# Load Balancing Routing in Time-Sensitive Networks

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***Abstract*—In the research the load balancing routing model in Time-Sensitive Networks is proposed. The novelty of the solution is a type of optimality criterion, the use of which minimizes the circuit delays. The proposed solution is compromise in terms of computational implementation as compared to the previously known models, in which the equality of the circuit delays of packets were considered as limitations, rather than optimality criterion.**

***Keywords—QoS; TSN; routing; paths; flow; model; load balancing; delay***

## I. INTRODUCTION

The perspective direction of the modern communications systems development is the design of Time-Sensitive Networks (TSN), where the main objectives are following [1, 2]:

- making the timing and synchronization more simple, robust, and accurate;
- creating the adequate protocols for serving the time-stamped latency-sensitive data;
- ability of the bandwidth reservation for particular flows with the guarantees over the specified delay, jitter and zero packet loss;
- allowing a fault-tolerance for the particular flow to have a redundant paths through the network ensuring that network failures will not cause a packet loss;
- possibility for any flow to reserve the level of Quality of Service (QoS), whether Unicast or Multicast, regardless of upper layers protocols;
- convergence of the existing QoS solutions with the TSN network while maintaining the TSN guarantees;
- support of all features of TSN for the best-effort traffic.

To achieve these objectives it is important to have an effective means to ensure quality of service, particularly in terms of average delay and packet jitter, which is critical for applications such as audio-visual broadcast (AVB), Internet of Things and others.

In this regard, routing protocols must also be introduced by procedures to enhance their functionality in terms of the required values of time QoS metrics. Therefore, the paper proposes the improvement of mathematical model of load balancing routing, adapted to the requirements of TSN technology.

## II. LOAD BALANCING ROUTING MODEL BASED ON QUALITY OF SERVICE PARAMETERS

Let us express the network by the graph $G=(V,E)$, where $V$ is the set of nodes, and $E$ is the set of edges, describing the network routers and links, respectively. In addition, for each link $(i,j)\in E$ there is the capacity $c_{ij}$ assigned. Consider the set $K$ be the set of flows between the source and destination nodes. For each $k\in K$, let $d_k$ be the bandwidth requirement for the *k*th flow, while $s_k$ and $t_k$ are the source and destination nodes, respectively. For each $(i,j)$ link and for each requirement let the control variable $x_{ij}^k$ represents the fraction of required *k*th bandwidth provided by the link $(i,j)$. Assume that all the variables $x_{ij}^k$ are non-negative real numbers:

$$0\le x_{ij}^k\le 1\,. \tag{1}$$

In addition, the flow conservation constraints must be considered during the solving the routing problem [3]:

$$\begin{cases}\sum\limits_{j:(i,j)\in E} x_{ij}^k-\sum\limits_{j:(j,i)\in E} x_{ji}^k=0,\ k\in K,\ i\ne s_k,\ t_k,\\ \sum\limits_{j:(i,j)\in E} x_{ij}^k-\sum\limits_{j:(j,i)\in E} x_{ji}^k=1,\ k\in K,\ i=s_k,\\ \sum\limits_{j:(i,j)\in E} x_{ij}^k-\sum\limits_{j:(j,i)\in E} x_{ji}^k=-1,\ k\in K, i=t_k.\end{cases} \tag{2}$$

According to the system of equations (2), the traffic incoming into the transit node has to be equal to the traffic outgoing from this node (other than source and destination nodes) for each *k*th flow in the network. Moreover, the link capacity utilization constraint also considered:

$$\sum_{k\in K} d_k x_{ij}^k\le c_{ij}\,,\ \ (i,j)\in E\,. \tag{3}$$

Given that the proposed solution is aimed to the application in TSN, the concept of the average packet delay $\tau_\pi^i$ in the *i*th circuit is introduced in analogy to the research [4]. For this purpose let us denote by *r* the cyclomatic number of the graph $G=(V,E)$, which defines the number of independent circuits as follows:

$$r=n-m+1\,, \tag{4}$$


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where $n$ is the number of links; $m$ is the number of nodes in the network.

For example, consider the network structure shown in Fig. 1, where the number of links is 5, and the number of routers is 4. Then, the number of independent circuits is equal to 2. Wherein the first circuit $\pi_1$ is formed by the first, second and third links connected in series according to their orientation. While the second circuit $\pi_2$ includes fourth, fifth and third links.

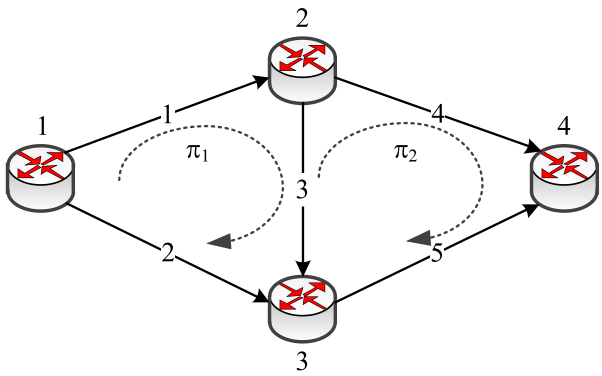


Fig. 1. Example of the network structure with the set of circuits.

According to the circuits introduced on the network structure, the expressions for the calculation of the circuit delays can be written:

$$\tau_\pi^1 = \tau_{12} + \tau_{23} - \tau_{13} ;$$

$$\tau_\pi^2 = \tau_{24} - \tau_{34} - \tau_{23} ,$$

where $\tau_{ij}$ ($i, j = \overline{1, m}$; $i \neq j$) is the average packet delay in the $i$th link and can be calculated using expression, for example, of serving the self-similar traffic [5]:

$$\tau_{ij} = \frac{\rho_{ij}^{1/2(1-H)}}{d_k x_{ij}^k (1-\rho_{ij})^{H/(1-H)}} , \quad (5)$$

where $\rho_{ij} = d_k x_{ij}^k / c_{ij}$ is the $(i, j)$ link utilization; $H$ is the Hurst parameter.

With the purpose of calculation of the average packet delay in communication link, other mathematical expressions can be used also depending on the flow model and the packet service discipline.

To ensure the minimal values of the end-to-end delays and jitter as the optimality criterion for solutions of the load balancing routing it is advisable to use the condition of the form:

$$J = \sum_{i=1}^{r} \tau_\pi^i \to \min . \quad (6)$$

Furthermore, the tending of the circuit delays to zero allows prevention of the routing loops, minimization of the multipath jitter value and equality of average packet end-to-end delays for different paths [6, 7].

Thus, the initial routing problem was reduced to the problem of mathematical programming, concerning to the class of nonlinear optimization. This is related to the fact that a nonlinear relation (5) connects the components of the objective function (6) with the control variables.

## III. Conclusion

The model of load balancing routing in the Time-Sensitive Networks is proposed, where the initial problem is formulated as an optimization. The novelty of the solution is a type of optimality criterion, the use of which minimizes the circuit delays that in turn helps to reduce the end-the-end delay, multipath jitter, as well as the probability of occurring the loops in the calculated routes of packet delivery. The proposed solution is compromise in terms of computational implementation as compared to the previously known models, in which the equality of the circuit delays of packets were considered as limitations, rather than optimality criterion.

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