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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** \( (A\text{win}_i) \)
  - 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** \( (R\text{win}_i) \)
  - Defines the contention window to avoid repeated collisions
  - Controls collisions caused by future transmissions
Adaptive MultiVariable Control (3/3)

- **Resource consumption model**

\[
x_i = R(P_i, Awin_i, Rwin_i) \quad \text{coll}_i = CL(P_i, Awin_i, Rwin_i)
\]

\[
= e_1 \cdot P_i + e_2 \cdot Awin_i + e_3 \cdot Rwin_i \quad = f_1 \cdot P_i + f_2 \cdot Awin_i + f_3 \cdot Rwin_i
\]

\[
+ e_4 \cdot P_i \cdot Awin_i + e_5 \cdot P_i \cdot Rwin_i \quad + f_4 \cdot P_i \cdot Awin_i + f_5 \cdot P_i \cdot Rwin_i
\]

\[
+ e_6 \cdot Awin_i \cdot Rwin_i + e_7 \quad + f_6 \cdot Awin_i \cdot Rwin_i + f_7
\]

- **Least square fitting**

- **Noise processing**

\[
x_i^m(t) = w \cdot x_i^m(t) + (1 - w) \cdot x_i^m(t - 1)
\]

\[
coll_i^m(t) = w \cdot coll_i^m(t) + (1 - w) \cdot coll_i^m(t - 1)
\]
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

\[ \max \ k \cdot U_i(x_i) - (1-k) \cdot (C_i(x_i) + W_i(x_i)) \]

\[ \text{s.t. } X_{\text{MIN}} \leq x_i \leq X_{\text{MAX}} \]

- 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

\[
\begin{align*}
\max \quad & V(P_i, A_{win_i}, R_{win_i}) = k \cdot \log R(P_i, A_{win_i}, R_{win_i}) \\
\quad & - (1 - k) \cdot \frac{n_{i \text{share}} - 1}{B} \cdot R(P_i, A_{win_i}, R_{win_i}) \\
\quad & + (1 - k) \cdot \left( \frac{CL(P_i, A_{win_i}, R_{win_i})}{B} + \frac{1}{n_i \text{share}} \right)
\end{align*}
\]

s.t. 
\[
0 < P_i < 1 ; \\
A_{WINMIN} \leq A_{win_i} < A_{WINMAX} ; \\
R_{WINMIN} \leq R_{win_i} < R_{WINMAX} ;
\]
MG-Local Framework (2/3)

- **Lagrange Transformation**

\[
\begin{align*}
\text{max} & \quad V(P_i, A_{\text{win}_i}, R_{\text{win}_i}) + \lambda_i^{p1} \cdot P_i - \lambda_i^{p2} \cdot (P_i - 1) \\
& - \lambda_i^{ca1} \cdot (\text{CAMIN} - A_{\text{win}_i}) - \lambda_i^{ca2} \cdot (A_{\text{win}_i} - \text{CAMAX}) \\
& - \lambda_i^{cr1} \cdot (\text{CRMIN} - R_{\text{win}_i}) - \lambda_i^{cr2} \cdot (R_{\text{win}_i} - \text{CRMAX})
\end{align*}
\]

- **Dual Problem**

\[
D(P_i, A_{\text{win}_i}, R_{\text{win}_i}, \lambda_i) = \text{max} \quad L \\
\text{min} \quad D(P_i, A_{\text{win}_i}, R_{\text{win}_i}, \lambda_i)
\]
MG-Local Framework (3/3)

- Control Policies

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

\[
A_{win_i}(t) = A_{win_i}(t-1) + k_{ca} \cdot \frac{\partial L}{\partial A_{win_i}} \]

\[
R_{win_i}(t) = R_{win_i}(t-1) + k_{cr} \cdot \frac{\partial L}{\partial R_{win_i}} \]
Experimental Results

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

- **System Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>Packet size</td>
<td>512 B</td>
</tr>
<tr>
<td>Channel capacity</td>
<td>244 pps</td>
</tr>
<tr>
<td>Transmission range</td>
<td>200 meters</td>
</tr>
<tr>
<td>Carrier sensing range</td>
<td>400 meters</td>
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</tbody>
</table>
Three-Link Experiment

link 1

link 2

link 3

wireless node

transmission link with direction
## Three-Link Results

<table>
<thead>
<tr>
<th></th>
<th>Link 1 (pps)</th>
<th>Link 2 (pps)</th>
<th>Link 3 (pps)</th>
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</thead>
<tbody>
<tr>
<td>ID</td>
<td>122.07</td>
<td>81.38</td>
<td>122.07</td>
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<tr>
<td>AM</td>
<td>116.32</td>
<td>61.68</td>
<td>114.54</td>
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<tr>
<td>SP</td>
<td>120.71</td>
<td>25.41</td>
<td>121.02</td>
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<tr>
<td>SVC</td>
<td>67.23</td>
<td>44.45</td>
<td>67.35</td>
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<tr>
<td>GB</td>
<td>68.93</td>
<td>42.65</td>
<td>69.21</td>
</tr>
<tr>
<td>CSMA/CA-ET</td>
<td>182.10</td>
<td>1.02</td>
<td>182.09</td>
</tr>
<tr>
<td>CSMA/CA-HT</td>
<td>65.37</td>
<td>55.55</td>
<td>65.30</td>
</tr>
</tbody>
</table>
Large Random Networks

MAC-Layer Packet Loss Rate

Throughput (bps)

End-to-end delay (seconds)

Fairness Index

- AM
- SP
- SVC
- GB
- CSMA

Offered Load (pps)
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?