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On the Use of Learning Automata for Energy Saving in Optical Backbone Networks

Constantine A. Kyriakopoulos [1] Georgios I. Papadimitriou [1]
Petros Nicopolitidis [1]

Dept. of Informatics
Aristotle University
Thessaloniki, Greece

Emmanouel (Manos) Varvarigos [2]

Dept. of Computer Eng. and Informatics
Patras University
Greece

Abstract

Optical backbone networks offer reliable long distance connectivity with low error rate and high bandwidth. Lightpath routing in these networks can be fulfilled while aiming at either performance or energy efficiency, according to current user needs. In this paper, an innovative hybrid scheme for creating node-to-node connections that is based on Learning Automata and can be oriented to performance or energy efficiency, is proposed. It is suited for network's Operation phase when a node bypass technology is absent. This phase requires low delay while routing, so complexity is reduced to a polynomial form by the use of an adaptive mechanism. Simulation results verify scheme's efficiency.

Keywords: learning automata, optical networks, energy efficiency, routing

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1 Introduction

The size of the Internet is increasing rapidly and its adoption has reached unexpected levels. Since its backbone mainly consists of optical networks, energy efficiency becomes more important as adoption rate keeps increasing [1]. Optical communications should be efficient and at the same time, consume small amounts of energy.

The main subject of this work relates to energy-aware [2] lightpath establishment in optical backbone networks. This procedure initiates with a set of traffic requests that will be routed upon an optical backbone network. The way these requests will be routed according to their occupied resources, has explicit consequence to network's energy consumption. So, a method is proposed which is based on Learning Automata (LA) [3] and Traffic Grooming [4][8] that can perform energy-aware routing and lightpath establishment, aiming at reducing power consumption. Specifically, a snapshot of the network under full load is created, captured and analyzed, with the purpose of calculating its energy footprint. The way the procedure of lightpath establishment takes place and develops, based on a heuristic method, represents the core of this research.

LA are adaptive mechanisms that require feedback from the environment to converge to a certain state. In the context of network routing, feedback from a destination node can be exploited by intermediate nodes for reducing e.g., data path's length. As time increases, LA that reside at intermediate nodes exploit this feedback value and converge to certain neighbours, leading to paths with properties correlated to destination's feedback. Each LA that resides in a node, evaluates all physical neighbours with a probability number. After each feedback value from a destination node, this LA increases the probability number of the neighbouring node that leads to the destination and decreases all other probabilities of neighbouring nodes. So, subsequent tries to reach the same destination have more chances to follow the same route. When all LA converge to certain neighbours, the path that is formed carries the properties that stem from the feedback value, e.g., low number of hops.

The problem of inefficient exploitation of the available bandwidth during routing which leads to consumption of high amounts of energy, was confronted by this research. So, elaborate reuse of pre-established lightpaths by an adaptive mechanism that tries to perform routing, is at the core of the proposed method. It is a hybrid method that was designed and simulated, performing

[1] Email: kyriak, gp, petros @csd.auth.gr
[2] Email: manos@ceid.upatras.gr

lightpath routing and establishment with two goals to be fulfilled, either reducing energy consumption or preserving high performance level. When the heuristic functions in Energy Efficiency [6] mode, power saving is higher at the cost of path elongation and a higher propagation time. When in Performance mode, routes are short with low propagation time at the cost of higher energy consumption. Both operating modes were simulated and tested for efficiency against a non-bypass method that uses the shortest path between each connection node-pair to route. The main assumption that took place in this research about network's physical layer lies in the absence of a bypass technology.

The rest of this paper is organized as follows. Related research of this field is presented in Section 2. The proposed hybrid heuristic is analyzed in Section 3 and simulation results follow in Section 4.

2 Related Research

The Virtual Topology (VT) in an optical network [7] consists of a graph structure with node connectivity between pairs when the signal remains in the optical domain. Most energy-efficient heuristics for optical backbone networks need to be able to find routes with special traits, leading to less power consumption. Since this is an NP-Hard problem (all possible lightpath combinations must be tested), adaptive tools are needed to convert complexity to a polynomial form, especially when the network functions during the operation phase (incoming traffic requests are being served dynamically, one by one in a First-Come First-Served fashion). Research for finding the shortest paths [3] on a dynamic graph topology based on LA, yielded satisfying results for tackling complexity's practical barrier, when topology's traits differentiate dynamically. Energy-aware heuristics along with a formulation, are also demonstrated to save energy in [9]. There are also strategies [11] to create energy-efficient routes.

The traffic matrix (also used in this research) carries bandwidth requirements between each node pair (one request) and is initialized in the beginning of simulation. The formula of [2] can be used, i.e., $X \in \{20, 40, ..., 100\}$ Gbps (the average value used for producing the waveforms) and the actual demand as a real number is produced by using a uniform distribution in range of [10, 2X-10] Gbps. As energy-consuming components [5] (used in this research), line amplifiers are considered with energy consumption $E_e = 8$W per unit, transponders with $E_t = 73$W per unit, and router ports with $E_r = 1000$W per unit. Every physical link includes two (pre and post) amplifiers at its end points and one in every 80 km in between. The maximum -per wavelength-bandwidth is 40 Gbps and every fiber can include up to 16 of them. Every neighboring node pair can be interconnected with an unlimited number of fibers. Total energy consumption [2] can be computed with the following formula (1) in Watt.

$$(1) \quad E_{Total} = \sum_{i \in N} E_r(D_i + \sum_{j \in N} C_{ij}) + \sum_{m \in N} \sum_{n \in N_m} E_t w_{mn} + \sum_{m \in N} \sum_{n \in N_m} E_e A_{mn} f_{mn}$$

D_i is the number of ports that are used to aggregate data traffic from low end routers and equals to $\lceil (\sum_{d \in N} l^{id})/B \rceil$, l_{id} is the traffic demand between node pair (i,d) and B is the maximum wavelength bandwidth. C_{ij} is the number of wavelength channels (wavelengths that start from i and end to j with an uninterrupted physical single-hop light connection) upon the lightpath *(i,j)* and the summary denotes how many wavelength units are starting from node i and end to all other topology nodes. w_{mn} is the number of used wavelengths on physical link *(m,n)*. Finally, f_{mn} is the number of deployed fibers on the same physical link and A_{mn} is the number of amplifiers which equals to $\lceil \frac{L_{mn}}{S} - 1 \rceil + 2$. L_{mn} is the distance measured in kilometers and s is constant and equals to 80km (the distance between two consecutive intermediate line amplifiers except the last one).

3 Proposed Hybrid Routing Scheme

The proposed scheme consists of two operational modes, i.e., oriented to energy efficiency or performance. When the network operates in former mode, routing takes place with the main purpose of minimizing energy consumption. Paths are being evaluated according to their computable contribution to energy consumption. When in latter mode, lightpath routing is being fulfilled with the goal of providing network's performance as the highest priority. In this case, paths are being evaluated according to their propagation time that is mainly correlated to the number of hops they contribute.

The underlying functionality is provided by Learing Automata which can be configured to converge to paths that lead to energy efficiency or performance. When a new node-pair connection is about to be established, there is a set of pre-established lightpaths from previous traffic requests that can be reused by the new request which is about to be routed. Two LA are placed in every VT's node -one used by energy efficiency's mode and the other by performance's mode. This is not just a shortest path problem, but an attempt to find a sequence of lightpaths that offer high available bandwidth as

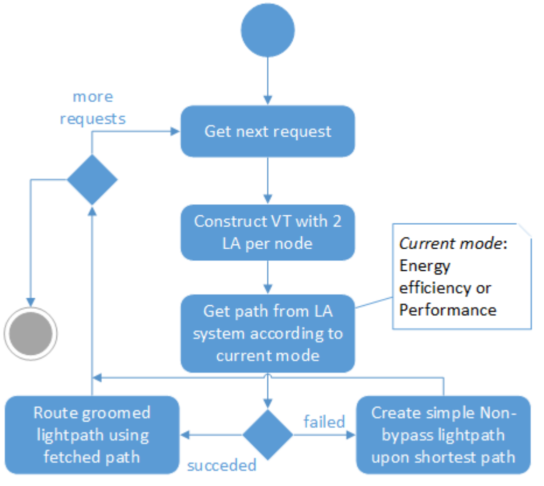

Fig. 1. Heuristic's hybrid functionality

a route. The lightpath with the lowest offered bandwidth, defines the available bandwidth of that route. LA utilization in this case comes in handy for the purpose of reducing complexity to a polynomial form instead of exponential. The next node to be chosen during traversal is fetched from the respective current node's LA. This LA stores transition probabilities to all node's neighbours that emerge from VT's current state. Since LA require multiple iterations to converge to certain neighbours, the attempt to reach the destination node is repeated multiple times. When a path for a request to be routed is found, all pre-established lightpaths that reside along its nodes are groomed. Heuristic internals in UML Activity Diagram of Figure 1. The linear probability updating scheme [3] is provided by formulae (2) and (3) which are applied when a valid path is found after an iteration. Automata that reside along path's nodes are being updated.

$$p_j\left(k+1\right) = p_j\left(k\right) - L \cdot b\left(k\right)\left(p_j\left(k\right) - a\right), \forall j \neq i \tag{2}$$

$$p_i\left(k+1\right) = p_i\left(k\right) + L \cdot b\left(k\right)\sum_{i \neq j}\left(p_j\left(k\right) - a\right) \tag{3}$$

When k iterations took place for neighbour i, the probabilities of all other neighbours decrease using the first formula. The sum of this decrease gets added to the current probability value of neighbour i using the second formula. This depends on the $b(k)$ feedback value of the valid path. L denotes the problem of convergence speed against accurate estimation and a value of 0.15 also yields adequate [3] results in this environment. The value of a makes probability numbers not to reach zero value.

The choice [10] of neighbouring node -the one with the highest cost G- is provided by formula (4). T represents the current simulation time while *R(i)* is the time (in generic time units) when neighbour i was last chosen. Variable p_i is the estimated probability value for neighbour i and l is its 'length' (higher values of l denote more available bandwidth connecting the current node to this neighbour). M is the number of neighbours. This formula ensures that unpopular neighbours will still be chosen even though more scarcely.

$$G\left(i\right) = \left(T - R\left(i\right)\right)^2 \cdot \frac{p_i}{l_i},\ 1 \leq i \leq M \tag{4}$$

An important parameter for LA is their feedback value. When a valid path is fetched from the LA system it is promoted, so subsequent traversals have better chances to converge to it. This is being realized via a feedback value that is applied to Automata of path's nodes (except the last one -the previous LA points to this one). This floating point feedback value in range [0, 1], depends on path's characteristics according to current network's functioning state. When in Energy Efficiency mode, feedback equals to route's available bandwidth, i.e., the lowest available bandwidth of its lightpaths it consists of, divided by the maximum allowed bandwidth per lightpath, i.e., 40 Gbps. So, paths that offer higher available bandwidth will be promoted more frequently. When in Performance mode, the number of nodes of the shortest path between end nodes, divided by the node number of the found path. So, when the new path is short and reaches the shortest one, feedback will tend to become equal to 1 and thus shorter paths will be promoted more frequently.

4 Results

All simulation experiments were conducted upon two representative backbone network topologies, NSFNet and USNet, assuming no support of a bypass technology. The adaptive LA system demonstrates the advantage of being able to find energy-efficient paths in large backbone topologies under polynomial complexity. In case a brute technique had replaced the LA system, large topologies with low average traffic demand (more available lightpaths with spare bandwidth to participate in search domain) would render the execution infeasible. The simulator was designed and implemented in C++14 using the GNU Compiler.

In Figure 3, power savings of the two modes are depicted as average traffic demand increases. The comparison of each of the two modes is against a typical non-bypass method (percentage of saved power against it) that uses the shortest path between end-nodes. As the average traffic demand gets higher,

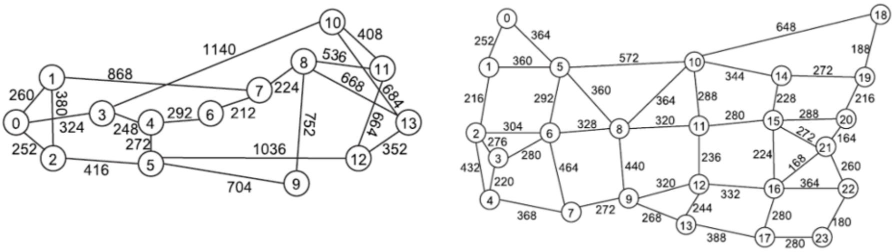

Fig. 2. NSFNet & USNet topologies

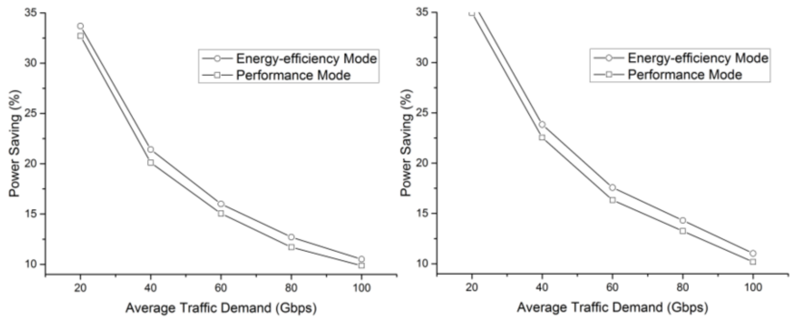

Fig. 3. Power saving in NSFNet & USNet

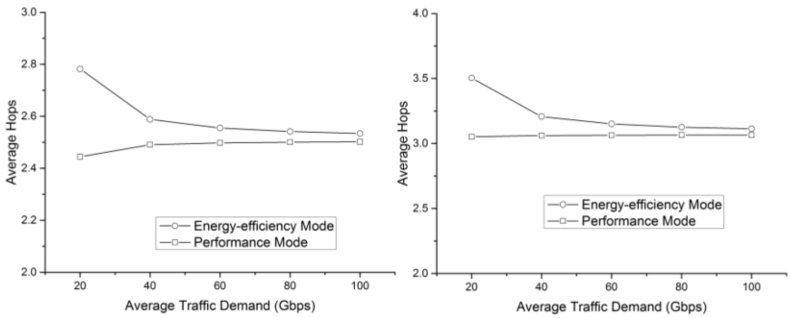

Fig. 4. Hops in NSFNet & USNet

power saving decreases due upper limit of allowed bandwidth per wavelength. There are no lightpaths that carry spare bandwidth higher than 40 Gbps, so these requests cannot be groomed.

In Figure 4, since performance is directly related to path hop-count, the average number of hops is lower in this mode. Concluding, Energy Efficiency mode promotes less energy consumption at the expense of path elongation and Performance mode promotes shorter paths at the expense of higher amount of energy consumption.

5 Conclusion

The proposed lightpath routing method consists of two modes, one for energy efficiency and one for performance. The former consumes less amount of energy at the expense of path elongation and the latter uses shorter paths at the expense of higher amount of consumed energy. The current operational mode can be closely tied to end-user needs. The proposed approach utilizes a LA-based heuristic as a way to reduce complexity from exponential to a polynomial form while finding adequate paths for lightpath grooming. The scheme is suitable for optical networks without available bypass technology.

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