

SwiTching And tRansmission (STAR)

Project Coordinator

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Participants

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AGH University of Science and Technology, Poland

Overview

- Collaborators, sponsors, project dates
- Project objectives
- WP1 Photonic Switch design and optimisation (Lead Cambridge, Leeds, INRIA, AGH)
- WP2 Optimum physical topology design (Lead Leeds, Cambridge, INRIA, AGH)
- WP3 Optimum routing protocols and resource allocation strategies (Lead AGH, Leeds, INRIA, Cambridge)
- WP4 Demonstration (Lead INRIA, AGH, Cambridge, Leeds)
- Relevant Deliverables
- Valorisation, dissemination
- Collaboration, Future work and Year 1 publications (14 Publications (7 journal, 7 conference papers))

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Project start date: 1 January 2013

Project end date: 31 December 2015

Collaborators



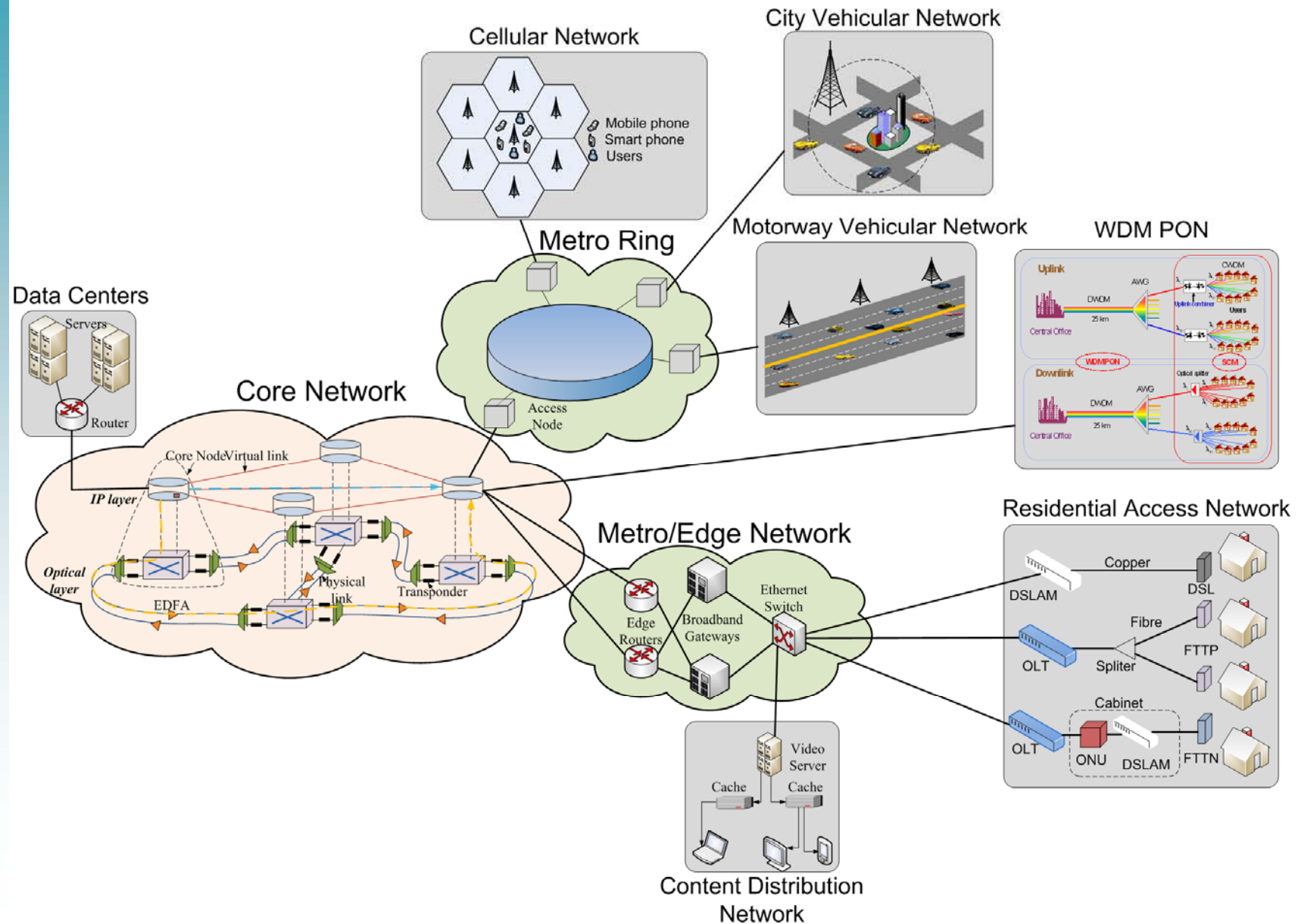
Sponsors



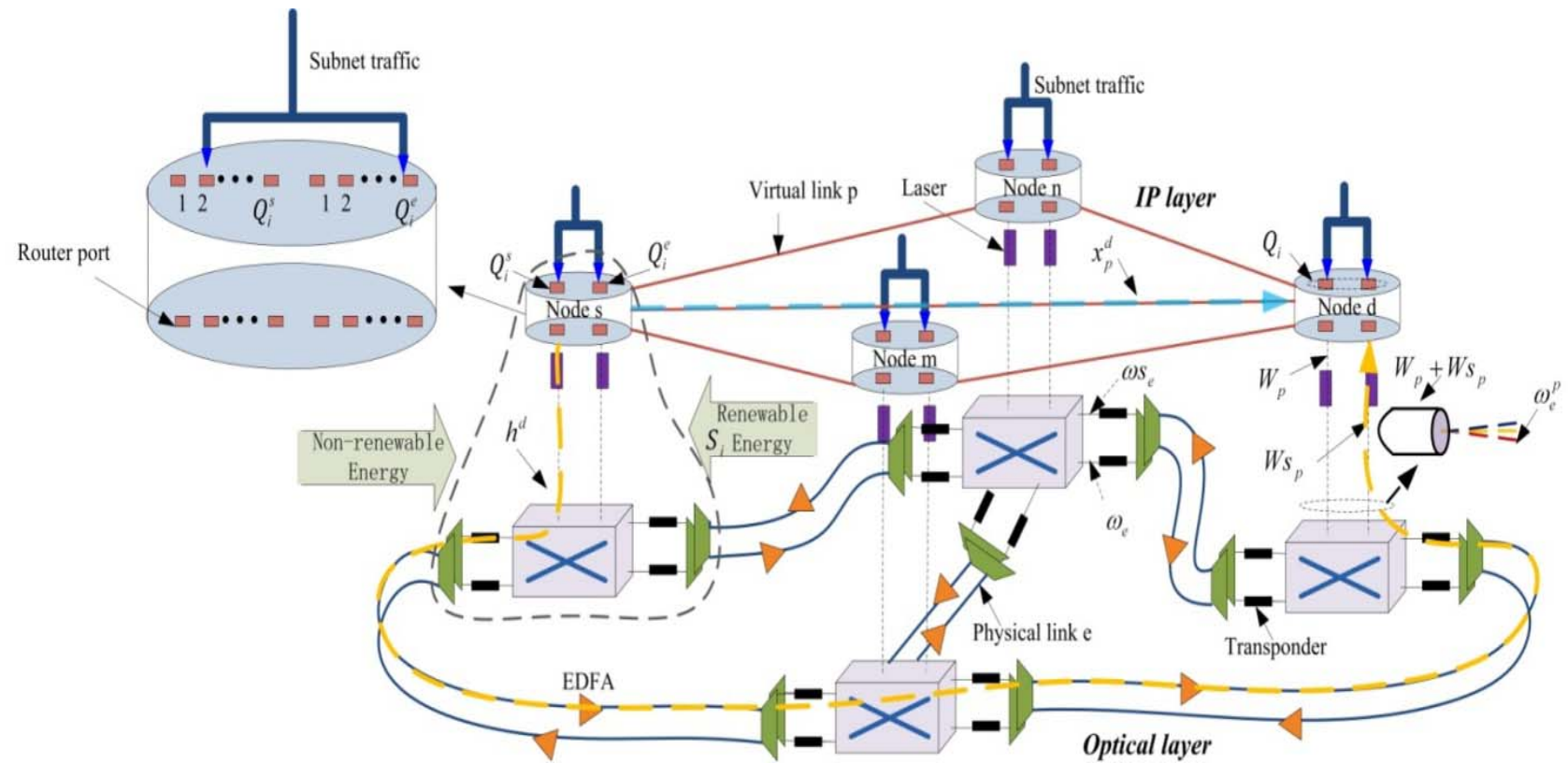
STAR project Objectives

- GreenTouch energy saving target of a factor of a 100 for Core Switching and Routing.
- A key observation in core networks is that most of the power is consumed in the IP layer while optical transmission and optical switching are power efficient in comparison, hence the inspiration for this project.
- The objectives of the project are:
 1. to save energy by reducing IP routing and introducing more point-to-point transmission (via switches), with a power saving by a factor of at least 20.
 2. to design and demonstrate energy efficient large photonic switch architectures with 1 to 2 orders of magnitude power consumption reduction.
 3. to investigate power consumption savings obtained through more switching (instead of IP routing) using large switch architectures.

End-to-end network



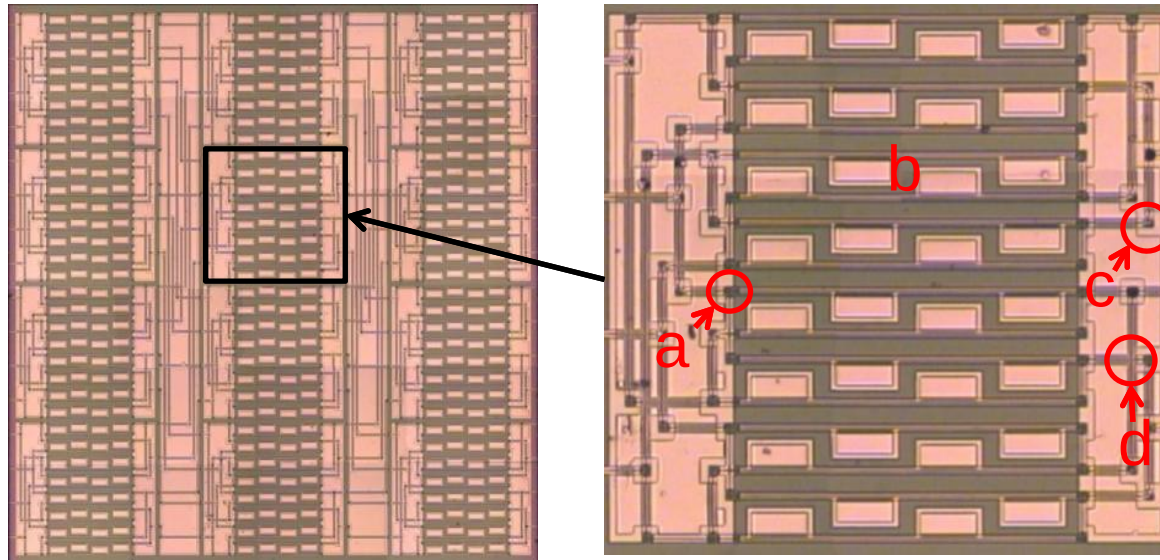
IP over WDM core network



Overview

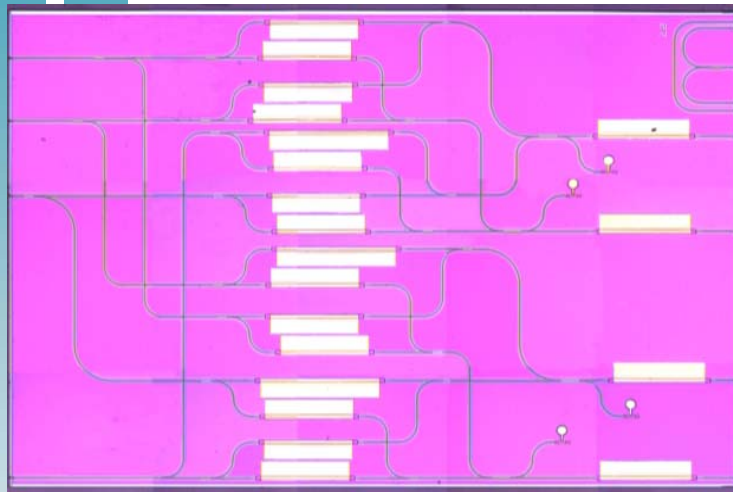
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Cambridge Switch Evolution: 16x16 port switch



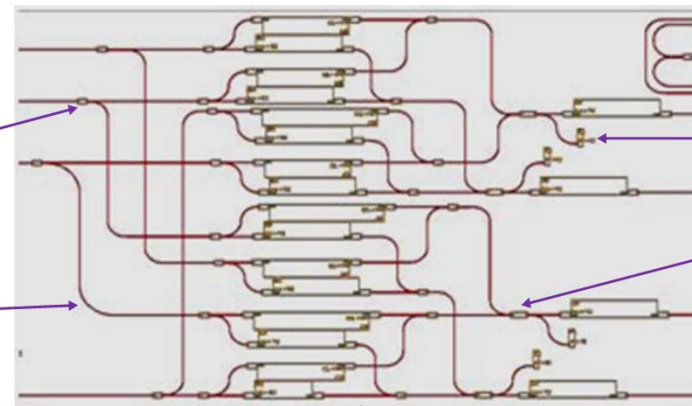
- Very compact 6.3 mm x 6.5 mm
 - Contains 192 active switching elements
 - Also an additional 922 features on the interconnecting shuffle networks
 - All active, consumes 16 W
 - 10Gb/s / path => 100pJ / bit
- **Reduce power consumption**

Active–Passive optical switch with monitors



1 x 2 MMI
power splitter

90 degree
waveguide bend



Photodiode

2x2 MMI Power
splitter

Input passive shuffle network	Active Gating SOA Array	Output passive shuffle network	Booster SOA Array
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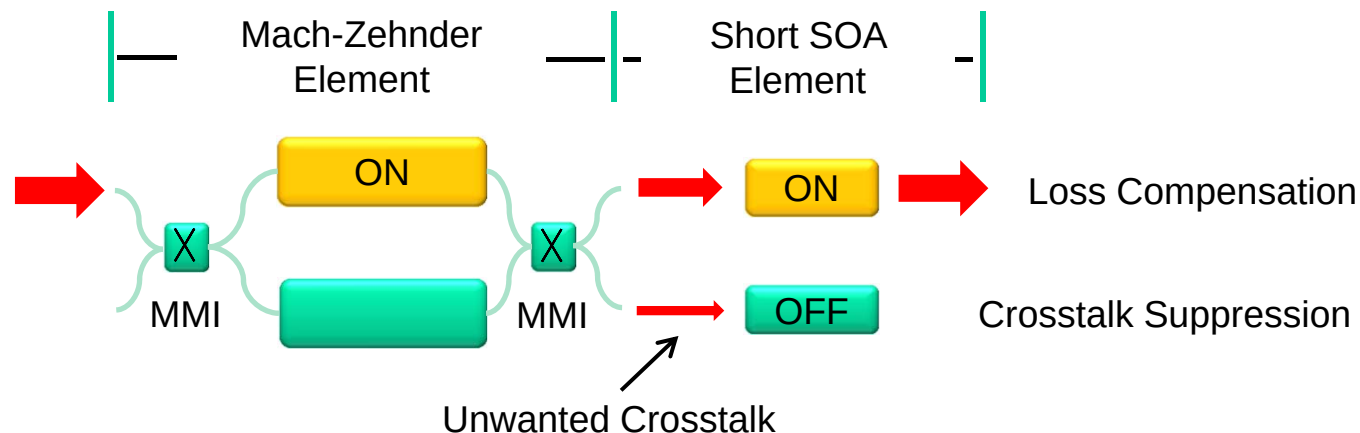
- 4 x 4 port active-passive switch in InP
- Produced in EuroPIC project
- Can control output power using Novel on-chip monitors
- Emulation of 16 x 16 port switch consumes 4.3 W (26 pJ/bit)
- 4 × improvement on the all active switch

Towards a Low-energy Large-scale Switch

Large-scale switch designs must overcome two limiting factors:

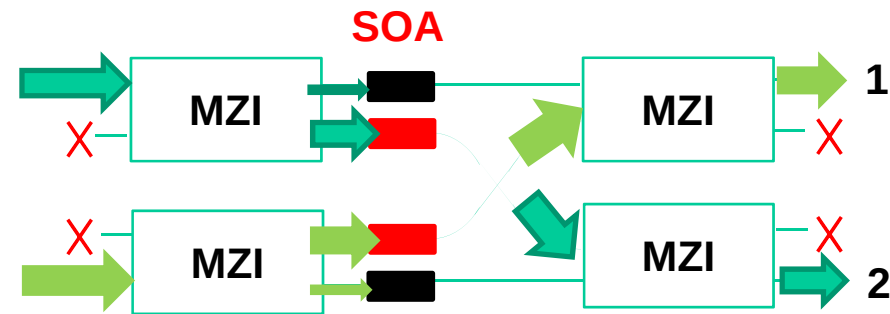
- Crosstalk
- Excess noise due to large optical gain

We have therefore proposed a hybrid combination of both SOAs and MZIs

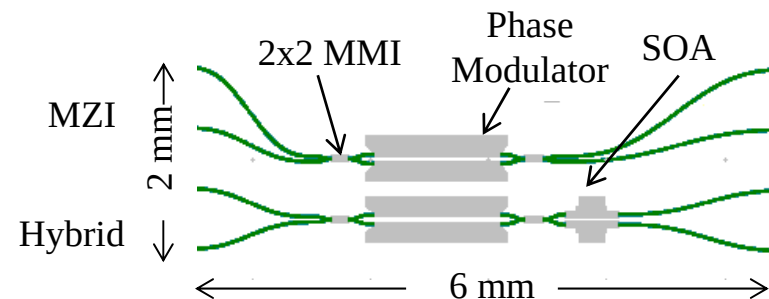


MZIs are low-energy switching components while short SOAs provide modest gain at low power consumption.

Dilation for Further Crosstalk Suppression



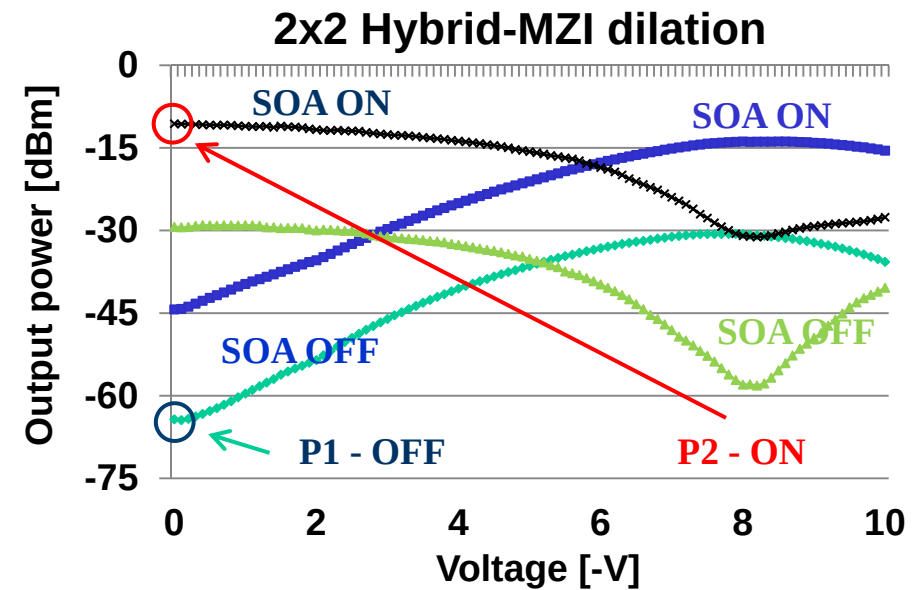
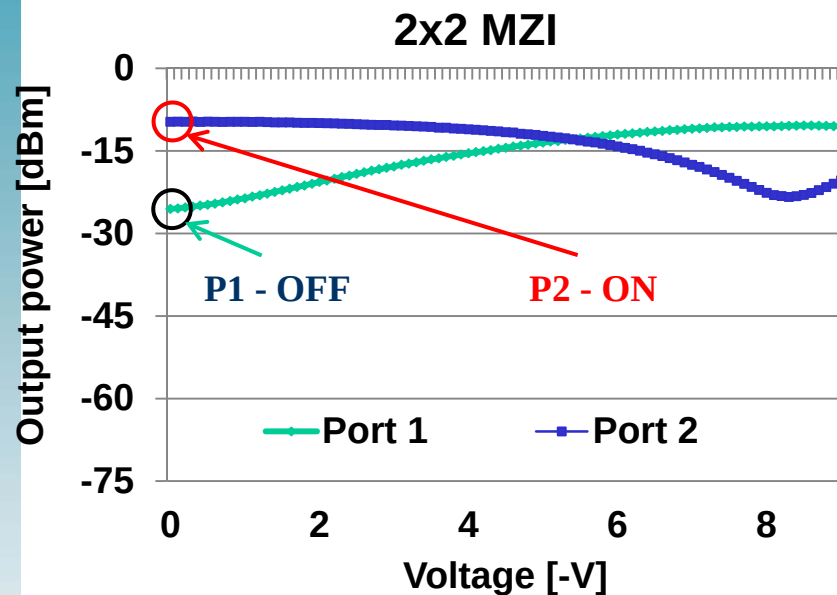
The dilation structure dramatically suppresses the crosstalk (to the square of the original value), as only one signal is routed through each MZI element.



Fabricated hybrid switch test structure

A test structure was fabricated via Europic/PARADIGM Program using standardised building block. A hybrid stage comprises a MZI followed by two short SOAs.

Transfer Characteristic of new switch

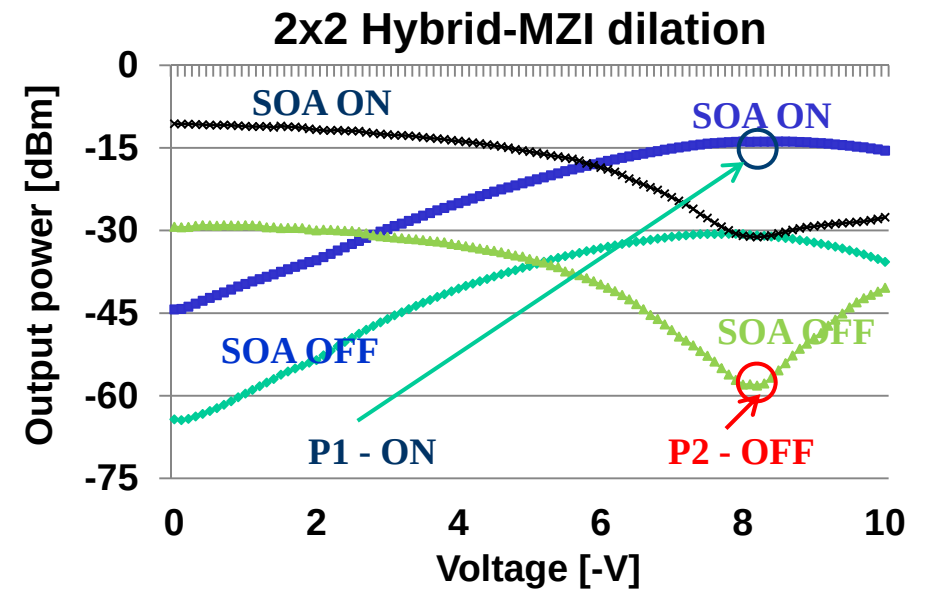
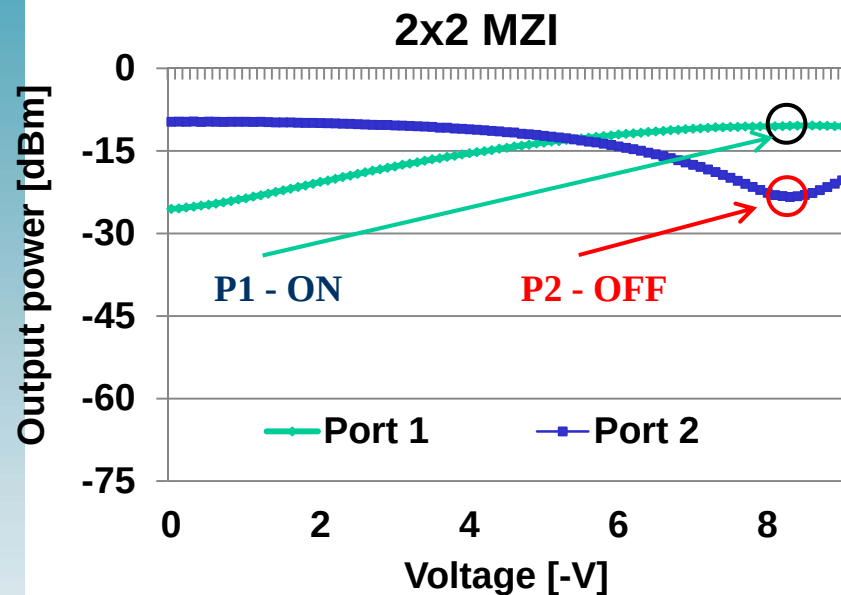


Measured crosstalk and on-chip loss

Switch in 2x2 size	MZI	Hybrid	MZI-MZI dilation	Hybrid-MZI Dilation	Hybrid-Hybrid Dilation
Crosstalk [dB]	-14	-36	-25	-46	As Hybrid-MZI
On-chip loss [dB]	4.6	1.7	9.5	6.7	3.3

- Extra short SOAs provide additional 20dB extinction including 6.2dB gain.
- A 2x2 hybrid switch can achieve crosstalk of -46dB.

Transfer Characteristic of new switch

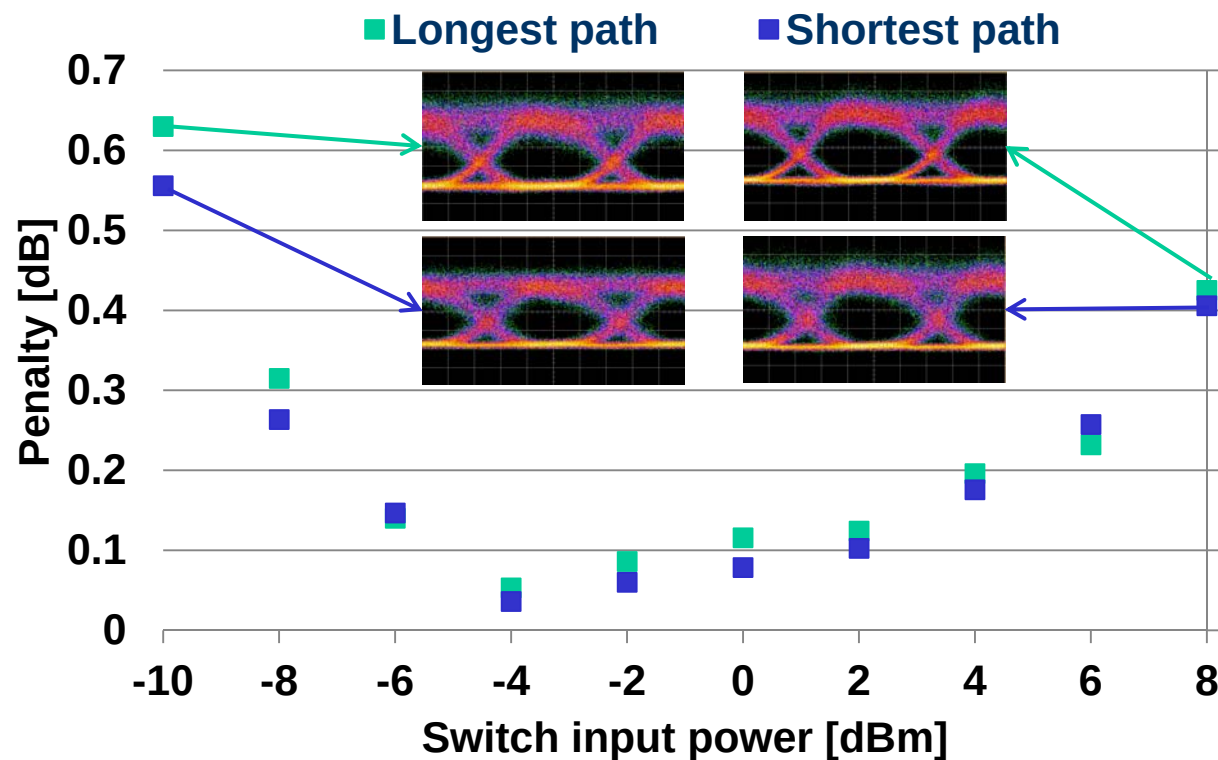


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Experiment emulating 4x4 Hybrid Switch

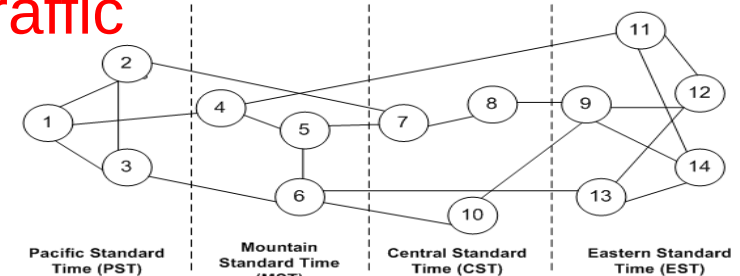
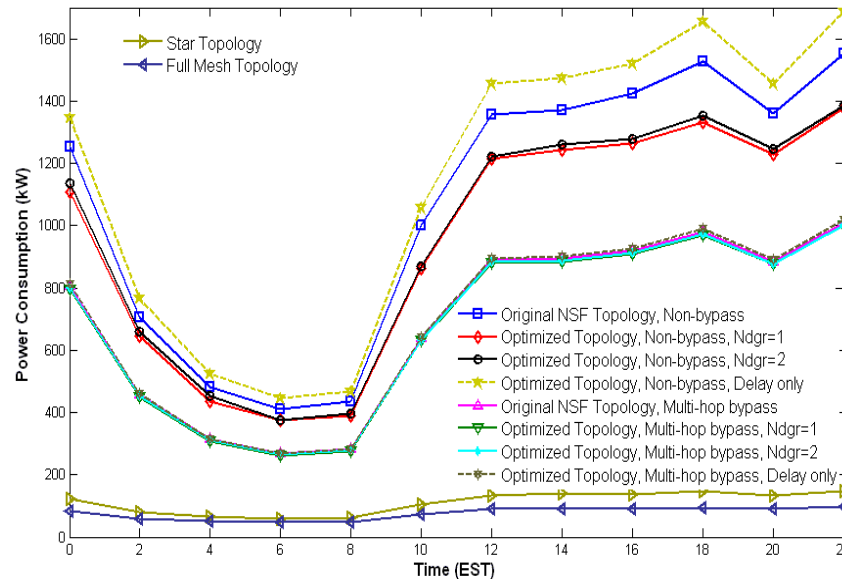


- The 4x4 hybrid switch achieves 17dB input power dynamic range with penalty under 0.4dB – indicate an excellent scalability
- The 4x4 hybrid switch consumes 6pJ/bit at 10Gbit/s and a 16x16 hybrid switch is predicted to use **15pJ/bit** power for single wavelength operation and **1.5pJ/bit for WDM** (10 channels)

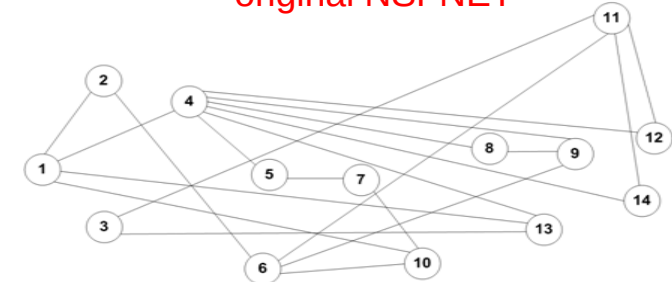
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Optimum topology design with symmetric and asymmetric traffic



original NSFNET



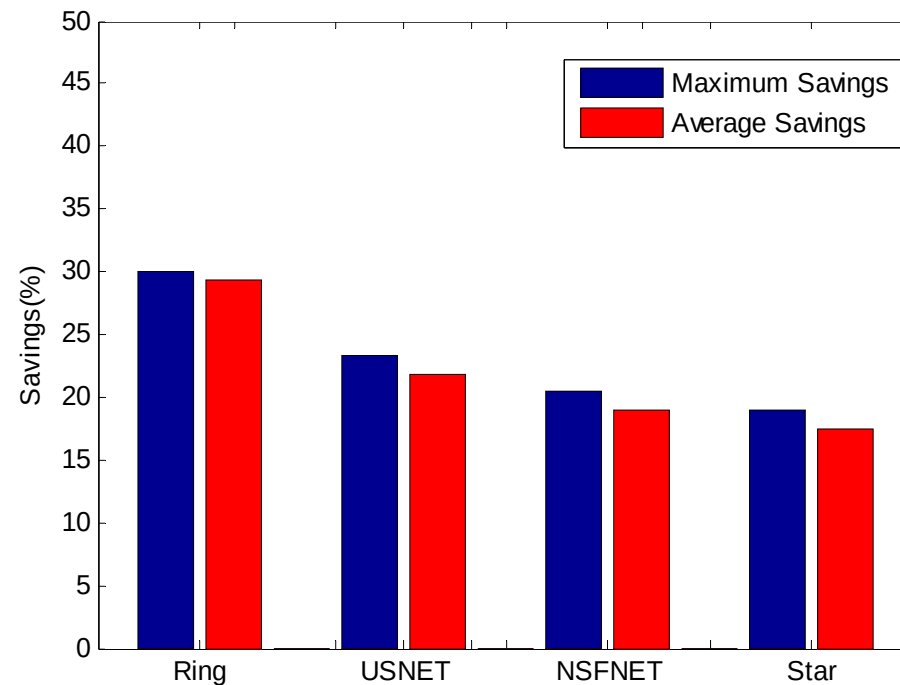
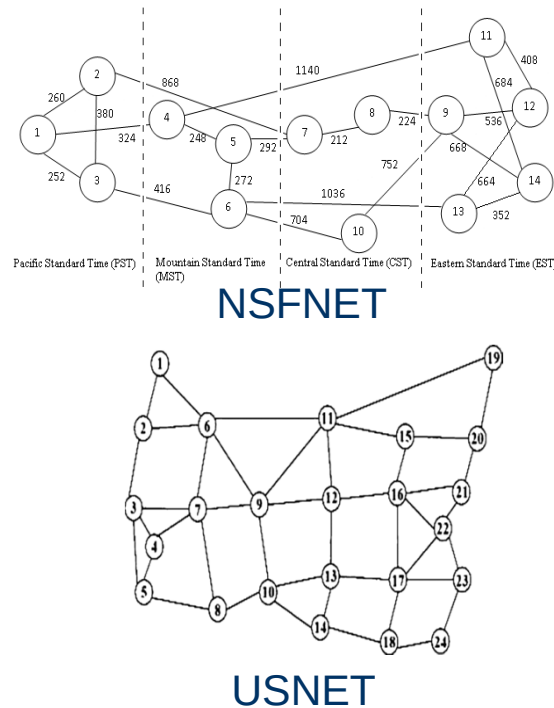
optimised topology with 21 links and symmetric traffic

- We have investigated the energy efficiency of the physical topology of IP over WDM networks under different scenarios in terms of IP over WDM approaches (non-bypass and bypass), nodal degree constraints and traffic symmetry.
- The optimum physical topology under a symmetric full-mesh connectivity traffic matrix considering a limited number of links, has resulted in a limited power savings of 10% .
- Optimizing the **physical topology without a limit on the number of links** results in a full-mesh topology with **95% power savings** compared to the original NSFNET.
- A scenario with a **single data center** case resulted in **22% power saving**.

Network Coding for Energy Efficiency in IP over WDM Networks

- We have proposed the use of network coding to improve the energy efficiency of non-bypass IP over WDM networks, where IP routers are used at intermediate nodes.
- A MILP optimization model is developed for IP over WDM networks with network coding functionality.
- Issues addressed include :
 - Optimum number and location of network coding elements in the network.
 - Different topologies impact.
 - Network average hop count impact.

Energy Efficient Network Topologies under Network Coding

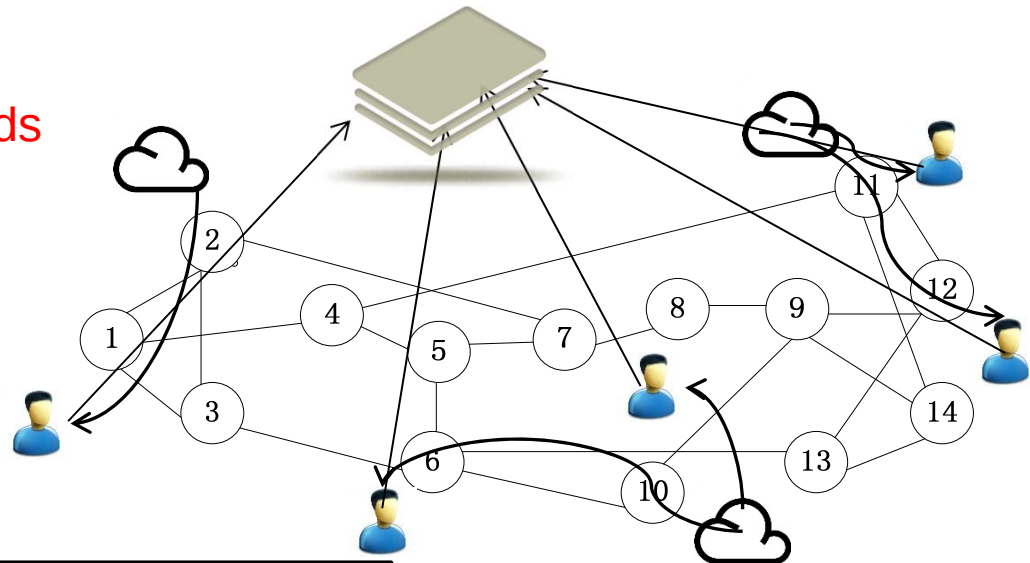


- Savings up to **23%** and **20%** are achieved through the use of network coding in the **USNET** and **NSFNET** topologies, respectively.
- A **ring topology** increases the savings to **30%** while the star topology has lower savings than the savings associated with the original NSFNET topology.
- Note that a full mesh topology where all nodes are connected through a single hop eliminates the need for network coding.

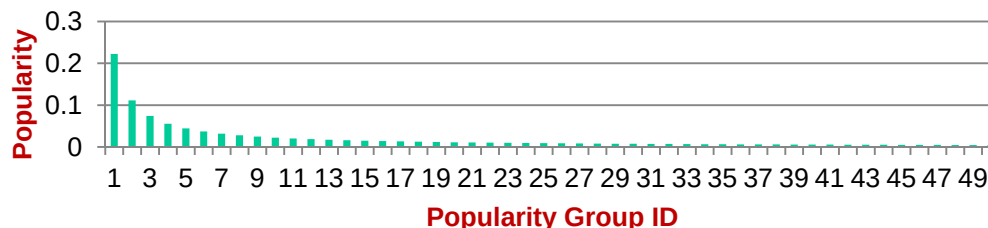
Distributed Energy Efficient Resources

We develop a MILP model for cloud content delivery in IP/WDM networks to answer whether centralised or distributed content delivery is the most energy efficient solution. Two kinds of decision variables are optimized for the cloud service model:

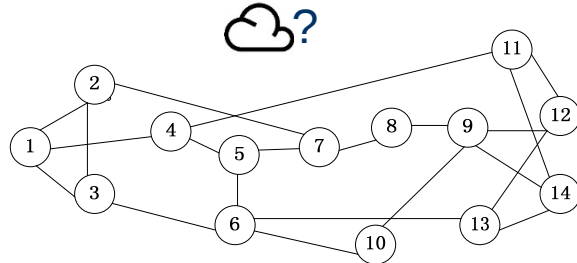
- External decision variables:
 - No of data centres / clouds
 - Location of DCs / clouds
- Internal decision variables:
 - Number of servers
 - Number of switches
 - Number of routers
 - Storage capacity



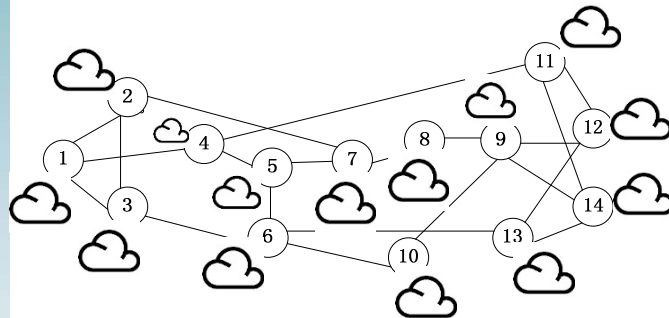
Zipf Distribution



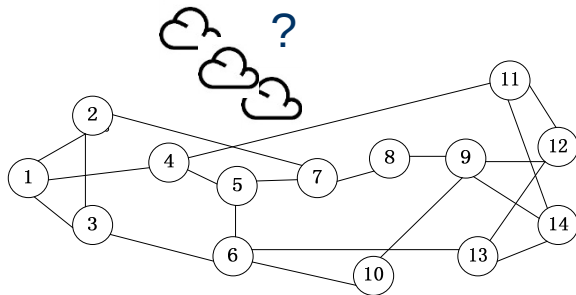
Scenarios



Forcing Single Cloud:
No Power Management (SNPM)
Using Power Management (SPM)



Forcing Max Number of Clouds (14):
Full Replication (MFR)
No Replication (MNR)
Popularity Based Replication (MPR)



Optimal Number of Clouds:
Full Replication (OFR)
No Replication (ONR)
Popularity Based Replication (OPR)

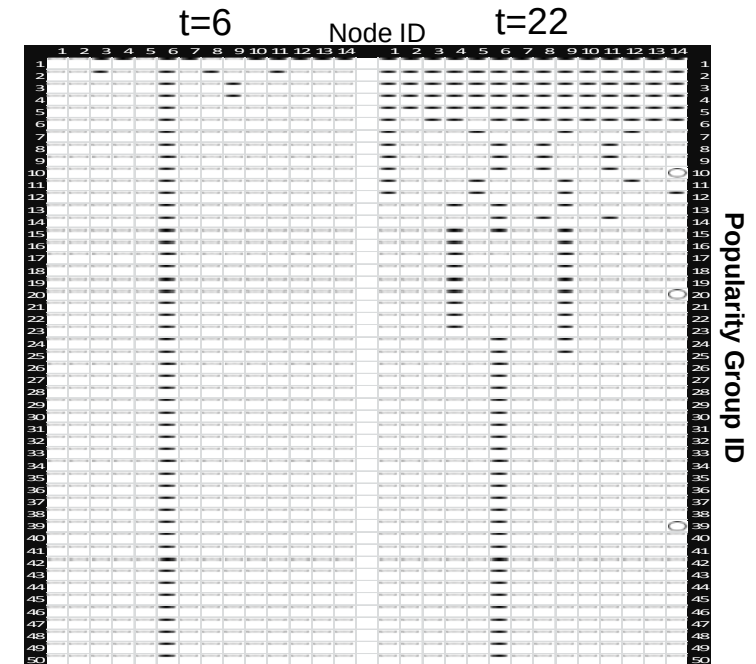
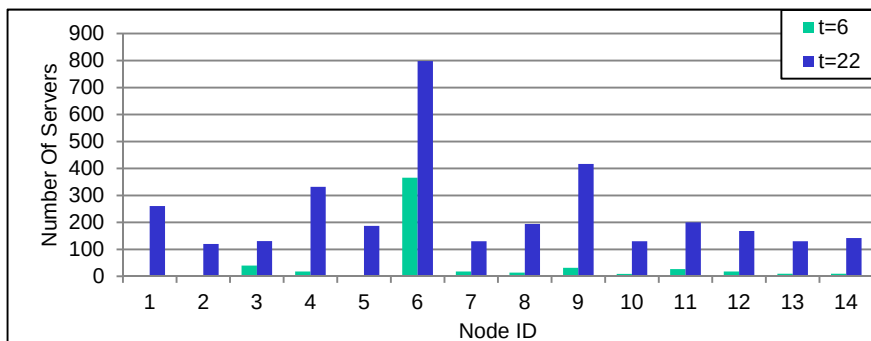
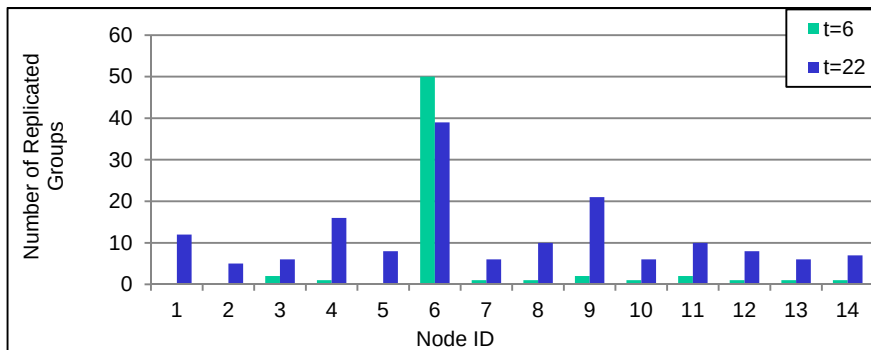
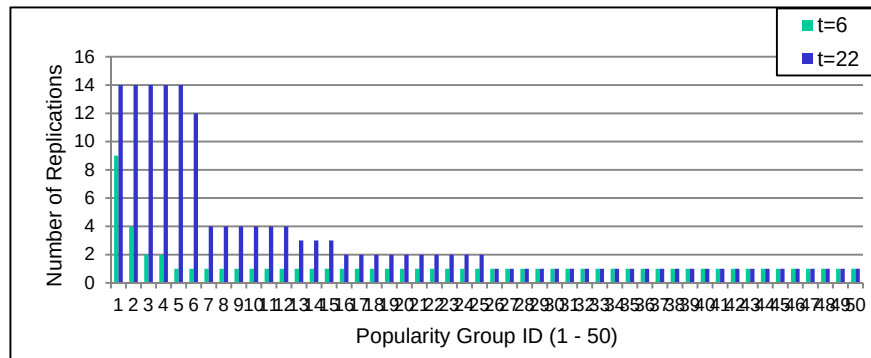
With Power Management

Popularity Based Content Replication (OPR)

Storage=75.6*5TB

● Object replicated here

○ Object not replicated



OPR Content Replication Scheme

Scenario	Total Savings	Network Saving
OPR	40%	72%
MPR	40%	72%
OFR	37.5%	56.5%
SPM	36.5%	37%
ONR	36.5%	37%
MNR	36.4%	36.5%
MFR	25.5%	99.5%

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Cloud computing services

- Short time scale anycast connections in automatically switched all optical network with data centers (DCs)
- Idle servers consume power (P_{idle})
- Putting idle server into sleep mode reduces power consumption by P_{idle} per server
- Only selected DCs are able to put servers into sleep mode (new DCs)
- Rest of DCs have not been modernized yet and all servers must be powered (old DCs)

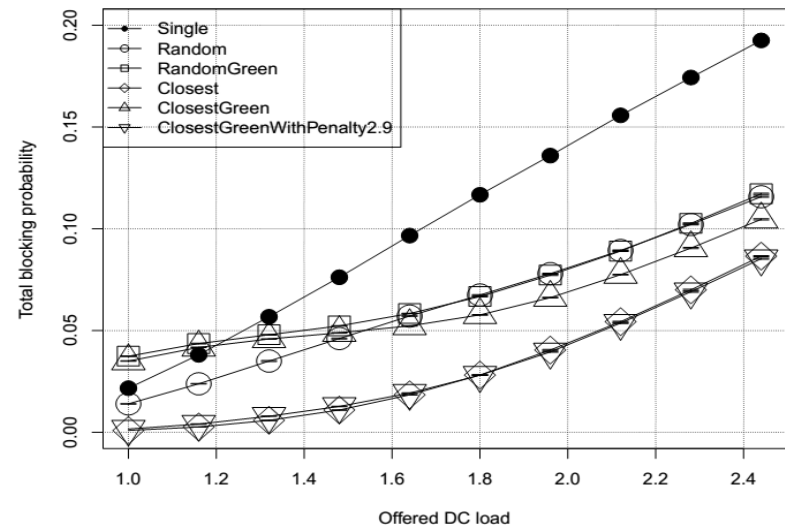
Energy aware anycast routing

- Two reference scenarios:
 - *random* – establish lightpath to randomly chosen DC
 - *closest* – establish lightpath to the closest (hop manner) DC
- Three proposed and evaluated strategies:
 - *randomGreen* – perform *random* for old DCs, only in case of failure perform *random* for new DCs
 - *closestGreen* - perform *closest* for old DCs, only in case of failure perform *closest* for new DCs
 - *closestGreenWithPenalty* - establish lightpath to the closest (hop manner) from available DCs, but distance to new DCs multiplied by *penalty* [1,inf) parameter

Utilize old DCs as P_{idle} will always be consumed. Unused new DCs may enter sleep mode to save energy

Results and conclusions

- *randomGreen* and *closestGreen* offer the highest energy consumption reduction
- *closestGreenWithPenalty* offers lower reduction, but is able to retain network performance at the level comparable with the *closest*
- *Penalty* parameter balances the trade-off between energy consumption and network deterioration
- Next step: putting restrictions on maximum number of transactions served in DC
- Power savings of about 50% for RandomGreen and closestGreen, load dependent
- Power saving of about 30% for closestGreenWithPenalty, load dependent



Re-engineering survivability mechanisms

Sleep mode + recovery methods

- Case 0: hop-based shortest-path routing of working and protecting paths (risk benchmark)
- Case 1: energy-efficient routing of working and protection paths (one-step approach)
- Case 2: energy-efficient routing of working paths, then turning-off for unused links (two-step approach):
 - Various options for recovery
 - Spectrum of options: dedicated protection, shared protection, re-routing (might use turned-off links), unprotected

Measures: energy-efficiency vs. risk (expressed as availability [mean], VaR [extreme values], CVaR, etc.)

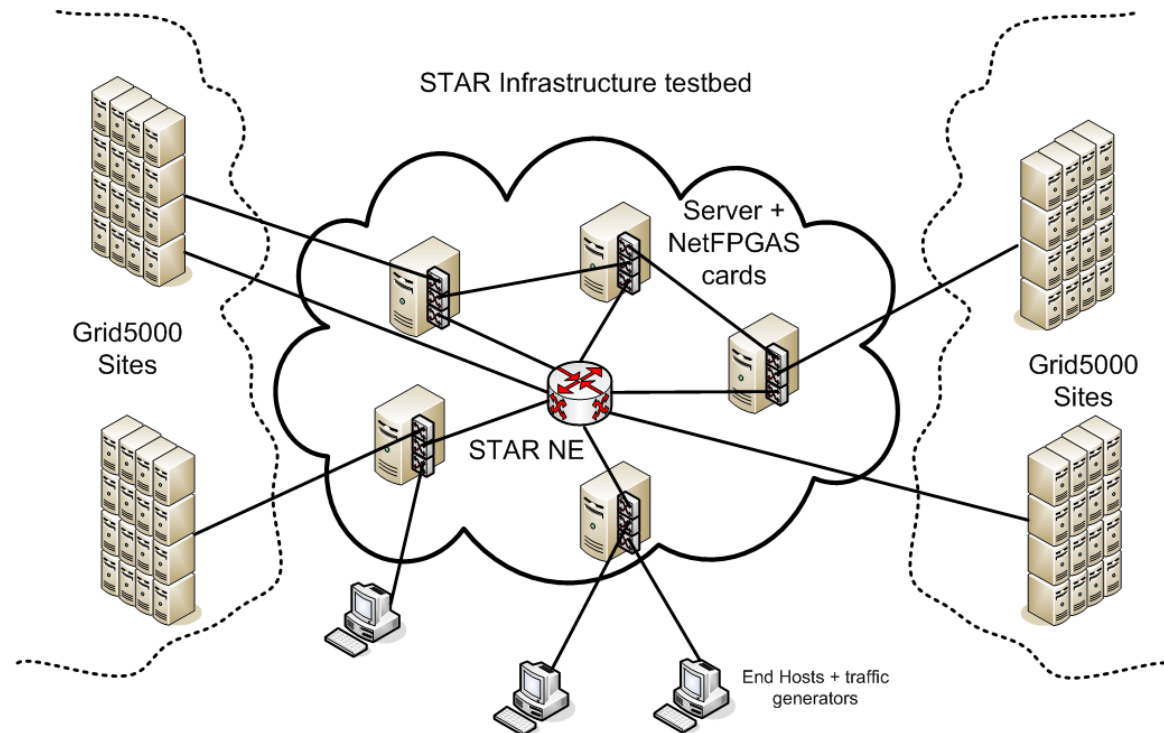
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Use cases and Routing in STAR

- Predicted ICT energy requirements
 - Network traffic + usage profiles
 - Continuing to explore relevant usecases : Multi cloud / datacenters federation - BigData transport/replication
- Exploring alternative routing technologies and models
- Integrating energy efficiency improvements (sleep modes) and topology management

STAR Demonstration Platform



First design - Under deployment in 2014
Supported by a large set of electrical monitoring sensors

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Valorisation

- University of Leeds is leading the Wired Core & Access Networks (WCAN) working group in GreenTouch®.
- STAR core network Energy Saving Measures and MILP models selected and used as the basis for the GreenTouch® (50+ member organisations) GreenMeter® and white paper, now used by ALU, France Telecom, China Mobile etc
- Energy Efficient Switch Plenary presentation and Demo at the Greentouch® consortium open meeting held in Paris, Nov 2013.
- Our contributions in GreenTouch study has led to invited talks at INFOCOM'2013, EU Future Internet Assembly, 2013 and new collaboration with Huawei.
- New UCAM design software to optimize SOA switches and hybrid MZ-SOA switches with interfaces to commercial laser simulators.
- AGH advanced and flexible simulation environment for all optical networks with data centres and risk based survivability mechanisms for energy aware networks.

Other dissemination of results

- 11 invited / keynote talks at eg. INFOCOM'13, GLOBECOM'13, Celtic-Plus 2013, EC E1 Future Internet Cluster Meeting 2013, ICTON'13, TIWDC'13, EU Future Internet Assembly 2013, EEHPDC-2013, GreenTouch® plenary 2013.
- 3 Tutorials (3-4 hours) at IEEE ICC'13, ICC'14, SoftCOM'13 on energy efficiency.
- Major international conference organisation
 - Co-chairing the IEEE ICC'14 "Green Communications and Computing" track.
 - Co-chairing IEEE ICC'15 "Green Communication Networks and Systems" track.
 - Organising and hosting the ACM e-Energy 2014 conference, Cambridge.
 - Co-organizers of the ExtremeGreen 2013, 2014 Workshop.
- EU project collaboration
 - Collaboration with the EU FP7 Towards Real Energy-efficient Network Design (TREND) led to the joint organization of a workshop with TREND on energy efficiency at INFOCOM 2013.

Transnational collaboration

- The partners have collaborated closely in year 1 with Alcatel-Lucent and the other GreenTouch® members leading to the uptake of the work on topology optimization, sleep cycles and optical switch design in the GreenTouch® GreenMeter®, June 2013 White paper.
- Collaborated during year 1 with BT on a case study on optimum energy efficient content delivery over virtual topology optimised networks, which led to the submission of a joint (with BT) IEEE/OSA Journal of Lightwave Technology paper.
- On going collaboration between Alcatel-Lucent, UCAM and UNIVLEEDS is expected to lead to new energy efficient node designs.
- Collaboration with the EU FP7 Towards Real Energy-efficient Network Design (TREND) led to the joint organization of a workshop with TREND on energy efficiency at INFOCOM 2013, on “Green and Energy Efficient Networking”

Future work

- Measure the performance of 8x8 port SOA switches and 4x4 port hybrid MZ-SOA switches.
- Operate hybrid MZ-SOA switches at increased data-rates per port, aiming to gain a further order of magnitude energy efficiency enhancement.
- Design and seek routes to fabrication for larger port-count hybrid MZ-SOA switches.
- Regular meetings are now being held UCAM, Alcatel-Lucent and UNIVLEEDS focusing on the design of an energy efficient node architecture that uses the SOA switches designed. This activity is expected to grow in year 2.
- Re-consider the energy efficiency of the physical topology of IP over WDM networks taking into account the embodied energy (Leeds)
- Renewable energy and clouds content replication schemes (collaboration Leeds, INRIA, Cambridge, AGH and BT).
- Energy efficient traffic scheduling in IP over WDM networks (collaboration Leeds, UCAM, Alcatel-Lucent and INRIA).

Future work

- Focus on energy aware anycast routing mechanisms for inter data centres networks.
- Risk analysis of survivability mechanisms considered for green networks.
- Further studies on anycasting, risk analysis with Orange Polska.
- A testbed architecture and validation methodology for WP4 (Demonstration)

Publications (7 journal, 7 conference papers)

1. Dong, X., El-Gorashi, T. E. H. and Elmirghani, J. M. H., "On the Energy Efficiency of Physical Topology Design for IP over WDM Networks," *IEEE/OSA Journal of Lightwave Technology*, vol. 30, pp. 1931-1942, 2012.
2. Lawey, A., El-Gorashi, T. E. H. and Elmirghani, J. M. H., "Distributed Energy Efficient Clouds over Core Networks," to appear in *IEEE/OSA Journal of Lightwave Technology*, vol. 32, No. 7, pp. 1261 – 1281, 2014.
3. Ye, Y., Jimenez Arribas, F., Elmirghani, J.M.H., Idzikowski, F., Lopez Vizcaino, J., Monti, P., Musumeci, F., Pattavina A., and Van Heddeghem, W. "Energy Efficient Resilient Optical Networks: Challenges and Trade-offs," *IEEE Communications Magazine*, 2014, accepted for publication subject to revision.
4. Cheng, Q., Wonfor, A., Penty, R.V., White, I.H., "Scalable, Low-Energy Hybrid Photonic Space Switch," *IEEE/OSA Journal of Lightwave Technology*, vol.31, No.18, pp.3077, 3084, 2013.
5. Cheng, Q, Wonfor, A., Wei, J. L, Penty, R. V., and White, I. H. "Monolithic MZI-SOA Hybrid Switch for Low-Power and Low Penalty Operation", *Optics Letters*. Accepted for publication.
6. Anne-Cécile Orgerie, Marcos Dias de Assunção and Laurent Lefèvre "A Survey on Techniques for Improving the Energy Efficiency of Large Scale Distributed Systems", To Appear in *ACM Computing Surveys*.
7. P. Borylo, A. Lason, J. Rzasa, A. Szymanski, A. Jajszczyk, Cloud computing services provided by energy-aware optical networks – a survey, *Przegląd Telekomunikacyjny, Wiadomości Telekomunikacyjne*; ISSN 1230-3496. — 2013 R. 86 nr 10, paper in Polish.

Publications (7 journal, 7 conference papers)

8. Xiaowen Dong, Taisir E.H. El-Gorashi and Jaafar M. H. Elmirghani, "Joint Optimization of Power, Electricity Cost and Delay in IP over WDM networks," in Proc of the IEEE Int. Conf. on Commun. (**ICC'13**), Budapest, Hungary, 9-12 Jun, 2013.
9. *Ahmed Lawey, Taisir E.H. El-Gorashi and Jaafar M. H. Elmirghani, "Energy Efficient Cloud Content Delivery in Core Networks," in Proc. of the IEEE Global Telecomm Conference (**GLOBECOM'13**), pp. 1-6, Atlanta, Georgia, 9-13 December 2013.*
10. Wang, K., Wonfor, A., Pentty, R.V., White, I.H., "Demonstration of cascaded operation of active-passive integrated 4×4 SOA switches with on-chip monitoring for power control and energy consumption optimization," **OFC/NFOEC, 2013**, vol., no., pp.1,3, 17-21 March 2013.
11. Cheng, Q., Wonfor, A., Wang, K., Olle, V.F., Pentty, R.V., White, I.H., "Low-Energy, Scalable Hybrid Crosspoint Switch Design," **CLEO 2013** (Optical Society of America, Washington, DC, 2013), CtuL1.003.
12. Cheng, Q, Wonfor, A., Wei, J. L, Pentty, R. V., and White, I. H., "Modular Hybrid Dilated Mach-Zehnder Switch with Integrated SOAs for Large Port Count Switches", **OFC2014**. Accepted for publication.
13. A. Lason, J. Rzasa, A. Szymanski, A. Jajszczyk, Energy aware routing and aggregation in multilayer optical networks, 15th International Conference on Transparent Optical Network, **ICTON'13**: Cartagena, Spain, June 23–27, 2013
14. P. Borylo, A. Lason, J. Rzasa, A. Szymanski, A. Jajszczyk, Anycast Routing for Carbon Footprint Reduction in WDM Hybrid Power Networks with Data Centers, paper accepted for IEEE **ICC 2014**, Sydney, Australia, June 2014.

Other dissemination of results

UNIVLEEDS

Invited Talks

1. Invited talk, "GreenTouch Green Meter and Core Network Modelling," at EC E1 Future Internet Cluster Meeting: Green and Energy-efficient Networking Workshop, Brussels, 21-24 Oct. 2013.
2. Invited talk, "Green Operator Networks: Topology, Routing and Data Centres", IEEE 24th Tyrrhenian International Workshop on Digital Communications (TIWDC 2013), Genoa, Italy, 23-25 Sept. 2013.
3. Invited talk, "Energy Efficient Cloud Content Delivery in Core Networks Employing Renewable Energy", IEEE 24th Tyrrhenian International Workshop on Digital Communications (TIWDC 2013), Genoa, Italy, 23-25 Sept. 2013.
4. Invited talk at IEEE 15th International Conference on Transparent Optical Networks (ICTON'13), Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Core Network Physical Topology Design for Energy Efficiency and Resilience," Proc IEEE ICTON 2013, Cartagena, Spain, June 23-27, 2013.
5. Invited talk at EU Future Internet Assembly, "Green ICT: What would be the cost of doing nothing?", 9 May 2013, Dublin.
6. Invited talk at IEEE INFOCOM 2013, TERND/GreenTouch workshop on Green Communications, Lawey, A.Q., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Distributed Energy Efficient Resources," Torino, 19 April 2013.
7. Invited talk at CHIST-ERA Projects Seminar 2013, Elmirghani, J.M.H., "SwiTching And tRansmission (STAR)," Brussels, 27 March 2013.
8. Keynote talk at Celtic-Plus Event 2013, "GreenTouch vision, Targets and Research Activities," Kayseri, Turkey, 6 March 2013.

Other dissemination of results

UNIVLEEDS

Tutorials at major international conferences (invited, peer reviewed)

1. Invited tutorial (4 hours), "Energy Efficient Core and Content Distribution Networks," IEEE 21st International Conference on Software, Telecommunications and Computer Networks (SoftCOM'2013), split, Croatia, 18-20 Sept, 2013.
2. Tutorial at IEEE ICC 2013 (3.5 hours), Elmirghani, J.M.H., "Greening the Internet," Short course at IEEE International Conference on Communications (ICC'13), Budapest, 9-13 June 2013.
3. Tutorial at IEEE ICC 2014 (3.5 hours), Elmirghani, J.M.H., "Greening Core, Data Centre and Content Distribution Networks," Short course at IEEE International Conference on Communications (ICC'14), Sydney, 10-14 June 2014.

EU projects collaboration

Collaboration with the EU FP7 Towards Real Energy-efficient Network Design (TREND) led to the joint organization of a workshop with TREND on energy efficiency at INFOCOM 2013, on "Green and Energy Efficient Networking" and to a joint paper with TREND, paper [5] on the list of publications (see page 4).

Major international conference organisation

1. Co-chairing the IEEE ICC'14 "Green Communications and Computing" track. Received 105 papers, organised about 350 reviews and accepted 38 papers, please see <http://icc2014.ieee-icc.org/index.html>.
2. Co-chairing IEEE ICC'15 "Green Communication Networks and Systems track".

Other dissemination of results

UCAM

1. UCAM presented their results on the energy efficient switch as the Plenary presentation at the Greentouch consortium open meeting held in Paris, November 2013.
2. University of Cambridge is organising and hosting the ACM e-Energy 2014 conference (<http://conferences.sigcomm.org/eenergy/2014/index.php>). Richard Penty is the General Co-Chair of the Organization committee.

INRIA

Workshop organisation

1. Laurent Lefevre co-organizer of the ExtremeGreen 2013 Workshop : Extremen Green & Energy Efficiency in Large Scale Distributed Systems, Delft, The Netherlands, May 2013

Invited participation

1. Laurent Lefèvre : Participation in the panel of the IEEE Globecom 2013 Workshop on Cloud Computing Systems, Networks, and Applications (CCSNA) December 9-13, 2013, Atlanta, USA
2. Laurent Lefevre, Invited Keynote : "Impact of Application and Service Knowledge for Energy Efficiency in HPC", International Workshop on Energy Efficient High Performance Parallel and Distributed Computing (EEHPDC-2013), Co-located with ACM HPDC 2013 , New York City, NY, USA, June 17th, 2013

Other dissemination of results

AGH

- Selected aspects elaborated within the STAR project are going to be presented as elements of the tutorial "Risk-based Resilient Networks Design" to be given at DRCN 2014, March 31st, 2014, Ghent, Belgium.
- The new research area of green networking is also reflected in Eng. and Master theses defended at AGH University of Science and Technology.