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Energy Efficient Core Networks Using Network Coding

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ABSTRACT
In this paper we investigate the use of network coding to improve energy efficiency of core networks. A mixed integer linear programming model is developed to optimize routing in network coding enabled non-bypass IP/WDM networks considering unicast traffic flows. We quantify the power savings obtained by implementing network coding. The results show that network coding can improve the energy efficiency of non-bypass IP/WDM networks by up to 33% compared to conventional architectures.

Keywords: Energy Efficiency, IP/WDM, MILP model, Network coding.

1. INTRODUCTION

The research community has dedicated significant efforts in the past few years towards improving the energy efficiency of information and communication technology (ICT) systems. The exponential increase in users' traffic as well as the high inefficiencies of the current ICT systems pose economic and environmental disadvantages, calling for better solutions. The GeSI SMARTer 2020 report [1] estimates the total emission of ICT to increase from 1.9% in 2011 to 2.3% of the global emissions by the year 2020. In this work, we investigate the use of network coding to improve the energy efficiency of core networks.

Network coding, first introduced by Ahlswede et.al [2], upgrades the functionality of intermediate nodes from simply storing and forwarding traffic flows to performing coding operations on traffic flows. Performing coding in intermediate nodes results in improving the resource efficiency and throughput in the network and leads to added security. The authors in [3] provide a good review of network coding and its applications.

The use of network coding has been widely investigated in wireless networks for multicast scenarios. However, the unicasting nature of the optical transport medium in which only the destination nodes receive the intended flow has limited the application of network coding in optical networks to passive optical networks where the Optical Line Terminal (OLT) multicasts downlink traffic to multiple Optical Network Units (ONUs) [4]-[6], and provides protection against single failures where multiple paths are used between source and destination [7]. The work in [8] investigated network coding in multicast scenarios and all optical communication by the using multicast enabled optical switches.

In this work we propose, for the first time to the best of our knowledge, the use of network coding to improve the energy efficiency of IP/WDM networks in unicast settings. Network coding helps to reduce the number of IP router ports (the mot energy consuming devices) used in intermediate nodes in non-bypass IP/WDM networks.

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 [9]-[16] shown in figure 1, IP routers aggregate traffic from edge routers and transport them through optical fibres which provide the required high bandwidth. Electrical signals are converted into optical signals using transponders, and switched optically by the optical cross connect to the IP router. In each fiber, multiplexers / demultiplexers are used to multiplex and demultiplex the wavelengths. Erbium doped fiber amplifiers (EDFAs) are used to amplify the optical signals to support long distance transmission.

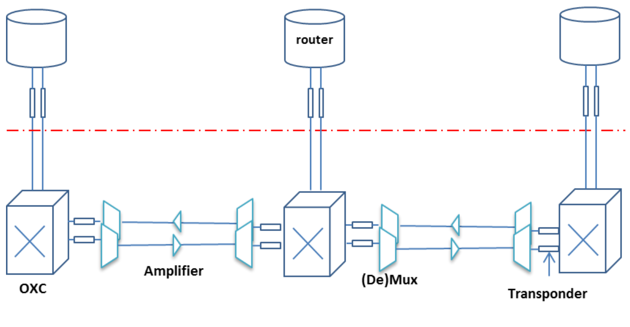


Figure1: The architecture of an IP/WDM network.

Routing of traffic from source to destination is implemented using either the lightpath non-bypass approach or the bypass approach. In the former approach traffic flows are routed from its source to destination optically without passing through the IP layer of intermediate nodes while in the latter the flows have to visit the IP layer in each intermediate node. In this paper we focus only on the non-bypass case.

Figure 2 compares network coding (in a three nodes network) to the conventional routing approach. In Figure 2(a), considering the conventional routing scheme, the intermediate node only stores and forwards the X and Y flows whereas in Figure 2 (b) the intermediate node encodes the flows using the logical xor operation and multicasts them back to nodes *n* and *k*.

In the conventional routing case, two conventional ports are required at each intermediate node, one to connect to each end node and a port at each end node, resulting in a total of 4 conventional ports. Employing network coding reduces the number of IP router ports at intermediate nodes by replacing the two conventional ports in the intermediate node by a single network coding enabled port (NC) port. Therefore the total number of ports is reduced from 4 conventional ports to 1 NC port at the intermediate node and 2 conventional ports at end nodes.

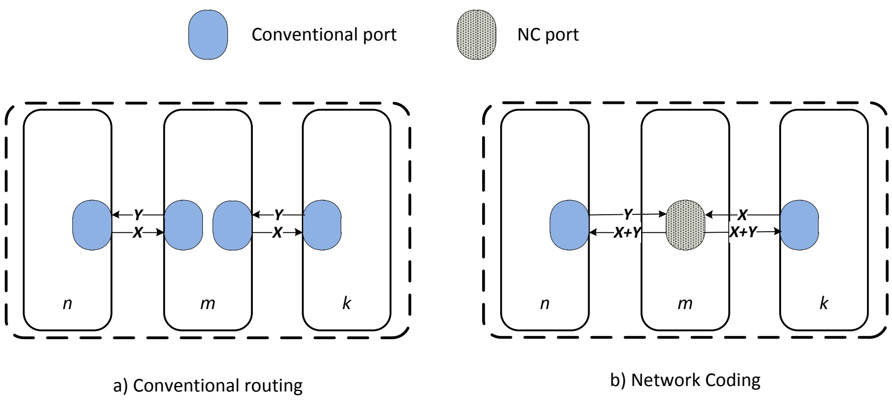


Figure2: Conventional routing and Network coding in a three nodes example

Figure 3 illustrates the proposed architecture of a network coding enabled IP/WDM node. In addition to the transmitter and receiver found in conventional ports, a receiver is needed to allow the port to receive the two flows to be encoded. Storage is required to synchronize data before encoding. The flows are encoded using the "XOR" unit. The transmitter is connected to a coupler in the optical layer to facilitate multicasting, and an amplifier is used to compensate for the power loss due to splitting. The fact that the coding is done in the IP layer makes the additional storage and the simple XOR code low cost as the storage functionality is already in existence in conventional ports, and the XOR functionality can become part of the processing.

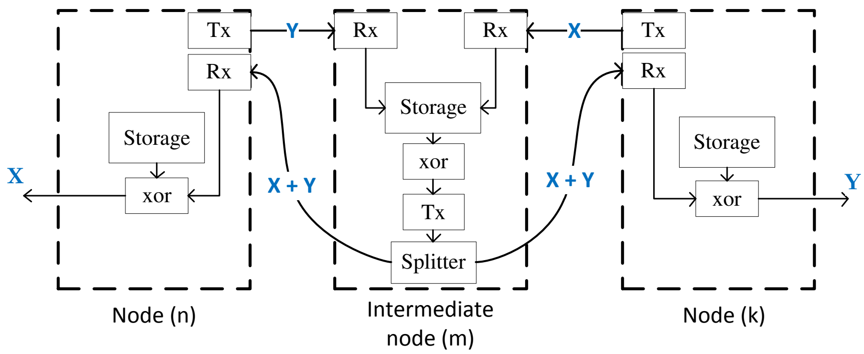


Figure3: Network coding nodes architectures

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 non-bypass IP/WDM networks by optimizing the use of network resources. The model optimizes the number and location of NC ports given the network topology and traffic demands.

3. RESULTS

We investigate the power savings obtained by implementing network coding in example networks. We consider two network topologies of different average hop counts: the NSFNET network and the USNET network. The NSFNET, shown in Figure 4a, has 14 nodes and 21 links and an average hop count of 2.17, while the USNET, Figure 4b has 24 nodes and 43 links with an average hop count of 3. The traffic demands between nodes pairs of the network at different times of the day is generated following a uniform distribution of values from 20 Gb/s to 120 Gb/s where the peak occurs at 22:00 in each time zone [10]-[16] .

The power consumption of the network devices are shown in Table 1 [17]-[21]. We assume the power consumption of the network coding enabled ports to be 1100 Watts to account for the extra elements of the NC port.

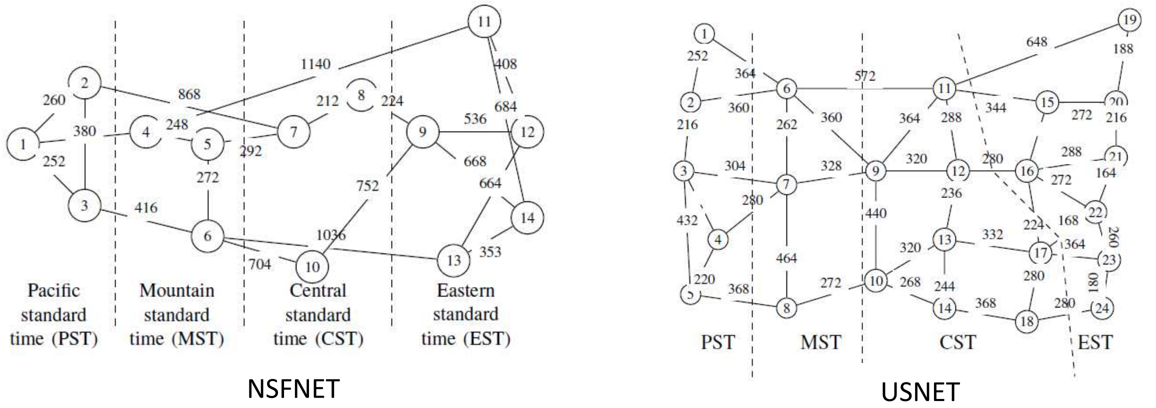
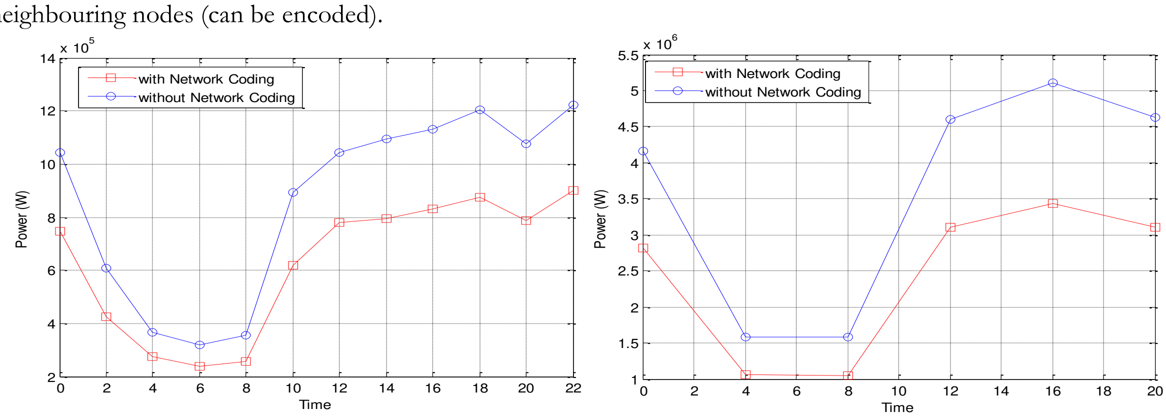


Figure4: (a) NSFNET topology and (b) USNET topology

Table 1: Network Parameters.

Parameter	Value
Distance between neighboring EDFAs	80 km
Number of wavelengths in a fiber	16
Capacity of each wavelength	40 Gbps
Power consumption of a normal port	1 kW
Power consumption of a network coding port	1.1 kW
Power consumption of a transponder	73 W
Power consumption of an Optical Switch	85 W
Power consumption of a MUX/DeMUX	16 W
EDFA's power consumption	8 W

Figure 5 shows an average power savings of 27% obtained by introducing network coding to the NSFNET topology. The power savings increase to 33% for the USNET topology. This increase is due to the higher hop count of the USNET. The higher hop count means that more conventional ports will be replaced by NC ports. A higher hop count, however, will also increase the number of conventional ports needed to establish flows between neighbouring nodes where the traffic flows cannot be encoded. The total power savings obtained by network coding depend on the ratio of the traffic between neighbouring nodes (cannot be encoded) and the non-neighbouring nodes (can be encoded).



a) NSFNET power consumption

b) USNET power consumption

Figure5: power consumption for NSFNET and USNET with and without network coding

4. CONCLUSIONS

This paper has introduced the use of network coding to improve the energy efficiency of non-bypass IP/WDM networks. We formulated an MILP model to evaluate the potential power savings obtained by implementing network coding. The model results suggest that network coding can achieve daily average savings of 27% and 33% considering NSFNET an USNET, respectively.

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