Challenges in designing wireless mesh networks to support high bandwidth-demanding applications

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Carrier Grade Wireless Mesh Networks
June, 9th 2009
Santander, Spain

Outline

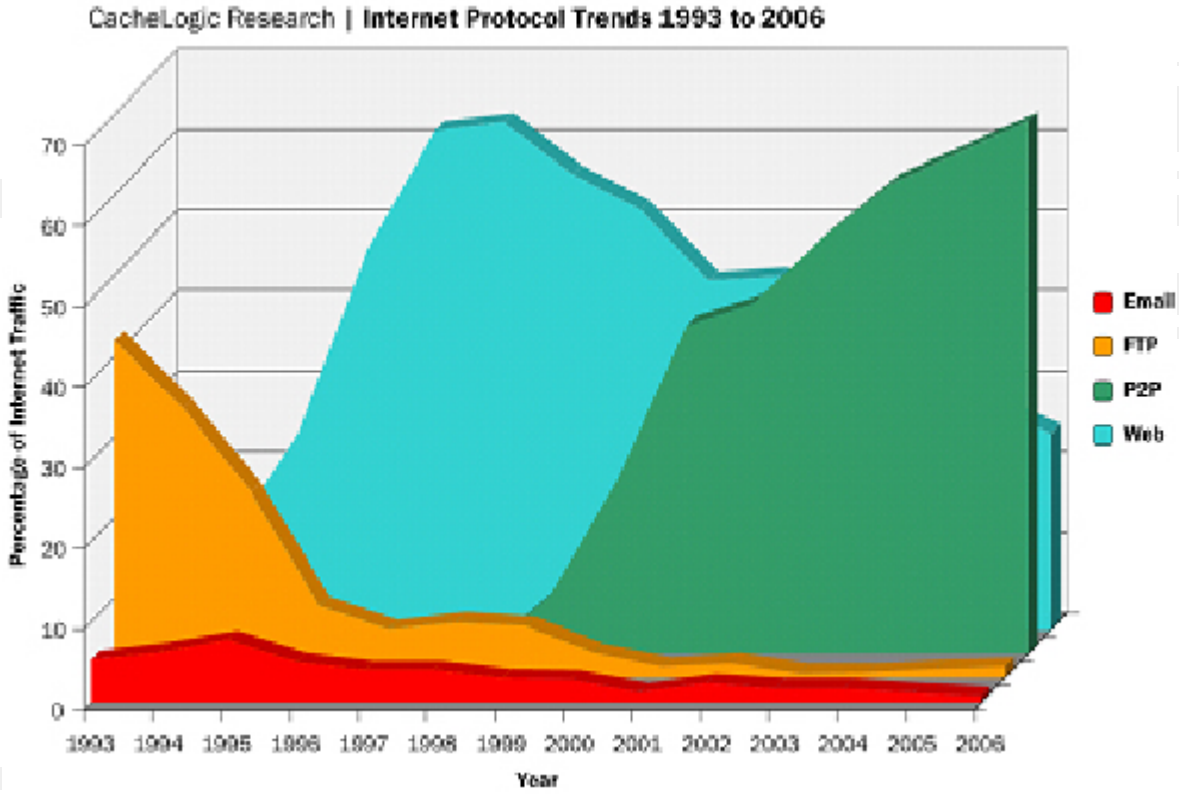
- Challenges related to peer-to-peer traffic
- The Wireless Mesh Network scenario
- Issues specific to the WMN scenario

Wireless Mesh Networks

- Wireless mesh networks are emerging as an attractive model for next generation wireless access networks
- A key for its success is the ability to support the full spectrum of Internet applications
- The last few years have seen a huge growth of peer-to-peer applications
  - ✓BitTorrent, Kazaa, Skype, GoogleTalk, PPLive, CoolStreaming

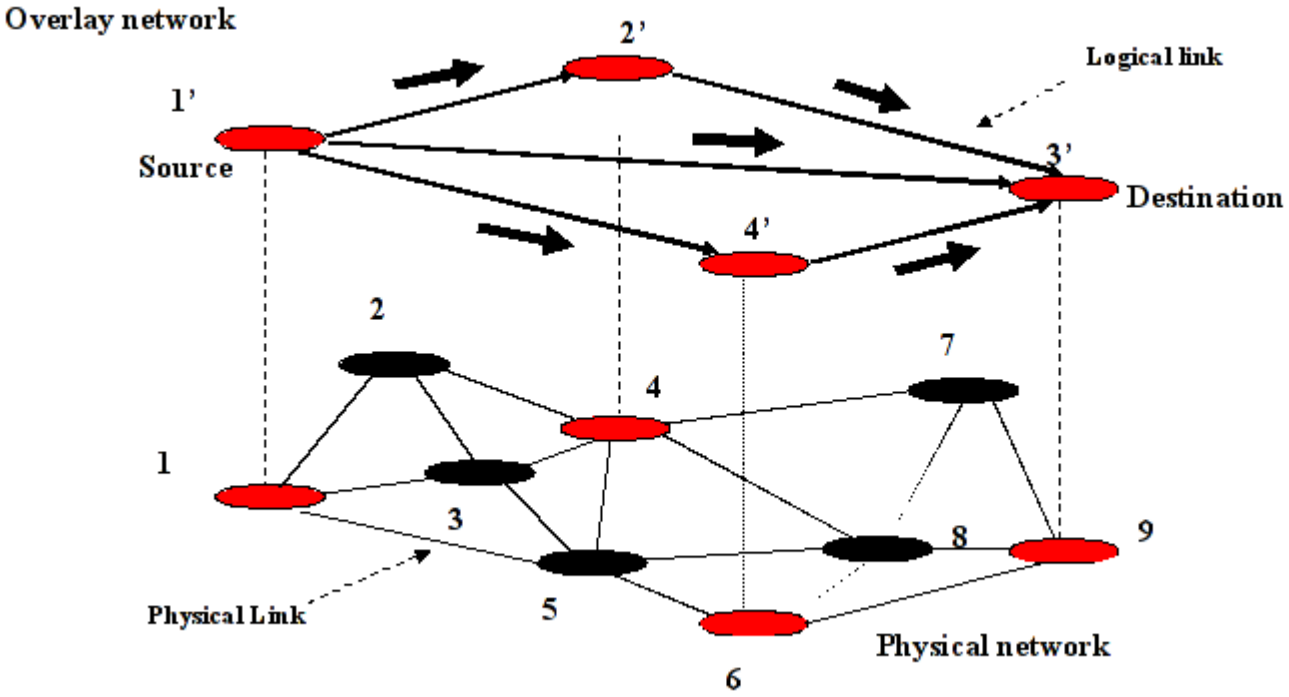
P2P traffic

- More than 50% of the Internet traffic is generated by peer-to-peer applications



Overlay networks

- Managing P2P traffic is challenging even in the case of wired networks
  - ✓P2P systems organize their peers as an "overlay" network



Overlay networks

- To retrieve a content, the P2P system determines a set of peers while being unaware of the underlying network
  - ✓ Traffic crosses network boundaries multiple times
- Often, peers probe the Internet
  - ✓ By means of simple tools such as ping and traceroute
  - ✓ By employing more sophisticated active measurement techniques

Challenges

- Traffic routing oscillations are among the causes of the behavior of peers
  - ✓ Peers may redirect traffic on *low delay* paths
  - ✓ ISPs' TE tools may change link weights and hence the underlay routing
  - ✓ New measurements from peers make them select other peers hence changing the overlay routing again
  - ✓ …

Possible solutions

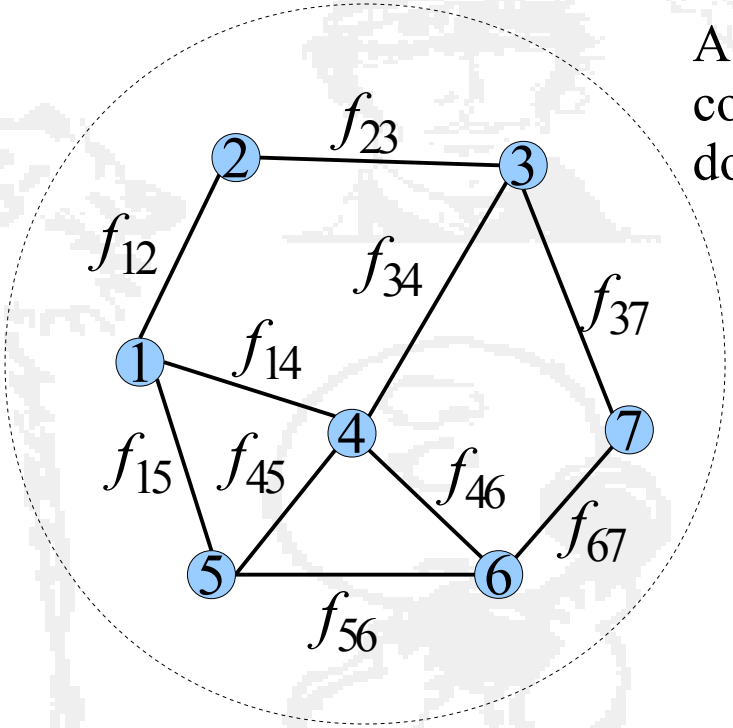
- P2P systems should be informed about the underlying network conditions by a network *service* or *Oracle*
- An IETF Working Group on "Application Layer Traffic Optimization" (ALTO) has been recently chartered
  - ✓ Aiming “to design and specify a service that will provide applications with information to perform better-than-random initial peer selection”

Back to WMNs

- Network services proposed so far are limited to just report network measurements to the requesting applications
- We believe that an Oracle designed for a WMN should offer additional functionalities
  - ✓Wireless links are deeply different from wired links
  - ✓The capacity of a wireless link depends both on tunable parameters (e.g., transmission power and rate) and on the amount of interference from other nodes

Interference in WMNs

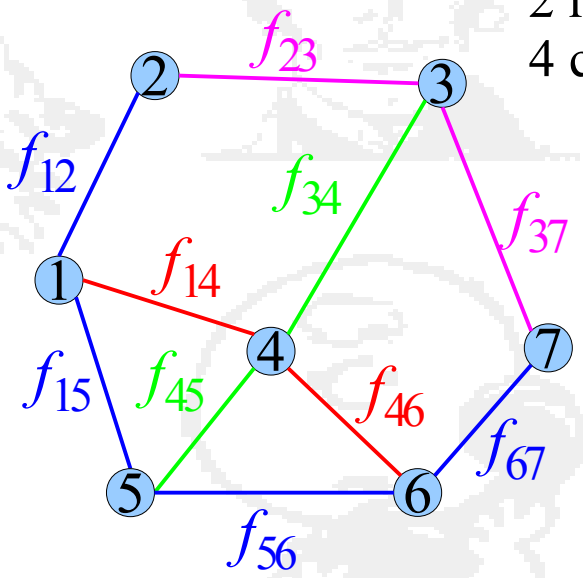
- Interference poses limits on the amount of bandwidth usable on wireless links



$$f_{12}+f_{14}+f_{15}+f_{23}+f_{34}+f_{37}+f_{45}+f_{46}+f_{56}+f_{67}\leqslant C$$

Multi-radio WMNs

- Nodes can be endowed with multiple radios to alleviate interference and increase throughput



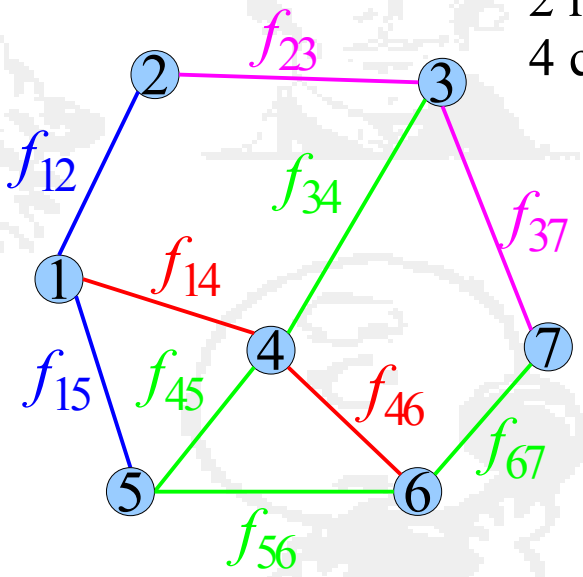
2 radios/node
4 channels

Multiple collision domains:

$$f_{12}+f_{15}+f_{56}+f_{67}\leq C$$
$$f_{23}+f_{37}\leq C$$
$$f_{14}+f_{46}\leq C$$
$$f_{34}+f_{45}\leq C$$

Multi-radio WMNs

- The way channels are assigned impacts the amount of bandwidth available on links



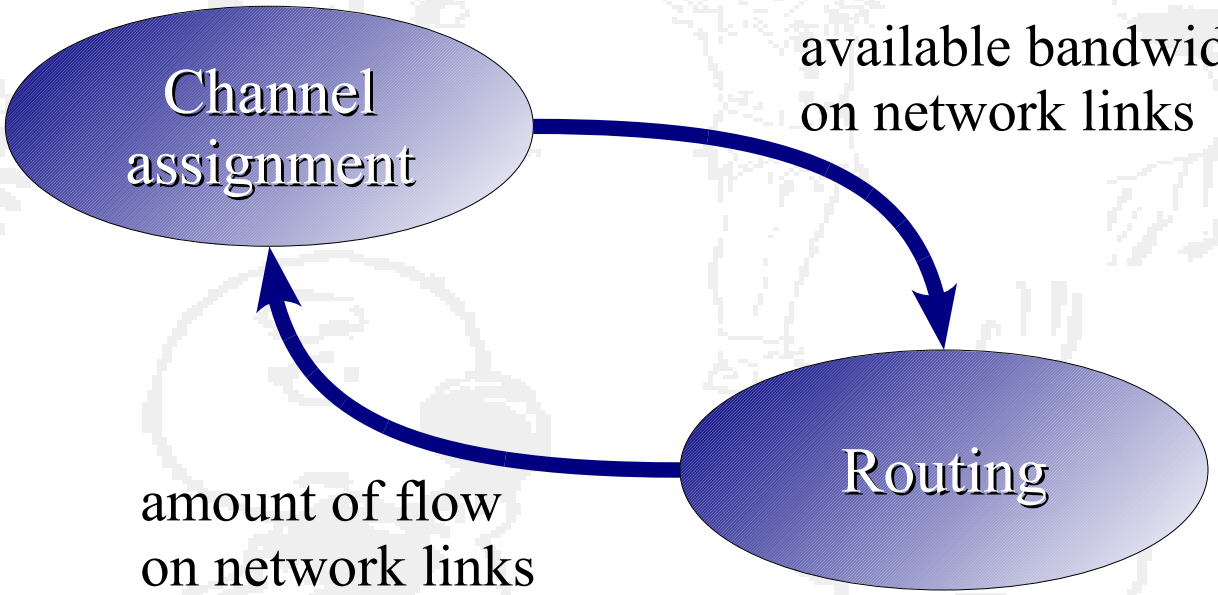
2 radios/node
4 channels

Multiple collision domains:

$$f_{12} + f_{15} \leq C$$
$$f_{23} + f_{37} \leq C$$
$$f_{14} + f_{46} \leq C$$
$$f_{34} + f_{45} + f_{56} + f_{67} \leq C$$

Multi-radio WMNs

- Channel assignment and routing are inter-dependent problems



Multi-radio WMNs

- The channel assignment problem has been studied jointly with the routing problem
- Objectives:
  - ✓Maximize aggregate network throughput
  - ✓Achievability of a demand vector
  - ✓Maximize the minimum end-to-end rate
  - ✓Impose fairness criteria on the rates
  - ✓…

Channel assignment & routing

- The joint channel assignment and routing problem is NP-complete
  - ✓ Determine pre-computed flow rates
    - A flow rate is determined for every link based on the given optimization objective
  - ✓ Determine the channel assignment
    - Channels are assigned to radios in the attempt to make such flow rates schedulable
  - ✓ Adjust the pre-computed flow rates
    - Flow rates may be adjusted in order to obtain a set of schedulable flow rates given the computed channel assignment

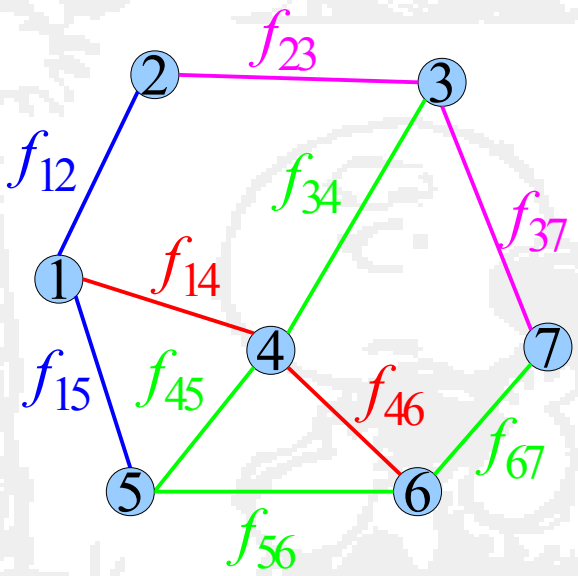
Multi-radio WMNs

- Not only channels, but also transmission rates and powers affect the bandwidth availability of wireless links
  - ✓ $\sum_i f_i \leqslant C \rightarrow \sum_i \frac{f_i}{r_i} \leqslant 1$
  - ✓ Decreasing the transmission rate or increasing the transmission power may reduce the size of the collision domain of a link

S Avallone, D Pellegrino, P Peruggini, F P D'Elia, and G Ventre. A new channel, power and rate assignment algorithm for multi-radio wireless mesh networks. In Proceedings of IFIP Wireless Days 2008, pages 1-5. IEEE, November 2008.

Routing in WMNs

- A solution to the joint channel assignment and routing problem provides a set of flow rates that are schedulable given the computed channel assignment



How can mesh routers autonomously take routing decisions such that the actual rates on the network links approximate the computed flow rates?

Routing in WMNs

- We developed a new *Layer-2.5 forwarding paradigm* that features:
  - ✓ the ability to keep the link utilization close to the computed flow rate despite variations in traffic demands
  - ✓ Fast recovery from temporary node/link failures
  - ✓ Low protocol overhead

S. Avallone, I. F. Akyildiz, and G. Ventre. A channel and rate assignment algorithm and a layer-2.5 forwarding paradigm for multi-radio wireless mesh networks. IEEE/ACM Transactions on Networking, 17(1):267-280, February 2009.

L2.5 forwarding paradigm

- Mesh routers do not build routing tables
- Each mesh router requires the knowledge of:
  - ✓ The computed flow rates for its own links
  - ✓ Its own *hop count vector* and the hop count vectors of its neighbors
    - Hop count vectors are built una tantum and are not affected by temporary changes in the network topology

L2.5 forwarding paradigm

- The source router adds a *L2.5 header* and initializes the *hop count* field
  - ✓ the initial value is α>1 times the hop count of the source to the destination
  - ✓ The forwarding paradigm ensures that a packet arrives at the destination in a number of hops not greater than such initial value
- The knowledge of the hop count vectors allows a node u to partition its neighbors for a given destination i into:
  - ✓ those with the same hop count to i: $N_i^{=}(u)$
  - ✓ those with u's hop count to i plus 1: $N_i^{+}(u)$
  - ✓ those with u's hop count to i minus 1: $N_i^{-}(u)$

L2.5 forwarding paradigm

- Each intermediate router decrements the hop count field in the L2.5 header and compares it to its hop count to the destination
  - ✓ If they are equal, the packet can only be set to a neighbor in $N_i^-(u)$
  - ✓ Otherwise, a neighbor can also be selected among those in $N_i^=(u)$ and even $N_i^+(u)$
- In case of temporary unavailability of a link/node, the corresponding node can be removed from the set of candidate next hops

L2.5 forwarding paradigm

- Among the candidate neighbors, the next hop is chosen in order to keep the link utilizations close to the computed flow-rates
- The candidate neighbor with the largest *gap* is selected

$$\Delta(v) = \frac{f(u \to v)}{\sum_{\forall u \to i} f(u \to i)} - \frac{b(v)}{\sum_{\forall u \to i} b(i)}$$

  - where $b(v)$ is the amount of bytes sent to neighbor v in the last time interval

L2.5 forwarding paradigm

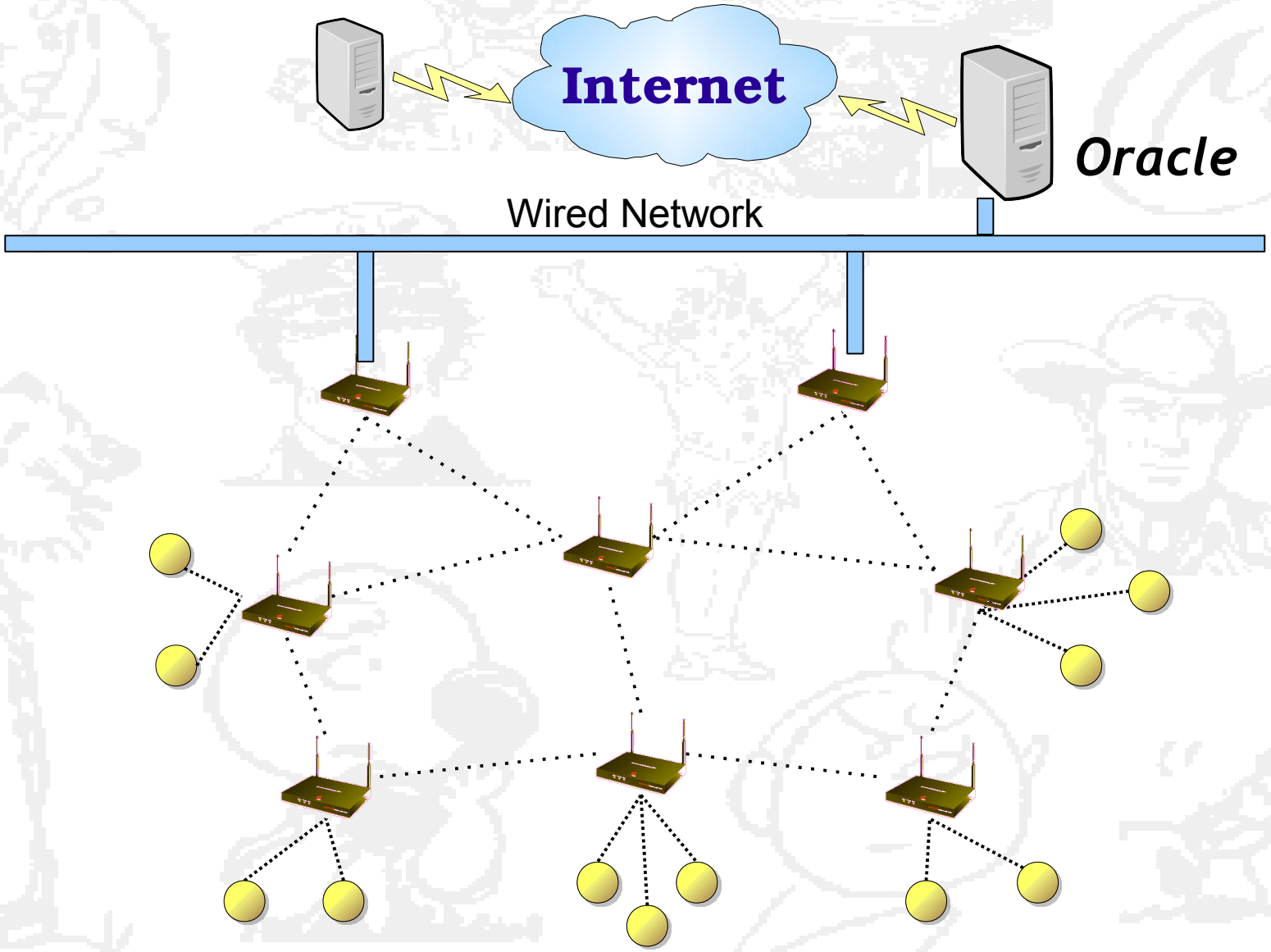
- The L2.5 forwarding paradigm outperforms (a modified version of) AODV in terms of:
  - ✓ Ability to keep the link utilizations close to the computed flow rates
  - ✓ Aggregate throughput
  - ✓ Robustness against node/link failures

S. Avallone, F. P. D'Elia, and G. Ventre. Layer 2.5 Routing in Multi-Radio Wireless Mesh Networks. In Proceedings of IEEE WiMesh (co-located with IEEE SECON), June 2009.

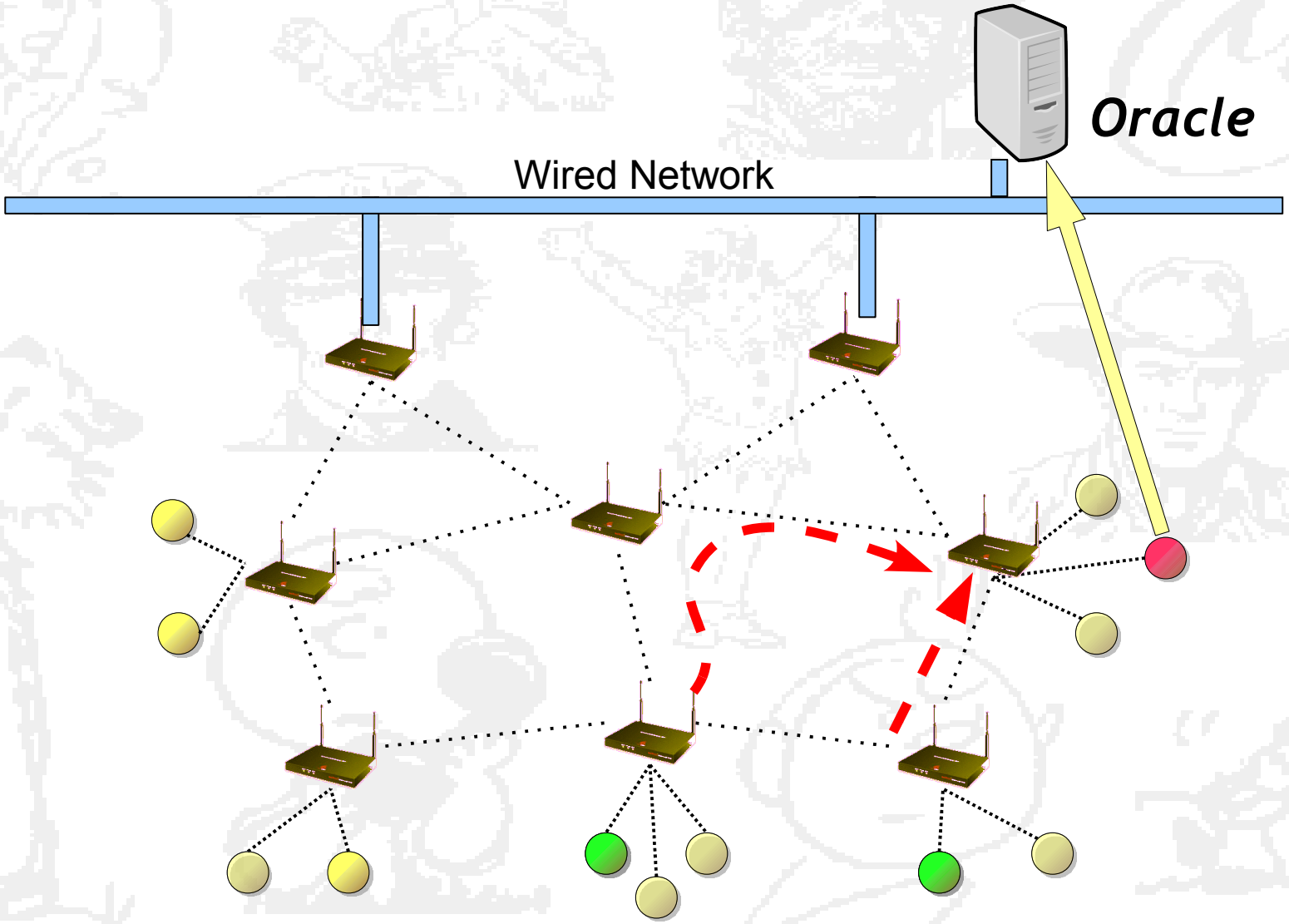
L2.5 forwarding paradigm

- *Potential* drawbacks:
  - ✓TCP reordering
  - ✓Unaware of link quality
  - ✓Performance depends on the quality of the computed flow rates

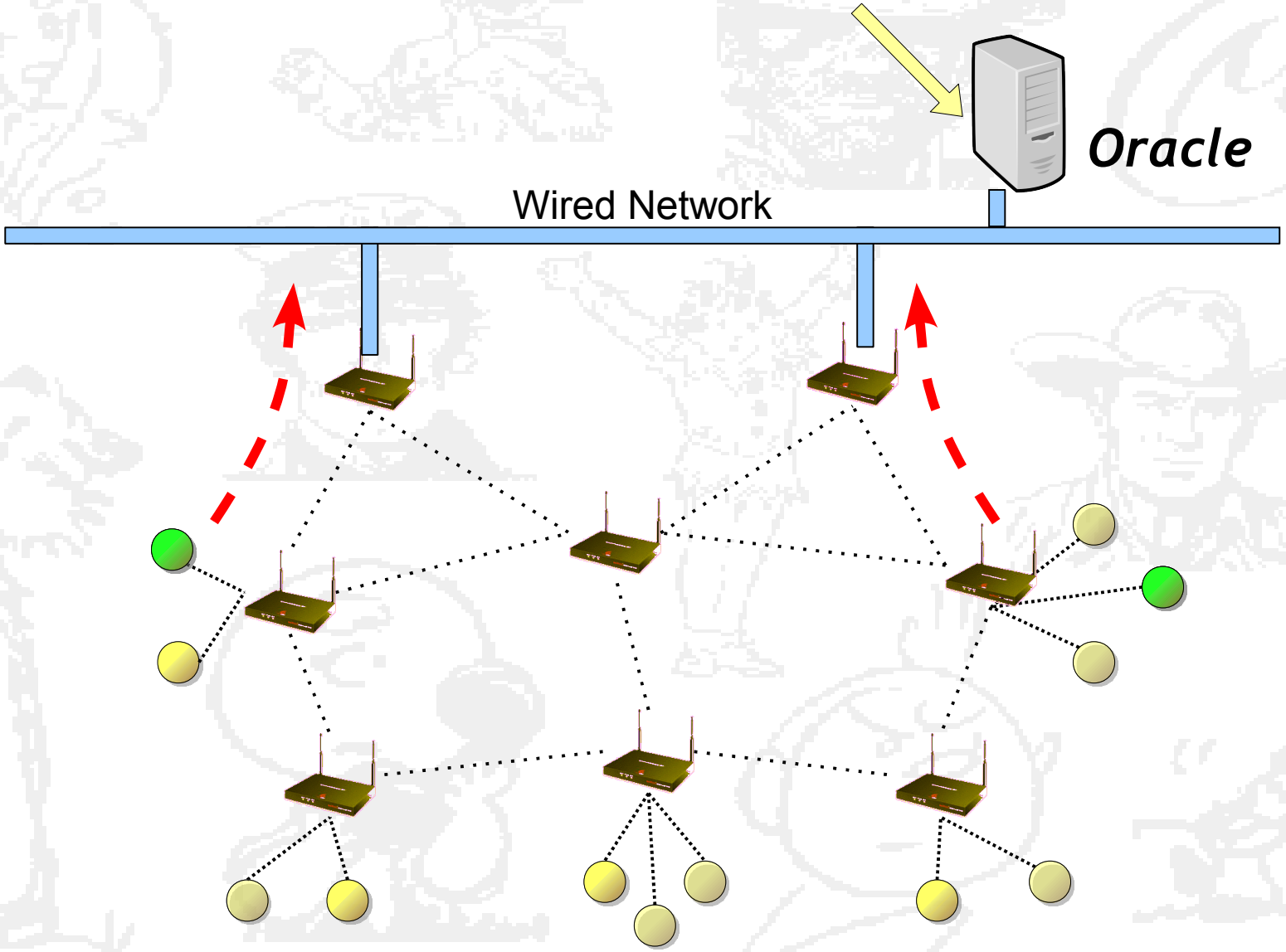
A Wireless ISP



A customer contacts the Oracle



Another Oracle contacts the Oracle



The WISP case

- Wireless links are highly configurable
  - ✓Channel, rate and power ⇨ available bandwidth
- *Not only the Oracle can rank/sort the customer peers, it can also compute a new channel, power and rate configuration that best fits the current traffic load*

Issues specific to the WMN case

- Identify the most suited peers based on routing, network configuration and current conditions
- Identify the conditions that trigger a network re-configuration
- Compute a configuration that best fits the traffic load
  - ✓The new configuration should be similar enough to the previous one

Thanks for your attention!

Any question?