Designing Multihop Wireless Backhaul Networks with Delay Guarantees

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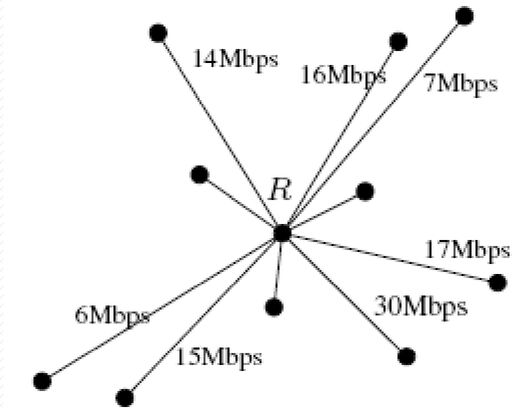
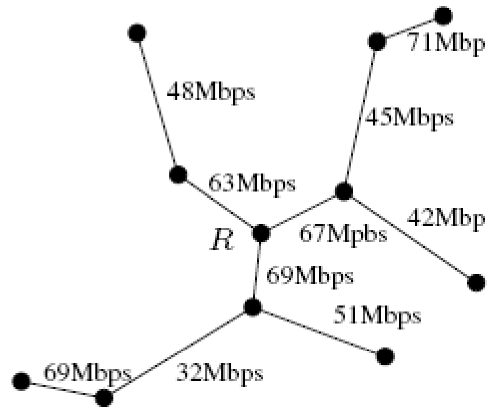
Outline

- Introduction
- Network Model
- A Generalized Link Activation Framework
- Routing
- Simulation Results
- Conclusions

Introduction

- With the technical improvements and standardization of long-haul, non-line-of-sight (NLOS) wireless technologies such as WiMAX, wireless backhaul is fast becoming a cost effective alternative to wired technologies.
- However, several challenges remain in allowing multihop wireless backhaul networks to match the throughput and delay guarantees of wired backhauls.





Network Model

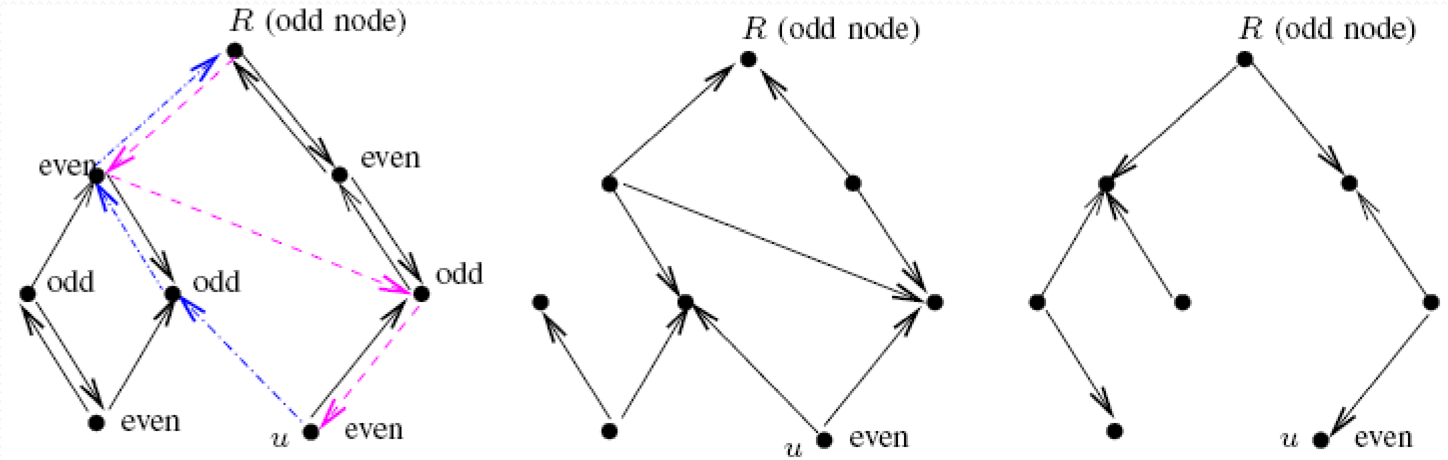
- *Physical layer*
  - WiMAX standard
- *Interference Model*
  - separate links in the backhaul may interfere with each other
- *The Backhaul Design Problem*
  - self-interference
  - cross-link interference

A Generalized Link Activation Framework

- The goal of link activation framework is to enable local scheduling of packets such that interference is avoided.
  - *Even-Odd Link Activation*
- Then describe conditions for admissible traffic that ensure that the backhaul network is not overloaded.
  - *Admissible Traffic and Subchannel Assignment*

Even-Odd Link Activation

- Each node has been labeled as either an *even* or an *odd node.*
  - This labeling is performed by the routing phase.
- The Even-Odd scheduling framework uses a simple link activation scheme: each directed link is active every alternate timeslot.



Admissible Traffic and Subchannel Assignment

- node constraint

$$\begin{cases} \sum_{e \in E_{in}(v)} w(e) & \leq & 1 \\ \sum_{e \in E_{out}(v)} w(e) & \leq & 1. \end{cases} \quad \forall v \in V$$

- Link constraint

$$F(e) \quad \leq \quad C(e) \cdot w(e)/2 \qquad \forall e \in E$$

- the connections are *admissible in the Even-Odd* scheduling framework if

$$\begin{cases} \sum_{e \in E_{in}(v)} \frac{F(e)}{C(e)} & \leq & 1/2 \\ \sum_{e \in E_{out}(v)} \frac{F(e)}{C(e)} & \leq & 1/2. \end{cases} \quad \forall v \in V.$$

Routing

- ILP Formulation
  - PathsOpt ILP
- Heuristics
  - Modified Dijkstra's algorithm
  - MinMax+SP
  - MinMax

PathOpt ILP

Maximize α;

Subject to:

(i) For $w \in V, i \in \Omega$,

$$\sum_{v \in V}(F_i(v,w) - F_i(w,v)) = \begin{cases} -\alpha f_i & \text{if } w = s(i) \\ \alpha f_i & \text{if } w = t(i) \\ 0 & \text{if } w \neq s(i), t(i) \end{cases}$$

(ii) For $e \in E, i \in \Omega, x_i(e) \leq x(e)$

(iii) For $e \in E, i \in \Omega, F_i(e) \leq x_i(e) \cdot C(e)/2$

(iv) For $v, w \in V, x(v,w) + \pi(v) + \pi(w) \leq 2$

(v) For $v, w \in V, \pi(v) + \pi(w) \geq x(v,w)$

(vi) For $v \in V, i \in \Omega, \sum_{w \in V} x_i(v,w) \leq 1$

(vii) For $((u_1,v_1),(u_2,v_2)) \in \mathcal{I}$,
$\pi(u_1) + \pi(u_2) \geq x(u_1,v_1) + x(u_2,v_2) - 1$

(viii) For $((u_1,v_1),(u_2,v_2)) \in \mathcal{I}$,
$\pi(u_1) + \pi(u_2) \leq 3 - x(u_1,v_1) - x(u_2,v_2)$

(ix) For $v \in V$, $\sum_{e \in E_{in}(v), i \in \Omega} \frac{F_i(e)}{C(e)} \leq \frac{1}{2}$

(x) For $v \in V$, $\sum_{e \in E_{out}(v), i \in \Omega} \frac{F_i(e)}{C(e)} \leq \frac{1}{2}$

- (i): the standard conservation of flow constraints for each connection
- (ii): guarantees that *x(e) = 1 if link e is selected for at least one* connection
- (iii): guarantees that the bit rate of connection *i on links that are not selected for i is 0*
- (iv), (v): guarantee that selected links are between nodes with different parities
- (vi): guarantees that each connection remains on a single path
- (vii), (viii): ensure that any pair of interfering links that are both selected must be assigned different parities
- (ix), (x): ensure that the admissibility conditions are satisfied

Modified Dijkstra's algorithm

- Dijkstra's algorithm iteratively constructs a shortest path tree from the root *R*.
- At any stage of the algorithm there is a partial tree *T' and we find the shortest edge from T' to* some node not in *T'*.
  - directed versions of the edge will not interfere with any directed version of any edge already in *T'*
  - use 1/*C(e) as the distance along link e*

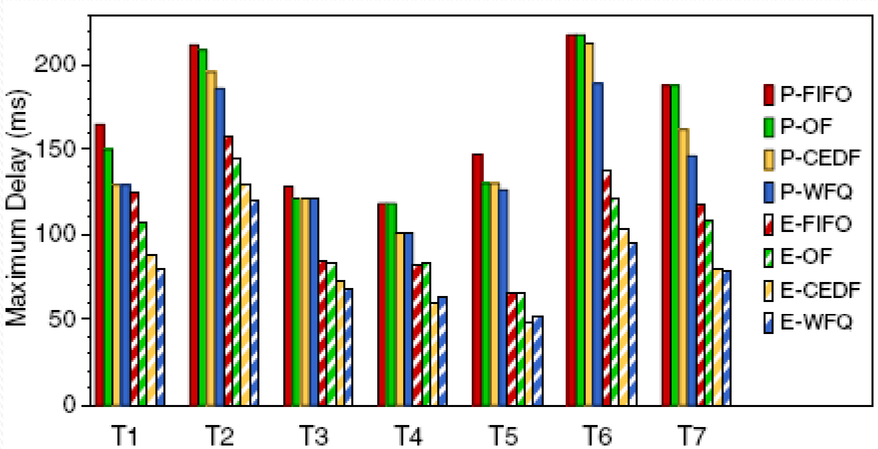
MinMax+SP

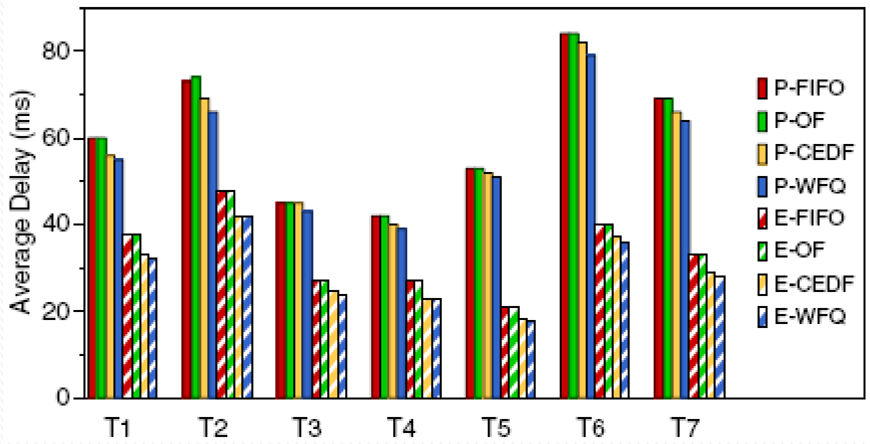
- Order the nodes by increasing length of their shortest path to *R*.
- Then for each node *v in order do the following.*
  - Route the connection from *v to R along the path* whose resulting maximum node load is minimum among all possible paths.
  - Update the node loads accordingly.

MinMax

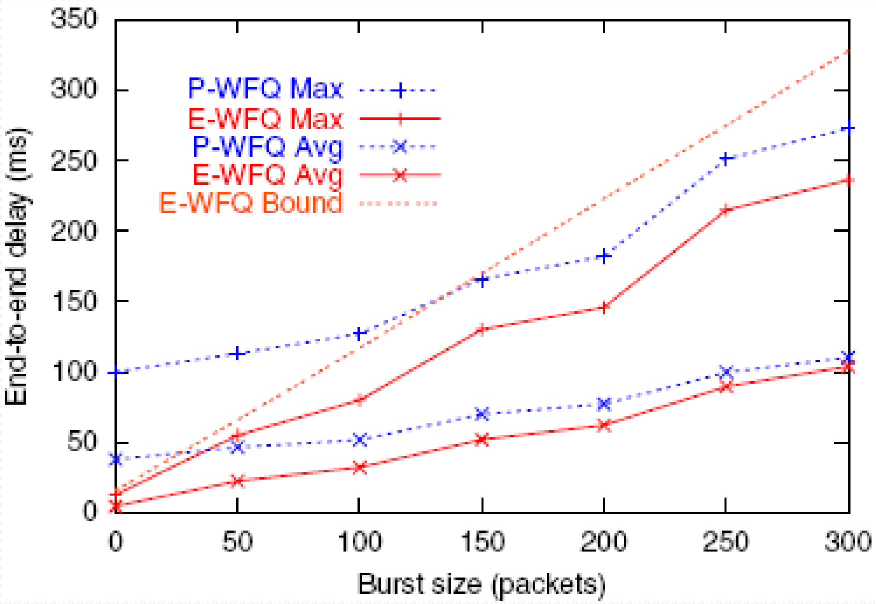
- similar to the first except
- The order in which connections are routed is not fixed from the start.

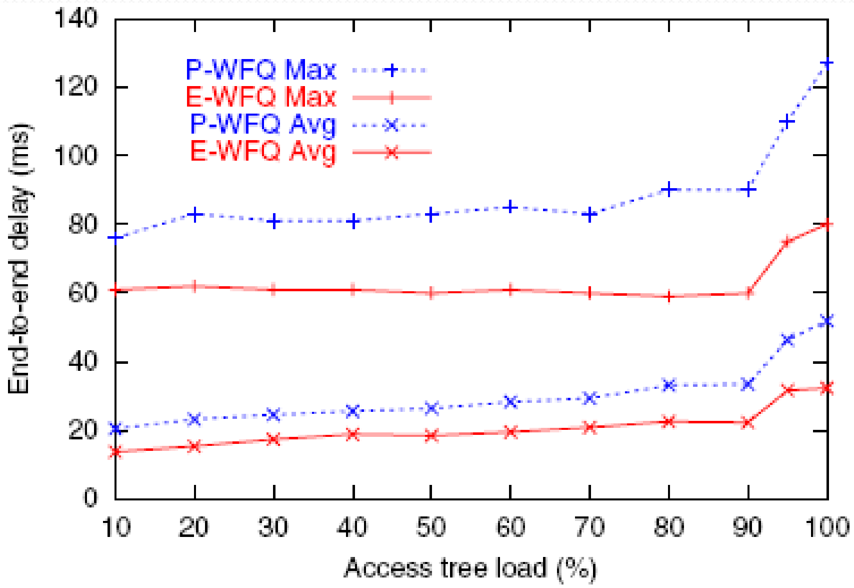
Simulation Results





Simulation Results





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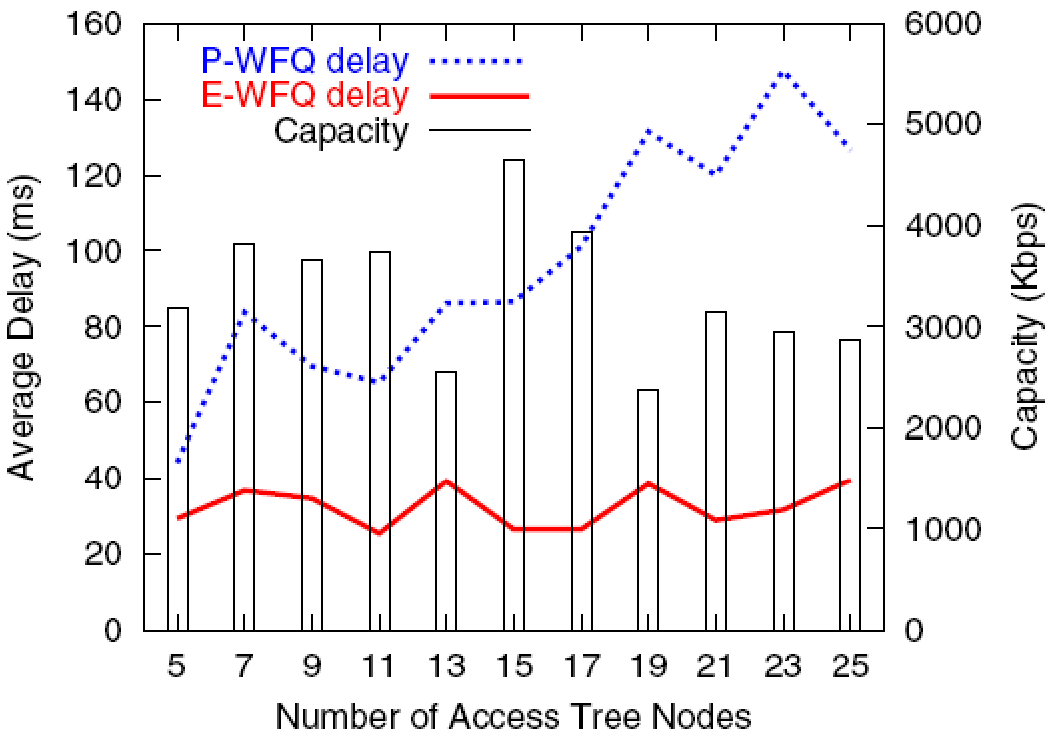

Conclusions

- The authors provide a simple yet generalized link activation framework, which we call the Even-Odd framework, for scheduling packets over this wireless backhaul.
- And present an optimal formulation as well as heuristic approaches to constructing efficient backhaul routes.