QoS-aware Routing in Infrastructure-less B3G Networks

Natallia Kokash

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http://www-rocq.inria.fr/solidor/welcome.html
Valérie Issarny, Roberto Speicys Cardoso and Pierre-Guillaume Raverdy

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE
INRIA
centre de recherche PARIS - ROCQUENCOURT

Introduction

- STREP IST-PLASTIC project
- Infrastructure-less multi-network environment
- Background on routing protocols
    - Optimized Link State Routing (OLSR)
    - QoS-aware OLSR-extensions
- B3GQOLSR - QoS-aware OLSR-based protocol for the B3G network
- Experimental evaluation
- Related work/References
- Conclusion and Future Work

PLASTIC: http://www.ist-plastic.org/

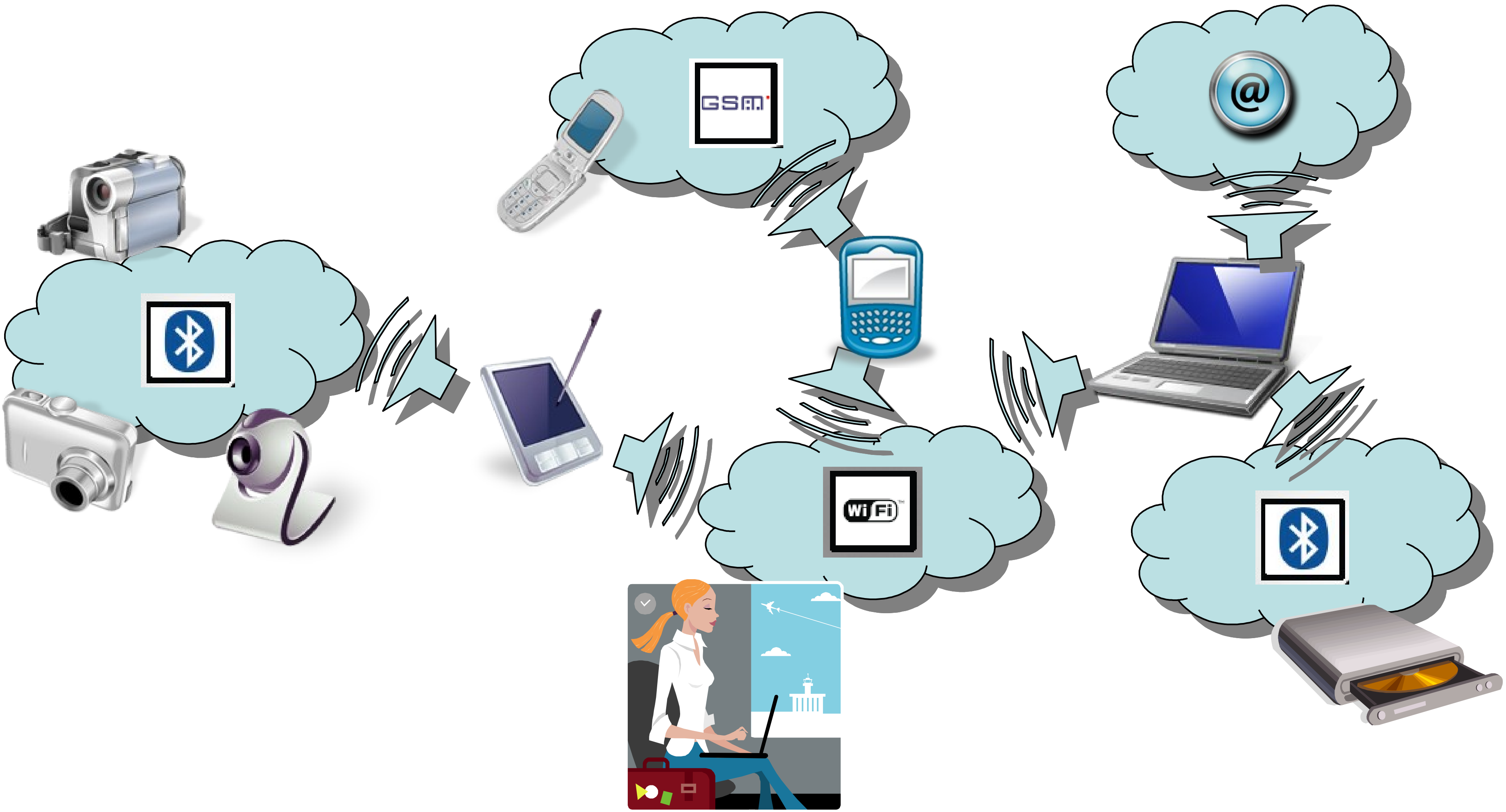
PLASTIC=Providing Lightweight & Adaptable Service Technology for Pervasive Information & Communication

- January 2006 – September 2008
- development of services targeted at mobile devices

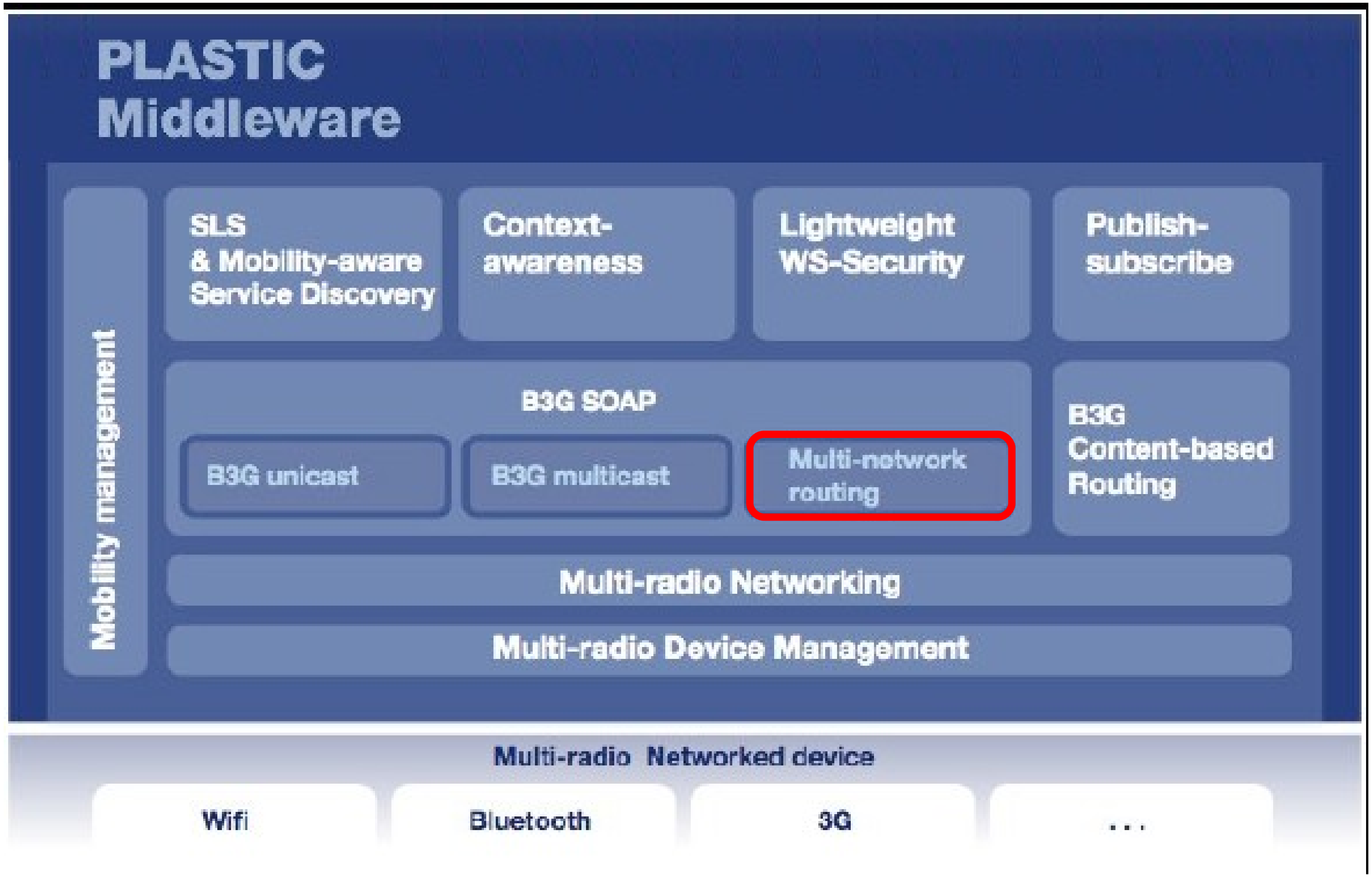
PLASTIC platform

- A development environment leveraging model-driven development of SLA- and resource-aware services, which may be deployed on various networked nodes, including handheld devices,
- A service-oriented middleware leveraging multi-network environments for services run on mobile devices, enabling context-aware and secure discovery and access to such services,
- A validation framework enabling off-line and on-line validation of networked services regarding functional and extra-functional properties.

Multi-radio devices &
Infrastructure-less multi-network environment



PLASTIC Service-Oriented Middleware



Requirements to a routing protocol

Routing is the process of selecting paths in a network along which to send network traffic

Ad-hoc (improvised or spontaneous) networks

- An ad hoc network is formed by a collection of mobile nodes without any centralized access point or existing infrastructure
- Nodes and links may appear/disappear

Multi-networks

- Links (networks) are different
  - different technologies (WiFi, Bluetooth)
  - different QoS (+ may vary over time)
- Nodes (devices) have different characteristics

Overlay networks

- Users may not want to use all resources (e.g., available bandwidth)

Routing protocols

Proactive vs. Reactive routing:

•Reactive protocols (on demand)

- Does not try to keep routing information to all nodes
- Routes are discovered upon request
- E.g., AODV (Ad hoc On-Demand Distance Vector)

•Proactive protocols (table-driven)

- Tries to keep up-to-date routing information to all nodes
- Routing information is updated periodically or when a change is recoginzed)
- E.g., OLSR (Optimized Link State Routing)

Other routing protocols

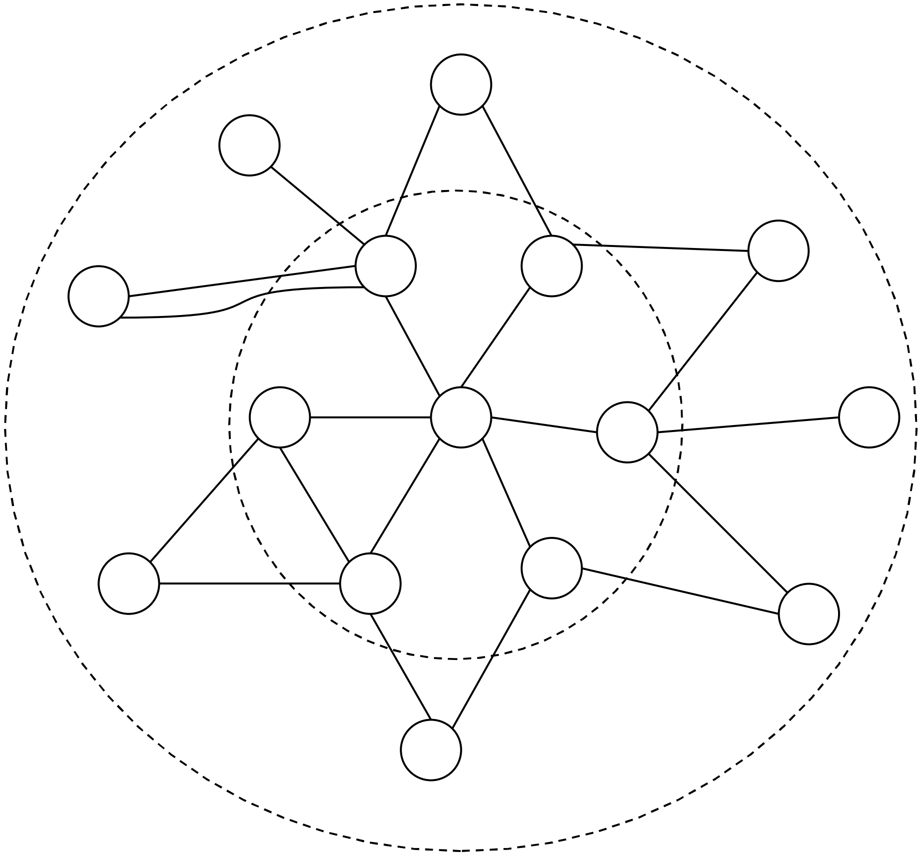
- Adaptive (Situation-Aware)
  - The choice of proactive or reactive routing depends on some metric
  - E.g., TORA (Temporally-Ordered Routing Algorithm)
- Hybrid (Pro-Active/Reactive) Routing
  - The choice of proactive or reactive routing is predetermined for typical cases
  - E.g., ZRP (Zone Routing Protocol)
- Hierarchical Routing Protocols
  - The choice of proactive or reactive routing depends on the hierarchic level where a node resides
  - E.g., DDR (Distributed Dynamic Routing Algorithm)
- Geographical Routing Protocols
  - Acknowledges the influence of physical distances and distribution of nodes to areas as significant to network performance
- Power Aware Routing Protocols
- Other Protocols
  - E.g., B.A.T.M.A.N. (Better Approach To Mobile Adhoc Networking)

Link State Routing (LSR)

In case of a reactive protocol it is easy to detect when and what services a user accesses – problems with security and privacy!

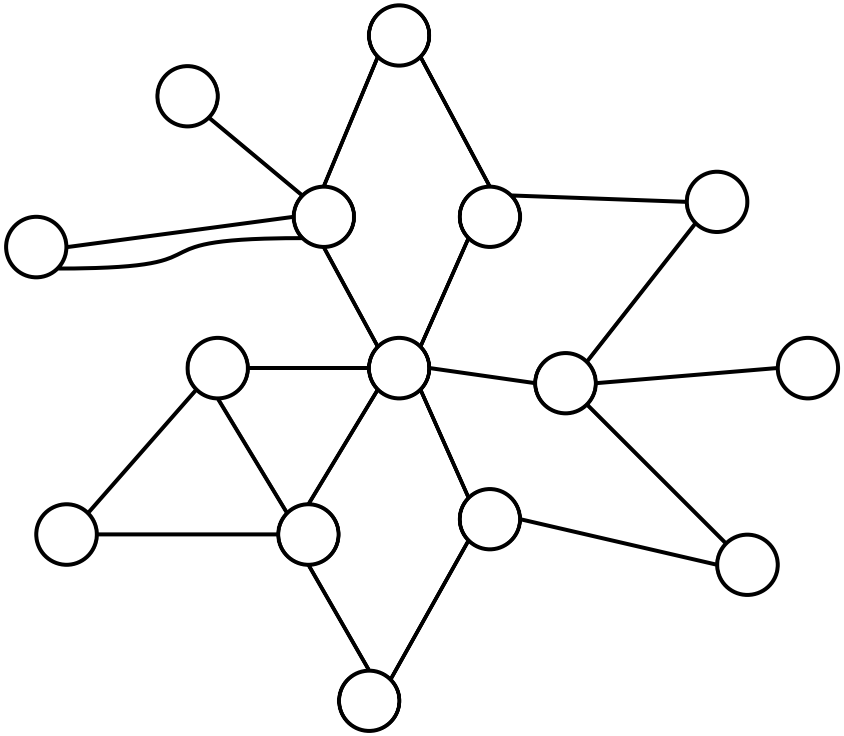
- LSR is traditionally used for proactive routing in ad-hoc mobile networks
- Each node uses a map of the network in the form of a graph
- To produce such a map, each node floods the entire network with information about what other nodes it can connect to
- Each node independently assembles this information into a map
- Each node independently determines the least-cost path from itself to every other node using a standard shortest path algorithm
- The result is a tree rooted at the current node such that the path through the tree from the root to any other node is the least-cost path to that node.
- This tree serves to construct the routing table, which specifies the best next hop to get from the current node to any other node.

Neighbour sensing

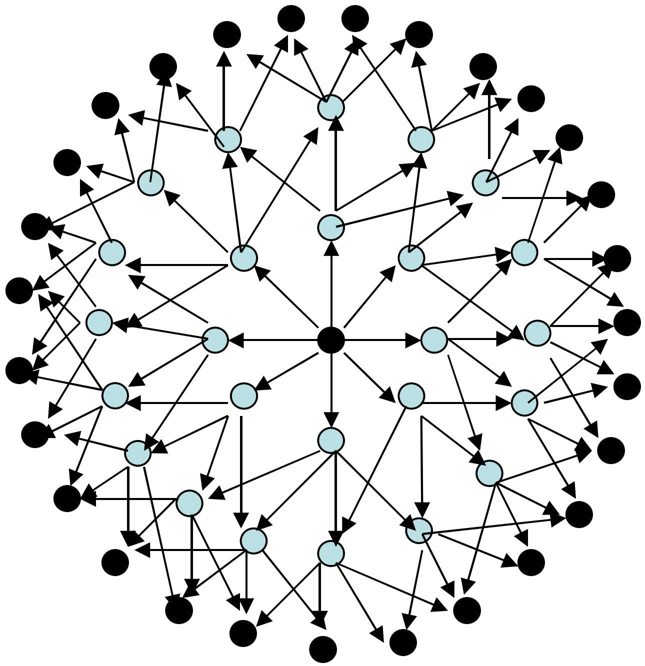


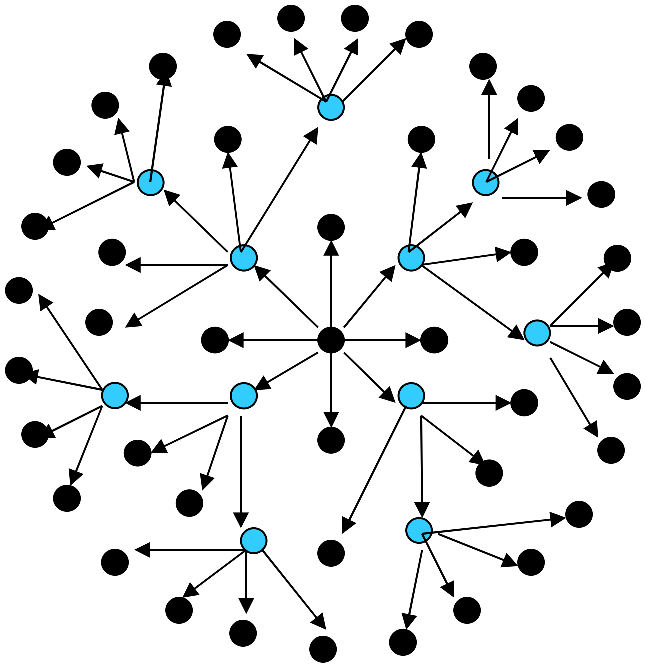
Optimized Link State Routing (OLSR)

- Developed by the Hipercom INRIA team http://www.ietf.org/rfc/rfc3626.txt
- OLSR optimizes LSR through selective flooding using Multi Point Relay (MPR) set
- MPR set is a set of neighbours selected by each node that are used to forward its messages
- MPR set is selected as a minimal set of neighbours to cover all its 2-hop neighbours (in this way network connectivity is preserved)



Flooding optimization in dense networks





24 retransmissions to diffuse a message up to 3 hops

11 retransmission to diffuse a message up to 3 hops

Retransmission node

Retransmission node

Qamar A. Tarar "Mobile ad-hoc networks based on wireless LAN"

OLSR Messages

- Each node periodically sends HELLO messages
  - Used to establish neighbour links
  - Include ID, a set of all neighbours, MPR set
  - Hello messages are NEVER retransmitted
- Each node selected as MPR by at least one of its neighbours sends Topology Control (TC) messages
  - Used to build routing tables
  - Include ID, a subset of the neighbour set (advertised neighbours – normally coincide with the MPR selector set) – in this way OLSR reduces also the size of a control message
  - Retransmitted ONLY by nodes selected into MPR set

Some other OLSR features

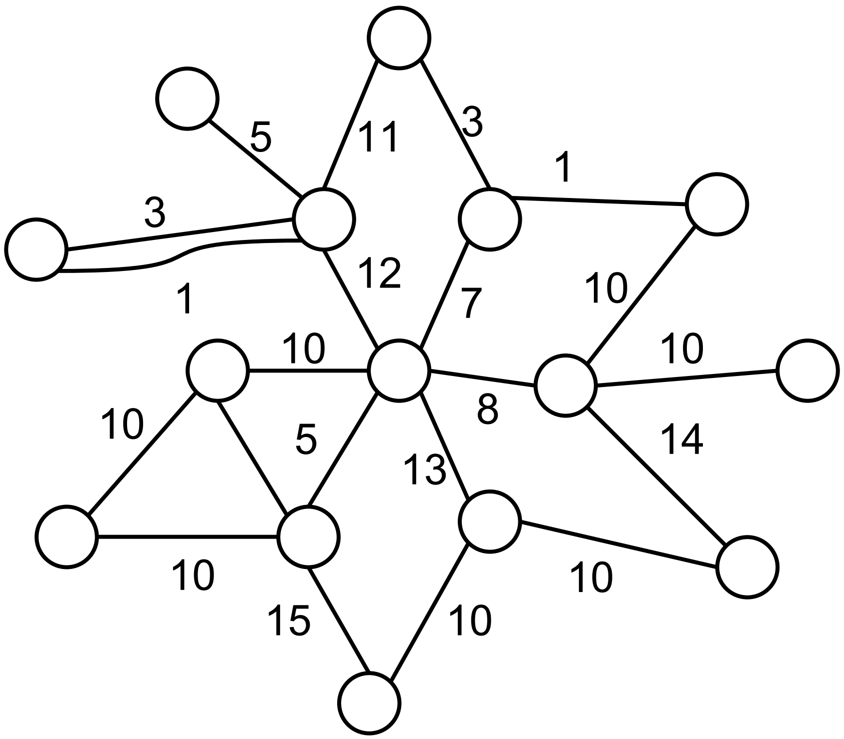
- Node willingness to participate
  - 5 levels (never, low, default, high, always) influence on MPR selection
  - Nodes can change their willingness to reduce/increase network traffic passing through them (e.g., depending on their battery load)
- MPR Redundancy
  - If mobility of neighboring nodes increases, it may have sense to select more MPRs
- Multiple Interface Declaration (MID) messages
  - Used in a network with multiple interface nodes to map interface addresses to main addresses
- Host and Network Association (HNA) messages
  - Used to inject external routing information into an OLSR network

OLSR characteristics

- Advantages
  - As **stable** as LSR
  - **Proactive**
  - Does not depend on any **central entity**
  - **Tolerates** loss of control messages
  - Supports node **mobility**
  - Good for **dense** network
  - Guarantees the **shortest path** between any two nodes
- Disadvantages
  - Higher **computational overhead** comparing to LSR
- Drawbacks of OLSR with respect to the PLASTIC requirements
  - Does not support **multi-networks** and **link mobility**
  - **No QoS support** – a number of extensions exist, but still not what we want

Quality-aware OLSR extensions

- QOLSR [Ge at al.2003]
  - Select a set of neighbours to access all 2-hop neighbours by a path with max bandwidth (min delay)
  - Does not preserve the OLSR flooding efficiency
- Solution: distinguish 2 MPR sets [Nguyen&Minet, 2006]:
  - MPR-F for flooding (= MPR in OLSR)
  - MPR-B for routing with optimal bandwidth (generally bigger than MPR in OLSR)

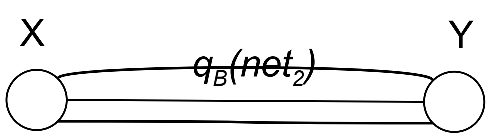


QoS-aware OLSR-based routing for B3G networks

- Technical challenges
  - Addressing (different networks, no global names): PLASTIC@: f(network, device, user)
  - Heterogeneous protocols: communication over SOAP
- Select 2 MPR sets:
  - MPR set for forwarding as in OLSR
  - MPR set for building routes optimal according to each of QoS characteristics (MPR-Q)

QoS-aware OLSR-based routing for B3G networks

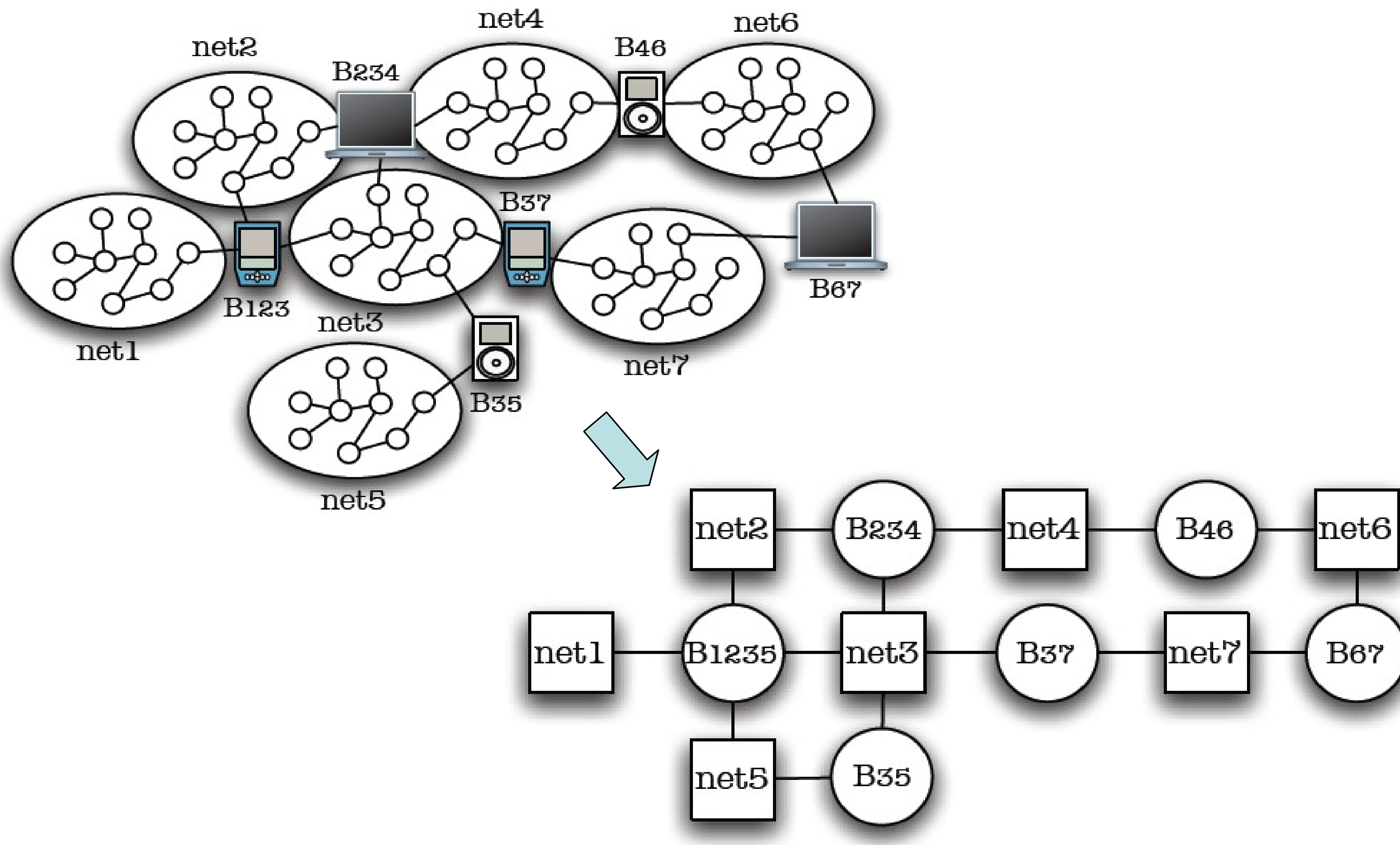
- Multi-QoS:
  - Bandwidth (video games, movies, TV) – heterogeneity of links and their load
  - Delay (on-line games, auctions) – mainly on nodes
  - Cost (information exchange)
  - Willingness to carry traffic of others (reflects battery load)
  - …



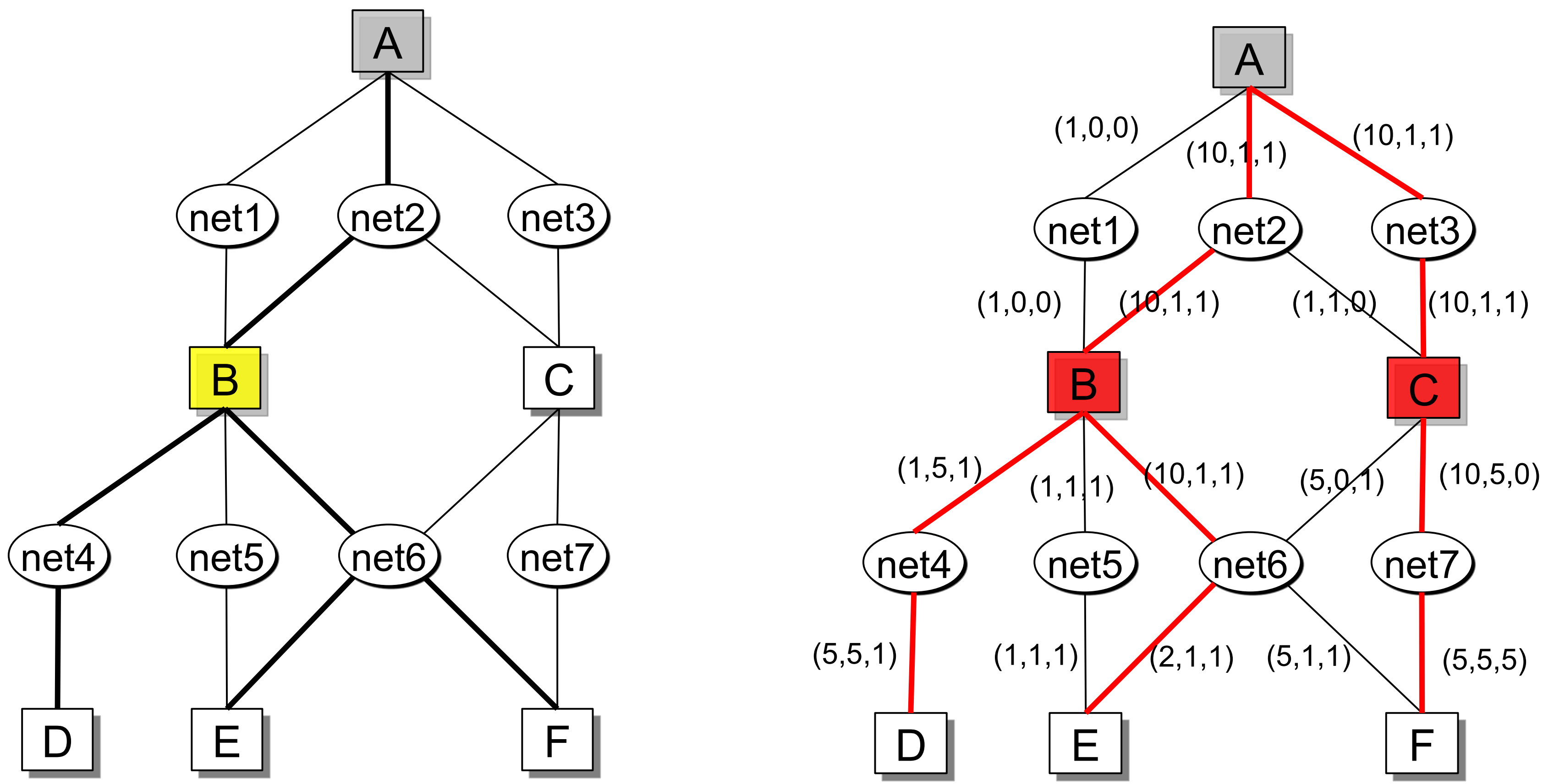
- $q_B(X,Y)$ – *possible bandwidth between X and Y*
- $q_B(net_i)$ – *theoretical bandwidth of the network* net_i
- $q_B(X, net_i)$ – *bandwidth of the* net_i *user X wants to share with others*
- $q_B(X, net_i) \leq q_B(net_i)$
- $q_B(X,Y) = max(q_B(X,Y, net_1),\ldots, q_B(X, Y, net_k))$,

where $q_B(X,Y, net_i) = min(q_B(X, net_i), q_B(Y, net_i))$

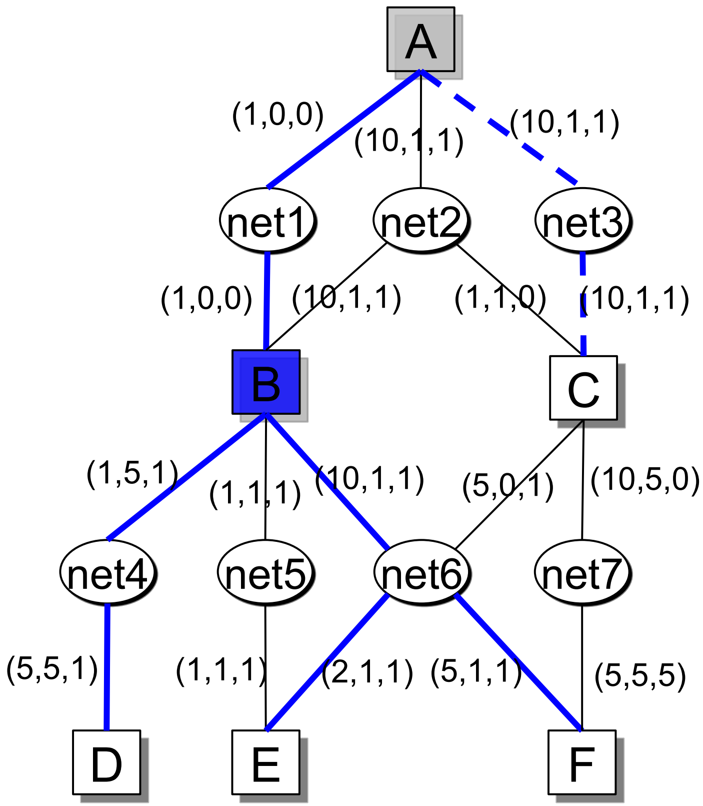
Network model

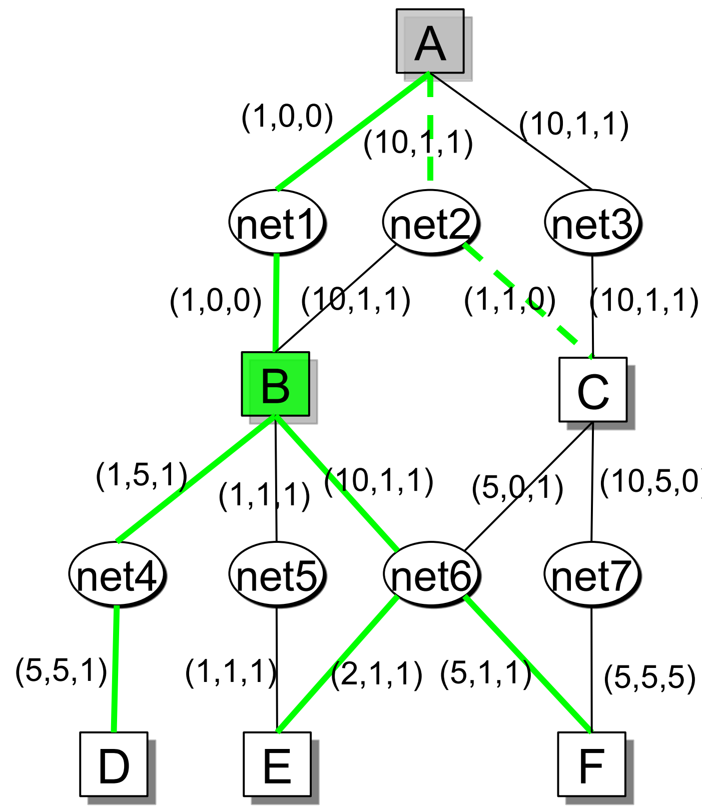


MPR-F and MPR-Q selection (minimize flooding and maximize bandwidth)

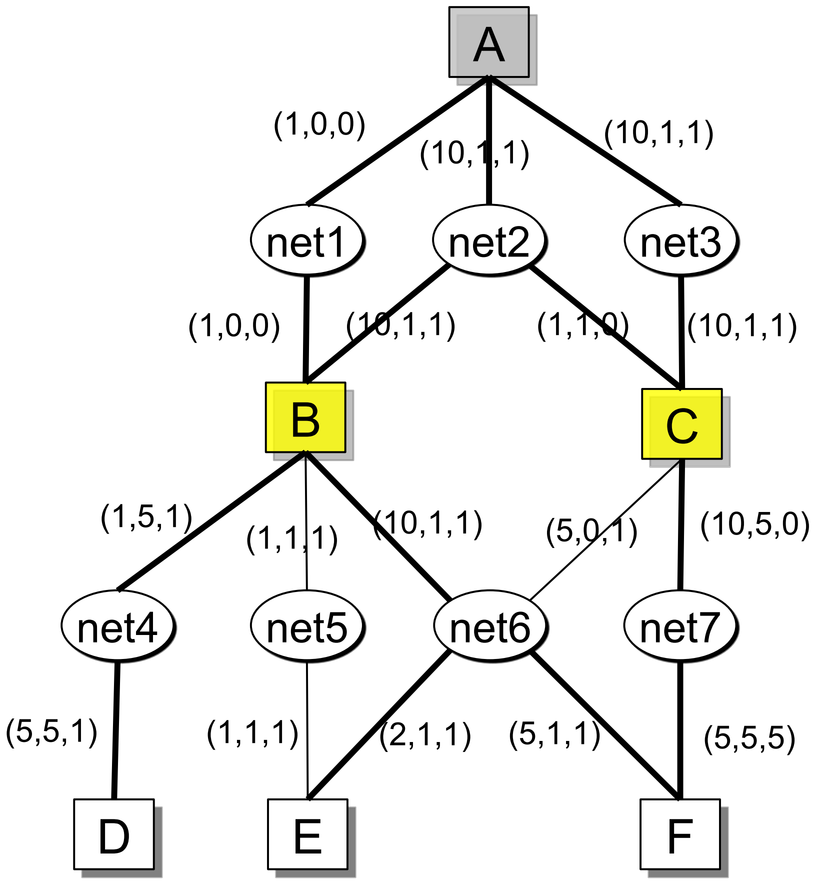


MPR-Q selection: minimize cost and delay





MPR-Q selection: optimize all 3 QoS factors



Note: There exists a correlation among QoS characteristics

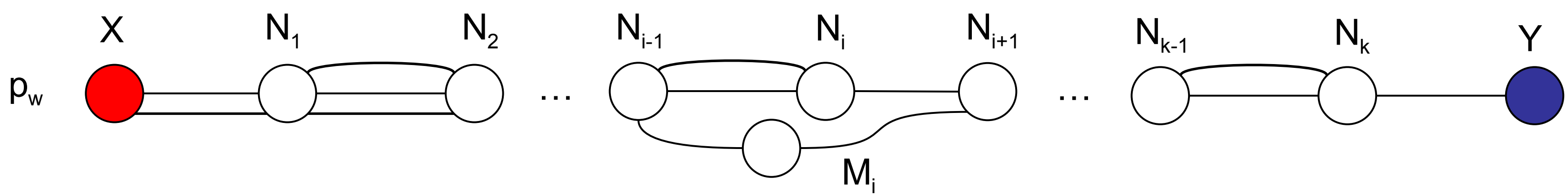
e.g., GPRS is the most expensive, but has the lowest bandwidth

MPR-Q selection algorithm

- Exclude neighbours with willingness WILL_NEVER
- Include neighbours with willingness WILL_ALWAYS
- Include neighbours which are unique that cover some 2-hop neighbour
- Include neighbours with max bandwidth
  - if there are several: min delay, min cost, best coverage
- Include neighbours with min delay
  - if there are several: already in MPR-Q set, max bandwidth, min cost, best coverage
- Include neighbours with min cost
  - if there are several: already in MPR-Q set, max bandwidth, min delay, best coverage

B3GQOLSR characteristics

Our protocol guarantees that a route among any two nodes with an optimal QoS characteristic upon request will be found



– To discover a path from X to Y, Dijkstra algorithm is applied to a graph defined by the local routing table of the node X

– Suppose that the unique widest path p_w is not included in this table, i.e., there exists a set of neighbor pairs $S = (N_j, N_{j+1}) \in p_w$ for which

  – either no links have been advertised in TC messages

  – or these messages did not reach X s

– TC message propagation is analogous to OLSR (proven to be correct)

– Therefore, a TC message, advertising a maximal bandwidth link between N_j and N_{j+1} was not generated, that is, the node N_{j+1} did not select N_j as its MPR-Q

– Let (N_i, N_{i+1}) be such a pair closest to X and consider an MPR-Q set selected by the node N_{i+1}: Suppose that it selected $M_i \neq N_i$ as MPR-Q to cover the node N_{i-1}. From this follows that

$$q_B(N_{i+1}, M_i, N_{i-1}) = min(q_B(N_{i+1}, M_i), q_B(M_i, N_{i-1})) \geq min(q_B(N_{i+1}, N_i), q_B(N_i, N_{i-1})) = q_B(N_{i+1}, N_i, N_{i-1})$$

– From symmetry of q_B follows $q_B(p_w') = q_B(X, \ldots, N_{i-1}, M_i, N_{i+1}, \ldots, Y) \geq q_B(X, \ldots, N_{i-1}, N_i, N_{i+1}, \ldots, Y) = q_B(p_w)$, what contradicts our assumption that p_w is the unique widest path between X and Y

Implementation

- First Java implementation of OLSR and its QoS extensions
- XML messages over SOAP
  - Basic OLSR message
    - Message type, originator address, source address, message sequential number, validity time, time-to-live, hop count
  - HELLO
    - Willingness, networks, set of neighbours, set of MPRs
  - TC
    - TC number, set of advertised neighbours (MPR-Q)
  - HELLO-Ext
    - QoS of the node, QoS of neighbours, set of advertised neighbours (MPR-Q)
  - TC-Ext
    - QoS of advertised neighbours

Mobility

•Node disappears = no HELLO message is received (will be deleted when its validity time expires)

•Difference from OLSR because of the need to deal with multi-networks:

- A network can disappear, but the neighbour will be accessible through other links
- In contrast to OLSR we have to keep time of availability confirmation for each network (link)
- Each HELLO message can be received several times – it may have sense to keep a **duplicate set** of processed HELLO messages as well (in OLSR, only a duplicate set of TC messages is kept)
- We must reselect MPR-Q set every time QoS characteristics significantly vary

Flexible (user-oriented) route selection

•With B3GQOLSR any user can independently choose what route to use for a certain service

- A route with the minimal delay
- A route with the minimal cost
- A route with the maximal bandwidth
- A route with the minimal delay and a certain bandwidth
- A route with the minimal cost and a certain bandwidth
- The shortest route in terms of number of hops to the destination

Experimental evaluation

•Network simulators like NS2 do not support multi-network environments with link mobility

•We generate 10 random networks with 10, 20, 30, 40 and 50 nodes (bridges) each (in total 50 different network topologies)

•Each bridge can be connected to 1 to 4 networks at most, reproducing the scenario where user devices may feature up to 4 different network connections (Bluetooth, GPRS, ad hoc WiFi and structured WiFi)

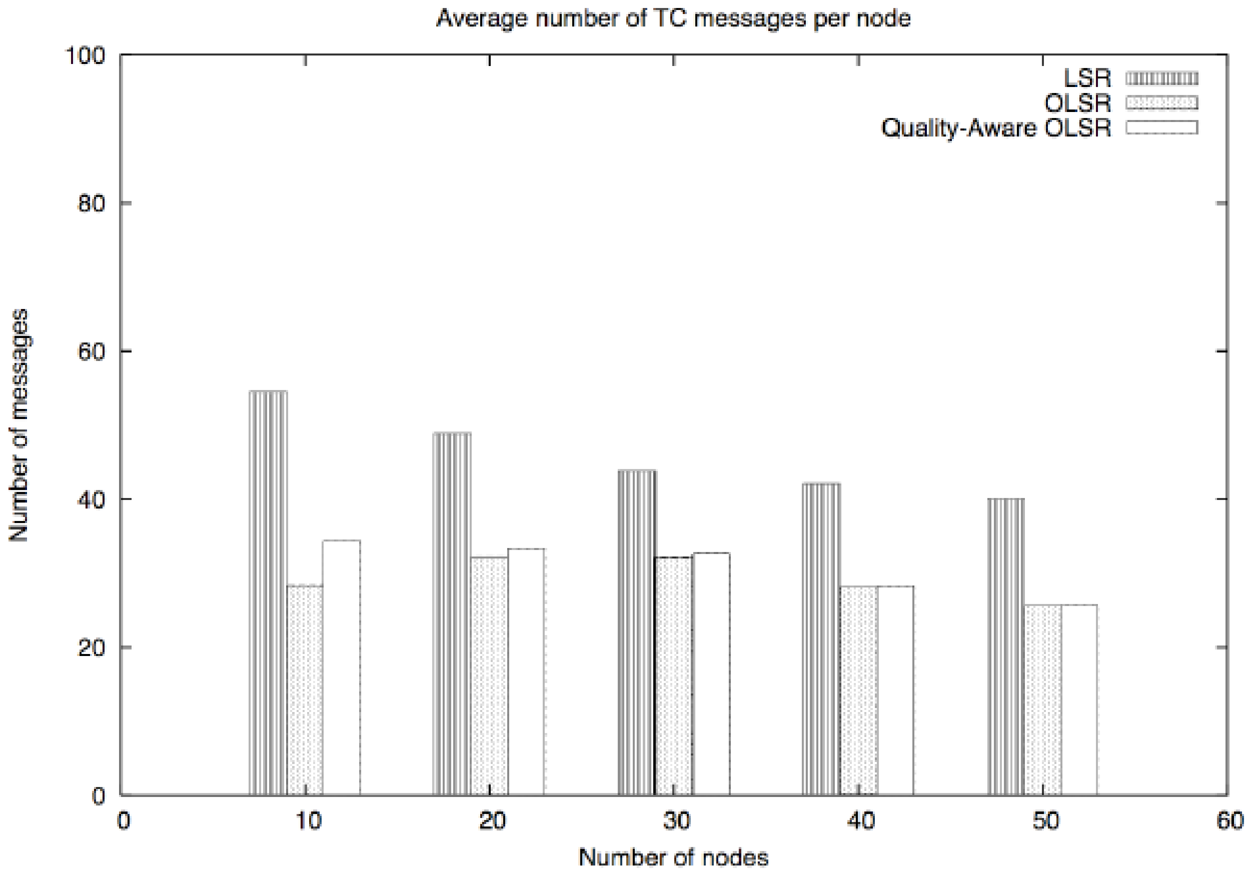
•Each network interface is associated to a QoS profile containing its bandwidth, delay and cost

We consider 4 different types of interfaces with 3 different proles each containing changing QoS values, resulting in 12 different proles

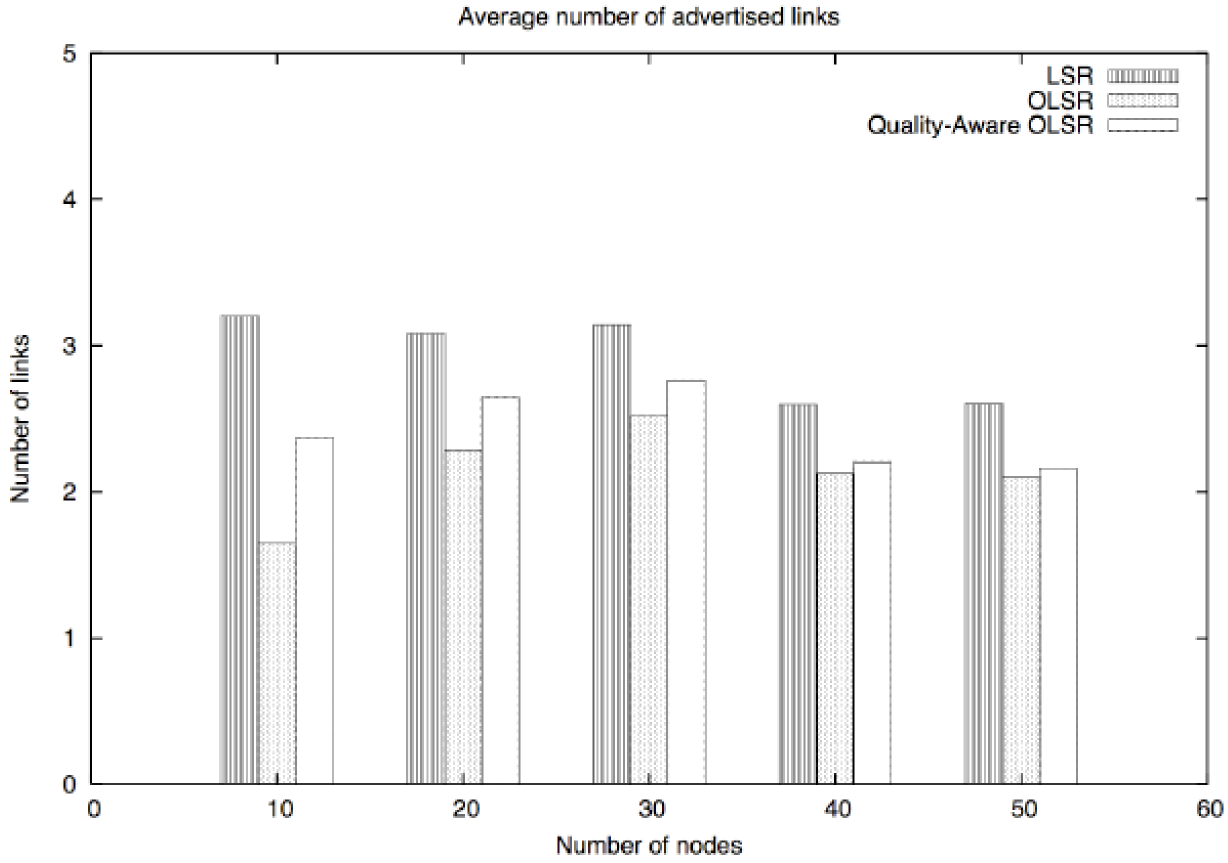
Experimental evaluation

- **Goal:** evaluate B3GQOLSR performance comparing to LSR and OLSR
- LSR
  - The **worst case** in terms of **control traffic overhead** (nodes advertise all connected networks and topology messages are forwarded to all nodes on the environment)
  - The **best case** in terms of **flexibility** (nodes advertise all links, LSR enables discovery of all available routes)
- OLSR
  - The **worst flexibility**
  - The **best control traffic optimization** (only MPRs forward control messages and the MPR set is minimal)
- Each node runs three protocols: LSR, OLSR and B3GQOLSR
- Nodes send HELLO messages every 2 seconds and TC messages every 5 seconds as recommended by the OLSR specification (RFC 3626, IETF, 2002)
- We compare
  - the number of topology control (TC) messages generated in average by network nodes
  - the number of advertised links in average for each of the three protocols
  - the average size of OLSR MPR set with the average size of the MPRQ set generated by B3GQOLSR

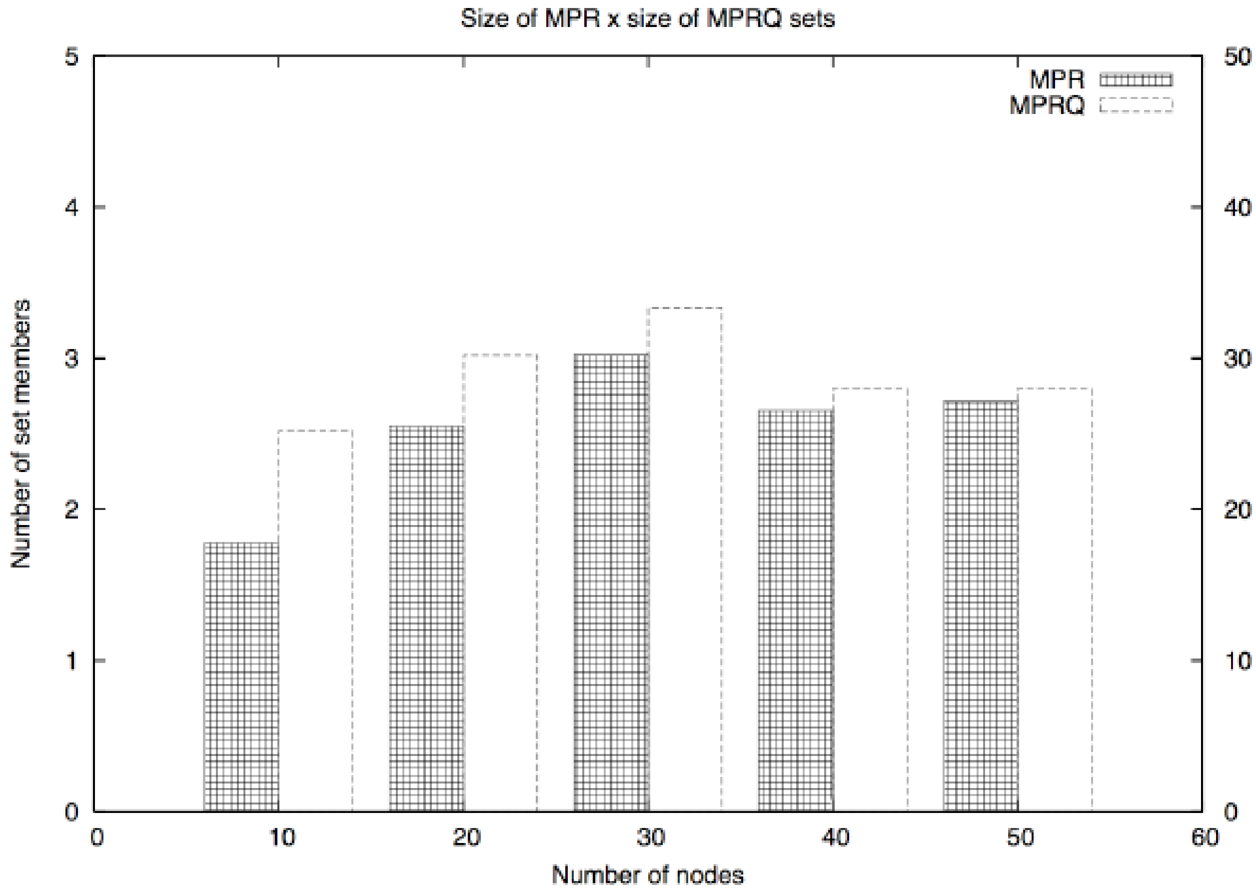
Measuring overhead: Number of Topology Control Messages



Measuring overhead: Number of advertized links (characterizes the size of TC messages)



Measuring overhead: Size of MPR and MPR-Q sets (reflects the number of message retransmissions)



Conclusions and Future Work

- We presented a proactive protocol for QoS-aware routing in infrastructure-less B3G environments where a dedicated infrastructure for QoS management cannot be assumed
- Proved its properties to find optimal routes according to each of three QoS metrics
- Implemented and evaluated on a number of network configurations

- The main drawback is **high computational cost** (comparing to LSR and OLSR)

Future work

- Use historical information about node **availability** and **trust** as additional criteria to select MPR-Q nodes
- This would permit a node to not take into account the quality information announced by a node with **bad reputation** based on past experience
- and enable selection of nodes with slightly worse bandwidth but that historically present **good availability**
- Integrate an **admission control** mechanism to the protocol to enable users to **reserve bandwidth** for a given access

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