Evaluating the Effectiveness of Geographic Routing Based on RIPE Atlas Data

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Abstract — **In this paper, we attempt to estimate the effectiveness of geographical routing in the global network. The concept of the length of the telecommunications link is introduced. In order to calculate the length, the physical principle of finite speed of light and the minimum time of packet delay on the investigated route are used. The effectiveness ratio of geographic routing is taken to equal the ratio of telecommunication length to geographical distance between the end points of a route. The telecommunications measurement infrastructure RIPE Atlas allows collection of data from probes scattered around the world. On the basis of these data, values of the coefficients of the efficiency of geographic routing for different autonomous systems are calculated.**

Keywords — **effectiveness ratio of geographic routing, RIPE Atlas, telecommunication length**

I. INTRODUCTION

ROUTING in a global network is a complex mechanism aimed at finding the best routes. Optimality criteria may vary depending on the requirements. In this paper, we will focus on the efficiency of geographic routing [1]. Based on the RIPE Atlas data, the length of the routes compared with the geographical distances between the endpoints will be analyzed. Such comparisons allow us to formulate and describe the concept of an effective geographical routing and to analyze geographic routes for the world's major Internet centers [2].

In terms of the parameters affecting the quality of network connections (IP Performance Metrics [3]), the efficiency of geographic routing is associated with minimizing packet delay [4]. If the length of the lines is shorter, the time of such delivery should be shorter. There are three parameters that describe the quality of communication. These include network jitter, packet loss and available bandwidth. The concept of efficiency of geographic routing indirectly affects network jitter [5].

Nevertheless, the delay of packets in the global network affects the applications associated with the communication of network users [6]. This observation applies primarily to the two-way exchange of voice data and videoconferences. The main difficulties arise when the time of the bilateral packet transmission over the network (there and back) is more than three seconds. In this case, the interaction effect or lively dialogue is completely lost. If Round-trip Time is less than one second, the impact of the network is not noticeable to the participants of the dialogue [7].

The RIPE Atlas system was chosen for the measurement infrastructure for determining the packet delay [8]. This infrastructure was created under the auspices of the European Regional Internet Registries (RIPE NCC) and covers all major Internet centers, especially the traffic exchange points where the lion's share of packets are serving while cruising in the global network.

The measuring mechanism RIPE Atlas processes data of the simplest utilities like *ping* and *traceroute* and makes it possible to measure delay, packet loss and network jitter on selected directions. Also, key points of routes are highlighted that correspond to these directions. In principle, each network administrator can perform such measurements from his or her own network. But the power of RIPE Atlas in measuring infrastructure is that it reduces such measurements to a single database and processes the results. Nevertheless, using the methodology described in this article, each administrator can evaluate the effectiveness of geographic routing for his or her network independently.

II. THE MAIN THEORETICAL PRINCIPLES

In order to evaluate the effectiveness of geographic routing, it is necessary to apply the nature of packet delays in computer networks. There are two main reasons to explain delays in the network [9]. The first is related to physical principles and is due to the spread of the signal at a fast but finite speed that equals the velocity of light in the medium. This component is dependent on the length of the links constituting a route and passes all the intermediate nodes. This component of the delay is called propagation delay.

The second type of delay is associated with packet processing at the points of transmission and reception, as well as at the points of intermediate routers. This value is random and described by the queuing theory. It distinguishes among delay processing, transmission, expectations, etc.

In order to evaluate the effectiveness of geographic routing, it is sufficient to estimate the propagation delay, which allows one to judge the length of the lines. In 2004,

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experiments of groups headed by Choi [10] and Hohn [11] indicated that the minimum delay $D^{fixed}(W)$ for the packet size W is an affine function of its size:

$$D^{fixed}(W) = W \sum_{i=1}^{n} 1/C_i + \sum_{i=1}^{n} \delta_1, \qquad (1)$$

where C_i is the capacity of the corresponding section of the route, and δ_i is physical delay of a packet. In order to confirm this assumption, a minimum delay of packets of the same size for three different routes was calculated experimentally by function, and, according to the delay, the packet size W was constructed.

Taking into account the variable part of the delay, the universal expression for the one-way packet delay can be reduced to the form:

$$D = D_{min} + \frac{W}{B} + d_{var}, \qquad (2)$$

where D_{min} is the smallest possible packet delay when the packet size is minimal. B is the available bandwidth [12].

In equation (2), different types of delays are divided. The first term, D_{min}, describes the propagation of the signal, and the next two terms are responsible for different types of packet processing. This is a contribution of the queuing theory. It should be noted that the variable part of delay d_{var} may be described by a logarithmic distribution

$$F(D,W) = \begin{cases} 0, D < D_{min} + W \ / \ B \\ 1 - exp\left(-\frac{D - D_{min} - W/B}{j}\right) \\ D \geq D_{min} + W \ / \ B \end{cases} \qquad (3)$$

This expresses a generating function for the variable part of the delay

$$d_{var} = \frac{W}{B} - j \ln(1 - F(D)) \qquad (4)$$

where the value $F(D)$ is given by a random number generator, and j represents the delay variation (network jitter). With the help of the generating function, a sequence of values of the packet delay can be obtained that is suitable for use in simulating calculations.

In order to evaluate the effectiveness of geographical routing, a minimum value of packet delay D_{min} is selected for the test sequence. This value can be used to estimate the total length of the lines that connect the two points with a fixed IP address.

During testing, it is necessary to use packets of minimum possible size. Then, in a series of m measurements, the expectation of the minimum packet delay $E[min\ D]$ can be estimated as

$$E[min\ D] = D_{min} + \frac{j}{m} \qquad (5)$$

That is, for large values of the sample ($m = 100$) and for considerable distances, l_g ranges from a few hundred kilometers ($l_g \gg \frac{c_{opt} j}{m}$, $j \sim 10^{-2}\ ms$), and the second term in equation (5) can be neglected. Bandwidth refers to the speed of light in the fiber. The jitter value is chosen in the order of tens of milliseconds.

For any two devices connected to the global network, we can find two independent characteristics to assess the geographic routing. The first characteristic represents the distance between these points and is measured by geographic coordinates. If we know the location of both devices, it is easy to do. The second distance can be evaluated as the total length of the communication lines l_t that are used to organize the exchange of packets. In order to estimate the telecommunication length l_t, we use the value D_{min}, found experimentally.

We can now introduce a new value, which is called the effectiveness ratio of geographic routing k. This factor k is the ratio of the telecommunication length l_t to its geographical analogue l_g

$$k = \frac{l_t}{l_g} \qquad (6)$$

The higher the ratio, the less efficient the geographic routing in a direction. For each autonomous system in the Internet, we can evaluate the effectiveness of geographic routing for several main directions of traffic and then find the average value. This value can characterize the autonomous system under study.

III. SELECTING THE MEASUREMENT INFRASTRUCTURE

In order to obtain data on the value of the delay, it is necessary to select the measurement infrastructure. In the simplest case, we can do without any infrastructure and use the utility ping. Receiving several dozen values, we must select the smallest of them. After that, the efficiency of geographic routing is easy to find.

This approach has several drawbacks. The first is that the ping command measures round-trip time (RTT) [13], i.e., the delay in sending the package back and forth. In this case, a one-way delay measurement is preferred, as described in RFC2679 [14]. In order to use round-trip time when finding the effectiveness ratio of geographic routing, you make sure that routes of packets on the way there and back are the same. This condition is not always fulfilled, and the inspection is possible with the command traceroute. However, this utility should be started not only from the device located at the beginning of the route but also from the device located at the opposite end. This is the second fundamental flaw of independent measurements.

Taking into account the comments made, it can be seen that the ideal measurement system for our purposes is the RIPE Test Box [15], which measures one-way packet delay with microsecond accuracy. Unfortunately, this system was decommissioned in June 2014. Another advantage of this system is that the time synchronization is carried out with the help of GPS, which allows to one find, with great accuracy, the geographical coordinates of the measuring sites. However, this system has an insufficient number of measurement boxes due to the high cost of the server and GPS device.

Therefore, only two measuring systems, PingER [16] and RIPE Atlas [17,18], are suitable for our purposes. Both these systems measure round-trip time between the measuring units and also establish routes. The difference between these systems is that PingER is implemented at the software level, while RIPE Atlas basically has a hardware solution. Both of these systems are widespread, and the geographical coordinates of their units are easy to find for the subsequent calculation of the exact distance between the study units.

As we participated in the program RIPE Test Box and were among the first users of the new system RIPE Atlas, we have established a trusting relationship with specialists of the RIPE NCC control center. This fact predetermined selection of RIPE Atlas as a major measuring tool in our study.

The RIPE Atlas project is a new measurement infrastructure established by the Regional Internet Registry (RIR) for Europe (RIPE NCC) and involves the deployment of a large number (> 50,000) of simple and inexpensive portable measuring devices, so-called probes. Probes provide data on RTT and loss of sending test packets. In February 2014, the system was used by more than 3,500 probes, and about half of them worked in IPv6.

According to this map, we can determine the geographical coordinates of the probes to find the distances between them.

There is a hierarchy of probes. Besides conventional devices, there are so-called anchors that communicate with all probes. Statistical data from the anchors are freely available, and these data are used for our calculations.

Among all possible routes, those in which forward and reverse paths are the same have been selected. In this round-trip time, D^{RTT} should be divided in half for use in the calculation of the effectiveness ratio of the geographic routing. As the speed of signal propagation, we choose the speed of light in the fiber, assuming that all the main channels were carried over a fiber optic circuit. Thus, we obtain the final calculation formula

$$k = \frac{cD_{min}^{RTT}}{2nl_g} \qquad (7)$$

where $c = 3 * 10^8$ *m/s* is the speed of light in vacuum, $n = 1{,}505$ is the refractive index of the fiber and D_{min}^{RTT} is the minimum time delay of two-way communication, fixed in the RIPE Atlas base.

IV. RESULTS AND DISCUSSION

In order to test the method outlined in the second section, more than 20 RIPE Atlas probes were selected, covering the world's major Internet centers. Since the results were very similar, the analysis will be described with eight points in more detail. The nodes are located as follows:

- Melbourne, the number of the RIPE Atlas probe is 6044. It is located within an autonomous system 38796
- New York, RIPE Atlas ID 6024, as 5580
- Barcelona, RIPE Atlas ID 6048, as 13041
- Tokyo, RIPE Atlas ID 6033, as 2500
- Tunisia, RIPE Atlas ID 6051, as 5438
- Moscow, RIPE Atlas ID 6046, as 47764
- Amsterdam, RIPE Atlas ID 6031, as 1101
- Stockholm, RIPE Atlas ID 6037, as 59521

Additionally, data from probes located in Helsinki, Paris, Athens, Dublin, Reykjavik, Oslo, Poznan, Belgrade, Paolo Alto, Montevideo and some other locations were collected and processed. Data from these probes will not be analyzed in detail. We will give only the final value of the coefficients k, averaged for each of the nodes.

Based on the data about the minimum of the round-trip time D^{RTT} and geographic distance l_g between nodes, it is easy to calculate the effectiveness ratio of the geographical routing of all of the directions. The results of these calculations are summarized in Table 1.

From Table 1, it is clear that the telecommunications length l_t is always greater than the geographical length l_g. This fact has two simple explanations. The first is that the length of the connection cable between two points is always greater than the shortest distance between these two points, measured in a straight line. When laying communication cables, terrain and ownership of land and length for technological purposes are always considered.

The second reason is that routers process packets along the path from one node to another and are not optimally placed along a possible route is a straight line. A perfect illustration of the second reason is a measurement conducted on the probe located in Tokyo. In routing packets to nodes located in Europe, the transit routes through North America are used. This leads to a significant increase in packet delay, which is critical for a number of Internet applications.

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It may also be noted that the farther the probes are spaced apart the lower the effectiveness ratio of geographic routing. For intra-European routing, it is difficult to recognize optimal efficiency since the values of the ratio in most cases exceed two and often exceed three. That is, the telecommunications length is two or even three times longer than the geographical length. But, due to the fact that the geographical distances are small, one-way delay is less than 50 *ms*, which is a good indicator [19].

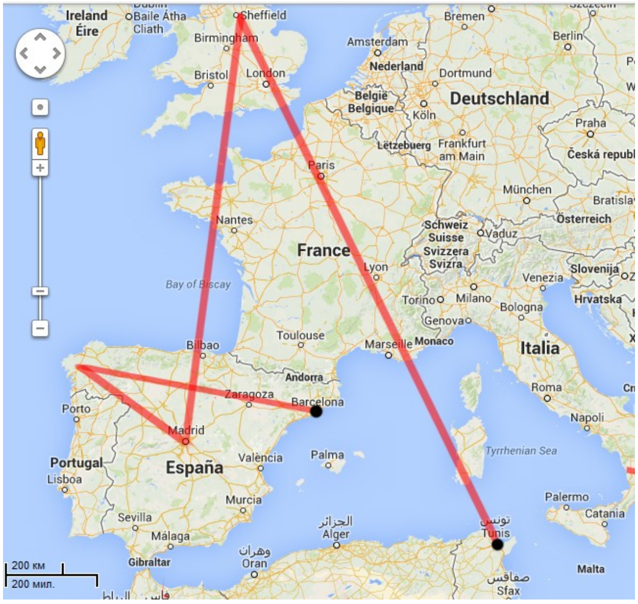

Fig. 2. The route between Barcelona and Tunisia

TABLE 1: VALUES EFFECTIVENESS RATIO OF THE GEOGRAPHIC ROUTING.

	Melbourne	New York	Barcelona	Tokyo	Tunisia	Moscow	Amsterdam	Stockholm
Melbourne		1.46	2.15	1.55	2.27	2.17	1.85	2.15
New York	1.46		1.96	1.51	2.40	1.77	1.40	1.66
Barcelona	2.15	1.96		3.12	6.55	3.40	3.65	3.18
Tokyo	1.55	1.51	3.12		2.57	3.09	3.15	3.32
Tunisia	2.27	2.40	6.55	2.57		2.76	2.24	2.40
Moscow	2.17	1.77	3.40	3.09	2.76		2.23	2.14
Amsterdam	1.85	1.40	3.65	3.15	2.24	2.23		1.89
Stockholm	2.15	1.66	3.18	3.32	2.40	2.14	1.89	

Analysis of these data shows that the lowest value of the ratio is in New York. This is not surprising as, in New York, there is the highest number of traffic exchange points. Most of the world's telecom operators tend to place their equipment here, thus tying links. The second argument in favor of New York is the considerable distance from other nodes and the possibility of laying cable on the ocean floor, almost always the shortest route.

Large values of the effectiveness ratio of the geographic routing for European probes are explained by the fact that the main exchange point is located in Northern Europe. Therefore, a significant part of the traffic from the southern regions and from North Africa is forced to make significant deviations from the shortest route. A perfect illustration of this situation is the routing between Barcelona and Tunisia (see Fig. 2). However, as noted above, because of the short distances, the common amount of delay is not critical.

V. CONCLUSION

In this paper we analyze the effectiveness of geographic routing for the modern configuration of the global network. In the theoretical part, the attempt is made to divide the length of the packet delay into two main components. The first of these components is due to propagation of the signal by physical principles. The second component of the delay is associated with signal processing and packets on telecommunication devices described by the theory of queuing.

The effectiveness ratio of geographic routing is defined as the ratio of telecommunication length l_t to its geographical analog l_g. In order to calculate the telecommunication length, a minimum of packet delay spent on transfer between nodes is used.

We justify the choice of telecommunications infrastructure for the measuring of packet delay between the main directions of the flow of traffic in the global network. RIPE Atlas is selected as the measurement infrastructure and covers a sufficient density for all continents.

For selected points located in major telecommunications centers, the results of measurements are analyzed and values of the effectiveness ratio of geographic routing are calculated. The lowest values of this ratio are found in New York and the largest in Tokyo.

REFERENCES

[1] Subramanian L., Padmanabhan V. N., Katz R. H. Geographic properties of Internet routing //*USENIX Annual Technical Conference, General Track*. – 2002. – С. 243–259.

[2] Lakhina A. et al. On the geographic location of Internet resources //*Selected Areas in Communications, IEEE Journal on*. – 2003. – Т. 21. – №. 6. – С. 934–948.

[3] Paxson, V., Mahdavi, J., Mathis, M., Almes, G. (1998). Framework for IP performance metrics. – RFC 2330, May 1998.

[4] Almes G., Kalidindi S., Zekauskas M. A one-way delay metric for IPPM. – RFC 2679, September, 1999.

[5] Demichelis C., Chimento P. IP packet delay variation metric for IP performance metrics (IPPM). – RFC 3393, November 2002.

[6] Zhang L., Zheng L., Soo Ngee K. Effect of delay and delay jitter on voice/video over IP //*Computer Communications*. – 2002. – Т. 25. – №. 9. – С. 863–873.

[7] Ngatman M., Ngadi M., Sharif J. Comprehensive study of transmission techniques for reducing packet loss and delay in multimedia over ip //*International Journal of Computer Science and Network Security*. – 2008. – Т. 8. – №. 3. – С. 292–299.

[8] RIPE N. C. C. RIPE Atlas //*https://atlas.ripe.net*. – 2010.

[9] Kyrbashov, B., Baronak, I., Kovacik, M., Janata, V. Evaluation and investigation of the delay in voip networks //*Radioengineering*. – 2011. – Т. 20. – №. 2. – С. 540–547.

[10] Choi, B. Y., Moon, S., Zhang, Z. L., Papagiannaki, K., Diot, C. Analysis of point-to-point packet delay in an operational network //*Computer networks*. – 2007. – Т. 51. – №. 13. – С. 3812–3827.

[11] Hohn N., Papagiannaki K., Veitch D. Capturing router congestion and delay //*IEEE/ACM Transactions on Networking* (TON). – 2009. – Т. 17. – №. 3. – С. 789–802.

[12] Sukhov, A. M., Kuznetsova, N. Y., Pervitskii, A. K., Galtsev, A. A. The distribution function of package delay in the global network for the control theory problems //*Telecommunications and Radio Engineering*. – 2013. – Т. 72. – №. 3.

[13] Almes G., Kalidindi S., Zekauskas M. A round-trip delay metric for IPPM. – RFC 2681, September 1999.

[14] Almes G., Kalidindi S., Zekauskas M. A one-way delay metric for IPPM. – RFC 2679, September 1999.

[15] Zhou, X., Jacobsson, M., Uijterwaal, H., Van Mieghem, P. IPv6 delay and loss performance evolution //*International Journal of Communication Systems*. – 2008. – Т. 21. – №. 6. – С. 643–663.

[16] Matthews W., Cottrell L. The PingER project: active Internet performance monitoring for the HENP community //*Communications Magazine, IEEE*. – 2000. – Т. 38. – №. 5. – С. 130–136.

[17] Bagnulo, M., Burbridge, T., Crawford, S., Eardley, P., Schoenwaelder, J., Trammell, B. Building a standard measurement platform //*Communications Magazine, IEEE*. – 2014. – Т. 52. – №. 5. – С. 165–173.

[18] Brownlee N. On searching for patterns in traceroute responses //*Passive and Active Measurement*. – Springer International Publishing, 2014. – С. 67–76.

[19] Calyam, P., Ekici, E., Lee, C. G., Haffner, M., Howes, N. A “GAP-Model” based framework for online VVoIP QoE measurement //*Communications and Networks, Journal of*. – 2007. – Т. 9. – №. 4. – С. 446–456.