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The Process of Network Flows Distribution based on Traffic Engineering Method

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ABSTRACT

The article investigates the process of optimization of network flow distribution based on the traffic engineering method. This method allows the use of separate measurement paths, reducing the likelihood of the overflow of measuring structures. Traffic engineering was considered and investigated by using a math model. The features that used alternative paths under the conditions of failure in the information transmission channel are presented. It is emphasized that providers cannot rely solely on routing protocols. Some paths will be overwhelming, while others will be idle. For the load balancing, a set of two or more nodes can be used to route between two endpoints, taking into account aggregate traffic needs.

Key words: router, local network, traffic engineering, mathematical model, flow, configuration, protocol.

1. INTRODUCTION

High bandwidth and low latency have always been the main requirements for LAN technologies. However, the current state of the telecommunications services market has changed rapidly. It is not enough for an ISP to simply provide access to its IP backbone. User needs have changed.

Today, access to integrated network services, virtual private networking (VPN), and access to a range of smart services are relevant. In modern networks, compared to classic networks, the description of traffic is significantly complicated by some factors, such as a large variety of network configurations, a wide range of transmission speeds, significant static nature of information flows, etc [1]. The term Traffic Engineering refers to the methods and mechanisms for the balanced loading of all resources of a computer network by rationally choosing the route of traffic on the local network. The traffic management mechanism allows users to set the optimal route for all data flows between nodes [2].

1.1 Literature analysis and problem statement

[1] The engineering synthesis variant of the telecommunication network, which is the combined process of combining different math methods is presented. All significant network performance indicators including economic and constructive were described.

However, in [2] the authors give a detailed analysis of various problems that appear in the network. Especially when vendors and providers need to separate flows by different features.

The article [3] consists of the researches of parameter optimization for telecommunication networks. If the topology of the network does not change, it is possible to set forth the optimization task of the line carrying capacity. Such tasks can be changed by the provider. But only the theoretical part of the question is considered.

In [4] the development results of a selection method for the composite radioisotope coatings parameters and determining their reflective properties in a wide frequency range are presented. Parameters necessary for calculating reflective properties are indicated. The basic design relationships for evaluating the reflective properties of the objects with a large-scale distribution are given and can be used.

The authors in [5] propose a method to identify structural properties of multicast network configurations, by decomposing networks into regions through which the same information flows. This decomposition allows users to show that different networks are equivalent from a coding point of view and offers a means to identify such equivalence classes. It also allows providers to divide the network coding problem into two almost independent tasks: one of graph theory and the other of classical channel coding theory. This approach to network coding enables users to derive the smallest code alphabet size sufficient to code any network configuration with two sources as a function of the number of receivers in the network.

The paper [6] shows MPLS. This technology not only guarantees the quality of service of IP networks but in addition to provides scope for traffic engineering it offers many enhanced features of IP networks as it does not replace IP routing, but works along with existing and future routing technologies to provide high-speed data forwarding between label-switched routers together with QoS.

In this [7] article, a novel approach is considered, based on Particle Swarm Optimization technique. The general idea behind using dynamic neighborhood topology is to overcome premature convergence of the PSO algorithm, by well exploring and exploiting the search space for a better solution quality. Parallel computation is used to accelerate calculations, especially for complex optimization problems. The simulation results demonstrate the performance of the proposed algorithm in solving a series of significant benchmark test functions.

The report [8] provides broader information about IP technology and routing protocols. Internet architecture and problems in IP networks are illustrated when different internet protocols are used. The small focus is providing on the demand-oriented real-time applications and data traffic for QoS parameters in IP network. Evaluation of QoS guarantee parameters such as delay, jitter, and throughput are described with state of art study results mainly for real-time applications in IP network. Finally, traffic engineering implementation and working is described and proposed to achieve better network performance.

[9] The problem of forecasting network traffic in TCP/IP networks based on statistical observational data. It’s determined that existing protocols don’t provide long-term forecasting, which is necessary for network upgrades. The model of a forecast of network traffic taking into account features of accumulation of statistical data: the presence of a priori trajectories, a posteriori character of forecasting, finiteness of variance.

The research made in [10] based on QoS methods. It’s considered in solving many practical problems involving differential equations. Therefore, it is necessary to investigate the methods of hidden removal of information in high-speed networks.

The article [11] consists information about method of encoding data. The proposed methodology can provide specific level of security for sensitive information, banking transaction and e-commercial. But only the theoretical part of the question is considered.

So, the problem of optimization of network flow distribution based on traffic engineering method is important and relevant. In spite of application this method it is strictly important to calculate the main statistical parameters of network elements, such as routers. Therefore, traffic engineering can route the packets through explicit paths to optimize network resource utilization and traffic performance.

1.2 The aim of research

In traditional routing, IP traffic is routed through the transmission from one point to another, namely from the sender to the recipient. This does not always take into account the lowest aggregate metric of the network layer.

It should be noted that if there are several equivalent alternative paths, the traffic is divided between them. This makes the load on the channels and routers more balanced. But if the routes are not fully equal, there is no traffic distribution between them.

Another major disadvantage of the traditional methods of routing traffic on IP networks is that routes are selected without taking into account the current load of network resources. Even if the shortest route is already congested, the packets will still be transmitted over certain routes. Existed redundancy effects on that some devices on the network are overloaded and others are not used at all. The basic QoS methods will not solve this problem. It is necessary to introduce qualitatively new mechanisms. Especially if the design concerns state-owned entities or corporate networks that transmit sensitive data. Therefore, traffic management techniques are a relevant issue today.

2. THE MAIN SECTION

Traffic engineering allows providers to emulate the user's local network capabilities. Traffic engineering allows the user to control individual network routes, reducing the likelihood of the overflow and increasing the cost of transmitting IP traffic over the LAN.

The purpose of traffic engineering is to maximize the use of all network resources. Typically, IP networks have many alternative routes that take traffic to their destination. If the users rely solely on routing protocols, some routes will be overflowed, while others will be idle [3].

Traffic Engineering: creates a single approach that allows optimization of IP traffic routing, taking into account the constraints imposed by the capacity and topology of the network backbone; the routes flow through the network, taking into account available network resources; uses constrained routing, that is, chooses the shortest route that meets traffic flow requirements (traffic restrictions) to transmit traffic; recognizes network failures and failures that change the network topology and adapts to a new set of constraints.

The physical nature of the large ranges of change in the characteristics of random bitstream transmission processes is largely due to the irregularity of the source information generation. The advent of new network technologies has led to the emergence of new terminals that provide multimedia telecommunications, broadband access services, delivery time guarantee services, etc [4, 6].

2.1 Analysis and modeling of network flows

Traffic engineering allows the provider to connect to the user's network on time. Also, the provider is able to remotely control the bandwidth of channels and the time delay. This is achieved through the classification of data and the transmission of these data on routes that meet the requirements of inbound and outbound traffic.

It should be noted that traffic engineering works only with Link State Routing Protocols and does not work with Distance Vector Routing Protocols.

To solve the TE problem, new types of announcements are included in the protocols to distribute nominal and non-redundant (available for TE flows) bandwidth [5]. It is necessary to simulate the situation. Let's say that the user needs to send information from the network from R1 to R7. Figure 1 shows a process that automatically works across all networks.

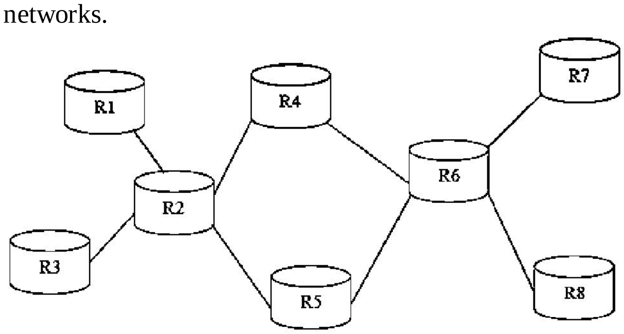

Figure 1: Normal data channel

To simplify the optimization task, the choice of paths for a given set of threads can be performed in turn, with the limitation being a total load of each network resource. Typically, for a local extension network, the performance of a single router will be sufficient to handle any traffic.

However, in comparison, the provider can maximize the number of downloaded channels that are used individually or are important. In the event of a channel failure between R2 and R4, the traffic engineer determines that the channel is not working and immediately transmits all data to the backup route via {R2, R5, R6} to R7. It is important to remember that traffic with labels transmitted to the backup channel must necessarily reach the router connected to the other end of the secure channel.

In Figure 2, the traffic is transmitted over the backup channel. The channel protection mechanism is also running. The network is aware of the crash and takes steps to find the best route. After the channel is restored, the original route will be restored with optimization timers.

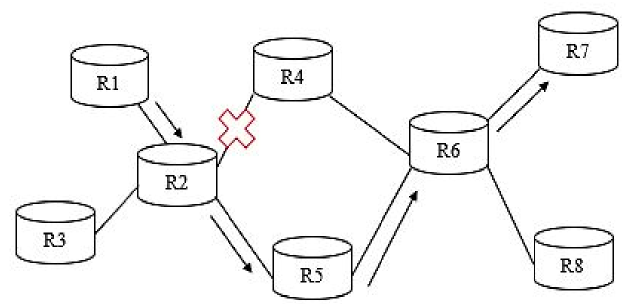

Figure 2: Organization of alternative data transmission route

It is clear that the search for TE paths, in turn, reduces the quality of the solution - while considering all flows, the provider can find more efficient use of resources [3]. In modern equipment, a TE variant with consistent flow consideration is used. It is easier to implement and closer to standard protocols for finding the shortest path for a single destination network.

The information about the found the rational route is used completely - not only the first transit node is remembered, as in the basic mode of IP routing, but also all intermediate nodes of the path together with the initial and final ones. That is, routing is from the source.

Therefore, it is enough that only border routers of the network are engaged in the search for routes, and the internal ones only provide them with information about the current state of the network, which is necessary for making decisions on changing the configuration, if necessary [6].

This approach has several advantages over the distributed path search model that underpins standard IP routing protocols. It allows the providers to:

1. Use external solutions when the routes are offline;

2. Each of the border routers work according to their own algorithms;

3. Unload the internal network routers from finding alternative routes.

Once the route is found, regardless of whether it was found by a border router or provider, it must be configured according to basic criteria. Thus, by analyzing the existing benefits of implementing traffic engineering, the provider can build a network graph based on conventional paths [7].

2.2 Construction of the math model of optimization of the network flow based on traffic engineering method

Traffic engineering problems are solved using graph theory and queuing methods, so it is necessary to describe the math model [8].

This network can be specified as an oriented graph $G = (X, E)$, where $X = \{x_j\},\ j = \overline{1,n} -$ multiple network nodes, $E = \{(r,s)\} -$ many communication channels.

Connection bandwidths specified $\{\mu_{rs}\}$, a channel matrix of requirements $H(k) = \|h_{ij}(k)\|, i, j = \overline{1,n}$, where $h_{ij}(k) -$ flow intensity $k -$class, which must be send from X_i node to X_j.

It's important to find such paths for the flow transfer and distribution $F(k) = [f_{ij}(k)]$ under which constraints are provided for the average delay $T_{set,k}$ and the share (probability) of loss of $k -$class packets PLR_k.

There is a basic expression for $T_{aver}^{(k)}$ – average delay for the $k -$class flow with relative priorities:

$$T_{aver}^{(k)}(\{\mu_{rs}\},F) = \frac{1}{H_{\Sigma}^{(k)}}\sum_{(r,s)\in E}\frac{f_{rs}^{(k)}\sum_{i=1}^{K}f_{rs}^{(i)}}{\left(\mu_{rs}-\sum_{i=1}^{K-1}f_{rs}^{(i)}\right)\left(\mu_{rs}-\sum_{i=1}^{K}f_{rs}^{(i)}\right)}. \quad (1)$$

The probability of packet loss (r,s) will be equal to the probability of the state when all-time channels are allocated under $k -$class flow in the communication line (r,s) will be occupied equal to:

$$P_{nom\,r,s}^{(k)} = P_0 * \left(\frac{f_{rs}^{(k)}}{\mu}\right)^{n_k} * \frac{1}{n_k!} * \left(\frac{f_{rs}^{(k)}}{n_k\mu}\right)^{N_k}, \quad (2)$$

where $\mu -$ channel throughput; $n_k -$ is the number of channels (r,s) allocated to transmit a $k -$class flow; $N_k -$ is the number of packets in the router queue; $P_0 -$ is the normalizing factor.

Determining the route of traffic on the main router can rely on IGP, BGP, or, finally, static routes within the network. Traffic control, namely, speed limits on borderline backbone routers can be done on a per-stream or aggregate-traffic basis. For the load balancing, a set of two or more nodes can be used to route between two endpoints, taking into account aggregate traffic needs.

Then the probability that $k -$class packets will not be lost in any of the network channels will be equal to:

$$\prod_{(r,s)\in E}\left(1 - P_{nom\,r,s}^{(k)}\right). \quad (3)$$

The probability of a lost $k -$class packet will be:

$$PLR_k = 1 - \prod_{(r,s)\in E}\left(1 - P_{nom\,r,s}^{(k)}\right). \quad (4)$$

The information about the transmission routes should be described. Then, the following requirements will be fulfilled:

$$T_{aver}^{(k)} \le T_{set,к} \quad (5)$$

$$PLR_k \le PLR_{зад,k}, k = \overline{1,K}, \quad (6)$$

This task can be called a generalized task and the algorithm for solving it consists of several steps. Consider an algorithm for solving a generalized problem using the example of flows of three classes $k = \overline{1{,}3}$.

The algorithm consists of $(2k + 1) -$stages. The particular problem of the corresponding $k -$class by the corresponding constraint is solved in each of these stages.

First stage. At this stage, the problem of distributing the flow $k - 1 -$class solved with limitation $T_{aver}^{(1)} \le T_{set,1}$.

There are few steps on this stage.

1. Define the initial conditional metrics:

$$l_{rs}(1) = \frac{\partial T_{aver}}{\partial f_{rs}}|f_{rs} = 0 = \frac{1}{n_{rs}\mu}. \quad (7)$$

2. The first requirement $h_{i,j1}$ is selected from the matrix $H(1)$. Then, define the shortest path$(\prod_{i_k j_k}^{min})$.

3. The flow distributed from the requirement $h_{i,j1}$:

$$f_{rs}{}^{1}(k) = \begin{cases} f_{rs}{}^{1}(0) + h_{i_k j_k},\ if\ r,s\ \in \Pi_{i_i j_i}^{min} \\ f_{rs}(0), in\ other\ cases. \end{cases} \quad (8)$$

The end of the first step.

Step $k - th$. Let's imagine that the $(k-1) -$steps have already held and the flow distribution $f_{rs}^{(i)}(k-1)$ found.

Consider step $k - th$

1. Define the conditional metric:

$$l_{rs}{}^{(1)}(k) = \frac{\partial T_{aver}}{\partial f_{rs}}|f_{rs} = f_{rs}^{(i)}(k-1). \quad (9)$$

2. The next requirement $(i_k j_k)$is selected from the $H(1)$ matrix. Then, define the shortest path $(\prod_{i_k j_k}^{min})$ from the $l_{rs}(k)$ matrix.
3. Check the opportunity to send requirement $h_{i_k j_k}{}^{(1)}$ by path $(\prod_{i_k j_k}^{min})$

$$\theta_k(\prod_{i_k j_k}^{min}) = \min_{r,s \in \prod_{i_k j_k}^{min}} \left\{\mu_{rs} - f_{rs}^{(i)}\right\} > h_{i_k j_k}. \quad (10)$$

If a condition (10) works, then the flow distributed from requirement $h_{i_k j_k}$ by path $(\prod_{i_k j_k}^{min})$:

$$f_{rs}(k) = \begin{cases} f_{rs}(k-1) + h_{i_k j_k}, if\ \ r,s\ \in \prod_{i_k j_k}^{min} \\ f_{rs}(k-1), in\ other\ cases. \end{cases}$$

Then proceeds to the next $(k+1)$ –step.
4. Searching for a route $(\prod_{i_k j_k}^{min})$ with minimal distance between nodes i_k and j_k. Especially, if a condition $\theta_k(\widetilde{\prod_{i_k j_k}^{min}}) > h_{i_k j_k}$ works, where $\theta_k(\widetilde{\prod_{i_k j_k}^{min}})$ – reserve of a path $(\prod_{i_k j_k}^{min})$, it would be determined by (10).

5. The flow distributed from the requirement $h_{i_k j_k}$. The new distribution of threads between the routers are found:

$$f_{rs}(k) = \begin{cases} f_{rs}(k-1) + h_{i_k j_k}, if\ r,s\ \in \widetilde{\prod_{i_k j_k}^{min}} \\ f_{rs}(k-1), in\ other\ cases. \end{cases}$$

All of these steps lead to the flows distribution $F_{(1)} = [f_{rs}(1)]$ with that condition $f_{rs}(1) < \mu_{rs}$.
The algorithm goes to the next step.

Second stage. At this stage, the allowable flow, which satisfies the restriction, are organized:

$$T_{aver}^{(1)}(F_1^0) \le T_{set,1} \quad (11)$$

First of all, the condition (11) is checked. If it works, then the algorithm goes to the third stage. Otherwise, the second stage is performed. It starts from the first step.

Step $k - th$
1. Define the conditional metric:

$$l_{rs}{}^{(k)} = \frac{\partial T_{aver}{}^{1}(F_1)}{\partial f_{rs}} | f_{rs} = f_{rs}^{(i)}(k). \quad (12)$$

2. The shortest path is defined (12): $\prod_{ij}^{min}(k)$.
3. The stream along the shortest paths between the nodes $V(k) = [v_{rs}(k)]$ with metric $l_{rs}(k)$ is founded.
4. The conditional of possible optimization of flow distribution F_1 by the $T_{aver}{}^{1}$ is checked:

$$\sum_{(r,s)\in E} l_{rs}{}^{(k)} f_{rs}(k) > \sum_{(r,s)\in E} l_{rs}{}^{(k)} v_{rs}(k). \quad (13)$$

If the condition (13) works, then there is a move to step 5. The flow allocation task is not solved with the specified channel bandwidths $\{\mu_{rs}\}$ and the service requirements matrix $H(1)$.

5. On the next action, the first requirements (i_k, j_k) is tracked (14):

$$\sum_{(r,s)\in \widetilde{\Pi_{ik,jk}}} l_{rs}{}^{(k)} f_{rs}(k) > \sum_{(r,s)\in \Pi_{ik,jk}{}^{min}} l_{rs}{}^{(k)} v_{rs}{}^{ik,jk}(k), \quad (14)$$

where $\widetilde{\Pi_{ik,jk}}$ – the route of transfer of the request i_k, j_k, which is used in the current distribution $F(1)$, $\Pi_{i1,j1}{}^{min}$- the shortest path in the metric $l_{rs}{}^{(1)}(k)$.
The flow $\Pi_{ik,jk}{}^{min}$ redirect and optimized for the requirement i_k, j_k.

6. The condition is checked $T_{aver}^{(1)}(F_1(k)) \le T_{set,1}$. If it works, then the second stage ends. Otherwise, the algorithm receives one more step $k = k + 1$. There is a move to the fourth step on the second stage.
Calculating the results of the second stage. Valid flow distribution for the first class is obtained:

$$T_{aver}^{(1)}\left(F_1{}^0(k)\right) \le T_{set,1}. \quad (15)$$

Third stage. At this stage, the execution for the flow $F_{(1)}^0$ is checked. The general condition for the flow is a limit on the proportion (probability) of packet loss

$$PLR_1 F_{(1)}^0 < PLR_{1,set}. \quad (16)$$

If a condition (16) works, then the third stage skips to and proceeds to 4. If not, the flow distribution $F_1{}^*$ is sought, under which both constraints (16) and (17) are satisfied.

For this purpose, it is necessary to formulate an additional task. For example, find the following flow distribution $F_1{}^*$ on a router that would be eligible: $\min PLR\ (F_1{}^*)$ at $T_{aver}(F_1{}^*) \le T_{set,1}$. To do this, describe the combined metric, where $\lambda \in (0,1)$.

$$l_{rs}{}^{(1)}(k) = \lambda \frac{\partial T_{aver}}{\partial f_{rs}} + (1-\lambda)\frac{PLR\ (F_1)}{\partial f_{rs}}. \quad (17)$$

1.For the flow $F_1 = [f_{rs}(1)]$ the metric is defined as follows (λ chooses on condition $\lambda \in (0,1)$.
$\tilde{l}_{rs}{}^{(1)}(1) = \lambda \frac{\partial T_{aver}}{\partial f_{rs}} + (1-\lambda)\frac{PLR\ (F_1)}{\partial f_{rs}}, f_{rs} = f_{rs}(1).$

2.The shortest paths in the metric $\tilde{l}_{rs}^{(1)}(1)$ and the flows in the shortest paths $v_{rs} = v_{rs}(1)$ would be checked:

$$\sum_{(r,s)} \tilde{l}_{rs}^{(1)} f_{rs}(1) > \sum_{(r,s)} \tilde{l}_{rs}^{(1)} v_{rs}(1). \quad (18)$$

If this inequality is fulfilled, the transition to the third step occurred. Otherwise, the execution of the algorithm stops because the router's flow and its metrics cannot be improved. The result - the task simply has no valid solution [9].

Next action it's a process to find the flow distribution of the second class F_2. However, conditions (15) and (16) for flow F_1 cannot be restricted. For this purpose, steps 4 and 5 are performed (which are similar to steps 2 and 3). In this case, the flow distribution F_2 is on the bandwidths of the remaining channels.

The conditions (15) and (16) are the same, as used before. The barrier or penalty function for the flow F_1 is not violated. The barrier function would be next:

$$g_1(T_{mid}, F_1, F_2) = \frac{1}{T_{mid,set} - T_{mid,1}(F_1|F_2)} + \frac{1}{PLR_{set} - PLR_1(F_1|F_2)}. \quad (19)$$

The penalty function would be next:

$$B(F_1, F_2) = max\{0, T_{aver}(F_1) - T_{set1}\} + max\{0, PLR(F_1) - PLR_{set1}\}. \quad (20)$$

Like the previous one, this problem is solved using the methods of graph theory and queuing theory.

2.3. Constructing the adjacency matrixes

Execution of the mathematical model under the condition of modeling the situation, we present the adjacency matrix.

As shown in Figure 1, we have a normal channel of information transfer between R1 and R7 routers. The network consists of many paths. Provided one of the channels is unavailable, the network reconfigures. After all, QoS conditions must always be met [10].

Table 1: The adjacency matrix for the normal data channel

Node	1	2	3	4	5	6	7	8
1	0	1	0	0	0	0	0	0
2	1	0	1	1	1	0	0	0
3	0	1	0	0	0	0	0	0
4	0	1	0	0	0	1	0	0
5	0	1	0	0	0	1	0	0
6	0	0	0	1	1	0	1	1
7	0	0	0	0	0	1	0	0
8	0	0	0	0	0	1	0	0

In this case, the alternate path will be designed instantly [11]. The adjacency matrix, provided in Fig. 2, is presented below:

Table 2: The adjacency matrix for of alternative data transmission route

Node	1	2	3	4	5	6	7	8
1	0	1	0	0	0	0	0	0
2	1	0	0	0	1	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	1	0	0	0	1	0	0
6	0	0	0	0	1	0	1	0
7	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	0

3. CONCLUSION

The algorithm for solving the problem of the flow distribution, taking into account the constraints on the average delay of packets of the corresponding classes and on the percentage of lost packets is described.

The proposed method is based on math method of random path and graph theory. Network optimization with average latency constraints for the flow and between the specified node pair are presented.

The math model and the adjacency matrixes allow the next result - every error, failure or overwhelming the router with too much traffic can have a negative effect on network performance. That's why providers must distributed network flows and paths between routers using traffic engineering method.

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