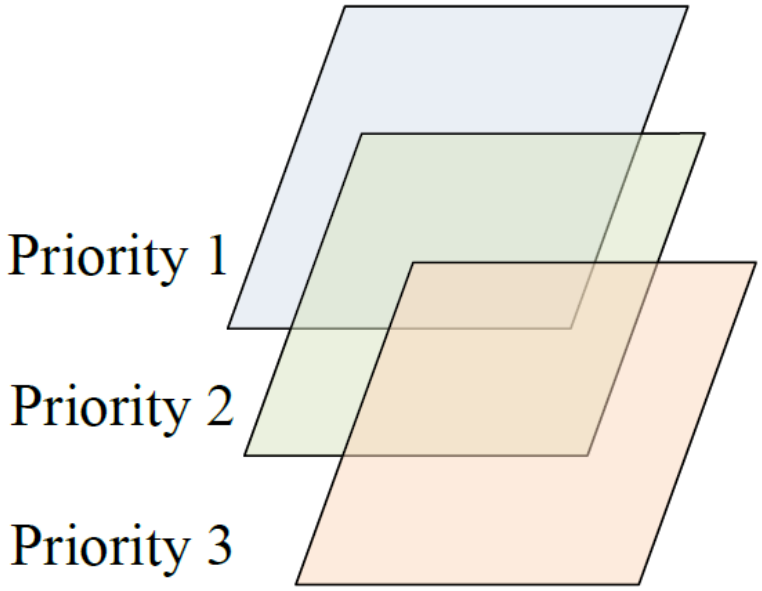
- Joint inter- and intra-flow
  - Within flow and between flows

Priority-Based Approaches

- New twist on the classic unequal error protection



Symbol-Level NC

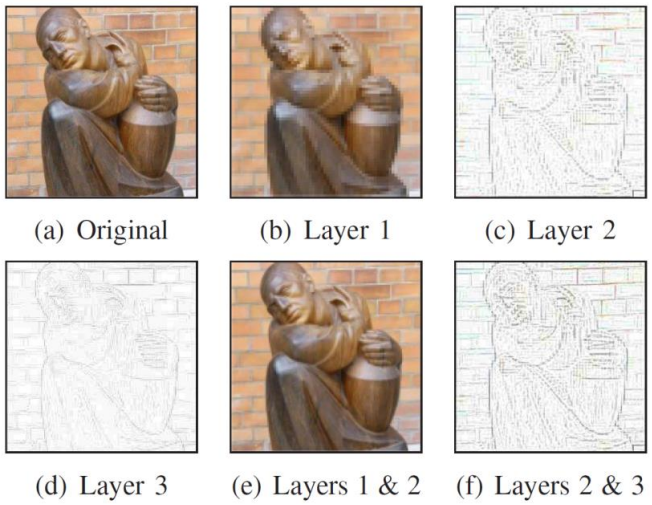


Video Streaming NC

Video Streaming

- Delivering video stream using different resolutions to satisfy different client needs/constraints

- Multi-Layer Coding (Multi-resolution)
  - Base layer
  - Enhancement layers



(a) Original (b) Layer 1 (c) Layer 2

(d) Layer 3 (e) Layers 1 & 2 (f) Layers 2 & 3

- Multiple Description Coding (MDC)
  - Multiple independent video substreams
  - Receiving more substreams increases the video quality

Substream_1	Resolution_1
Substream_2	Resolution _2
⋮	
Substream_N	Resolution _N

Inter-Layer Coding Strategies

- Random linear network coding (RLNC)

$$\alpha_1 L_1 + \beta_1 L_2 + \gamma_1 L_3$$
$$\alpha_2 L_1 + \beta_2 L_2 + \gamma_2 L_3$$
$$\alpha_3 L_1 + \beta_3 L_2 + \gamma_3 L_3$$

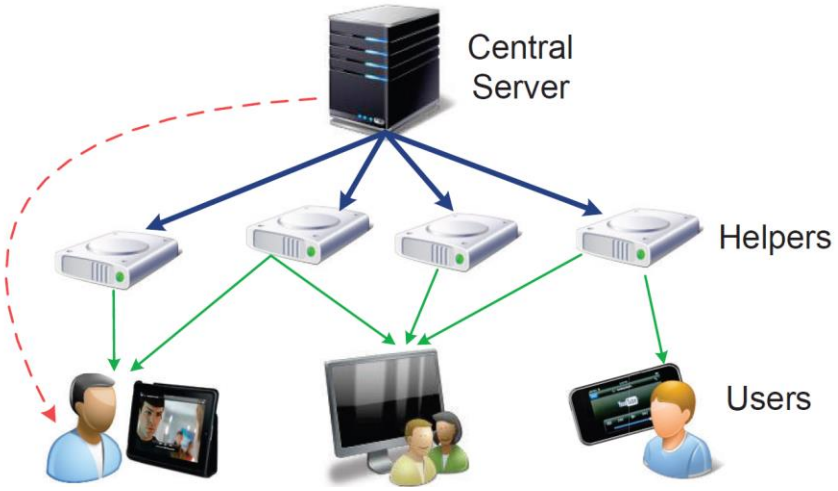
- Triangular coding
  - Prefix coding

$$\alpha_1 L_1$$
$$\alpha_2 L_1 + \beta_2 L_2$$
$$\alpha_3 L_1 + \beta_3 L_2 + \gamma_3 L_3$$

- Packets in lower layers are more important
  - Included in more coded packets
  - More chances to be decoded

Multi-Layer Video Streaming with Helpers

- Links
  - Cost: direct download from the server
  - Reliable links
- Link capacity
  - High capacity links: server to helpers
  - Low capacity links: helpers to users
- Use of helpers
  - System scalability for more users
  - Helpers: limited capacity and bandwidth

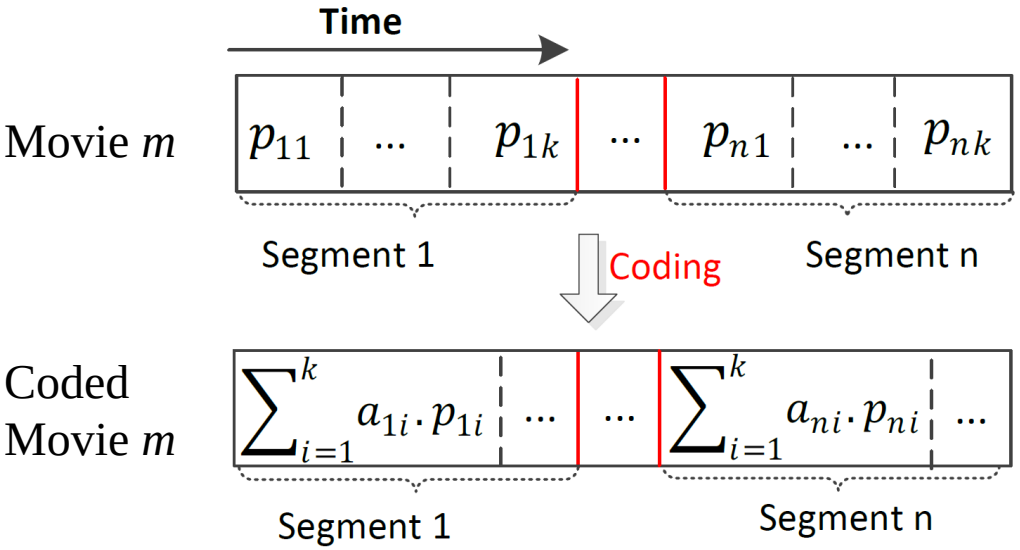


Resource Management

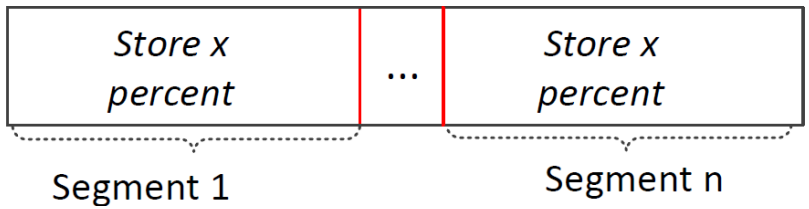
- Optimal resource management
- Questions:
  - **Content placement**: Which packets of each video should a helper node store?
  - **Bandwidth allocation**: Which packets, and to which users, should each helper serve?
- NP-complete

Resource Management (Network Coding)

- Network coding changes the problem to a linear programming



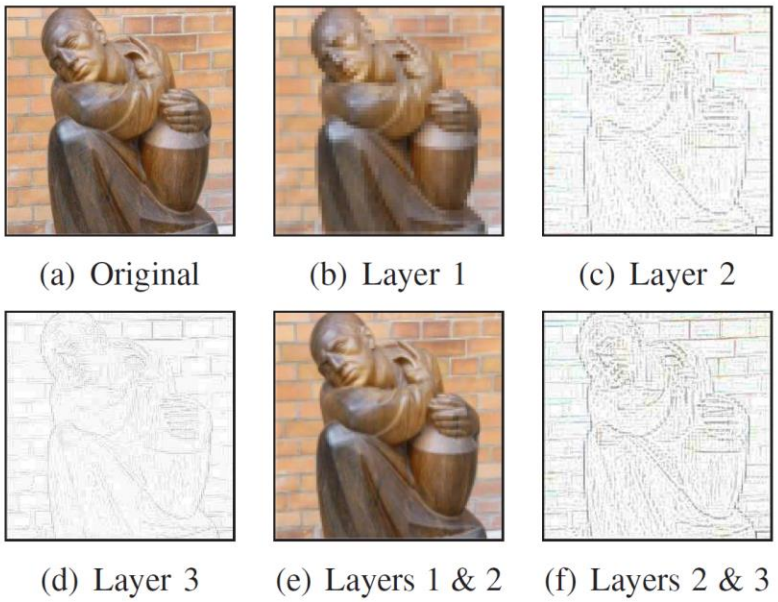
- Storing x percent of each segment



- No longer NP-complete
  - Flow-based model using network coding

Multi-Layer Video

- Benefits of multi-layer
  - Provides smooth playback for the users
  - Reduces the load on the server with a fixed number of users
  - More layers increases system scalability



(a) Original (b) Layer 1 (c) Layer 2

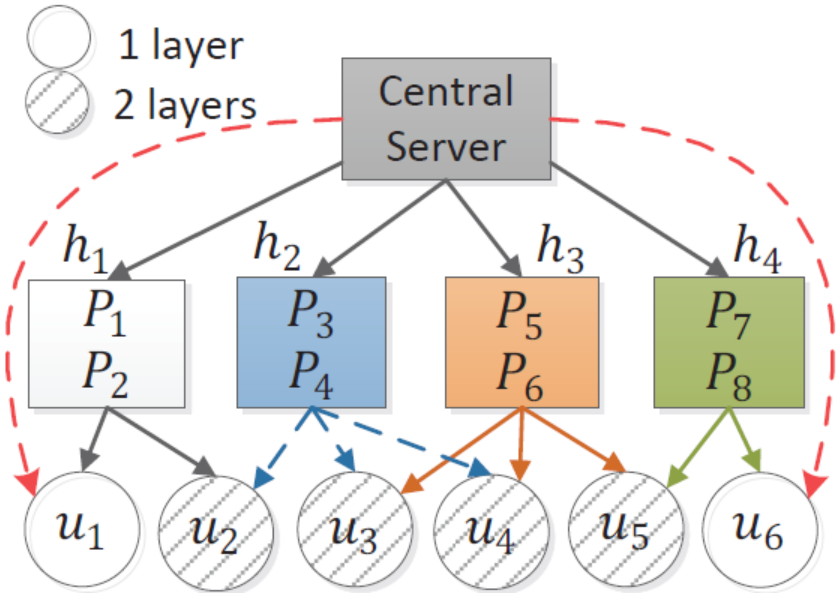
(d) Layer 3 (e) Layers 1 & 2 (f) Layers 2 & 3

Motivation

- Single video with 4 packets
- No-layer approach

  (Hao et al. 2011)
  - 4 packets in the same layer
  - Load on the server: 4

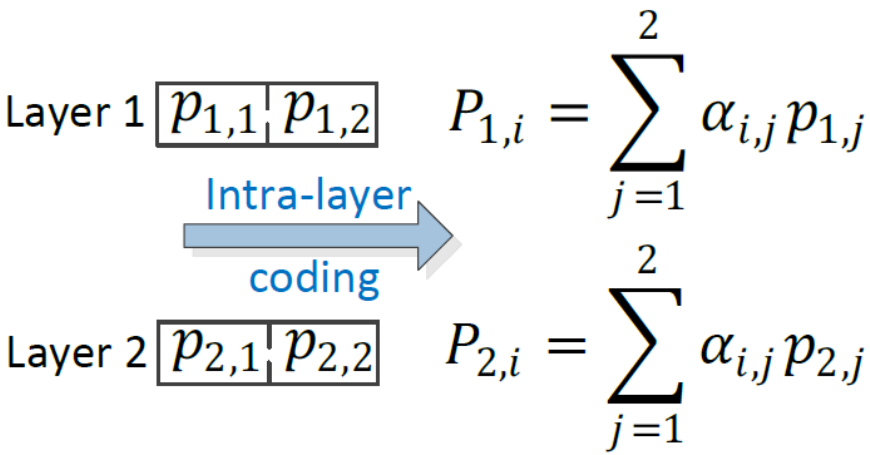
$$p_1 | p_2 | p_3 | p_4 \Rightarrow P_i = \sum_{j=1}^{4} \alpha_{i,j} p_j$$

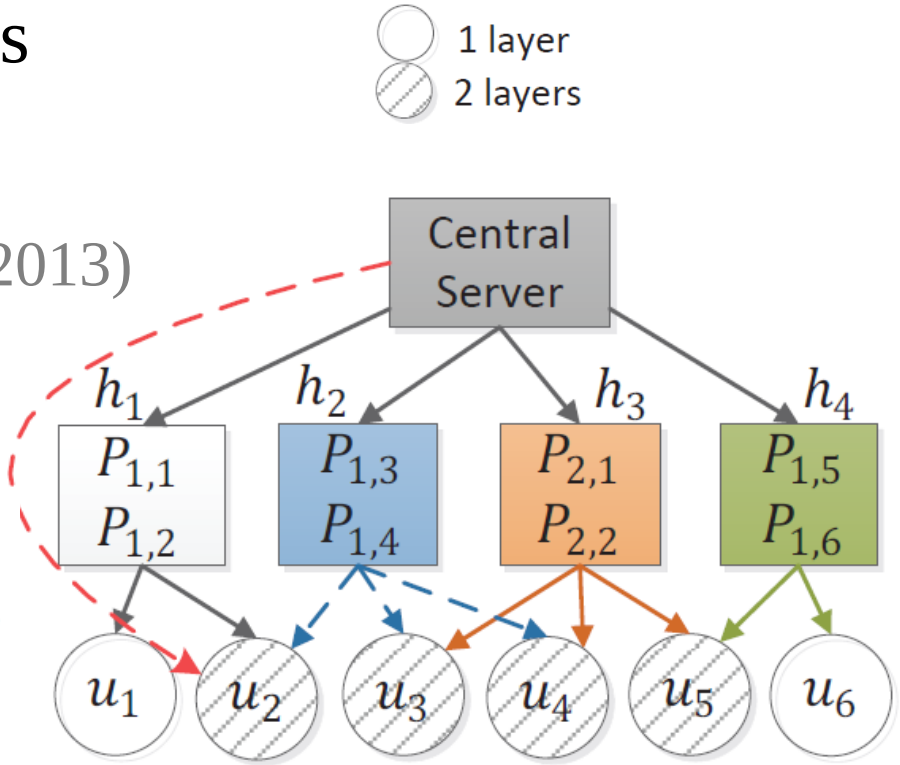


Motivation

- Single video with 4 packets
- Intra-layer approach

  (Ostovari, Khreishah, and Wu, 2013)
  - 2 packets per layer
  - Load on the server: 2





Motivation

- Single video with 4 packets
- Inter- and intra-layer coding

(Ostovari, Khreishah, and Wu, 2013)

  - Prefix coding (Triangular)
  - 2 packets per layer
  - Load on the server: 0

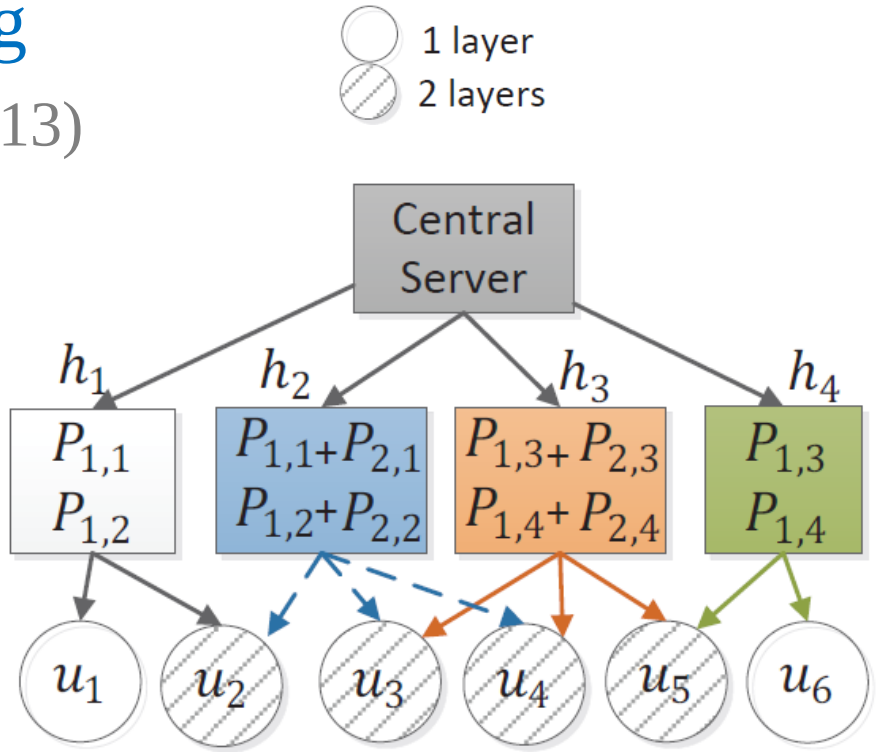
Layer 1 $p_{1,1}$ $p_{1,2}$

$$P_{1,i} = \sum_{j=1}^{2} \alpha_{i,j} p_{1,j}$$

Intra-layer coding

Layer 2 $p_{2,1}$ $p_{2,2}$

$$P_{2,i} = \sum_{j=1}^{2} \alpha_{i,j} p_{2,j}$$



Triangular coding

VoD with Intra-Layer NC

$$\max \sum_{i,k:u_i \in U, m_k = q_i} \sum_{j,l:h_j \in N(u_i), l \le c_i} x_{ji}^{kl}$$

Objective function (maximize upload rate from helpers to users)

$$s.t$$

$$x_{ji}^{kl} \le f_j^{kl} \times r_k, \quad \forall j,i,l,k : u_i \in N(h_j), m_k = q_i, l \le c_i$$

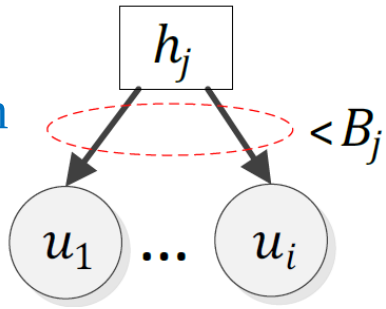
The upload rate of a helper cannot exceed the rate of the stored videos

- x_{ji}^{kl} : Upload rate of link from helper h_j to user u_i over layer l of video m_k
- f_j^{kl} : Fraction of the layer l of video k that is stored on helper h_j
- r_k : Rate of each layer of video m_k
- $N(u_i)$: Adjacent helpers to user u_i
- u_i's request: (c_i , q_i) = (quality level, video)

VoD with Intra-Layer NC

$$\sum_{i,k:u_i \in N(h_j), m_k = q_i} \sum_{l \le c_i} x_{ji}^{kl} \le B_j, \quad \forall j : h_j \in H$$

Bandwidth constraint from each helper to users



$$\sum_{k \in M} \sum_{l : l \le L} f_j^{kl} \times v_k \le S_j, \quad \forall j : h_j \in H$$

Storage constraint for each helper

$$\sum_{j : h_j \in N(u_i)} x_{ji}^{kl} \le r_k, \quad \forall i, k, l : u_i \in U, m_k = q_i, l \le c_i$$

Limits the total download of a user to the rate of the video

- B_j : The bandwidth limit of helper h_j
- S_j : The capacity limit of helper h_j
- M : Set of videos
- L : Maximum number of layers

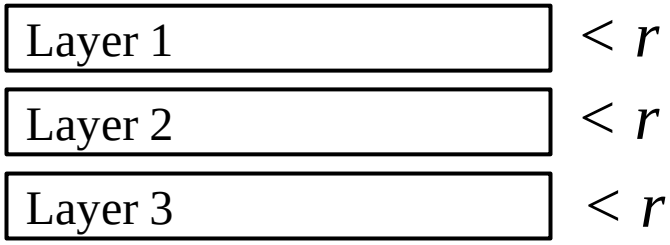
VoD with Inter- and Intra-Layer NC

- The difference is in the last constraint

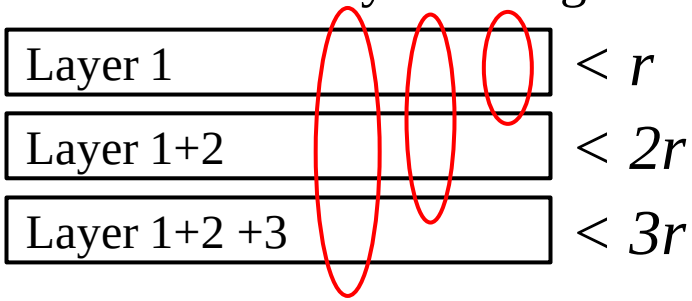
$$\sum_{l=1}^{l'} \sum_{j:h_j \in N(u_i)} x_{ji}^{kl} \leq r_k \times l', \quad \forall i,k,l' : m_k = q_i, 1 \leq l' \leq c_i$$

Prefix limit on the download rate of each layer

Intra-layer coding



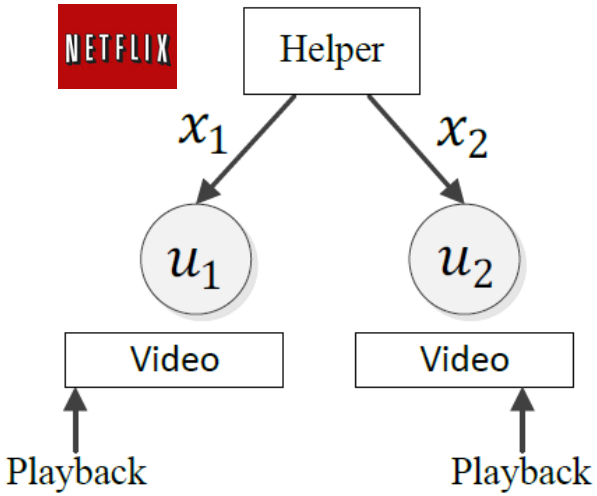
Inter and Intra-layer coding



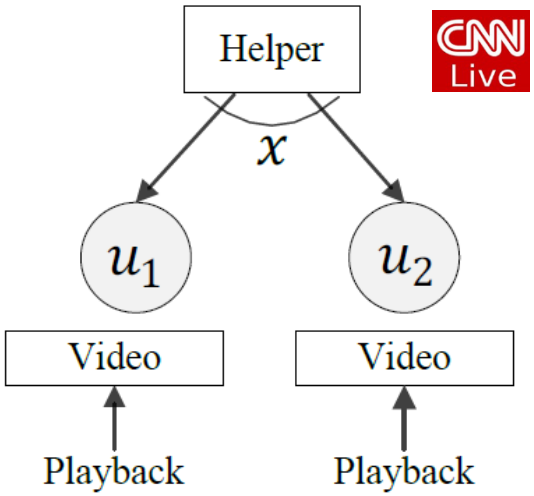
- l' : variable for the prefix relation
- The objective function and other constraints are the same

Live Streaming (TV)

- Videos are broadcast to the users
- Synchronous playback
  - Helpers do not need to allocate separate bandwidths to adjacent users that are watching the same video



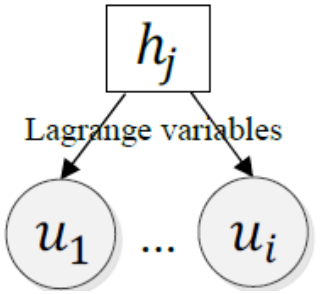
Total bandwidth: x_1+x_2

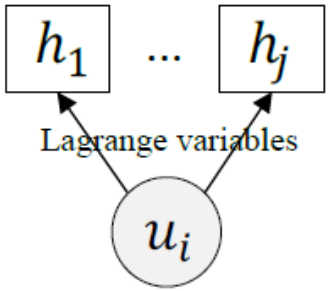


Total bandwidth: x

Distributed Algorithm

- Dual optimization
  - Solving Lagrange dual using the gradient method
- Helper h_j
  - Start from empty storage and dynamically adjust the amount of stored videos
  - Update and transmit Lagrange variables to adjacent users
- User u_i
  - Update and transmit Lagrange variables to adjacent helpers
- Step control
  - Slope of changes: fast convergence vs. oscillation





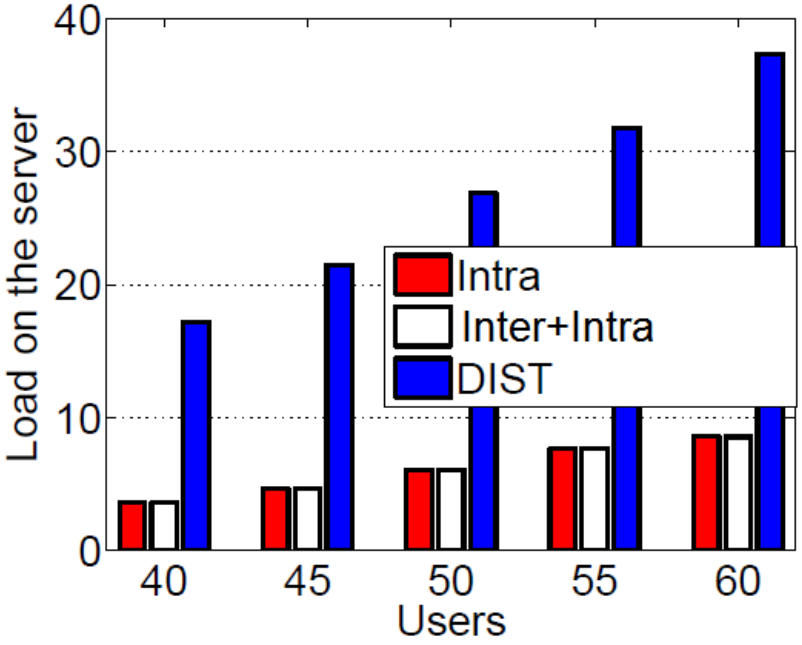
Simulations Setting

- MATLAB environment
- 100 random topologies
  - Random connections of helpers and users
  - Helpers: random bandwidth and capacity limit
  - Users: random requests
- Comparing with the optimal non-layer approach
- Measuring
  - Load on the server
  - Convergence to optimal solution in dynamic environments

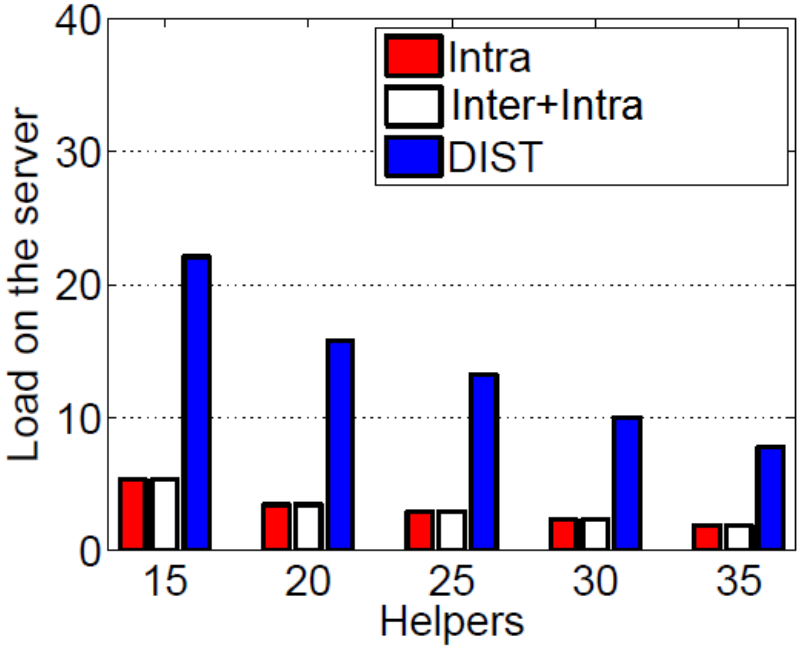
Video's rate	Video's size	Bandwidth capacity	Storage capacity	Num. of adjacent helpers to a user
[1,2] kbps	[0.5,2] MB	[2,4] kbps	[0.5,2] MB	[1,3]

Simulation Results (Load)

- VoD
- Number of videos: 5
- Number of layers: 5
- DIST: a non-layer approach with intra-layer coding (Hao et al. 2011)



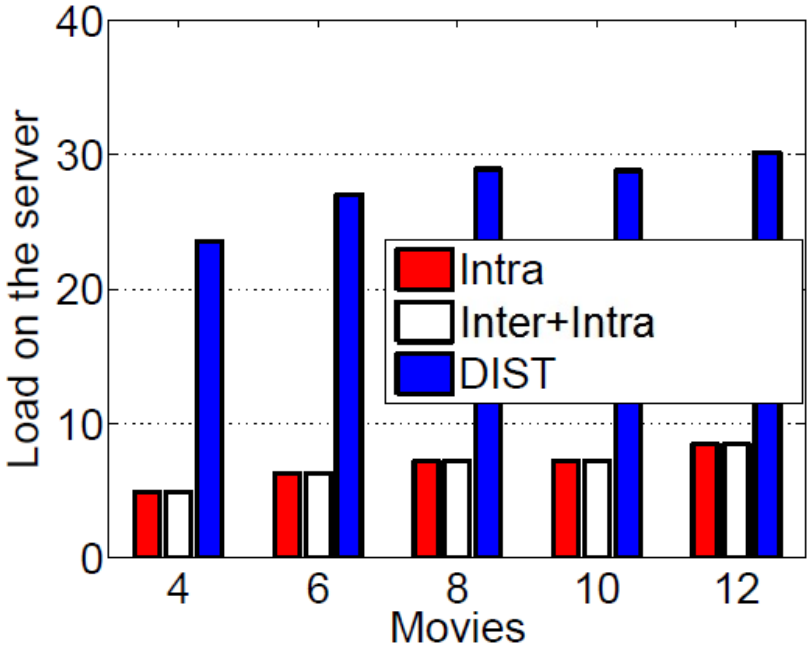
Number of helpers: 20



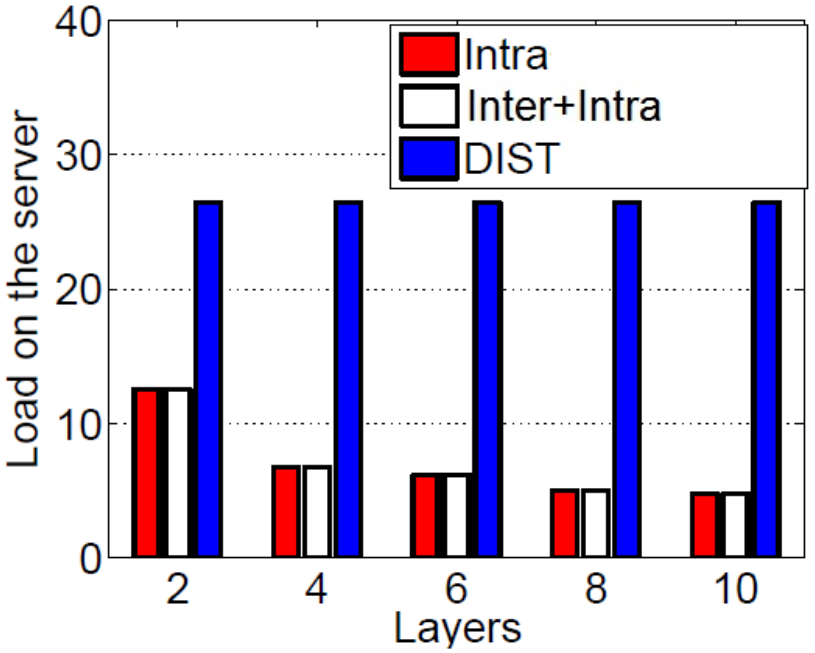
Number of users: 40

Simulation Results (Load)

- VoD
- Number of users: 50
- Number of helpers: 20



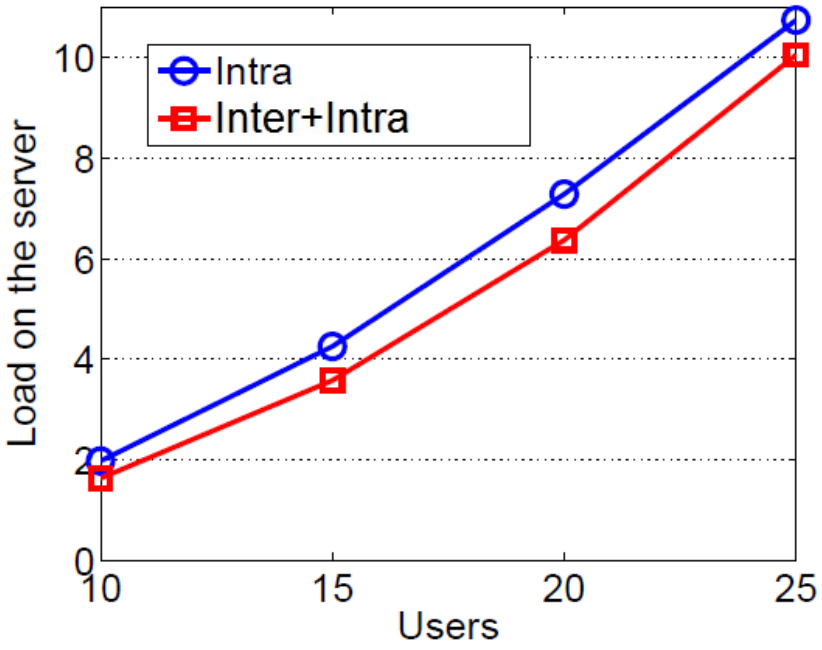
Number of layers: 5



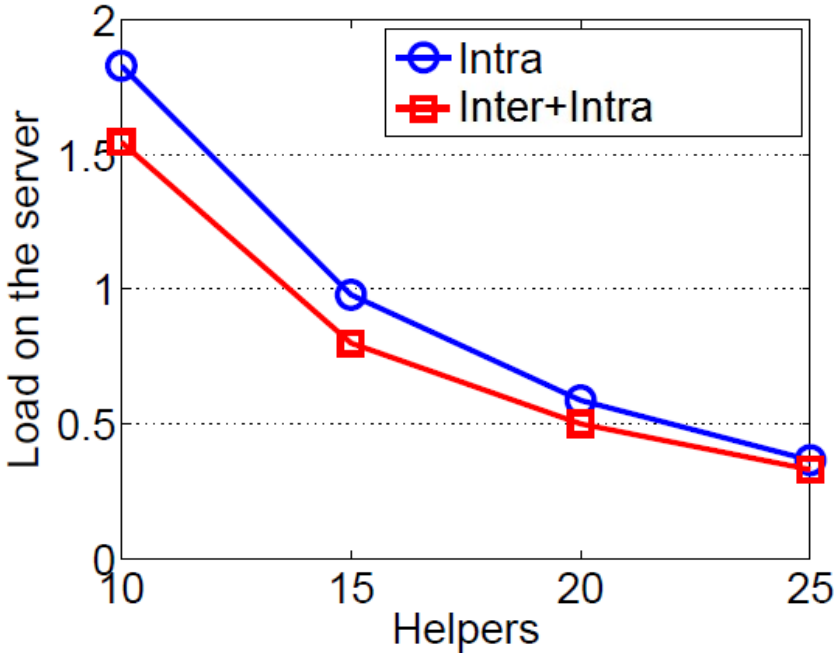
Number of videos: 5

Simulation Results (Load)

- VoD
- Number of layers: 4
- Single video



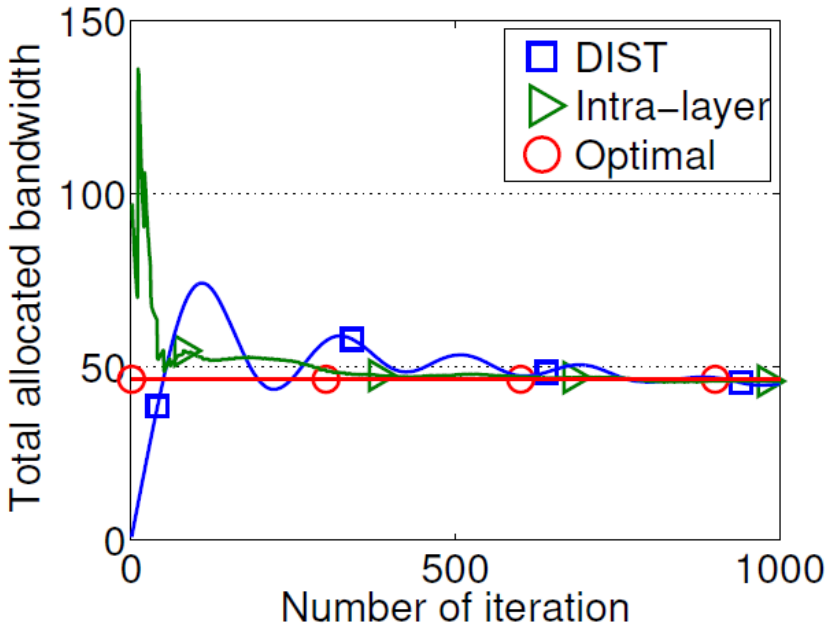
Number of helpers: 10



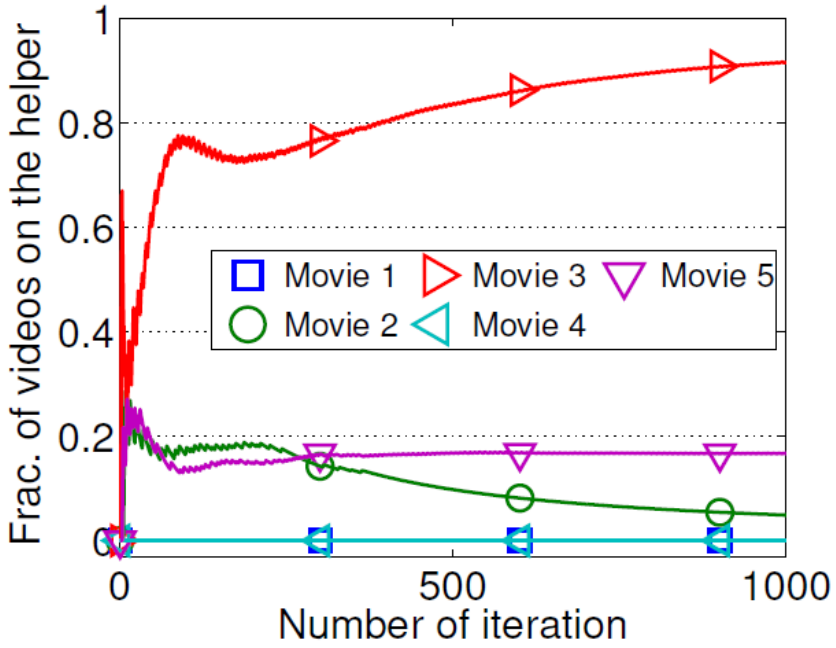
Number of users: 10

Simulation Results (Convergence)

- VoD
- Layers: 4
- Videos: 5
- Users: 50
- Helpers: 20



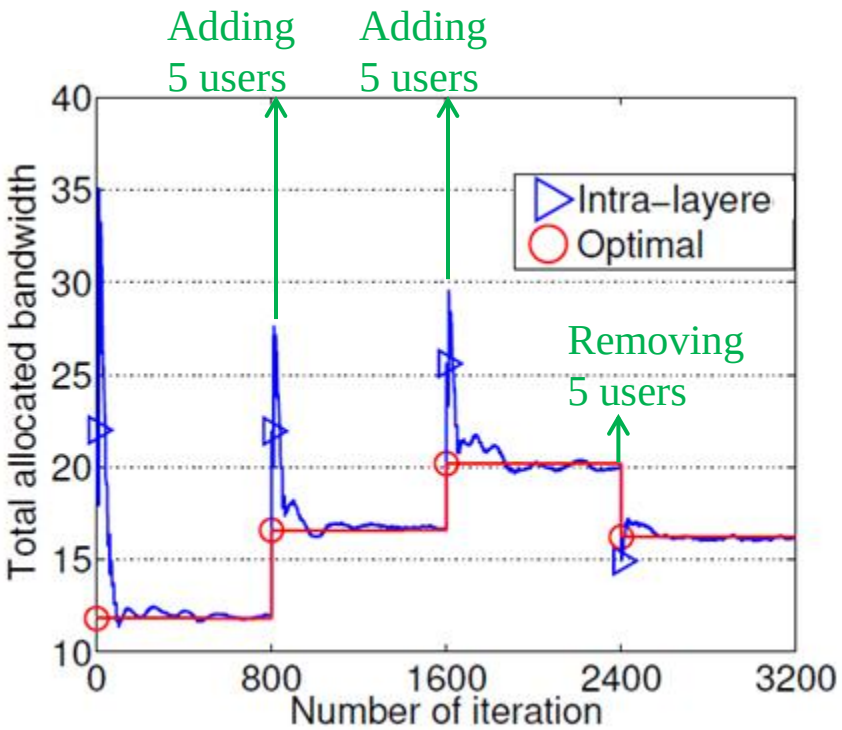
Convergence to the optimal solution (LP)



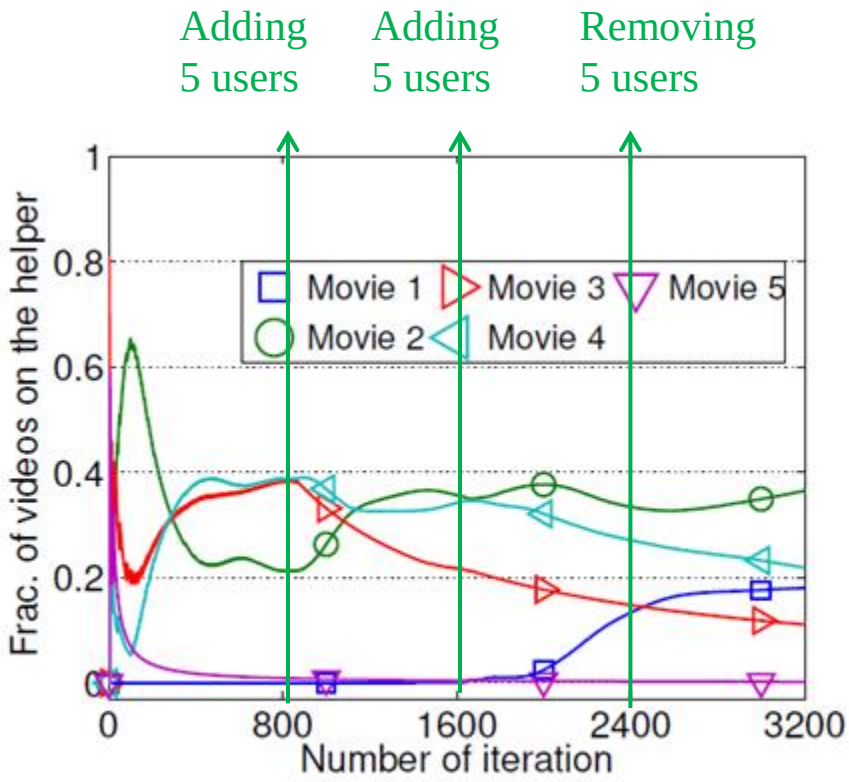
The fraction of each video on helper h5

Simulation Results (Dynamic Users)

- VoD
- Layers: 4
- Videos: 5
- Initial Users: 10
- Helpers: 10



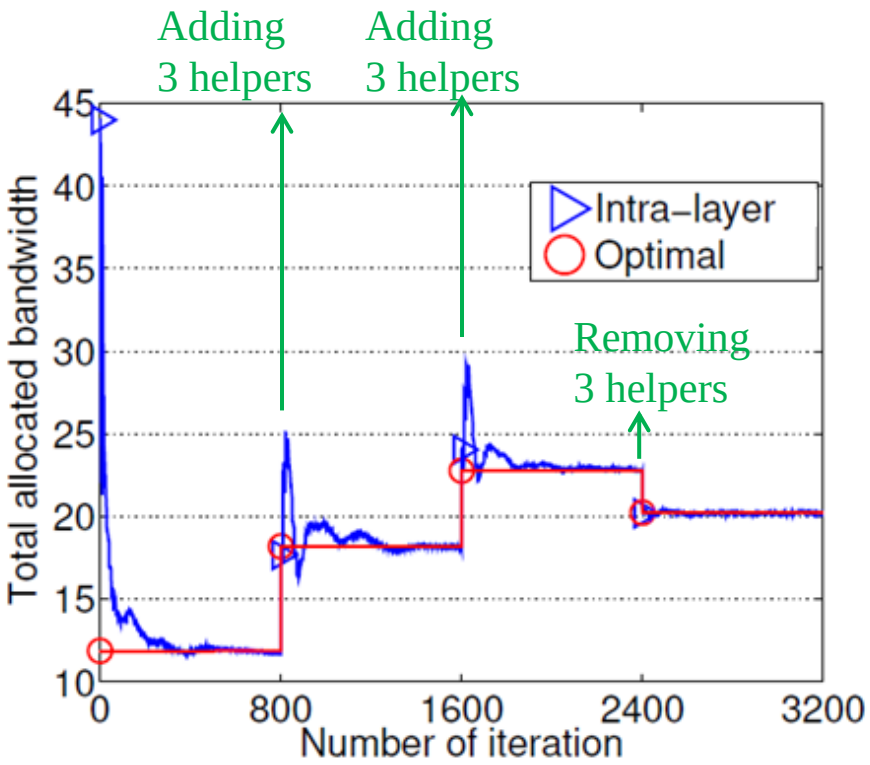
Convergence to the optimal solution (LP)



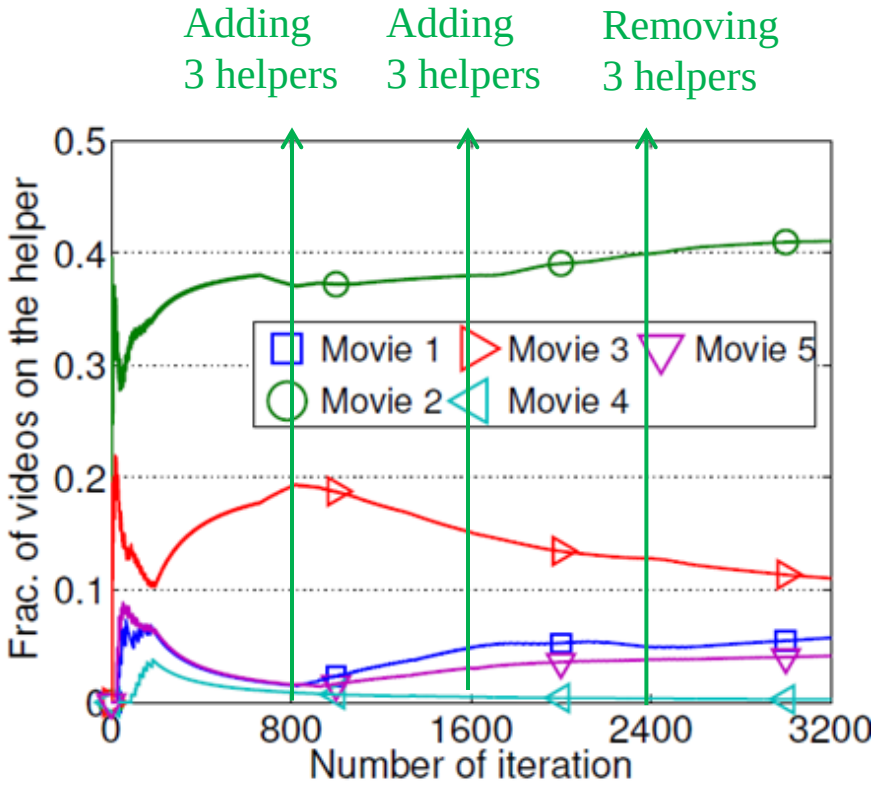
The fraction of each video on helper h8

Simulation Results (Dynamic Helpers)

- VoD
- Layers: 4
- Videos: 5
- Users: 20
- Initial helpers: 6



Convergence to the optimal solution (LP)



The fraction of each video on helper h3

Future Work and Challenges

- Other objectives
  - Fairness, layers with different weights, …
- Extension of layered VoD with unreliable links
  - Using symbol-level transmission work in layered VoD
- Cost-efficient helper provisioning
  - Based on user demands and resource availability
- Real implementation

Conclusions

Priority-Based Network Coding

- Data transmission
  - Transmitting the more important data with more redundancy
- Triangular coding in multi-layer video streaming
  - Increasing the number of received layers
- VoD and live streaming using helper nodes in multi-layer video streaming
  - Minimizing the load on the server