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SDNRoute: Integrated System Supporting Routing in Software Defined Networks

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ABSTRACT

In this paper we introduce the SDNRoute system which aims to support routing decisions in Software Defined Networks. Such a system is especially important in the context of the SDN as this concept makes it possible to perform routing in a dynamic and elastic manner. We focus on the SDNRoute architecture and research challenges that must be investigated to develop the system. Additionally, we provide preliminary approaches to solve the issues including optimization problem formulation. Recent state of the art is presented regarding not only academia works but also industry deployments. It is especially important as SDNRoute system is being designed for the purpose of commercial application.

Keywords: SDN, routing support systems, traffic engineering, network optimization, traffic prediction.

1. INTRODUCTION

The SDNRoute system supports a routing process in Software Defined Networks (SDN). It periodically determines routing policies for each upcoming time window. Information originating from several sources is utilized in the system. First of all, this data concerns current state of the network provided by the SDN controller. Monitoring and measurement module will be responsible for collecting network statistics. Secondly, based on the historical data SDNRoute system predicts traffic matrices for the upcoming time window. Additional input will be acquired from network applications, such as cloud orchestration software or mobile network controller. All of the data will be an input to the optimization module responsible for performing essential optimization which results in routing policies. The aim of those policies is to reduce risk of network congestion and effectively utilize available network resources in the upcoming time window. Additionally, SDNRoute system creates an opportunity to reduce energy consumption of network infrastructure. Impact of routing policies is validated in a virtual environment emulating clients network. Policies may be provided to the network controller only in case of positive validation. Finally, an integrator module is considered as a central element of the system that integrates all of the remaining modules. The architecture of SDNRoute system and its placement in the SDN concept are both presented in Fig. 1.

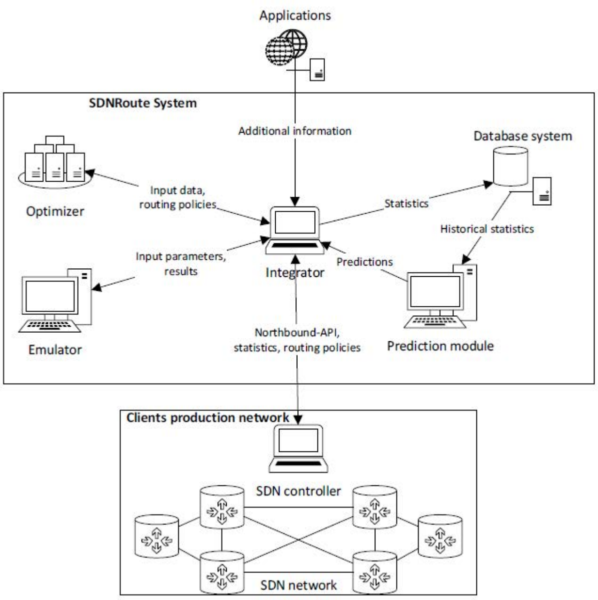

Figure 1. SDNRoute architecture.

The SDNRoute system is designed to take advantages of the SDN concept. Integration of numerous subsystems in SDNRoute solution enables efficient utilization of network resources. It improves attractiveness of SDN network and enables further innovations in the area of network optimization. SDNRoute system is designed to be deployed on the general purpose server. Modular architecture ensures scalability, flexibility and efficiency of the proposed solution.

2. RELATED WORK

Authors of [1] stated that variety of Internet applications with demanding requirements on latency and bandwidth require highly efficient network management enabled by the SDN concept and provided by the SDNRoute system. Heuristic optimization methods integrated with neural network paradigm are proposed in [2] as an approach to optimize Software Defined Networking. Selected concepts presented in the paper may be useful while designing heuristic algorithms for the optimization module of SDNRoute. Another valuable work proposes admission control mechanisms for unicast and multicast traffic aimed at maximizing throughput in Software Defined Network [3]. Traffic engineering is indicated as very important network application in the context of improving utilization of SDN infrastructure in work [4]. Authors focus on measurements, prediction and control

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solutions, neglecting optimization and emulation modules while much less attention is put to make solution deployable in production networks.

New industry concepts have been published since the project proposal was submitted. Packet Design proposed the SDN Management and Orchestration (MANO) Platform as a set of integrated, open and vendor-independent set of technologies to provide control of resources across wide area IP network [5]. Cisco developed Wide Area Network Automation Engine (WAE) to be the first Predictive Software Defined Networking Platform for WAN infrastructure [6]. Brocade developed Flow Optimizer application aimed at increasing network efficiency, improving resource utilization, mitigating network attacks and reducing network congestions [7]. The Flow Optimizer is designed for MPLS networks while SDNRoute is network technology agnostic.

3. RESEARCH CHALLENGES

This section contains main contribution of our work. Research challenges that have been thoroughly investigated in order to develop SDNRoute system are identified from the perspective of different system modules. Due to the limited space only selected problems are addressed while for some of them preliminary solutions are provided. Additionally, optimization model is proposed and first results are analyzed.

3.1 Monitoring and measurements module

First of all, traffic matrix between network nodes must be estimated. For this purpose, traffic generated by each network node must be measured with distinction per source and destination. Direct network measurements cover also load monitoring of each network link. The important problem of synchronization of statistics collected from different nodes is identified. Fuzzy logic approach is considered as a novel approach to the problem. Bloom Filters are considered as a tool to perform efficient and robust statistics gathering. It is an innovative approach that may improve overall system performance and reduce measurements overhead. Bloom filters may be used as an alternative to the existing tools, but also, can be utilized to select data flows that strongly impacts network performance and should be carefully monitored and measured (elephant flows). Another interesting approach regards optimization of node's forwarding tables with respect to the flows aggregation. It is considerably easier to collect counter values from a few aggregated entries and evaluate volume of the traffic in several groups, than query the switch for statistics of each separate flow entry. Already installed flows should be processed according to the policy active at the moment of their establishment to prevent flow disruption, while policies for new flows dynamically change in response to current network state. To achieve this, dedicated flow entry distribution algorithms have to be implemented in the OpenFlow controller. The algorithm should take advantage of the network equipment capabilities, like TCAMs which are expensive, energy consuming and their capacity is strongly limited.

3.2 Prediction module

Statistical methods are widely used to model and predict network traffic. Even if researchers reach for models combining few statistical components there are often limited to a single type of distribution, i.e., mixture of Gaussian distributions. Continued shift in mix of devices, applications and connections causes that traffic distribution is much more complex and more robust modelling methods should be applied. Introduction of a generalized mixture model seems to be an interesting research opportunity that may be considered as one of the method for traffic estimation and predictions. The determination of number of mixture components is usually trade-off with obtaining a flexible and appropriate underlying model and data over-fitting. Additionally, important research target is the influence of selected output parameters from prediction to the optimization procedure. At this moment it is not obvious which prediction parameters (i.e., mean, median, standard deviation, size and number of traffic peeks or all distribution parameters) should be used as an input for optimization.

3.3 Security issues

Analyzing the SDNRoute architecture, it can be concluded that the object most exposed to threats and attacks is the external interface that allows applications to contact the SDN controller. However, we should allow applications to control network resources (to ensure adequate quality of service and adapting network resources to the expected requirements). To enable secure communication between SDNRoute system and external applications, the interface will support the crucial security services: authentication (proof of identity), authorization (access control), data confidentiality (limit access to information) and integrity (assurance of data accuracy). Also, the interface should support non-repudiation method, avoiding that network operator can disown responsibility for his actions. Additionally, the secured interface should protect network operators against leakage of private information (i.e. communication between application and SDNRoute should not show the sensitive information about current status of operator's business). Two additional security modules are considered as an innovative contribution. First module to analyze the risk associated with requests from external applications. The module should determine the risk involving the rebuilding routing policy in the network. Reputation system monitors and dynamically evaluates the level of trust for each application/operator based on the current and past behaviors. Second module will be able to detect and prevent against DoS/DDoS ((Distributed) Denial of Service) attacks based on the active flows identification (five-tuple) and historical data.

3.4 Optimization module

Here, we present the initial optimization task and all its options. We follow book [8] and formulate the problem of node-link type. Thus, the obtained results are easier to be used if the switching decision for a new flow is performed separately in each switch on the flow path; also, it is easier to organize the weighted load balancing.

Indices and sets

$v = 1, 2,..., V$	nodes in the network;
$d = 1, 2,..., D$	demand flows between pair of nodes;
$e = 1, 2,..., E$	network interfaces (network arcs);
$k = 1, 2,..., K$	linear segment to approximate a convex link delay function of the link load;

Continuous non-negative variables

x_{ed}	amount of flow satisfying demand d on arc e;
y_e	total load allocated in link e to serve existing and new demands;
y_{sum}	total usage of resources;
w_e	utilization of capacity in link e;
w_{max}	max value over all link capacity utilities;
z_e	delay of packets transmitted via link e;
z_{max}	max value over all the link delays;
z_{sum}	summarized link delays;
n	total usage of energy in the network;

Constants

a_{ev}	= 1 if arc e starts in node v; 0 otherwise;
b_{ev}	= 1 if arc e finishes in node v; 0 otherwise
s_d	source node of demand d;
t_d	destination node of demand $d;$
h_d	predicted volume of new flow demand d;
r_e	traffic load already present in link e;
c_e	capacity of link e;
ξ_e	fixed unit cost of energy on link e;
κ_e	energy cost of switching on for link e;
f_{ek}	slope of the k-th linear segment approx. a convex delay function of link e load;
g_{ek}	constant term of the k-th linear segment approx. a conv. delay fun. of link e load;
p	energy budget affordable for the network;

Binary variables

u_e	= 1 if e will be switched on; 0 otherwise;

Constraints

$$\sum_e a_{ev} x_{ed} - \sum_e b_{ev} x_{ed} = \begin{Bmatrix} h_d & \text{if } v = s_d \\ 0 & \text{if } v \neq s_d \\ -h_d & \text{if } v = t_d \end{Bmatrix}, v \neq t_d \quad d = 1,2,\ldots,D \quad v = 1,2,\ldots,V \tag{1}$$

$$y_e = r_e + \sum_d x_{ed} \quad e = 1,2,\ldots,E \tag{2}$$

$$y_{sum} = \sum_e y_e \tag{3}$$

$$w_e = \frac{y_e}{c_e} \quad e = 1,2,\ldots,E \tag{4}$$

$$w_{\max} \geq w_e \quad e = 1,2,\ldots,E \tag{5}$$

$$z_e \geq f_{ek} y_{ek} + g_{ek} \quad e = 1,2,\ldots,E \quad k = 1,2,\ldots,K \tag{6}$$

$$z_{sum} = \sum_e z_e \tag{7}$$

$$z_{\max} \geq z_e \quad e = 1,2,\ldots,E \tag{8}$$

$$w_e \leq u_e \quad e = 1,2,\ldots,E \tag{9}$$

$$n = \sum_e \kappa_e u_e + \sum_e \xi_e y_e \tag{10}$$

$$n \leq p \tag{11}$$

Equation (1) represents the basic constraints that enforce the flow conservation in intermediary nodes and meeting the demand from the viewpoint of the source and destination nodes. Equation (2) is the links constraint used to find the total traffic sent via links. According to Eq. (3) the summation of all the traffic loads in the network provides the value of the total resource usage. Link utilization is found in Eq. (4) as fraction of the capacity available in the link burdened with the traffic load. The maximum value of the utilities is determined according to Eq. (5).

In the packet networks with statistical multiplexing the larger is link utilization, the larger delays are experienced by packets. We decided to cover this aspect in order to introduce quality improvements to the system. We use a model based on the M/M/1 queue to map the traffic loads to the link delays (see [8]). The model approximates the delay with the linear segments according to Eq. (6). We can use a standard linearization procedure without necessity of applying non-continuous variables as the convexity of the problem is not disturbed. Equations (7) and (8) determine the summarized and maximum delays, respectively.

Non-continuous variables represent the decision to switch on some links in the network. Equation (9) enforces that the link must be switched on if only some traffic is going to be sent through it, Eq. (10) finds the total energy usage cost based on the costs of switching the links on and the variable cost of traffic transfers. The energy usage is limited by the budget as determined by Eq. (11).

There are five different options we can apply for the goal functions, dependent on our main goal and the assumed Key Performance Indicators: min n, min z_{max}, min w_{max}, min y_{sum}, min z_{sum} .

Note that the first goal may lead to switching on as few links as possible which results in increased calculation times. If the cost κ_e is substantial in comparison to the relative linear cost of energy usage per traffic unit (ξ_e/c_e)

this goal function ensures the optimal solutions constructed as close to a tree topology. As energy usage is not in line with the other goal functions we are going to deal with poly-optimization issue in future work.

Our aim is to verify if we can obtain results using free solvers in the SDNRoute system. The IBM ILOG CPLEX, a commercial software, is used for reference. We have considered the CBC solution with respect to the optimization problem solution times. We tested the optimization problem solution on three different networks retrieved from the SNDLib library. The following networks were used: polska ($V = 12, E = 18, D = 132$), nobel-eu ($V = 28, E = 41, D = 756$), and germany50 ($V = 50, E = 80, D = 1324$). The results are shown in Fig. 2. The most important conclusions are that even calculations with CBC last at least one order more comparing to the CPLEX, they are still limited in the time frames that are acceptable from the viewpoint of the SDNRoute system. In one case, for the largest network, CBC solver cannot obtain optimal solution in the reasonable time. However CBC is very flexible and customizable, so its performance can be improved by using adjusted resolving strategy.

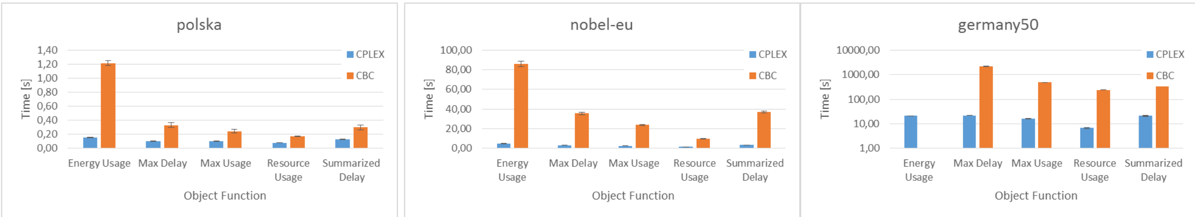

Figure 2. Comparison of the results for different goal functions and networks.

Flow-Aware Multi-Topology Adaptive Routing (FAMTAR) is a new multipath adaptive routing mechanism introduced in [9] that works based on the currently popular concept of flows and is responsible for finding new paths in case of congestion. Despite using offline optimization in SDNRoute congestions cannot be eliminated totally. Congestions can occur when: (i) the predicted traffic will be different from the actual one, (ii) the optimization will not be able to yield a result sufficient to carry the traffic, (iii) nodes or links fail. FAMTAR in the SDNRoute is invoked only when required. This is an interesting research problem to join static and dynamic optimization to improve SDN network performance. Network management optimization aims at not allowing congestions to happen. If they do, however, FAMTAR helps to deal with the negative effects.

4. CONCLUSIONS

In the paper we presented our concept of the predictive routing support system for the SDN controller. Routing policies, prepared by the system, address future requests is an innovative feature. Numerous input data streams will be taken into account during optimization process what will result in more efficient network resource utilization and load balancing over the whole infrastructure. Savings in terms of energy consumption are an additional feature of the proposed system. In the paper we presented selected research challenges and proposed solutions. Especially, optimization model with preliminary results was considered. The system advantages are crucial from the operators point of view as they will allow to handle more traffic and improve quality of service offered to applications. These two factors have direct impact on operators incomes.

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