Green ICT: Beyond Sleeping Memories

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Outline

- Today’s starting point in telecom EE
- Future trends in network Energy Efficiency
- Priorities for the call

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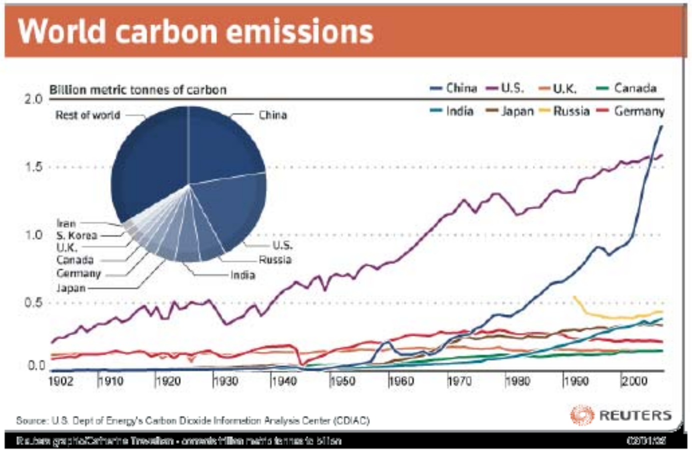
INTelligent Energy awaRe NETworks (INTERNET) project Collaborators, (£5.9m, 2010-2015)

World wide ICT Carbon footprint



Country	Network	Energy Consumption	% of Country Total Energy Consumption
USA	Verizon 2006[1]	8.9 TWh	0.24%
Japan	NTT 2001[2]	6.6 TWh	0.7%
Italy	Telecom Italia 2005[3]	2 TWh	1%
France	France Telecom-Orange 2006[4]	2 TWh	0.4%
Spain	Telefonica 2006[5]	1.42 TWh	0.6%

S.Roy, IEEE Intelec 2008

Smart Grids

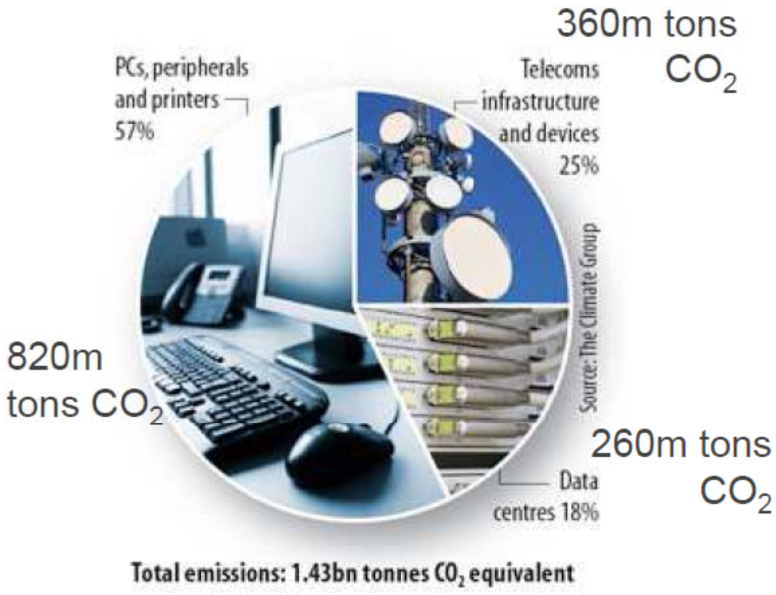
Smart Transportation

Smart Communities

Enabling a Low Carbon Economy

Smart Buildings

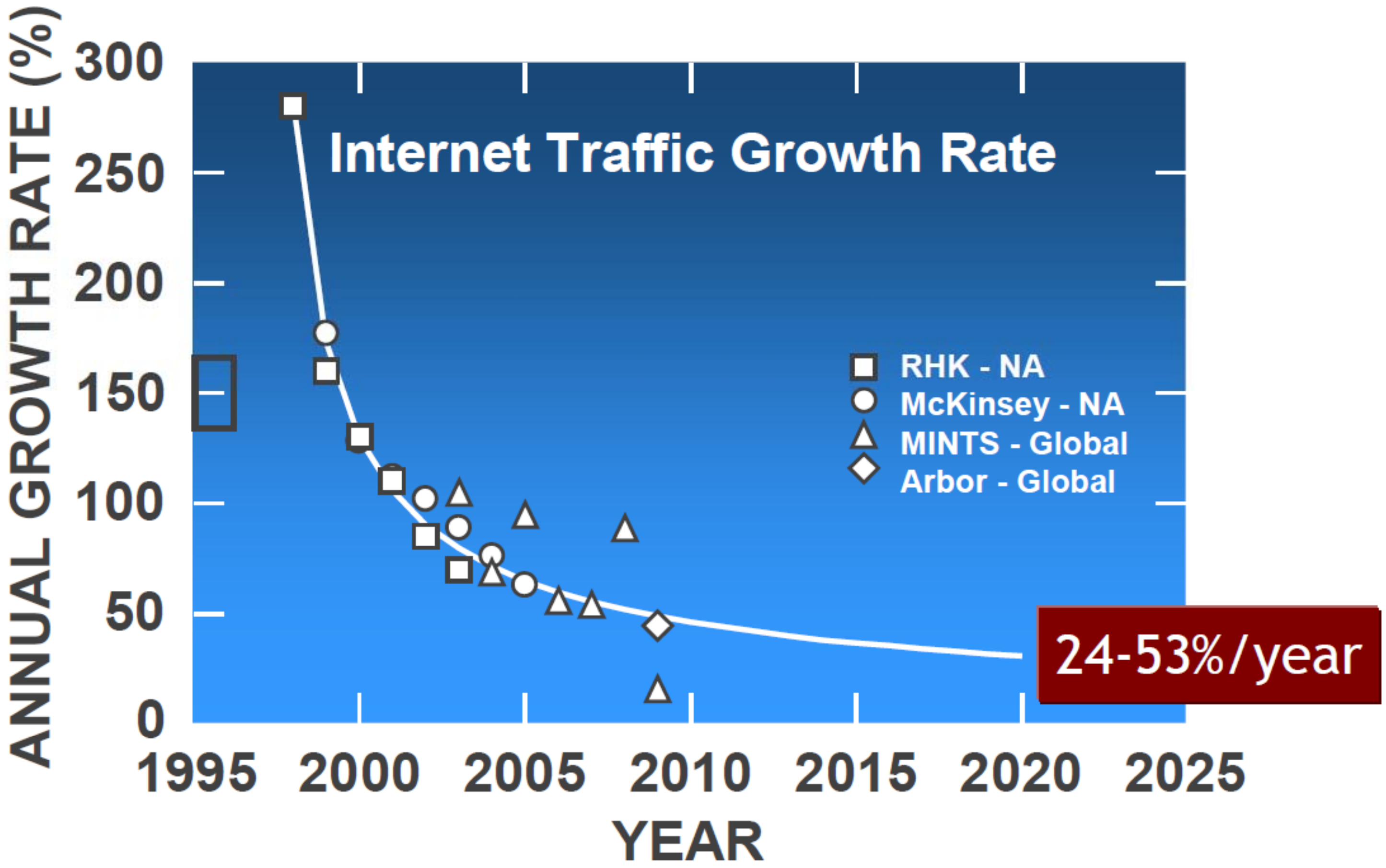
E-Health



- 2007 Worldwide ICT carbon footprint: 2% = 830 m tons CO_2
- Comparable to the global aviation industry
- Expected to grow to 4% by 2020

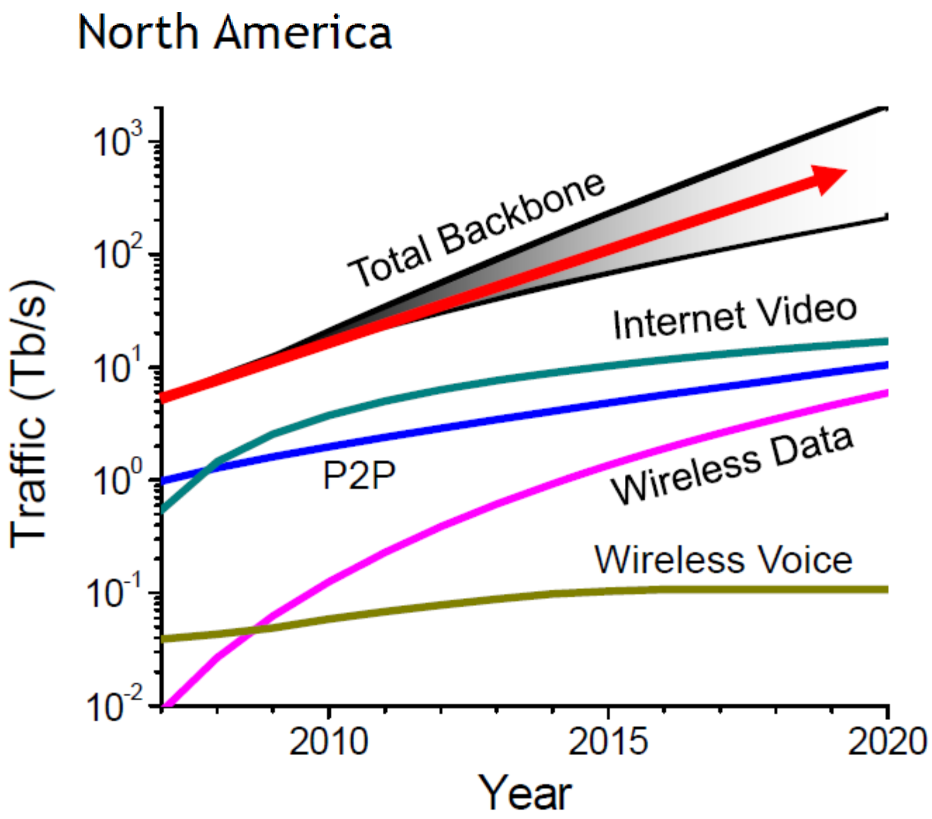
- Courtesy Thierry Klein, Alcatel-Lucent Bell Labs

Internet Traffic Growth Rate



- Courtesy Thierry Klein, Alcatel-Lucent Bell Labs, Sources: RHK, 2004; McKinsey, JPMorgan, AT&T, 2001; MINTS, 2009; Arbor, 2009

Exponential traffic growth



Doubling every 2 years

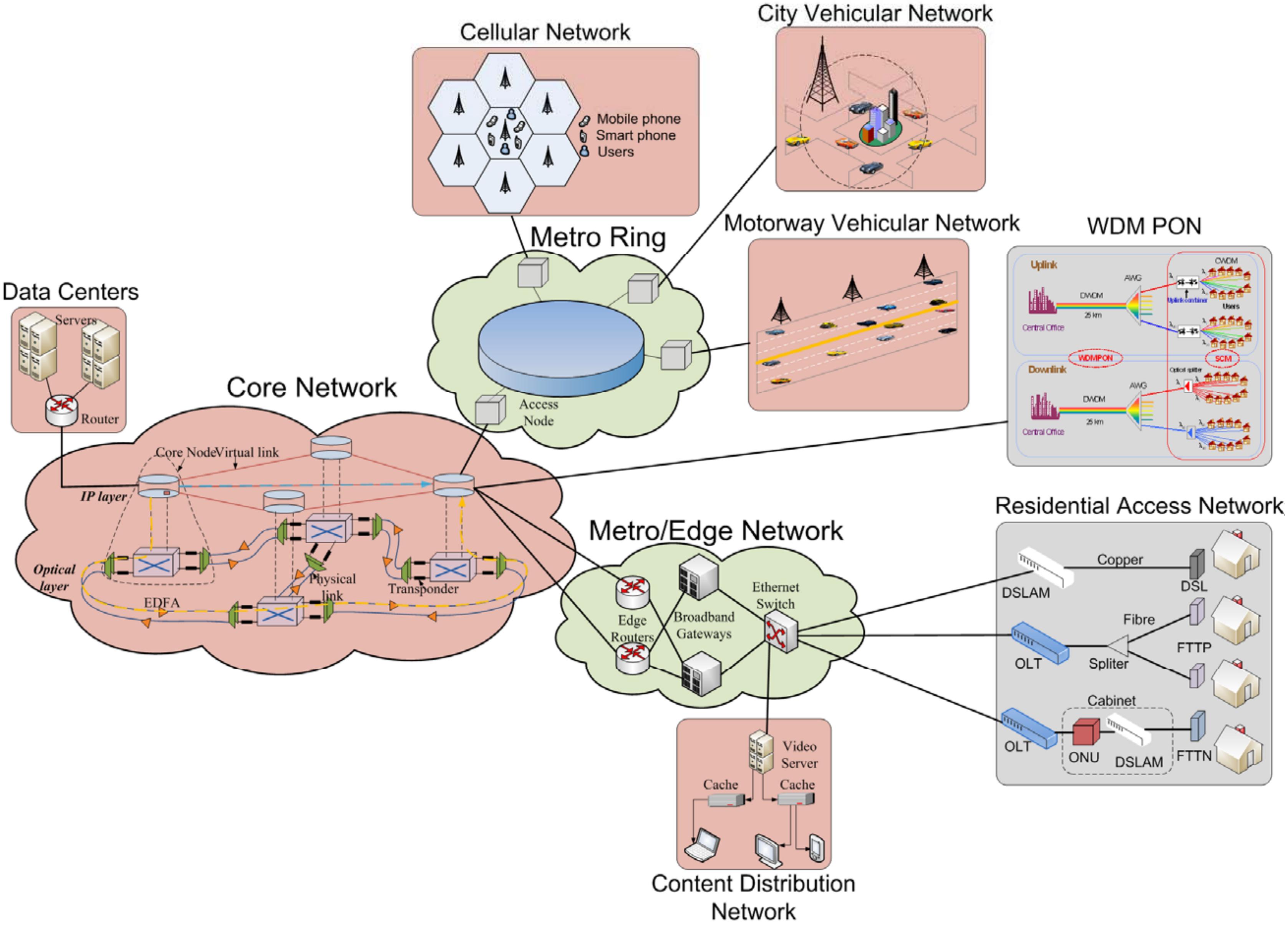
- **40% per year**
- **30x in 10 years**
- **1000x in 20 years**

Mix of services is important from energy perspective:

- **Mobile less efficient than fiber optics**

Data from: RHK, McKinsey-JPMorgan, AT&T, MINTS, Arbor, ALU, and
Bell Labs Analysis: Linear regression on log(traffic growth rate) versus log(time) with Bayesian learning to compute uncertainty

End-to-end network



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➔ Future trends in network Energy Efficiency

- Priorities for the call

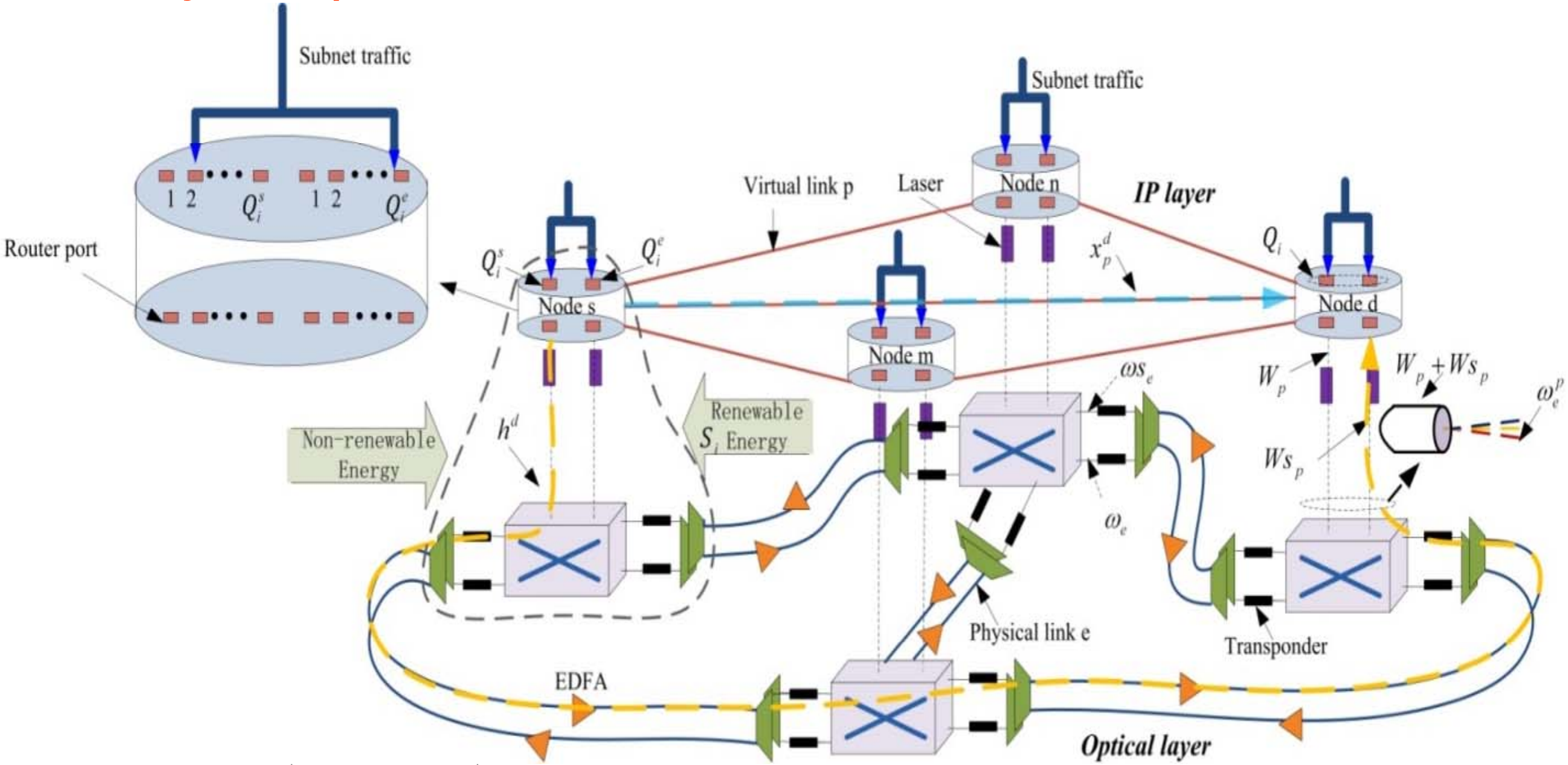
Future trends

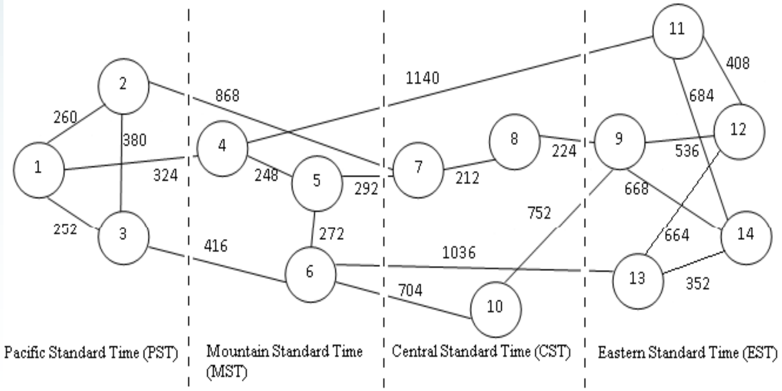
- Core and access networks
  - Energy efficient IP over WDM networks and renewable energy
  - Network topology optimisation
- Data centres and content distribution networks
  - Network design with data centres, energy-efficiency
  - Caching and IPTV / VoD networks
- Wireless networks
  - Energy and QoS in V2R motorway network: M-PRMA and 802.11p
  - Saving energy with QoS for vehicular communication in a city environment
  - Dynamic spectrum leasing and energy saving

Energy efficient IP over WDM networks and renewable energy

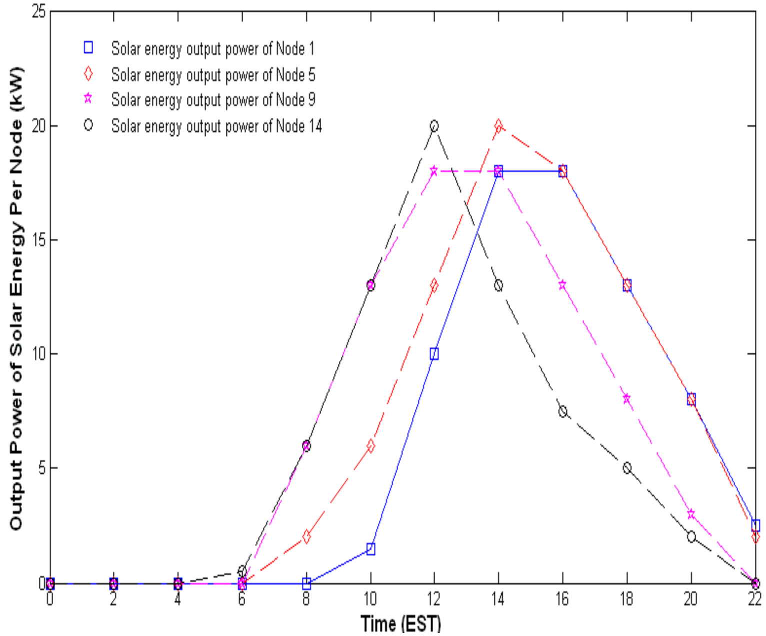
- Focus on reducing the CO_2 emission of backbone IP over WDM networks.
- Issues include
  - how to use renewable energy more effectively,
  - how to reduce the non-renewable energy consumption,
  - how to select the location of nodes that use renewable energy,
  - load dependent energy consumption of hardware.

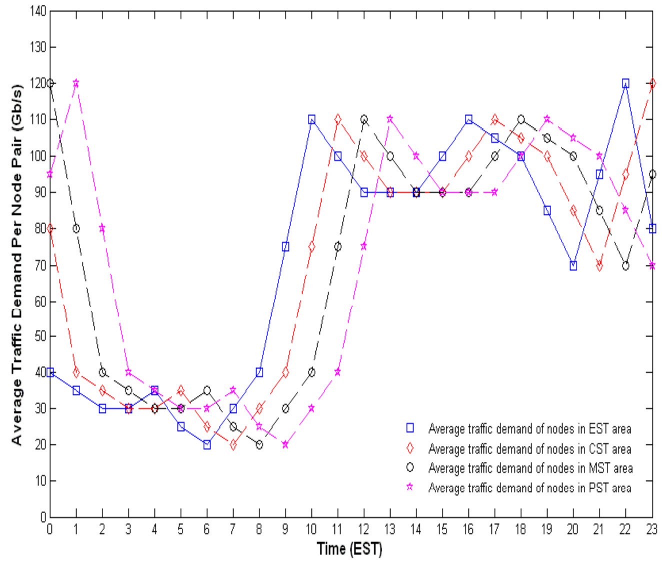
“Hybrid-power” IP over WDM network architecture





Energy saving and CO_2 reduction



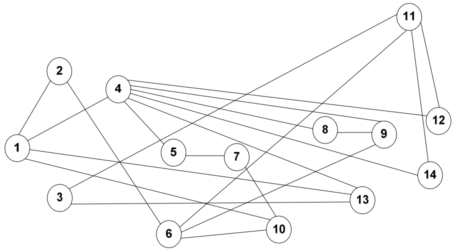


- With only 20 kW renewable in 5 nodes, ALR and REO-hop, the CO_2 reduction compared to the non-bypass case without solar energy is approximately 85% (maximum) and 65% (average).

- Note that the 85% and 65% savings are almost real energy savings since the renewable energy is low here and has limited effect.

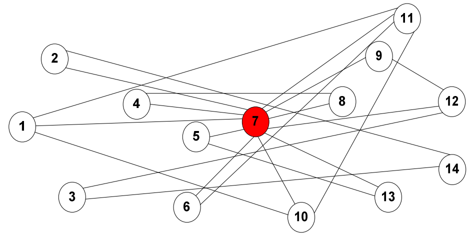
- When all nodes use 80 kW renewable energy, the CO_2 reduction is approximately 97% (maximum) and 78% (average).

Topology optimisation (city locations known), MILP



6%

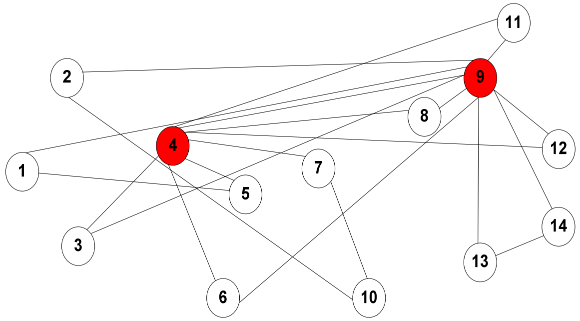
Symmetric users



22%

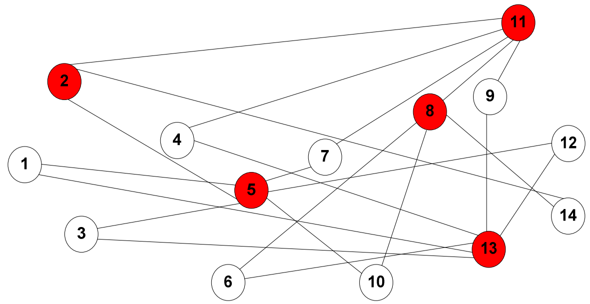
Ndgr=2,
Nlink=21

One large user



20%

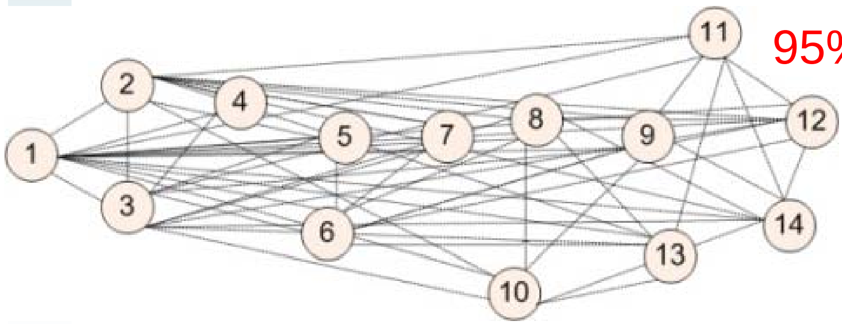
2 large users



8%

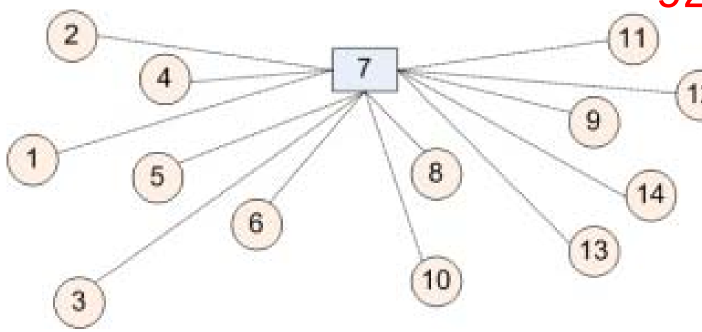
Ndgr=2,
Nlink=21

5 large users



95%

Mesh: Optimum topology from LP with no constraint on number of links, or node degree



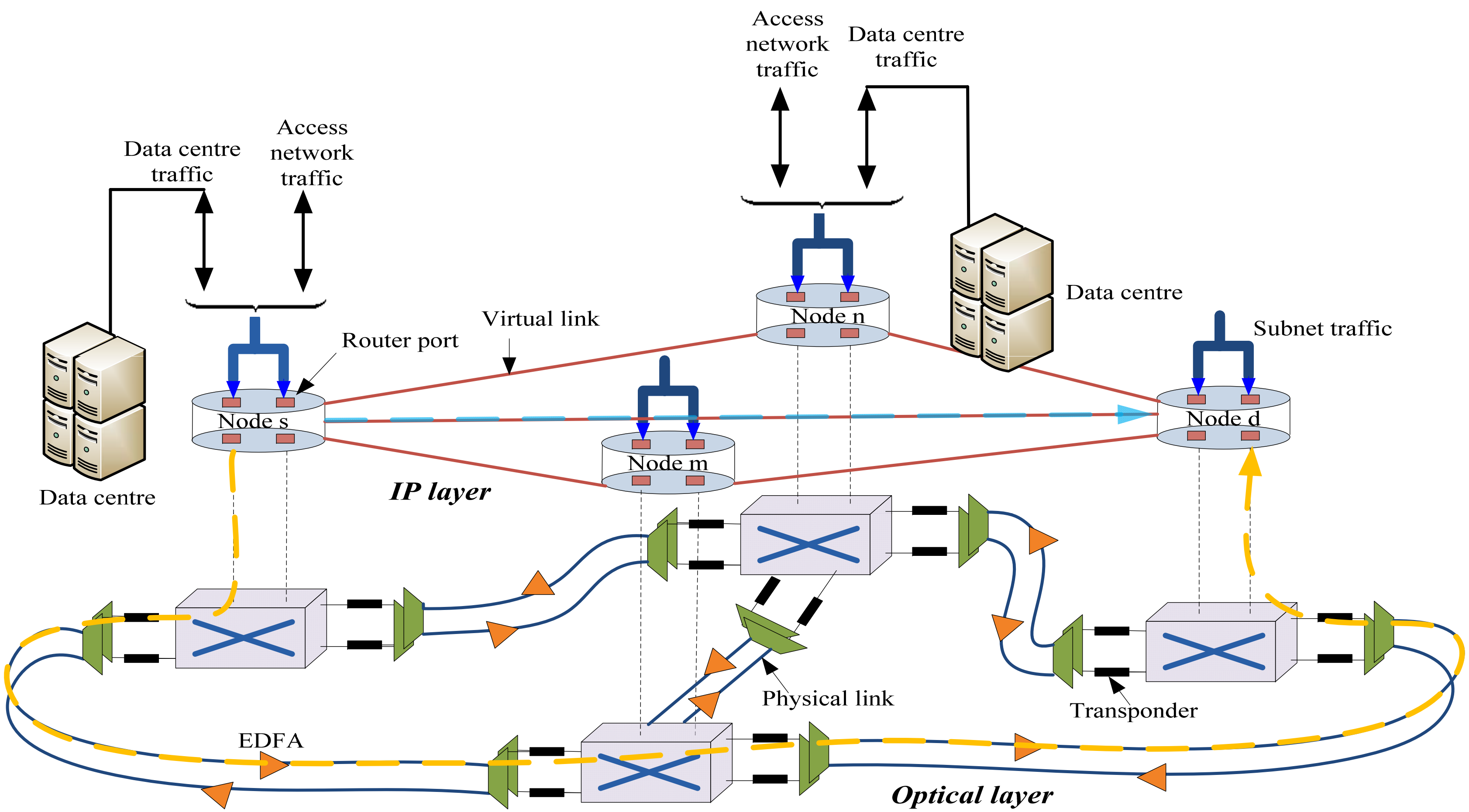
92%

Star: Nodes separation comparable to mesh, Less links, less resilience

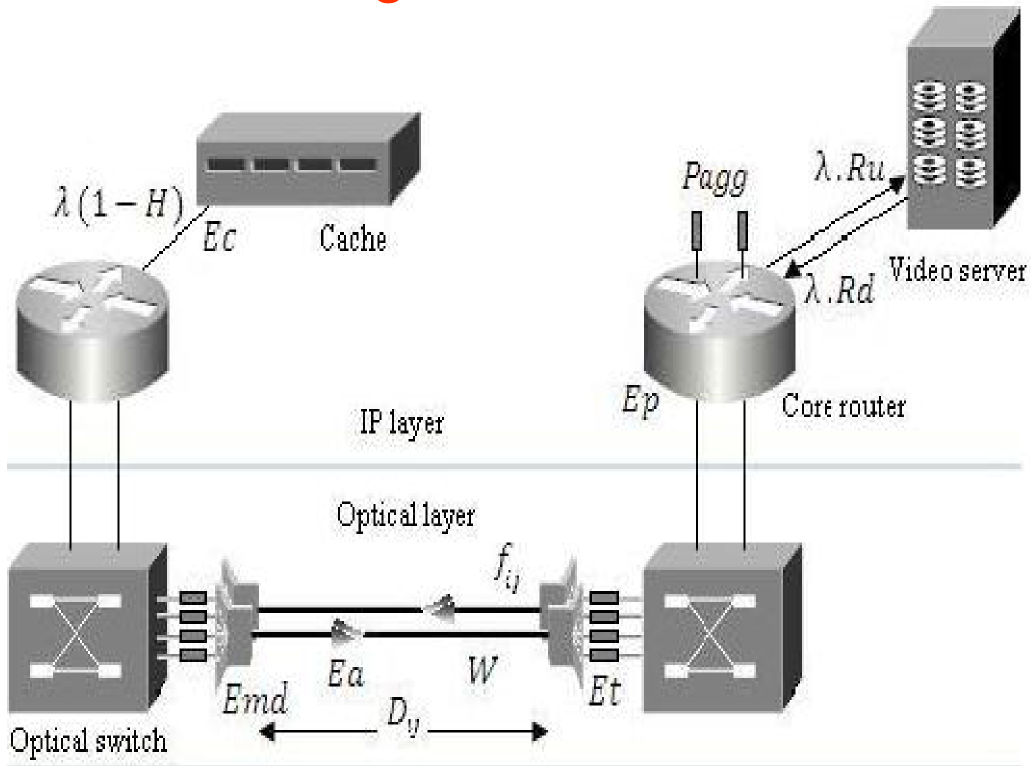
Network design with data centres, energy-efficiency

- Three problems :
  - **Firstly**, the optimization, Linear Programming (LP), of the data centres locations to minimize the Power consumption.
    - the IP over WDM routing approach (bypass and non-bypass), the regularity of the network topology and the number of data centres in the network.
  - **Secondly**, the energy savings introduced by implementing a data replication scheme in the IP over WDM network with data centres, where frequently accessed data objects are replicated over multiple data centres according to their popularity.
  - **Thirdly**, introducing renewable energy sources (wind and solar energy) to the IP over WDM network with data centres.
    - We evaluated the merits of transporting bits to where renewable energy is (wind farms), instead of transporting renewable energy to where data centres are.
    - We considered the impact of the electrical power transmission losses, network topology, routing, traffic.

Data centres in an IP over WDM network

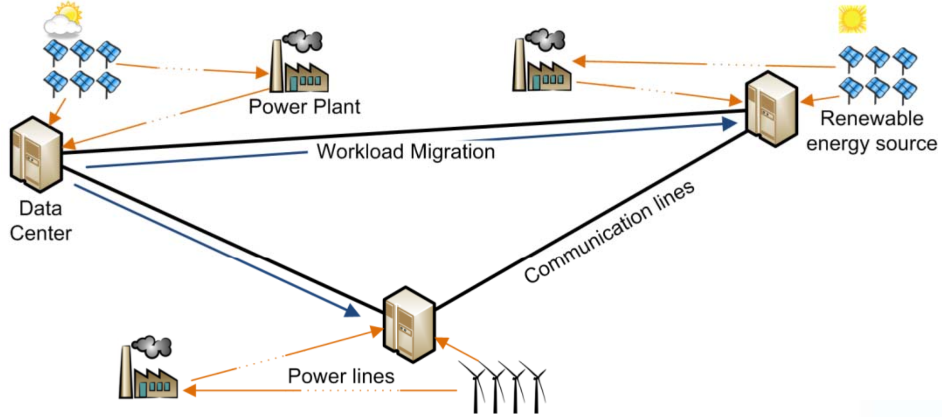


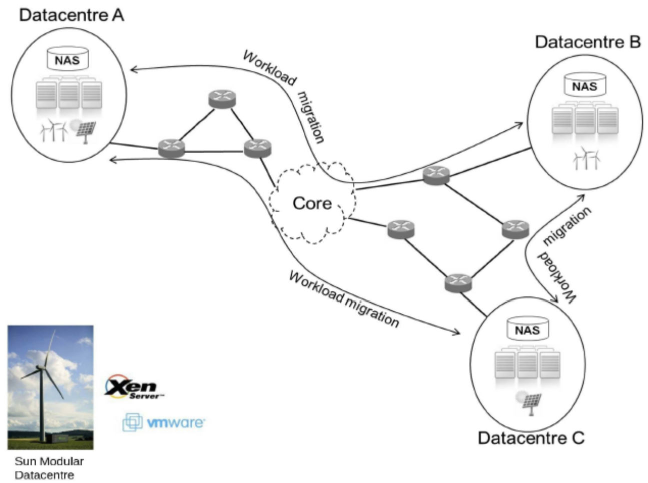
Energy efficient caching for IPTV on-demand services

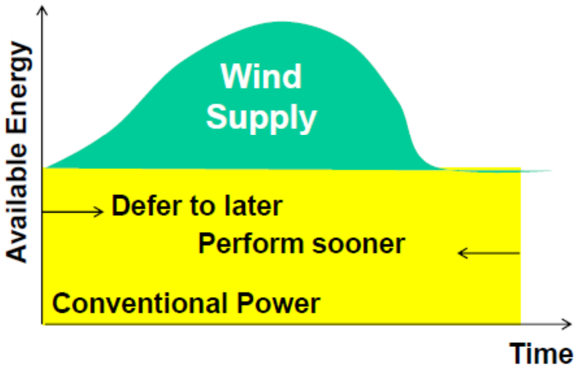


- By 2014 over 91% of the global IP traffic is projected to be a form of video (IPTV, VoD, P2P), with an annual growth in VoD traffic of 33%.
- In proxy-based architectures, proxies (or caches) are located closer to clients in order to cache some of the server's content.
- The goal is to minimize the power consumption of the network by storing the optimum number of the most popular content at the nodes' caches.

Virtual machine migration between geographically distant data centres



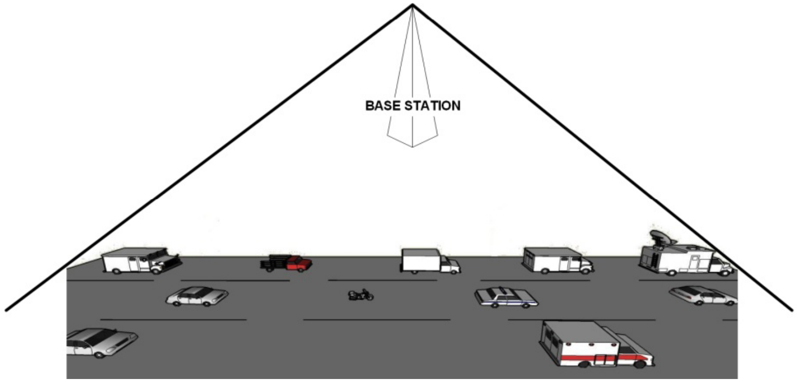


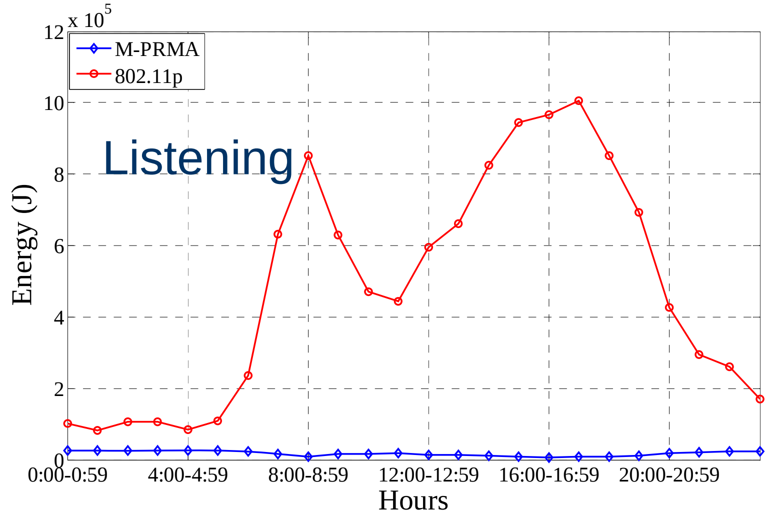


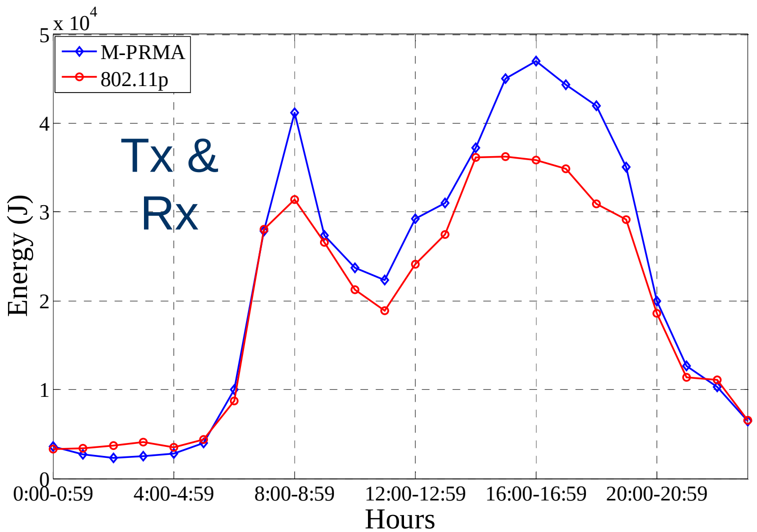
Energy and QoS evaluation of V2R motorway network: M-PRMA and 802.11p

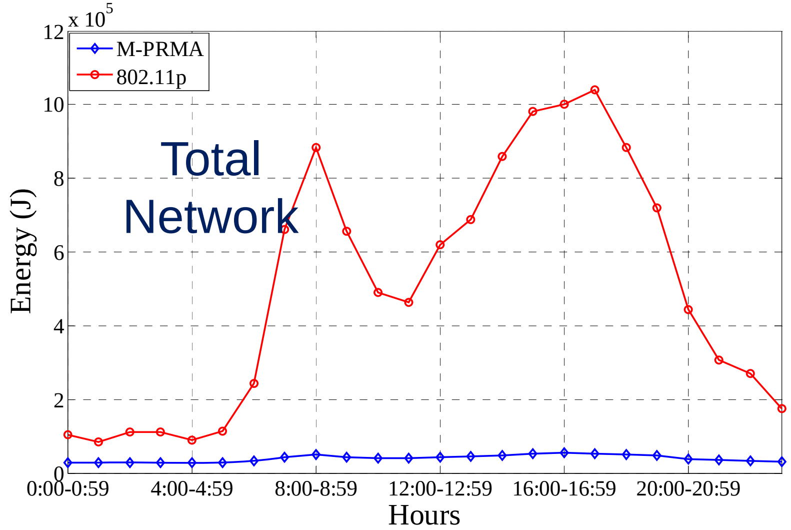
- Realistic mobility model through vehicular traffic traces.
- Integrate mobility model with a communication network layer to create a motorway V2R evaluation environment.
- Evaluate the total network power consumption.
- Consider sleep cycles to reduce the power consumption.
- 802.11p and M-PRMA for power consumption in V2R under realistic (experimental) vehicular flow in a motorway.

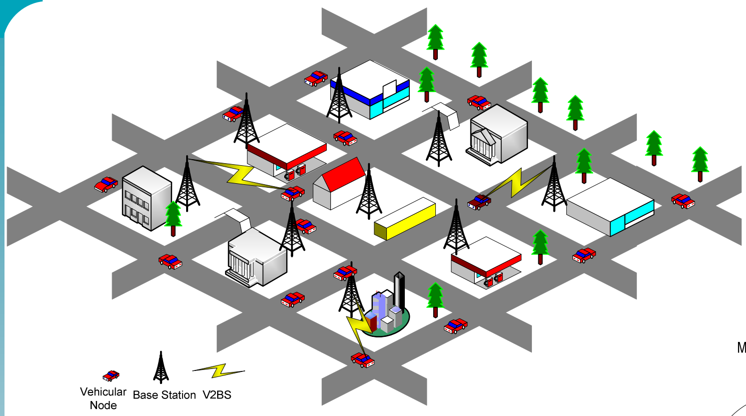
Results (power consumption)



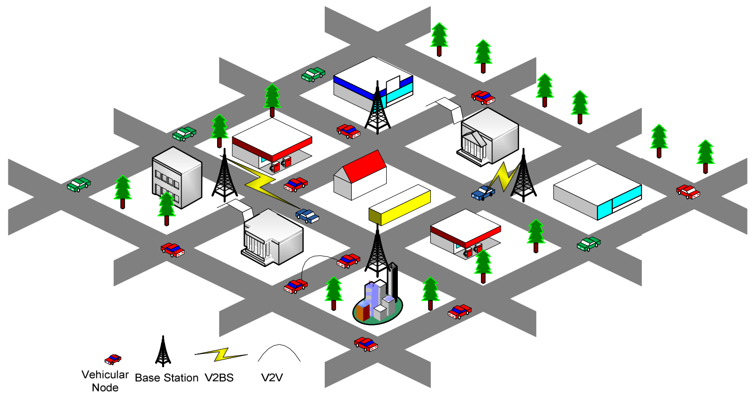




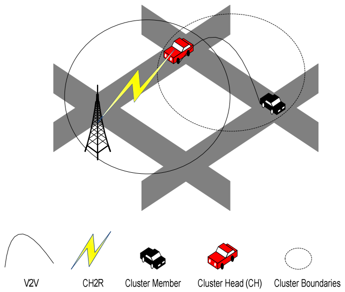




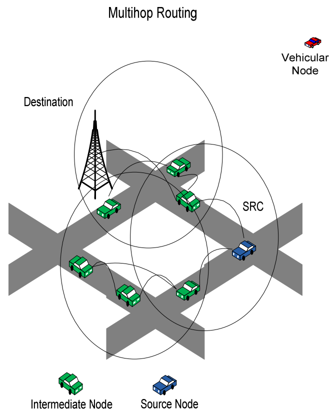
Vehicular Node
Base Station
V2BS



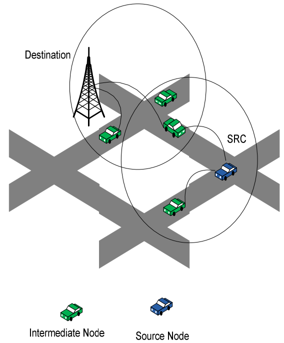
Vehicular Node
Base Station
V2BS
V2V



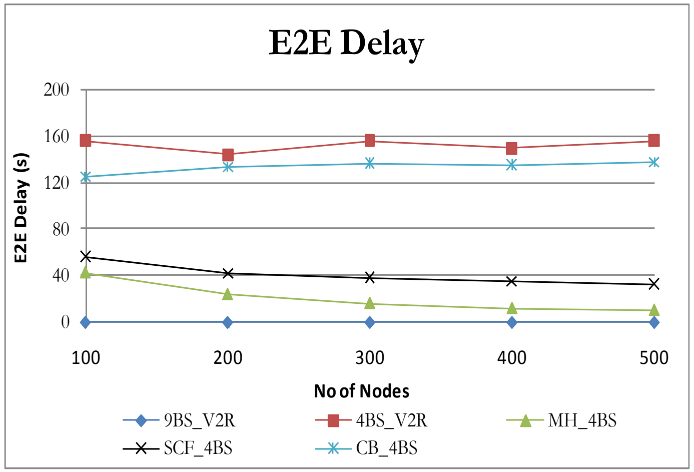
V2V
CH2R
Cluster Member
Cluster Head (CH)
Cluster Boundaries



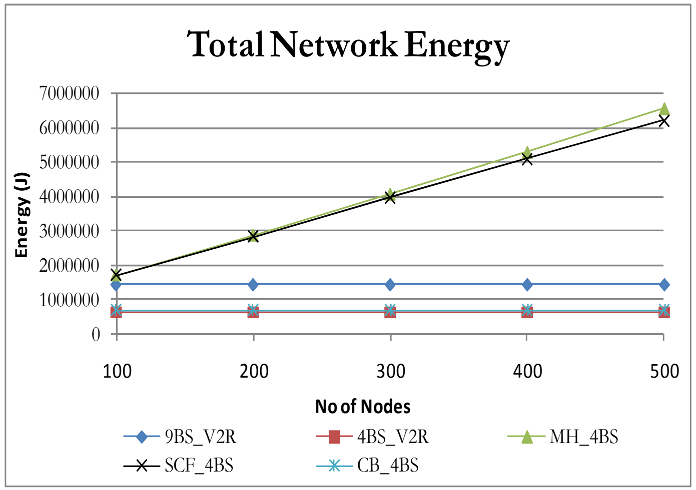
Multihop Routing
Destination
SRC
Intermediate Node
Source Node



Destination
SRC
Intermediate Node
Source Node

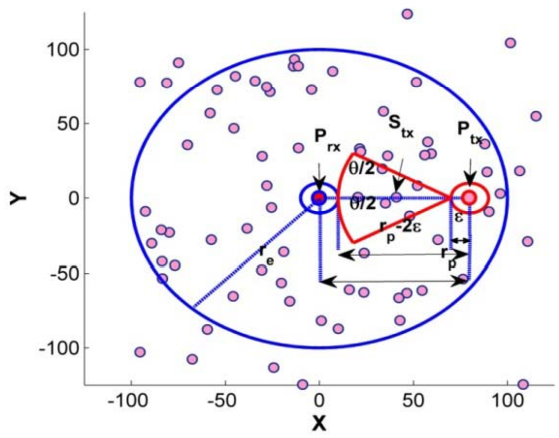


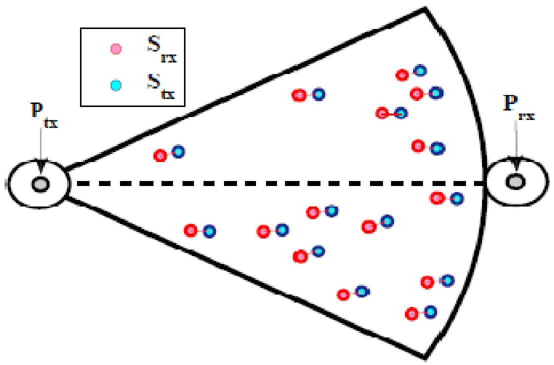
E2E Delay
E2E Delay (s)
200
160
120
80
40
0
100
200
300
400
500
No of Nodes
9BS_V2R
4BS_V2R
MH_4BS
SCF_4BS
CB_4BS

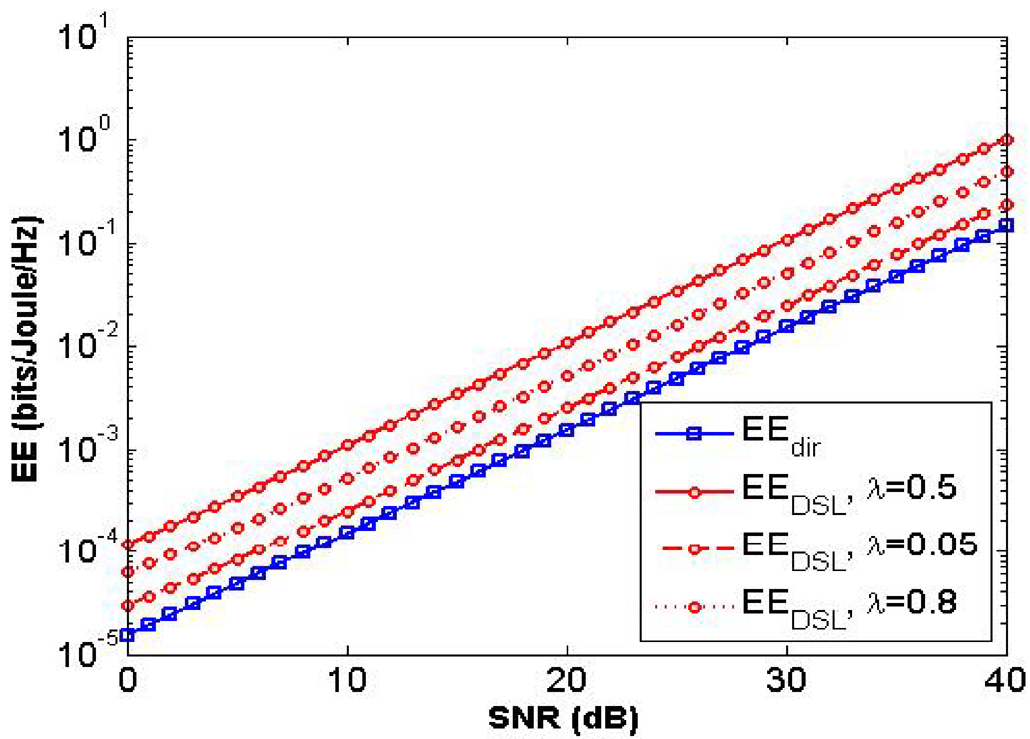


Total Network Energy
Energy (J)
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
100
200
300
400
500
No of Nodes
9BS_V2R
4BS_V2R
MH_4BS
SCF_4BS
CB_4BS

Dynamic spectrum leasing and energy saving



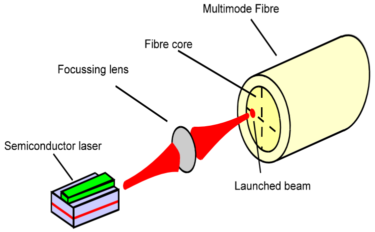


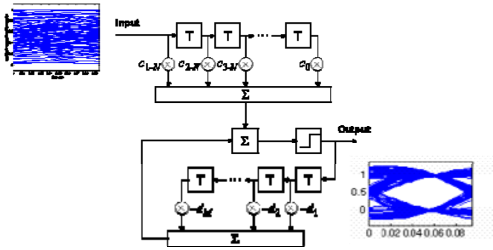


- DSL operation under geometric considerations can be significantly (up to 10 times) more energy efficient compared to direct communication, while maintaining the same time-rate product compared to direct communication.

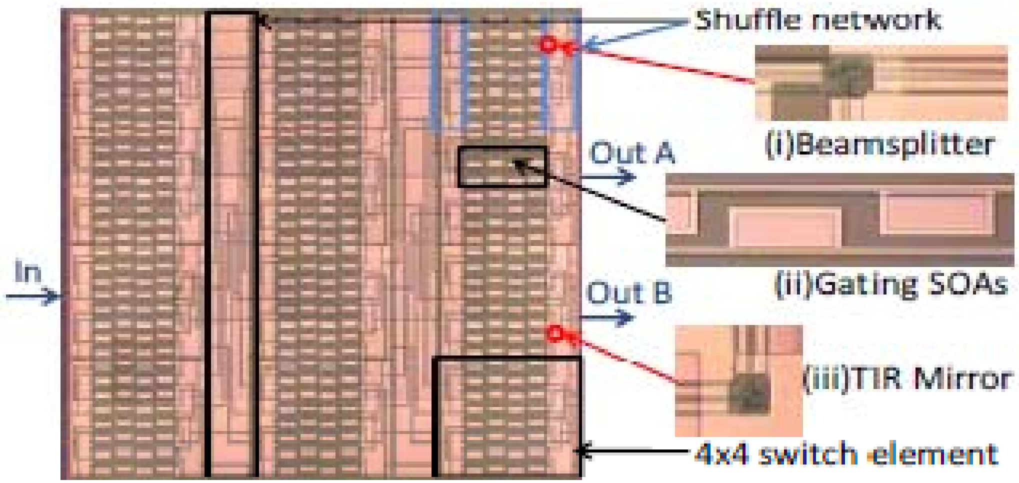
New hardware

Data communications

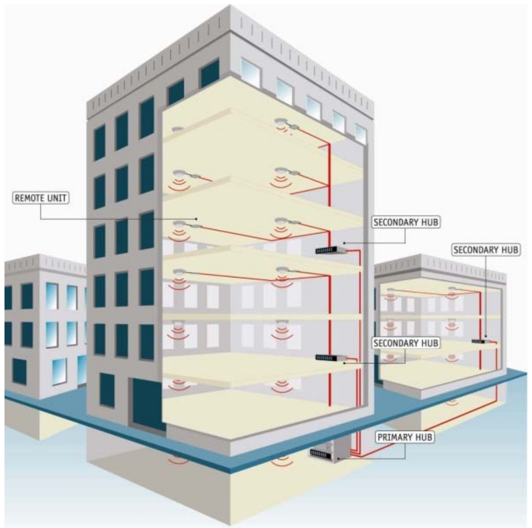




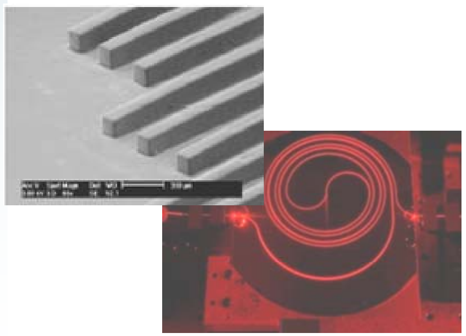
16x16 low power photonic switch

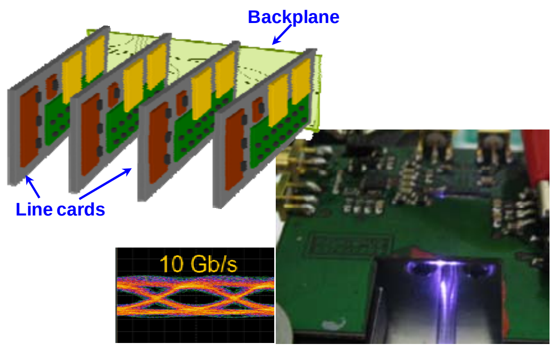


In building distributed antenna systems



Polymer optical interconnects, backplane





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➔ Priorities for the call

Priorities for the call

- “The carbon free network”
- “The routing free network”
- Content caching and access networks
- Different content popularity models
- Cooperative and relay wireless networks power efficiency

Priorities for the call

- Optimisation of wired-wireless access architectures, metro rings - wireless mesh, PON, RoF.

- Optical band and flow switching.

- Self-organising dynamic architectures for energy minimisation.

- Optimum architectures that take products CO_2 lifecycle into account (Embodied Energy).