A Utility-based Framework for Joint Channel, Topology, and Routing Control in Wireless Mesh Networks

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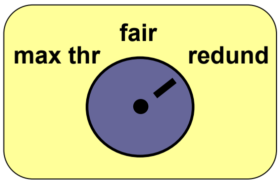
EU-MESH: Enhanced, Ubiquitous, and Dependable Broadband Access Using MESH Networks
FP7 ICT-215320 - www.eu-mesh.eu

Outline

- Motivation: Flexibility
- Problem and contribution, prior work
- Joint channel assignment & topology control
  - Objectives: utility functions of throughput
- Modules:
  - Channel assignment
  - Throughput estimation
- Experiments: linear and grid scenarios
- Joint channel, topology and routing control
  - Multipath routing
  - Capturing contention

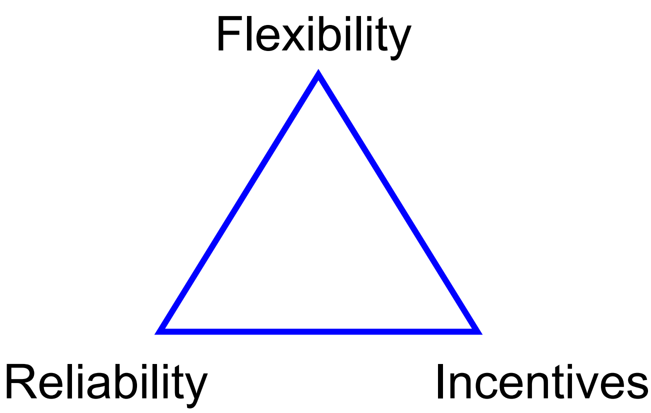
Flexibility

- Network's ability to operate with different target objectives or goals, e.g.
  - maximize throughput
  - fairness
  - redundancy



- Different from self-configurability, self-management, self-healing
  - self=automated, single target objective
- Flexibility also refers to aspects such as deployment flexibility (e.g. mesh networks)

Three issues key to design and operation of wireless access networks:



Flexibility: Why?

- Different providers ⇒ different operation objectives/policies
- Different applications ⇒ different requirements
  - Failed many times to predict future apps
- Economics: Same infrastructure/system components used to build different networks
- Throughput not always most important
  - Availability & consistency can be more important
  - Even if we improve thruput >20%, let alone 1% !

Flexibility and Open Systems

- Flexibility also important from industrial perspective
- Open access networks can trigger innovative applications
- Vyatta, Cisco, and Juniper open router OS
- Open mobile OSs: Apple's iPhone, Google's Android, Nokia's Symbian, LiMo

ANDROID

LiMo Foundation

SYMBIAN

How to achieve Flexibility

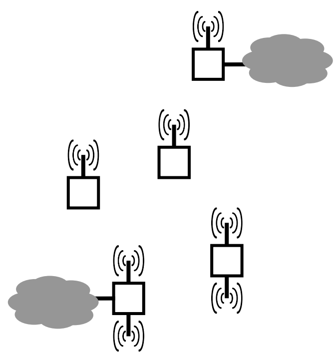
- Adaptive mechanisms (channel, power scheduling)
- Multiple channels/frequencies
- Adaptive topologies
- Adaptive routing
- Exploit multiple gateways

} wireless multi-hop & multi-gateway (e.g. mesh)

- *Selectable intelligence*

Joint Channel Assignment & Topology Control

- Model
  - network of mesh nodes with one or more interfaces
  - some mesh nodes connected to fixed network (gateways - GWs)
- Problem: assign channels to achieve some target objective
  - multi-objective



Prior work

- Assume node connectivity known a priori, or assume full connectivity, or assume common channel assigned to all nodes
- Objective to minimize interference, while maintaining some connectivity, or no explicit objective
  - some work jointly considers scheduling: objective min # of transmissions or max # of simultaneous transmissions
- Do not account for different transmission rates
- Typically based on heuristics
  - Order (rank) interfaces or links: based on traffic load, distance from GW, etc
  - Greedily assign channels to interfaces with decreasing rank: assign "best" channel to each interface

Flexibility for Channel & Topology Control

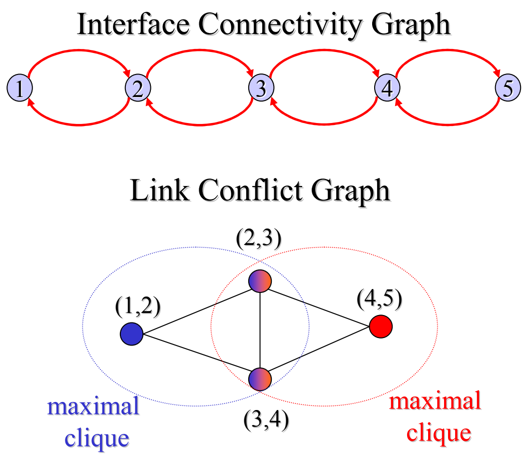
- Node/interface connectivity not known a priori
  - jointly perform channel assignment & topology control
  - ensures connectivity to gateway for all nodes
- Channel assignment based on different objectives
  - objectives expressed as utility functions of throughput
  - throughput estimation accounts for rate diversity
- *Different utility functions* result in *different channel assignments*
  - aggregate throughput
  - fairness in allocation of throughput among node pairs
  - redundancy: multiple links with different interfaces

PHY and MAC models

- PHY model
  - trans. rate function of SINR, receiver sensitivity & noise
  - signal attenuation
  - interference = sum of all interferers
  - adjacent (non-orthogonal) channel interference model
- MAC model
  - fair channel sharing
  - no collisions
  - saturated conditions
  - access time inversely proportional to trans. rate

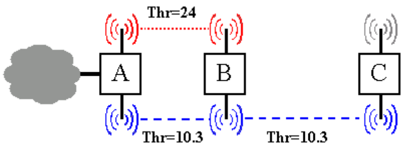
Link throughput estimation

- All links of a maximal clique have equal throughput share
- Links belonging to more than one cliques are assigned throughput of most congested clique
- Congestion in maximal clique depends on
  - Link transmission rate
  - Number of links
- Perform max-min sharing of remaining resources

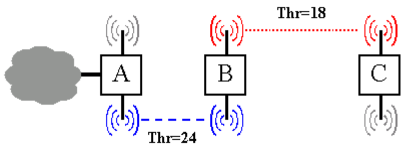


Comparison of objectives

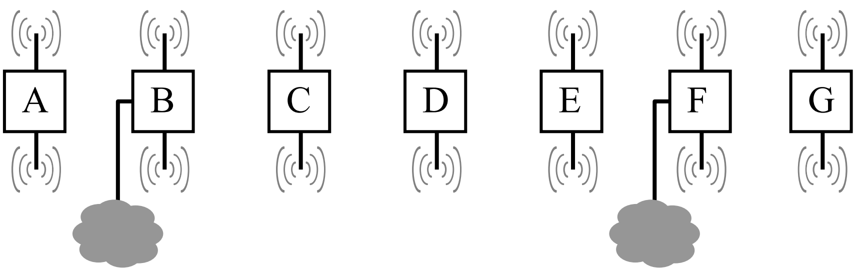
- Throughput objective:
  Thr_{A-B}=34.3, Thr_{B-C}=10.3
  Thr_{total}=44.3



- Fairness objective:
  Thr_{A-B}=24, Thr_{B-C}=18
  Thr_{total}=42



Linear 7 node / 2 GW



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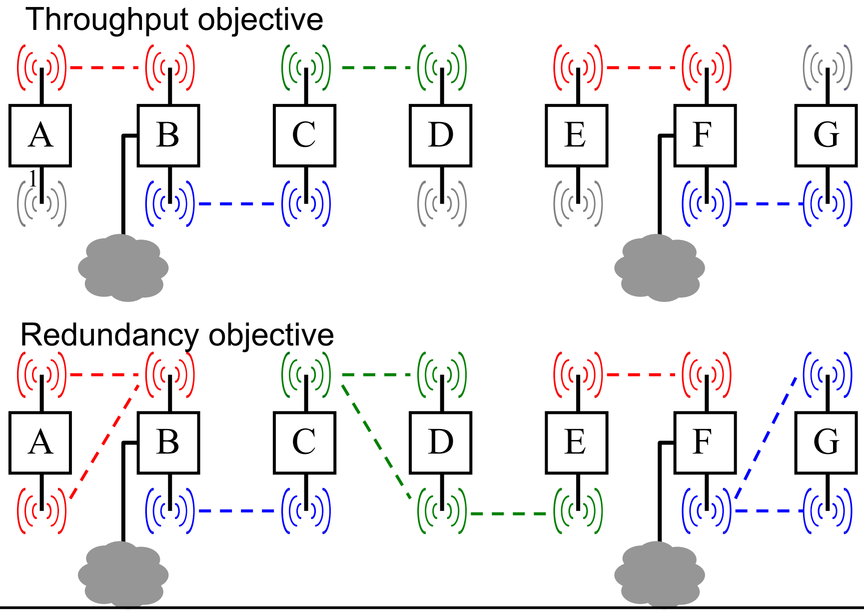
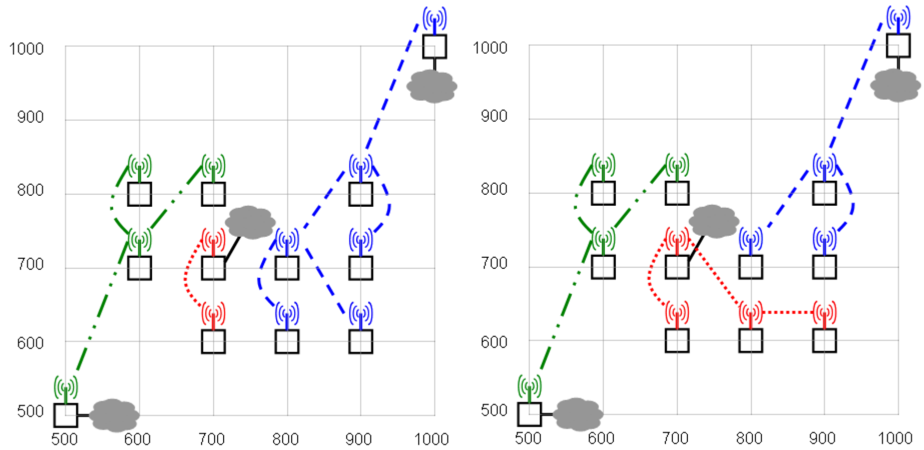


Grid scenario



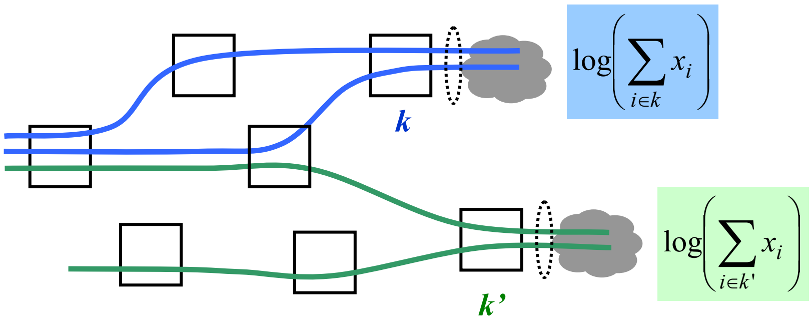
Throughput objective

Fairness objective

Load Balancing across Gateways

$$\text{Aggregate Utility} = \sum_{k \in G} \log\left(\sum_{i \in k} x_i\right)$$

- G: set of gateways
- $i \in k$: route from node i goes through gateway k



Multipath routing

- Can improve both efficiency and reliability
  - address channel errors and interference
- *Why not use all available paths?*
  - different pkt delays can be a problem
  - more paths not always better:

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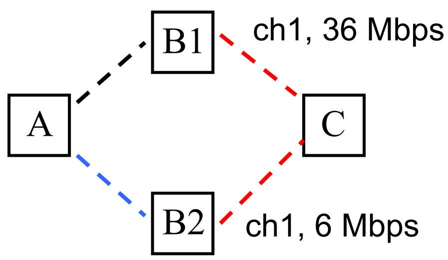


Top path A-B1-C only:

$$Thr \approx 36 - oh$$

Both paths:

$$Thr' \approx \frac{1}{\frac{1}{36} + \frac{1}{6}} - oh'$$

First attempt at Reliability-only Multipath Metric

- End-to-end reliability of k paths:

$$\text{E2e Reliability} = 1 - \prod_{k \in K} (1 - q_k)$$

where q_k reliability of path k (p_l failure prob of link l):

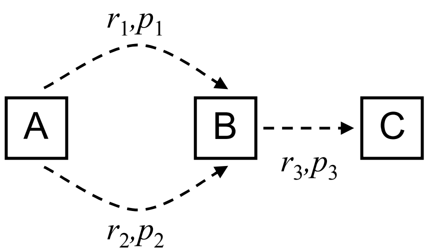
$$q_k = \prod_{i \in k} (1 - p_l)$$

- Assumes link disjointness, among others

Multipath routing metrics

- Account for contention and interference between wireless links
  - contention when operating on same channel
  - interference when operating on adjacent channels
- Account for both capacity and error/failure probabilities
  - short-term errors
  - long-term failures
  - link/node disjointness

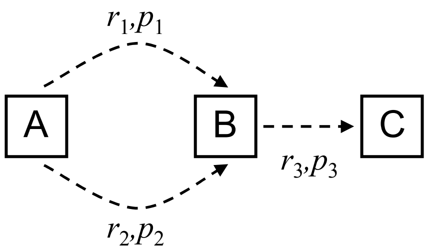
Multipath routing metrics (cont.)



- Average Throughput (p's are error probs)

$$AT = \min\big((1-p_1)r_1 + (1-p_2)r_2, (1-p_3)r_3\big)$$

Multipath routing metrics (cont.)



- Average Throughput (p's are error probs)

$$AT = \min\big((1-p_1)r_1 + (1-p_2)r_2, (1-p_3)r_3\big)$$

- Average Available Capacity (p's are failure probs)

$$AAC = (1-p_1)p_2(1-p_3)\min(r_1, r_3) + p_1(1-p_2)(1-p_3)\min(r_2, r_3) + (1-p_1)(1-p_2)(1-p_3)\min(r_1 + r_2, r_3)$$

Capturing MAC Contention

- Upper bound for throughput of link i

$$x_i = \frac{L_i}{\sum_{j \in N_i} \frac{L_j}{R_j}}$$

  - Ni: set of links interfering with i (including i)
  - Rj: j's transmission rate
  - Lj: j's packet size

- Assumption: Saturated transmitters, fair MAC sharing

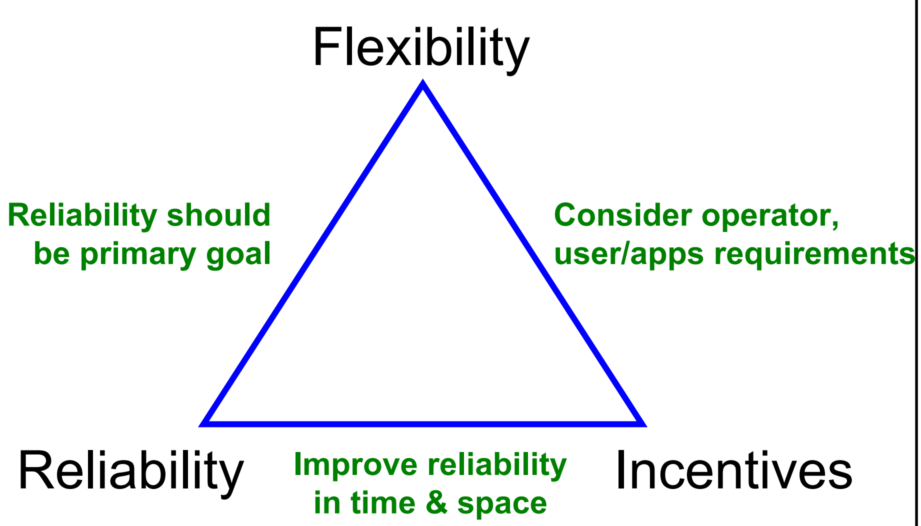
CATT: Contention-Aware Transmission Time

- CATT metric for link l: packet transmission time estimate based on throughput approximation

$$CATT_l = \sum_{j \in N_l} \frac{L_j}{R_j}$$

  - CATT captures influence on link l of all transmitters that interfere with l
  - Both inter- and intra-flow interference
- Cost W of path p

$$W_p = \sum_{l \in p} CATT_l$$



Thank You!

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