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MG-Local: A Multivariable Control Framework for Optimal Wireless Resource Management

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Outline

- Introduction
- MG-Local Resource Management
- Performance Results
- Implementation and Application
- Conclusions

Introduction

- **User Perspective**
  - Increasing application variety
  - Growing traffic demands
  - Diverse Quality of Service (QoS) requirements

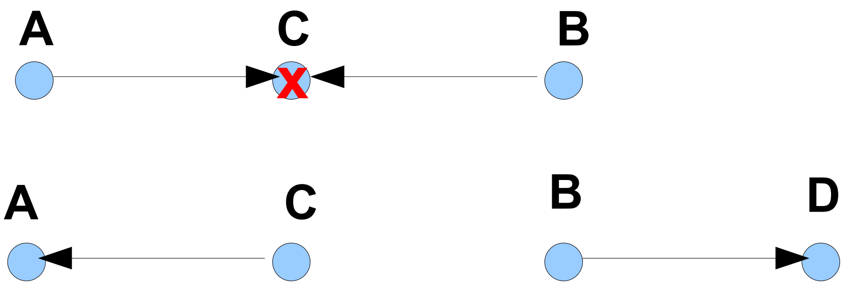
- **Network Perspective**
  - Limited resources
  - Lossy transmissions
  - Time-varying network conditions

Challenges

- **Effective control vs. dynamic interference**
  - Adaptive multivariable control
- **Efficient resource utilization vs. waste**
  - G-Local optimization
- **Fair resource allocation vs. diversity and interference**
  - Configurable and adaptive fairness
- **Control overhead vs. control-message passing**
  - Local information inference

Adaptive Multivariable Control (1/3)

- **Temporal interference**
  - Earlier transmissions
  - Simultaneous transmissions
  - Future transmissions
- **Spatial interference**
  - Hidden terminals
  - Exposed terminals



Adaptive Multivariable Control (2/3)

- **Transmission probability (P_i)**
  - Defines the probability to transmit when the physical carrier sensing detects a busy medium
  - Controls both hidden and exposed terminals
- **Avoidance window ($Awin_i$)**
  - Specifies the maximum number of slots that a node can randomly select to wait before starting transmission
  - Controls collisions caused by simultaneous transmissions
- **Resolution window ($Rwin_i$)**
  - Defines the contention window to avoid repeated collisions
  - Controls collisions caused by future transmissions

Adaptive MultiVariable Control (3/3)

- **Resource consumption model**

$$
\begin{aligned}
x_i &= R(P_i, Awin_i, Rwin_i) \\
&= e_1 \cdot P_i + e_2 \cdot Awin_i + e_3 \cdot Rwin_i \\
&+ e_4 \cdot P_i \cdot Awin_i + e_5 \cdot P_i \cdot Rwin_i \\
&+ e_6 \cdot Awin_i \cdot Rwin_i + e_7
\end{aligned}
\qquad
\begin{aligned}
coll_i &= CL(P_i, Awin_i, Rwin_i) \\
&= f_1 \cdot P_i + f_2 \cdot Awin_i + f_3 \cdot Rwin_i \\
&+ f_4 \cdot P_i \cdot Awin_i + f_5 \cdot P_i \cdot Rwin_i \\
&+ f_6 \cdot Awin_i \cdot Rwin_i + f_7
\end{aligned}
$$

- **Least square fitting**
- **Noise processing**

$$
\begin{aligned}
x_i^m(t) &= w \cdot x_i^m(t) + (1-w) \cdot x_i^m(t-1) \\
coll_i^m(t) &= w \cdot coll_i^m(t) + (1-w) \cdot coll_i^m(t-1)
\end{aligned}
$$

G-Local Optimization (1/2)

- Reduces the gap between resource allocation and utilization
- Supports various fairness criteria
- Approaches the global optimum via local inference without message passing
- Has the advantages of both global and local optimization

G-Local Optimization (2/2)

- **Formulation**

$$max \quad k \cdot U_i(x_i) - (1-k) \cdot (C_i(x_i) + W_i(x_i))$$

$$s.t. \quad XMIN \leq x_i \leq XMAX$$

- **Components**
  - Consumption utility $U_i = \log(x_i)$
  - Consumption cost $C_i = \frac{1}{x_f} \cdot x_i$
  - Waste cost $W_i = \frac{coll_i}{B} + \frac{(x_f - x_i)}{B}$

MG-Local Framework (1/3)

- **Combines the adaptive multivariable control and G-Local optimization**

$$
\begin{aligned}
\max \; V(P_i, Awin_i, Rwin_i) = \; & k \cdot \log R(P_i, Awin_i, Rwin_i) \\
& - (1-k) \cdot \frac{n_i^{share} - 1}{B} \cdot R(P_i, Awin_i, Rwin_i) \\
& + (1-k) \cdot \left(\frac{CL(P_i, Awin_i, Rwin_i)}{B} + \frac{1}{n_i^{share}} \right)
\end{aligned}
$$

$$
\begin{aligned}
s.t. \quad & 0 < P_i < 1; \\
& AWINMIN \le Awin_i < AWINMAX; \\
& RWINMIN \le Rwin_i < RWINMAX;
\end{aligned}
$$

MG-Local Framework (2/3)

- **Lagrange Transformation**

$$
\begin{aligned}
max \quad & V(P_i, Awin_i, Rwin_i) + \lambda_i^{p1} \cdot P_i - \lambda_i^{p2} \cdot (P_i - 1) \\
& - \lambda_i^{ca1} \cdot (CAMIN - Awin_i) - \lambda_i^{ca2} \cdot (Awin_i - CAMAX) \\
& - \lambda_i^{cr1} \cdot (CRMIN - Rwin_i) - \lambda_i^{cr2} \cdot (Rwin_i - CRMAX)
\end{aligned}
$$

- **Dual Problem**

$$D(P_i, Awin_i, Rwin_i, \lambda_i) = max \quad L$$

$$min \quad D(P_i, Awin_i, Rwin_i, \lambda_i)$$

MG-Local Framework (3/3)

- **Control Policies**

$$P_i(t) = P_i(t-1) + k_p \cdot \frac{\partial L}{\partial P_i}$$

$$Awin_i(t) = Awin_i(t-1) + k_{ca} \cdot \frac{\partial L}{\partial Awin_i}$$

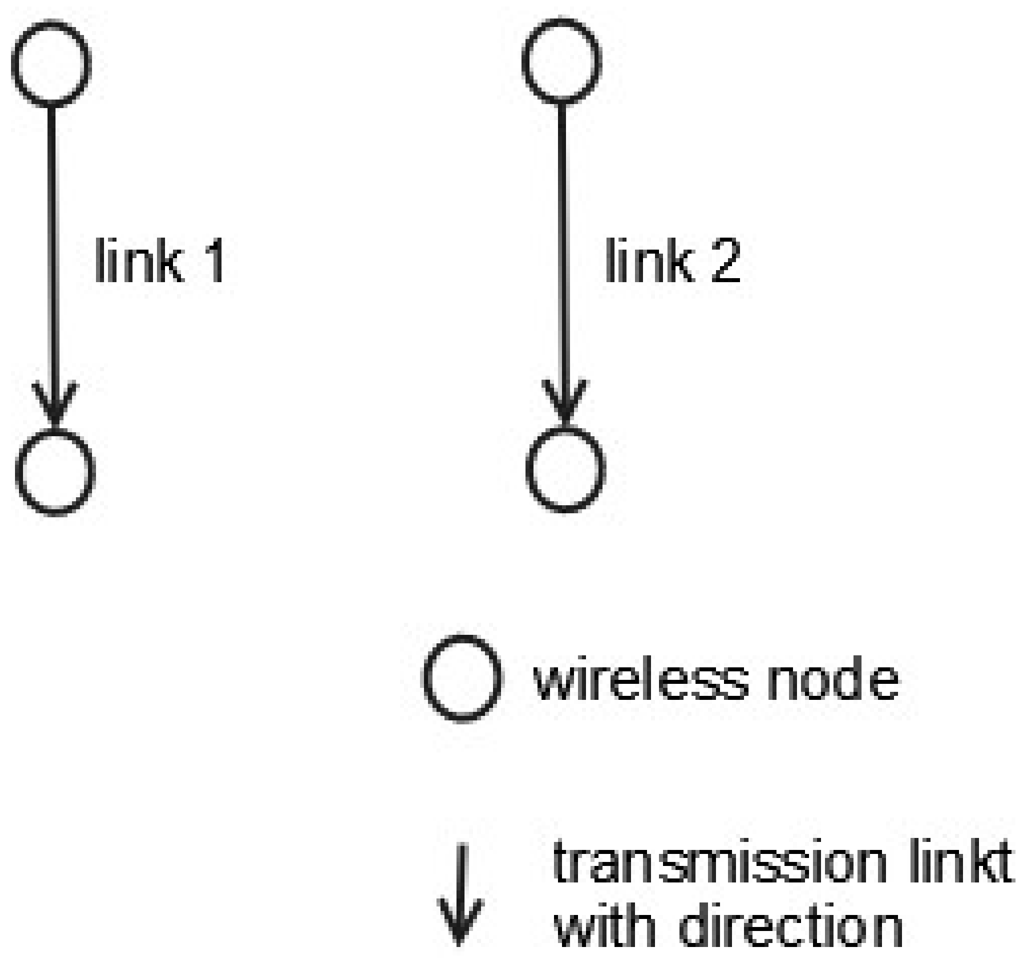
$$Rwin_i(t) = Rwin_i(t-1) + k_{cr} \cdot \frac{\partial L}{\partial Rwin_i}$$

Experimental Results

- **Comparative Study**
  - CSMA/CA
  - Single Variable Control
  - Global Optimization
  - Multivariable control with SPSA
- **System Parameters**

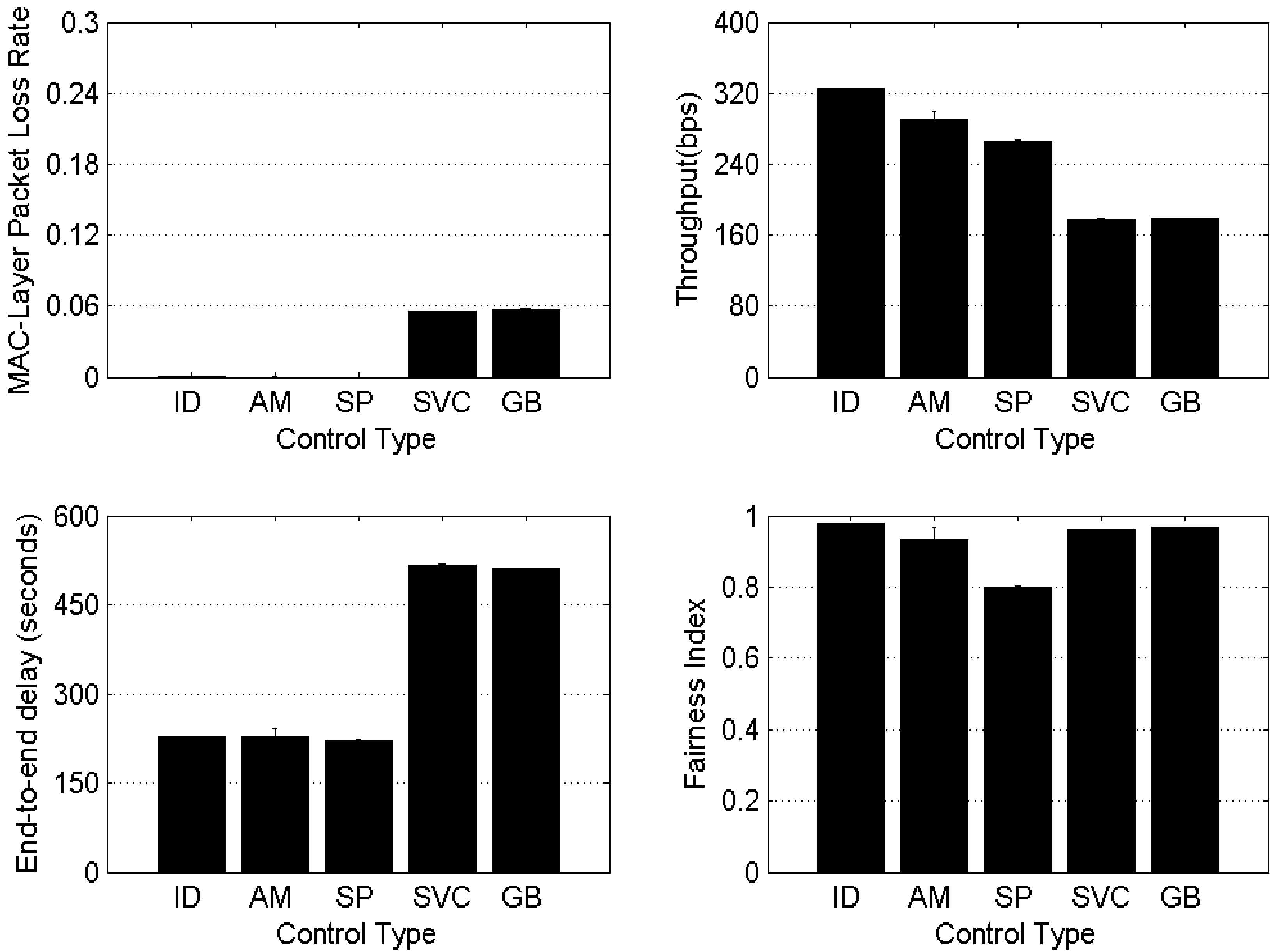
Parameters	Value
Packet size	512 B
Channel capacity	244 pps
Transmission range	200 meters
Carrier sensing range	400 meters

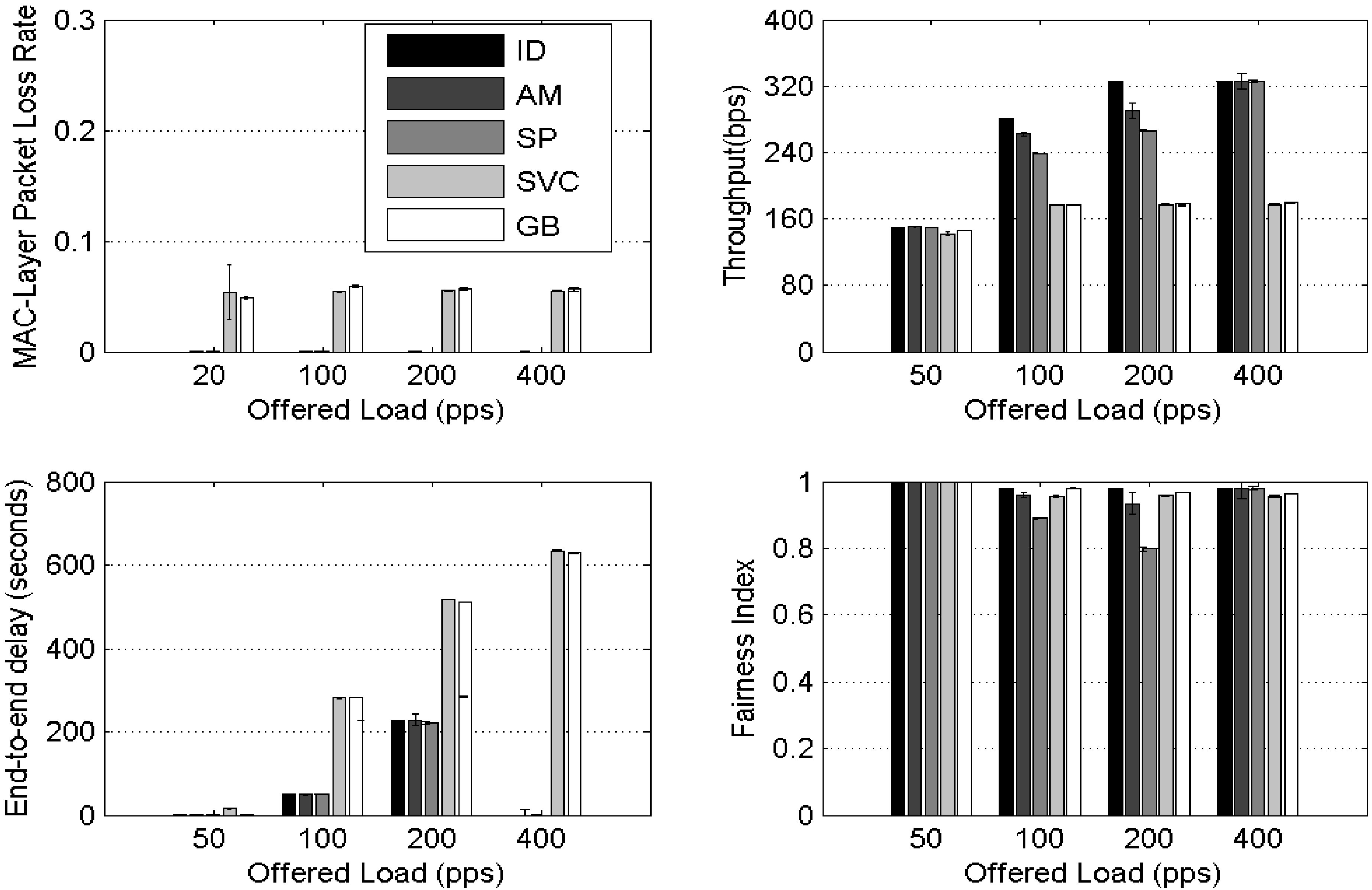
Three-Link Experiment



Three-Link Results

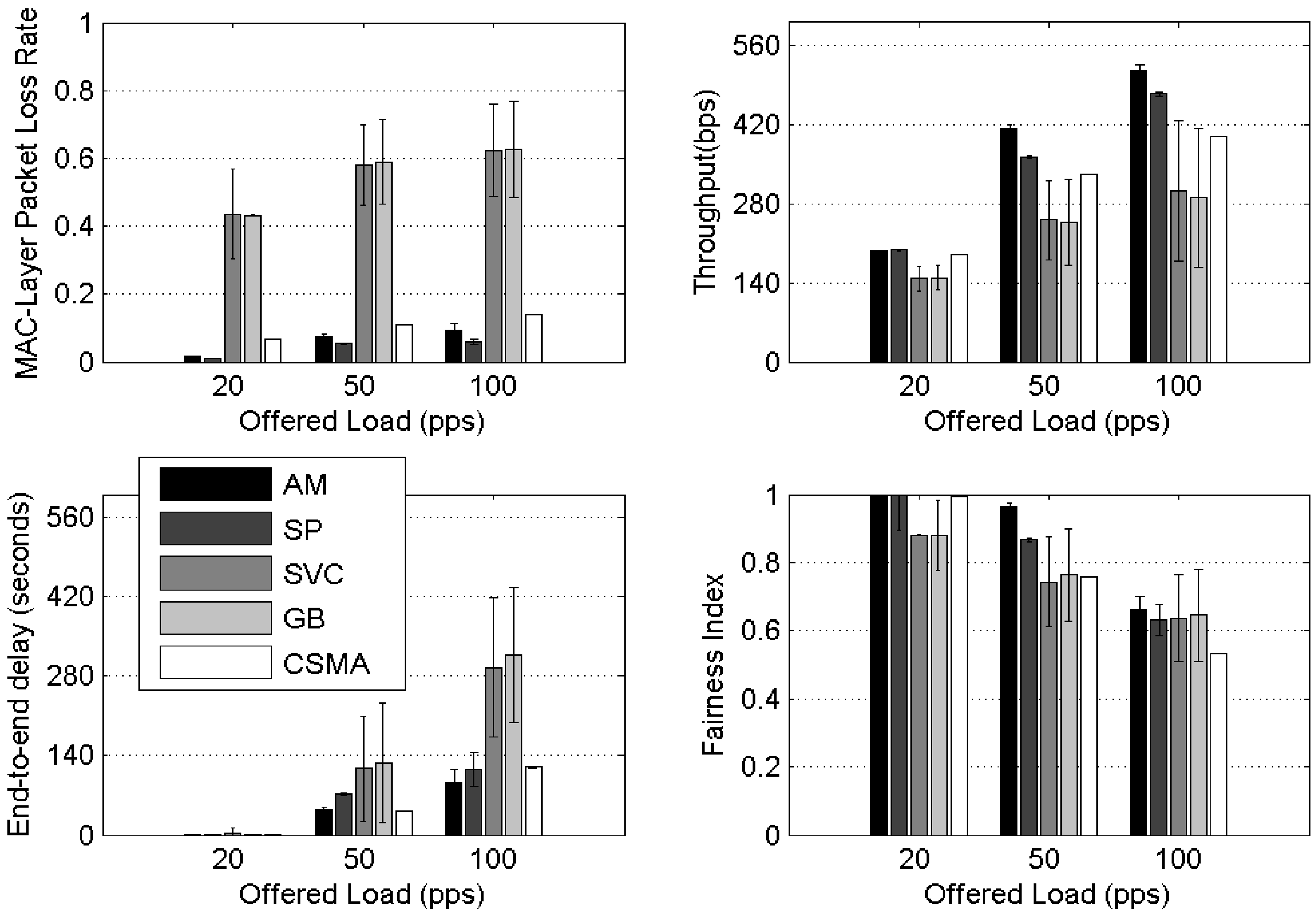
	Link 1 (pps)	Link 2 (pps)	Link 3 (pps)
ID	122.07	81.38	122.07
AM	116.32	61.68	114.54
SP	120.71	25.41	121.02
SVC	67.23	44.45	67.35
GB	68.93	42.65	69.21
CSMA/CA-ET	182.10	1.02	182.09
CSMA/CA-HT	65.37	55.55	65.30

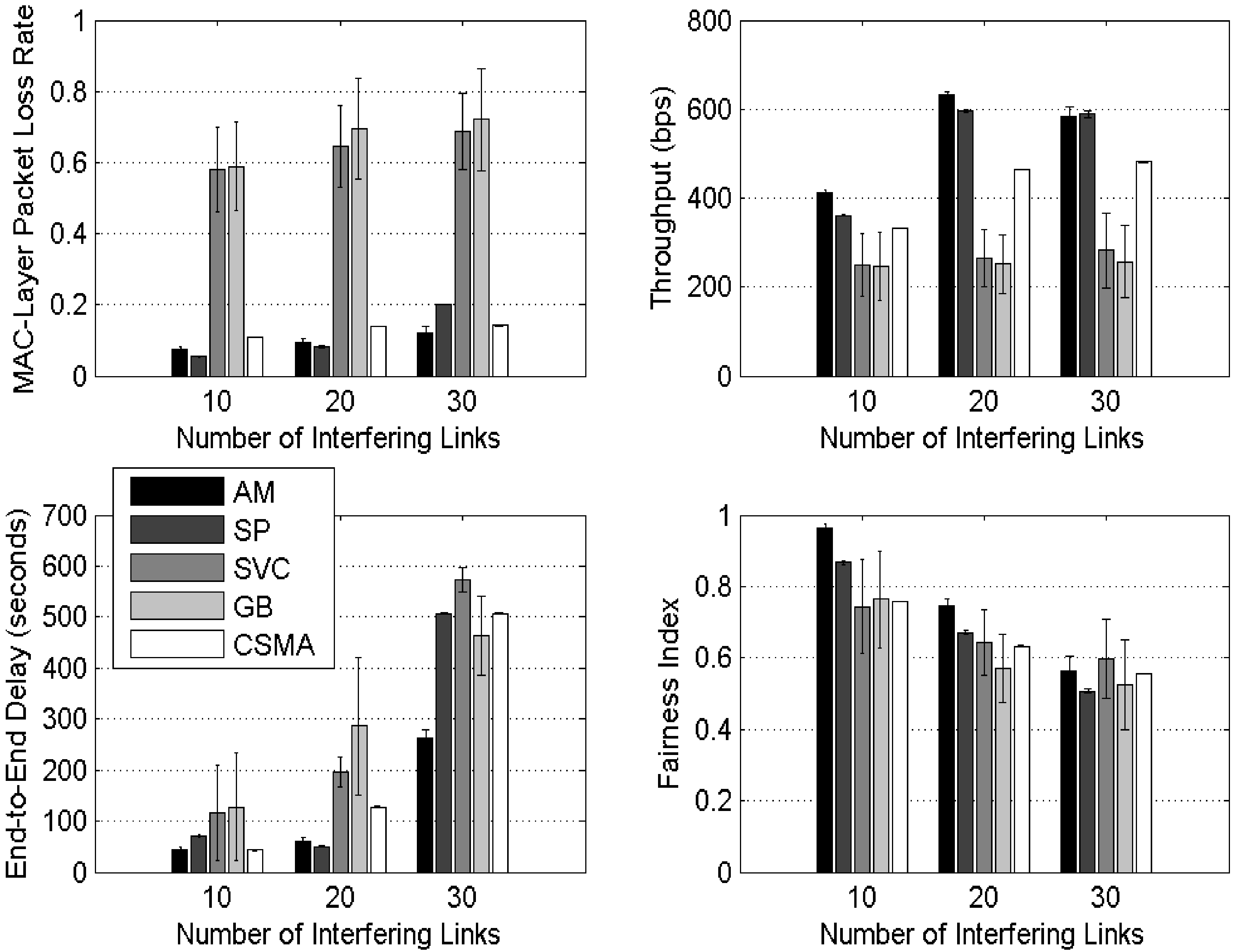

MAC-Layer Packet Loss Rate
0.3
0.24
0.18
0.12
0.06
0
ID AM SP SVC GB
Control Type
Throughput(bps)
400
320
240
160
80
0
ID AM SP SVC GB
Control Type
End-to-end delay (seconds)
600
450
300
150
0
ID AM SP SVC GB
Control Type
Fairness Index
1
0.8
0.6
0.4
0.2
0
ID AM SP SVC GB
Control Type



MAC-Layer Packet Loss Rate
0.3
0.2
0.1
0
20
100
200
400
Offered Load (pps)
ID
AM
SP
SVC
GB
Throughput(bps)
400
320
240
160
80
0
50
100
200
400
Offered Load (pps)
End-to-end delay (seconds)
800
600
400
200
0
50
100
200
400
Offered Load (pps)
Fairness Index
1
0.8
0.6
0.4
0.2
0
50
100
200
400
Offered Load (pps)

Large Random Networks





MAC-Layer Packet Loss Rate
Throughput (bps)
End-to-End Delay (seconds)
Fairness Index
Number of Interfering Links
AM
SP
SVC
GB
CSMA

Conclusions

- **We propose a novel framework of resource management: MG-Local**
  - Improve network control via adaptive multivariable control
  - Achieve optimal trade-off between fair allocation and efficient utilization
  - Provide configurable fairness support
  - Incurs zero message passing via local information inference
- **Work in progress**
  - Extend MG-Local to multi-hop wireless networks
  - Extend MG-Local to achieve cross-layer congestion and collision control

Thank you!

Questions?