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A Method of Data Distribution in Overlay Networks

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Original Research Article

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Abstract: The main principles and mechanisms of data transmitting in overlay network are defined in the work. The different traffic engineering mechanisms that took place in the process of data flow management are analyzed. Regarding the obtained results, the method of data distribution is proposed in the paper. The main feature of proposed method is the ability to analyze the aggregate type of traffic – priority and non-priority data flow. The ability to use the residual computing resources for non-priority data flows in this case based on weight coefficient. The using of residual channel resources give the ability to smooth the data between channels of the overlay network. The program realization of developed data distribution method is proposed as a result.
Keywords: overlay network, data intensity, distribution, direct route, optimization function.

INTRODUCTION

Modern global network infrastructure is a complex heterogeneous system with the continuous process of evolution [1]. However, it is a complex task for the service provider to follow the rapidly changing technologies of service provision. Service providers faced with many problems during the modernization of network infrastructure and control mechanisms [2, 3]. The problems connected with both development process (difference in software and hardware functionality of network equipment lead to failure in network infrastructure work) and economic profitability. The application of different overlay network techniques is gain a big popularity today. Such techniques give the ability to organize the networks with flexible functionality and guaranty level quality of services without the additional considerable expense. In general, overlay network is a virtual network organized over the existing physical infrastructure and supported or build on standard network protocols [4].

The network data distribution mechanisms at the overlay network do not affect the traditional routing protocols operating at the lower levels, avoiding an extremely undesirable procedure for modifying existing principles [5]. Two main goals is achieved by deploying of overlay network: the virtual network topology is constructed with implementation arbitrary (for example, multipath) routing mechanisms while the physical network continues to be controlled by traditional protocols that use their own routing mechanisms, for example, shortest path; the interaction of network nodes participating is organized by special centralized management mechanisms [6].

The description of the model of the traffic engineering based on overlay network (Overlay TE) was first presented in [7, 8] and indicated the possibility of using virtual channels for routing traffic, independent of the topology of the real transport network. One of the first developments for IP-based networks is the Resilient Overlay Networks (RON) architecture [4]. RON is designed to provide fault-tolerant routing of end nodes over a wide area network and is able to find paths between its own networks nodes in case when no direct BGP routes between them. Increased network connectivity compared to traditional network architecture, evaluation of channel utilization, as well as a shorter time for the convergence of the search process routes compared to the BGP protocol the advantage of RON. The main disadvantage is a lack of support for multi-path routing.

The Distributed Adaptive Coordinated Resource Management (DACoRM) protocol [9] uses the information about the distributed network of nodes for the development and coordination of actions for managing network traffic.

The DACoRM protocol, unlike RON, allows balancing MTR (multi-topology routing). The main disadvantage of DACoRM is the lack of the ability to automatically an overlay network generation. It is assumed that the overlay manager is configured manually before network exploitation.

The poor scalability caused by quadratic increasing the amount of service traffic with an increase in the number of nodes participating in the overlay and, as a consequence, loss of efficiency of the distributed control system should be matched as general disadvantages of data distributed protocols in overlay networks [10]. Thus, the solution of the task of developing methods that allow more efficient usage the capabilities of the existing network infrastructure is relevant. A method of dynamic traffic balancing in an overlay network with the ability to account for aggregated data flows is proposed in the paper.

Overviews of data distribution mechanisms functionality in overlay network

All network nodes that take a part in network infrastructure functionality during services provision are divided into logical groups. Nodes belonged to one group are organized into overlay network, the main task in overlay network is effectively data distribution between involved nodes. The structure of overlay network is shown in Figure 1.

The overlay network is decentralized network with dynamical data management the behavior between group of nodes including the connection and disconnection of new nodes. Traffic management functions are distributed among all nodes participating in the superimposed network. The main tasks performed by the nodes of the overlay network can be divided as follows [1, 2]:

- Overlay network management procedures. These procedures include the new node connection to the existing network, service information exchange, automatic activation and deactivation of nodes, detection channel and nodes failures.
- Overlay network status monitoring procedures. These procedures include network characteristics definition, monitoring the current load of channels, estimate the current number of incoming streams,
- Data forwarding and distribution management. These procedures include forecasting of incoming load, control the intensity of the incoming load, calculation of the data distribution for single and aggregation flows.

In proposed data distribution method assumed that some of the incoming user non-priority data flows can be redirect to reserved channels or returned to the direct route in the case of total load reducing. The algorithm of Edmonds-Karp [11] is put to the basic of proposed method. The optimization function for data distribution is determined by next rule:

$$\theta(D^{IN} ,\{ R_1 ,R_2 ,...,R_n \}) \to \max_{CP_\alpha} , \tag{1}$$

where $\theta()$ is optimization function, D^{IN} is intensity of data in overlay network, $R_1 ,R_2 ,...,R_n$ is chosen nodes that create a route of data transmission, CP_α is control data distribution policy. The end goal of traffic distribution task can be represent as:

$$D^{IN} \to \max_{CP_\alpha} | R_1 ,R_2 ,...,R_n . \tag{2}$$

The choice of data distribution route is achieved from equation (2). The routes for data distribution are ranged regarding to the next principle: less priority data forward to the route with less quality characteristics.

The next steps are involved in proposed method:

- The overlay network status monitoring procedures are executed.
- Regarding to the obtained on step 1 information the links between the nodes of overlay network are determined. The information about topology represent as matrix.

The next rules are used for matrix generation: if connection between nodes exist the value of cell corresponded interception of link matched as 1, if connection is not exist the value of cell matched as 0. Only the routes with value 1 are analyzed on the next steps of proposed method.

- The incoming data flow divided to priority (d^{p}) and non-priority (d^{np}) data regarding to the information of ToS field. The connection between nodes i and j for priority data id determines as $d_{ij}{}^{p}$, for non-priority - $d_{ij}{}^{np}$.

In this way, the value of priority data transmitted between nodes i and j on the direct (shortest) path determines as follow:

$$d_{ij}{}^{out-p}(t_U)=d_{ij}{}^{p}(t_U),\forall j=0,...,n\,|\,j\neq i\,, \tag{3}$$

where t_U is a current period of time.

- Calculation the data distribution according to the available channels resources. The total residual channel resources available to the *i*-th node for transmission of non-priority traffic to a certain j-th node can be expressed as follows:

$$f_{resij}(t_U)=\frac{f_{dir}(t_U)}{2}+\sum_{k\neq i,j} min\left\{\frac{f_{resik}(t_U)}{2};\frac{f_{reskj}(t_U)}{2n-4}\right\},\forall k=0,...,n\,|\,k\neq i,j, \tag{4}$$

where $f_{dir}(t_U)$ is value of direct route in time t_U, $f_{resik}(t_U)$ is residual channel resource at a time t_U.

Initially, the available channel resources of direct route are used for data transmission. In the case when resources of direct route are exhausted the data start to distributed through alternative reserved route. The maximal intensity of non-priority traffic ($d_{ij}{}^{out-np}(t_U)$) transmitted between *i*-th node and *j*-th node can be calculate as follows:

$$d_{ij}{}^{out-np}(t_U)=\begin{cases} d_{ij}{}^{np}(t_U),\ if\ d_{ij}{}^{np}(t_U)<\dfrac{f_{resij}(t_U)}{2}; \\ \dfrac{f_{resij}(t_U)}{2},at\ another\ case. \end{cases} \tag{5}$$

For each reserved channel that can be created between *i*-th node and *k*-th node or between *k*-th node and *j*-th node will be forwarded the next value of incoming data:

$$d_{ij}{}^{out-np}(t_U,k)=\frac{min\left\{\frac{f_{resij}(t_U)}{2};\frac{f_{resij}(t_U)}{2n-4}\right\}}{\sum\limits_{k\neq i,j} min\left\{\frac{f_{resij}(t_U)}{2};\frac{f_{resij}(t_U)}{2n-4}\right\}} I\left[d_{ij}^{np}(t_U)-\frac{f_{resij}(t_U)}{2}\right],\forall k\neq i,j, \tag{6}$$

where $I\left[d_{ij}^{np}(t_U)-\dfrac{f_{resij}(t_U)}{2}\right]$ is the filtration function.

- Calculation the common amount of priority and non-priority data that can be transmitted on reserved route can calculated as follow:

$$D_{ij}{}^{np}(t_U)=d_{ij}{}^{np}(t_U)+\sum_{k\neq i,j} d_{ik}{}^{np}(t_U,k)+\sum_{k\neq i,j} d_{kj}{}^{np}(t_U,k). \tag{7}$$

The common amount of data that can be distribute through channel between *i*-th node and *j*-th node can be calculated as follows:

$$D_{ij}^{\,p+np}(t_U)=\frac{d_{ij}^{\,p}(t_U)+D_{ij}^{\,np}(t_U)}{min\,\lambda_{ij}^{th}}, \tag{8}$$

where λ_{ij}^{th} is threshold value of channel.

The equation (8) give ability to evaluate the maximal overlay channels load and take into account the priority data as well as non-priority. The equation is adopted to the aggregation data flow.

Evaluation of the probability of data intensities distribution

Tracing individual data flows is a rather complex and resource-intensive task, and it is possible to simplify considerably the calculations using various approximations. As shown by numerous studies [86], devoted to the analysis of traffic of modern networks, the distribution of traffic intensity by separate flows is rather heterogeneous.

The high degree of heterogeneity, this is manifested in the case of considering the data flows on the transport layer. Ignoring the uneven distribution of the load can lead to incorrect decisions during rebalancing, which in turn can cause instability and low efficiency of the overlay network. A possible solution to this problem is to estimate the probability of data intensities distribution, which allows calculating the mathematical expectation of the load $E[D_i^{IN}]$ that is randomly generated by selected single data flow.

In this case, the total intensity of the aggregated flow should asymptotically approach the product the number of its constituent flows to the obtained value of the mathematical expectation $\sum_{i=1}^{n} E[D_i^{IN}]$. The obtained value of mathematical expectation as precise as much the amount of single flows into aggregation flow.

Approximating the measurement results by continuous probabilistic distributions give ability to determine the value of the mathematical expectation the intensity of a randomly selected stream for the current situation on the network.

Another approach can be implemented in case when the information about the current number of incoming data flows is available $N_i(t_U)=\sum_{\forall j\neq i} N(t_U,i,j)$. The evaluation of mathematical expectation is determined by the following simple expression:

$$E[D_i^{IN}]=\frac{\sum_{\forall j\neq i} d_{ij}^{\,np}(t_U)}{N_i(t_U)}, \tag{9}$$

After determining the value of the mathematical expectation of the random data flow intensity, the node can calculate the general data distribution.

Denote the number of single flows that included the aggregated non-priority traffic $\sum_{\forall j\neq i} d_{ij}^{\,np}(t_U)$ flow that follow the direct route between *i*-th node and *j*-th node as $R_{d(ij)}(t_U)$ and the number of single flows that included the aggregated non-priority traffic flow that follow the reserved route as $R_{d(ij)}(t_U,k)$. Where:

$$R_{d(ij)}(t_s)=\frac{d_{ij}^{\,np}(t_U)}{E[D_i^{IN}]}, \tag{10}$$

$$R_{d(ij)}(t_s,k)=\frac{d_{ij}^{np}(t_U,k)}{E[D_i^{IN}]}. \quad (11)$$

Experimental result

The software simulator that gives ability to analyze the overlay network behavior and investigate the data distribution was created for evaluation the effectivity of proposed method of data distribution in overlay network. The main phrases included in proposed simulator are depicted in Figure 1.

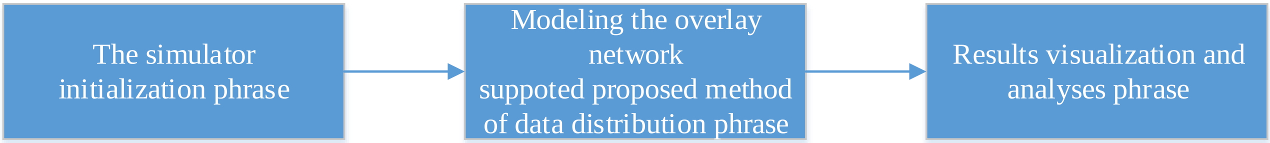

Fig-1: Modeling of overlay network operation

Initialization phrase. The simulation is initialized using a set of initial data that defines the external conditions of operation. The overlay network objects and links to the network object containing current node are defined on this phrase.

The next part of simulator realization corresponds to this phrase:

```
# Network initialization
set.network = network
# Current node ID
set.node_id = node_id
# Total number of nodes in overlay
set.num_nodes = num_nodes
# Neighbour links bandwidths and neighbour links threshold values
set.band_threshold = b_thresh
# Difine the Network topology
set.isActive = 1
set.nodes_activity = np.ones(num_nodes)
# Difine the number of flows
# Total number of priority data flows
set.flow_IN_p = p.zeros(num_nodes)
set.flow_p_intensity_expected = p.zeros(num_nodes)
set.flow_OUT_rough = p.zeros([num_nodes, num_nodes])
set.flow_OUT_precise = p.zeros([num_nodes, num_nodes])
set.flow_OUT_change = p.zeros([num_nodes, num_nodes])
# Total number of nonpriority data flows
set.flow_IN_np = np.zeros(num_nodes)
set.flow_np_intensity_expected = np.zeros(num_nodes)
set.flow_OUT_rough = np.zeros([num_nodes, num_nodes])
set.flow_OUT_precise = np.zeros([num_nodes, num_nodes])
set.flow_OUT_change = np.zeros([num_nodes, num_nodes])
# Number of flows to be remapped. Finalized precise estimation
# Flow control parameters
# Data distribution desition
# Matrix of residual channel resources
set.chan_resource = np.zeros([num_nodes, num_nodes])
def expSmoothing(set, alpha, x_current, s_previous):
'''N-N model, used for forecasts'''
s_current = alpha * x_current + (1 - alpha) * s_previous
return s_current
…
```

When all objects of overlay network are created the simulator proceeds to the second stage of the work. At this stage, the numerical simulation of network operation under given conditions is performed. The second stage is the calculation of the behavior of each node of overlay network during predefined time (t_U).

```
# Simulation process
sim_parameters = dict(useActualData=args.useActual, update_period=args.u,
forecast_opt_period=args.fper, forecast_opt_interval=args.fint)
network.simulate(**sim_parameters)
…
# Modeling time array
set.time_array = time_array
…
# Current real channel resources
for i in xrange(set.num_nodes):
for j in xrange(set.num_nodes):
if i != j:
res = set.b_threshold[i, j] - set.load_IN_p[i,
time_pointer, j]
# Filtering function
if res < 0:
res = 0
ch_resource_theor[i, j] = res
# Calculate maximal theoretical incoming nonpriority load
for i in xrange(set.num_nodes):
for j in xrange(set.num_nodes):
if i != j:
f_res_alt_sum, extra_load = 0, 0
# Summary channel resource of roundabout paths to jth
node
# (shortest path k=j, i.e. j-th array element, does
no contribution, because ch_resource[k=j,j] = 0)
f_res_alt_sum = np.sum([min(ch_resource_theor[i, k] /
2, ch_resource_theor[k, j] / (2 * set.num_nodes - 4)) for k in
xrange(set.num_nodes) if k != i and k != j])
…
# Maximum nonpriority traffic load through current node
max_np_load_theor[i, j] = ch_resource_theor[i, j] / 2
+ f_res_alt_sum
# Calculate passed and dropped loads for ideal network case
for i in xrange(set.num_nodes):
for j in xrange(set.num_nodes):
if i != j and set.nodes[i].isActive:
# Incoming traffic load passed into node
set.nodes[i].load_IN_passed_p_theor[j] =
min(set.load_IN_p[i, time_pointer, j], set.b_threshold[i, j])
set.nodes[i].load_IN_passed_np_theor[j] =
min(set.load_IN_np[i, time_pointer, j], max_np_load_theor[i, j])
# Incoming traffic load dropped
set.nodes[i].load_IN_dropped_p_theor[j] =
set.load_IN_p[i, time_pointer, j] - set.nodes[i].load_IN_passed_p_theor[j]
set.nodes[i].load_IN_dropped_np_theor[j] =
set.load_IN_np[i, time_pointer, j] - set.nodes[i].load_IN_passed_np_theor[j]
def getUpdates(set, node_id, update_message, activity):
''' Receive UPDATE messages from nodes and organize it into full
resources view (square matrix)
'''
set.ch_resource[node_id] = update_message
```

```
set.nodes_activity[node_id] = activity
…
# Virtual links utilization in LBO
for i in xrange(set.num_nodes):
for j in xrange(set.num_nodes):
if j != i:
set.link_util_LBO[time_pointer, i, j] =
(nodes[i].load_OUT_p[j] + np.sum([(nodes[i].flow_OUT_precise[k, j] *
nodes[i].flow_np_intensity_expected[k]) for k in xrange(set.num_nodes)]) +\
np.sum([(nodes[k].flow_OUT_precise[j, i] *
nodes[k].flow_np_intensity_expected[j]) for k in xrange(set.num_nodes) if k != I and k != j])) /
nodes[i].band_threshold[j]
```

The overlay network that include six nodes was used for experiment. The route between node 0 and node 1 is overloaded. The time interval t_U is establish in 10 second. The time rows set were used for simulate the incoming traffic for node 0 overload. The plots corresponded to incoming intensity of data for node 0 is shown in Figure 2.

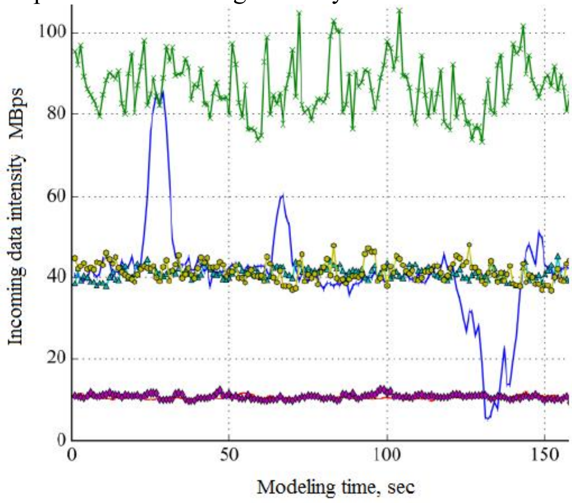

Fig-2: Incoming data intensity for each nodes of overlay network

The results of data distribution in overlay network without application of proposed method and with proposed method are represented in Figure 3.

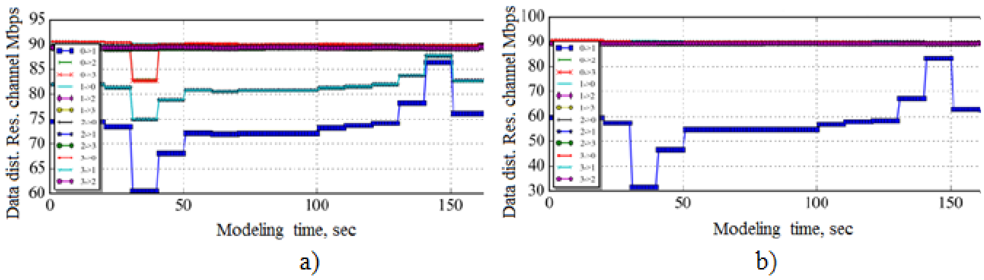

Fig-3: Data distribution between nodes of overlay network: proposed method application (a); without proposed method (b)

The results of the experiment show that under conditions of dynamic loads, both priority and non-priority incoming traffic, overlay network using the proposed algorithm is capable of transmitting traffic of higher intensity than a similar network without using this algorithm [13]. The explosive dynamics of incoming priority traffic negatively affects the performance of a conventional network, smoothing the bandwidth execution of an overlay node channel to 10-11%. The dynamic changes of the intensity of incoming data are significantly reflecting to the picture of the distribution of residual channel resources: the non-priority data with proposed method implementation are distributed between possible residual channels. The application of proposed method give ability to increase the effectivity of data transmission on 23%.

CONCLUSION

The concept of overlay network functionality are analyzed in the work. According to the main management and monitoring procedures used in overlay network proposed the method of data distribution. The proposed based on separation the incoming data on priority and non-priority. The decision about data distribution (routing) and route chose based on calculation the available channel resources for data transmission. The method gives ability to avoid channel overload due to flexible resources distribution and restriction of residual channels using. The proposed methods can be used for manage the single data flows as well as aggregation data flows.

The software simulator for modeling the overlay network that supported proposed method of data distribution was created. Analyze of result of experiment shows that proposed method allows to increase the effectivity of data transmission on 23%.

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