



low Energy CONsumption NETworks

***Energy-aware multi-level control system
for a network of Linux software routers***

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Project ECONET: low Energy CONsumption NETworks



Enabling the reduction of energy requirements of wired network equipment

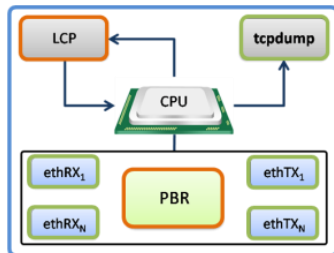
Automatic control of network performance



Local control policy

Dynamically adjust configuration of a router based on:

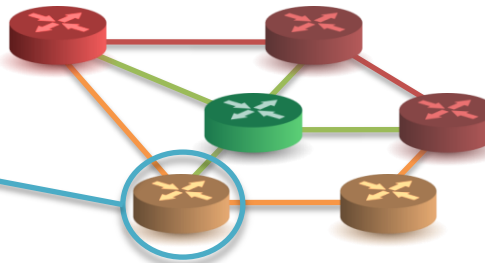
- traffic workload measurements,
- QoS requirements.



Routing and traffic engineering

Based on:

- traffic workload measurements,
 - QoS requirements,
 - performance capabilities of network nodes,
- dynamically adjust routing strategy and energy-aware configuration of routers to meet QoS goals at minimal cost.



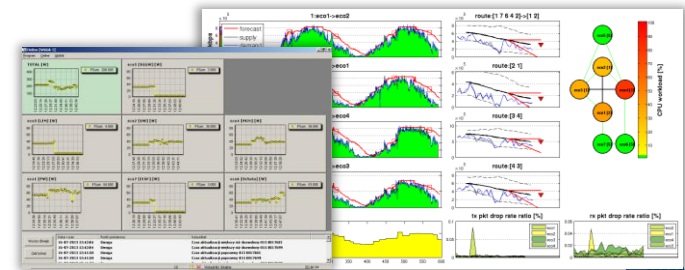
Operator-driven network performance management



Network-wide monitoring

Based on measurements of:

- traffic flows,
 - energy consumption,
- generate workload forecasts and reports on network performance.

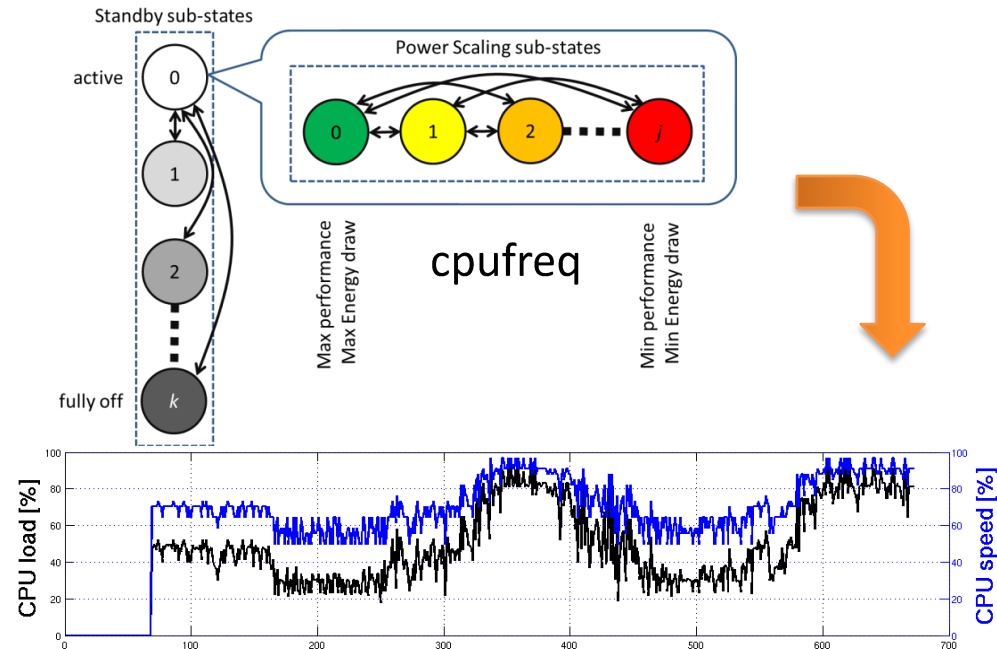
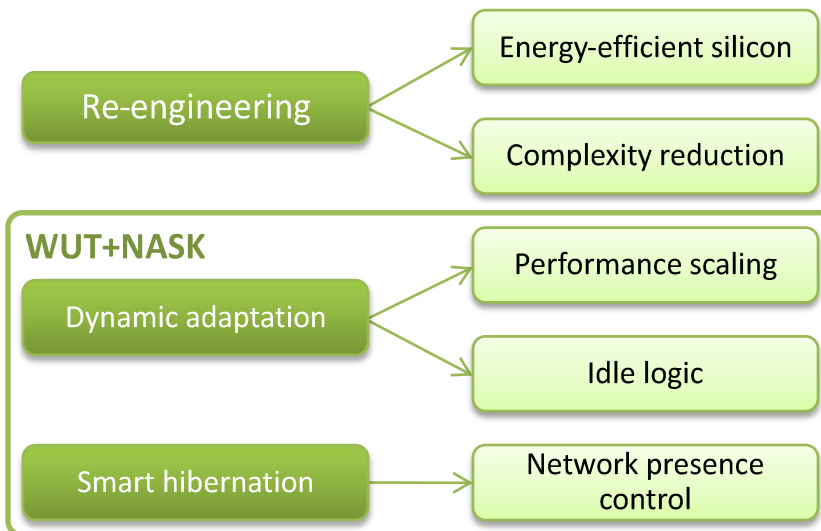


Project ECONET: low Energy CONsumption NETworks



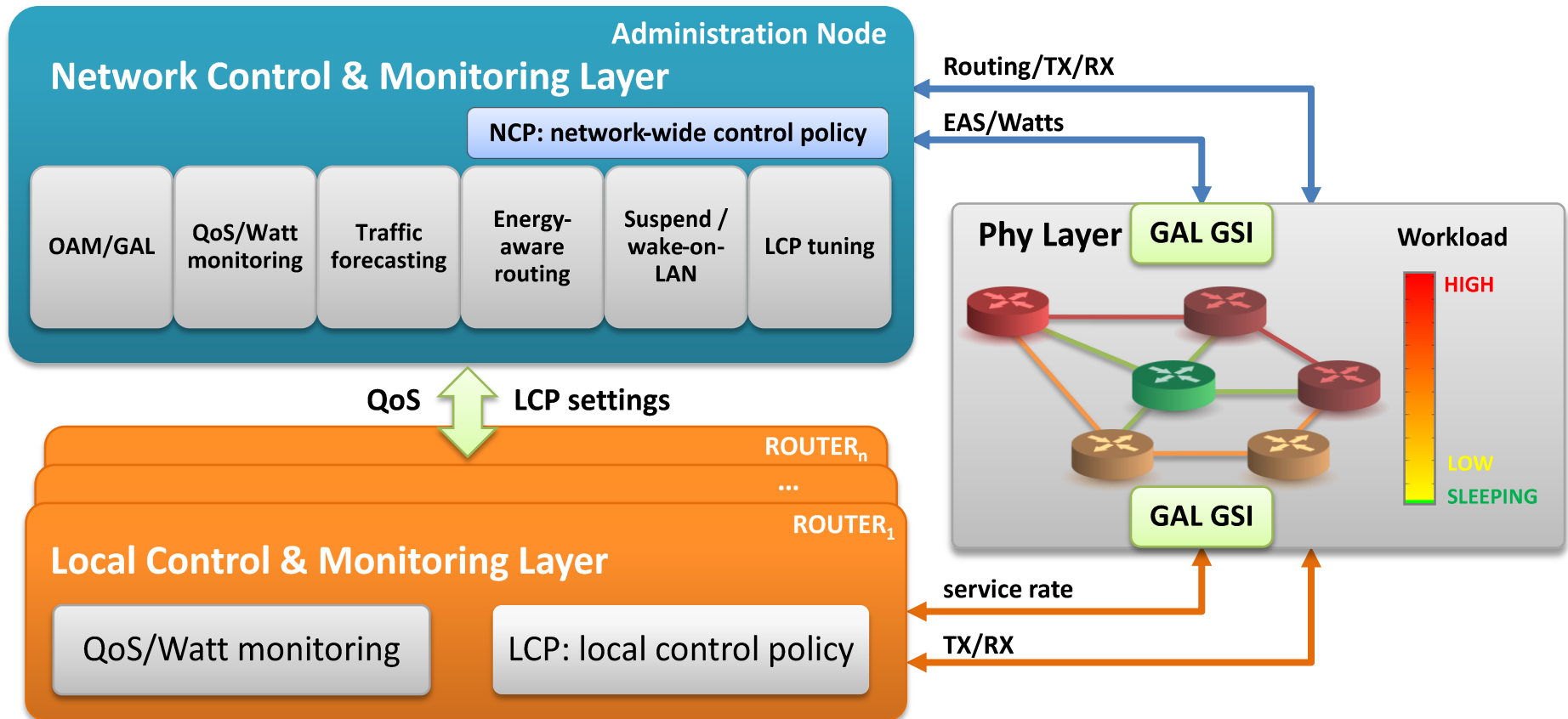
Enabling the reduction of energy requirements of wired network equipment

Figure: Advanced Configuration and Power Interface ACPI Specification Document. www.acpi.info.



WUT & NASK Contribution:

***An energy-aware multi-level control system
for a network of Linux software routers***



Control system architecture: control object

Experimental network



7 x Linux software routers:

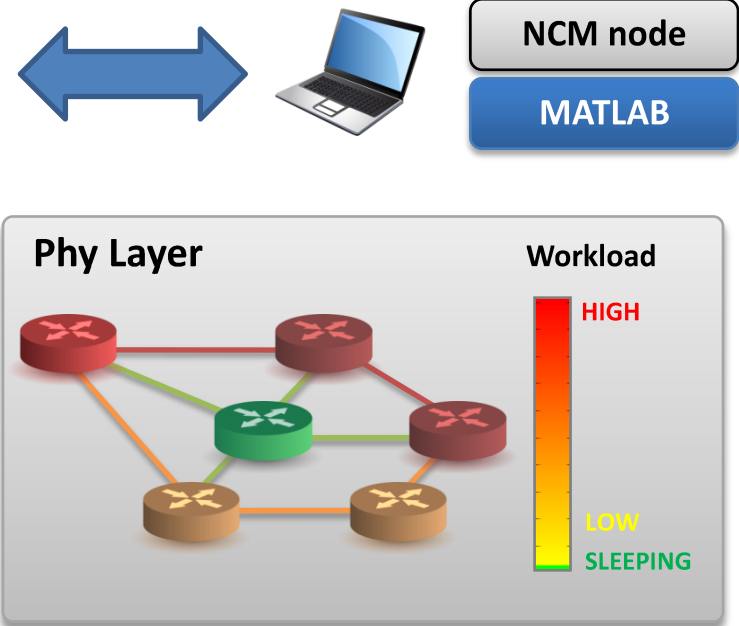
- DELL Precision T1650
- Intel Core i7-3770 [4-cores/8-threads]
- 16GB DDR3 1600MHz
- Broadcom 5719 QP 1Gb EEE NIC
- Linux kernel 3.6.10



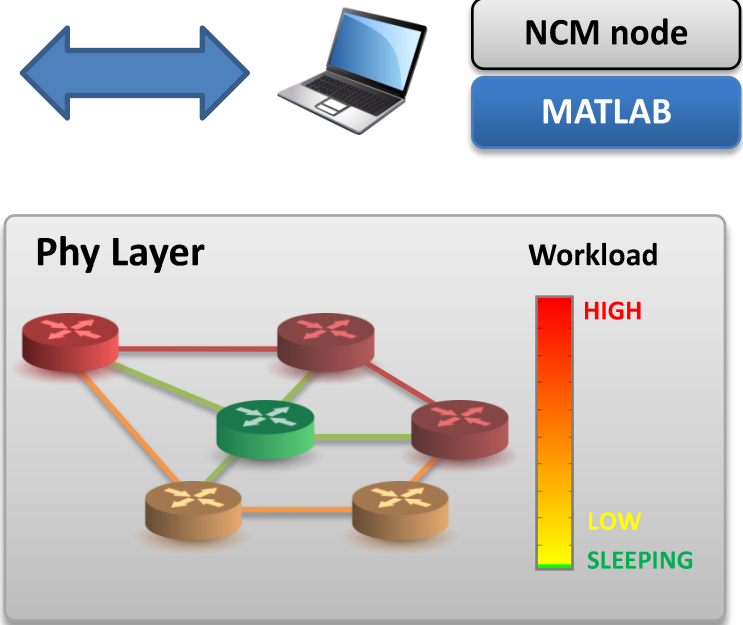
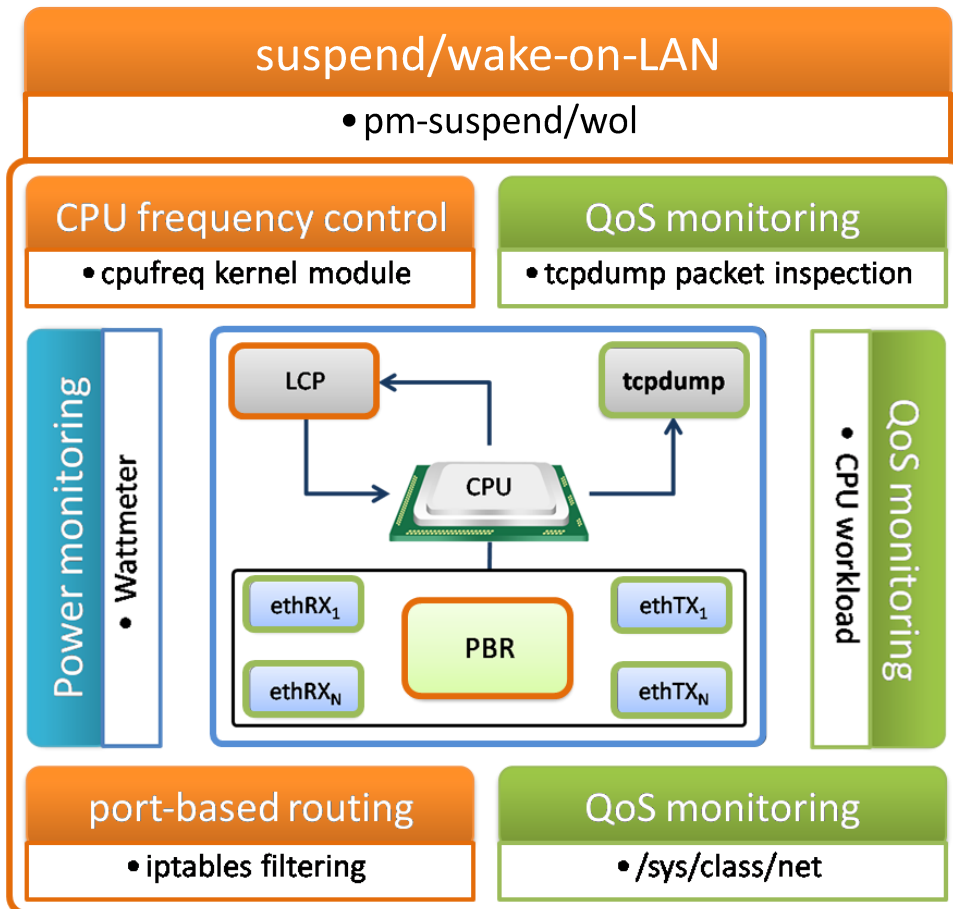
Power-consumption monitoring

7 x 1-phase electricity meters:

- wattmeter
- RS485 interface
- mysql database

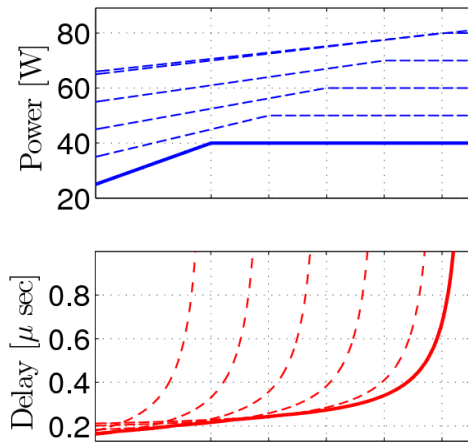


Control system architecture: control object

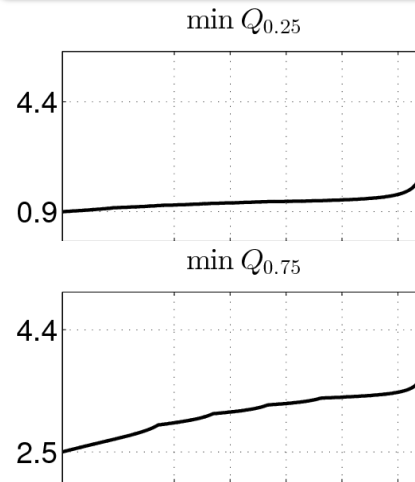


Control system architecture: local control and monitoring

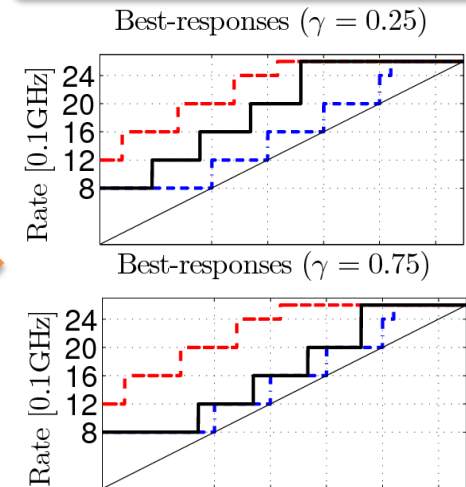
Experimental identification
of CPU QoS/EoPC profiles



Scalarization of performance
profiles



CPU frequency control
policy



Local Control & Monitoring Layer

ROUTER_i

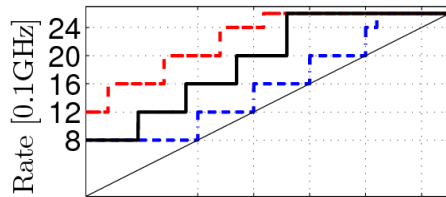
QoS/Watt monitoring

LCP: local control policy

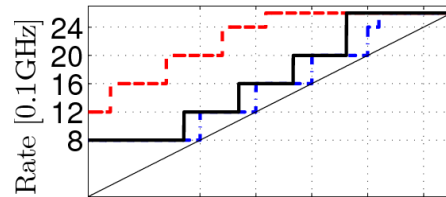
Control system architecture: local control and monitoring

CPU frequency control policy

Best-responses ($\gamma = 0.25$)



Best-responses ($\gamma = 0.75$)



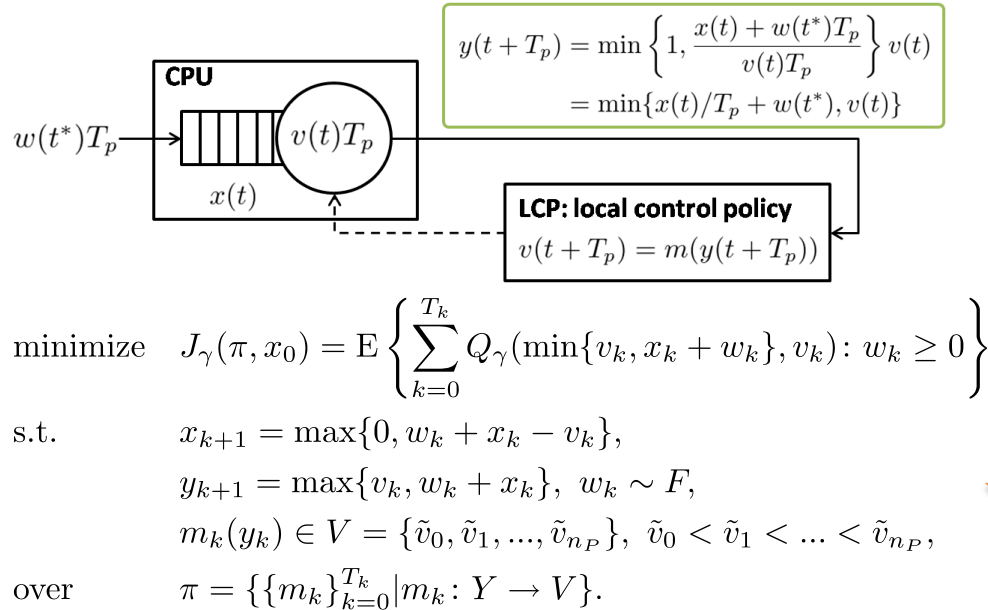
Local Control & Monitoring Layer

QoS/Watt monitoring

LCP: local control policy

ROUTER_i

CPU frequency governors for
Linux software router



Control system architecture: network performance control and monitoring

Administration Node

Network Control & Monitoring Layer

NCP: network-wide control policy

OAM/GAL

QoS/Watt
monitoring

Traffic
forecasting

Energy-
aware
routing

Suspend /
wake-on-
LAN

LCP tuning

Network performance monitoring

- SRC-DST traffic flows / pkt drop rate
- Routing paths / router state (active/suspended)
- CPU workload / frequency control strategy
- Power-consumption

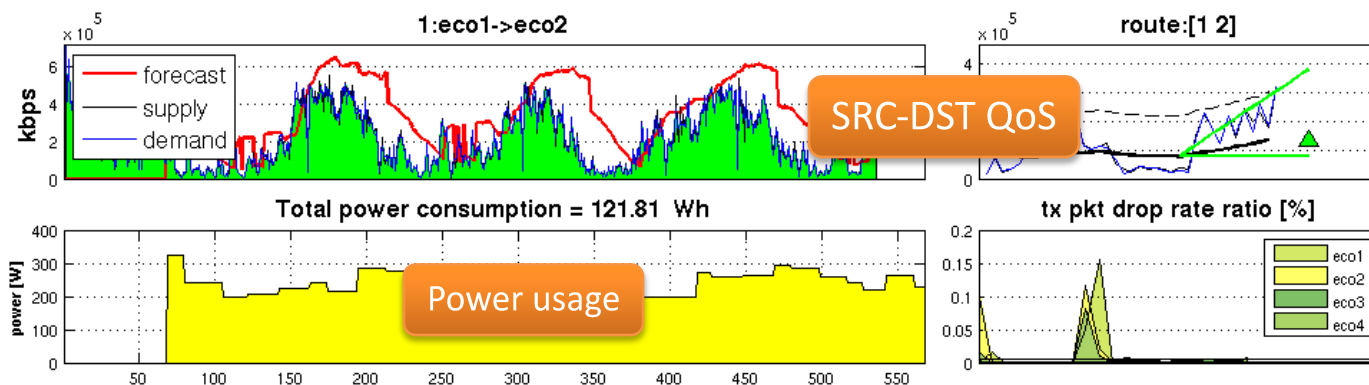


Figure:
Real-time network-wide performance monitoring.

Control system architecture: network performance control and monitoring

Administration Node Network Control & Monitoring Layer

NCP: network-wide control policy

OAM/GAL

QoS/Watt
monitoring

Traffic
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LCP tuning

Real-time traffic workload forecasting

- Traffic workload upper-bound forecast
- Fractional-diffusion-based model

Real-time energy-aware routing

- Repetitive optimization of routing matrix
- Parallel minimization of network-wide power consumption s.t. QoS constraints

Re-routing sampling period

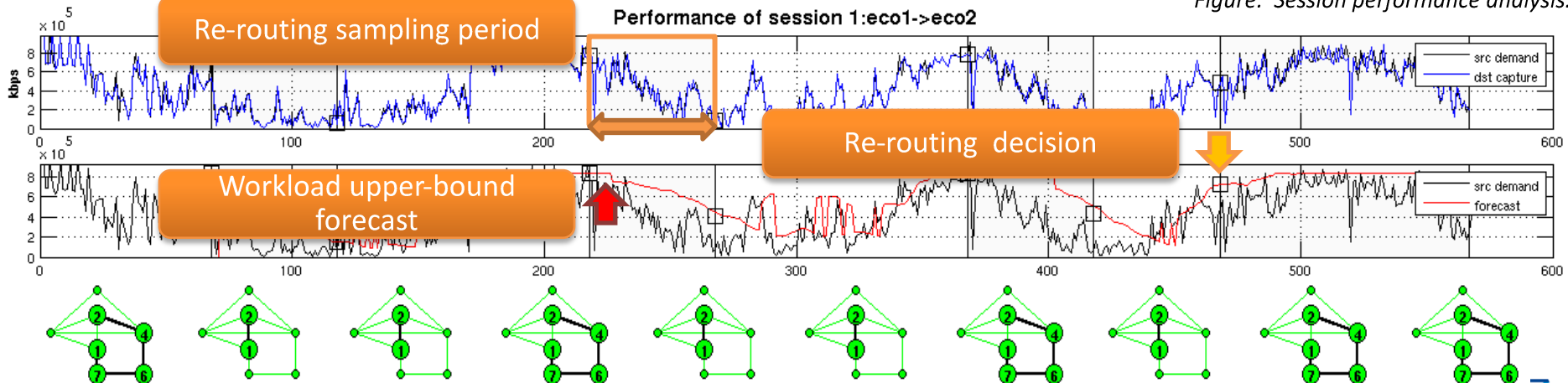
Performance of session 1:eco1->eco2

Figure: Session performance analysis.

Workload upper-bound
forecast

Re-routing decision

Routing path dynamics



Control system architecture: network performance control and monitoring

Administration Node Network Control & Monitoring Layer

NCP: network-wide control policy

OAM/GAL

QoS/Watt
monitoring

Traffic
forecasting

Energy-
aware
routing

Suspend /
wake-on-
LAN

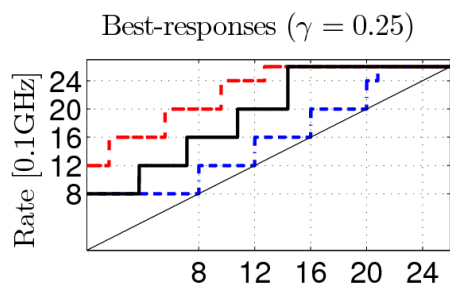
LCP tuning

Suspend / Wake-on-LAN

- Suspending unused routers to reduce power usage
- Activating routers if capacity required

LCP tuning (CPU frequency control)

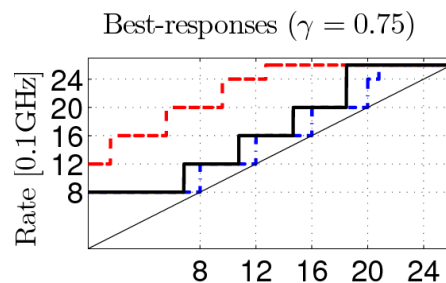
- Switching CPU frequency control strategies
- Adjusting Local Control Policy to short term workload dynamics



Power-reduction weight

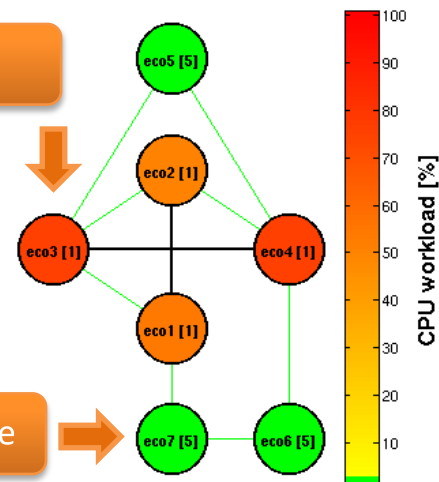
Performance-seeking LCP

Low-power-usage LCP

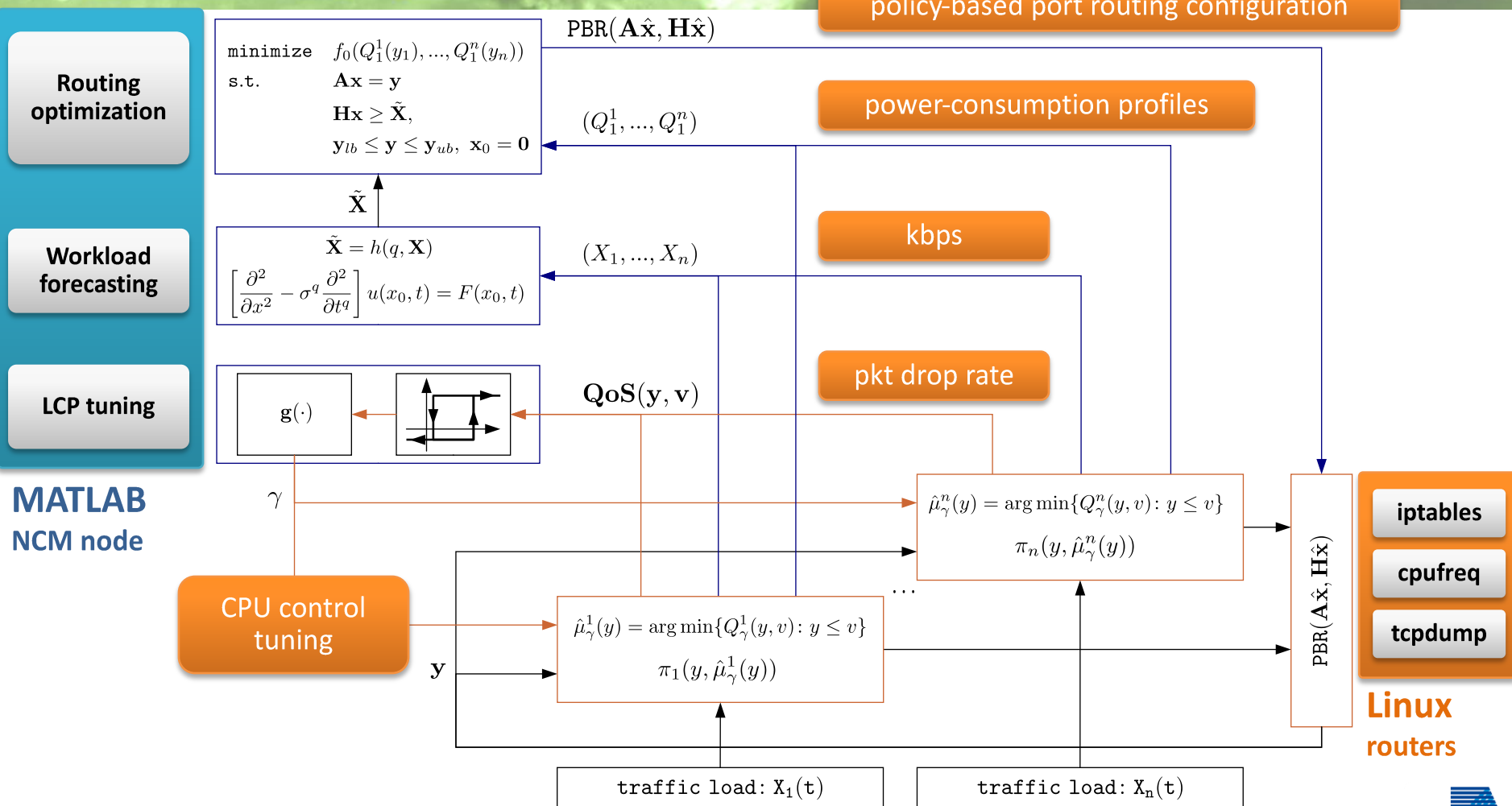


Active node

Suspended node



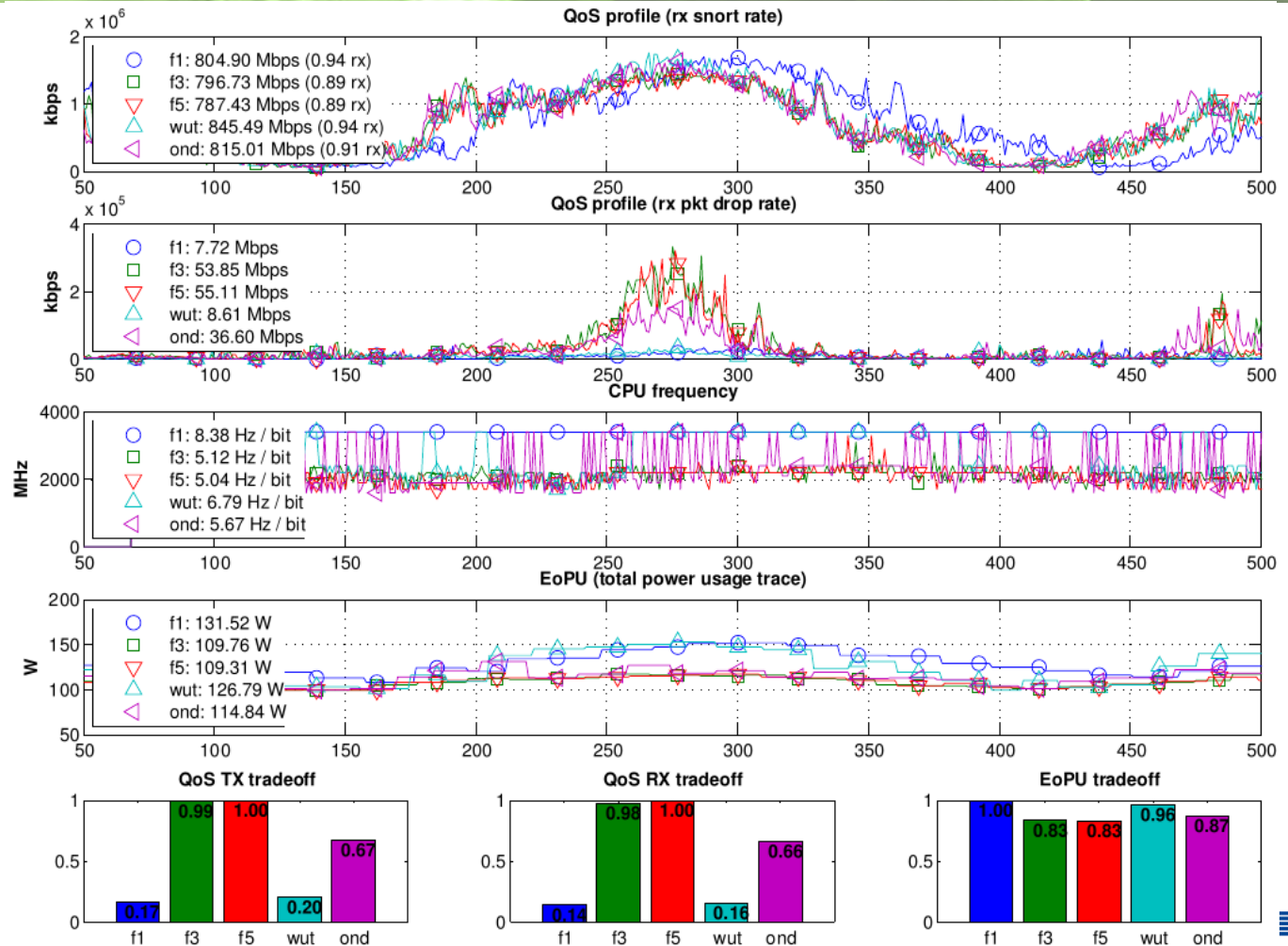
Control system architecture: control problem decomposition



Experimental study: performance of local control strategies

Scenario 1:

- 4 sessions
 - eco1 -> eco2
 - eco2 -> eco1
 - eco3 -> eco4
 - eco4 -> eco3
- NCP settings
 - routing OFF
 - LCP tuning
- LCP settings
 - fixed: f1, f3, f5
 - adjusted: wut
 - ondemand: ond



Experimental study: performance of network-wide control strategies

Scenario 2:

4 sessions

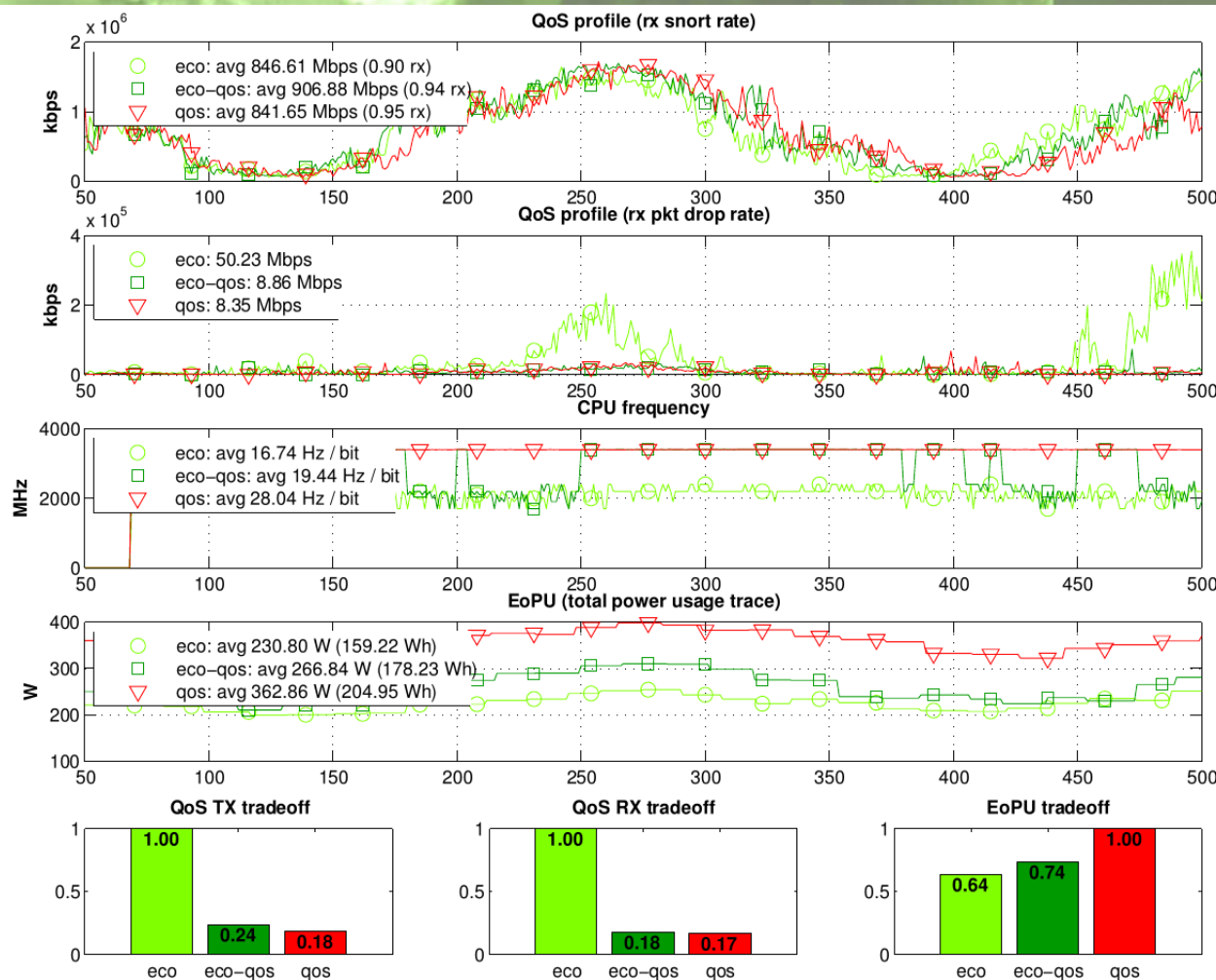
- eco1 -> eco2
- eco2 -> eco1
- eco3 -> eco4
- eco4 -> eco3

NCP settings

- static vs dynamic
- LCP tuning

LCP settings

- eco (f3)
- eco-qos (wut)
- qos (f1)





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