Optimization Based Rate Allocation and Scheduling in TDMA based Wireless Mesh Networks

Bo Wang, Matt Mutka, Eric Torng

CSE Department, Michigan State University

Outline

Introduction

System Model

Rate Allocation and Scheduling

Evaluation

Conclusion

Motivation

- TDMA based wireless mesh networks enable better QoS support
- Rate allocation should be supported by the underlying MAC protocol
- The coexistence of multicast and unicast traffic

Framework Overview

- A framework for both rate allocation and scheduling for multicast and unicast sessions in wireless mesh networks
- Contention graph is used to model the rate allocation and scheduling constraints
- Network Utility Maximization (NUM) based rate allocation
- Graph coloring based scheduling

Outline

Introduction

System Model

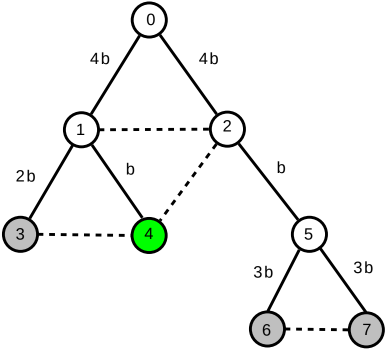
Rate Allocation and Scheduling

Evaluation

Conclusion

Routing Tree

- Downlink traffic from gateway node to mesh routers
- Use the "Weighted Connected Dominating Set" algorithm to construct a broadcast tree and then prune the tree to accommodate all the sessions



Session 0: node 0 to nodes 3, 6 and 7
Session 1: node 0 to node 4

Transmission Set

- A transmission consists of the following attributes
  - A sender
  - A list of recipients
  - The session carried by this transmission
  - Transmission rate used

Transmission ID	0	1	2	3	4	5
Sender	0	0	1	1	2	5
Recipient List	1, 2	1	3	4	5	6,7
Session List	0	1	0	1	0	0
Transmission Rate	4b	4b	2b	b	b	3b

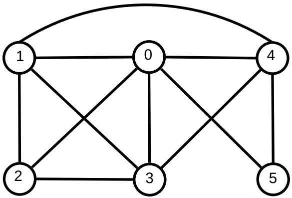
Table: Transmission Set Example

Contention Model

- Transmission i conflicts with transmission j if
  - Both transmissions share the same sender, or
  - Any recipient of transmission j is within the interference range of the sender of transmission i or vice versa

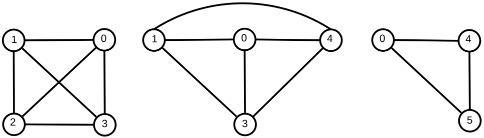
Contention Graph

- Vertex set contains all the transmissions
- An edge indicates that two transmissions conflict with each other



Clique and Independent Set

- A set of nodes is a clique if its induced subgraph is complete
- A maximal clique is defined as a clique that is not contained in any other clique
- An independent set is a set of nodes that are not connected by any edges



C1 C2 C3

Maximal Cliques

Scheduling Feasibility

- We consider periodic schedule which consists of time slots
- A vector of frequencies $\mathbf{f} = (f_1, ..., f_M)$ is feasible if there exists a schedule D such that the frequency of the ith transmission in schedule D is at least f_i
- A vector of frequencies $\mathbf{f}$ is clique feasible if

$$\sum_{i \in C_j} f_i \leq 1, \forall C_j \in C$$

Scheduling Feasibility (Cont'd)

- If the contention graph is a perfect graph, the clique feasibility is equivalent to scheduling feasibility of the frequency vector
- Assuming perfect contention graph, scheduling feasibility in terms of session rate

$$\mathbf{P}\mathbf{x} < 1$$

Chordal Graph

- Chordal graph is a type of perfect graph
- A graph is a chordal graph if it does not contain an induced k-cycle for $k \geq 4$
- Recognize a chordal graph: Lexicographic BFS algorithm with time complexity $O(m+n)$
- Transform a general graph to a chordal graph: LEX M algorithm with time complexity $O(mn)$

Why Chordal Graph

- Guarantee schedulability
- Facilitate efficient scheduling algorithm
- Linear time algorithm for obtaining the maximal cliques

Outline

Introduction

System Model

Rate Allocation and Scheduling

Evaluation

Conclusion

Least Overlapped First (LOF)

- LOF works with the original contention graph without triangulation
- At each step, LOF selects the independent set which has the maximum number of transmissions that do not intersect with the members of the existing schedule
- All sessions are assigned the same rate

Rate Allocation

- Cast the problem of rate allocation to the maximization of the total utility of the network
- Utility function $U_s(x_s) = r_s \ln(x_s)$, where r_s is the number of recipient of session s
- Utility maximization objective

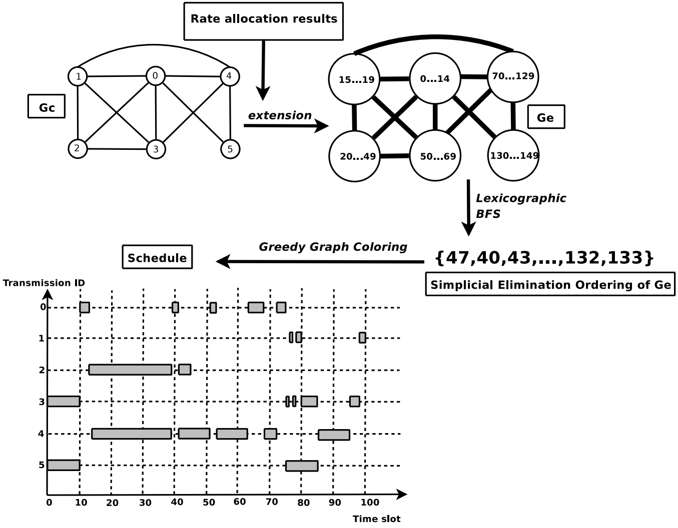
$$\max_{x_s \geq 0} \sum_{s \in S} U_s(x_s), \text{ subject to } \mathbf{Px} \leq 1$$

- Can be solved by using the Lagrange duality with worst-case polynomial-time complexity

Scheduling

- Graph coloring based scheduling: time slots are considered as colors to be assigned
- Greedy graph coloring is a heuristic algorithm with linear time complexity
- Greedy graph coloring algorithm is optimal for a chordal graph
- The rate allocation can be supported by the scheduling algorithm

Optimal Graph Coloring Illustration



Outline

Introduction

System Model

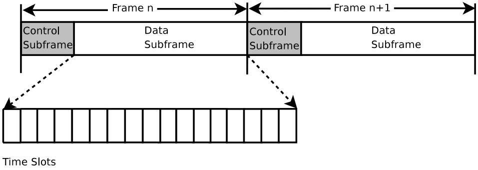
Rate Allocation and Scheduling

Evaluation

Conclusion

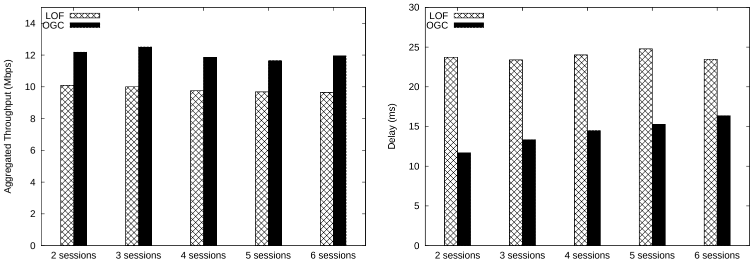
Simulation Setup

- NS2 simulator
- Flat area with 30 mesh routers and one gateway node
- TDMA MAC protocol similar to IEEE 802.16
- Gateway node performs rate allocation and establishes the network wide schedules



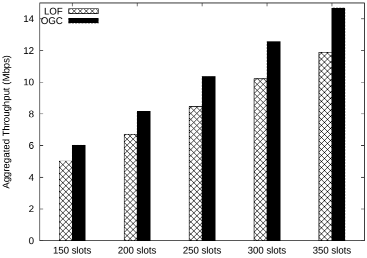
Simulation Results

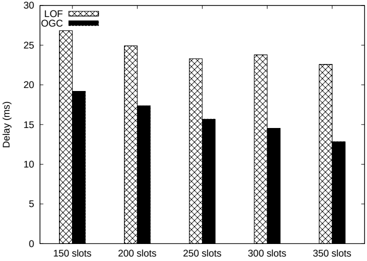
- Vary the number of sessions in the networks
- Throughput and delay comparisons



Simulation Results (Cont'd)

- Vary the number of time slots allocated for downlink data traffic
- Throughput and delay comparisons





Outline

Introduction

System Model

Rate Allocation and Scheduling

Evaluation

Conclusion

Conclusion

- Chordal contention graph to model resource allocation constraints
- Fair and efficient rate allocation to multicast and unicast sessions
- Graph coloring based scheduling with low time complexity

Questions

- Thank you for your time and attention!