A Fair Medium Access Control Protocol for Ad-hoc Networks with MIMO Links

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Introduction

- Multiple Input Multiple Output (MIMO) is an antenna technology that provides high spectral efficiencies
- MIMO is the key to handle multipath efficiently!
- Related works have addressed the problem of medium access control with switched beam antennas in ad-hoc networks [Choudhury et al. Mobicom 2002, Ramanathan et al. Mobihoc 2002]
- We address the problem of medium access control in ad-hoc networks with MIMO links
Outline

- Characteristics/capabilities of MIMO links
- Optimization considerations for the MAC protocol
- Centralized SCMA (Stream Controlled Medium Access) protocol
- Conclusions
Characteristics of MIMO links

- Do not require LOS and can operate in rich multipath environments
- Capable of diversity and spatial multiplexing gain
- Spatial multiplexing provides a linear increase in asymptotic capacity unlike the logarithmic increase with array and diversity gain
- Spatial multiplexing gain increases the link capacity
- Independent streams are transmitted simultaneously
- Diversity gain reduces error probability on link to increase reliability during fading
- Introduces dependency amongst transmitted streams
Capabilities of MIMO links

- Adaptive resource usage
  - Number of elements correspond to “degrees of freedom” (DOFs) or “resources” at a node
  - Data transmitted on the different elements is given the abstraction of “streams”
  - Resources can be used for transmission or interference suppression

- Flexible interference suppression
  - Can suppress as many interfering streams as the number of DOFs in uncorrelated fading

- Capacity-Range tradeoff
  - Diversity increases link reliability and consequently provides increased range
  - Spatial multiplexing increases system capacity
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- Characteristics/capabilities of MIMO links
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- Performance evaluation
- Conclusions
Simple CSMA/CA extension

- Is there a simple extension to CSMA/CA that can exploit spatial multiplexing?
- Yes, with appropriate tuning of timers and other constants
- CSMA/CA that spatially multiplexes on “k” elements is referred to as CSMA/CA(k)
- CSMA/CA(k) can provide close to “k” fold improvement
- Is this the best performance we can expect?
Optimization considerations (1)

- **Stream control**

  A → B
  Link 1
  200 m

  C → D
  Link 2
  200 m

  CSMA/CA(k)

  Link 1, $C_{L1} = 100$ Kbps

  Link 2, $C_{L2} = 100$ Kbps

  Stream controlled MAC

- **Consideration 1:** Multiple interfering links operating simultaneously using stream control achieve overall better throughput performance
Optimization considerations (2)

- **Flexible interference suppression**
  - Number of independent interfering streams important
  - Lesser number of DOFs required if interfering streams are highly correlated or arrive with very low power
- **Consideration 2:** Flexible interference suppression in conjunction with stream control helps create additional resources and hence additional gain

![Diagram showing network topology and stream control](image)
Optimization considerations (3)

- Passive receiver overloading

Consideration 3: Receivers belonging to multiple contention regions must not perform stream control
Outline

- Characteristics/capabilities of MIMO links
- Optimization considerations for the MAC protocol
  - Stream control
  - Flexible interference suppression
  - Passive receiver overloading
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Centralized SCMA

- **Goals**
  - Maximize network utilization subject to a proportional fairness model, by leveraging the optimization considerations

- **Key insights**
  - To eliminate passive receiver overloading problem, links belonging to multiple contention regions ("red" links) must operate on all resources
  - Stream control must be leveraged only by links belonging to single contention region ("white" links)
  - Flexible interference suppression can be leveraged by white links in conjunction with stream control
Components (1)

- Graph generations
  - Network topology is represented as a network graph
  - Contention between active links is captured in the flow contention graph

![Node graph](image1)

![Flow contention graph](image2)
Components (2)

- Clique identification, ranking and coloring
  - Maximal cliques in flow contention graph correspond to contention regions in the network
  - Ranking is done based on tuple (clique degree, max clique size)
  - Bottleneck links are colored red based on rank and non-bottleneck links are colored white
Components (3)

- Dual-level scheduling
  - Red links are scheduled first based on their rank
  - White links are scheduled next and perform stream control

Flow contention graph

```
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<th>c</th>
<th>d</th>
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```
Recap

- **Step 1**: Obtain the network graph and hence the flow contention graph.
- **Step 2**: Identify all maximal cliques in the flow contention graph and color bottleneck necks as “red” and non-bottleneck links as “white”.
- **Step 3**: Perform dual scheduling with white links alone exploiting stream control.
Conclusions

- Highlighted the characteristics and capabilities of MIMO links
- Identified optimization considerations to leverage the PHY layer capabilities
- Proposed centralized and distributed protocols for medium access control exploiting the optimizations
- Leverage the different gains in an efficient manner to propose joint MAC and routing protocols for ad-hoc network with MIMO links
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