MONET

Mechanisms for Optimization of hybrid ad-hoc
and satellite NETworks

FP7 INFSO-ICT-247176

Agenda

- **Context and Objectives**
- **Approach**
- **Achievements**
- **Next steps**
- **Consortium**

Context and Objectives

- **MONET – Mechanisms for Optimization of hybrid ad-hoc and satellite NETworks**
  - **Collaborative Project in Future Networks**
  - **Initiated in 2010 for 2.5 years**
  - **6 Partners @ 3.6 M€**

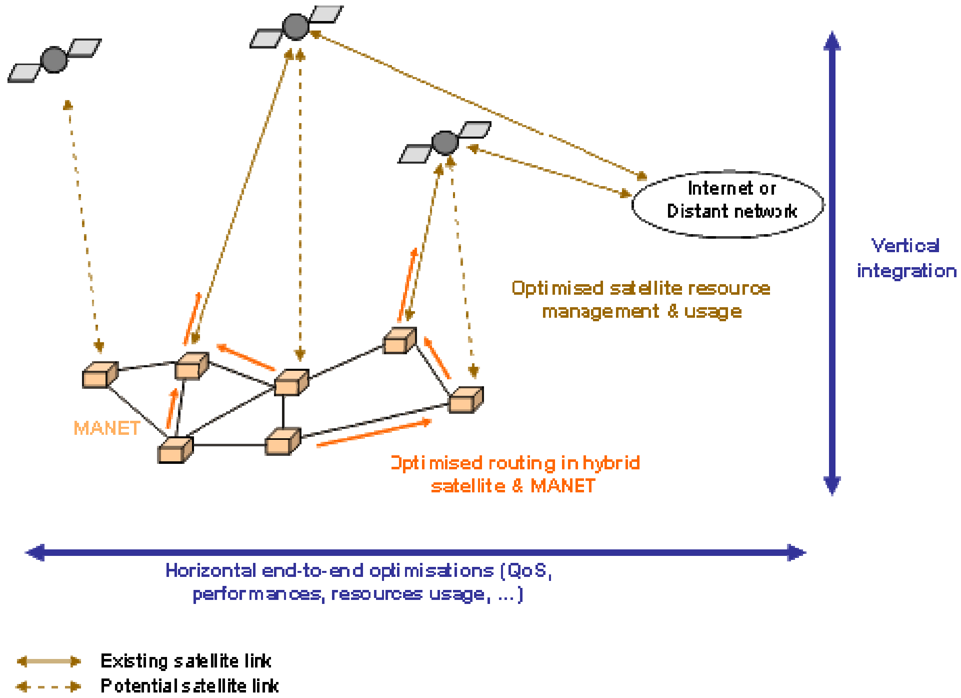
Context and Objectives

- Wireless Ad-hoc Networks provide field communication links among deployed personnel, automatically adapting the network topology to the field context.

- MSS for links between the field resources and other entities using easily deployable mobile communication units.

- Consider then:
  - Changing MANET
  - Nodes with links to backbone
  - Dynamic, changing links

- Concept of a hybrid MANET-Satellite network is a natural evolution of considering the problem of providing local and remote connectivity in a highly mobile, dynamic and often remote environment

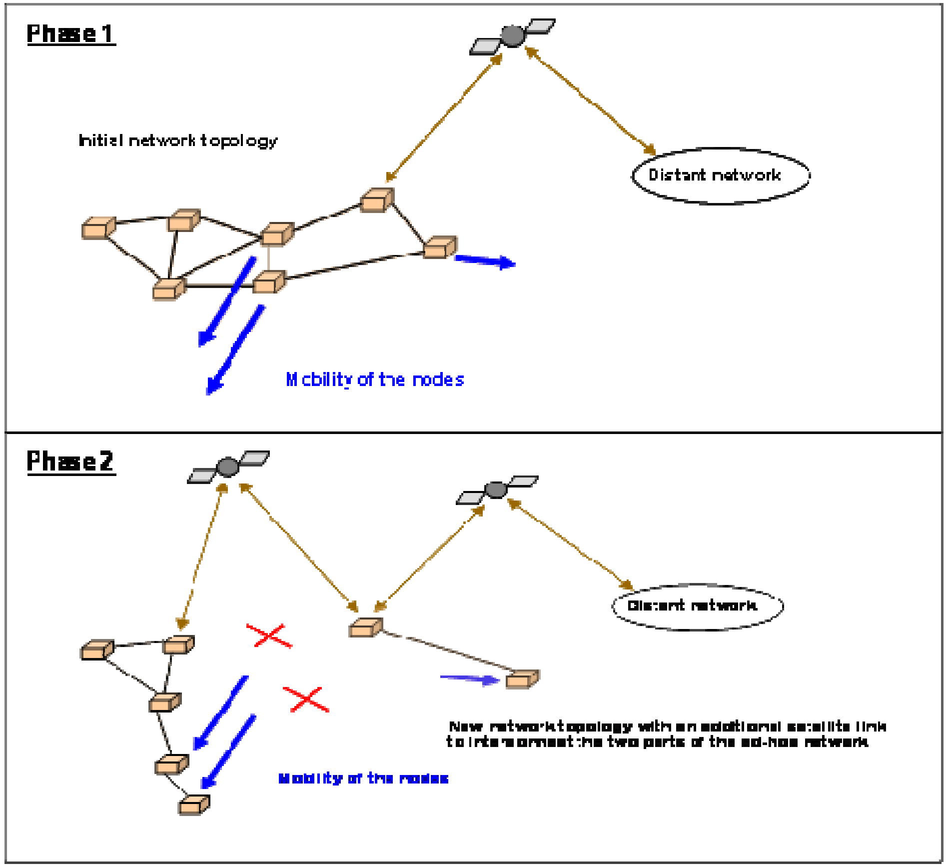


Context and Objectives

- To develop a complete understanding of the problems and complexity underlying the highly dynamic and heterogeneous environment of a hybrid MANET-Satellite network
- To optimize the use of satellite access links in a MANET through mechanisms that propose and implement changes in topology and resources used
- To provide seamless broadband services to everyone at any time in a hybrid MANET-satellite network thanks to optimized algorithms and network mechanisms
- To overcome performance bottlenecks and roadblocks in hybrid MANET-Satellite networks to enable a more pervasive and optimized network structure

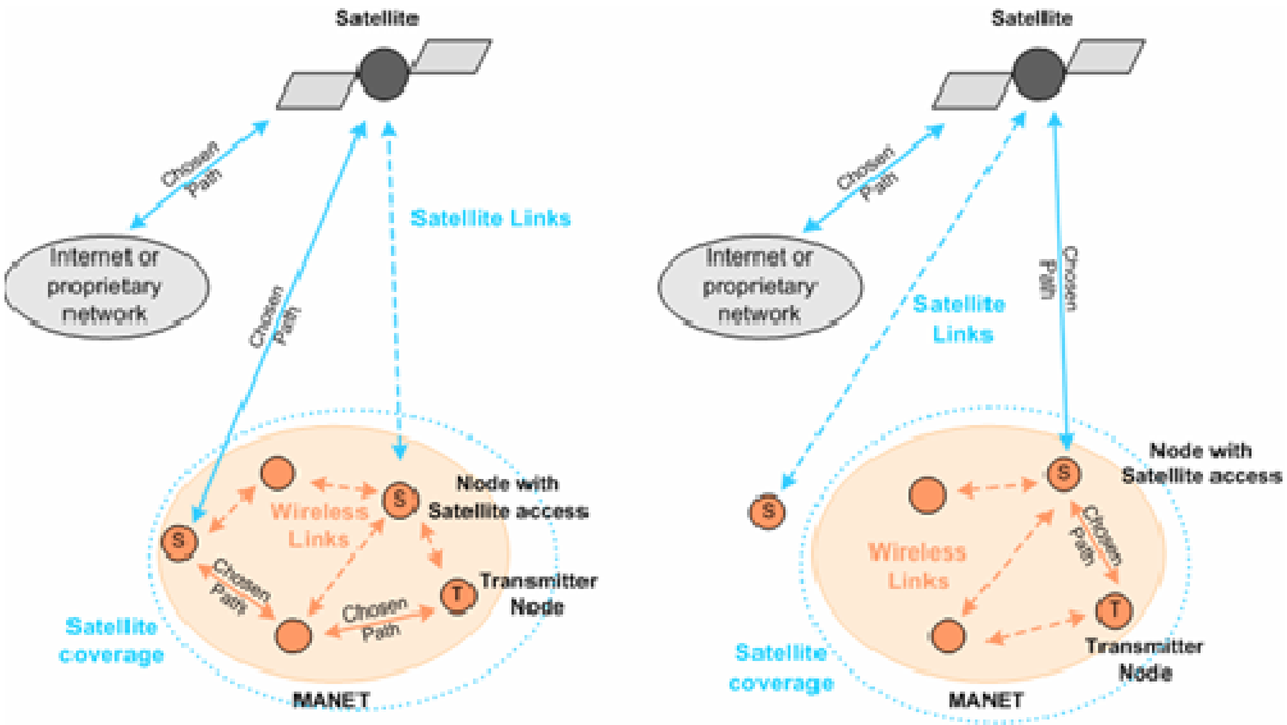
Approach

- Challenges Addressed – Satcom as relay between MANET clusters



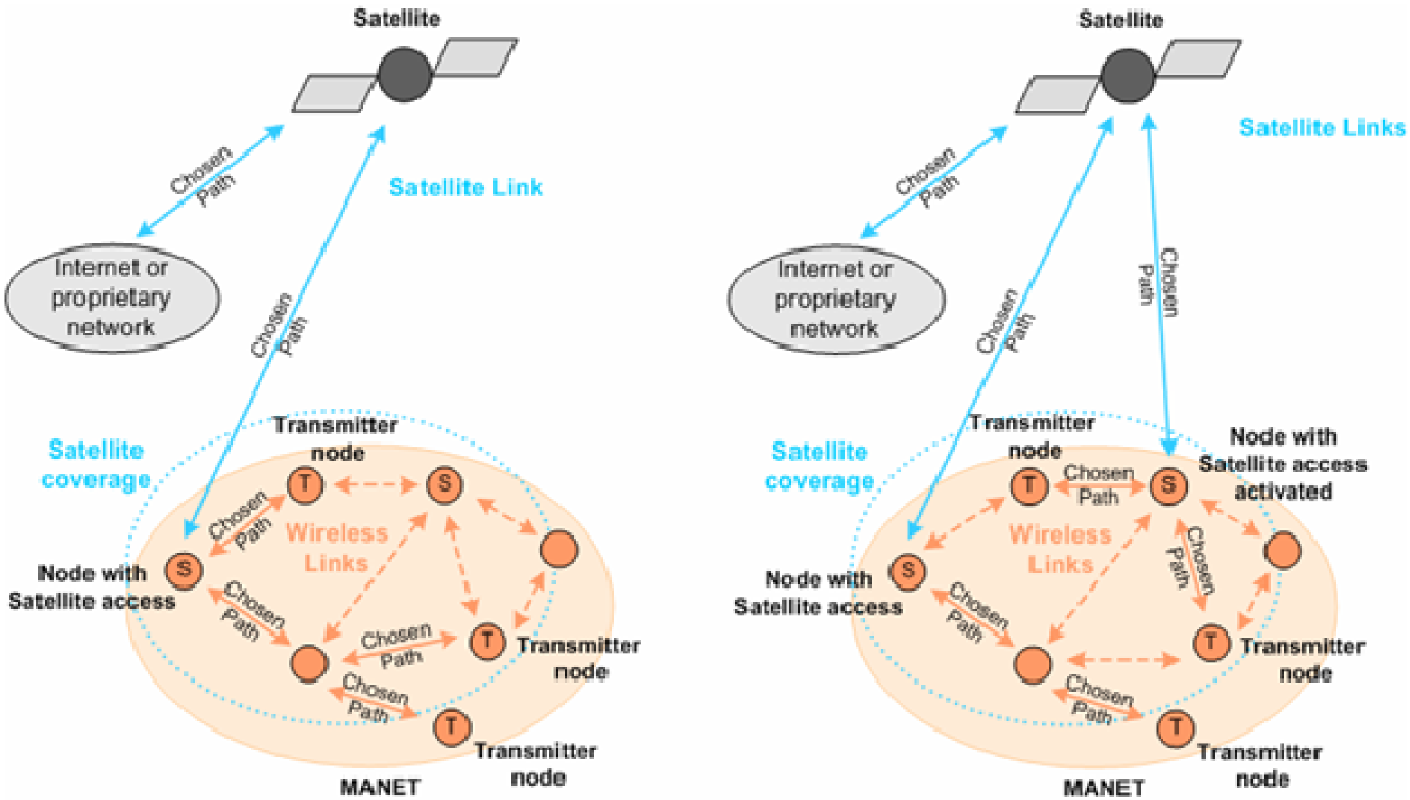
Approach

- Challenges Addressed – Automatic choice of Satellite access point



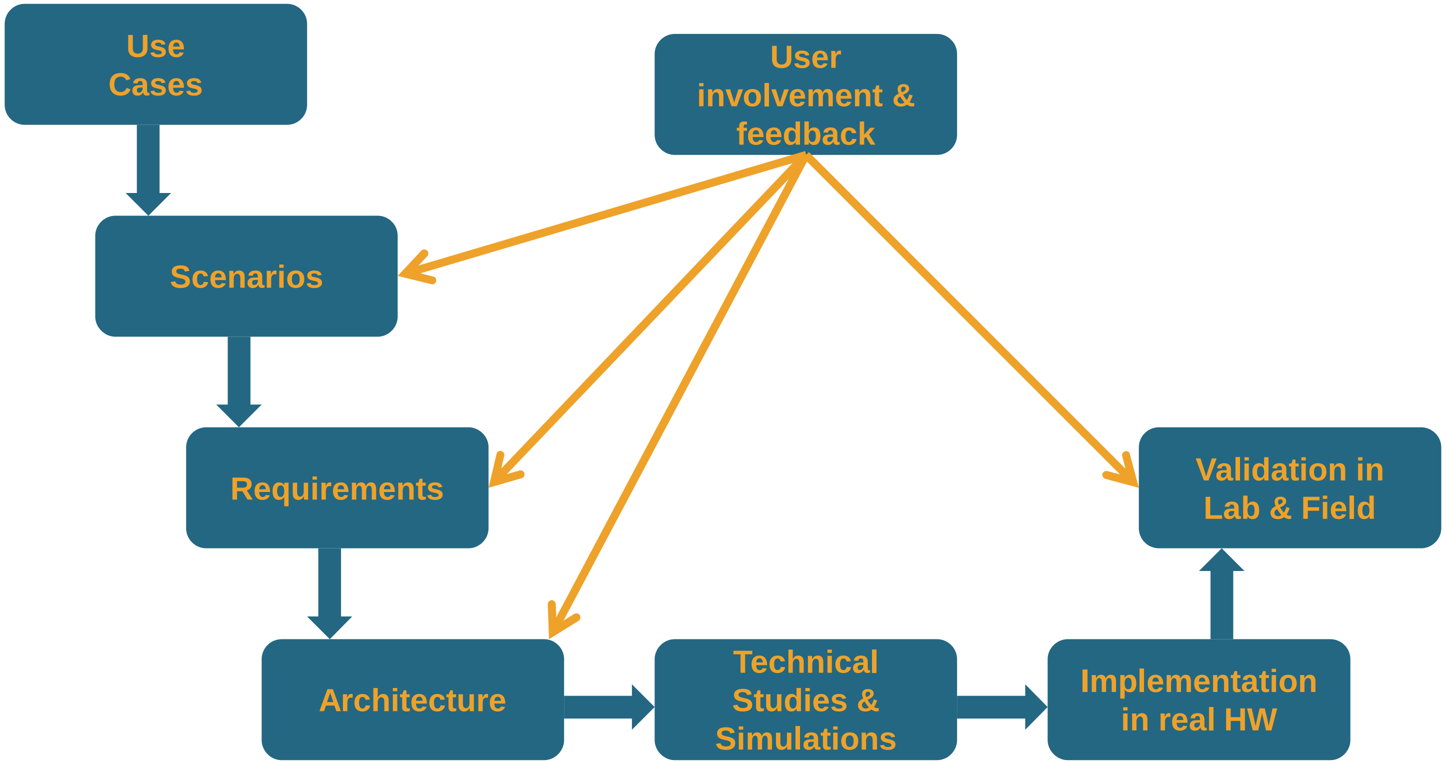
Approach

- Challenges Addressed – automatic adaptation to traffic conditions



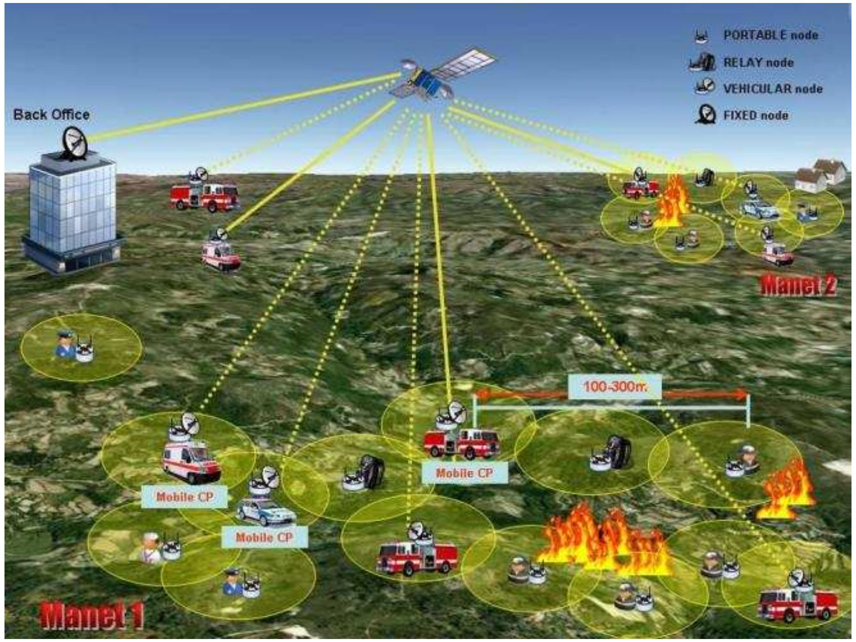
Approach

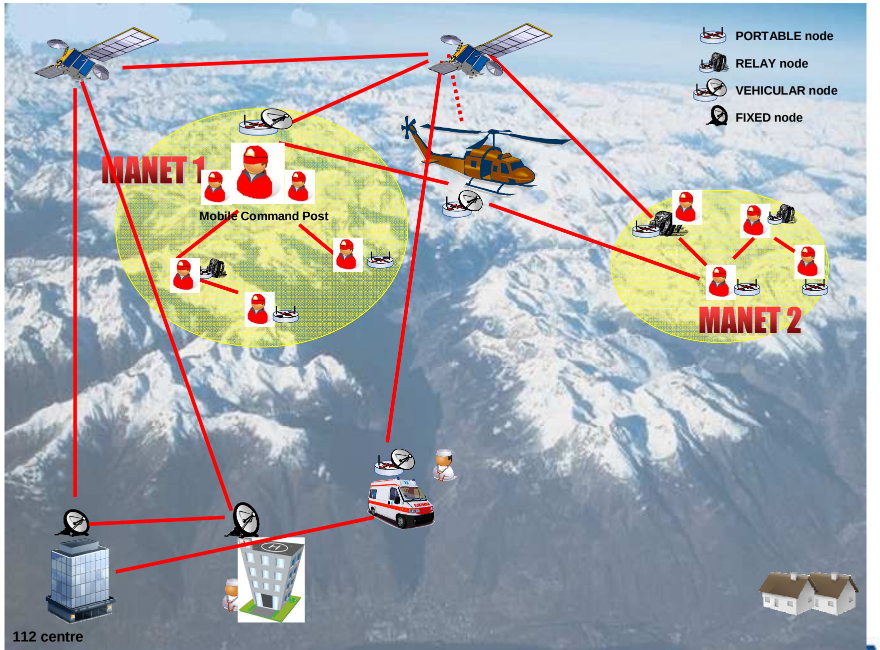
- User driven as much as possible



Approach

- **Study Scenarios designed with help from potential end-users**
  - **Emergency Comms. during/after disaster, border control…**

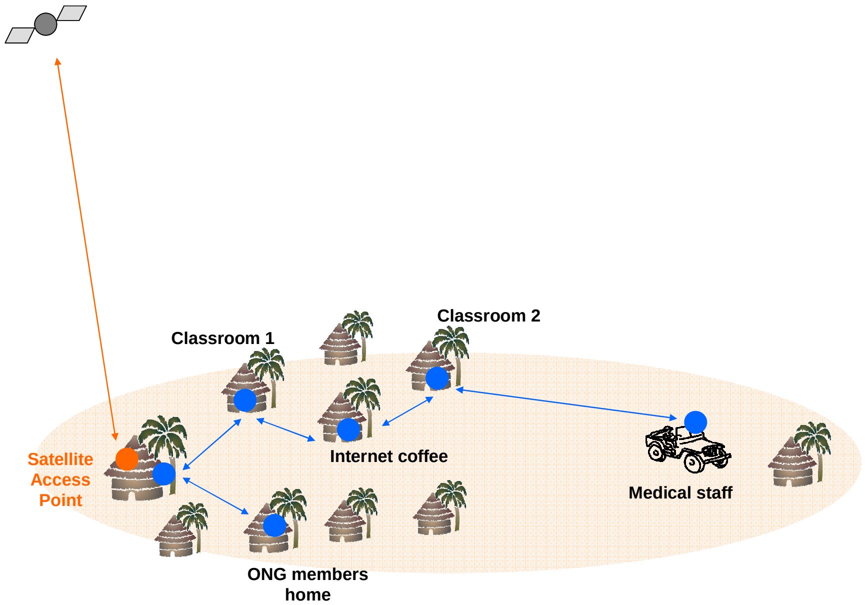


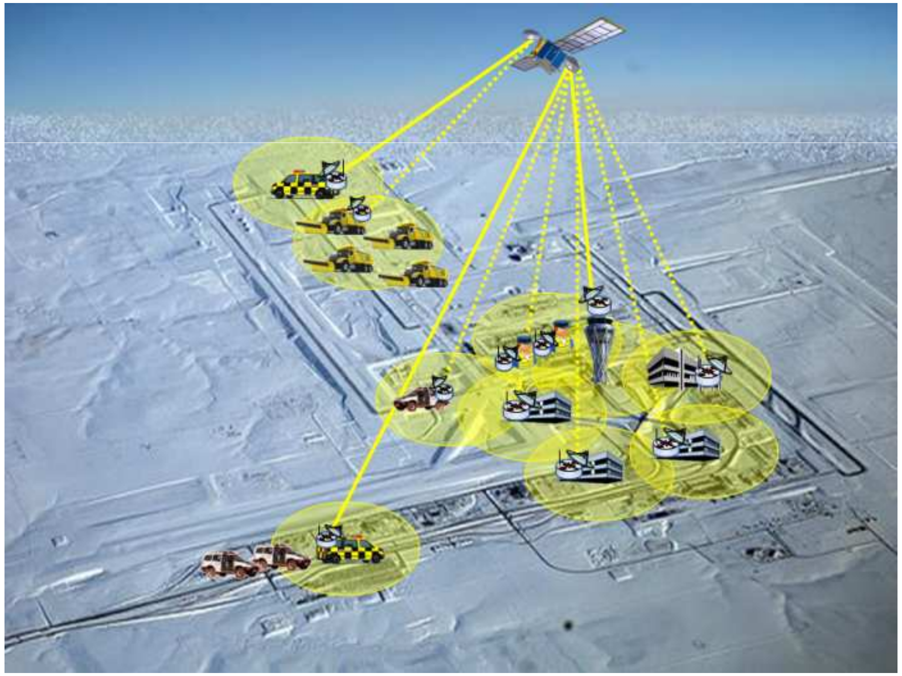


SEVENTH FRAMEWORK PROGRAMME

Approach

- **Study Scenarios (cont.)**
  - **… Remote access in rural areas, airport control**



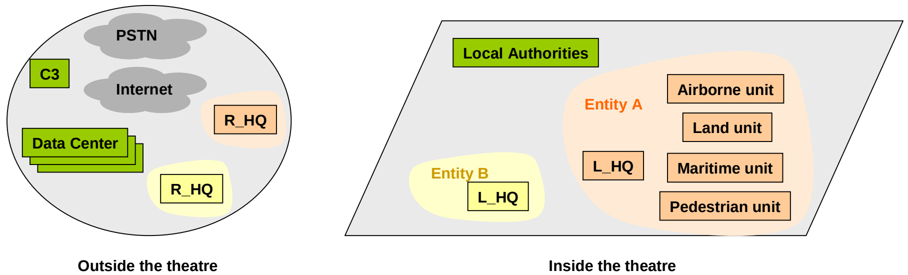


SEVENTH FRAMEWORK PROGRAMME

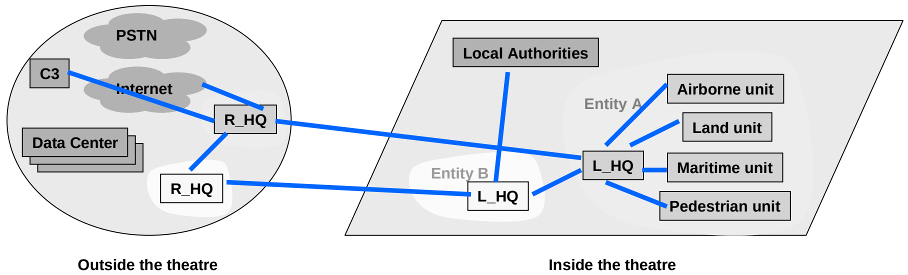
Achievements

- **Requirements**

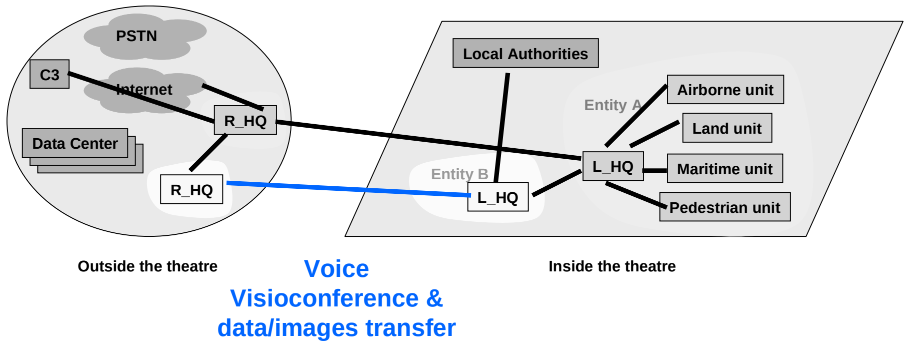
Step1
Entity & end-users identification



Step2
Connectivity requirements



Step3
Services & applications identification



Achievements

- **Requirements**
  - **Classification of traffic**
    - Based on the classification of MESA project
      - 5 classes of traffic
      - Distinction on the level of urgency and delivery of the traffic
  - **Requirements were identified WRT**
    - Connectivity
    - Mobility
    - Interfaces
    - Interoperability
    - Operational
    - Traffic and QoS
    - Security
    - Positioning
    - Data rates
    - Global capacity and Availability
    - Terminals (energy, size, weight)
    - Resilience
    - Cost

Achievements

- **MONET Architecture Approach**

- **Different node roles**
  - **Generic relay node**
  - **Satelllite access point node**

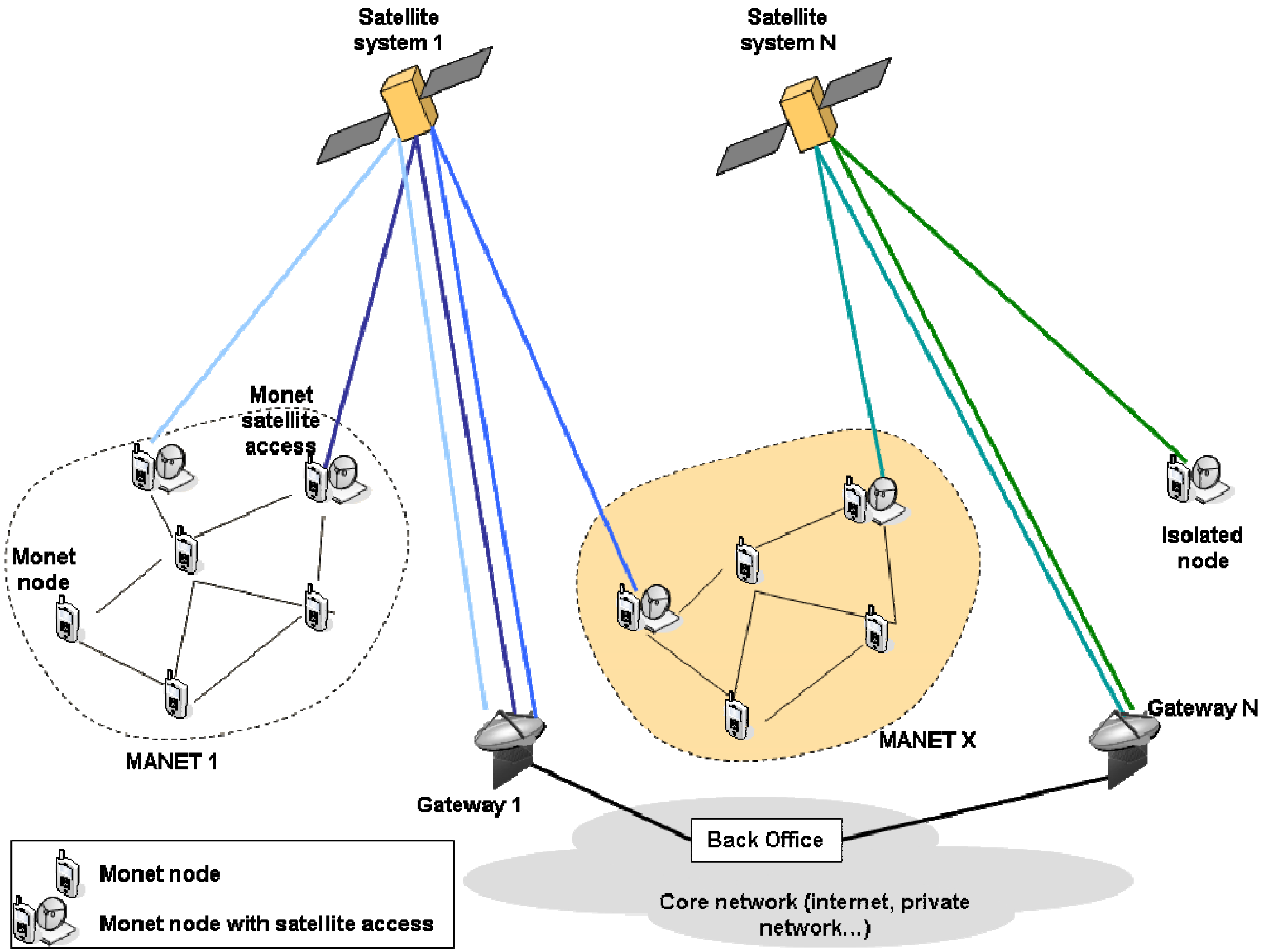
- **Support multiple radio interfaces**

- **Satellite star architecture although mesh is more interesting for MONET**

- **Mixed network management in MONET**
  - **Centralized at each cluster, usually around the satellite access point node**
  - **Distributed between different clusters**

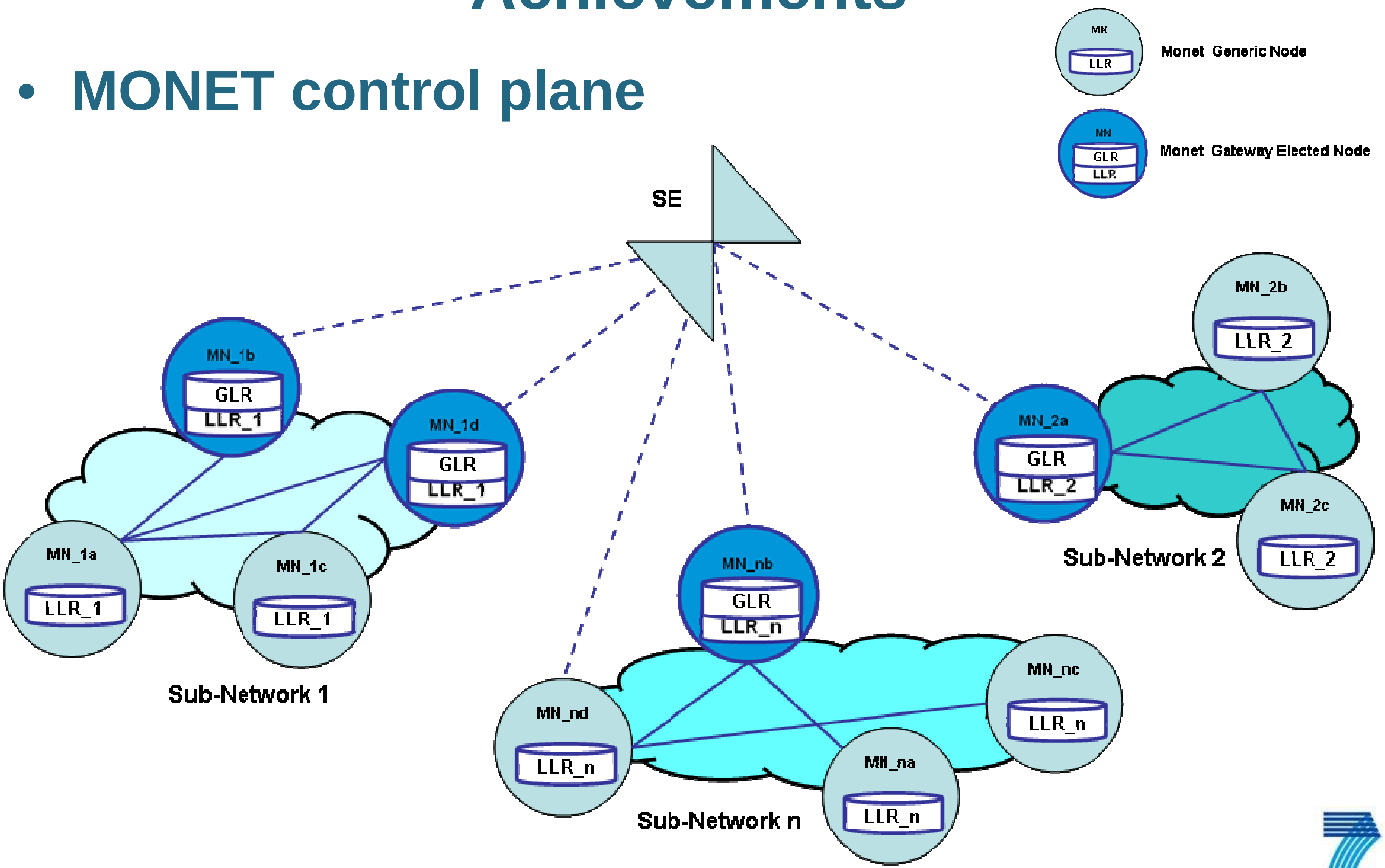
Achievements

- **MONET reference architecture**



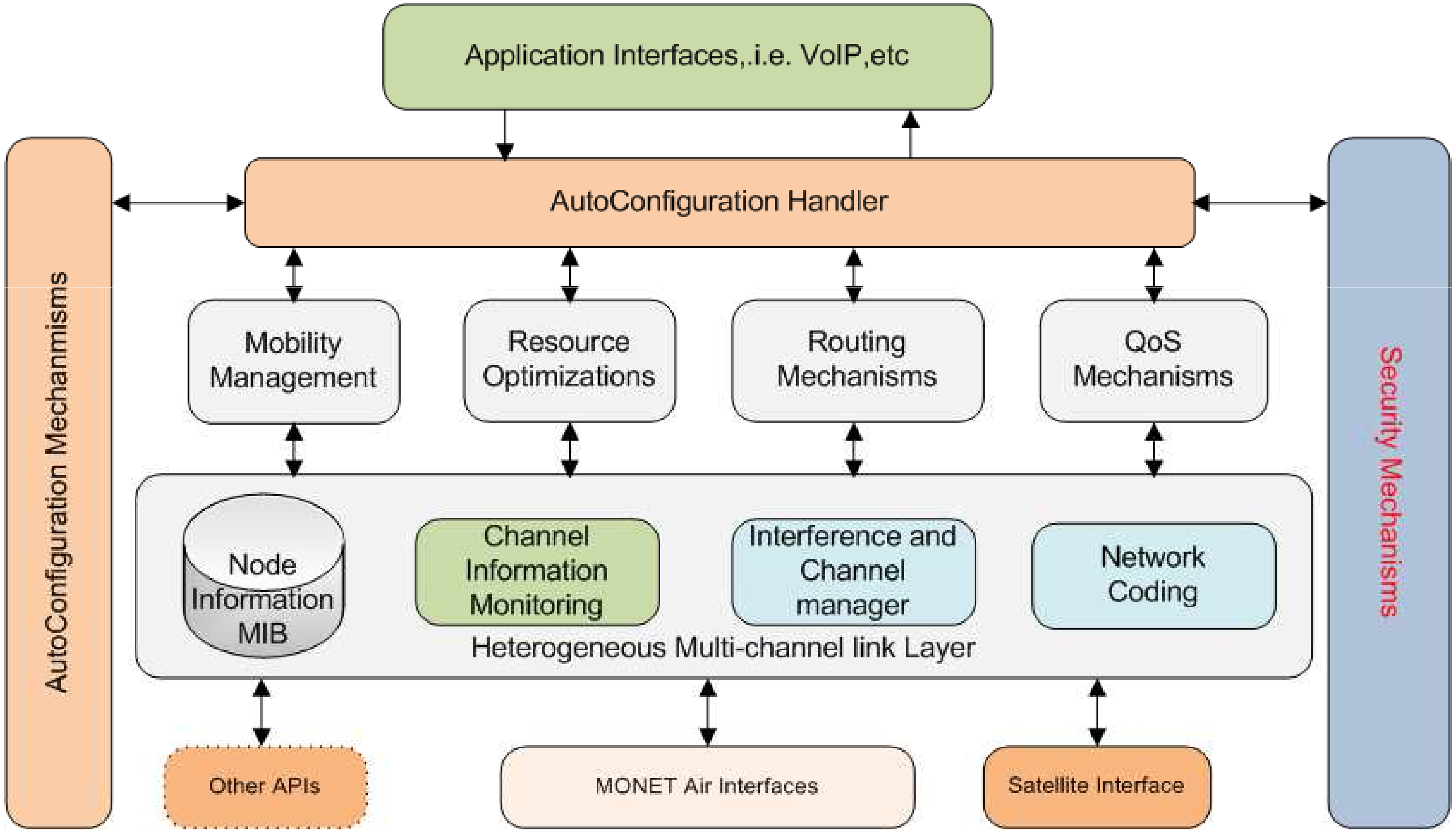
Achievements

- **MONET control plane**



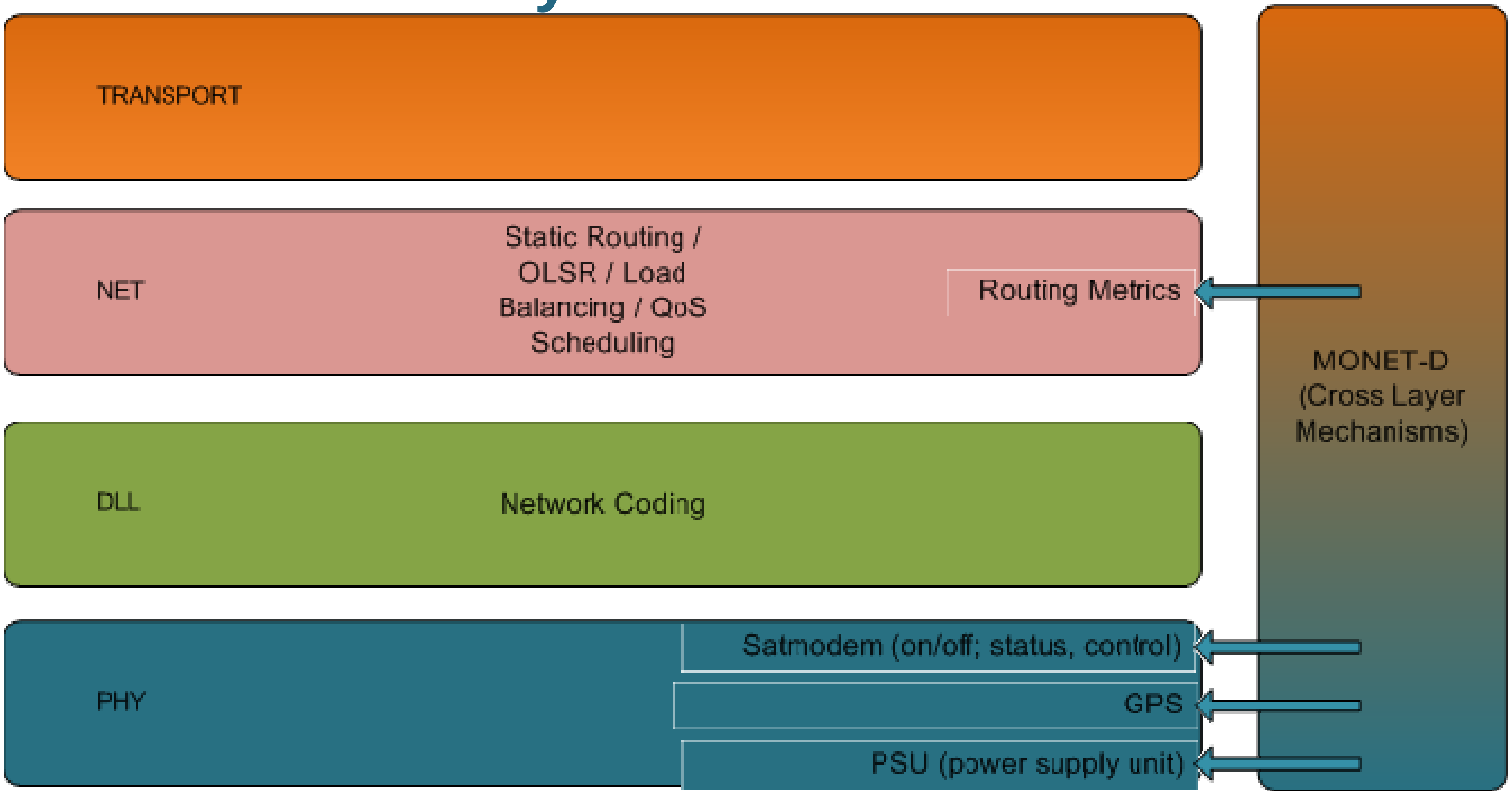
Achievements

- **MONET node architecture**



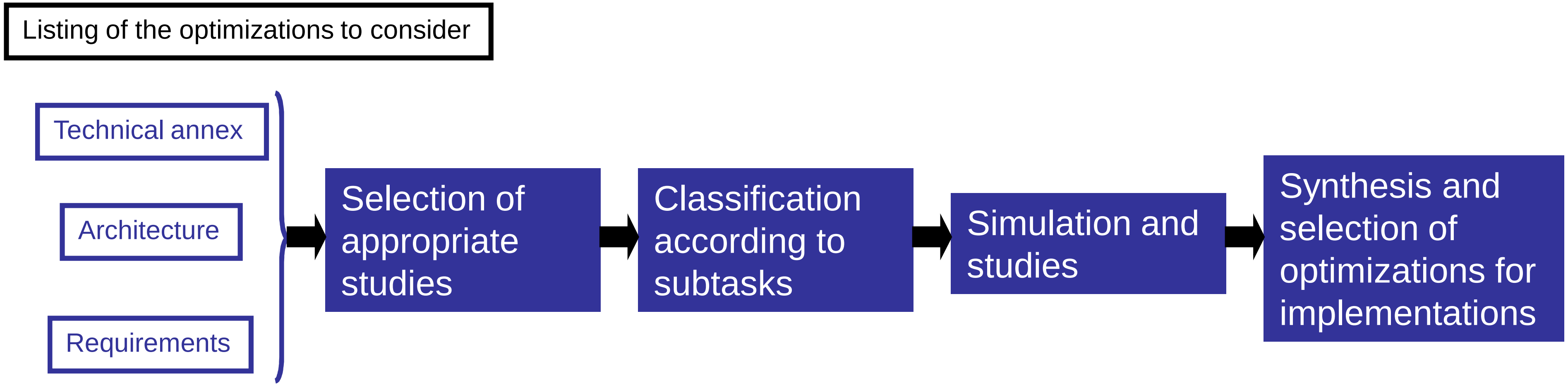
Achievements

- **MONET node layers**



Achievements

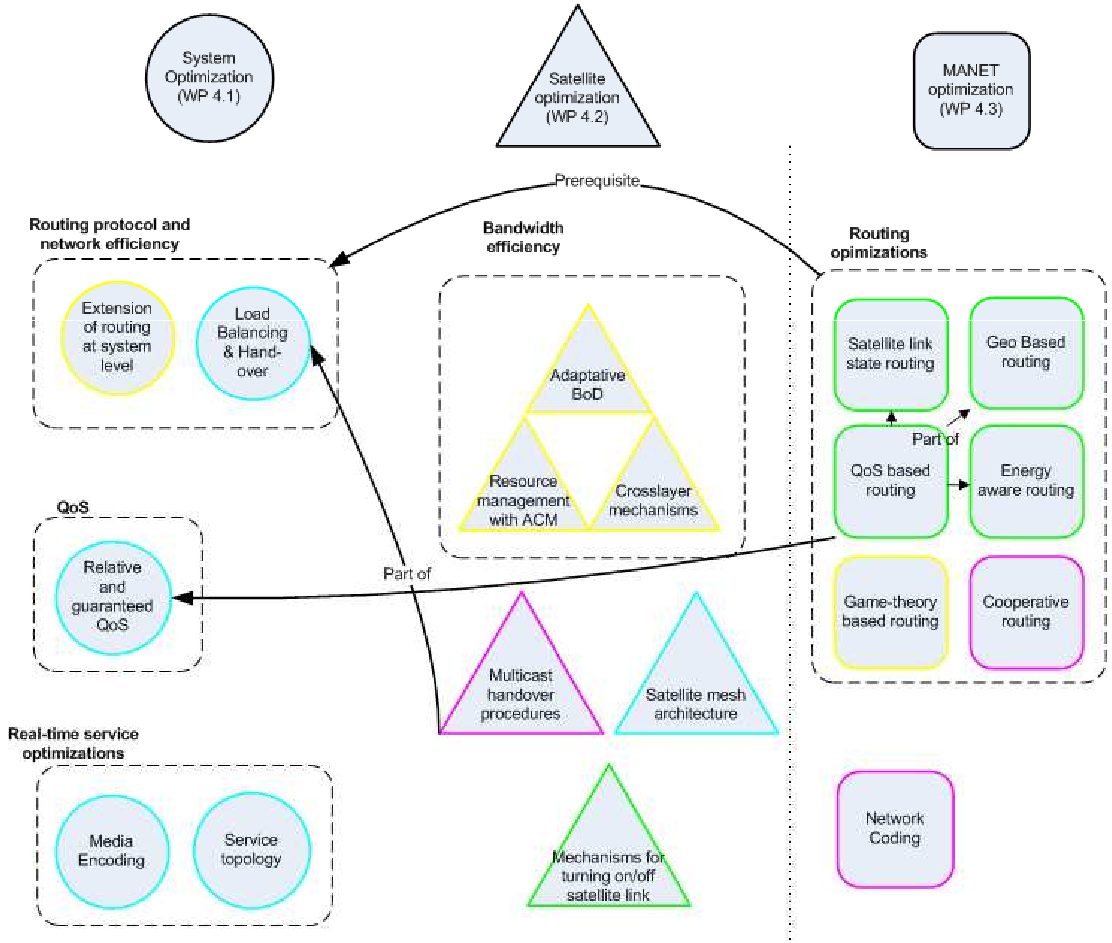
- **Technical Studies - Approach**



- **Selection based on traceability to requirements**
- **Focus on:**
  - **End-2-End – System level**
  - **Specificities of main system components**
    - **Satellite**
    - **MANET**

Achievements

- **Technical Studies considered**



Achievements

- **System level studies**

- **Extension of routing at system level – seamless handover between satellite access points when one fails using fault-tolerant Q-routing**

- **Load balancing when multiple Satlinks are available**

- **Optimized QoS scheduling scheme of differentiated services with pre-emption based on Diffserv**

- **Real time services – Session management and content transport**
  - **Service topology**
  - **Video enconding**

Achievements

- **System level studies**

- **Extension of routing at system level - Reduces packet loss substantially during handover procedure for both concentrated and distributed traffic.**

- **Load balancing improves network performance but highly dependent on scenario. Especially important when satlinks are not well distributed**

- **Optimized QoS scheduling improves latency for PTT high priority traffic, position reports and network critical data, however requires enforcement by all users to prevent starving (although guarantee depends highly on hops)**

- **Real Time services**
  - **Service topology**
    - **Satellite as backbone (for scalability purposes)**
    - **SIP for P2P communications**
    - **Multicast groups for multi-session (security Vs. flexibility; lack of control – cross-layer+multicast)**
  - **Video encoding - Network adaptive encoding**
    - **Intra application (e.g. SILK audio codec of Skype)**
    - **Extra application (e.g. scripts to apps like VLC or media player)**

Achievements

- **Satellite studies**

- **Satellite Mesh architecture**
  - **Including impacts of regenerative and OBP payloads**

- **Bandwidth efficiency**
  - **Adaptive BoD**
  - **Resource management with ACM**
  - **CAC**
  - **Crosslayer mechanisms**

- **Multicast handover procedures**

- **Mechanisms for turning on/off satellite terminal and network re-organization triggers**

Achievements

- **Satellite studies**

- **Satellite Mesh architecture**
  - Mesh reduces delays and improves multicast traffic
  - OBP improves link budget, adaptation to link conditions (FMT, ACM) reduces delays and improves connectivity

- **Bandwidth efficiency**
  - Adaptive BoD based on congestion pricing and game theory dynamically adapts queue length reducing total transmission delay (aggressive when abundant and soft when congested)
  - Resource management with ACM – focus on uplink frame structure. Dynamic framing enhances link capacity in clean sky and increases link availability under severe attenuation
  - CAC with RL with dropping control to solve MDP – ability to solve CAC online and to control blocking and dropping probabilities
  - Crosslayer mechanisms – back pressure algorithm between MAC and IP queues best performance for real-time traffic (e.g. video)

Achievements

- **Satellite studies**

- **Multicast handover procedures**
  - **Usage of anycast to adapt network to satellite access point unavailability, failure or multicast source change can reduce handover interruptions significantly (to 0-8 sec)**

- **Mechanisms for turning on/off satellite terminal and triggers**
  - **Due to power, cost, link-loss and QoS / bandwidth reasons**
    - **Passed directly to nodes instead of users**
    - **Commands or dedicated command interfaces**
    - **Hybrid terminals**
  - **Explicit and implicit triggers for network re-organization**
    - **Implementation through routing metrics and hello messages**

Achievements

- **MANET studies**

- **Multi-Interface Multi-Channel Routing**
  - **Cost aware MIMC Routing**

- **Geo-based routing for the MANET segment**
  - **Predictive – position + velocity – OLSR extension**

- **Energy aware routing for the MANET segment**
  - **Residual power + rate – OLSR extension**

- **Satlink based routing for the MANET segment**
  - **Node type, link active, link cost – OLSR extension**

Achievements

- **MANET studies**

- **Fault-tolerant and energy aware Q-routing**
  - **Proactive extension, and residual power, fault tolerance and mobility management metrics**

- **Cooperative K-anypath routing**
  - **Alternative way to support connectivity and cope with highly dynamic nodes prone to link failure (e.g. UAV)**

- **Joint Network coding algorithm**
  - **Take advantage of wireless broadcast nature of network coding to benefit MANET**
  - **Address coding-aware routing in OLSR**

Achievements

- **MANET Studies - Conclusions**

- **MIMC Routing**
  - **Improves path bandwidth stability and load balancing of the MANET by introducing interference and path load estimations in route discovery**

- **Geo-based, Energy aware and Satlink routing metrics**
  - **Reduced re-transmissions and timeout waits by using Geo-based routing**
  - **Minimum lifetime of each node and of the network increased by using energy aware routing (although e2e delay increases)**
  - **By including satlink info in routing it's possible to reduce communication costs.**
  - **Better network reaction times to battery loss and node mobility due to predictive metrics (balance between processing capability and network overhead)**

Achievements

- **MANET Studies – Conclusions**

- **Fault tolerant and energy aware Q-routing**
  - **Fault tolerance and mobility management can be achieved by extending Q-routing with energy metric and pro-activeness**

- **Cooperative K-anypath routing**
  - **Anypath routing can potentially reduce switching time for sparsely distributed nodes. Any candidate within selected path is still a shortest path**

- **Network coding**
  - **NC enhances performance and delivery ratio WRT OLSR but increases end-to-end delay slightly**

Achievements

- **Implementation – selection criteria**

- **Scalability of algorithm (based on qualitative analysis as a minimum);**

- **Feasibility of algorithm and capability to port algorithm to HW platform (i.e. ease of implementation);**

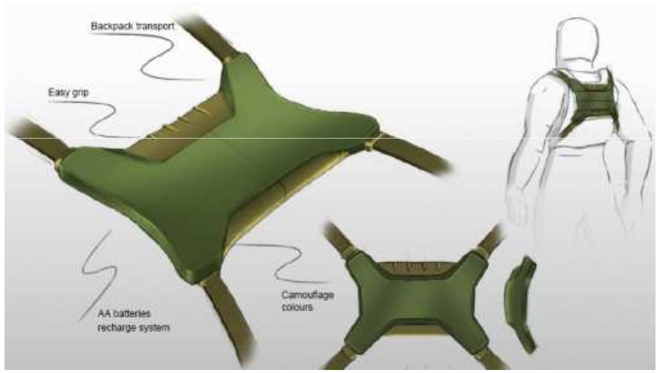
- **Relation to the requirements through correspondences made using the project's traceability matrix.**

Achievements

- **Implementation – MONET Nodes**
  - Capability to setup and operate a MANET and connect to Satellite terminals
  - Protocols and interfaces supported
  - Associated services and services cost (for the satellite);
  - Openness (capability to program the device);
  - Energy consumption and portability;

Achievements

- **Implementation – MONET Nodes**
  - **TEKEVER product – WAC**
  - **Inmarsat BGAN terminals**

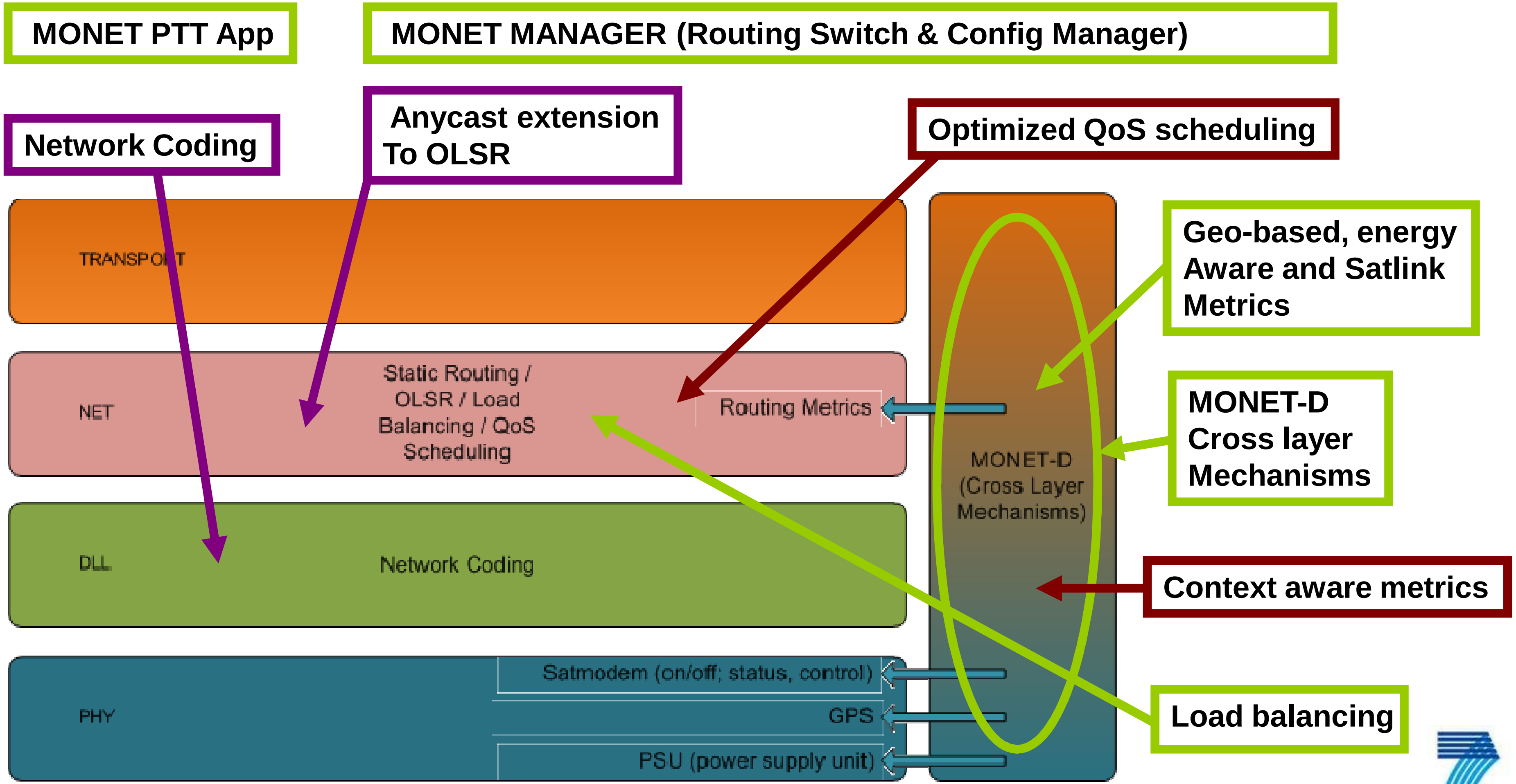


Achievements

- **Implementation**
  - Push To Talk application
  - Network routing basic protocols
  - MONET-D
  - MONET Manager (incl. routing switch and config Manager)
  - Geo-based, Energy aware and context aware routing metrics
  - Simplified Satlink based routing metric
  - Load Balancing algorithm
  - QoS scheduling
  - Anycast extension to OLSR
  - Network coding

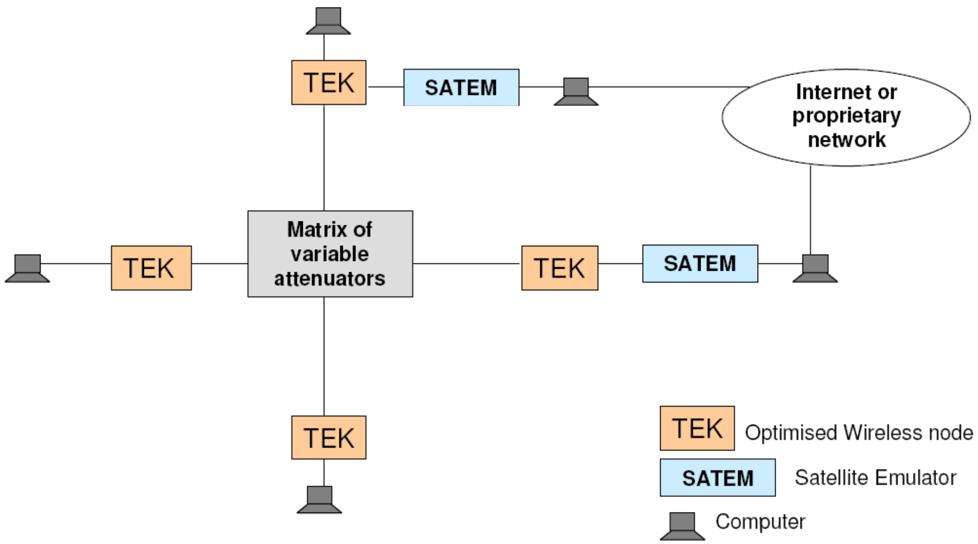
Achievements

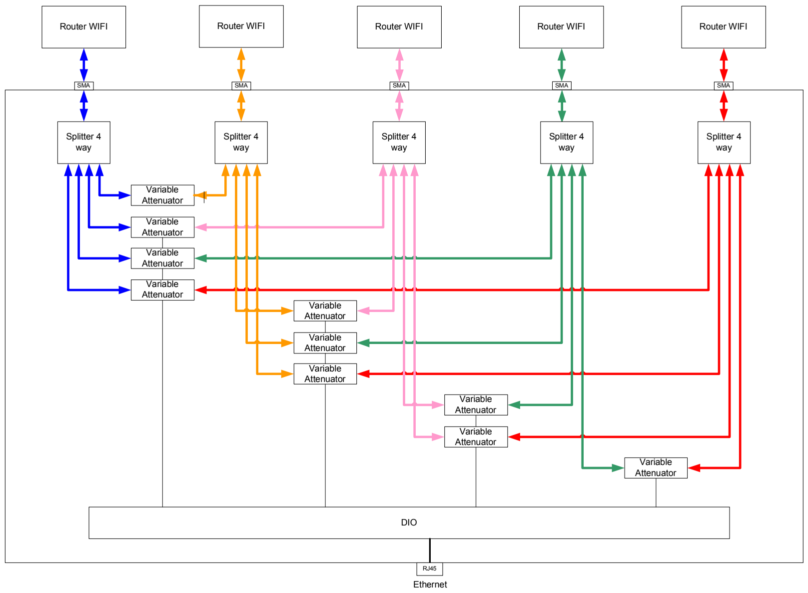
- **Implementation**



Achievements

- **Laboratory testing**
  - **HW in the loop testing using attenuation matrix to simulate and control RF environment**





Next Steps

- **Field trial**
  - **Demonstrate the advantages of using Satcom to interconnecting MANETs**
  - **Validate in the field some of the studies performed during the project (e.g. QoS, scheduling, load balancing, automatic choice of satellite access point, etc.)**
  - **To be held in Madrid on September 4th from 9:00 to 16:00**
  - **Invitations will be sent to all interested parties**
- **We are interested in your opinions and feedback**

So do get involved!

Next Steps
Field Trial Agenda

08:30-09:00	*Registration*	
09:00-09:05	Welcome	Field trial Welcome *ISDEFE - Field Trial responsible*
09:05-09:15	Individual presentations	Individual presentation of each participant and the role which they play in the project Participants: MONET members and the whole audience
09:15-09:30	MONET overview Presentation	General overview of MONET project *TEKEVER - Project Coordinator*
09:30-09:50		Field test objectives and execution *ISDEFE - Field test responsible*
09:50-10:30	*Displacement to INTA*	
10:30-11:30		MONET Field Trial Execution *MONET members and the whole audience*
11.30-11.45	*Coffee Break*	
11:45-12.45		MONET Field Trial execution *MONET members and the whole audience*
12:45-13:15	*Displacement to ISDEFE*	
13:15-14:15	*Lunch*	
14:15-15:15	MONET Field trail conclusion	Field Test questionnaire and conclusions *MONET members and the whole audience*
15:15-15:30	Wrap up and conclusions	Field Test main conclusions. Closure *ISDEFE - Field test responsible*

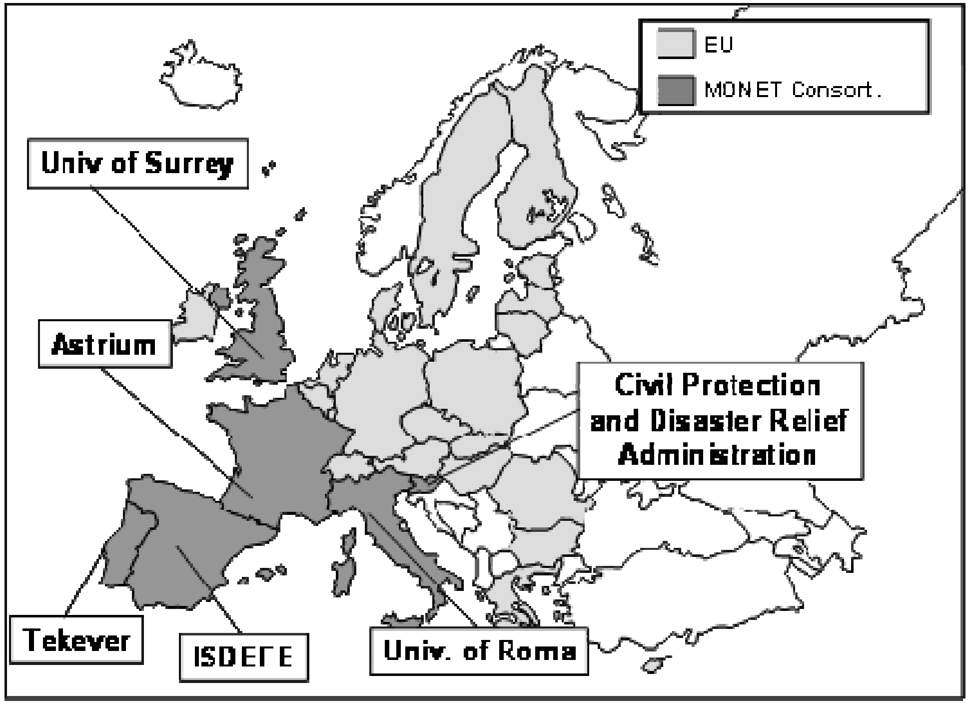
Next Steps

- **Field trial**
  - **Trial scenario developed in cooperation with end-user partner URSZR**
  - **Simulated forest fire with deployment of two teams**

SEVENTH FRAMEWORK PROGRAMME

Consortium

- TEKEVER (PT) – coordinator
  - MANET Segment optimization; MONET Node provider
- CRAT – U. Rome (IT)
  - Satellite segment optimization research; Architecture
- U. Surrey (UK)
  - MONET architecture; MANET and Satellite segment optimization
- ISDEFE (ES)
  - Scenarios definition, Requirements and Field test
- Astrium (FR)
  - System level optimization, Satellite Segment optimization and Testing
- Administration for Civil Protection and Disaster Relief (SI)
  - End-user, Scenarios definition, Requirements and Testing



Q&A

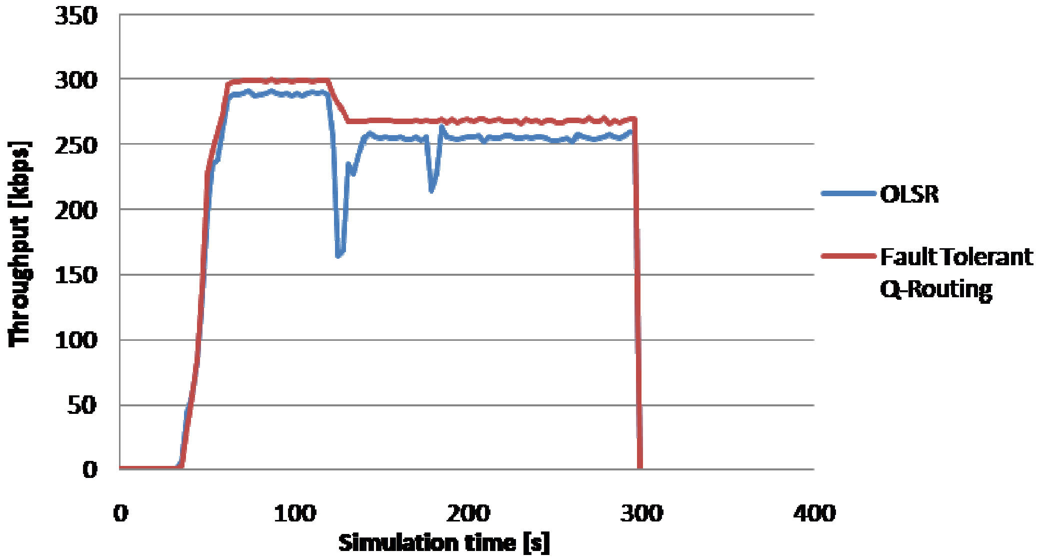
Project Contacts
Mr. André Oliveira
TEKEVER
Tel: +351 213 304 300
Fax: +351 213 304 301
Email: ict-monet@tekever.com
Project website: http://www.ict-monet.eu

Back-up Slides

Results and Feedback

Fault Tolerant System Routing - Fairly Distributed Traffic

The two gateways are used in a quite-fair way before the satellite gateway handover:

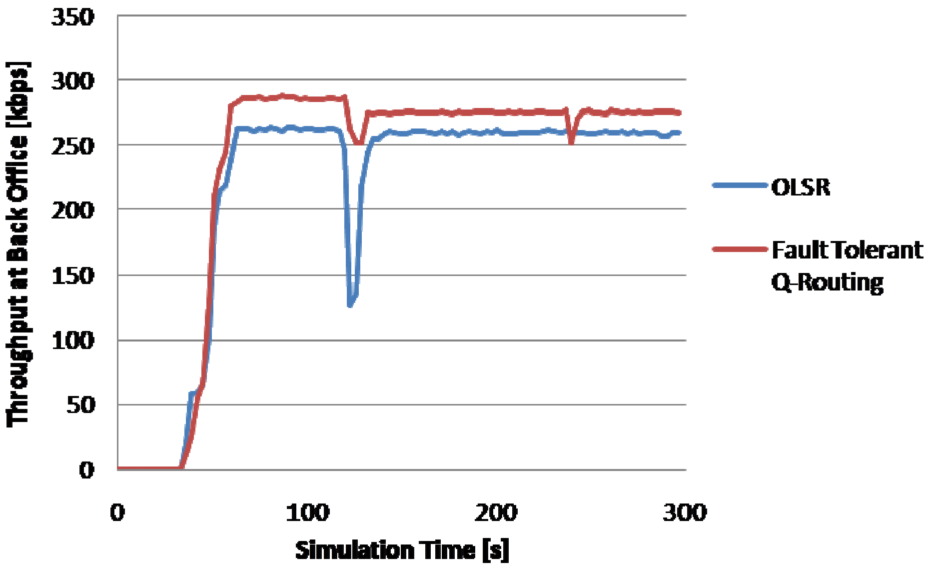


- **Fault Tolerant Q-Routing <u>perfectly</u> manages the handover without loss.**
- **OLSR produces a loss of traffic of about 33% of traffic on average along 15s of the handover procedure duration time (reaching a peak of 49% of loss at 126s).**
- **Lower throughput behaviour of both protocols after the gateway disconnection is due to the <u>increased number of collisions</u> as the traffic is <u>totally directed to a single gateway node, focusing the traffic in a single portion</u> of the rescue area.**

Results and Feedback

Fault Tolerant System Routing - Concentrated Traffic

Traffic is concentrated to the lower gateway and will be totally redirected to the upper gateway.



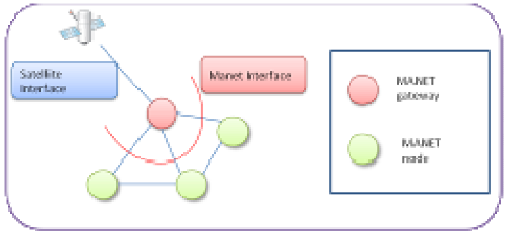
- **Also Fault Tolerant Q-Routing suffers the complete switching of traffic but in a limited way and it anyway better controls the link failure compared to OLSR protocol with a smaller loss of packets:**
  - **Shorter handover time compared to OLSR (50% less);**
  - **Throughput increase in the handover phase of about 70%.**

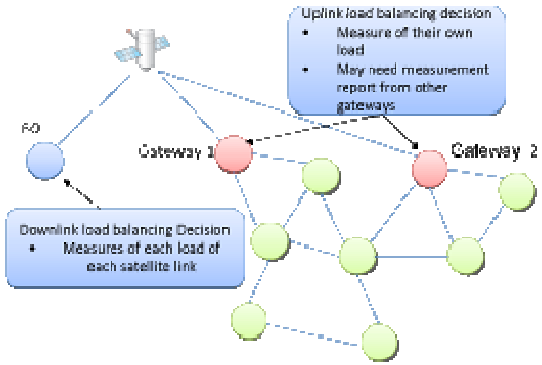
SEVENTH FRAMEWORK PROGRAMME

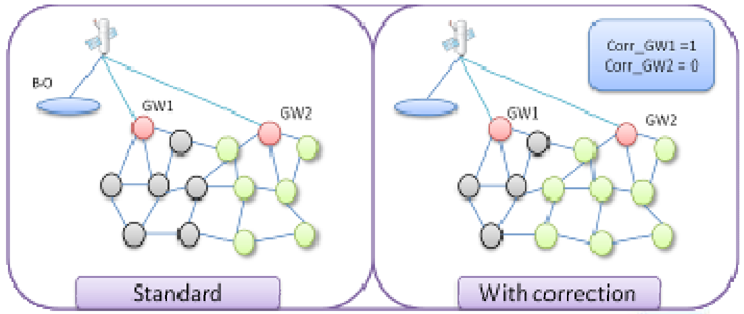
Results and Feedback

Load balancing over Gateways

- Objectives of the proposed optimization
  - Reduce double congestion issue: on the satellite link & on the MANET interface of the gateway
  - Perform per user load-balancing
  - Between several satellite links / satellite systems
- Decision implementation
  - Forward link: Load-balancer entity in the BO
    - Central entity – Limit the information exchange
  - Return link: Gateway decision
    - Need of inter-gateway exchange of information
- Execution implementation
  - Dynamic & based on threshold events
  - OLSR modified to add a correction value in routing table



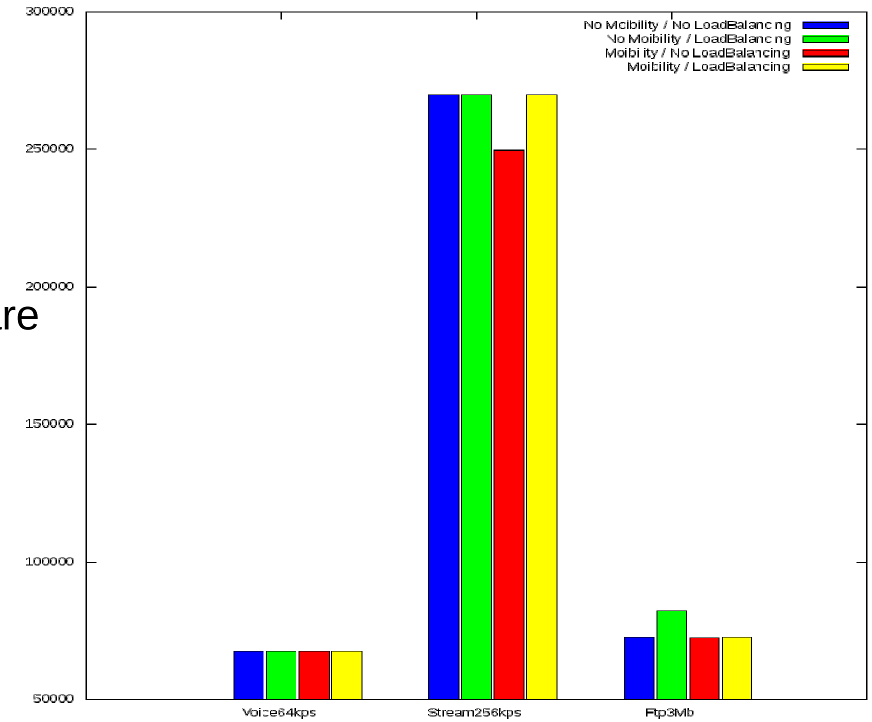




SEVENTH FRAMEWORK PROGRAMME

Results and Feedback
Load balancing over Gateways

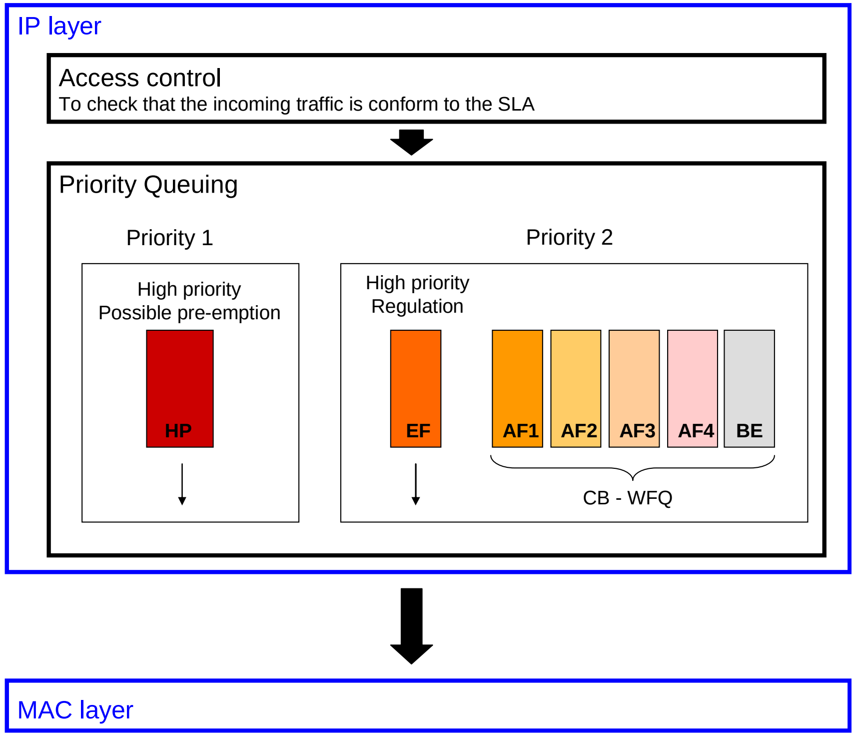
- Simulation results
  - Improve overall performances
    - Improve UDP performances – possible impact on TCP performances
  - More efficient when network partly overloaded
  - Small improvement when all the nodes are overloaded or no node overloaded



Results and Feedback
Relative & guarantee QoS

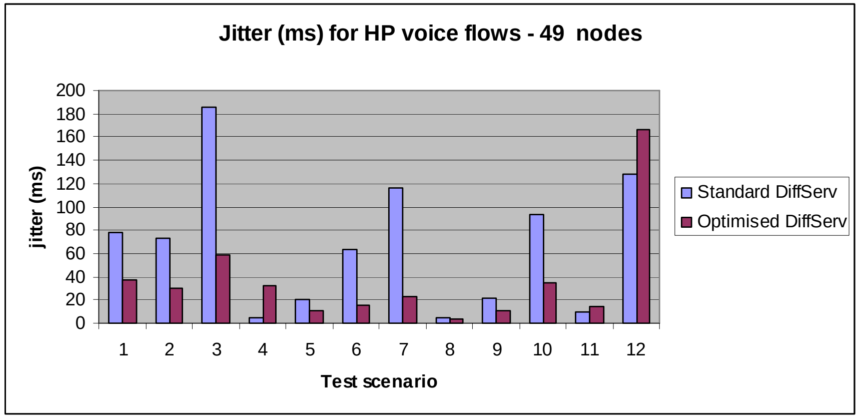
- Objectives of the proposed solution
  - Try to provide guarantee service for HP traffic
  - Minimise traffic load
  - Pre-emption mechanism for HP flows
  - Compatible with OLSR routing protocol

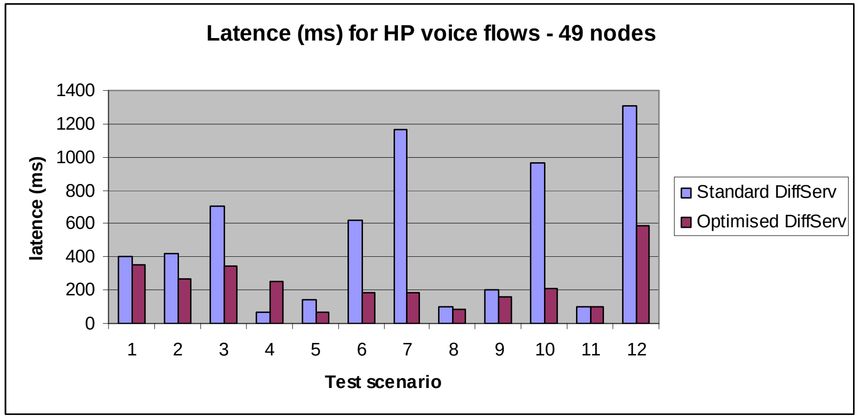
- Optimised solution
  - Access control
  - In-band signalling
  - Traffic classification based on protocols & IP address
  - WFQ combined to PQ
  - Pre-emption for HP

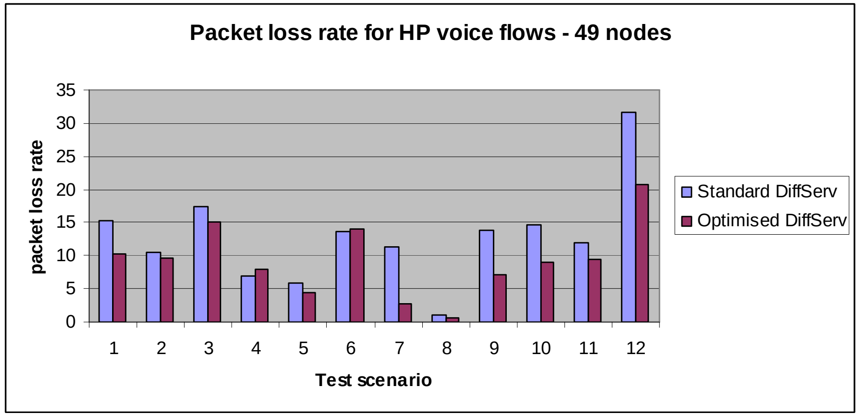


Results and Feedback
Relative & guarantee QoS

- Simulations results
  - Improved performances for HP traffic
  - HP transmitted thanks to pre-emption mechanism even when network congested
  - No major degradation of other classes' performances
  - Remark: MAC layer choice is key



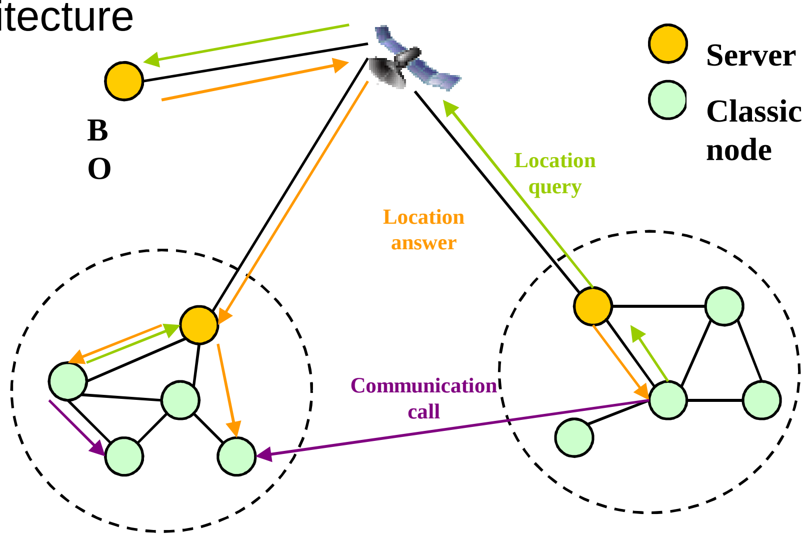




Results and Feedback

Real-time services optimization: Service architecture

- Objectives of the proposed solution
  - Provide a reliable multimedia session architecture
  - Take into account MONET specificities
  - Minimize additional traffic generated
  - Ensure scalability

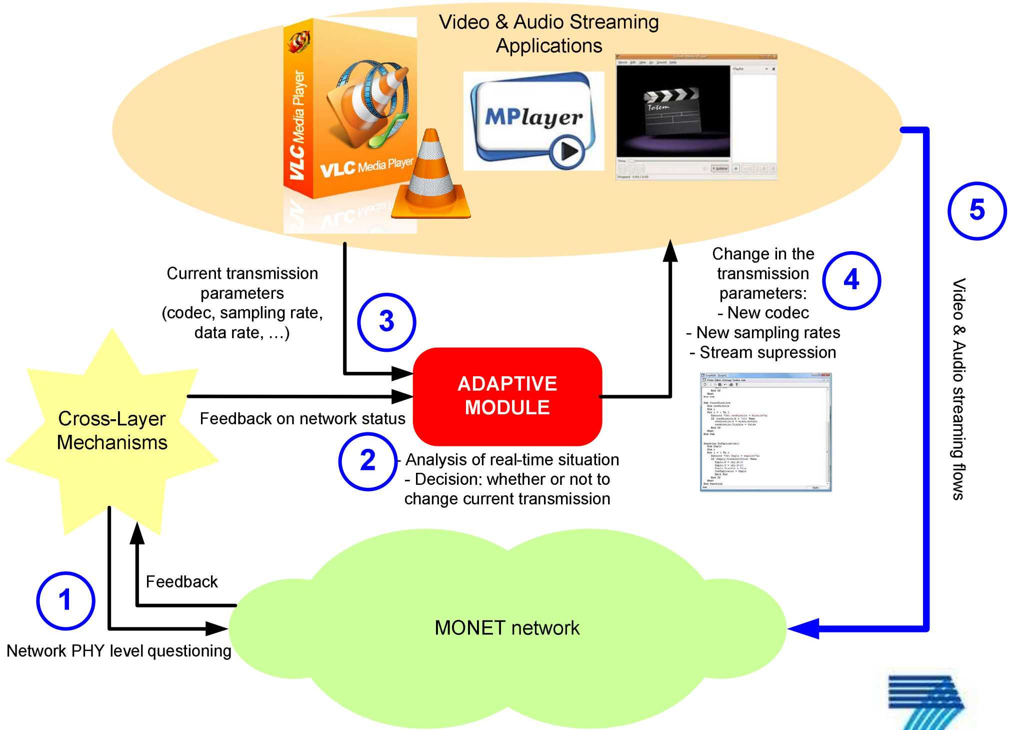


- Concept:
  - Semi-distributed approach
    - Each MANET elects a server node for service publication
    - The server nodes coordinates through the satellite link and the Back-Office
  - The server nodes are in charge for advertising its MANET nodes services
  - Resiliance is ensured by the election of a deputy server node
  - Multi-user is done by multicast signalling (reduces overhead)

Results and Feedback

Real-time services optimization: Codec enhancement

- Bit rate adaptation
  - Assessment of the several possible levels of optimisation
    - Network-adaptive video coding, feedback from network conditions over protocols, dedicated QoS, efficient routing algorithms, cross-layer optimizations
- Network adaptative coding
  - Application external adaptation including cross-layer
  - Intra-applications adaptations:
    - Auto-adaptative codec
    - Adaptative applicatons
    - Smooth Adaptative Streaming



Results and Feedback
Mesh vs Star architectures

- Benefits for MONET from OBP techniques
  - Improve link budget efficiency

    Separation between up and down links allows a potential gain of 3dB on the overall link budget (avoid to amplify noise & interf. from the uplink on the downlink) + satellite amplifier can operate close to saturation with one single carrier.
  - Adaptation to link conditions

    Separation between up and down links allows to adapt transmission parameters to the atmospheric propagation (FMT – Fade Mitigation Techniques)
  - Smaller terminal

    Link budget gain can be used either to improve performances or to reduce terminal size.
  - Improve reactivity

    Hub less architecture (regenerative OBP payload) – satellite control access and resources allocation performed on board.
  - Improve connectivity

    Connectivity can be improved thanks to transparent OBP payload and fully flexible & dynamic with regenerative OBP payload. Possible cross-beam and cross-band connectivity.

Results and Feedback

Mesh vs Star architectures

- Benefits for MONET from MESH topology
  - Improve delay

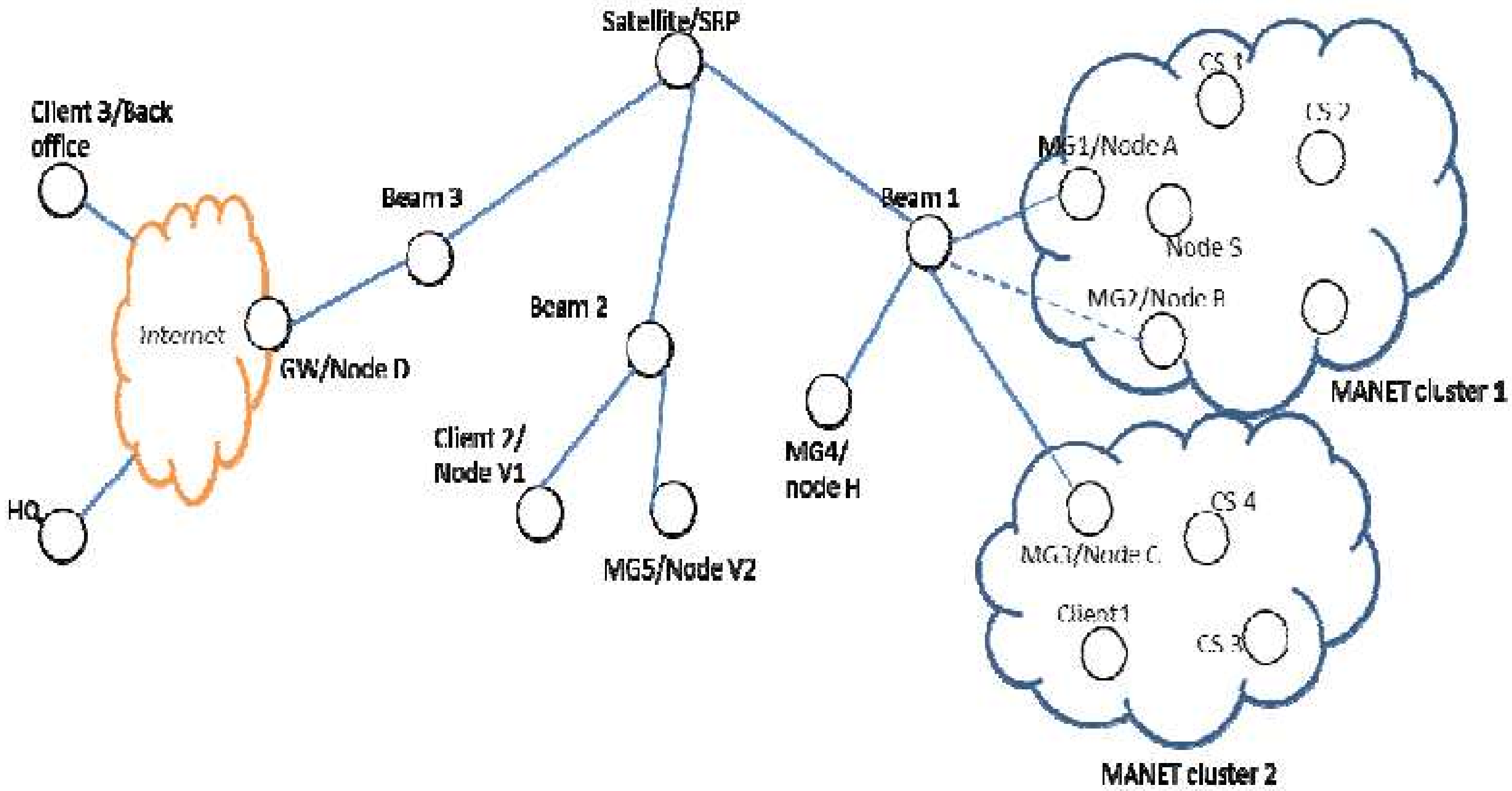
    Reduce latency between the source & destination by avoiding double satellite hops. Impact on real-time traffic like VoIP and on TCP performances.
  - Improve spectral resource use

    Reduce bandwidth usage on the satellite-gateway link.
  - Multicast traffic

    Switching or routing on-board allows to duplicate the traffic on-board, and the satellite can takes benefit from its broadcast position.

Results and Feedback
Satellite as Access Point or Relay among MANETs

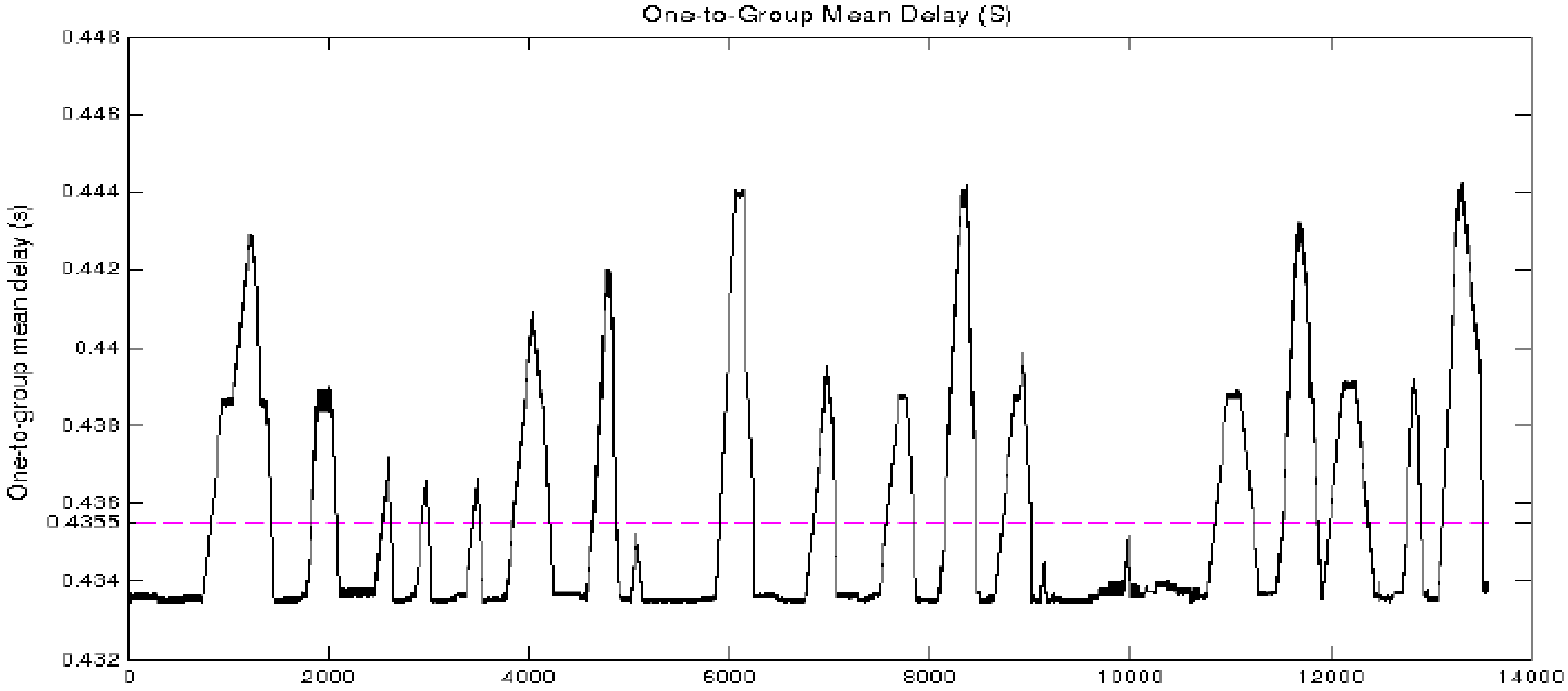
- Simulation on multicast handover



SEVENTH FRAMEWORK PROGRAMME

Results and Feedback
Satellite as Access Point or Relay among MANETs

- Delay and variance



SEVENTH FRAMEWORK PROGRAMME

Results and Feedback
Frame Optimization

Example (SATIP6)

Fade M… (FMT)

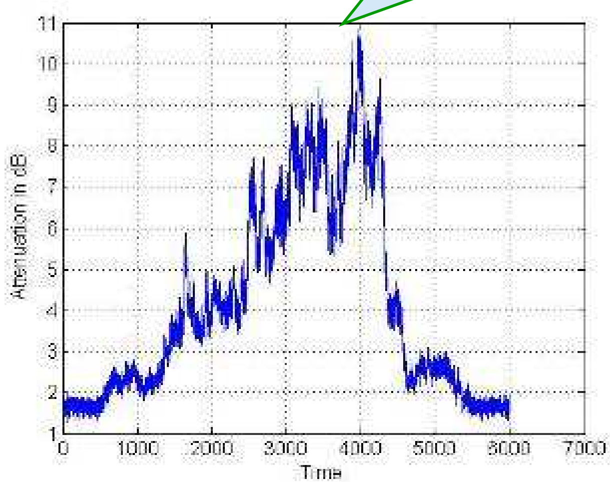
DV… ate ac…

Av… ic Rat… (DRA) scheme

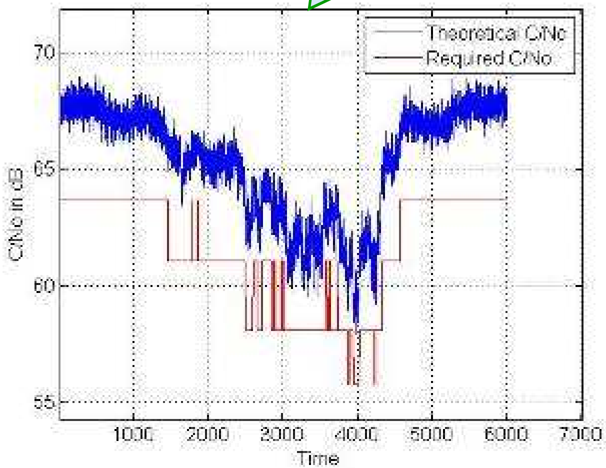
Simulated rain attenuation time series for an uplink availability of 99.9%

The C/N0 … the codin… scheme a… according…

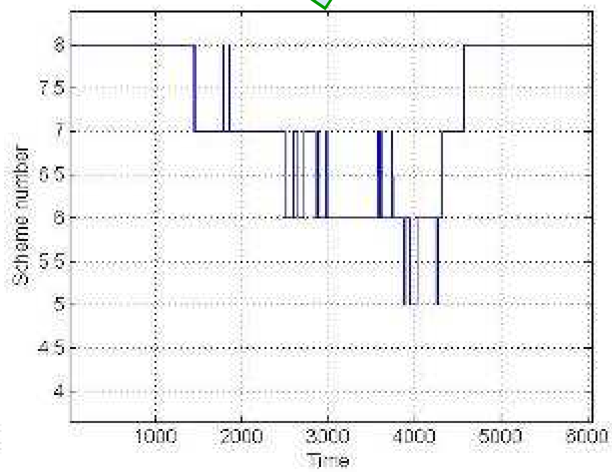
The packet loss ratio is decreased at the price of reducing the information bit rate



Rain event with maximal attenuation of 11 dB



Return link, individual terminal: theoretical and required C/N0

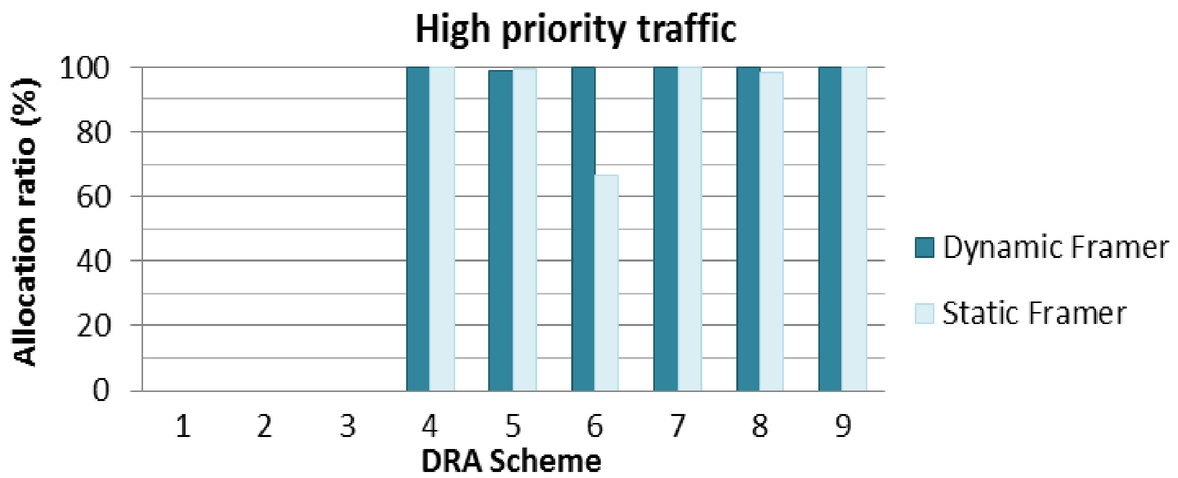


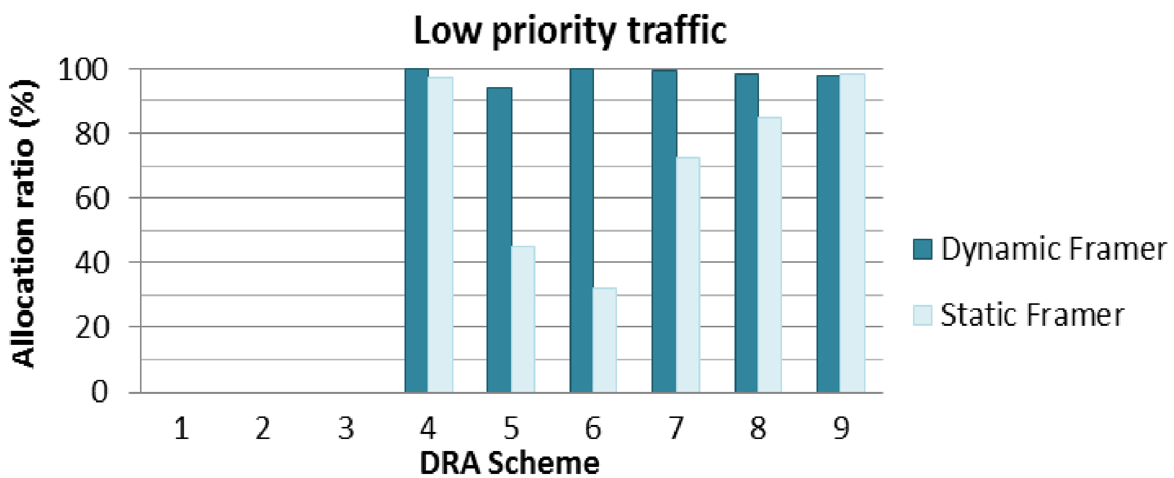
Return link, individual terminal: evolution of the DRA schemes

SEVENTH FRAMEWORK PROGRAMME

Results and Feedback
Frame Optimization

Simulations





SEVENTH FRAMEWORK PROGRAMME

Results and Feedback
Frame Optimization

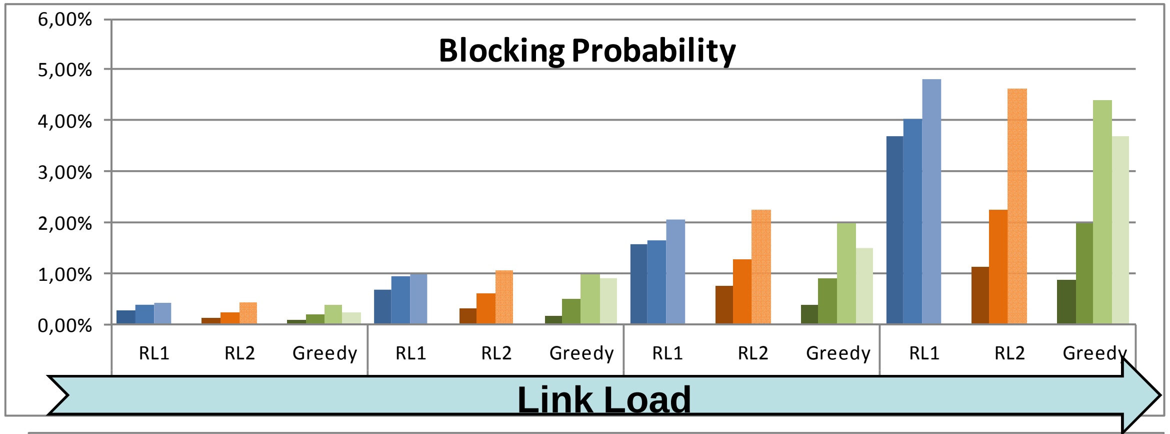
Conclusions

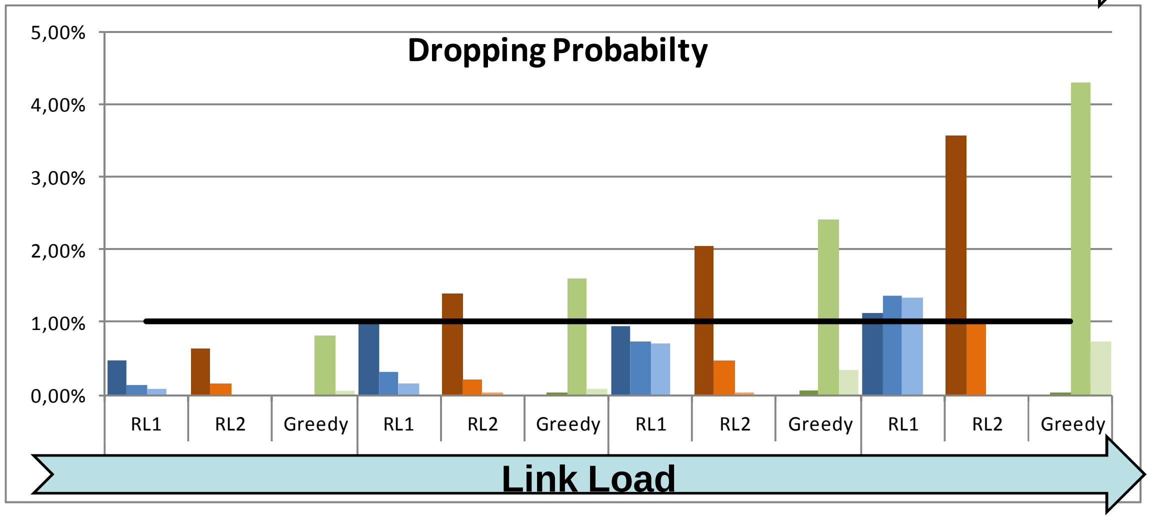
ACM important for the MONET system to

- **increase the <u>satellite network efficiency</u>**
- **increase the <u>satellite link availability</u>**
  - **<u>satellite link available also in fading conditions</u> thanks to the ability of changing coding and modulation schemes**

Results and Feedback
Admission and Dropping Control

Simulation results





Greedy
- **Accept whenever is possible**

RL1
- **Maximum load + fairness + dropping probability constraints**

RL2
- **Maximum load**

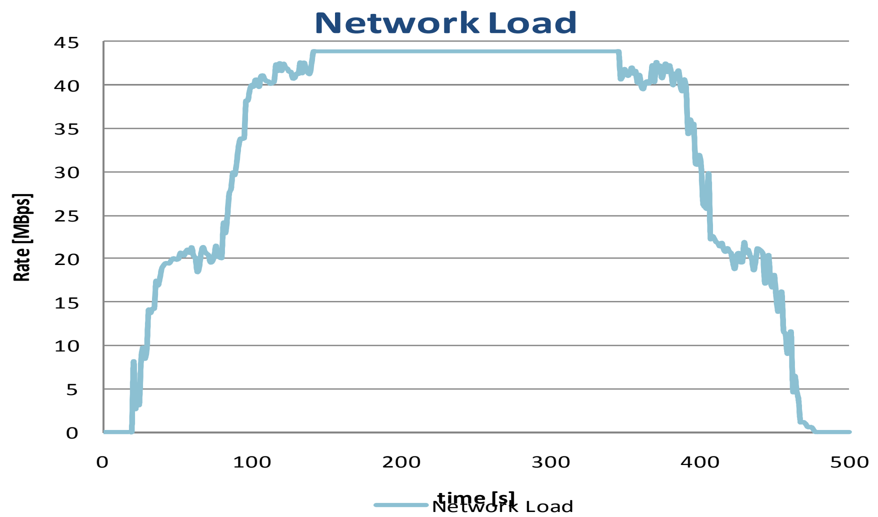
Results and Feedback
Admission and Dropping Control

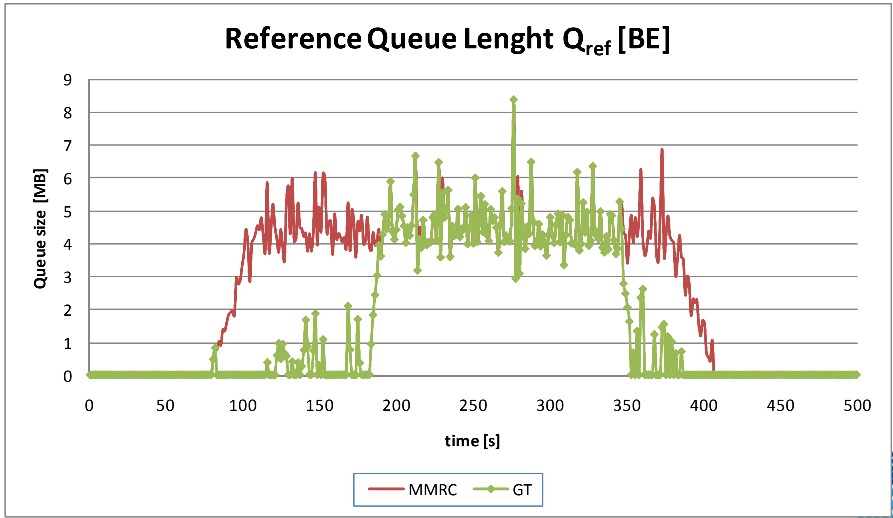
Conclusions

- **Practical approach to admission and dropping control in networks with time-varying link capacity**
  - **Exploit the existing MDP framework to define a constrained MDP**
  - **Define an unconstrained MDP via the Lagrangian approach**
  - **Develop a Reinforcement Learning algorithm to solve on-line the MDP**
- **Beside the standard admission policy, the algorithm returns a dropping policy to control the call dropping due to the variable link capacity and to guarantee the PTT class**
- **CAC important for the MONET system to**
  - **increase the satellite network efficiency**
  - **provide effective pre-emption mechanisms for high priority calls (e.g. for push-to-talk classes)**

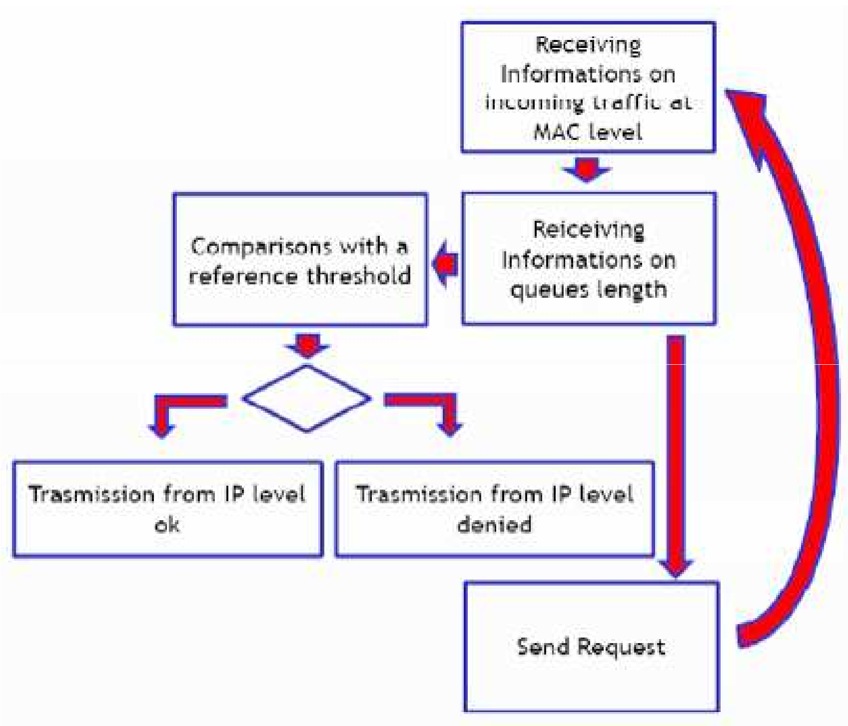
Results and Feedback
Dynamic Bandwidth Allocation – Simulations

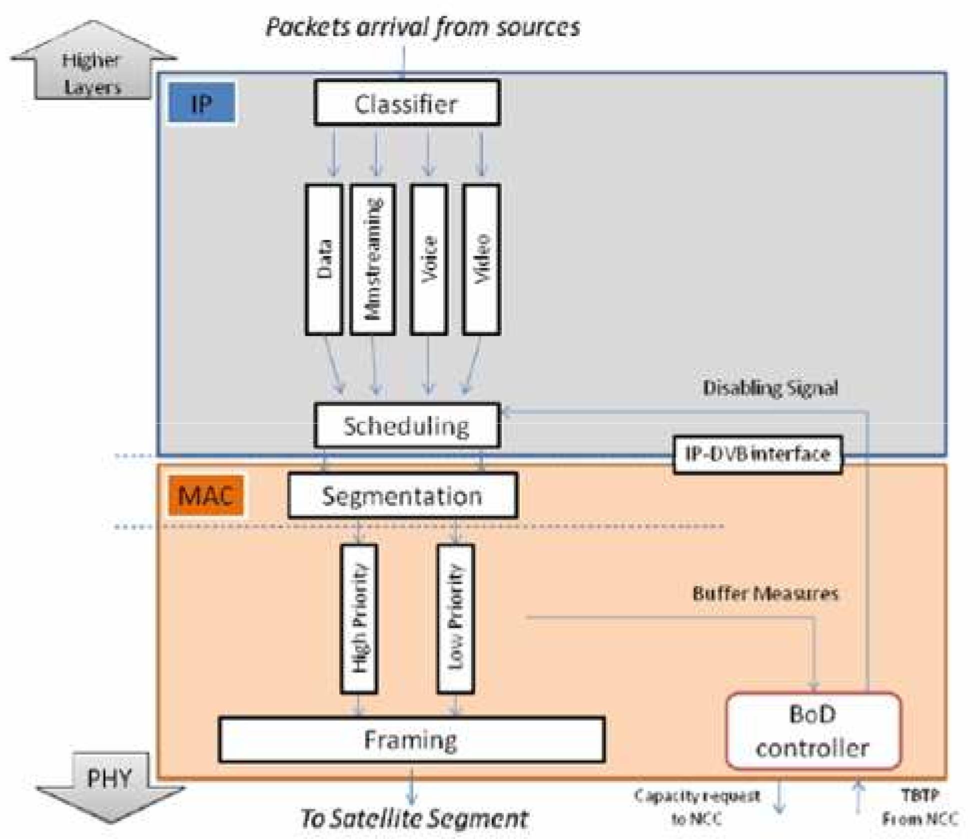
	ST0	ST1	ST2	ST3
Voce [RT] (64 kbps)	8	8	8	8
Flusso Multimediale [CD] (128 kbps)	6	6	6	6
Video [CD] (800 kbps)	6	6	6	6
Dati [BE] (1000 kbps)	8	8	8	8
Tempo Inizio Trasmissione (sec)	20	80	140	200
Tempo Fine Trasmissione (sec)	440	380	320	260





Results and Feedback
Cross Layer – Back pressure approach



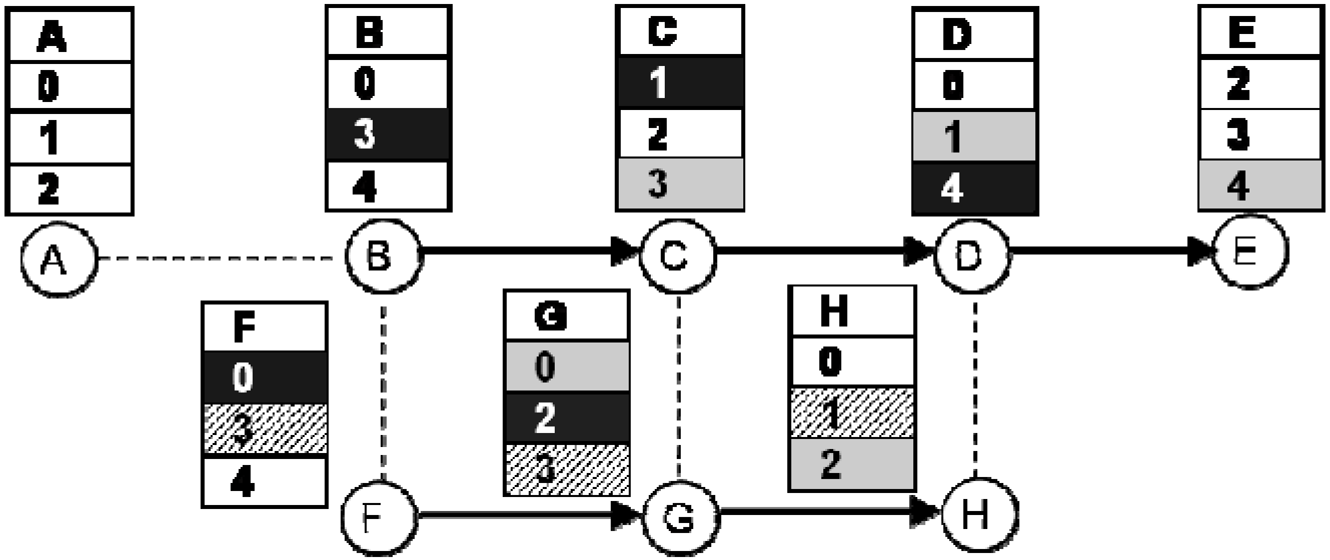


SEVENTH FRAMEWORK PROGRAMME

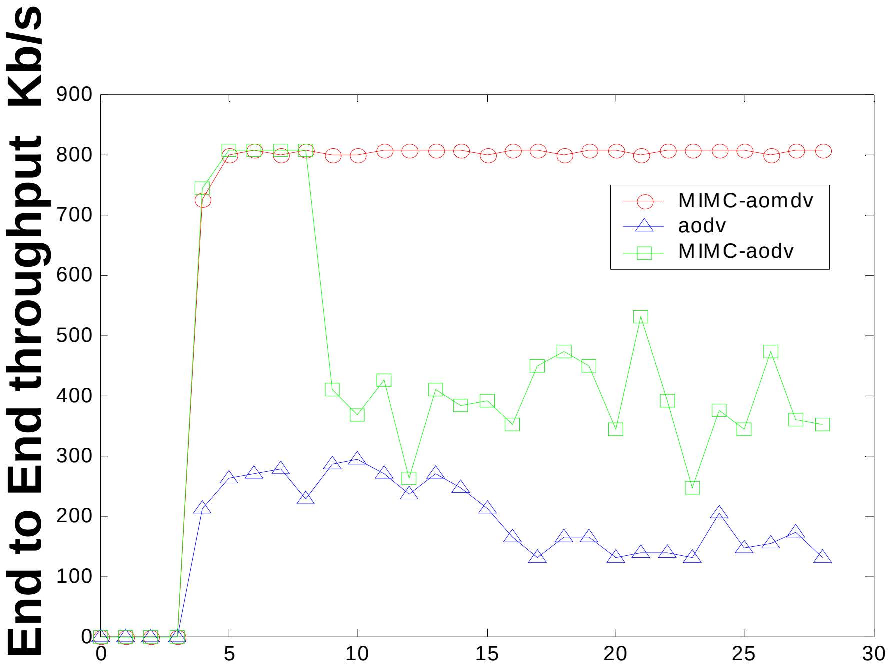
Results and Feedback

Multi-Interface Multi-Channel Routing

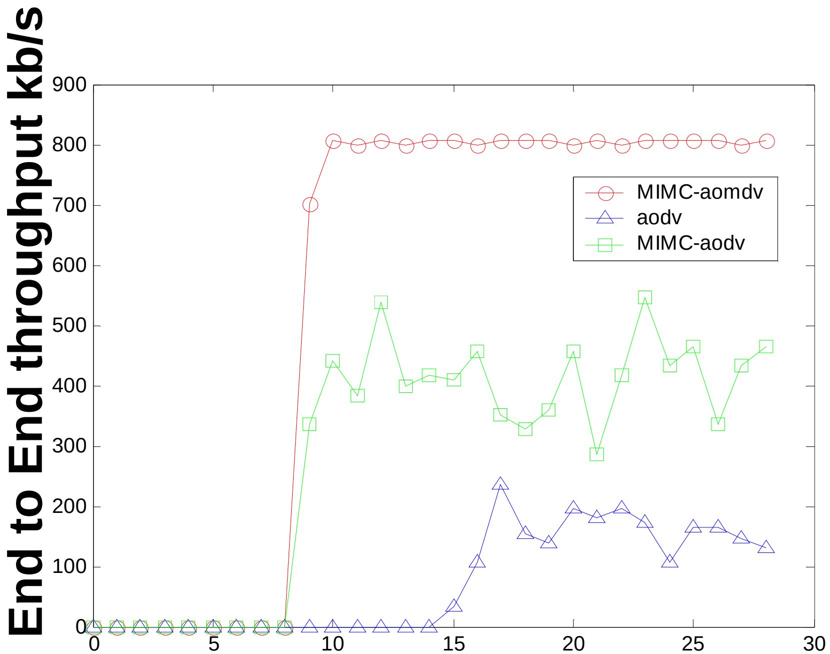
- Flow Stability
  - Parallel transmission within nodes' interference range
  - Flow (B,E) and Flow(F,G). Nodes (B,C,D) and Nodes(F,G,H) are within interference range



Results and Feedback
Multi-Interface Multi-Channel Routing



(a)Throughput of flow form B to G

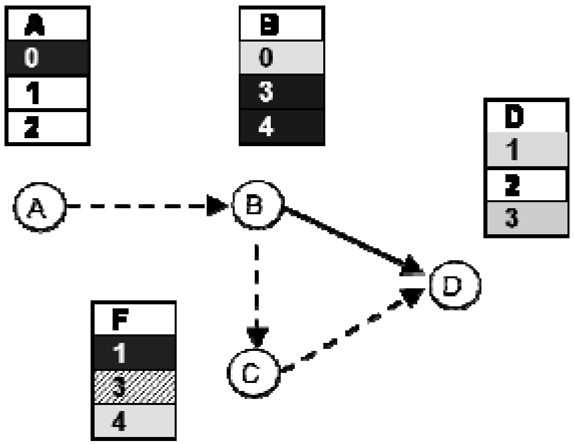


(b)Throughput of flow form F to H

Results and Feedback

Multi-Interface Multi-Channel Routing

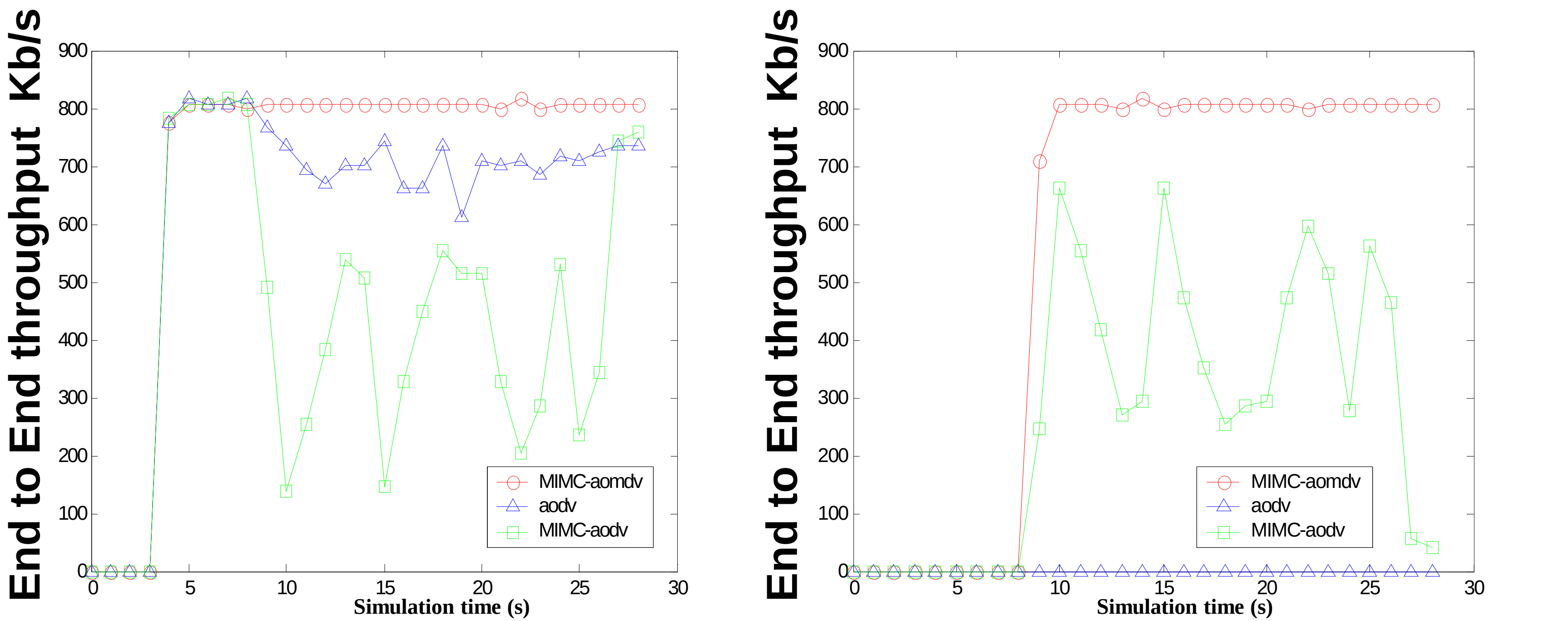
- Load balancing topology
  - Flow (A,D) and flow(B,D)
  - Path A->B->D uses channel 0-3
  - Path B->C->D uses channel 4-1



SEVENTH FRAMEWORK PROGRAMME

Results and Feedback

Multi-Interface Multi-Channel Routing



(a) Throughput of flow form B to D

(b) Throughput of flow form A to D

Throughput comparison for scenario 2

Results and Feedback

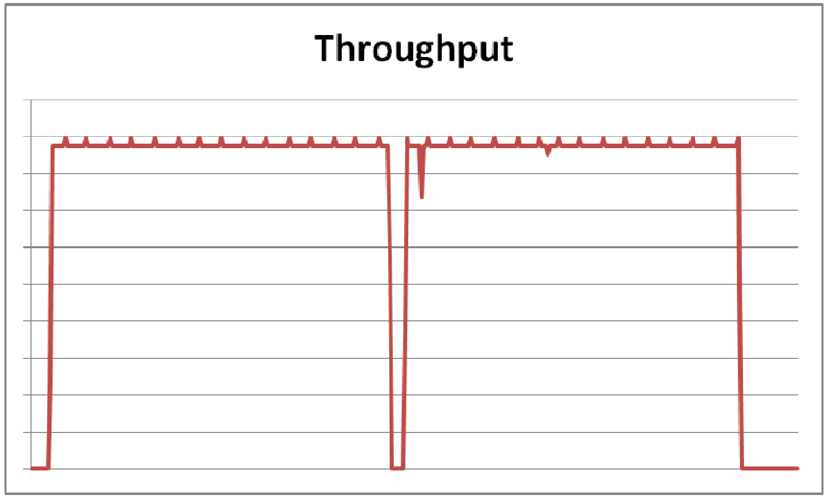
Multi-Interface Multi-Channel Routing

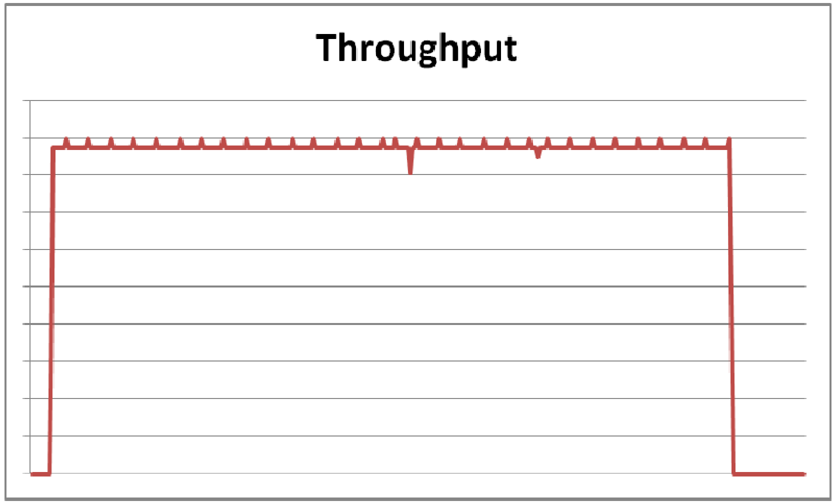
- Conclusions
  - Defined new interference and path load estimation methods
  - Improved the disjoint path criteria and reverse/forward path finding
  - Proposed RREQ/RREP waiting mechanism, path selection and flow based data forwarding procedure
  - MIMC can effectively improve the throughput of data flows in MANET

Results and Feedback

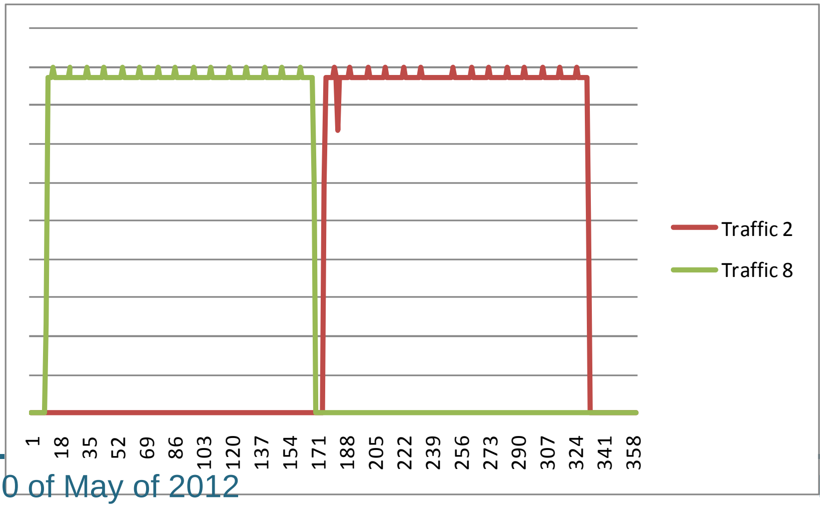
Geo-based and Energy Aware Routing

- **NS2 Simulations – Single Flow – Throughput and traffic**

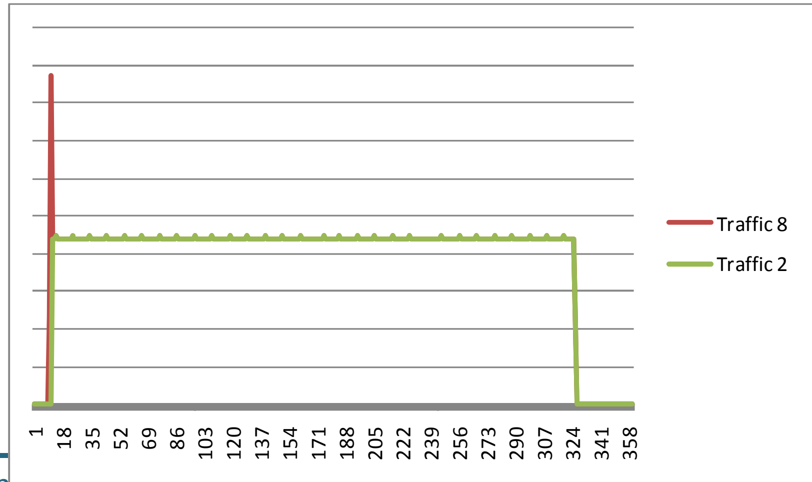




- **Regular OLSR**



- **Power aware OLSR (battery level)**

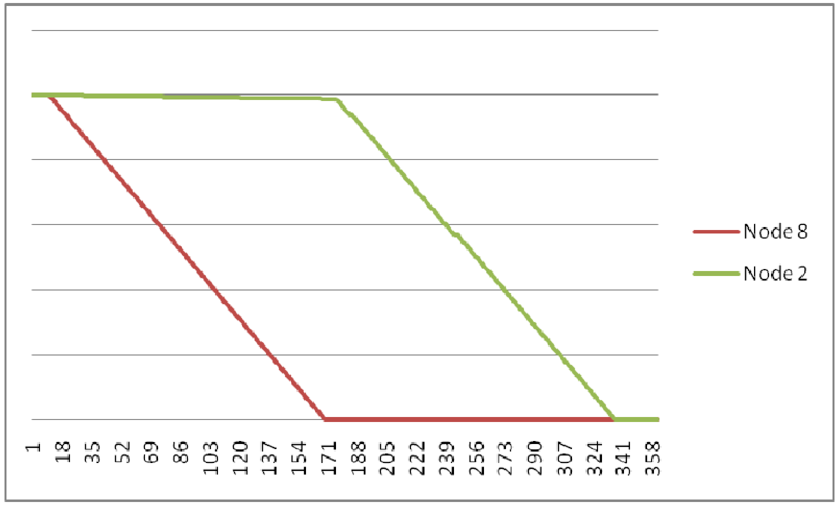


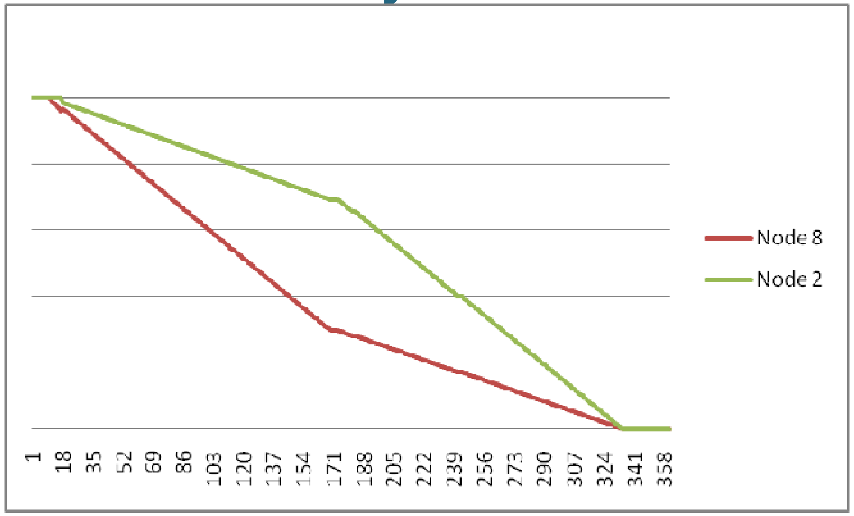
SEVENTH FRAMEWORK PROGRAMME

Results and Feedback

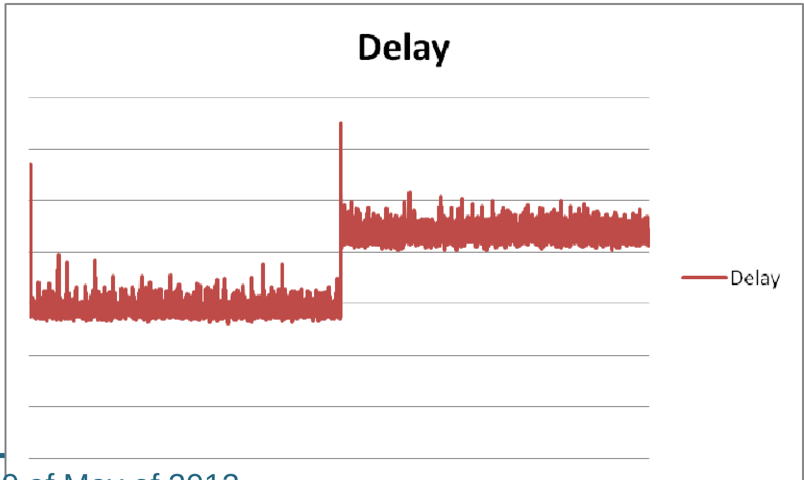
Geo-based and Energy Aware Routing

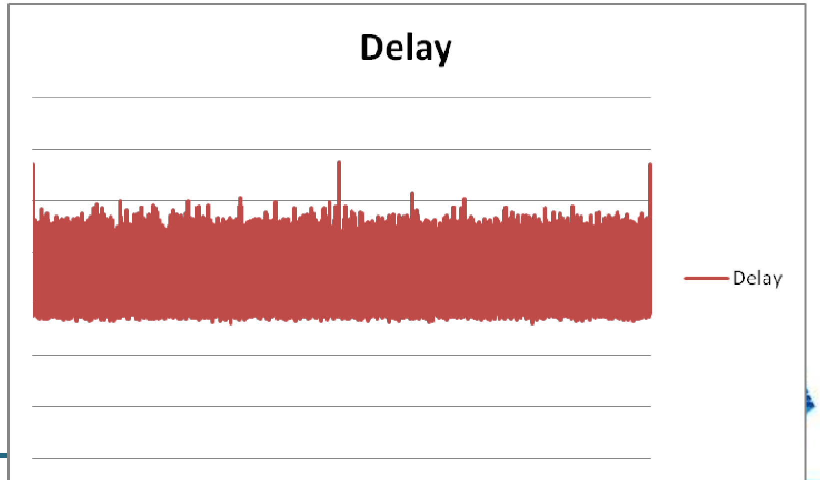
- **NS2 Simulations – Single Flow – Lifetime and delay**





- **Regular OLSR**
- **PA-OLSR (91% increase in lifetime)**



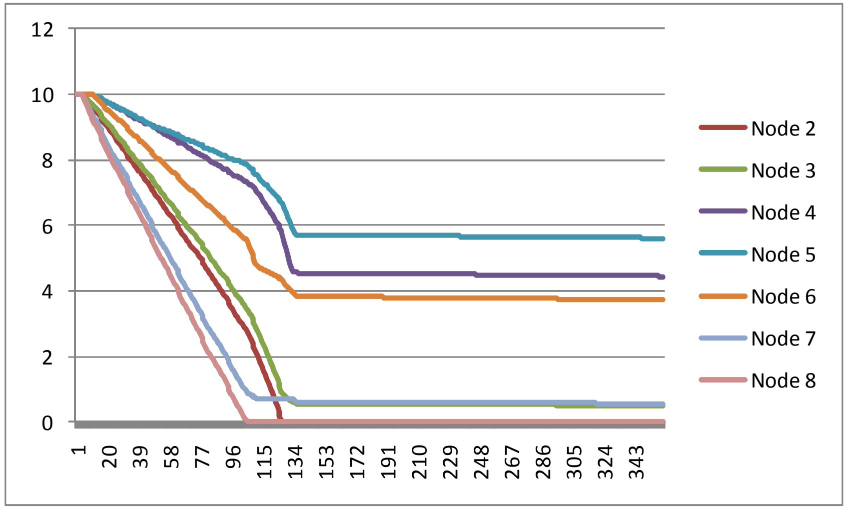


SEVENTH FRAMEWORK PROGRAMME

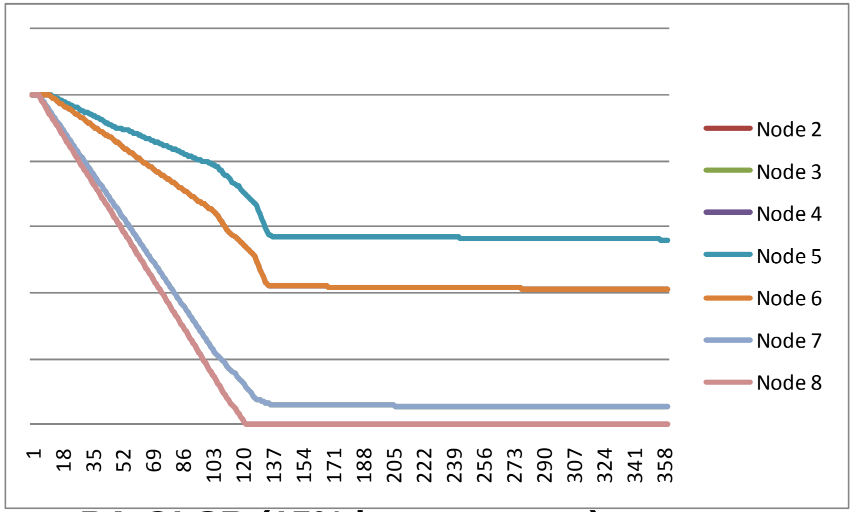
Results and Feedback

Geo-based and Energy Aware Routing

- **NS2 Simulations – Multi to One - Lifetime**



- **Regular OLSR**



- **PA-OLSR (15% improvement)**

SEVENTH FRAMEWORK PROGRAMME

Results and Feedback

Geo-based and Energy Aware Routing

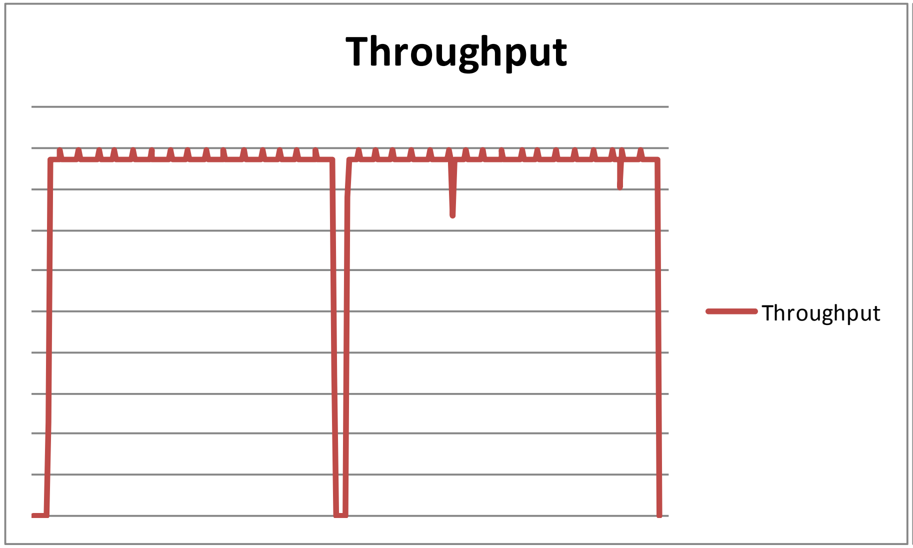
Conclusions

- **Advantages**
  - **Better network reaction time (less drops in throughput and higher levels of connectivity)**
  - **More balanced energy consumption**
  - **Overall network lifetime remains the same but individual nodes lifetime increases**
  - **More beneficial to single flow scenarios (91% lifetime increase in single flow to 15% in multi to one)**
- **Disadvantages**
  - **Higher delay due to interleaving of packets**
  - **16% increase in HELLO msg size (2 bytes)**
  - **Addition of discharge rate to metric smoothes transitions and improves network reaction**
- **Other options**
  - **Smaller TC and HELLO msgs can be obtained if consumption rate is computed based on sequential level measurements but at cost of higher reaction time**

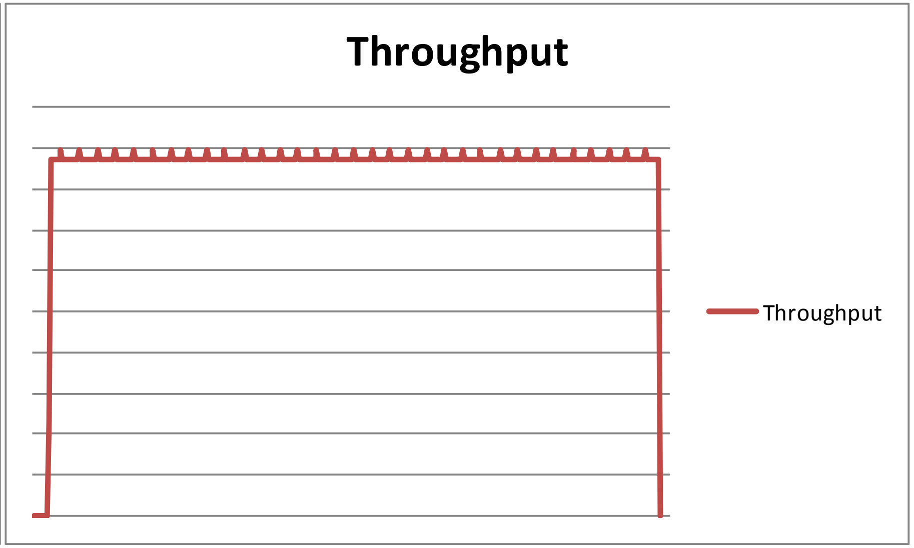
Results and Feedback

Geo-based and Energy Aware Routing

- **NS2 Simulations – Single flow - Throughput**



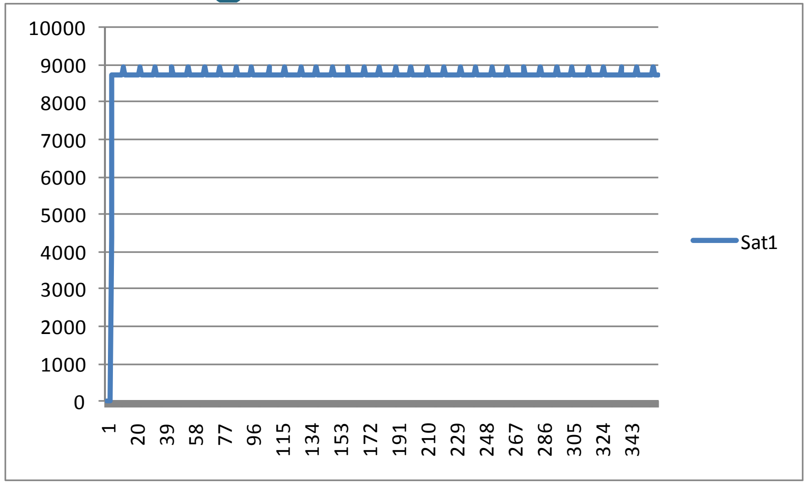
- **Regular OLSR**

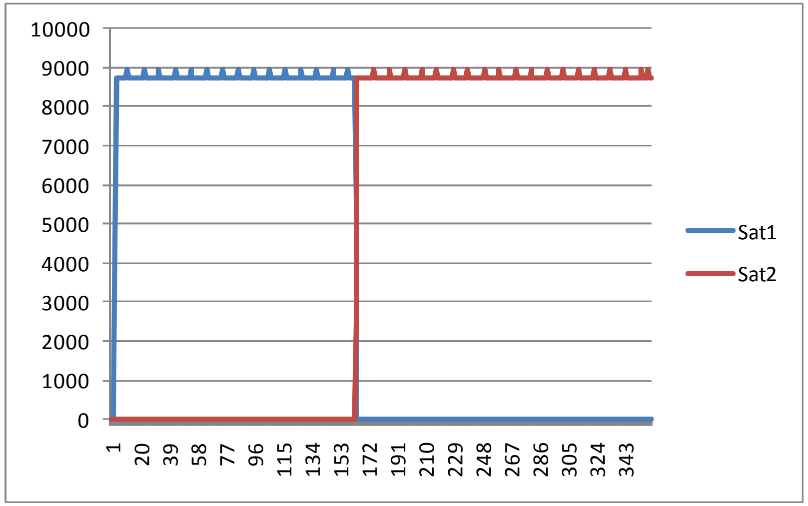


- **Position-Aware OLSR**

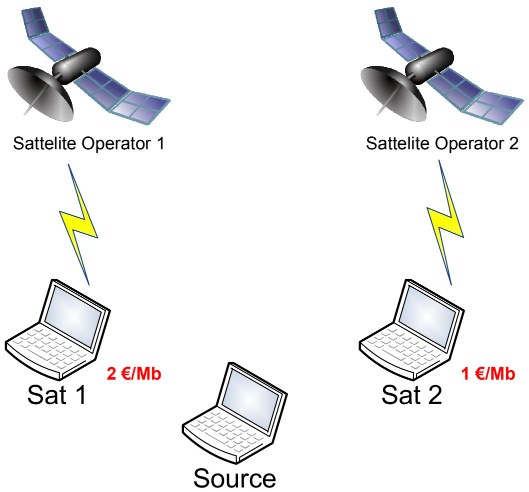
- **Conclusions**
  - **Faster reaction of network to loss of connectivity due to movement**
  - **Better performing network for very dynamic topologies**
  - **Lower number of re-transmissions and timeout waiting**
  - **Slightly higher lifetime**

Results and Feedback
Satlink Based Routing





- **NS2 Simulations**
  - **64 Kbits CBR satlink 1 @ 2€/Mb**
  - **Midway through simulation cheaper link becomes available**
  - **72% decrease in cost at overhead of 3240 bytes on TC messages**
  - **Combination of different parameters in weighted sums possible**
    1. **Compute routing paths and weigh them according to parameters**
    2. **Compute best gateways in terms of parameters and then determine routing paths**

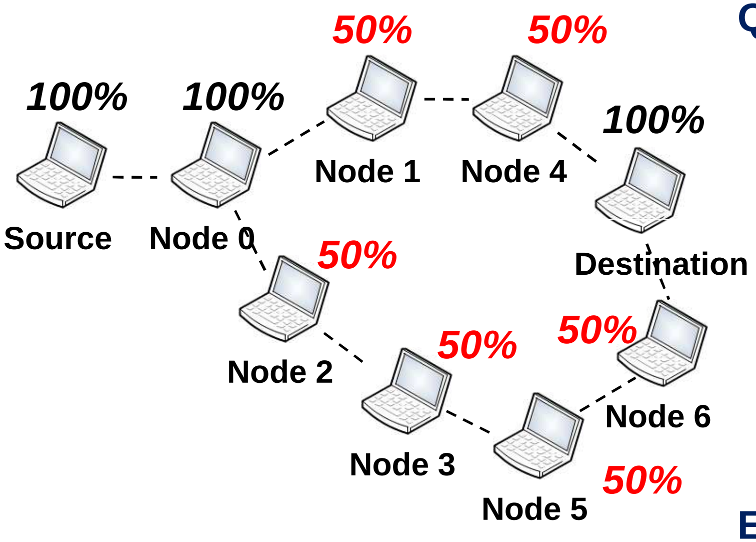


Results and Feedback

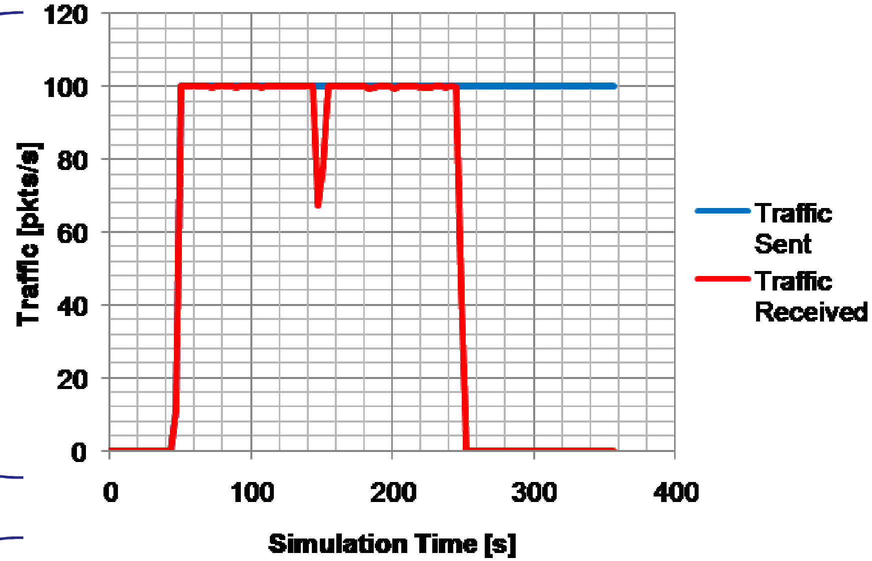
Residual Energy metric – Single flow Scenario

One flow at 100kbps from Source to Destination

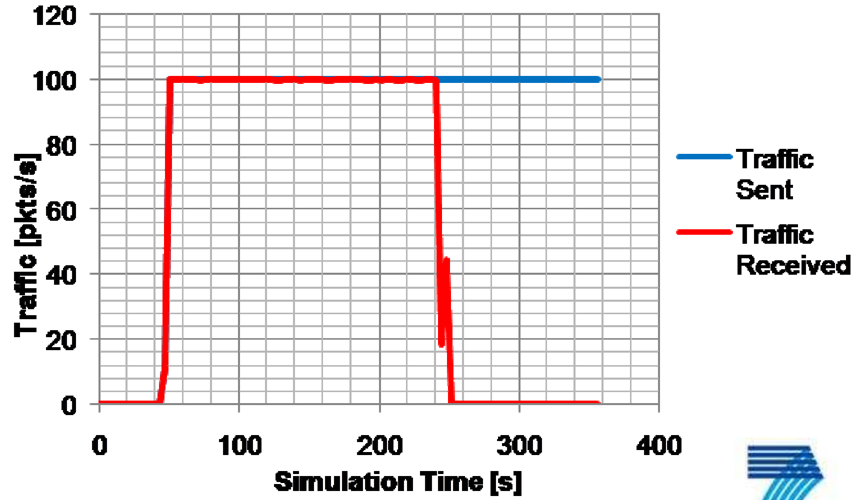
1 Hello per second



Simple Q-Routing



Energy-aware Q-Routing

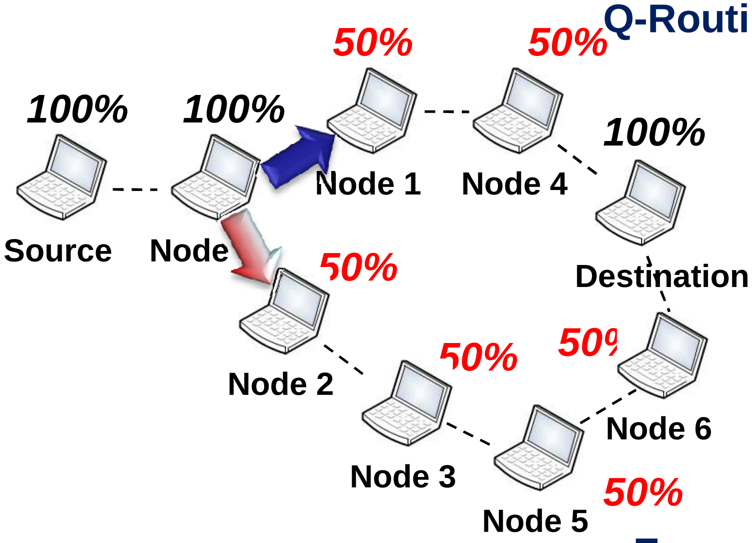


Same flow duration

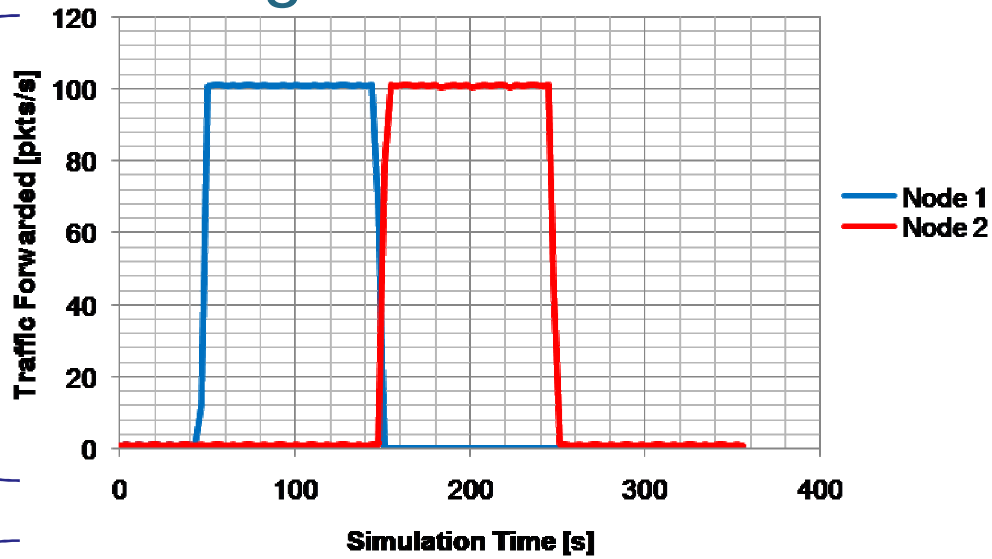
SEVENTH FRAMEWORK PROGRAMME

Results and Feedback

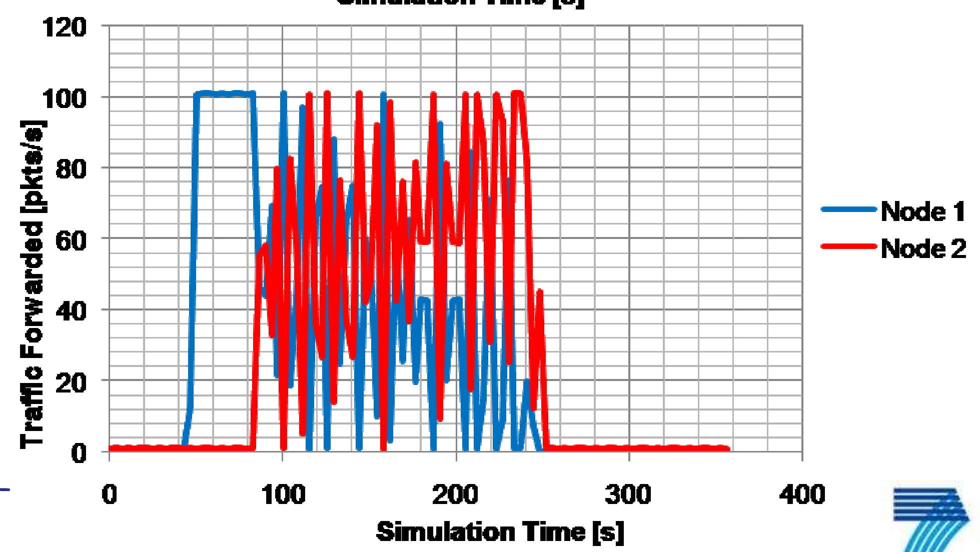
Residual Energy metric – Single flow Scenario



Simple Q-Routing



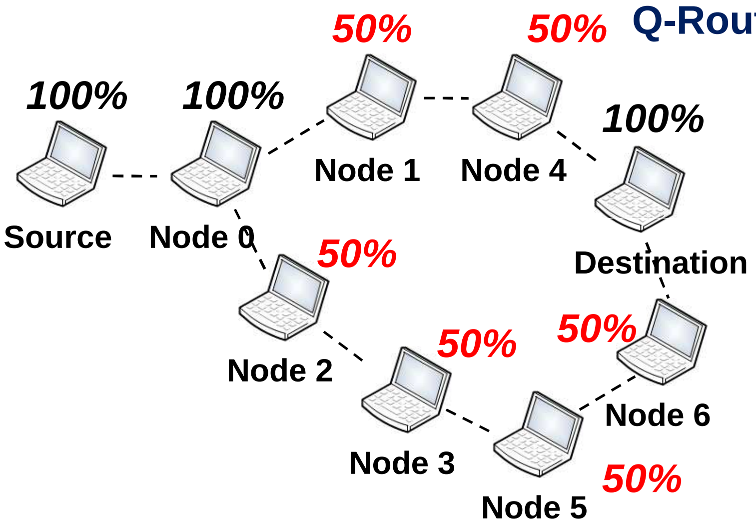
Energy-aware Q-Routing



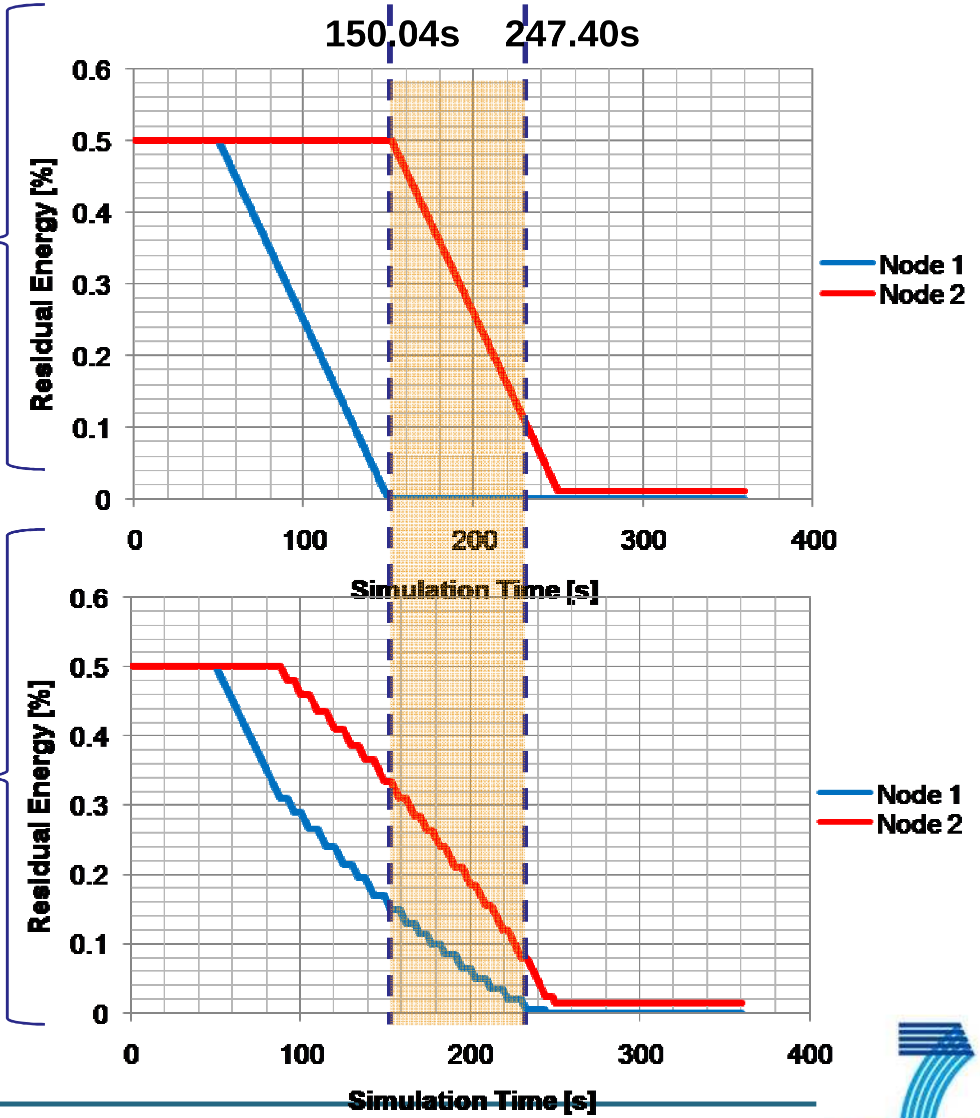
Simultaneous utilization of two different paths

Results and Feedback

Residual Energy metric – Single flow Scenario



Simple Q-Routing



Energy-aware Q-Routing

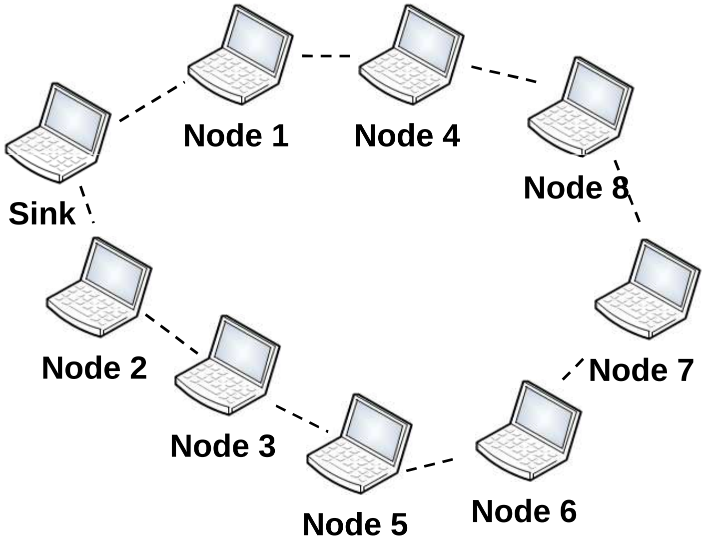
- **Minimum node lifetime increased of about 65%**
- **Energy balancing in both nodes**

Results and Feedback

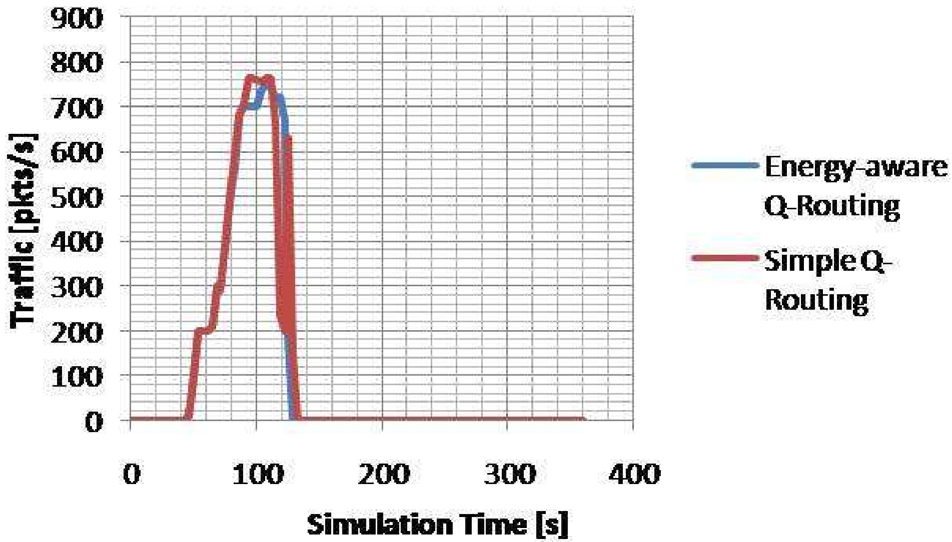
Residual Energy metric – Multi to one scenario

Each node is a source node of a 100kbps traffic flow towards the sink node.

1 Hello per second



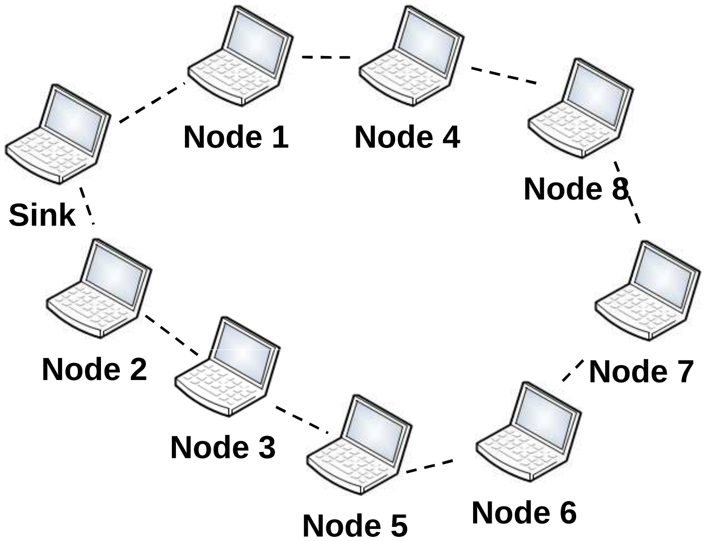
Same overall throughput in Sink node



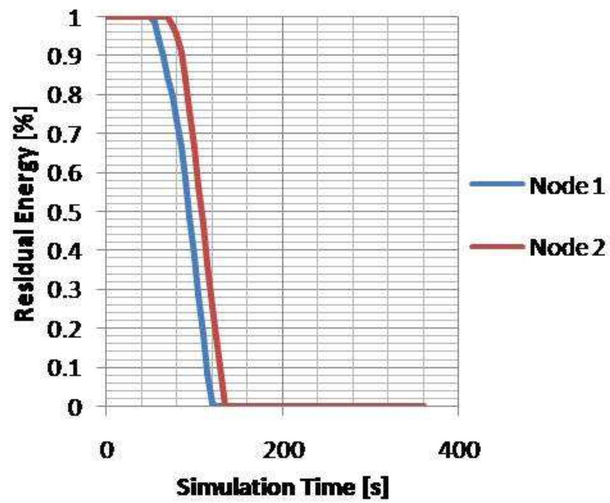
SEVENTH FRAMEWORK PROGRAMME

Results and Feedback

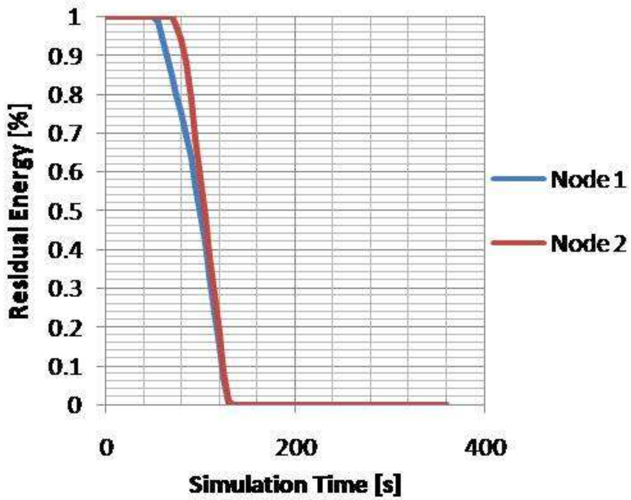
Residual Energy metric – Multi to one scenario



Simple Q-Routing



Energy-aware Q-Routing



- **Minimum node lifetime increased of about 8.5%**
- **Energy balancing in both nodes closest to the Sink**

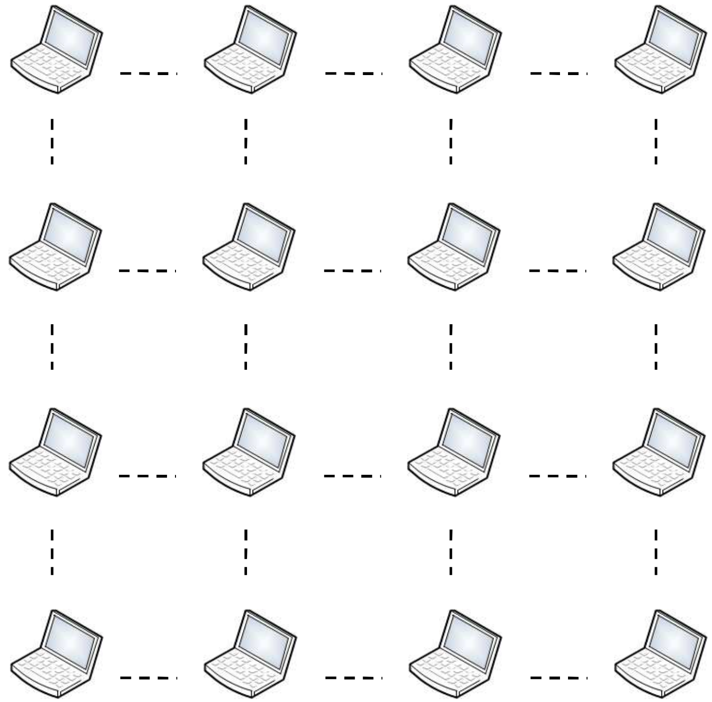
SEVENTH FRAMEWORK PROGRAMME

Results and Feedback

Residual Energy metric - Grid topology

Flow characteristics:

- ***Each edge-node sends a traffic flow to the opposite edge-node***
- ***Bandwidth of each flow: 100kbps***



Hello exploration:

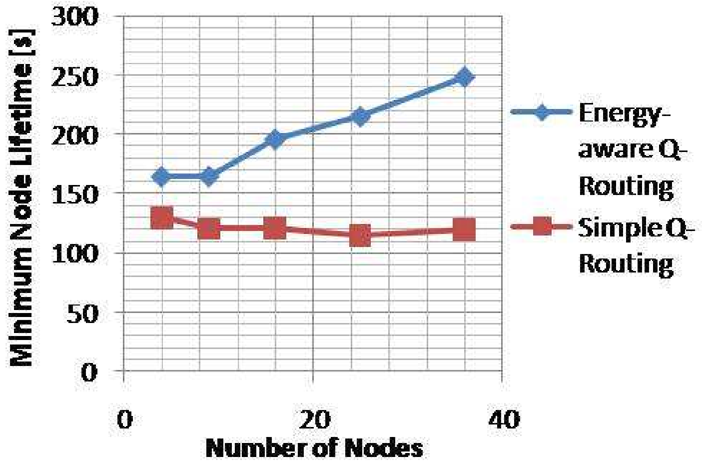
- ***Frequency : 1 hello per second***

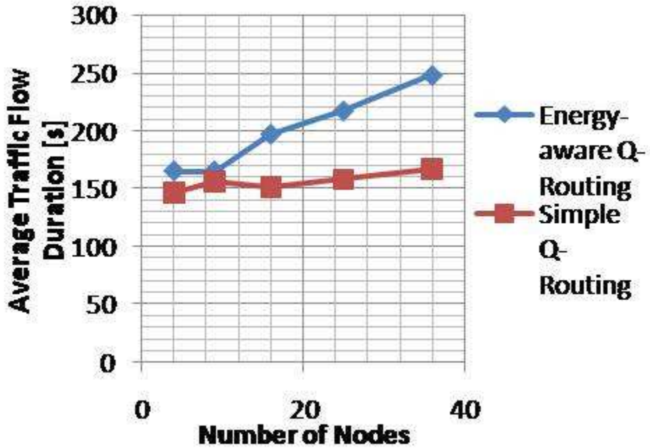
Objective:

- **To study the flows duration and the minimum lifetime when the number of network nodes grows**

Results and Feedback

Residual Energy metric – Grid topology

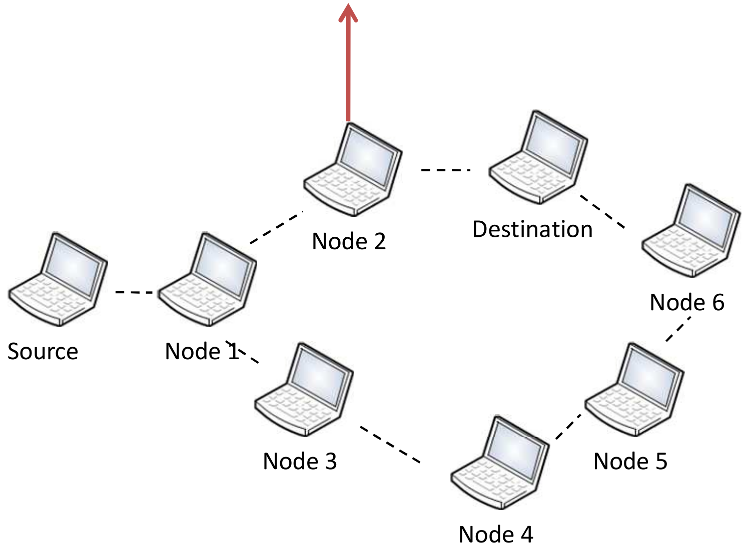


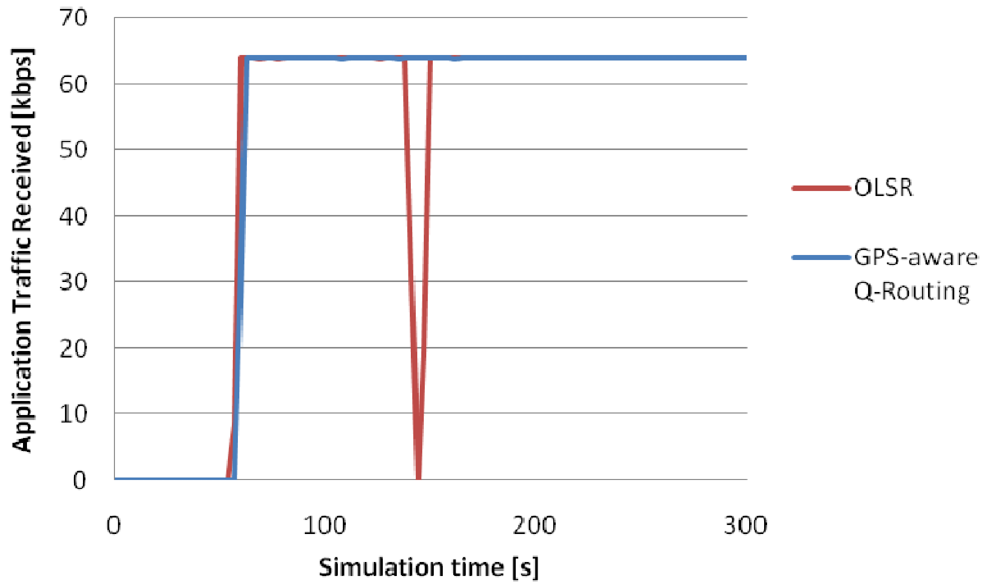


- **Simple Q-Routing chooses one path a time, causing the discharge of vital nodes, independently from the number of nodes**
- **Oppositely Energy-aware Q-Routing balances the traffic in function of the energy of the nodes, increasing both the minimum lifetime and the average traffic flow duration**

Results and Feedback

Link Availability metric – Scenario





- **PCM constant audio flow at 64kbps (see D2.3 requirements)**
- **Node 2 starts to move from its initial position at time 120s and reaches the terminal unconnected position at simulation time 190s, moving with a constant speed of 2m/s**
- **The transitory phase is well-managed by the GPS-based metric without brusque falls, as instead happens if OLSR is used**

Results and Feedback

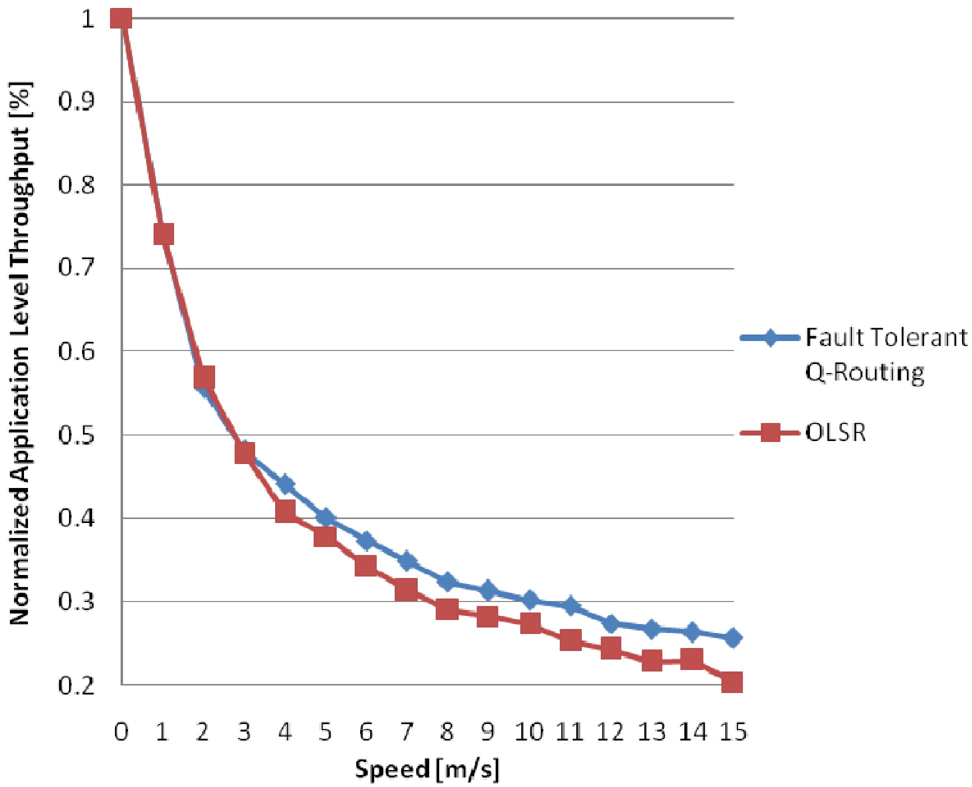
Mobility and Link Availability metrics (1/2)

- **Simulated scenario characteristics:**
  - **Square area of 400m X 400m**
  - **20 nodes**
  - **Random Waypoint mobility model with a prefixed speed.**
  - **Four bidirectional GSM G.711 audio flows at 13.6kbps run between 4 network nodes.**
  - **The simulations (with a duration of 300s each) have been performed varying the speed between the interval 1-15m/s**

- **Mobility factor and link availability metrics are jointly used by aggregation**
- **Comparison has been performed with OLSR**

Results and Feedback

Mobility and Link Availability metrics (2/2)



- **When the speed grows, mobility factor and link availability metric start to assume a great importance, reaching a peak of increase compared to OLSR of about <u>25.9% at speed 15m/s</u> (on average 10% better)**

Results and Feedback

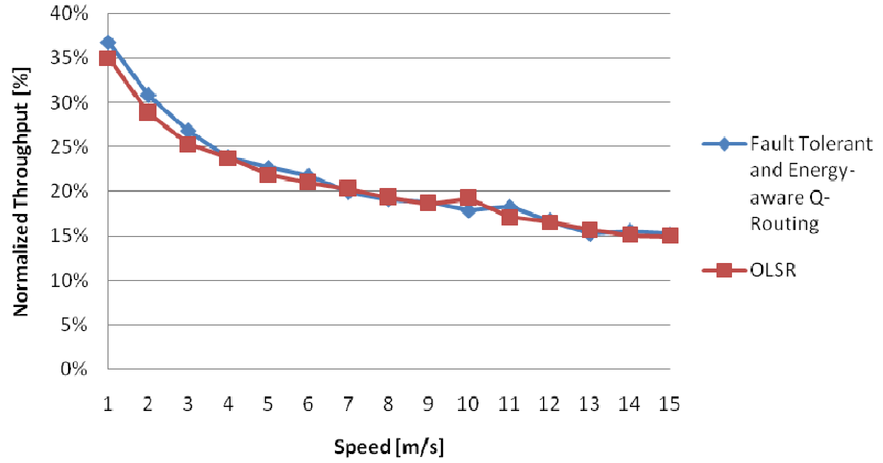
All metrics together (1/2)

- **Simulated scenario characteristics:**
  - **Square area of 400m x 400m**
  - **20 nodes**
  - **Random Waypoint mobility model with a prefixed speed.**
  - **Battery empirically allows to transmit about 10MB before the discharge.**
  - **Four bidirectional video flows at 512kbps (see D2.3 for video service requirements) runs between 4 network nodes.**
  - **The simulations (with a duration of 300s each) have been performed varying the speed between the interval 1-15m/s**

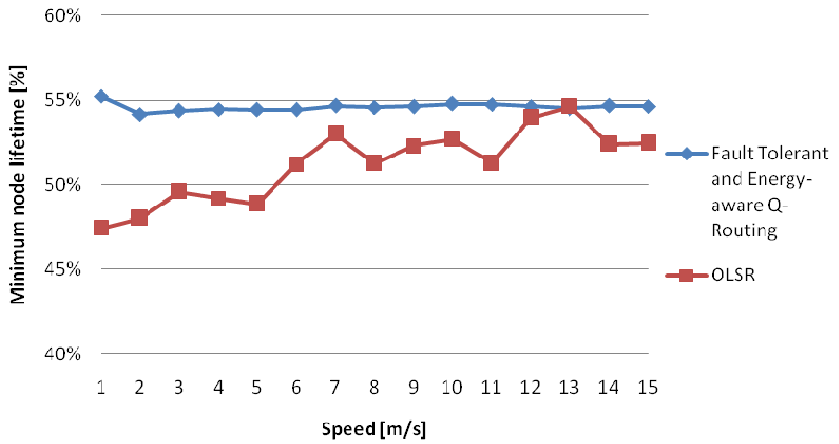
- **All three metrics are jointly used by aggregation**
- **Comparison has been performed with OLSR**

Results and Feedback
All metrics together (2/2)

- **The throughput increase of Fault-Tolerant and Energy-aware Q-Routing compared to OLSR averaged along 1-15m/s speeds is of 1.74% and reaches a peak of 6.95% at speed 2m/s.**



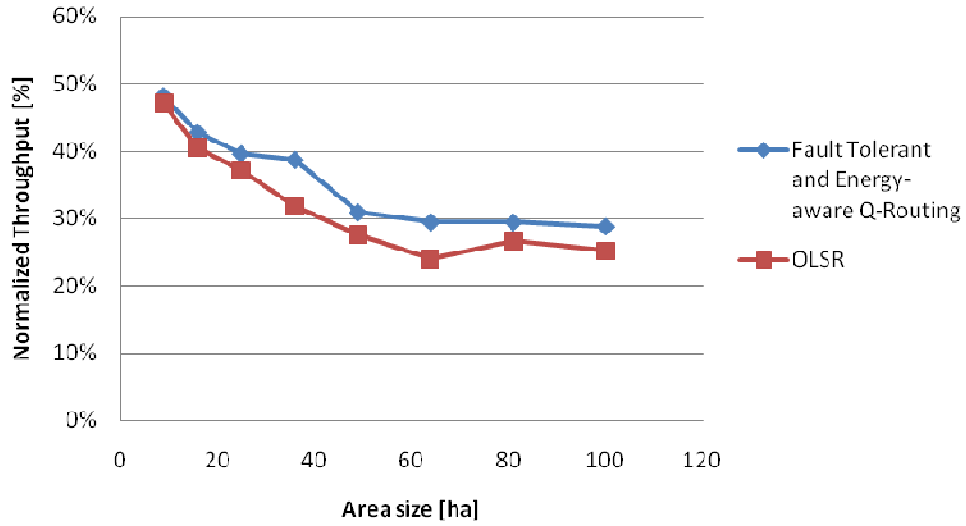
- **The minimum lifetime increase of Energy-aware and Fault Tolerant Q-Routing compared to OLSR averaged along 1-15m/s speeds is of 6.79% and reaches a peak of <u>16.49% at speed 1m/s</u>**



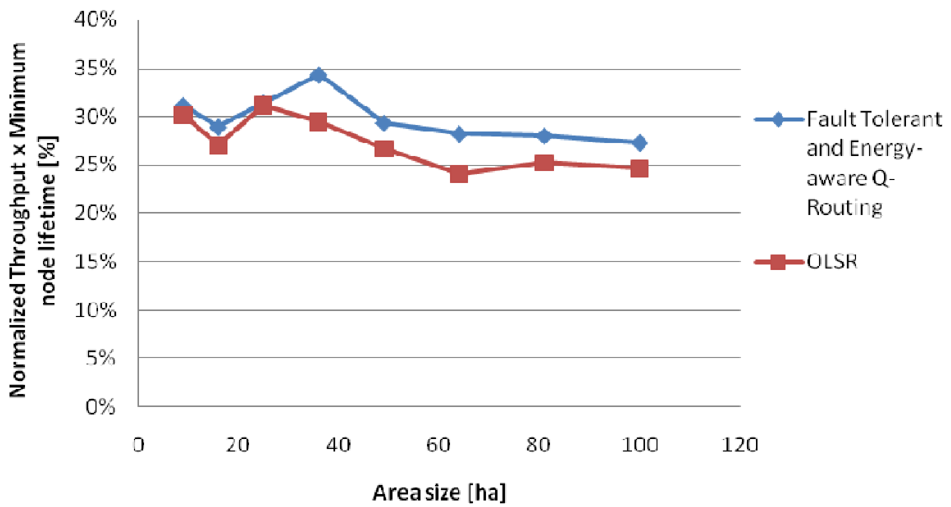
Results and Feedback

Scalability when area size grows

- **Fixed speed to 2m/s and**
- **Single-node battery is able to empirically send 24MB of traffic**
- **Eight video flows at 512kbps**
- **20 nodes moving following a Random Waypoint model**



- **Average throughput increase: 13% (peak 22.3% at 800ha)**
- **Average throughput x Minimum Node Lifetime increase: 9.5% (peak 17.3% at 800ha)**



SEVENTH FRAMEWORK PROGRAMME

Results and Feedback

Conclusions

- Q-Routing algorithm extended with a proactive extension and using residual energy, fault tolerance and mobility management metrics:
  - Minimum node lifetime is increased (leading to a more fair energy balancing in particular at human speeds)
  - Application level throughput is increased, especially at medium-high speeds (among the MONET requirements contained in deliverable D2.3).
- The algorithm has been compared with a simple Q-Routing and the OLSR diffuse protocol, in scenarios with application flows, concurrent users, intervention areas and speed in line with MONET requirements, also considering scalability issue.

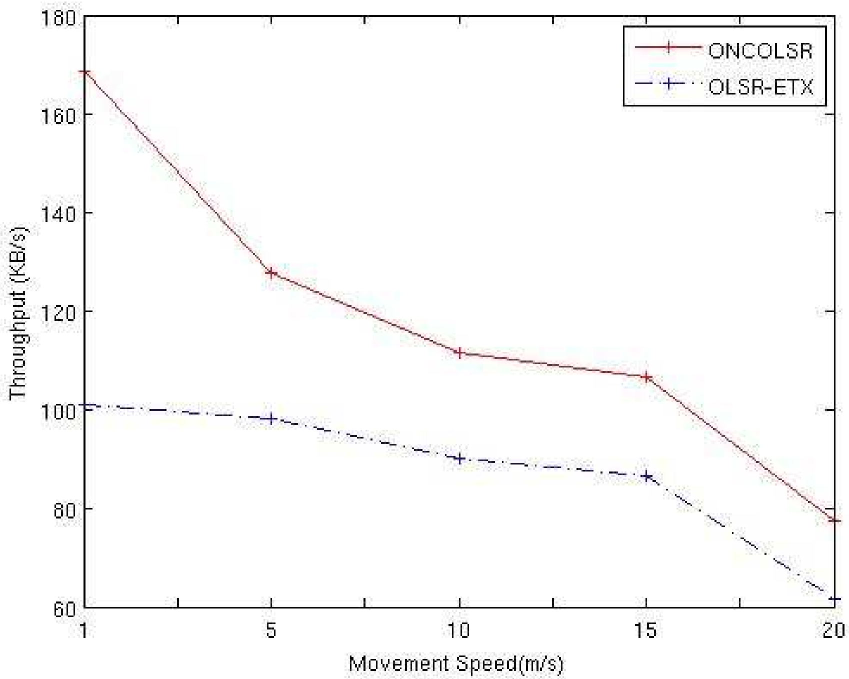
Results and Feedback

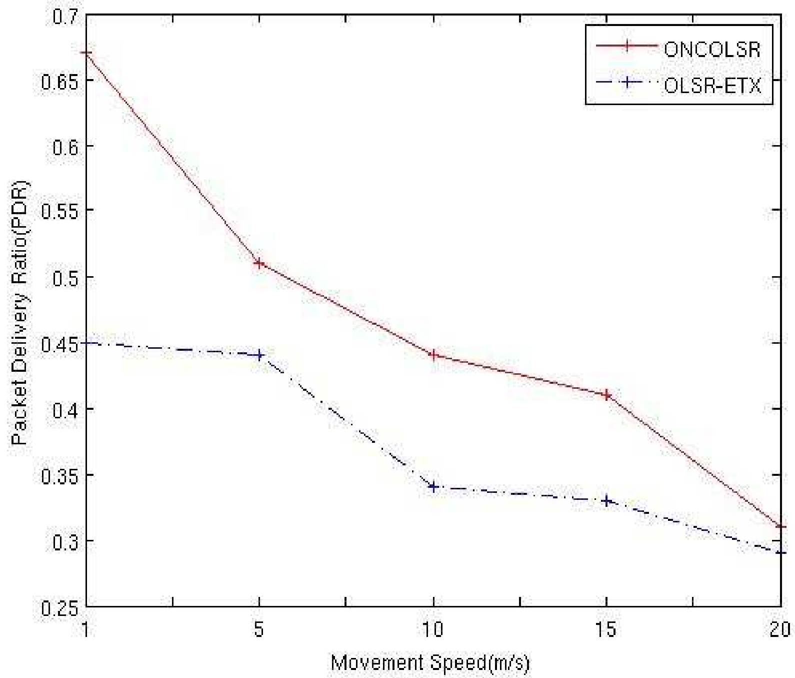
Cooperative k-Anypath Routing for MONET

- Conclusion
  - Optimal ETX is defined. K-anypath routing is developed.
  - Any candidate with selected path is still a shortest path.
  - At least k candidate nodes can perform forwarding nodes. This is potentially reducing the routing switching time due to the candidate node failure.
  - K-anypath routing has been implemented in matlab so far.

Results and Feedback

Joint Network Coding into OLSR





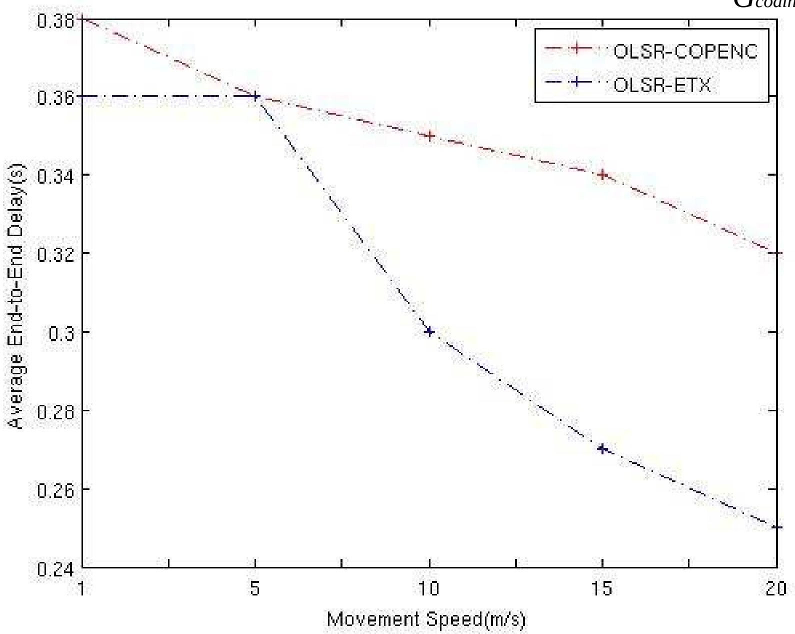
- **Average Throughput with NC vs OLSR-ETX increases 35%**
- **Average Packet Delivery ratio with NC vs OLSR-ETX increases 26%**

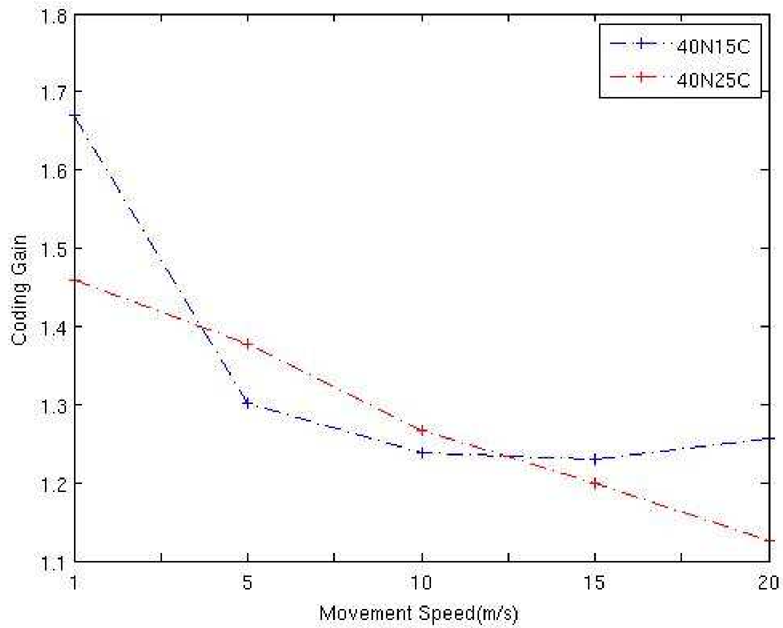
Results and Feedback

Joint Network Coding into OLSR

- Average end-to-end delay with network coding is slight increased compared to OLSR-ETX. This delay doesn't count on CPU process power.
- Coding Gain $G_{coding\_gain} = \frac{Throughput_{nc}}{Throughput_{etx}}$ is about 1.1-1.68x

$G_{coding\_gain} =$





Results and Feedback

Joint Network Coding into OLSR

- Conclusion
  - NC enhances performance and delivery ratio to OLSR
  - NC increases end-to-end delay slightly
  - Coding Gain benefits from coding structure detection.
  - Future work could be multicast session with NC, correlated source with network coding.