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Network Coding for Energy Efficiency in Bypass IP/WDM Networks

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ABSTRACT
Network coding has been proven to be an effective approach towards achieving the network capacity and resources efficiency. However, most of the work achieved has been under the umbrella of wireless networks. In this paper we investigate the use of network coding to improve energy efficiency of the IP/WDM optical core considering unicast traffic flows by implementing coding at the optical layer of intermediate nodes. The mixed integer linear programming results show that network coding can improve the energy efficiency by up to 28% on the NSFNET compared to conventional non-bypass approach. The results show that the network coded bypass approach also outperforms the conventional bypass approach.
OCIS codes: (060.0060) Fiber optics and optical communications; (230.0230) Optical devices;

1. INTRODUCTION

The search for energy efficient networks has been a strong theme in networking research in the last few years owing to its ecological and economic impact. A considerable amount of effort has been dedicated towards closing the gap between the exponential traffic increase that leads to energy consumption increase and the operational energy efficiency. The latter has improved [1]-[10] but at a rate lower than traffic growth rate over the past decade. One of the approaches that have shown potential in improved throughput is network coding [11], [12] which performs coding at intermediate nodes as a network level generalization of source and channel coding that is performed at source and destination only. The majority of network coding is performed on wireless networks that are inherently broadcasting in nature. Network coding is used therefore in wireless for multicast applications mainly. Very little has been done on the unicast flows for wired bidirectional networks. These kinds of flows represent the majority of traffic in wired networks which makes the problem interesting and its investigation worthwhile [13].

In our previous work [14] we showed that network coding could provide savings around 33% for common core networks compared to the conventional non-bypass architectures, by XORing bidirectional flows at intermediate nodes and decoding them at end nodes, router ports become more energy efficient than what they have been in the conventional case. In this work we evaluate this approach when it is applied to the bypass case, where flows bypass the IP layer of intermediate nodes and only undergo electro-optical conversion in the intermediate translucent optical cross connects.

The rest of this paper is organized as follows: In Section 2, we discuss the use of network coding in core networks. In Section 3, we present and analyse the power saving obtained through the implementation of network coding in non-bypass IP/WDM networks. Finally the paper is concluded in Section 4.

2. NETWORK CODING IN IP/WDM NETWORKS

The IP/WDM network represents the state of the art implementation of core networks. In this network [3]-[10] shown in figure 1, optical fibres are used to transport traffic that is aggregated by routers in the IP layer and converted into optical signals using transponders. The optical fibre carries a multitude of wavelengths which are multiplexed and de-multiplexed through optical multiplexers / de-multiplexers, and switched optically by the optical cross connects. To supports long distance transmission, Erbium doped fibre amplifiers (EDFAs) are used to amplify the optical signals and are placed at regular distances.

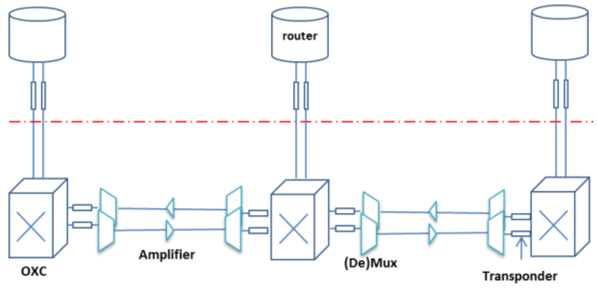

Figure1: The architecture of an IP/WDM network.

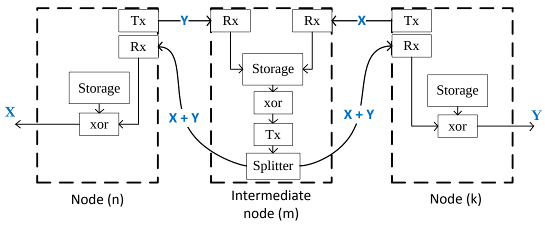

Figure2: Network coding nodes architectures

The existence of two physical layers, introduces two approaches for routing the flows from source to destination using either the lightpath non-bypass or bypass approaches. In the non-bypass approach traffic flows pass through the IP layer of each intermediate node while in the bypass approach the traffic only passes through the IP layer. In this paper we focus only on the bypass case.

The implementation of network coding shown in [14] introduced energy savings by using a single network coding router port at each intermediate node rather than two router ports in the conventional routing case. Here we use the same approach but implemented on transponders rather than the router ports. Bidirectional bypass flows get encoded in intermediate translucent optical cross connects. Figure 2 shows the architecture we proposed in [14] of a network coding enabled IP/WDM node. The same principle is used when applied to transponders in the bypass case when intermediate nodes undergo optical-electrical-optical conversion. A coded transponder will have an additional receiver that is connected to a different neighbouring node from the original receiver, and flows are encoded together using the simple XOR gate, which are multicast to the two neighbouring nodes through a coupler. An amplifier is used to compensate for the power loss due to splitting. At end nodes, the decoding can be performed at the IP layer as it is already in use, similar to the non-bypass case.

In this work, we report the results associated with a Mixed Integer Linear Programming (MILP) model we developed to minimize the total power consumption of network coding enabled bypass IP/WDM networks by optimizing the use of network resources. The constraints of the model include the flow conservation constraint [4], the capacity conservation constraints [6], the bypass routing constraints [3], and the bidirectional flows encoding constraints. The model decides the optimum number and locations of encoding transponders, the energy consumption of the network for different coded ports power consumption. We compare the power consumption of the model with two other MILP models for the conventional bypass and non-bypass cases, both minimizing the network power consumption satisfying the flow and capacity conservation constraints , as well as the bypass and non-bypass flow routing constraints respectively. We perform also a sensitivity analysis considering different values of the encoded ports to cover for the possibility of higher power consumption for coded transponders as well as suggest the possible improved savings that can be attained by improving the coded transponders power consumption. The results were obtained using AMPL/CPLEX software running on a High performance computer with 16 cores processor and 256 GB of RAM.

3. RESULTS

We consider the NSFNET topology shown in figure 3, which has 14 nodes and 21 links and an average hop count of 2.17. The traffic demands between node pairs of the network at different times of the day is generated following a uniform distribution allowing for the 12-fold increase of backbone traffic between 2010 and 2020 [15] expected by GreenTouch [16]. This is in contrast to the 2010 values used in our previous models, which had traffic varying between 20 Gb/s and 120 Gb/s where the peak occurs at 22:00 in each time zone [4]-[10].

The power consumption of the network devices are shown in Table 1 [11]. We used wavelengths of capacity 400 Gbps matching the traffic increase and assume the power consumption of the network coding enabled ports to be 10% and 50% more than the conventional counterparts accounting for the extra components. We also show the results for the ratios of 0% up to 100% increase in power consumption values of transponders.

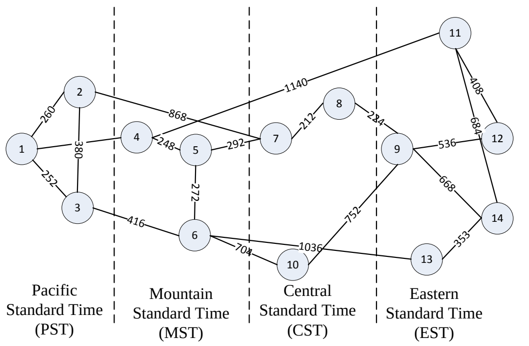

Figure3: The architecture of an IP/WDM network.

Parameter	Value
Distance between neighboring EDFAs	80 km
Number of wavelengths in a fiber	32
Capacity of each wavelength	400 Gbps
Power consumption of a normal port	46.7 W
Power consumption of a network coding transponder	360 W
Power consumption of a transponder	332.6 W
Power consumption of an Optical Switch	8.5 W
EDFA’s power consumption	15.3 W

Table 1: Network Parameters [15].

Figure 5a shows an average power savings of 28% and 19% obtained by introducing network coding to the NSFNET topology under the bypass approach compared to the non-bypass approach considering 10% and 50% increase in coded transponders power consumption respectively. It also shows that network coding reduces the conventional bypass approach energy consumption by 18% and 9% respectively for the two investigated transponders consumption values. In Figure 5b, network power consumption is plotted for different network coding transponder power consumption values. Such sensitivity analysis helps in determining the maximum allowed ‘network coding transponder’ power consumption where the network coding still produces a power saving compared to other schemes (bypass and non-bypass routing schemes). The results show that network coding produces power savings of 18% and 28% compared to bypass and non-bypass IP over WDM routing at our estimated network coding transponder power consumption of 330W at 400 Gb/s in 2020 and using the other 2020 GreenTouch projected values in Table 1 [15]. More importantly, the sensitivity results in Fig. 4b show that our proposed network coding approach outperforms non-bypass and bypass IP/WDM networks even if the network coding transponder was to consume a high power of 660W in the bypass case (at 400 Gb/s) and even higher in the non-bypass case showing the flexibility of our approach even in the face of variable circuit implementation options and power consumption per network coding transponder.

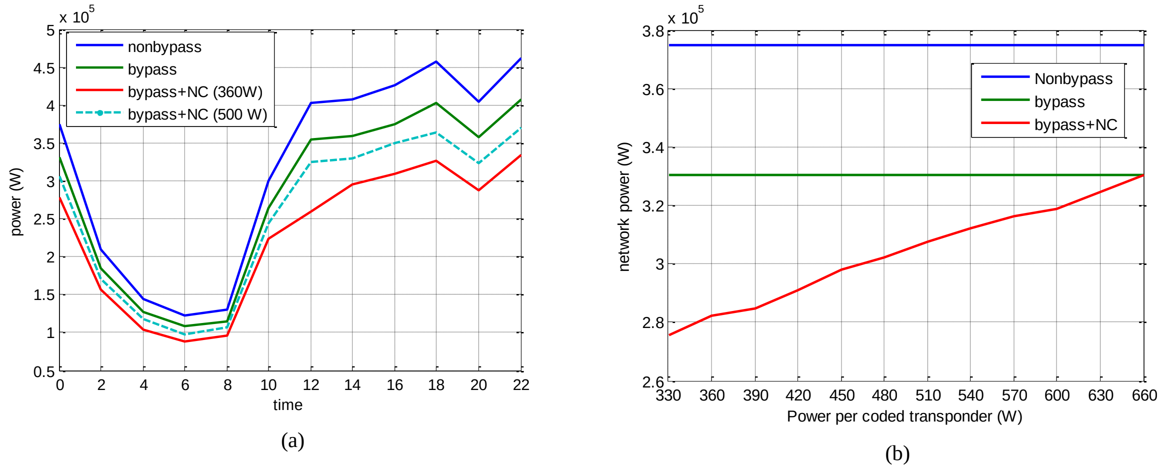

Figure 4. Power consumption of the network (a) at different time of the day (b) for different coded transponders power values

4. CONCLUSIONS

This paper has investigated the energy efficiency gained by introducing network coding in bypass IP/WDM networks. The MILP model results suggest that network coding can achieve daily average savings of 28% considering NSFNET topology compared to non-bypass routing.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Y. Zhang, P. Chowdhury, M. Tornatore, and B. Mukherjee, "Energy Efficiency in Telecom Optical Networks," Communications Surveys & Tutorials, IEEE, vol. 12, pp. 441-458, 2010.

[2] Hammadi, Ali, and Lotfi Mhamdi. "A survey on architectures and energy efficiency in data center networks." Computer Communications 40 (2014): 1-21.

[3] G. Shen and R. Tucker, "Energy-Minimized Design for IP Over WDM Networks," Optical Communications and Networking, IEEE/OSA Journal of, vol. 1, pp. 176-186, 2009

[4] X. Dong, T. El-Gorashi, J.M.H. Elmirghani: IP Over WDM Networks Employing Renewable Energy Sources, IEEE Journal of Lightwave Technology, vol.29, no.1, pp. 3-14, Jan. 2011.

[5] X. Dong, T. El-Gorashi, J.M.H. Elmirghani: Green IP Over WDM Networks With Data Centers, IEEE Journal of Lightwave Technology, vol.29, no.12, pp.1861-1880, June 2011.

[6] X. Dong, T. El-Gorashi, J.M.H. Elmirghani: On the Energy Efficiency of Physical Topology Design for IP Over WDM Networks, IEEE Journal of Lightwave Technology, vol.30, no.12, pp.1931-1942, June 2012.

[7] A.Q. Lawey, T. El-Gorashi, J.M.H. Elmirghani: Distributed Energy Efficient Clouds Over Core Networks, IEEE Journal of Lightwave Technology, vol.32, no.7, pp.1261-1281, April 2014.

[8] N.I Osman, et al.: Energy-Efficient Future High-Definition TV, IEEE Journal of Lightwave Technology, vol.32, no.13, pp.2364,2381, July 2014.

[9] A.Q. Lawey, T. El-Gorashi, J.M.H. Elmirghani: BitTorrent Content Distribution in Optical Networks, IEEE Journal of Lightwave Technology, vol.32, no.21, pp. 4209-4225, Nov 2014.

[10] L. Nonde, T. El-Gorashi, J.M.H. Elmirghani: "Energy Efficient Virtual Network Embedding for Cloud Networks, IEEE Journal of Lightwave Technology, vol.33, no.9, pp. 1828-1849, May 2015.

[11] R. Ahlswede, et al.: Network information flow, IEEE Transactions on Information Theory, vol. 46, pp. 1204-1216, 2000.

[12] C. Fragouli and E. Soljanin, Network coding applications. Now Publishers Inc, Delft, The Netherlands, 2007.

[13] Alcatel-Lucent Bell Labs , "Video Shakes Up the IP Edge, A Bell Labs Study on Rising Video Demand and its Impact on Broadband IP Networks, Alcatel-Lucent Bell Labs Strategic White Paper", December 12, 2012. [Online]. Available: http://www.tmcnet.com/tmc/whitepapers/documents/whitepapers/2013/7583-alcatel-lucent-video-shakes-up-ip-edge.pdf , Last accessed 30 March 2016.

[14] M. Musa, T. El-Gorashi, and J. Elmirghani, "Energy Efficient Core Networks Using Network Coding," in Transparent Optical Networks (ICTON), 2015 17th International Conference on, July 2015.

[15] GreenTouch, "GreenTouch Final Results from Green Meter Research Study." [Online]. Available: http://www.ourenergypolicy.org/wp-content/uploads/2015/06/GreenTouch_Green_Meter_Final_Results_18_June_2015.pdf , Last accessed 30 March 2016
[16] Online: "http://www.greentouch.org", Last accessed 30 March 2016.