Hybrid SDN Architecture for Resource Consolidation in MPLS Networks

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Abstract—**This paper proposes a methodology for resource consolidation towards minimizing the power consumption in a large network, with a substantial resource overprovisioning. The focus is on the operation of the core MPLS networks. The proposed approach is based on a software defined networking (SDN) scheme with a reconfigurable centralized controller, which turns off certain network elements. The methodology comprises the process of identifying time periods with lower traffic demand; the ranking of the network elements, based on their utilization and criticality; the rerouting of the traffic off the least utilized elements; and finally, the switching off of the appropriate nodes or links. An algorithm for traffic rerouting, based on the MPLS traffic engineering techniques is proposed and its performance is evaluated in terms of the achieved energy efficiency in accordance with predefined connectivity and quality of service constraints.**

Keywords—energy efficiency; SDN; MPLS; traffic engineering; resource consolidation

I. INTRODUCTION

The development of 3G and 4G wireless technologies introduced an immense number of new services and applications, which generate a huge demand for high-speed access [1]. With this surge in traffic growth, the network operators face the need to develop and implement new efficient and cost-effective solutions, characterized by all-IP Ethernet backhaul and a large increase in mobile backhaul and core capacity. The increase of bandwidth demand also leads to significant transformation in the backhaul requirements and migration to all-IP Ethernet backhaul. The predominant technology of choice is identified to be the Internet protocol/multiprotocol label switching (IP/MPLS) [2] and its newly develop variation, MPLS Transport Profile (MPLS-TP) [3]. Another key requirement in the process of capacity planning of the core and backhaul networks is to ensure the provisioning of sufficient bandwidth that guarantees certain service level agreement (SLA) requirements. To battle traffic bursts, the bandwidth usually is over-provisioned in relation to the measured average rate. This design practice tends to meet the peak demand in the network and accommodates the future traffic growth, but results in consistently energy inefficient network operation in low demand periods [4].

Various energy-saving models, considering the future Internet architectures, while improving the current network design, are presented in [5]. This paper is focused on a resource consolidation technique that aims to reduce the network energy consumption by concentrating the traffic in a small subset of nodes/links and the switching off of the network elements that remain unused. Several different approaches for resource consolidation have been proposed. In [6], a dynamic link metric technique that aggregates the traffic based on dynamically changing the link weights has been described. The algorithm suggests a simple alternation of the open shortest path first (OSPF) routing protocol but targets only links and not entire nodes. Furthermore, the links are chosen based on the utilization parameters only, which might lead to a suboptimal ranking of the network elements. An approach that targets, both links and nodes, and utilizes an optimized technique for element ranking has been discussed in [5]. The technique, however, offers a suboptimal solution, as it requires the periodic waking up of the network elements in order to keep their place in the network. The authors of [7] focus on accurate network elements ranking by utilizing the Shapley value as a criticality index. The algorithm performs accurate node ranking, but does not focus on the links, as they consider the achievable energy savings by switching off the negligible links. After the selection of the optimal subset of nodes that will remain powered off, routing weights optimization and equal cost multipath traffic distribution is performed. This approach offers a concise analysis on the achievable energy savings and the impact on the quality of service (QoS) parameters, but its computational complexity may prove to be a drawback in real-life implementation. Furthermore, the authors do not consider the network control plane mechanism for implementation. In [8] an integer linear programming (ILP) formulation of the problem of switching off of the network elements is defined and a greedy heuristics for iterative switching off of the network nodes and the links is proposed. The authors, however, do not consider the impact on the QoS parameters and do not offer a network control plane mechanism for implementation.

The main purpose of this research work is a practical solution for the resource consolidation and switching off of the network elements towards minimized power consumption. We propose a novel architecture, based on a centralized software defined networking (SDN) controller, which allows for a modular implementation of the different network functionalities in the form of software applications. This

provides greater flexibility in the choice of the traffic matrix estimation, the network elements ranking, the routing and the traffic engineering techniques. Furthermore, the paper proposes an algorithm for the resource consolidation based on the MPLS traffic engineering techniques that offers a real-life implementation solution. Finally, the impact of the QoS constraints on the achievable energy savings has been estimated.

The paper is organized as follows. Chapter II describes the implemented architecture, gives an overview of the switch off/on-process and examines the proposed re-routing algorithm. Chapter III presents the simulation setup and input parameters, Chapter IV discusses the simulation results in terms of achievable energy savings, and Chapter V provides conclusive remarks and outlines the planned future work.

II. Proposed Architecture

Usually, the resource overprovisioning in the core networks is quite high. This is based on the observation that the network utilization experiences considerable variations, based on the time of the day, time of the week, etc. For example, there is a high traffic demand in the peak hours of the day as opposed to the much lower demand during the night [9]. During the low demand time intervals, theoretically, it should be possible to concentrate the traffic in a small subset of nodes or links, which will allow the unused nodes/links to be switched off. The paper describes an SDN-based scheme for resource consolidation, proposes an algorithm for traffic rerouting and turning off of the network elements in MPLS-based networks and evaluates the performance of the algorithm in terms of the achieved energy conservation in accordance with a predefined connectivity and QoS constraints.

A. SDN MPLS

The possibility of the hybrid implementation of the MPLS network capabilities via the SDN controller is a hot topic in the telecommunications sector nowadays. The combination of MPLS data forwarding capabilities with SDN's orchestration capabilities has been suggested to bring multiple advantages that could help the network operators to quickly adapt to the emerging service trends and take full advantage of the technological improvements [10]. Several approaches have been proposed in the literature. In [11], an architecture that retains the MPLS data plane, but implements the control plane using the SDN network operating system (NOS) and a set of software modules that perform the various network control functions, is described. The forwarding decisions are then communicated to the network devices (OpenFlow switches) in the form of flow tables via the OpenFlow protocol. The authors claim significant reduction of the implementation and the configuration complexity, but do not comment on the impact of the network performance. In [12], a different approach that aims to combine the effective switching capabilities, already existing within the MPLS core, and the flexibility and superior control of SDN, is proposed. The architecture introduces a new element in the SDN paradigm, called "fabric controller". The idea is to provide the host-network relationship and complicated network services by a common SDN controller, identified as an "edge" controller,

while the simple packet transport functions will be communicated by a separate control plane and would function as the "fabric controller". This may lead to a more efficient packet switching within the core.

The approach used is partially based on the model described in [12]. In order to benefit from the traffic forwarding capabilities of the MPLS technology, the proposed architecture retains the core forwarding functions of a traditional MPLS network. The goal is to develop a solution that can be more easily implemented in existing network infrastructures, while offering distinct SDN advantages, such as reduced network complexity, centralized control and efficient utilization of network resources. MPLS networks implement a connection-oriented model, which directs the traffic based on labels contained in an MPLS header, thus avoiding complex look-ups in the routing table. The packets follow predefined paths between pairs of ingress and egress edge routers, called label switching paths (LSPs). LSPs are defined by traditional IP routing protocols executed by the MPLS edge routers and are established by a signaling protocol, such as Resource Reservation Protocol with extension for Traffic Engineering (RSVP-TE). Unlike traditional MPLS networks, in the proposed architecture the majority of the control plane functionalities are performed by the centralized controller, which in turn controls the edge routers. The edge routers are then responsible only for initiating RSVP signaling accurately at the required time, specified by the controller. This allows for the dynamic configuration of the RSVP-TE LSPs, based on a specified time or the traffic variations.

A general scheme of the solution is shown in Fig. 1. Essentially, the functionalities of the controller will be implemented as network applications on top of the network operating system (NOS) and will communicate with the underlying network elements via the OpenFlow protocol. The controller performs the following actions:

- Monitors the network traffic;
- Ranks the network nodes - based on the traffic demand matrix estimation;
- Creates and manages a dynamic database – the database identifies the network elements that can be switched off and is based on the following:
  - Statistics for customer consumption – the utilization of the network resources varies depending on the time of the day, time of the week, etc.;
  - Real-time network statistics – critical parameters should be monitored in order to react to unexpected traffic demand;
- Performs *Constrained Shortest Path First* (CSPF) routing decisions;
- Controls the MPLS edge routers – which in turn perform the RSVP signaling accurately at the required time;
- Turns on and off the appropriate network elements.

In the following we describe the process of the operation of the proposed resource consolidation technique and functionalities mentioned above.
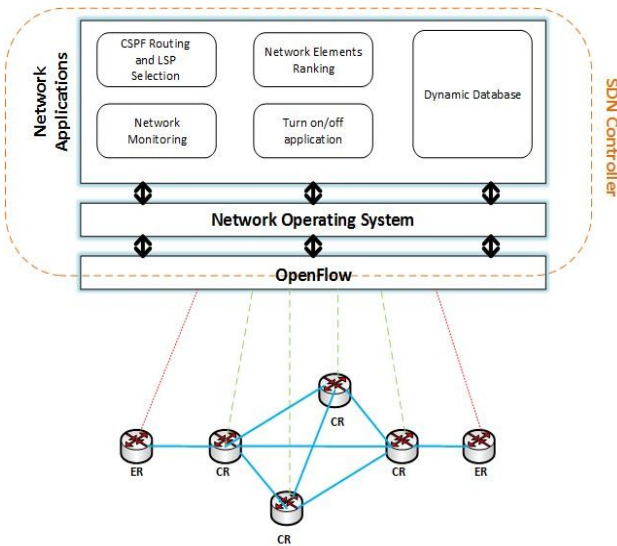
Fig. 1. Hybrid SDN MPLS architecture with centralized controller.

B. General overview of the switch off/on process

The main purpose of the centralized controller is to coordinate the switch off/on process and to react immediately to changes in the customer demands. The process of turning on and off the network nodes/port should meet certain connectivity and QoS constraints. The final goal is to minimize the total power consumption of a large core network, in which the resource overprovisioning is quite big. A general flow diagram of the switch off/on process is presented in Fig. 2.

The switch on/off process should go through the following steps:

1. **Estimate the traffic demand matrix** – in order to estimate the bandwidth requirements for every time period, an internal traffic demand matrix is calculated. The calculation of a separate matrix for the periods of interest gives an estimation of the bandwidth requirements for every time frame. Various traffic demand matrix calculation techniques have been discussed in [4, 13, 14, 15]. One possible example is a calculation, based on the MPLS LSP traffic accounting statistics [4]. For a more accurate estimation, there are various commercial tools that can be used. A good example is the Cisco MATE Collector that uses the demand deduction technique [15], as it is suggested to be particularly accurate for predicting the overall utilization after a failure, a topology change, or a metric change. From the resulting traffic demand matrix, the appropriate overprovisioning factor can be determined.

2. **Determine the overprovisioning factor** – this describes the amount of bandwidth that has to be overprovisioned in order to meet the SLA requirements for the delay, jitter and loss, in the case of unexpected traffic bursts. The detailed process of

how to determine the overprovisioning factor is described in [4].

3. **Time division** - the time periods of the day/week that are characterized with significant variations in the traffic demand are determined. This can be determined on the basis of the obtained traffic demand matrix or manually determined by the network operator.

4. **Threshold and alarms** – based on the traffic demand matrix and the overprovisioning factor the SLA requirements for each time period can be translated into bandwidth requirements. The maximum link utilization threshold can therefore be calculated. Based on the results, alarms can be configured by the network monitoring system. In the case when the link utilization exceeds the predetermined threshold for a certain period of time, the nonoperational network elements will be turned back on.

5. **Node/link ranking** – based on the data from the traffic demand matrix the network elements can be ranked according to different parameters. The nodes can be classified according to parameters, such as the number of links, the central processing unit (CPU) and the memory utilization. The link can be classified according to the interface metrics, (e.g., throughput, average utilization). The different network elements classification techniques can be found in [5, 7, 16]. The process is performed by the application module, implemented on top of the NOS. The ranking can be based on the so-called local centrality measure [16]. The method estimates the node significance by calculating the number of the nearest and the next nearest neighbors. The elements are then ranked based on a local centrality measure and the history of utilization.

6. **Initial database** – based on the node ranking results, the order, in which the network elements will be switched off can be determined. A database containing information about the node and the link priority is then created. Different tables will be created for every time period. Once more, the purpose of the database is to mark the order, in which the element will be switched off and will be used as a base for future operation, in order to speed up the process. The nodes and the links with a higher priority will be switched off first.

7. **Operational database** - a second instance of the database is created. This instance will be dynamically changed during the switching off process in order to store any resulting changes in the order, in which the element has been switched off. The changes are expected to occur after the traffic from a switched off element is rerouted.

8. **Reroute traffic off the least utilized** links - in order to avoid packet loss, the traffic is rerouted before the links/nodes can be switched off. For this, traffic engineering (TE) techniques are utilized. In the case of an MPLS-based core network, we suggest the use

of (RSVP-TE). Once the traffic is rerouted, the links/nodes can be switched off. The process of traffic rerouting will be explained in details in the following section. Essentially, an alternative (i.e., LSP) will be established, excluding the node that has been marked for switching off.

9. **Check for alarms** – the new LSP will be established by the edge routers and signaled via RSVP. At this point, the traffic will be rerouted through the new path. The path will be chosen by the CSPF module of the controller and is supposed to have enough available bandwidth. However, the utilization threshold might still be exceeded. If this is the case, then the original path should be reestablished and the switch off process will move to the next network element. The change will be recorded in the operational database.

10. **Switching off** – in the case, when there are no alarms indicating excessive link utilization, the switch off process will move to the next element in the operational database.

C. Rerouting algorithm

The main purpose of the proposed algorithm is to steer traffic off the network node that has been marked for switching off in order to prevent unwanted packet loss and to enable a safe disconnection procedure. The algorithm has been implemented within the "CSPF Routing and LSP selection" module, which communicates with the MPLS
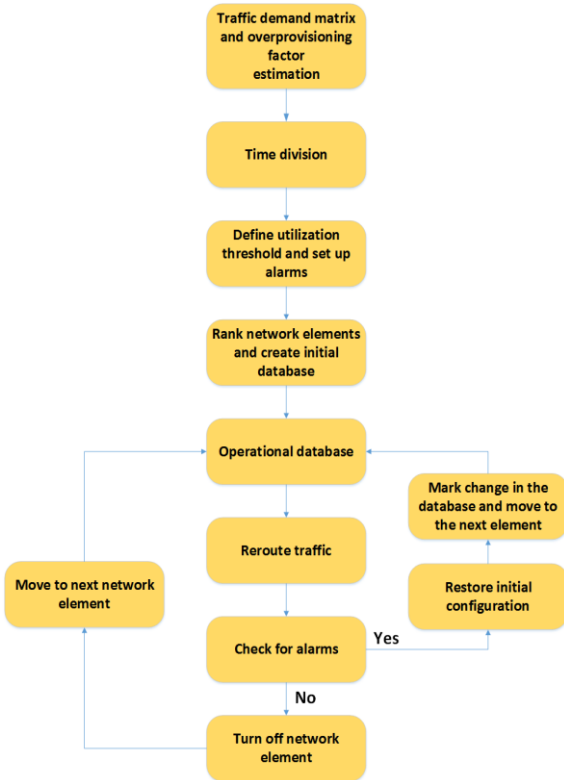

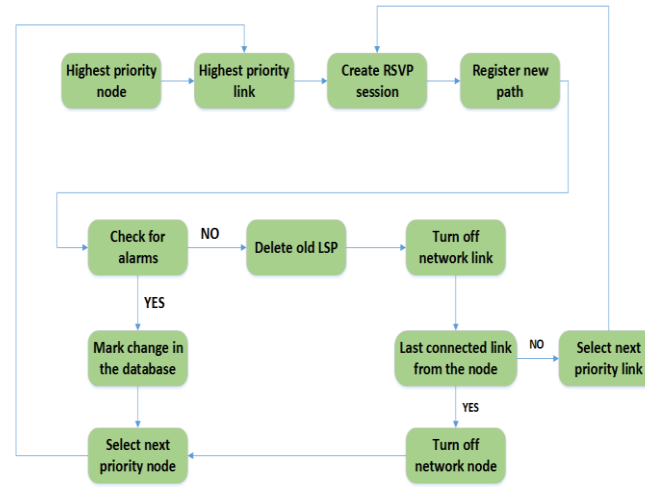Fig. 2. Flow diagram of the switch on/off process.

Fig. 3. Re-routing algorithm flow diagram.

edge router (ER) via the OpenFlow protocol. The algorithm takes as an input the ordered set of IP addresses, produced by the CSPF routing, which defines the new LSP. The node under consideration is determined by the corresponding entry in the operational database. A flow diagram of the procedure is presented in Fig. 3. The algorithm performs the following actions:

1. **Select the highest priority node** – this is the node determined by the "network elements ranking" application module as the least utilized node and is indicated by the corresponding entry in the Operational Database.

2. **Select the highest priority link** – this is the least utilized link connected to the selected node.

3. **Create the RSVP sessions** – the LSPs that pass through the selected link are identified and alternative LSPs are calculated for each path, using the implemented CSPF algorithm. The selected node is excluded from the calculation by setting the advertised bandwidth to a minimum. The alternative LSPs are identified as ordered sets of IP addresses and an RSVP-TE session is initiated by each corresponding ER.

4. **Register the new paths** - the new paths are registered in the routers' forwarding equivalence class (FEC) tables. After the RSVP path reservation messages have been propagated, the traffic is forwarded through the new paths.

5. **Check for alarms** – here it is checked whether the utilization requirements are fulfilled after the traffic rerouting. In the case when the utilization threshold is exceeded, the old path would be reestablished and the next priority node would be selected from the corresponding database entry. If no alarms are detected for a defined period of time, the old LSP is deleted and the link is switched off.

6. **Last connected link** – the next step is to check if there are more active ports on the selected node. If

there are any, the next priority link is selected from the corresponding entry of the operational database.

7. **Turn off the node** – if there are no more active ports on the selected node, the node is switched off and the process moves to the next priority node.

8. **End** – the process ends when no alternative LSPs are identified by the CSPF algorithm.

The algorithm is evaluated in terms of the achieved energy conservation in accordance to a predefined connectivity and QoS constraints. The simulation tool is used is OMNET++.

III. SIMULATION SETUP

The evaluation of the proposed approach is based on a test case, which considers a simplified version of a real network topology of a national telecommunications service provider. The evaluation focuses on the MPLS-based super core part of the provider's network. The topology is implemented using OMNeT++ 4.3.1 IDE, equipped with INET 2.3.0 open-source communication networks package.

A. Topology Overview

The network that was chosen for the tests follows the hierarchical design of four levels – super core, core edge, metro and access. The high performance super core consists of 8 sites in four major cities. The core edge layer consists of 40 sites, situated in major cities around the country that aggregate the traffic from the metro and access layer. The evaluation focuses on the super core part of the topology for the following two key reasons, namely:

- Huge resource overprovisioning – the core network planning takes into account the future rise of the traffic demand and ensures high redundancy of the links and nodes in order to prevent losses in case of failure.

- High power consumption – the high-performance network elements and long high-bandwidth links consume considerably larger amount of electrical power and temporal turning off such elements can ensure large power savings [9].

The super core layer consists of 8 sites in 4 major cities. The simplified super core network topology is shown in Fig. 4. A full mesh topology is constructed between the major cities and partial mesh between the super core sites, connected by 10-Gbps trunk optical channels. The core edge routers are situated in different big cities and each of them is dual-homed to two independent super core sites. The connection channels are typically with capacity of 2.5 Gbps or 1 Gbps. In the current simulation, the traffic has been aggregated by 5 core edge sites as shown in Fig. 4.

B. Simulation Setup

The simulation aims to verify the operation of the proposed technique and to estimate the achievable energy savings. A set of pre-selected network elements is iteratively switched off and the influence of the network performance is examined.
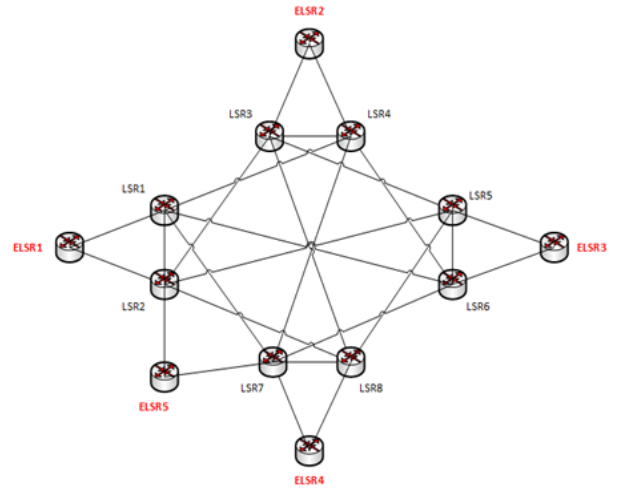

Fig. 4. Simplified super core network topology.

The selected network topology is implemented using the NED editor of OMNeT++ 4 IDE. The super core layer of the provider's network is realized using Label Switching Router (LSR) modules, provided by the INET framework. The channels between the nodes are characterized by two parameters – data rate and delay. The data rate of the channels, connecting the super core nodes is fixed to 10 Gbps. The data rate of the links, connecting the edge nodes to the core nodes is not limited in order to avoid congestion. The latency parameter for each node is calculated based on its real physical length (propagation delay), allowing 5% increase, based on the routing and switching delay [17]. The edge core layer is not examined here, therefore, , only five edge label switching routers (ELSR) are used, for simplicity. Each edge core router aggregates the outgoing traffic for a set of hosts that generate IP packets. The incoming traffic is destined for separate hosts, that act as traffic sinks. The traffic generators produce bursts of traffic and communicate directly by means of IP, (without the use of transport protocols such as TCP or UDP). The traffic patterns are shaped by defining start time, send interval, packet length, number of packets and destination address. Three different groups of hosts are distinguished, based on the packet length parameter – small packets with uniformly distributed size between 40B and 45B, packets with uniformly distributed size between 1290B and 1310B and large packets uniformly distributed size between 1450B and 1500B. These packet sizes are identified in [18] as predominant in the Internet traffic.

The edge routers communicate with the controller and are responsible for RSVP signaling. The routers are implemented with the use of the RSVP-TE capable router module in INET. These are the modules that communicate directly with the centralized controller and initiate the RSVP sessions in the specified time. They receive information about the correct paths by the controller in the form of ordered set of IP addresses. In the current simulation, the FEC information and RSVP session information are specified as xml format. The controller's operation is implemented via the xml script with the use of the *scenario manager* module. The controller reroutes the traffic by initiating a new RSVP session; binds the
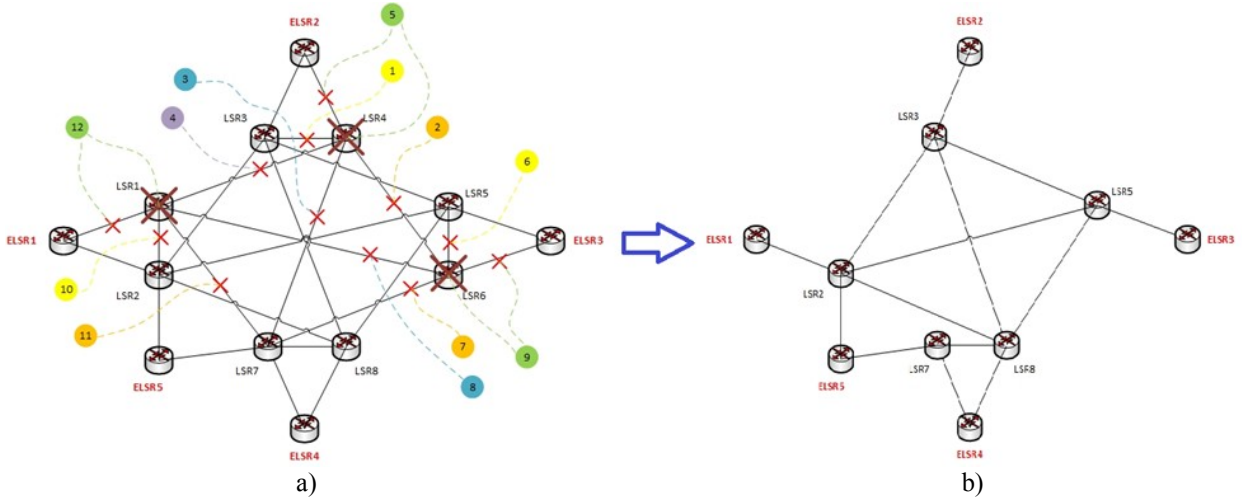
Fig. 5. Switching off scenario: a) switching off sequence; b) resulting topology.

newly defined path to the FEC that is linked to the corresponding destination; deletes the old path's LSP and disconnects the network elements in a predefined order. The sequence, in which the network elements are switched off, and the resulting topology are shown in Fig. 5. After each consecutive turning off, is the algorithm will verify whether the resulting network satisfies the predefined SLA parameters. For the current simulation, the latency and the packet loss values are considered. The latency is defined as the maximum delay from a provider edge router to another provider edge router and is determined to be ≤20ms. The packet loss is defined as the average percentage of lost packets over the simulation period. The packet loss is measured for every interface as the ratio between the transmitted packets and the dropped packets. The maximum packet loss value is set to 0.15%.

IV. RESULTS

The obtained results focus on two major points: the influence of the switch-off process on the network performance and the estimation of the achievable energy savings.

A. Network Performance Indicators

As a starting point for the evaluation, the initial network state parameters (maximum network utilization, the packet loss and the variations in the packet delay) are estimated. The maximum utilization scalar value is measured on every network interface. It should be noted that the values are chosen to be smaller than 80% as the core network is scaled to handle traffic bursts without degrading the SLA parameters, which corresponds to a realistic core network utilization scenario. The end-to-end delay parameter is examined, both, in terms of the maximum achieved scalar values and as a vector representation of the time variations of the delay. The maximum values are measured to be just under 16 ms, however, the majority of packets are observed to experience delay values lower than 8 ms. The occasionally higher values result from the bursty nature of the generated traffic. During

the initial network stage, no packet loss is measured on any of the network interfaces.

After the initial parameters have been established, the switch-off process is activated and the changes in the network performance are examined. At every switch off step, the packet loss and maximum delay values are verified. If the values are above the acceptable level (i.e., delay>20 ms, packet loss 0.15%), the amount of the generated traffic is reduced until the SLA-required performance gets restored. Finally, the achieved energy conservation under the predefined connectivity and SLA constraints is evaluated.

Fig. 6 shows the mean utilization vector line charts for the interfaces of three different core router nodes, labelled as LSRx. The interfaces of every node are denoted as LSRx.pppg[x]. Each line chart represents the variations of the mean utilization of the interfaces of a separate node as a function of time. Three separate nodes that undertake the rerouted traffic after switching off of network elements are selected for examination. As it can be expected, we can observe an occasional increase in the utilization of the operational router interfaces at the time points when a network element has been switched off. For example, at 10s, a new LSP is created between the LSR3 and LSR5 to accommodate for the additional traffic, rerouted from the path between LSR4 and LSR6. The link between these two points is then switched off. The chart indicates a steady rise in the mean utilization of LSR3.pppg[2] (Fig. 6a - green). At 15s, new LSP is created between LSR3 and LSR8 to account for the turning off of the link between LSR4 and LSR7. An increase in the utilization of LSR3.pppg[3] (Fig. 6a - blue) and LSR8.pppg[1] (Fig. 6c - green) was observed. At 25s, two LSPs in both directions are created between LSR5 and LSR8, which results in a untilization increase of LSR5.pppg[2] (Fig. 6b - blue) and LSR8.pppg [1] (Fig. 6 - green). The utilization increase, specific for every interface, is dependent on the random variations in the generated traffic and influences the routing decisions of the CSPF routing protocol, which define the creation of the new LSPs. Therefore, varying traffic patterns might result in rerouting the traffic through varying

alternative paths and the establishment of different LSPs to the ones mentioned above.

The major consequence from the increase in utilization of certain elements is degradation in the observed SLA parameters. An increase in the end-to-end delay values was detected at 15s or when the second network element is switched off. From Fig.6a it can be noticed that there is a decline in the network performance when the mean utilization of the link rises above 60%. At 20s, 25s and 30s, a further increase in the end-to-end delay values can be observed. In the current simulation, the packet loss parameter is controlled by varying the queue length in the core routers. Sufficient queue length was allowed to eliminate packet loss and the packet delay was examined as a key performance parameter [19].

B. Estimation of the Achieved Energy Efficiency

The achieved energy conservation is calculated as a ratio of the number of the switched-off elements versus the total number of network elements. Each switched-off node is accounted as 16.67 links. The ratio is derived from the energy consumption values for core network elements, discussed in [8]. The achieved energy savings versus the percentage reduction of traffic is shown in Fig. 7.

a)

b)

Fig. 6. Mean utilization vector: a) LSR3 b) LSR5 c) LSR8.
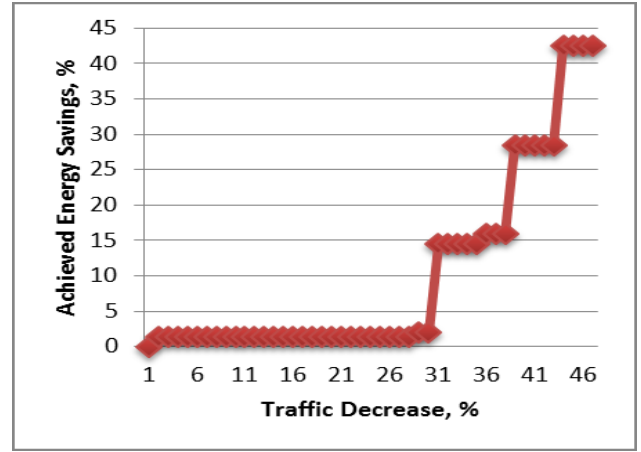
Fig. 7. Achievable energy savings chart.

Two main observations can be derived from the obtained results. Firstly, considerable energy savings can be obtained only from the switching off of entire network nodes. At the same time, the energy conservation obtained by powering off the network links is negligible. Secondly, a safe switching off can be performed after the traffic demand decreases by at least 33%.

The first network link that was turned off was the link between LSR3 and LSR4. This link is a redundant back up link, which is not utilized under normal operating conditions. Turning off this link naturally does not affect the network performance. The second link is an operational link between LSR4 and LSR6. The turning off does not affect severely the SLA parameters. The turning off of the third link (between LSR4 and LSR1) results in a high increase of the end-to-end delay value. The normal network performance is restored after the traffic decreases by more than 33%. Switching off of the subsequent network elements required much smaller decrease in generated traffic. An entire network node and the five links connected to it can be turned off at 34% decrease. The following two links can be turned off at 39% and the second node and the remaining connected links – at a decrease of 42% in traffic generation. The last possible third network node is safely turned off when the traffic decreases by at least 47%. The total achieved energy savings reach 42.52%.

V. CONCLUSION AND FUTURE WORK

An energy saving methodology, that is based on the resource consolidation and turning off of underutilized network elements, was proposed. The methodology focused on MPLS core networks, where the resource overprovisioning is considerable. The concept was based on the observation that the network utilization experiences considerable variations, based on time of the day, time of the week, etc. It was demonstrated that during the time intervals of low demand, it was possible to concentrate the traffic in a small subset of nodes or links, which allowed the unused nodes/links to be switched off. The paper proposed a centralized architecture, with an SDN controller and underlying MPLS enabled core routers. An algorithm for redirecting the traffic off the least utilized network elements, based on the MPLS TE engineering
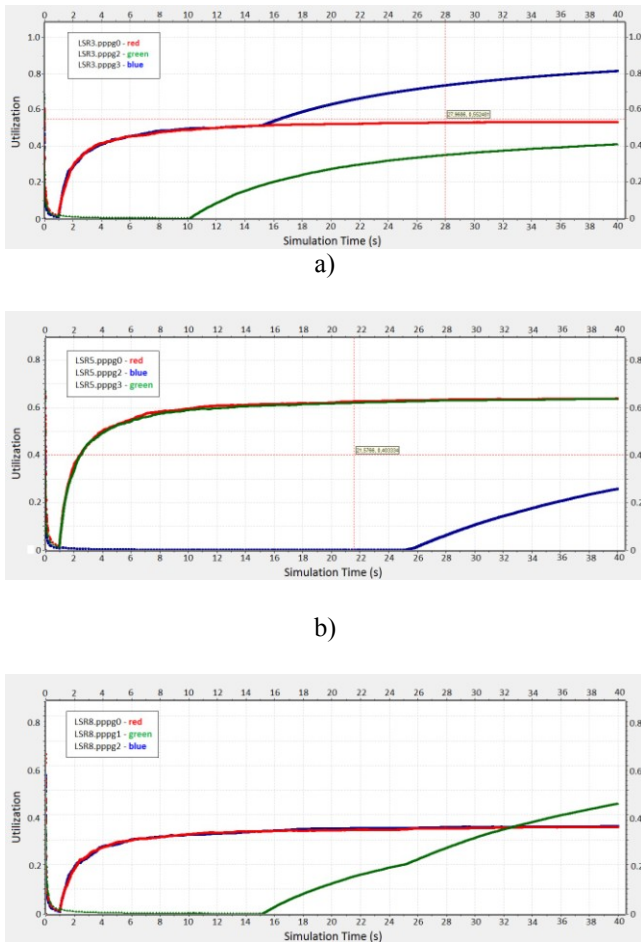
techniques, was proposed. Its performance was examined on a realistic network topology, based on the core network architecture of a national telecommunications services provider. It was demonstrated that the turning off procedure results in a degradation of the network performance in terms of latency and packet loss due to the increased utilization of some of the links. It was observed, however, that the proposed algorithm allowed the safely turning off of network elements without a loss of data packets due to the interface switch off. The performance of the algorithm was then evaluated in terms of the achieved energy conservation in accordance with a predefined connectivity and QoS constraints. The elements were iteratively switched off and the generated traffic was decreased until the SLA requirements were fulfilled. The results showed an achievable conservation of up to 45.52% when the traffic was decreased by 47%.

The performed experiment demonstrated that considerable energy savings are possible in the periods of low utilization. A better performance, however, can be achieved if the load balancing and the traffic distribution techniques are utilized when the traffic is rerouted off selected networks elements. That might be realized, for example, by implementing better routing techniques, such as the SDN application modules. Furthermore, fault recovery mechanisms in the case of a link or node failure will be examined in the planned future research.

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