

Energy Saving Routing Strategies in IP Networks

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Energy problem in the networks

- The ICT represents one of the main power-hungry sector of our life;
- It is responsible of about 8% of the worldwide electricity consumption and the Internet account is estimated about the 15% of ICT power consumption;
- Nowadays the access network dominates the network energy budget;
- The always increase request of bandwidth will carry to a real energy problem in the core network [SIGCOMM];



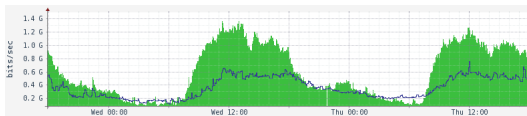
Maruti Gupta and Suresh Singh

Greening of the internet,

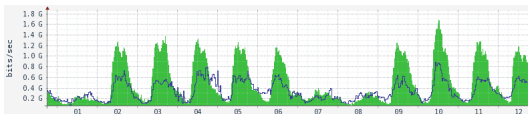
In Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications

Energy problem in the networks

- Network devices are deeply inefficient:
 - 1 they are always active;
 - 2 their consumption are independent of traffic load;
- Networks are usually designed to avoid congestions during peak traffic periods;



(a) Daily traffic demand.



(b) Weekly traffic demand.

- Green Networking investigates new solutions to adapt the power consumption to the actual traffic load;

The goal of Green Networking

- Goal of the green networking is make the network consumption load dependent;
- There are many different ways to do that [INF08]
 - **Re-engineering** approaches are devoted to introduce more energy-efficient technologies;
 - **Dynamic adaptation** approaches are aimed at modulating capacities of network device resources according to current traffic loads and service requirements;
 - They works locally and in the scale of milliseconds
 - **Sleeping and standby** approaches are founded on power management primitives, which allow devices or part of them turning themselves almost completely off, and entering very low energy states, while all their functionalities are frozen.
 - A coordinated strategy is needed. They consider big time interval (hours)



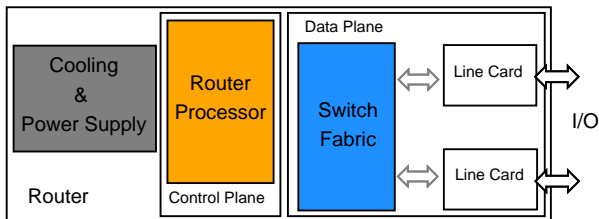
Chabarek, Sommers, Barford, Estan, Tsiang, Wright

Power Awareness in Network Design and Routing,

INFOCOM 2008. The 27th Conference on Computer Communications. IEEE, April 2008

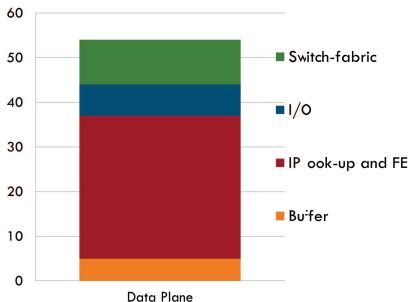
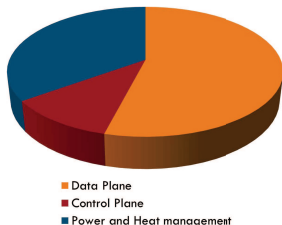
Modeling a Router

- A router can be thought as the union of three blocks function:
 - 1 *Router Processor*: it manages the whole system and implements control plane functionalities;
 - 2 *Linecards*: represent the I/O functions of a router. They operate from layer 1 up to layer 3;
 - 3 *Switching Fabric*: it interconnects linecards to each other realizing the switching operation.



Consumption of a Router

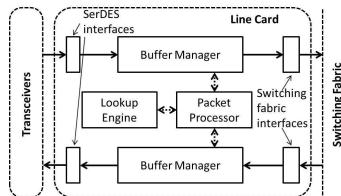
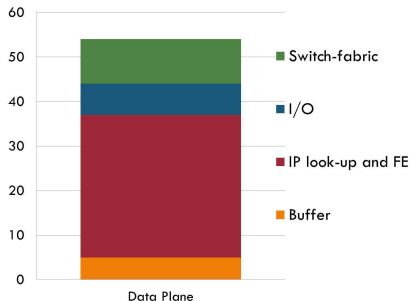
- Consumptions of a router are divided as follow;



- Most power hungry processes are those performing per-packet operations;
- I/O and buffering do not consumes too much since we are considering local consumption;

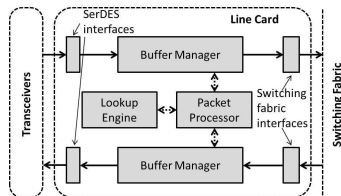
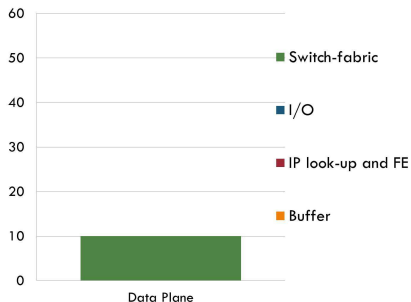
How to reduce the power consumption at the Data Plane

- Two possible ways to reduce the consumption at the data plane:



How to reduce the power consumption at the Data Plane

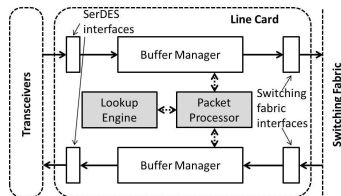
- Two possible ways to reduce the consumption at the data plane:



- Sleep Mode:** when a LC is in this state its consumption is close to zero;

How to reduce the power consumption at the Data Plane

- Two possible ways to reduce the consumption at the data plane:



- Sleep Mode:** when a LC is in this state its consumption is close to zero;
- Function Freezing:** in this state the forwarding engine of an LC does not operate, allowing to save energy;

The principle of Energy Saving Routing

- The typical goal of Energy Saving Routing techniques is to find a routing pattern that:
 - Minimizes the number of active devices during low traffic periods;
 - Guarantees QoS requirements (e.g. max congestion);
- The most used approach is the Sleep Mode, i.e., those devices can be in two states:
 - **On**, they work as usual;
 - **Off**, they cannot process packets;
- Find this routing is NP-hard [ToN] and heuristics are needed;
- A trade-off between efficiency and impact on the network performance must be taken into account;



Chiaraviglio, Mellia, Neri

Minimizing ISP network energy cost: formulation and solutions,
[IEEE/ACM Trans. Netw. 20, 2 \(April 2012\)](#)

From Flow-Based to Destination-Based Routing

- Let $\mathcal{G}(\mathcal{V}, \mathcal{E})$ be the graph representing the network, then the Energy Saving Problem with Sleep Mode can be formulated as follows:

$$\mathbf{P1} : \quad \min \sum_{(i,j) \in \mathcal{E}} x_{i,j} \quad (1)$$

$$s.t., \quad \sum_{d \in \mathcal{V}} f_{i,j}^d \leq x_{i,j} c_{i,j} \quad \forall (i,j) \in \mathcal{E} \quad (2)$$

$$\sum_{i \in \mathcal{V}} f_{i,j}^d - \sum_{i \in \mathcal{V}} f_{j,i}^d = \begin{cases} -t_{j,d} & \text{if } j \neq d \\ \sum_{s \in \mathcal{V}} t_{s,d} & \text{if } j = d \end{cases} \quad \forall j, d \in \mathcal{V} \quad (3)$$

- In an IP environment:
 - It is not possible to distinguish between different flows;
 - Routing decisions are taken according to the destination address;
 - New sets of constraints are needed;

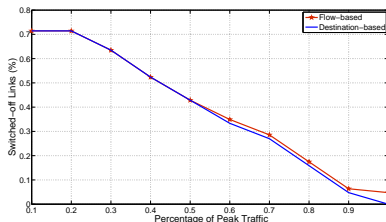
Destination-Based Routing

- Energy Saving Routing strategies search a solution in the space represented by eq. 2, 3 and the following constraints:

$$f_{i,j}^d \leq n_{i,j}^d \sum_{s \in \mathcal{V}} t_{s,d} \quad \forall (i,j) \in \mathcal{E}, d \in \mathcal{V} \quad (4)$$

$$\sum_{j \in \mathcal{V}} n_{i,j}^d = \begin{cases} 1 & \text{if } i \neq d \\ 0 & \text{if } i = d \end{cases} \quad \forall d \in \mathcal{V}, (i,j) \in \mathcal{E} \quad (5)$$

- Energy saving strategies in an IP network have a smaller feasible space where to search for solutions with respect to an MPLS network;

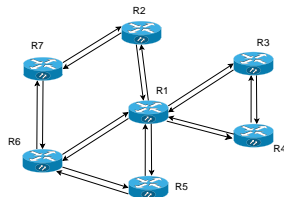


- *Integrated strategies*: they work together with the IP routing protocol in order to switch off links, trying to avoid IP topology reconfiguration procedures;
 - **ESIR**;
 - **DNHV**: a distributed algorithm that uses the signaling messages of RSVP in order to synchronize the switching off decisions taken by single nodes;
- *Overlay strategies*: work independently of the IP routing protocols, neglecting the impact of the topological changes;
 - **ESACON**: a greedy heuristic that exploits the algebraic connectivity as a reference parameter to decide what links to switch off;
 - **ESTOP**: an algorithm that makes use of the edge betweenness in order to evaluate the importance of a link;
- In the follow we will discuss about ESIR;

ESIR: an example of Integrated Strategy

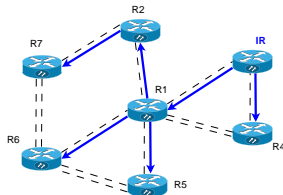
- The basic scenario is an IP network where OSPF (Open Shortest Path First) is running as routing protocol;
- OSPF is a link state routing protocol:
 - 1 By means of Link State Advertisement (LSA), all nodes know the topology;
 - 2 Each node perform Dijkstra Algorithm and get the Shortest Path Tree (SPT);
 - 3 If a link changes its state, then a new execution is needed;
- An Integrated energy saving strategy is able to reduce the number of active links in a transparent way with respect OSPF;

Exportation Mechanism



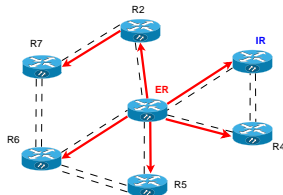
| Dest. | R1 | R2 | R3 | R4 | R5 | R6 | R7 |
|-------|----|----|----|----|----|----|----|
| NH | | | | | | | |

Exportation Mechanism



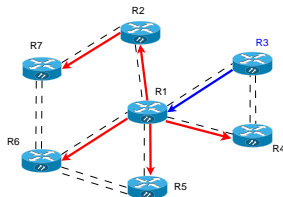
| Dest. | R1 | R2 | R3 | R4 | R5 | R6 | R7 |
|-------|----|----|----|----|----|----|----|
| NH | R1 | R1 | - | R4 | R1 | R1 | R1 |

Exportation Mechanism



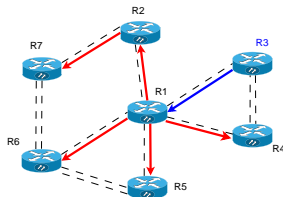
| Dest. | R1 | R2 | R3 | R4 | R5 | R6 | R7 |
|-------|----|----|----|----|----|----|----|
| NH | - | R2 | R3 | R4 | R5 | R6 | R2 |

Exportation Mechanism



| Dest. | R1 | R2 | R3 | R4 | R5 | R6 | R7 |
|-------|----|----|----|----|----|----|----|
| NH | R1 | R1 | - | R1 | R1 | R1 | R1 |

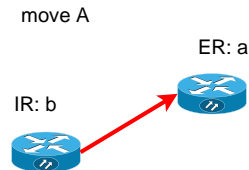
Exportation Mechanism



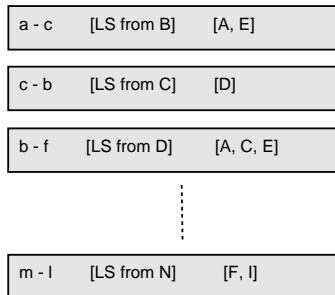
| Dest. | R1 | R2 | R3 | R4 | R5 | R6 | R7 |
|-------|----|----|----|-----------|----|----|----|
| NH | R1 | R1 | - | R1 | R1 | R1 | R1 |

- a node can be importer just one time;
- a node having a path modified by an exportation cannot be an exporter;
- IR and ER must be adjacent nodes;

Moves and Compatibility

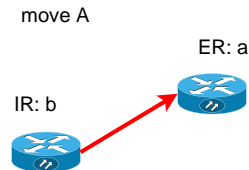


$b - a$ $E_{\text{sleep}}(A)$ $M_{\text{nc}}(A)$

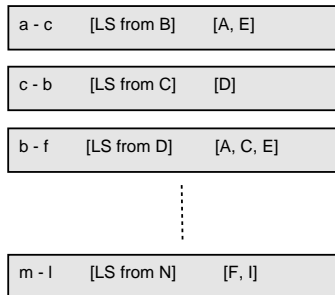


- A move is a collection of three informations: i) the link between IR and ER; ii) the set of links that the exportation switches off; iii) the set of exportations not more available;

Moves and Compatibility

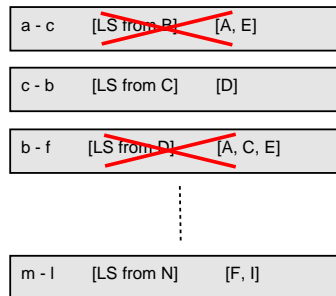
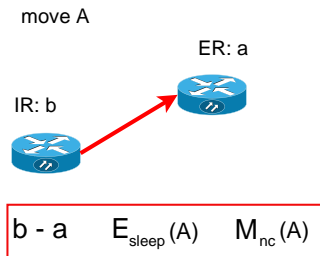


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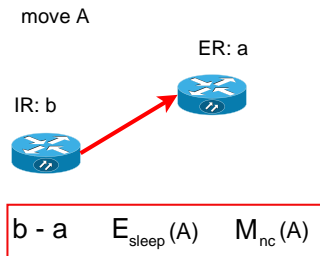
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- If a move B is still performable after the execution of a move A, then we say that B is compatible with A ($A \propto B$);

Moves and Compatibility



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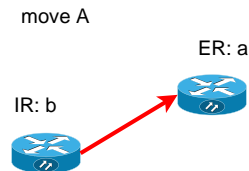
Moves and Compatibility



| | | | |
|-------|------------------------|----------------------|---|
| a - c | [LS from B] | [A, E] | 0 |
| c - b | [LS from C] | [D] | 1 |
| b - f | [LS from D] | [A, C, E] | 0 |
| ⋮ | | | |
| m - l | [LS from N] | [F, I] | 1 |

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Moves and Compatibility



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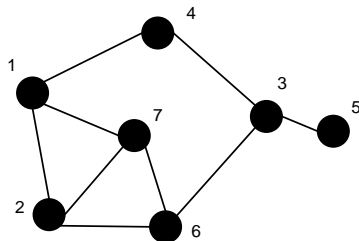
| | | | |
|-------|------------------------|----------------------|---|
| a - c | [LS from B] | [A, E] | 0 |
| c - b | [LS from C] | [D] | 1 |
| b - f | [LS from D] | [A, C, E] | 0 |
| ⋮ | | | |
| m - l | [LS from N] | [F, I] | 1 |

- A move is a collection of three informations: i) the link between IR and ER; ii) the set of links that the exportation switches off; iii) the set of exportations not more available;
- If a move B is still performable after the execution of a move A, then we say that B is compatible with A ($A \propto B$);
- Compatibility is a symmetric property.

The graph of moves

- All compatibility vectors can be put together to build a matrix C ;
- C is a matrix with the following features:
 - 1 Is a square matrix;
 - 2 Is composed only by 0 and 1;
 - 3 Is a symmetrix matrix;
- C is the adjacency matrix of a graph, the graph of moves;

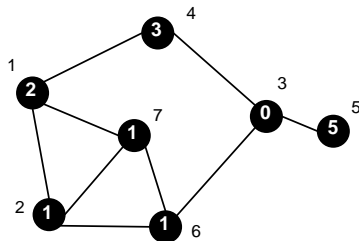
| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 |



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| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 |



Equivalence between problems

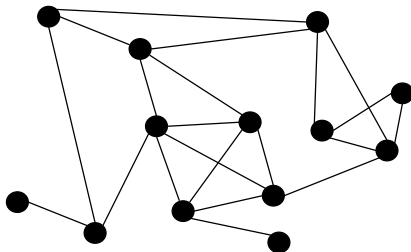
- The ESIR problem consists in finding the set of moves (exportations) that allows to switch off the highest number of links;
- Let x_i be a binary variable:
 - it is equal to 1 if the i -th move is applied;
 - 0, otherwise;
- Instead of considering the graph of move $G(M, C)$, we consider its complement $\overline{G}(M, \overline{C})$;
- Our goal is the follow:

$$\max \sum_{i \in M} x_i \text{ s.t. } x_i + x_j \leq 1, \forall (i, j) \in \overline{C}$$

- This formulation leads with the Maximum Stable problem;
- Here we consider its complement: the Maximum Clique problem;

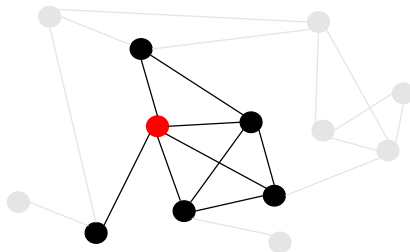
The Max Compatibility Heuristic

- A clique is a subset of nodes so that the induced sub-graph is full meshed;
- At each step the move that maximizes the "residual graph" is added to the solution;



The Max Compatibility Heuristic

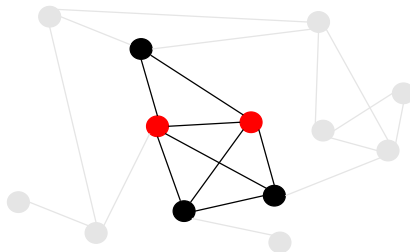
- A clique is a subset of nodes so that the induced sub-graph is full meshed;
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- Before add a move in the solution set, its impact on link load is considered;

The Max Compatibility Heuristic

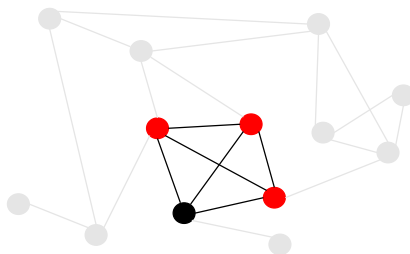
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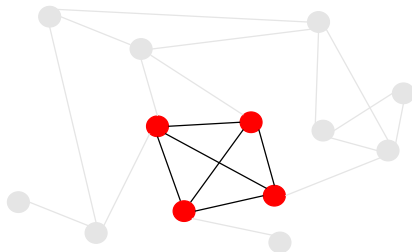
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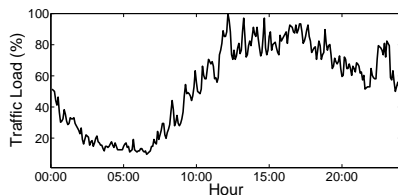
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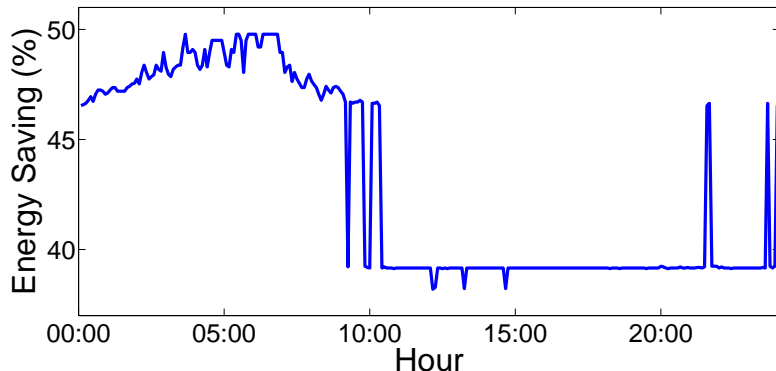
Simulation setup

- We test performance of ESIR over the France Telecom (FT) backbone network;
- This network is made by 38 nodes and 72 links;
- Real traffic matrices are considered;



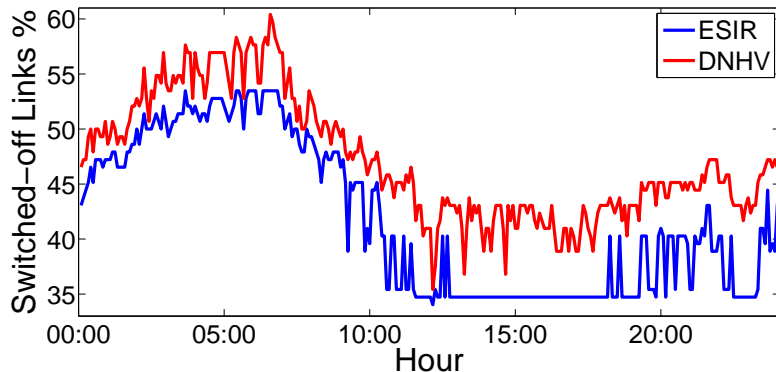
- Link capacity assigned considering:
 - Peak traffic matrix;
 - Shortest path rule;
 - Block of capacity of 40 Gbps;
 - An over-provisioning factor of 50%;
- Each capacity block has a consumption of 250 W;

ESIR: Percentage of Energy Saving



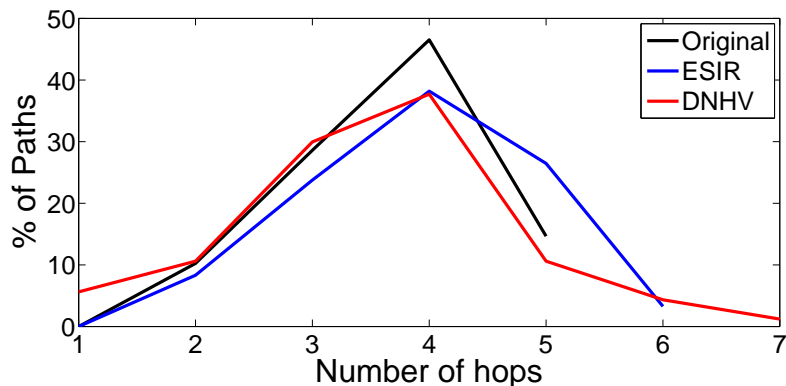
- The percentage of energy saving during the day got by applying ESIR;

ESIR: Comparison with other algorithms



- In DNHV an ER shares with the IR just one path instead of the whole tree;

ESIR: Distribution of Path Length



- The lowest traffic matrix has been considered;

- First contribution of the present Thesis is the proposition of a new bound for the energy saving in IP network;
- Secondly, we provide practical routing algorithms able to reduce the power consumption up to 50%;
- In order to improve the saving possibilities the Function Freezing has been defined;
- Future efforts must be in the direction of implementing the proposed Integrated algorithms in a real device;