Efficient Resource Management in Wireless Mesh Network

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EU-MESH
Enhanced, Ubiquitous, and Dependable Broadband Access using MESH Networks, FP7 ICT-215320
COOPERATION

EU-MESH Project

- FP7 ICT-1-1.1, Call 1 (May 2007)
- Start date, duration: 1 Jan 2008, 30 months
- 9 partners from 7 EU member states:

FORTH-ICS
Consiglio Nazionale delle Ricerche
Technische Universität Berlin
SUPSI Scuola Universitaria Professionale della Svizzera Italiana
MŰEGYETEM 1782
PROXIMETRY
THALES
forthnet
ozone

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Partners

1. Foundation for Research and Technology – Hellas (FORTH), GR: ***Coordinator***
2. National Research Council (CNR), IT
3. Technical University Berlin, DE
4. SUPSI, CH
5. Budapest University of Technology & Economics (BME), HU

} Research/ Academic

6. Proximetry Poland, PL } SME, wireless mgmt software
7. Thales, FR } Systems integrator/manufacturer
8. Hellenic Telecommunications and Telematic Applications Company (Forthnet), GR
9. Ozone, FR

} Telecom/wireless provider

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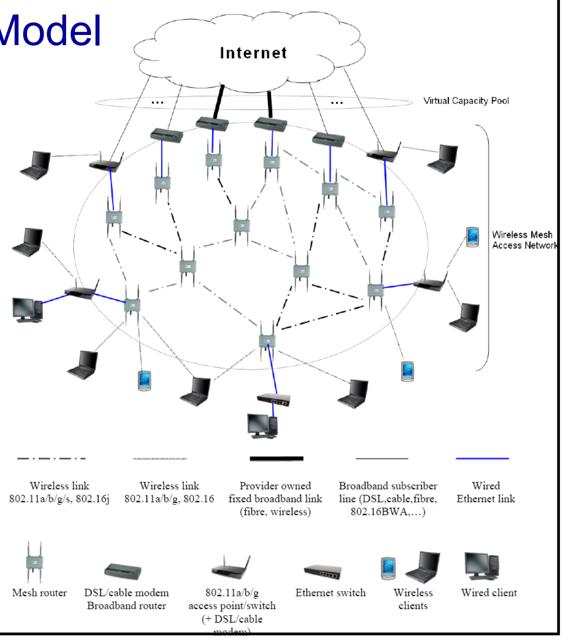
EU-MESH Network Model

- Wireless mesh network provides access to virtual capacity pool
- Virtual capacity pool aggregates capacity from many subscriber & provider links
- Access for stationary and mobile users
- Support for QoS, dependability, and security



Objectives and key issues

- *Develop*, *evaluate*, and *trial* a system of *software modules* for building *wireless multi-radio multi-channel mesh networks* that
  - support scalable end-to-end QoS while efficiently utilize wireless spectrum and control interference
  - enable fast deployment and reduce management complexity and cost, while providing dynamic and reliable connectivity
  - support enhanced proactive & reactive security, and seamless mobility based on cross-layer monitoring in single and multi-operator environments
  - seamlessly integrate mesh networks with fixed technologies to provide pervasive ultra-high capacity broadband access to both stationary and mobile users, through a converged infrastructure
- Implement and evaluate system in two existing metropolitan scale deployments (Paris and Heraklion)

Jointly consider QoS, mobility, and security

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Key Research & Technical Achievements

- Requirements and Architecture (WP2)
  - Technical requirements and functionalities considering jointly QoS, mobility, and security
  - Initial design of cross-layer architecture
- Mesh Configuration and Link Control (WP3)
  - Hybrid channel access scheme for interference reduction
  - Initial design of auto-configuration & self-healing procedures
  - Initial design of real-time, technology independent cross-layer monitoring system
  - Dynamic approximation of mesh nodes' coverage

Research & Technical Achievements (cont.)

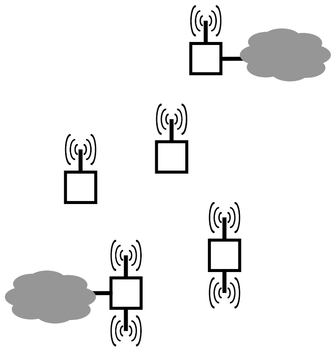
- Resource, QoS, and Mobility Mgmt (WP4)
  - *Channel assignment in metropolitan mesh networks and utility-based joint channel assignment & topology control*
  - *Congestion-aware routing metrics capturing contention, rate diversity, and interference*
  - Queuing theoretic network model for capacity estimation in multi-homed mesh networks
- Security (WP5)
  - Framework for secure link-state routing protocol
  - Authentication supporting fast handover in multi-operator environment and continuous access control enforcement
  - Route segment protection scheme based on IPsec
  - Anomaly-based intrusion detection for jamming attacks

Rest of this talk

- Joint channel assignment & topology control
  - flexibility in having different target objectives
- Channel assignment in metropolitan networks
  - timescales of channel assignment and rate control
- Contention aware routing
  - inter- and intra-flow contention

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

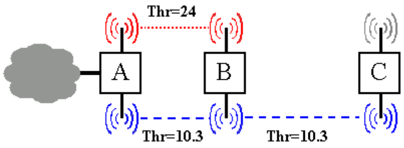


Flexibility for Channel & Topology Control

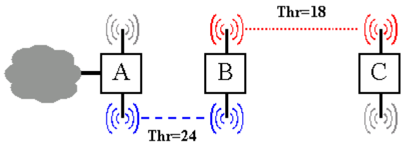
- Node/interface connectivity not known a priori
  - jointly perform channel assignment & topology control
  - ensures connectivity to gateway for all nodes
- Channel assignment based on different objectives
  - objectives expressed as utility functions of throughput
  - throughput estimation accounts 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

Comparison of objectives

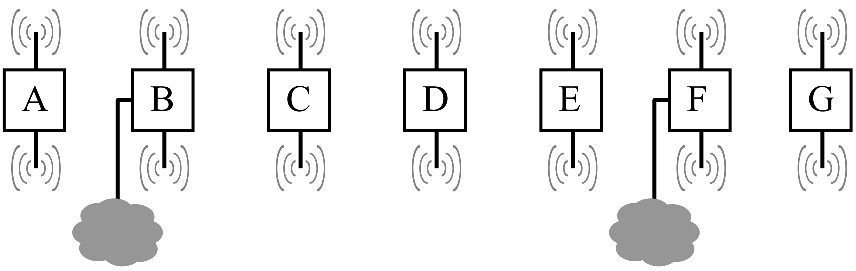
- Throughput objective:
  $Thr_{A-B}=34.3$, $Thr_{B-C}=10.3$
  $Thr_{total}=44.3$



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

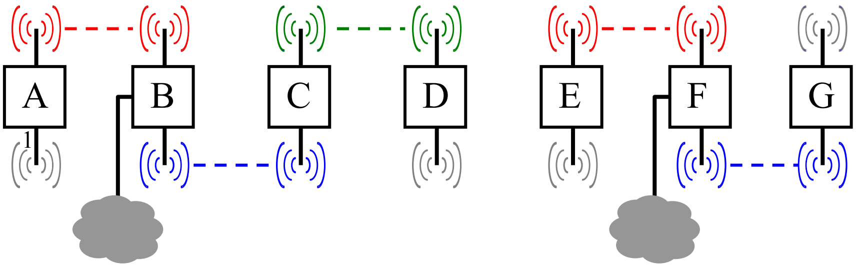


Linear 7 node / 2 GW

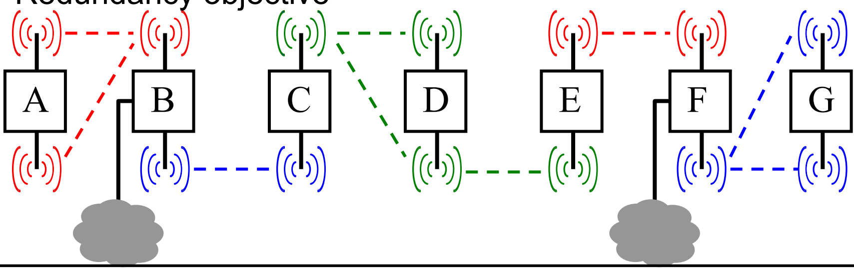


Linear 7 node / 2 GW

Throughput objective



Redundancy objective



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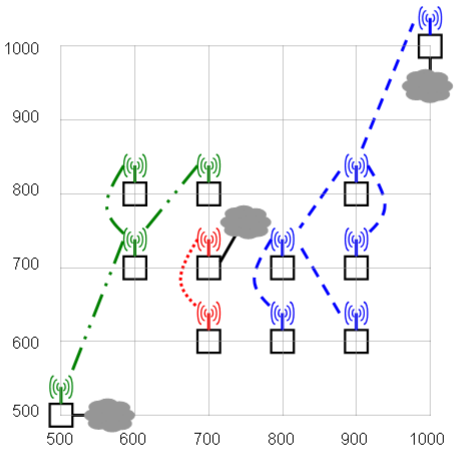
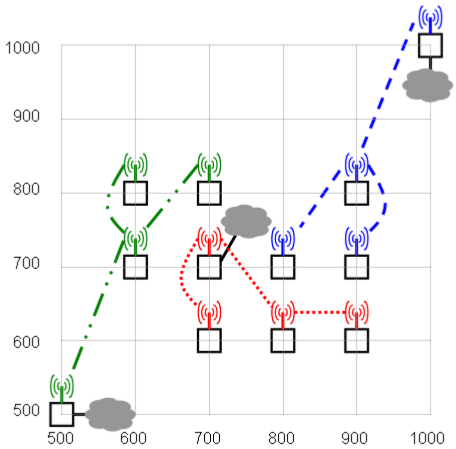
Grid scenario



Throughput objective



Fairness objective

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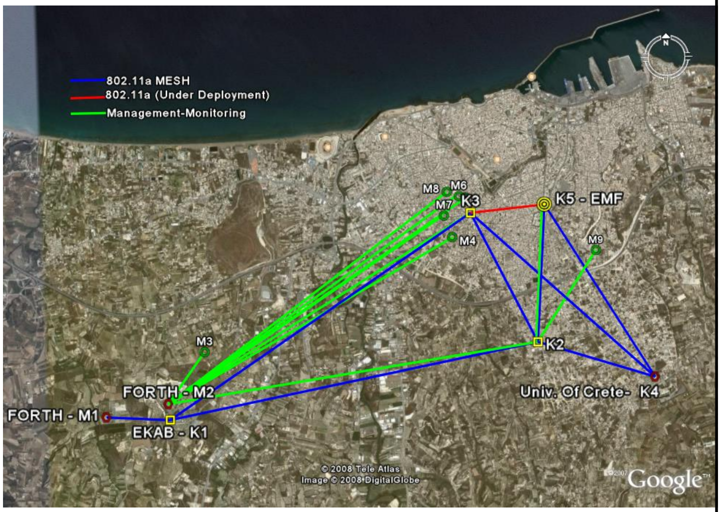
Heraklion Metropolitan MESH Test-bed

- 60 Km² coverage
- 14 nodes, 5 core multi-radio nodes
- 1.6 – 5 Km links
- Antennas: 19/21/26 dBi panel
- Three fixed network connections (FORTH & UoC)
- Independent mgmt / monitoring network



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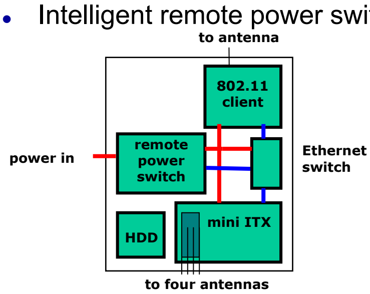
Multi-radio mesh node

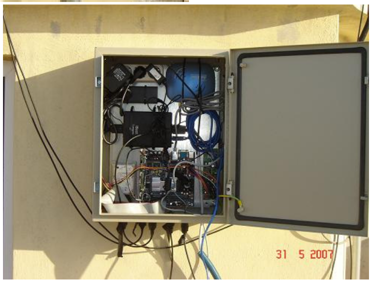
- Mini-ITX board (EPIA SP 13000, 1.3 GHz C3, 512 MB ram)
- Four mini PCI Atheros-based 802.11a/g wireless cards
- Gentoo 2006 i686 Linux (2.6.18), MadWiFi version 0.9.2
- OLSR deamon version 0.4.10
- Independent 802.11a client for management/monitoring
- Intelligent remote power switch



Component layout

Actual node

Actual deployment pictures



Channel assignment algorithm

interference model
- multi-point link conflict graph
- measurement-based interference estimation using test-traffic

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link ordering
- distance from fixed network gateway
- increasing SNR
- random

↓

channel selection metric
- one-way SNR
- two-way SNR
- two-way packet delay

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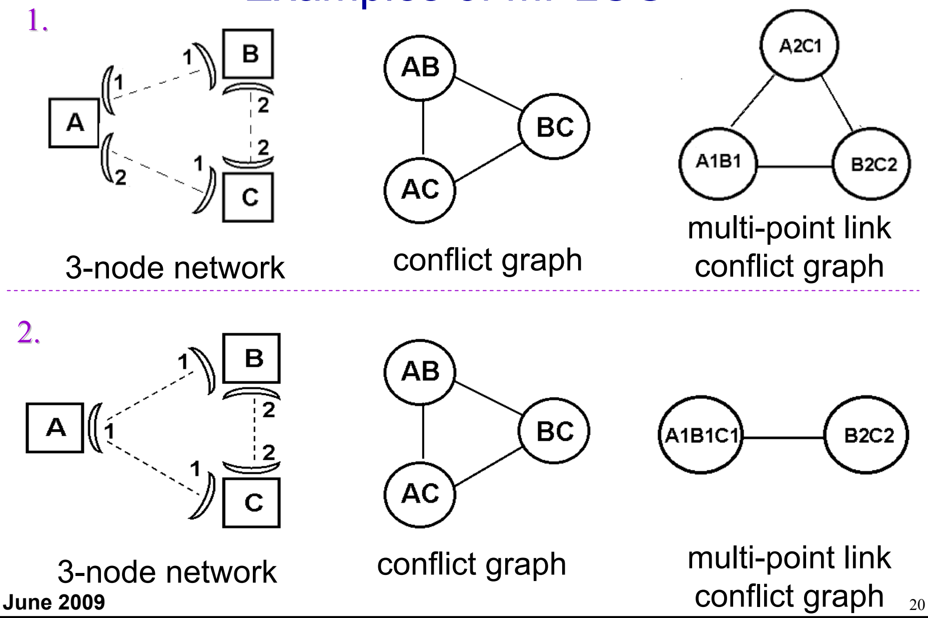
Multi-Point Link Conflict Graph - MPLCG

- Conflict graph for modeling intra-network interference
  - vertices correspond to a link between two nodes
  - in multi-radio nodes with directional antennas, not all interfaces equivalent
- New proposal: Multi-Point Link Conflict Graph
  - vertex represents a multi-point communication link - set of two or more interfaces belonging to different nodes
  - edge between two vertices indicates that the two corresponding links interfere with each other
  - requires a priory knowledge of the communication graph which identifies the interfaces that will communicate with each other

Examples of MPLCG



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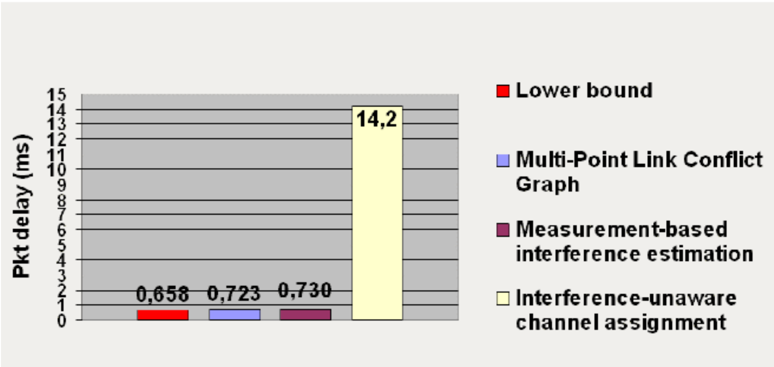
Comparison with lower bound and interference unaware approach



- MPLCG, measurement-based interference estimation: avg pkt delay approximately ***11%*** higher than lower bound
- interference-unaware scheme: ***20 times*** higher avg delay

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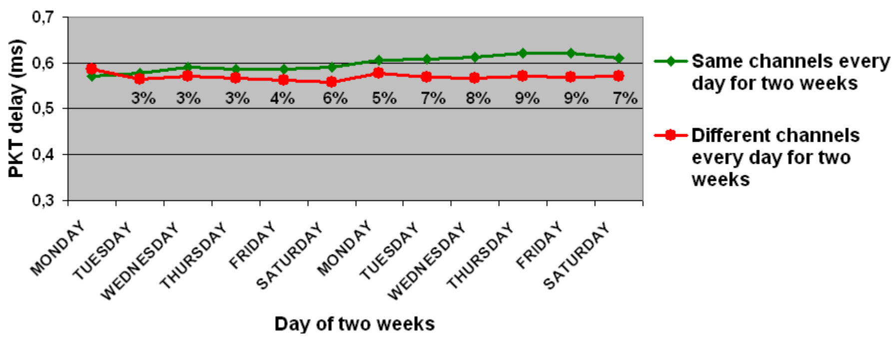
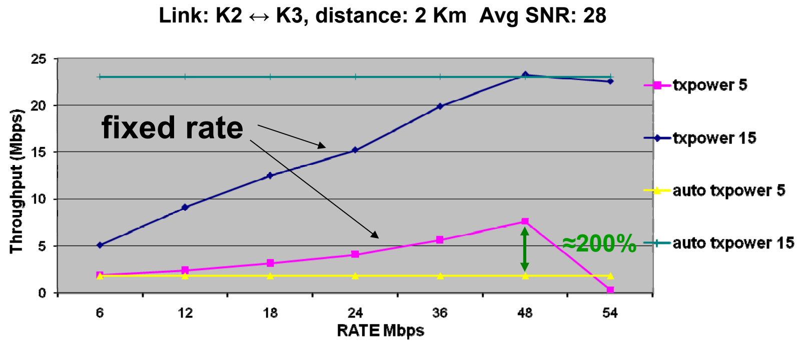
Same and different channels for two weeks



- fixed channel assignment for up to two weeks remains close to channel assignment performed every day
- for time interval of two weeks channel assignment should not be updated

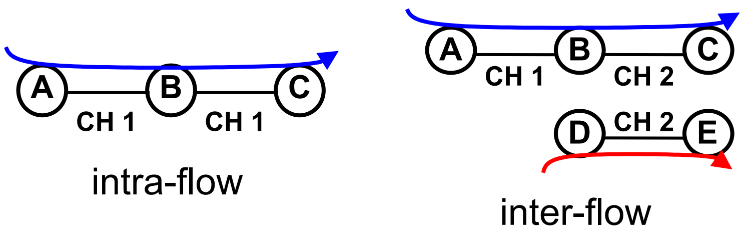
Rate control in metropolitan links



- Low SNR: fixed-rate can achieve significantly higher throughput compared to auto-rate
- High SNR: fixed-rate & auto-rate achieve same performance

Routing metric in multi-rate WMNs

- Isotonicity: necessary property of routing metric to apply Dijkstra algorithm & hop-by-hop routing
- Contention: intra-flow and intra-flow



- Contention level depends on # of flows and transmission rate

Approximation for maximum throughput

- Upper bound for throughput at transmitter i

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

  - Ni: set of transmitters interfering with i (including i)
  - Rj: j's transmission rate
  - Lj: j's packet size
- Assumption: Saturated transmitters, fair MAC sharing
  - extensions to address these

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

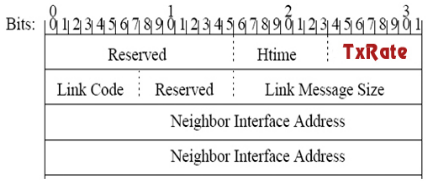
$$W_p = \sum_{l \in p} CATT_l$$

CATT implementation in OLSR

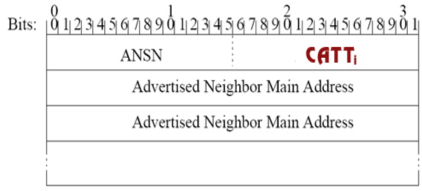
- Assume same pkt size

$$CATT_l = \sum_{j \in N_l} \frac{1}{R_j}$$

- OLSR (Optimized Link State Routing) has two types of messages
- Mesh node obtains TxRate from wireless driver
- Node broadcasts TxRate in Hello messages
- Node computes CATT metric
- Node broadcasts CATT metric in TC messages



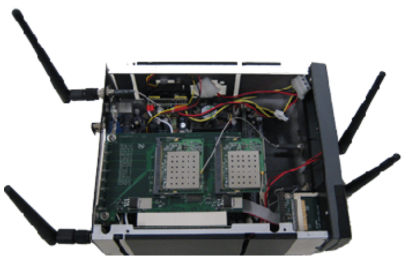
Hello msg header



TC msg header

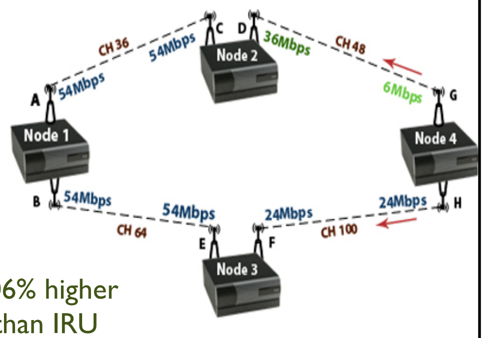
Wireless multi-radio mesh test-bed

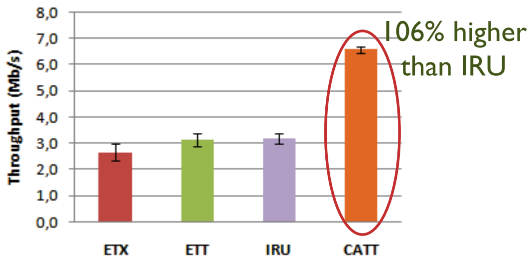
- 6 (now 14) four-radio nodes
- Mini-ITX (VIA EPIA Nehemiah M10000G) with 1GHz, 512 MB (DDR400)
- MikroTik Router BOARD 14 4 MiniPCI to PCI adapter
- 4 High Power Super A/G Atheros 802.11a/b/g
- Ubuntu 7.04 Linux kernel 2.6.20-16-generic, MadWiFi 0.9.3.1
- OLSR daemon 0.4.10



Asymmetric link scenario: constant rate traffic

- ETT, ETX & IRU mostly select path 1-2-4: Rate on D is higher (36Mbps) than F (24Mbps)
- CATT captures the interference due to low rate of interface G (6Mbps)





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