Deriving a Dynamic Power Management Model for Next Generation Network Core Routers

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Drivers for Green Networking

- Experts estimate that IP traffic will continue to grow at 43% per annum, doubling every 1.4 years [1]
- This drives an increased demand for power in routers and switches of 4% pa [2]
- This drives an increased demand for new network equipment which requires the extraction of materials (phosphorus, mercury) and produces carbon dioxide (CO_2).

Global Warming

The GeSI study posits that 460 Mt of CO2e emissions could be saved by making use of telecommuting, videoconferencing, e-paper, e-commerce and online media [2] but this drives growth in networks

How can networks support the aims of The Climate Change Act (2008), Meet their Carbon Reduction Commitment (CRC)[3] and avoid Increased energy costs, in a future with unstable energy supplies?

Major Power Saving Techniques for Communications Network

Sleeping : Switching device into sleeping mode while not actively in use.
Slowing : Reducing voltage level and link rate while demand is low [4].

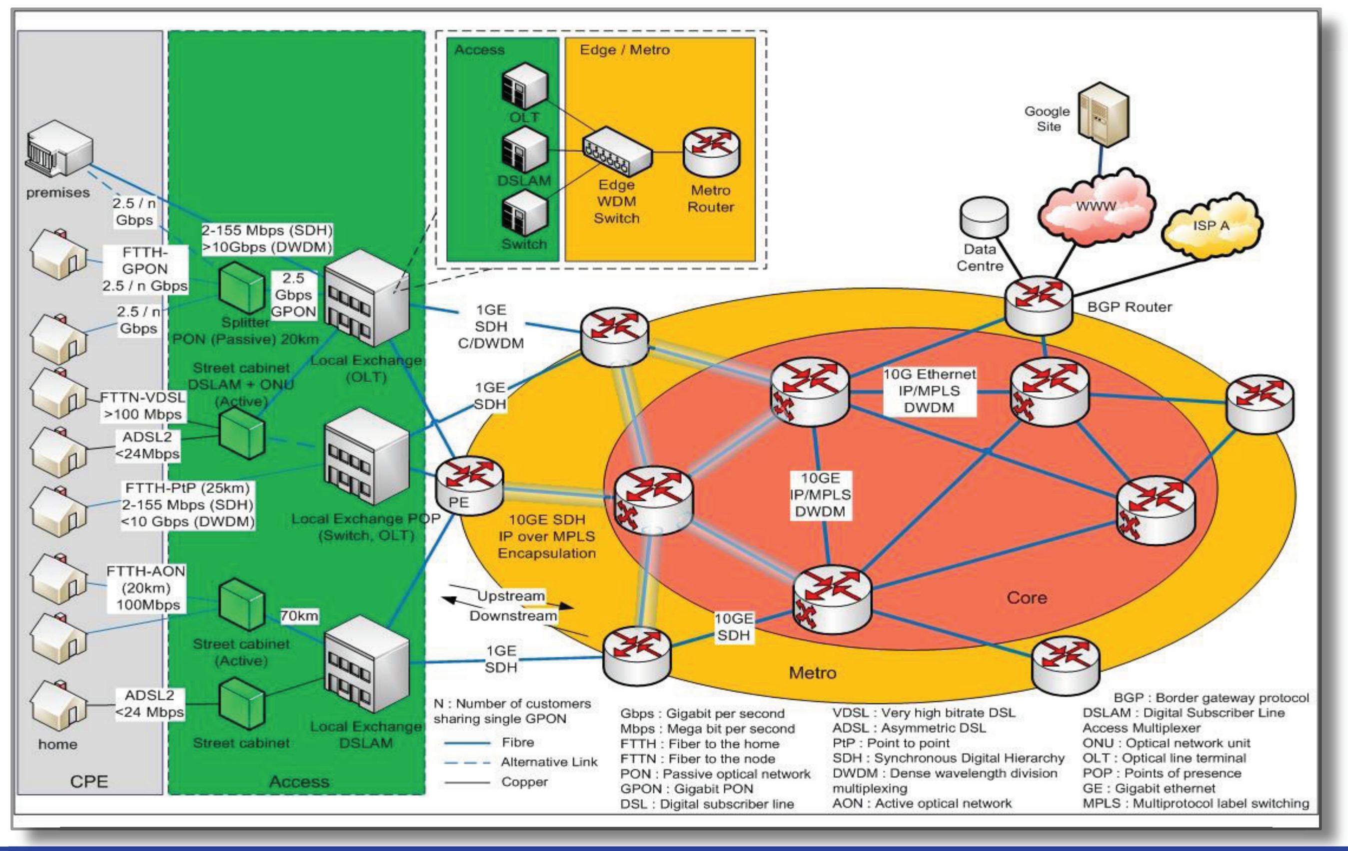
Constraints in Employing Energy Saving Techniques

Saving techniques may compromise performance and availability

- May affect QoS SLAs by delaying real-time applications such as voice
- May prevent control plane traffic functioning properly
- May impact availability of services (e.g. emergency calls)
- Lack of hardware support (longer on/off switching time to obtain enough power saving)
- Need to maintain resilience and fault tolerance

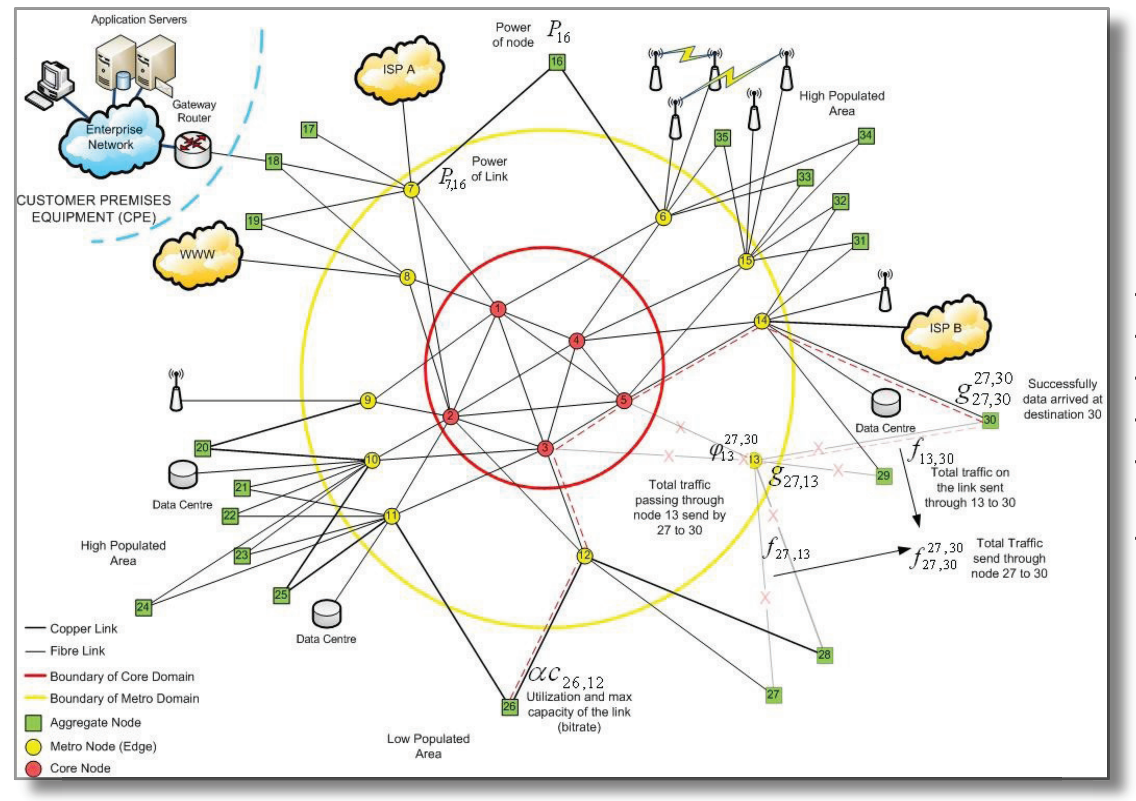
Exemplar Next Generation Network Architecture – Current Technologies

Several different technologies employed at the today's CPE and Access Network, data communication is aggregated and routed via high capable meshed metro and core routers to their destination.



Dynamic Power Management and Use-Case

Idea: Save power by transmitting data via less power hungry routes within multi-path environment; create more opportunity to sleep components through re-routing



Switching off port, line card or entire router might cause:

- Increasing queue size
- Increased packet drop
- Increased latency
- Increasing retransmissions
- Increased number of control messages
- Increasing hardware usage (forwarding engine, route engine, buffering etc.)

Constraints of Dynamic Power Management

- Overhead on alternative path should not comprise the QoE.
- Set thresholds for key parameters (e.g. upper bound of packet drop)
- Any delay at the nodes should be acceptable level for the real time applications.

Power of End to End Path

$$P_{SD}^{tot} = \sum_{i=s}^{d} \sum_{j=s+1}^{d} Pl_{ij} + \sum_{i=s}^{d} Pn_i$$

POWER Model (Pn_i); Amplifiers on the Link (Pl_{ij})

P_{SD}^{tot} : Total power from source to destination
Pn_i : Power consumption of node
Pl_{ij} : Power consumption of a link (amplifiers) [5]
D : Source S : Destination

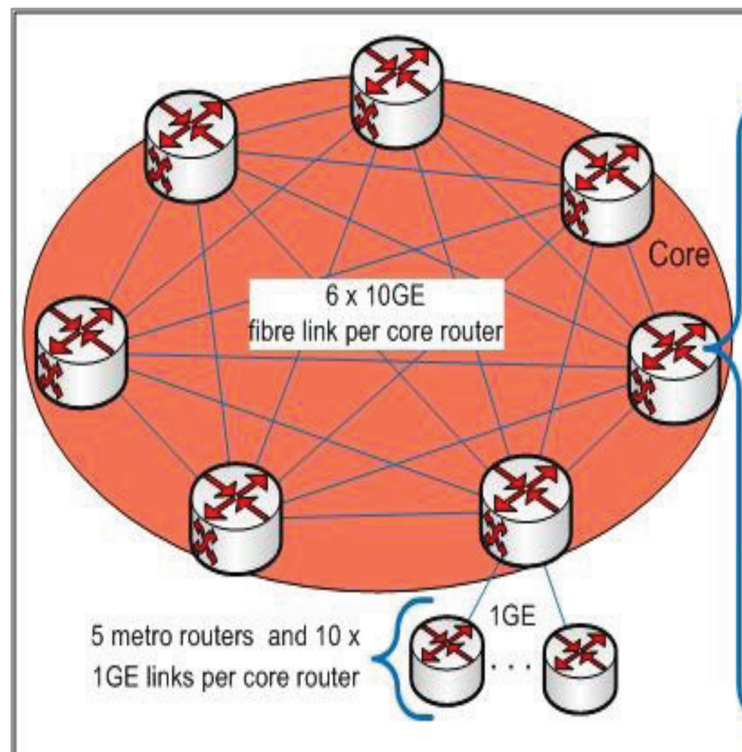
Power consumption of a link [5]

$$Pl_{ij}^{tot} = \left\lfloor \frac{Ll_{ij}}{k} \right\rfloor Pa$$

Ll_{ij} : Length of link
Pa : Power consumption of amplifier
k : Distance required to locate amplifiers

Consumption of a Power Saving Enabled Core Router on the Field

Each router has a set of information tables namely the Router Configuration Table and Workload Table. These are populated with information gathered in the management plane, using calculations performed by the system or router itself.



Router Configuration Table

Model : Cisco CRS-1 (16 Slot)			Max Power Draw: 10 KW			
Slots	Ports	On\off	Bitrate	Average utilization	Predicted utilization	Link
Slot 1	port 1					
	...					
	port n					
...	...					
Slot n	port 1					
	...					
	port n					

Workload Table

Sub components	Utilization %			states			
	100	...	5	sleep	slow	backup	...
Routing	0.11						
Switch Fabric	0.10						
Buffer	0.05						
Forwarding Engine	0.32						
O/E conversion	0.07						
Power conversion & Cooling	0.35						

Power Model (Single Router)

$$Pn = P^{max}\left(\left(\beta_a^{col}\left(1-\alpha_{slp}^{dev}\right)+\left(\alpha_{slp}^{dev} * \beta_{slp}^{col}\right)\right) + \sum_{i=1}^{Ns^{tot}} x_i^{slot} \sum_{j=1}^{Np_i^{tot}} x_{ij}^{port} \sum_{i=1}^{S} \alpha_i^{port} \frac{\beta_i^{o/e}+\beta_i^{buf}+\beta_i^{fe}+\beta_i^{r}+\beta_i^{sf}}{Ns^{tot} * Np_i^{tot}}\right)$$

Pn : Actual power consumption of a node on the field
P^{Max} : Maximum power consumption of a device announced by vendor
Ns^{tot} : Total number of Slot within a device
Np_i^{tot} : Total number of port within i^{th} slot
x_i^{slot} : Boolean value of slot (0: slot empty 1: slot on)
x_{ij}^{port} : Boolean value of port (link) (0: port empty 1: port on)
S : Number of states (1,2,...,S)
α_i^{port} : Percentages of the states which ports stays in
α_{slp}^{dev} : Percentage of the sleep state which device stays in
β_i : Parameters of component utilization by i^{th} state
$\beta^{o/e}$: O/E line interface β^{buf} : Line card buffer β^{fe} : Forwarding engine
β^{r} : Routing engine β^{sf} : Switch Fabric β^{col} : Cooling & power conversion
β_a^{col} : Parameter of cooling in active state β_{slp}^{col} : Parameter of cooling in sleeping state


Cisco CRS-1, 4-Slot Core router (2x Route Processor, 4x4 port optical line card) [6]

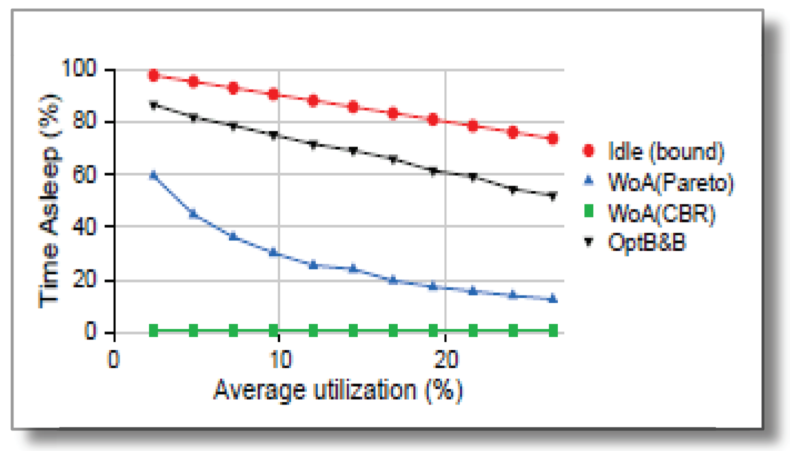
Conditions and Assumptions

Non Power Aware Router Assumptions:

- Utilization of the device is 3% in the Backup (idle) state
- As utilization increases, so does workload increases proportionally on Switch Fabric, Routing, Buffering and Forwarding engine, however Power conversion - cooling and O/E conversion stays same (0.35,0.07) [7][8]

Power Aware – Sleep, Router Assumptions:

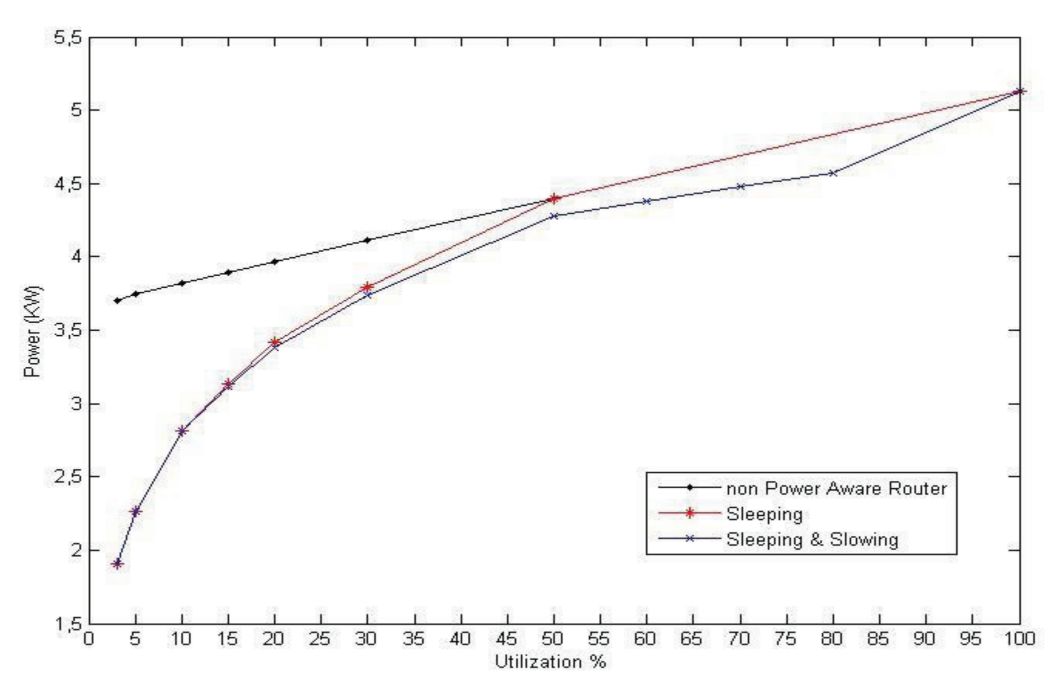
- System determines best sleeping time interval between neighbours
- Routers switching on/off time is 1ms and uses dummy packet prior to data transmission (no data loss during wake up), and it uses buffer and burst strategy to create more sleeping time[9]
- Workloads for the sleeping is 0.02 for cooling and 0.03 for the O/E conversion no power draw at the rest of the sub components.
- Sleeping time pattern is similar to WoA (Wake on Arrival) (pareto) line in following figure [9]



Power Aware – Sleep & Slow, Router Assumptions:

- System determines future bit rate
- Switching time is less than 1ms, so there is no significant delay and packet loss
- There are 10 uniform bitrates between 1Gbps and 10Gbps and 1 between 100Mbps and 1Gbps to switch between [9]
- The operational bitrate is higher than the predicted bitrate to avoid rate oscillations

Core Router (on the field) – MATLAB Plot



- Figure shows energy saving by Sleeping and Slowing technique per core router under different utilization
- Significant power is consumed by an idle core router if no intelligent and context-aware power saving technique is enabled. Based on our MATLAB calculations, idle router consumption is 3699 W and fully utilized router is 5125W for configuration in slide 5.

Conclusion

- Significant power consumed by an idle router with no power management
- Sleeping is more beneficial up to 30 % utilization, slowing is beneficial for higher utilization
- Sleep & Slow beneficial under 20 % utilization, slowing (without sleeping) is beneficial for higher levels
- Networks often are very lightly utilised except during peak periods
- Up to 48 % energy saving is achievable for a core router in an idle state, 39% saving for 5% utilized, 26% saving for 10% and 14% saving for 15%

Future Work

- Future work will involve further investigation on beta values and derivation of energy models in the presence of constraints and also to explore opportunities for use of optimisation techniques

References

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