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

Karthikeyan Sundaresan
Raghupathy Sivakumar
Mary Ann Ingram
Tae-Young Chang
GNAN Research Group, Georgia Tech
http://www.ece.gatech.edu/research/GNAN/

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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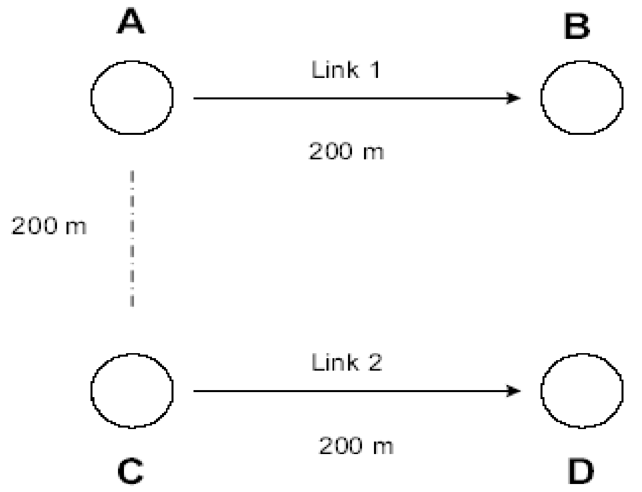
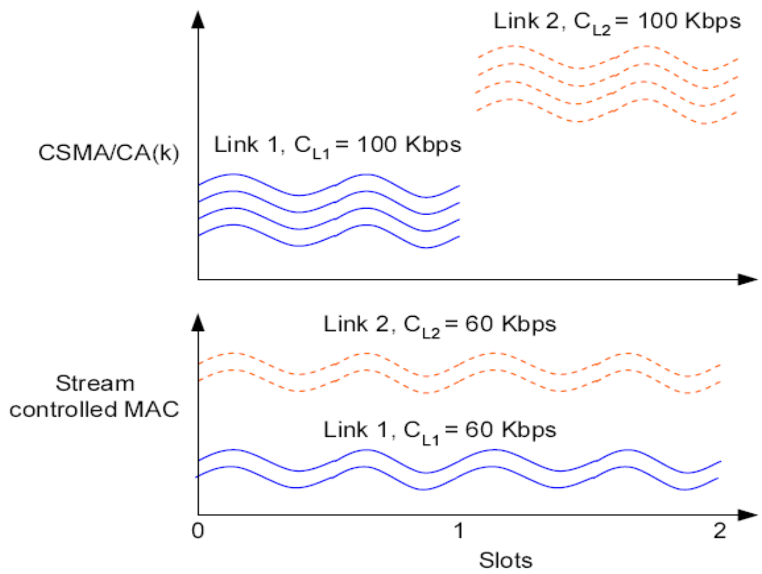
Simple CSMA/CA extension

- 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

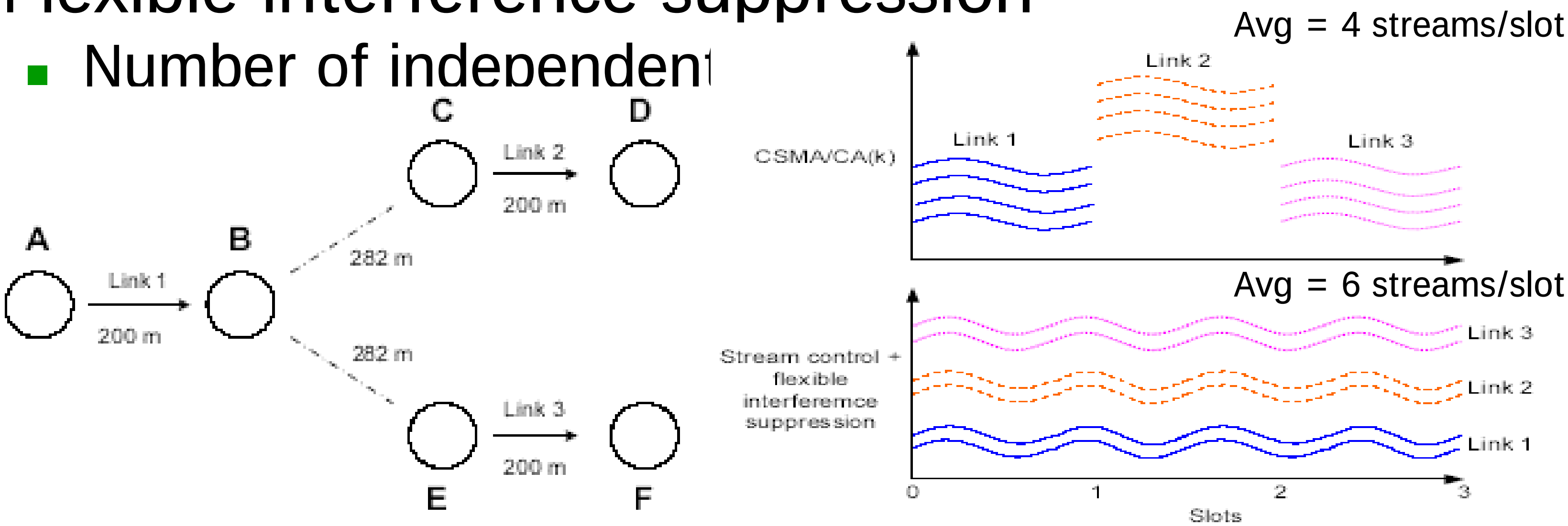




- Consideration 1: Multiple interfering links operating simultaneously using stream control achieve overall better throughput performance

Optimization considerations (2)

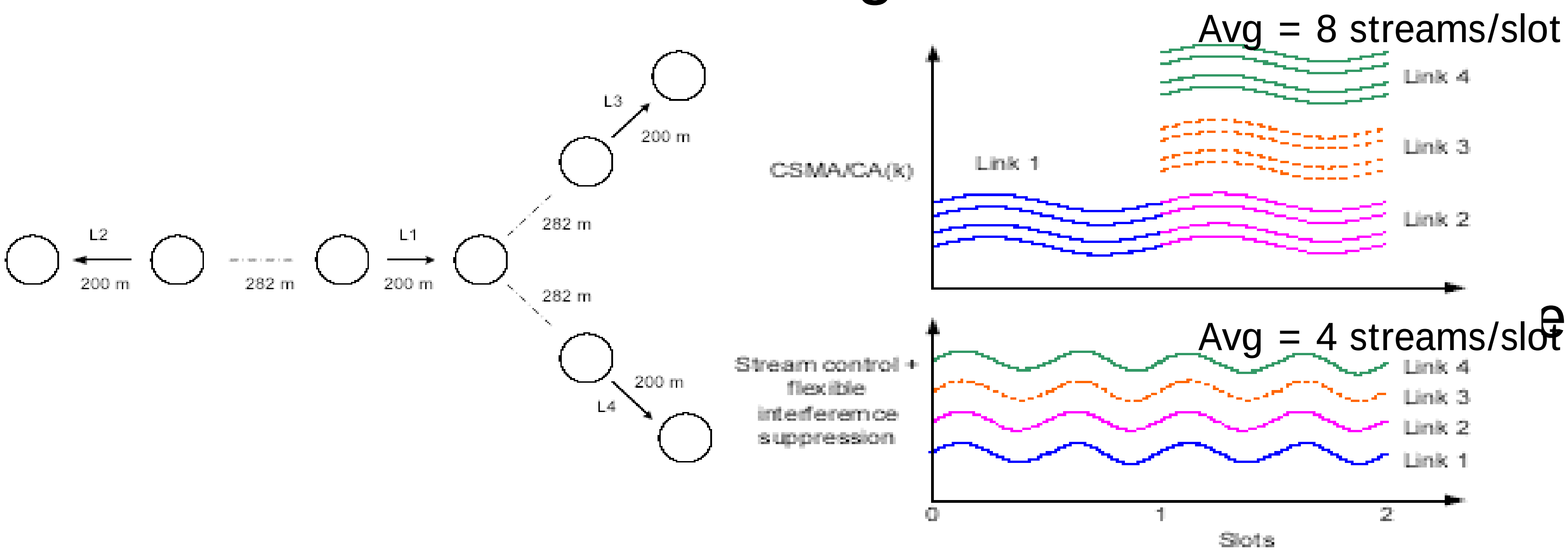
- Flexible interference suppression
  - Number of independent



- Consideration 2: Flexible interference suppression in conjunction with stream control helps create additional resources and hence additional gain

Optimization considerations (3)

- Passive receiver overloading



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

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  - 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

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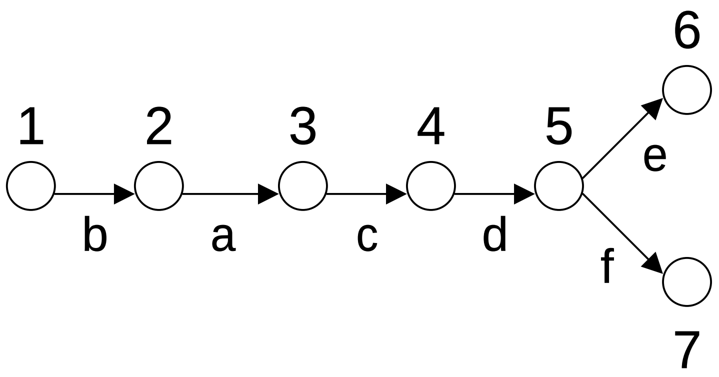
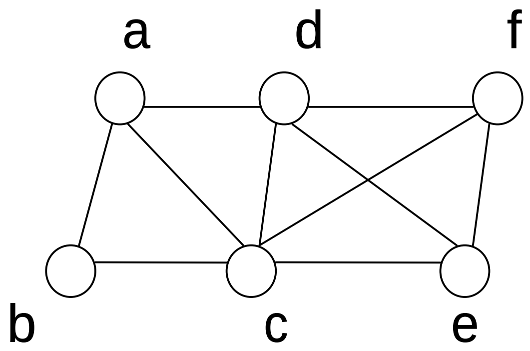
Components (1)

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



Node graph



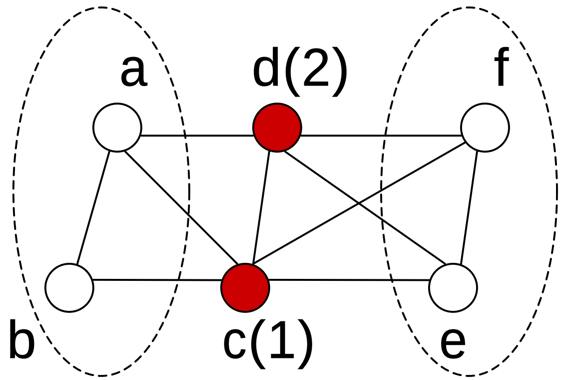
Flow contention graph

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

	a	b	c	d	e	f
Slot 1	0	0	4	0	0	0
Slot 2	0	4	0	4	0	0
Slot 3	2	2	0	0	2	2
Slot 4	2	2	0	0	2	2

Recap

- Step1: 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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