UDC 681.3.07

V.S. Khandetskyi, P.V. Khandetskyy

LOAD BALANCING IN AUTONOMOUS SYSTEMS OF COMPUTER NETWORKS THAT USE THE INTERNAL GATEWAY ROUTING PROTOCOLS

Abstract. We proposed a methodology using traditional metrics IGRP and EIGRP protocols when forming routes. It is shown that in regular network topologies Ethernet, built using narrow and wideband channels, reducing the coefficient of cost routes equalization to a certain value leads to improved a load balance. Further improvement of the balance achieved by aggregating narrowband channels, the optimum for this topology is threefold aggregation.

Keywords: metrics, routing, bandwidth, delay, topology, network, load balancing.

Introduction. Increase the intensity of traffic in channels of computer networks, or otherwise, of the load L, to the boundary values (L = 255) has a number of negative consequences. Among them: queue overflow of the buffer memory in port routers, loss of information flow packets with low priority, re-sending packets of high priority, the forced reduction of transmission speed routers located downstream flow of information, and so on. As a result, it leads to a significant increasing of packet delay D_c, lower real bandwidth route B_e, reliability R.

The way out of this situation is the distribution of flow through different routes leading to the destination. In the distance – vector routing protocol RIP provided introduction more than one route to one destination in the routing table and use a load distribution. On default Cisco routers can be used up to four of these routes, but of equal cost value [1]. If, for example, this router receives information about two routes with the same metric to the same destination network, it introduces two routes in the routing table and redirected packets of the flow using one and second routes by turns. Such networking is suitable if the channels bandwidth is equal for these routes. Otherwise it may be pinhole congestion. For example, if one channel bandwidth is 100 Mbps, and the other is 1Gbps, high-speed connection will be loaded no more than 10%.

Internal gateway routing protocols IGRP and EIGRP assume load distribution among the routes with a non-equal cost or otherwise non-equal metric. Here is used a coefficient of cost routes equalization

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CCRE η, which sets the range of the routes cost values, among which used the load distribution.

The main part. Metric of internal gateway routing protocols IGRP and EIGRP really defined the same way [2]:

$$M = \left[k_1 B_e + \frac{k_2 B_e}{256 - L} + k_3 D_c \right] \cdot \frac{k_5}{k_4 + R}. \tag{1}$$

Here B_e is bandwidth, D_c is cumulative delay along the route, L is load, R is reliability, $k_1 - k_5$ are factors that scale influence of individual parameters on the value of the metric. In protocol EIGRP parameters to B_e and D_c additionally introduced factor of 256, but it does not change the nature of relationships. Assume that the network is reliable, packet loss is not observed. In this case, $R = 255$. Assume k_4=1, and k_5=256. Then the expression (1) is transformed into the next.

$$M = k_1 B_e + \frac{k_2 B_e}{256 - L} + k_3 D_c. \tag{2}$$

In [3] analyzed the impact of channels load on the value of metrics M. It is shown that when k_1=1, k_3=1, k_2=100 and D_c=0,2B_e the impact of L on the M value begins to exceed 1% in the range $225<L\le255$. When the k_2 is unit this effect practically unnoticeable even at L = 255 (0.3%). In this case, the expression (2) is even simpler form:

$$M = k_1 B_e + k_3 D_c. \tag{3}$$

Later we use technology Ethernet, while accepted that $k_3 = 1$, and the impact of individual channel (connection) bandwidth on M three times more of delay is, $k_1 B_e = 3D_c$.

Consider a fragment of an autonomous system (AS), which has a periodic topology (Figure 1). Here R_i are routers, bold lines show main canals (trunk) with bandwidth V_m = 1Gbps, lean lines show standard Fast Ethernet channels with bandwidth V_u = 100 Mbps, shown by arrows distribution EIGRP routing information updates, where i – number of update phase.

Calculate the value of the channels metric. For channel V_u=100 Mbps value B_e = 100, recommended value D_c = 100 [1]. For the trunk V_m = 1Gbps B_e = 10, and D_c = 20. Herewith

$$M_u = 3 \cdot 100 + 100 = 400, \quad M_m = 6 \cdot 10 + 20 = 80. \tag{4}$$

Suppose that packets of information flow with the destination address Net (SubNet) coming top in the main channel on router R1. Coefficient of cost routes equalization CCRE η in the first stage of analysis chosen such that the flow of information distributed on all routes provided in Figure 1 network.

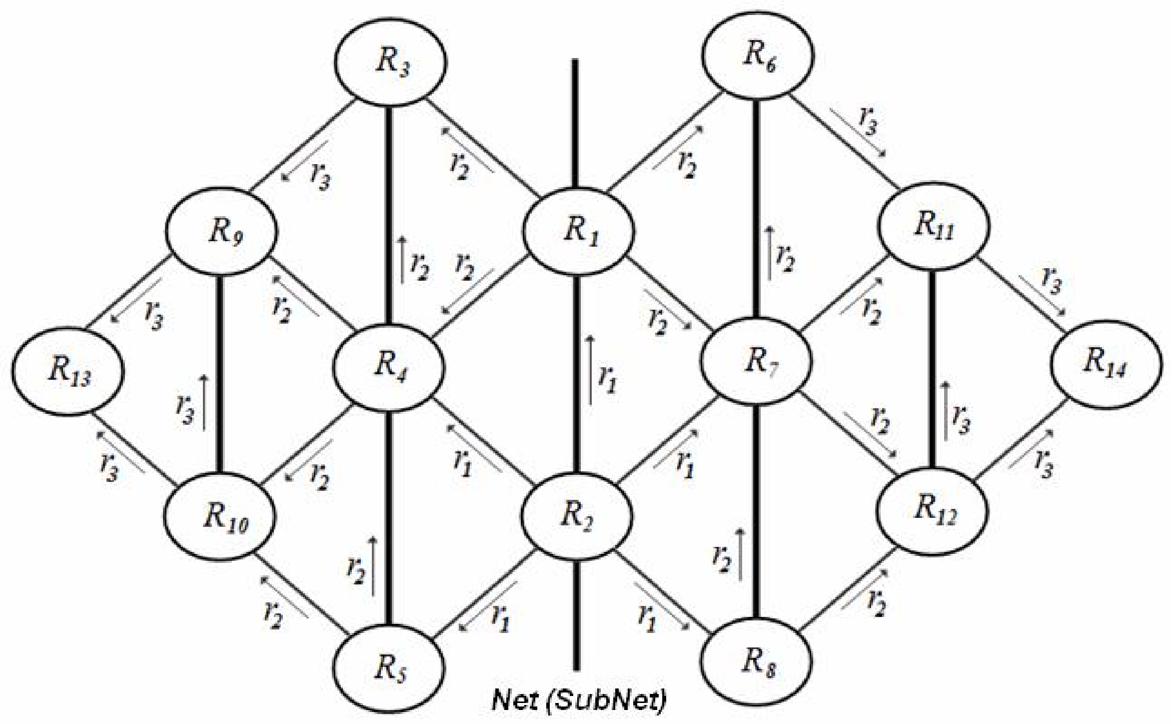

Fig.1 – Fragment of autonomous system. Topology is created by rhombic cells, which are located routers in the vertices, the legs of rhomb are narrowband channels and the diagonal is broadband main channel (trunk)

When determining the metrics of routes fundamental question is how the general route metric is calculated from the metrics of channels (connections) that make up this route. In networks that use the RIP, the task is easily solved – route metric is the number of hops that is actually the number of channels that connect neighboring routers. In applying the internal gateway routing protocols IGRP and EIGRP with metric of (3) we suggest differing approach to the problem.

Return to the network in Figure 1. Consider as an example the route R1-R3-R4-R2-Net. The channel R1-R3 according to (4) has $M = 400$. In the next section R3-R4, which is the trunk, bit rate is 10 times more than the rate of the previous channel R1-R3, and the delay $D_c = 20$. It is natural to assume that along the inhomogeneous route R1-R3-R4 bandwidth B_e is equal the bandwidth of slowest sections of this route, that is R1- R3, while the delay is increased by amount trunk R3-R4 delay D_c. Thus metric route R1-R3-R4 is: *M* (R1-R3-R4) = 3 · 100 + 100 + 20 = 420. By analogy with this metric of complete route is *M* (R1-R3-R4-R2-Net) · 3 = 100 + (100 + 20 + 100 + 20) = 540, where the cumulative delay along the route D_c = 240 is shown in parentheses.

Reason by analogy obtain metrics for all possible routes of information flow that goes to the router R1 and have a destination network Net. In the following calculations the numbers in the leftmost column indicate the number of intermediate routers for route from R1 to Net, and the value of the cumulative delay along the route shown in parentheses.

1. $M_1^{(1)}$(R_1-R_2 -Net)=6·10+(20+20) =100.
2. $M_1^{(2)}$(R_1- R_4 - R_2- Net)=3·100+(100+100+20) =520.
2. $M_2^{(2)}$(R_1- R_7 - R_2- Net)=520.
3. $M_1^{(3)}$(R_1- R_3- R_4 - R_2- Net)= 300 +(100+20+100+20) =540.
3. $M_2^{(3)}$(R_1- R_6 - R_7 - R_2- Net)= 540.
3. $M_3^{(3)}$(R_1- R_4- R_5 - R_2- Net)= 300 +(100+20+100+20) =540.
3. $M_4^{(3)}$(R_1- R_7- R_8 - R_2- Net)= 540.
4. $M_1^{(4)}$(R_1- R_3- R_4- R_5 - R_2- Net)= 300 +(100+20+20+100+20) =560.
4. $M_2^{(4)}$(R_1- R_6- R_7- R_8 - R_2- Net)=560.
4. $M_3^{(4)}$(R_1- R_3- R_9- R_4 - R_2- Net)= 300 +(100+100+100+100+20) =720.
4. $M_4^{(4)}$(R_1- R_6- R_{11}- R_7- R_2- Net)= 720.
4. $M_5^{(4)}$(R_1- R_4- R_{10}- R_5 - R_2- Net)= 300 +(100+100+100+100+20) =720.
4. $M_6^{(4)}$(R_1- R_7- R_{12}- R_8 - R_2- Net)= 720.
5. $M_1^{(5)}$(R_1- R_3- R_9- R_{10}- R_4 - R_2- Net)= 300+ +(100+100+20+100+100+20) =740.
5. $M_2^{(5)}$(R_1- R_6- R_{11}- R_{12}- R_7 - R_2- Net)= 740.
5. $M_3^{(5)}$(R_1- R_3- R_9- R_{10}- R_5 - R_2- Net)= 300+
   +(100+100+20+100+100+20) =740.
5. $M_4^{(5)}$(R_1- R_6- R_{11}- R_{12}- R_8 - R_2- Net)= 740.
5. $M_5^{(5)}$(R_1- R_4- R_9- R_{10}- R_5 - R_2- Net)= 300+
   +(100+100+20+100+100+20) =740.
5. $M_6^{(5)}$(R_1- R_7- R_{11}- R_{12}- R_8 - R_2- Net)= 740.
5. $M_7^{(5)}$(R_1- R_3- R_4- R_{10}- R_5 - R_2- Net)= 300+
   +(100+20+100+100+100+20) =740.
5. $M_8^{(5)}$(R_1- R_6- R_7- R_{12}- R_8 - R_2- Net)= 740.
6. $M_1^{(6)}$(R_1-R_4-R_3-R_9-R_{10}-R_5-R_2-Net)=300+
   + (100+20+100+20+100+100+20) =760.

6. $M_2^{(6)}(R_1\text{-}R_7\text{-}R_6\text{-}R_{11}\text{-}R_{12}\text{-}R_8\text{-}R_2\text{-Net})= 760.$
6. $M_3^{(6)}(R_1\text{-}R_3\text{-}R_9\text{-}R_{13}\text{-}R_{10}\text{-}R_5\text{-}R_2\text{-Net})=300+(100\cdot 6 +20) =920.$
6. $M_4^{(6)}(R_1\text{-}R_6\text{-}R_{11}\text{-}R_{14}\text{-}R_{12}\text{-}R_8\text{-}R_2\text{-Net})=920.$
6. $M_5^{(6)}(R_1\text{-}R_3\text{-}R_9\text{-}R_{13}\text{-}R_{10}\text{-}R_4\text{-}R_2\text{-Net})=300+(100\cdot 6 +20) =920.$
6. $M_6^{(6)}(R_1\text{-}R_6\text{-}R_{11}\text{-}R_{14}\text{-}R_{12}\text{-}R_7\text{-}R_2\text{-Net})=920.$
6. $M_7^{(6)}(R_1\text{-}R_3\text{-}R_9\text{-}R_4\text{-}R_{10}\text{-}R_5\text{-}R_2\text{-Net})=300+(100\cdot 6 +20) =920.$
6. $M_8^{(6)}(R_1\text{-}R_6\text{-}R_{11}\text{-}R_7\text{-}R_{12}\text{-}R_8\text{-}R_2\text{-Net})=920.$
6. $M_9^{(6)}(R_1\text{-}R_4\text{-}R_9\text{-}R_{13}\text{-}R_{10}\text{-}R_5\text{-}R_2\text{-Net})=300+(100\cdot 6 +20) =920.$
6. $M_{10}^{(6)}(R_1\text{-}R_7\text{-}R_{11}\text{-}R_{14}\text{-}R_{12}\text{-}R_8\text{-}R_2\text{-Net})=920.$

Two routes through 7 intermediate routers are not included. For illustrative efficiently value metrics is represented as follows.

1. $M = 100$.
2. $M = 520, 520$.
3. $M = 540, 540, 540, 540$.
4. $M = 560, 560, 720, 720, 720, 720$.
5. $M = 740, 740, 740, 740, 740, 740, 740, 740$.
6. $M = 760, 760, 920, 920, 920, 920, 920, 920, 920, 920$.

Specify $\eta = 10$. It permit to cover all metrics analyzed above routes for M(R1-R2-Net) · η = 1000. In the presence of N routes from the source to the network destination which N metrics come in to the range that is set η, load of the k - th route is determined by the formula:

$$L(M_k) = \frac{1}{M_k \cdot \sum_{1}^{N} \frac{1}{M_i}}. \tag{5}$$

Appropriate magnitudes of L for all analyzed routes are collected in Table 1. Maximal load of the channel with bandwidth 100 Mbps (channels R1-R3 or R1-R6) is 0,235. Load the trunk R1-R2-Net is 0.19. If traffic with L= 0,235 covers the entire channel bandwidth R1-R3, the traffic from L = 0,19 takes ΔV = 81 Mbps of the trunk.

Table 1

Distribution of routes load at η = 10.

Names routers	$M_1^{(1)}$	$M_1^{(2)}$, $M_2^{(2)}$	$M_1^{(3)}$-$M_4^{(3)}$	$M_1^{(4)}$, $M_2^{(4)}$	$M_3^{(4)}$-$M_6^{(4)}$	$M_1^{(5)}$-$M_8^{(5)}$	$M_1^{(6)}$, $M_2^{(6)}$	$M_3^{(6)}$-$M_{10}^{(6)}$	Σ

Metrics	100	520	540	560	720	740	760	920	
Load	0,19	0,0367	0,0353	0,034	0,0265	0,0257	0,0252	0,0207	
Quantity of routers	1	2	4	2	4	8	2	8	
Load of channel R_1-R_3			0,0353	0,034	0,0265	0,0771		0,0621	0,235
Load of channel R_1-R_4		0,0367	0,0353		0,0265	0,0257	0,0252	0,0207	0,170

Determine how to change this situation with decreasing η. Assume η = 8. In this case, the route to the destination will be limited by metric magnitude to 100 · 8 = 800, i.e. routes with M = 920 in the distribution of information flow will not accept participation. The appropriate metrics values of routes are shown in Table 2.

Table 2

Distribution of routes load at η =8

Names routers	$M_1^{(1)}$	$M_1^{(2)}$, $M_2^{(2)}$	$M_1^{(3)}$-$M_4^{(3)}$	$M_1^{(4)}$, $M_2^{(4)}$	$M_3^{(4)}$-$M_6^{(4)}$	$M_1^{(5)}$-$M_8^{(5)}$	$M_1^{(6)}$, $M_2^{(6)}$	Σ
Metrics	100	520	540	560	720	740	760	
Load	0,228	0,0439	0,0423	0,0407	0,0317	0,0308	0,030	
Quantity of routers	1	2	4	2	4	8	2	
Load of channel R_1-R_3			0,0423	0,0407	0,0317	0,0924		0,2071
Load of channel R_1-R_4		0,0439	0,0423		0,0317	0,0308	0,030	0,1787

It is seen that traffic through the main canal R1-R2-Net increased by 20% compared with the previous case. Traffic through the connection R1-R3 is decreased by 12% and through the connection R1-R4 is increased by 5%. Under the same conditions as in the previous case, traffic with load L=0,228 takes ΔV=110Mbps of the main channel.

Assume η = 6. Routes that are remaining in this case are given below.

1. M=100.
2. M=520, 520.
3. M=540, 540, 540, 540.

4. M=560, 560.

The appropriate metrics value of routes are shown in Table 3.

Table 3

Average load routes at η = 6

Names routers	$M_1^{(1)}$	$M_1^{(2)}$, $M_2^{(2)}$	$M_1^{(3)}$- $M_4^{(3)}$	$M_1^{(4)}$, $M_2^{(4)}$	Σ
Metrics	100	520	540	560	
Load	0,403	0,0775	0,0746	0,0720	
Quantity of routers	1	2	4	2	
Load of channel R_1-R_3			0,0746	0,0720	0,1466
Load of channel R_1-R_4		0,0775	0,0746		0,1521

Let analyze Table 3. Traffic through the main channel R1-R2-Net compared to Table 2 (η = 8) is increased by 77%, and compared to Table 1 (η = 10) - by 112%. Traffic through the R1-R3 compared to η = 8 decreased by 29%, and compared to η = 10 – by 38%. Traffic through the R1-R4 compared to η = 8 decreased by 15%, and compared to η = 10 – by 10,5%. When η = 6 load of channel R1-R4 slightly exceeded load of channel R1-R3. If the traffic of channel R1-R4 covers all existing bandwidth (100 Mbps), the traffic specified by L = 0,403 takes ΔV = 265 Mbps trunk R1-R2-Net.

The analysis shows when η is decreased from 10 to 6 traffic becomes more balanced, but a significant part of the main channel band is still free. This is due to the fact that in the series of Ethernet technologies when transited to a faster technology bandwidth is increased by 10 times.

Significantly improvement of routes load balancing for the topology under study (Fig. 1) can be achieved by aggregating narrowband channels. For example, when η = 6 using instead of a single channels Fast Ethernet aggregated channels with 300 Mbps bandwidth will expand the working bandwidth of the main channel to 800 Mbps.

Conclusions

1. When determining the metrics of routes in autonomous systems of computer networks that use internal gateway routing protocols, it is rational to add up not a general metric of connections formed a route, but use the cumulative delay of all

connections along the route, leaving bandwidth of the route on the level of bandwidth of slowest connection (channels).

2. In regular Ethernet network topologies, where each cell is represented by rhomb located routers in the vertices, the legs of rhomb are narrowband channels and the diagonal is a trunk, reducing the coefficient of cost routes equalization to a certain value leads to improve balance of traffic intensity among routes of the autonomous system.

3. Further improvement of a load balancing in the network is constrained by the fact that in most Ethernet technologies when change to adjacent one speed is variated by 10 times. Optimizing balance can be obtained by triple aggregation of narrowband channels.

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