VIDEO STREAMING OVER WIRELESS LAN WITH NETWORK CODING

M. Al-Hami, A. Khreishah, and J. Wu

Computer and Information Sciences

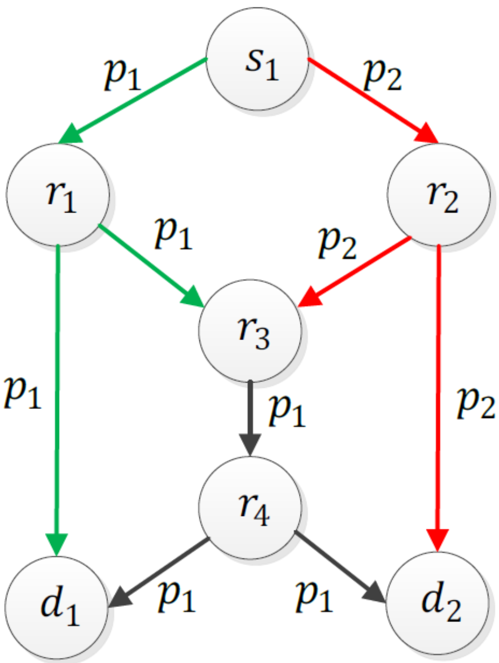
Temple University

Agenda

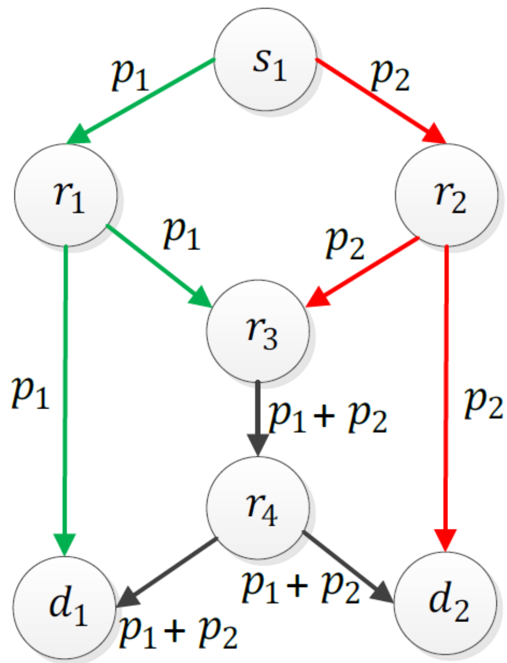
- Network Coding Background
- Priority-Based Network Coding
- Layered video streaming
- Simulation results
- Conclusions

Network Coding in Wired Networks

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



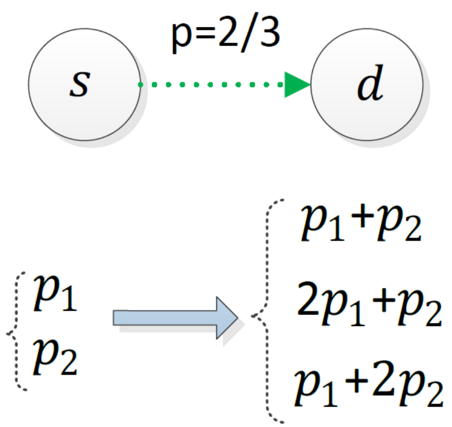
No coding



Coding

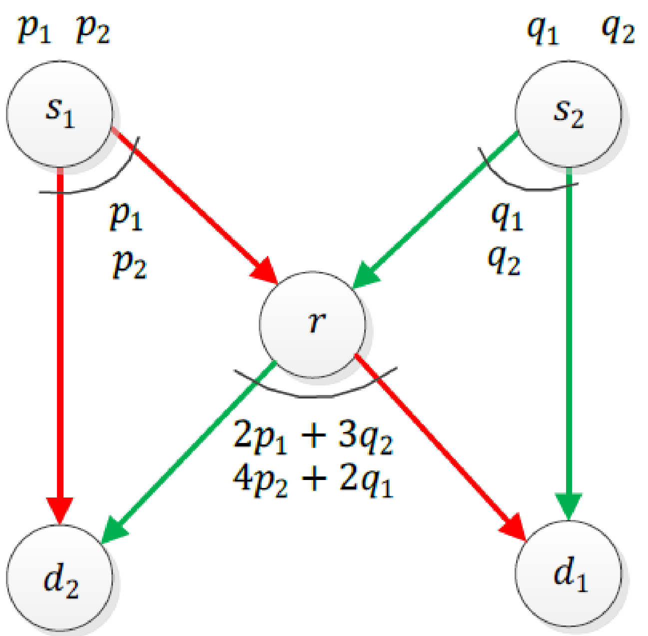
Network Coding in Wireless Networks

Intra-flow coding



- Reliability=2/3
- **3** transmissions

Inter-flow coding

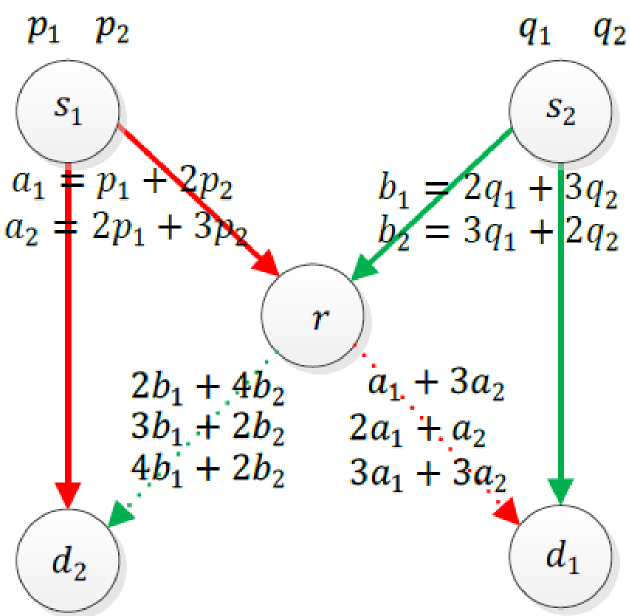


- Reliable links
- **2** transmissions by the relay

Network Coding in Wireless Networks

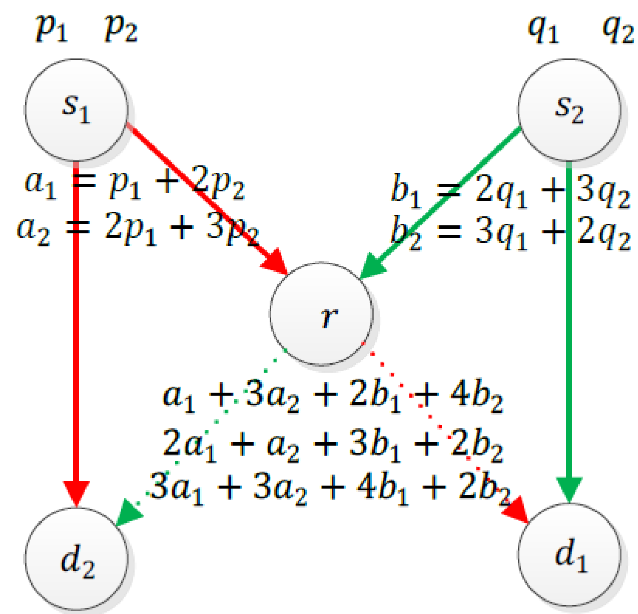
- Reliability from *r* to d_1 and d_2 is 2/3
- Other links are reliable

Intra- flow coding



6 transmissions by the relay

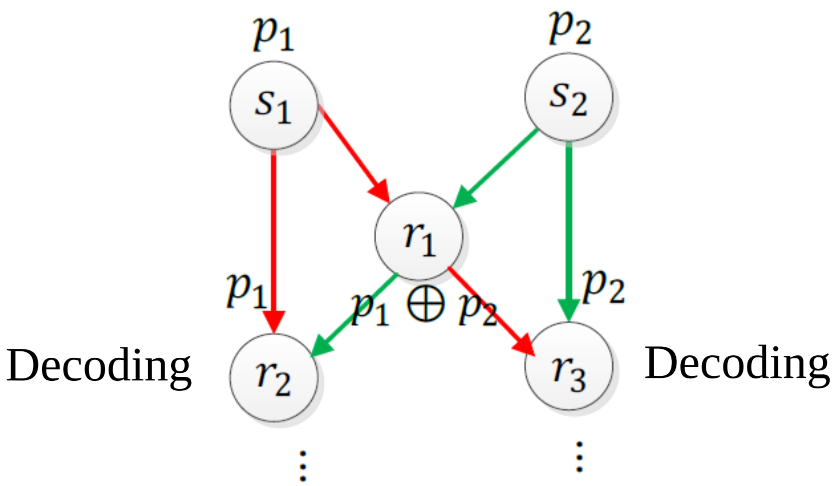
Joint inter- and intra-flow coding



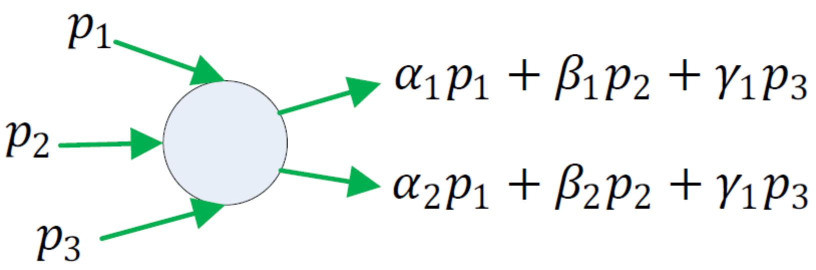
3 transmissions by the relay

Network Coding Classification

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

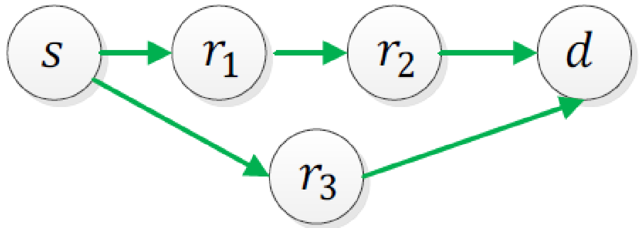


- Global
  - Decoding at the destination
  - Linear network coding (on a finite field)

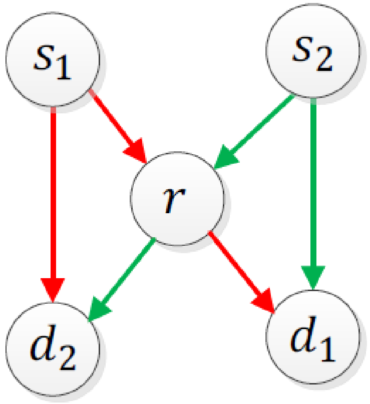


Network Coding Classification

- Intra-flow
  - Within a flow
  - Robustness enhancement



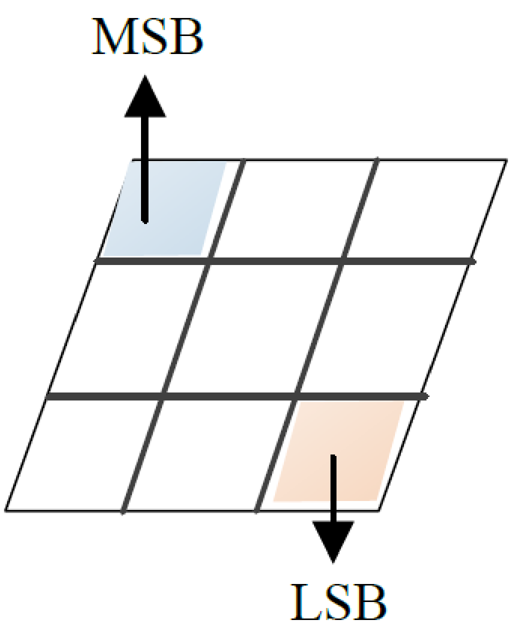
- Inter-flow
  - Between different flows
  - Throughput/capacity enhancement



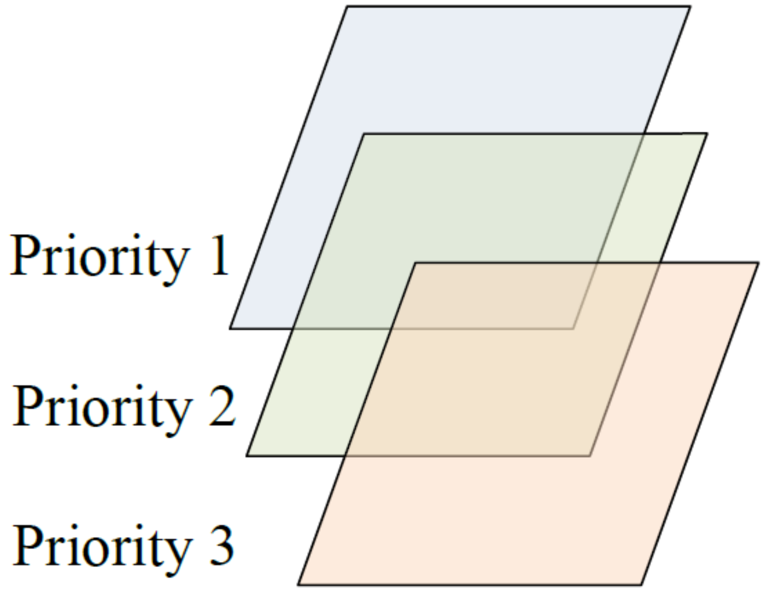
- Joint inter- and intra-flow
  - Within flow and between flows

Priority-Based Approaches

- New twist on the classic unequal error protection



Symbol-Level NC

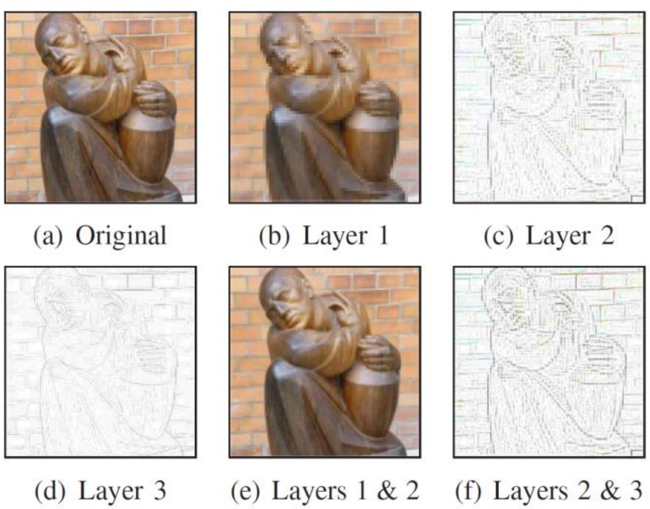


Video Streaming NC

Video Streaming

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

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



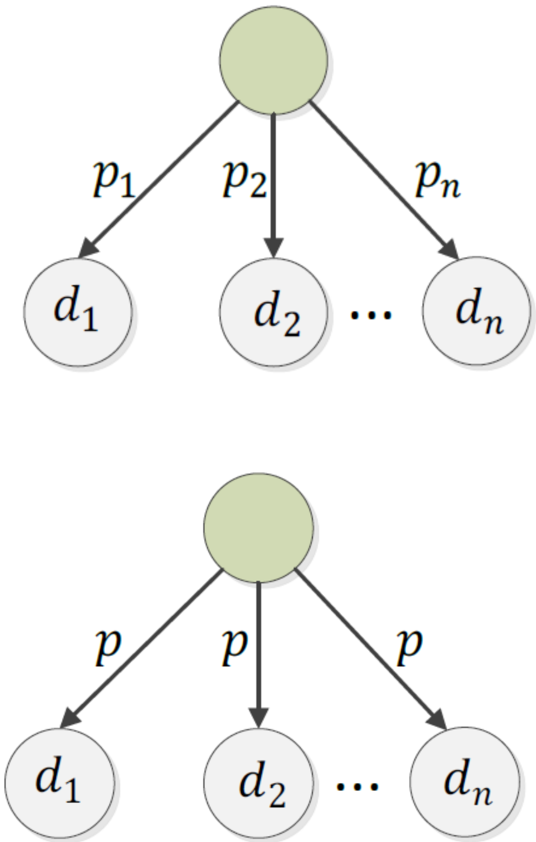
(a) Original (b) Layer 1 (c) Layer 2
(d) Layer 3 (e) Layers 1 & 2 (f) Layers 2 & 3

- 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

Setting and Objective

- One-hop WiFi networks
- Video stream: sequence of packets
- Packet deadline: X transmissions
- Layered streams : L layers
- Objective: maximizing throughput in terms of the total number of received layers by the users
- Intra-layer coding: linear coding
- Inter-layer coding: triangular coding



Lossy Bernoulli channel

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 chance to be decoded

Advantage of Triangular Coding

- Coefficients are not shown for simplicity
- 6 transmissions in round-robin pattern
  - Blue cells are received

No coding	*L1*	*L2*	*L3*	*L1*	*L2*	*L3*	Unable to decode
Triangular coding	*L1*	*L1* + *L2*	*L1* + *L2*+ *L3*	*L1*	*L1* + *L2*	*L1* + *L2*+ *L3*	Decodes 2 layers
Random linear coding	*L1* + *L2*+ *L3*	*L1* + *L2*+ *L3*	*L1* + *L2*+ *L3*	*L1* + *L2*+ *L3*	*L1* + *L2*+ *L3*	*L1* + *L2*+ *L3*	Unable to decode

Layered Video Decoding

- xi: number of transmission of layer i
- yi: received packets at layer i

Received packets on each layer	
Ideal Case:	$yi = p \cdot x_i = N$
Actual Case:	$yi > p \cdot x_i$, $yi < p \cdot xi$, $yi = p \cdot xi$

X	Strategy	N	p	Received Packets	Decoded Layers
64	[32,32,0,0]	8	0.25	[8,8,0,0]	2
64	[32,32,0,0]	8	0.25	[7,9,0,0]	2
64	[32,32,0,0]	8	0.25	[9,7,0,0]	1
64	[32,32,0,0]	8	0.25	[7,7,0,0]	0
64	[32,32,0,0]	8	0.25	[9,9,0,0]	2

- Consider all possible triangular schemes denoted as $(x_1, \ldots, x_l)$, where $\sum_{i=1}^{L} x_i = X$
- Ways of assigning X transmissions into L ways of generating the coded packets: $\binom{X-1+L}{L-1}$

Expected Throughput

- For one-layer case (with lossy Bernoulli channel):
  - Probability of receiving at least *N* transmissions out of *X* transmissions:

$$P[N] = \sum_{i=N}^{X} \binom{X}{i} \cdot p^{i} \cdot (1-p)^{X-i}$$

  - The expected throughput for each value of *N*:

$$E[N] = P[N] \cdot N = \sum_{i=N}^{X} \binom{X}{i} \cdot p^{i} \cdot (1-p)^{X-i} \cdot N$$

- For multiple layers case (with lossy Bernoulli channel):
  - The number of decoded layers *B*:

$$\sum_{j=B}^{B-k} y_j \geq (k+1) \cdot N, \quad \forall \; k \in [0, B-1]$$

Expected Throughput

- For multiple layers case:

  For any given strategy $\{x_1, \ldots, x_L\}$, the expected throughput $E[N]$ is the following:

$$\sum_{y_i \le x_i} \prod_{i=1}^{L} \binom{x_i}{y_i} \cdot p^{y_i} (1-p)^{x_i - y_i} \cdot B \cdot N$$

$$s.t. \quad \sum_{j=B}^{B-k} y_j \ge (k+1) \cdot N, \quad \forall \ k \in [0, B-1]$$

Expected throughput for multiple layers cases

B represents the number of decoded layers

- Large maximum throughput table based on different p, N, and L

  (Koutsconikolas et al. 2011)

Regression Techniques

- Applying regression on the maximum throughput table to approximate the relationship between *p*, *N*, and *L*, for *X* transmissions

Part of the generated table for 5 receivers, *X*=16

p1	p2	p3	p4	p5	Max ET	Best N	x1	x2	x3	x4	Decoded L
0.1	0.2	0.3	0.4	0.5	13.134	1	4	4	4	4	4
0.1	0.2	0.3	0.4	0.6	13.556	2	4	8	4	0	3
0.1	0.2	0.3	0.4	0.7	13.795	2	4	8	4	0	3
0.1	0.2	0.3	0.4	0.8	13.912	2	4	8	4	0	3
0.1	0.2	0.3	0.4	0.9	13.959	2	4	8	4	0	3
0.1	0.2	0.3	0.4	1	16.145	4	4	4	4	4	4
0.1	0.2	0.3	0.5	0.6	14.543	2	4	8	4	0	3
0.1	0.2	0.3	0.5	0.7	14.781	2	4	8	4	0	3
0.1	0.2	0.3	0.5	0.8	15.096	2	4	4	4	4	4
0.1	0.2	0.3	0.5	0.9	15.174	2	4	4	4	4	4
0.1	0.2	0.3	0.5	1	16.306	4	4	4	4	4	4
0.1	0.2	0.3	0.6	0.7	16.393	2	4	4	4	4	4
0.1	0.2	0.3	0.6	0.8	16.719	2	4	4	4	4	4
0.1	0.2	0.3	0.6	0.9	16.797	2	4	4	4	4	4
0.1	0.2	0.3	0.6	1	16.818	4	8	4	4	0	3
0.1	0.2	0.3	0.7	0.8	18.119	5	8	8	0	0	2
0.1	0.2	0.3	0.7	0.9	18.506	5	8	8	0	0	2
0.1	0.2	0.3	0.7	1	18.825	3	4	4	4	4	4
0.1	0.2	0.3	0.8	0.9	21.621	3	4	0	8	4	4
0.1	0.2	0.3	0.8	1	22.014	3	4	4	4	4	4
0.1	0.2	0.3	0.9	1	25.226	7	8	8	0	0	2
0.1	0.2	0.4	0.5	0.6	16.311	2	4	4	8	0	3
0.1	0.2	0.4	0.5	0.7	16.425	2	4	4	8	0	3
0.1	0.2	0.4	0.5	0.8	16.726	2	4	4	4	4	4
0.1	0.2	0.4	0.5	0.9	16.804	2	4	4	4	4	4

Regression Equations

$$N = \lfloor(-1.10476 - 2.36363 * p_1 - 3.24242 * p_2 + 3.757 * p_3 + 4.212 * p_4 + 0.757 * p_5)\rfloor$$
$$L = \lfloor(3.85714 + 1.36363 * p_1 + 0.2121 * p_2 - 1.969 * p_3 - 0.03 * p_4 + 0.333 * p_5)\rfloor$$

Regression Techniques

- Regression equations for different numbers of receivers

No of Receivers	N and L Regression Equations
1	$N = \lfloor(-0.1999999999999999 + 9.090909090909090909 * p_1)\rfloor$ $L = \lfloor(2.46666666666667 - 0.121212121212122 * p_1)\rfloor$
2	$N = \lfloor(-0.66 - 5.333 * p_1 + 9.2727 * p_2)\rfloor$ $L = \lfloor(3.2 + 0.242 * p_1 - 0.36363 * p_2)\rfloor$
3	$N = \lfloor(-1.052380 - 0.90 * p_1 - 1.83982 * p_2 + 7.229437 * p_3)\rfloor$ $L = \lfloor(3.63809 + 0.2813 * p_1 - 0.84415 * p_2 - 0.02164 * p_3)\rfloor$
4	$N = \lfloor(-1.42857 - 3.67965 * p_1 + 1.55844 * p_2 + 2.66233 * p_3 + 3.57142 * p_4)\rfloor$ $L = \lfloor(3.7619 + 0.90 * p_1 - 0.974 * p_2 - 0.99567 * p_3 + 0.47619 * p_4)\rfloor$
5	$N = \lfloor(-1.10476 - 2.36363 * p_1 - 3.24242 * p_2 + 3.757 * p_3 + 4.212 * p_4 + 0.757 * p_5)\rfloor$ $L = \lfloor(3.85714 + 1.36363 * p_1 + 0.2121 * p_2 - 1.969 * p_3 - 0.03 * p_4 + 0.333 * p_5)\rfloor$

Strategy Selection

- Categorizing groups according to the decoded layer
- Using majority voting to decide the strategy

p1	p2	p3	p4	p5	Max ET	Best N	x1	x2	x3	x4	Decoded L
0.1	0.2	0.3	0.4	0.5	13.134	1	4	4	4	4	4
0.1	0.2	0.3	0.4	1	16.145	4	4	4	4	4	4
0.1	0.2	0.3	0.5	0.8	15.096	2	4	4	4	4	4
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0.1	0.2	0.3	0.5	1	16.306	4	4	4	4	4	4
0.1	0.2	0.3	0.6	0.7	16.393	2	4	4	4	4	4
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0.1	0.2	0.3	0.7	0.9	18.506	5	8	8	0	0	2
0.1	0.2	0.3	0.9	1	25.226	7	8	8	0	0	2

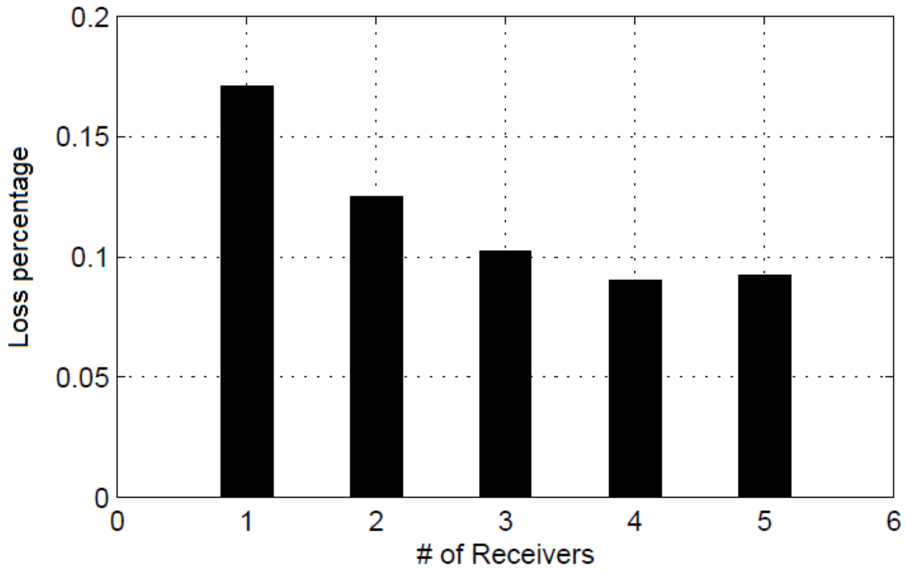
Best strategies that maximize throughput

Simulation Results

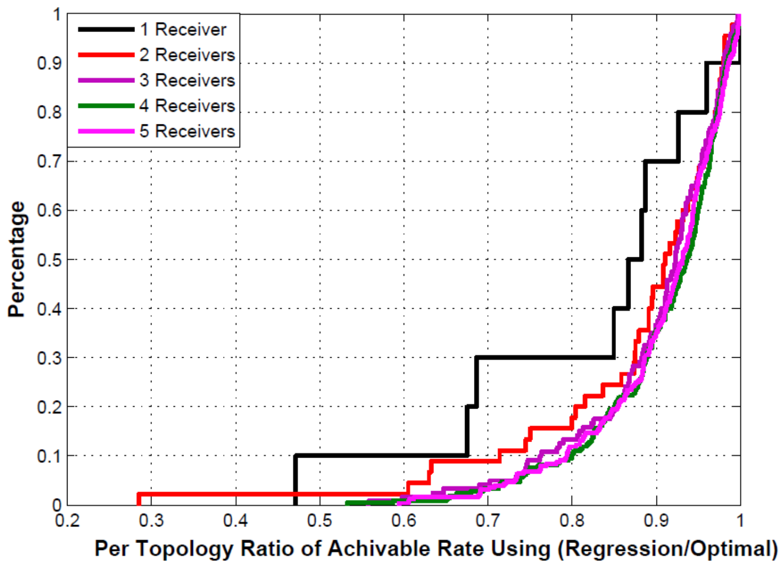
- Loss percentage for different receivers to the optimal approach

- Empirical CDF for different topologies and numbers of receivers
- Graph is biased toward the right

X = 16 transmissions



The ratio is approaching 1.0



Questions