# SEGMENT ROUTING IN DATA TRANSMISSION NETWORKS

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**A telecommunications network is a group of nodes and connections between them, the main purpose of the organization of which is to transmit information for a certain period of time. Since the network is only a tool, the technologies of applying this tool to the transmitted information may vary, i.e. the algorithms for transmitting information between nodes, choosing the order of transmission, building routes from one node to another may differ depending on the principles of network organization and the goals of information transmission. One of these technologies is Segment Routing (SR), created in order to improve the methods of working with the network, its vision and eliminate the problems inherent in the technologies previously used on these networks. Segment routing represents an important evolutionary step forward in the design, management and operation of modern data transmission networks. An important mechanism for optimizing the use of network resources is the load balancing mechanism. Data on the status of nodes and data transmission channels in the network can significantly facilitate the task of ensuring load balancing in the network. This article is devoted to an overview of segment routing technology, consideration of existing prerequisites for more active implementation and use of this technology.**

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## I. Introduction

The fundamental quality of telecommunication networks consists in their multi-connectivity. In other words, the signal transmission from point "A" to point "B" can be carried out along more than one route. For these purposes, special devices are used, which are called routers [1].

The main function of any network is to deliver data from the sender to one or more recipients with the necessary level of QoS (bandwidth, latency, delay variation, etc.). With the increase in the number of users, an increase in data transfer speed, as well as when using multicast, difficulties occur in any network. One of the tools that can cope with the growing demands is dynamic routing, its scheme is supported, for example, by the OSPF, IS-IS and BGP protocols [2].

Segment routing is, in essence, a way to organize a virtual network based on existing nodes and connections between them [3]. At the same time, the use of this technology eliminates the need to receive and store information about intermediate nodes located between the sender and recipient nodes, to deal with their configuration and management. It is the latter property that ensures the scalability and flexibility of the network architecture.

A router (node) in a segmented routing network is able to choose the explicit or shortest path over the Interior Gateway Protocol (IGP) [4]. Segments are sections of a path that a router can combine to form a complete route to a destination. Each segment has an identifier (Segment Identifier, SID), which is selected from a certain range and distributed throughout the network using new internal gateway protocol extensions [5]. It is the identifiers that make it possible to perform the primary engineering of data flows for their redirection between network nodes. Unlike traditional MPLS networks, in segment-routed networks, routers do not need to use Label Distribution Protocol (LDP) or Resource Reservation Protocol-Traffic Engineering (RSVP-TE) to assign and transmit their segment identifiers and generate forwarding information.

At the same time, the segment routing technology can act as an add-on to such a widely used MPLS technology, since segment routing is based on the principles of processing the MPLS header added to each data packet. An MPLS header may contain one or more labels. Multiple labels in an MPLS header are called a label stack. A label stack is a special kind of organization of a list of labels, organized according to the LIFO principle (Last in – First out), i.e. the last label pushed onto the stack will be popped first when the list is read. In an MPLS router, a packet with an MPLS label is sent to the next hop after looking up the label in the switching table instead of looking up the routing table, which is much faster, since the label processing can be performed not only by routers, but also by switches.

## II. Fundamentals of segment routing

Each router (node) and each connection (adjacency) has a corresponding segment identifier (SID) [6]. Host segment IDs are globally unique and represent the shortest path to the router, which is determined by the appropriate internal gateway protocol [7]. The network administrator allocates a host ID to each router in the reserved block. On the other hand, the adjacency segment identifier (adj-SID) is locally significant and represents a particular adjacency (egress interface) with a neighbor router. Routers automatically generate adjacency IDs outside of the reserved node ID block. Thus, the segment identifiers determine the path of transmission of data packets.

There are two kinds of segment identifiers:

– Pr fix SID – Segment ID that contains the IP address prefix computed by the internal gateway protocol on the service provider's core network. Prefix SIDs are globally unique. The node SID is a special form of the prefix SID that contains the node's loopback address as a prefix. It is declared as an index in the global SR block (SRGB) for a particular node.

– djacency SID – Segment ID that contains the adjacency of the local router to its neighbor. Essentially, an adjacency SID is a connection between two routers. Because the adjacency SID is specific to a particular router, it is locally unique. Thus, the adjacency SID is a local label that points to a specific interface and the interface of the next hop along the data packet path.

The Global Segment Routing Block (SRGB) is a range of labels reserved for segment routing. SRGB is a local property of the segment's routing node. When using segment routing, each node can be configured with a different SRGB value, and therefore the absolute value of the SID associated with the interior gateway protocol prefix segment can vary from node to node.

## III. The label stack as one of the key components of segment routing and a source of information for monitoring the data transmission network

One of the main sources of information for monitoring these networks can be a label stack. In segment routing, the segment may be the node itself, rather than the link between the nodes. In turn, the label (segment), which is for one node its own identifiers, for another will be in fact a command that must be executed.

Figure 1 shows a block diagram of the label stack processing process within the segment routing technology.

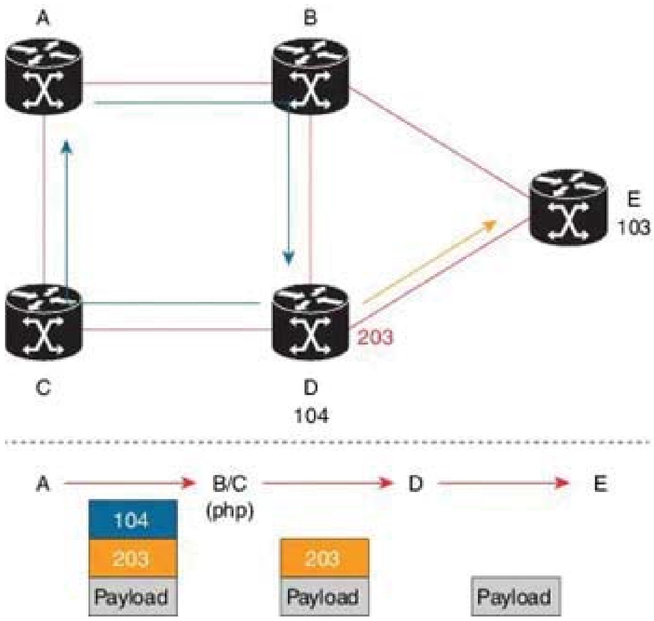


**Figure 1.** Block diagram of label stack processing within segment routing technology

Each node with the segment routing function involved checks the top label of the stack with its identifier and the identifiers of its neighbors. If the identifier matches the SID of the neighboring node, then the packet is transmitted to the specified node (FORWARD command), otherwise the top label is removed from the stack and the next label is read, which may contain both the SID of the next node or the port identifier for sending data to it. If the stack is empty, then the segment routing mechanism stops, and further data transfer continues using standard methods.

It is the label stack that allows to get a map of serially connected nodes in the network, however, the presence of the FORWARD command, which is undoubtedly convenient for using abstraction when building a route between remote nodes, does not allow to get the most accurate and detailed network map within this architecture. The most accurate data can only be obtained based on a fairly large sample of label stacks, and if the node was not noticed by the monitoring system at all for a long period of time, then its participation in the data transfer process can be questioned, because no route was built through this node, or additional processing of packet labels on this node was not performed.

Figure 2 shows an example of how a label stack is handled by a segment routing mechanism.

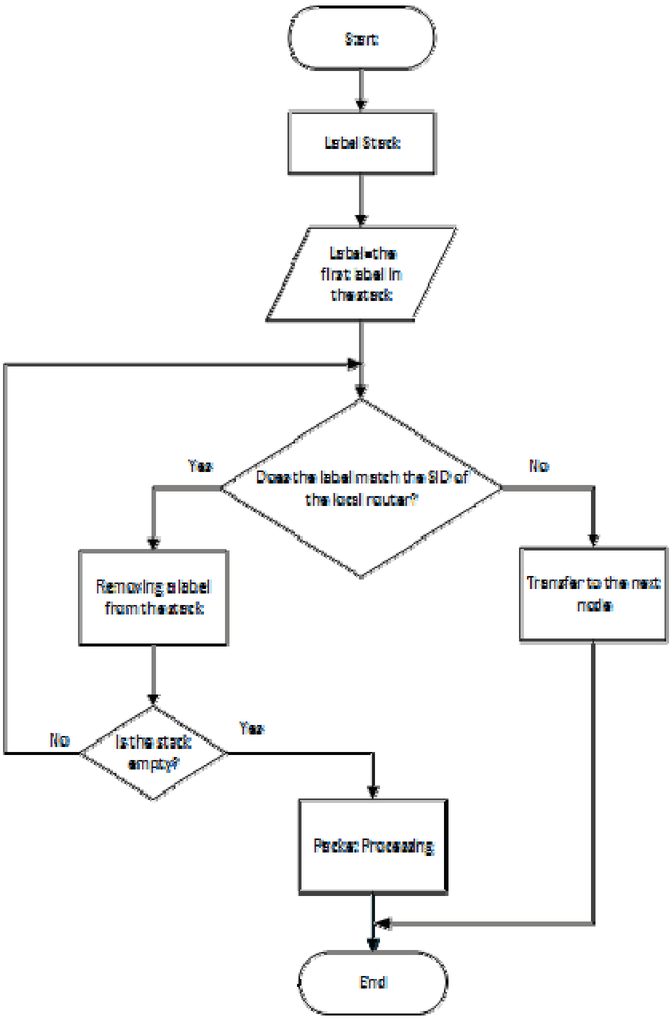


**Figure 2.** An example of processing a label stack by a segment routing mechanism

Segment IDs can be combined as an ordered list (stack) to perform traffic engineering functions [8]. The segment list may contain multiple adjacency segments, multiple node segments, or a combination of both, depending on the requirements for forwarding data packets. In the example shown in Figure 2, Router A could alternatively send a label stack (104, 203) to reach Router E using the shortest path and ECMP technology, and then through an available interface on Router D. Router A does not need to advertise other hosts in network about the new path, and the state information remains constant on the network. Router A ultimately enforces a routing policy that determines the data flows that are destined for Router E and the route to forward them.

With the constant removal of the label stack for each packet passing in a given network, as well as with the availability of information about the characteristics of the network nodes and data transmission channels between them, it is possible to calculate the load of each specific route in the network, each node in the network, as well as each specific connection in the network. networks. Suppose that the network has 2 channels with a capital capacity of 100 Mbps and 1 Gbps, a static route between segments on the first channel, even with an increase in the number of data streams, will quickly exhaust its bandwidth limits. But, thanks to the ability to track the congestion of data transmission channels, it is possible to detect potential problems in advance and take measures to rebuild routes before a critical situation occurs, as well as identify and eliminate bottlenecks in building routes. It should be noted that within the segment routing, due to its flexibility, there is a UFP (Unified Forwarding Pane) mechanism that allows to combine data transmission networks of various sizes, for example, LAN, MAN and WAN. At the same time, their independence from each other at the level of management and administration processes is preserved [9].

## IV. **Provision traffic engineering and management mechanisms**

Traffic Engineering (TE) is the ability to control the direction of traffic in order to fulfil certain conditions (channel reservation, network load distribution, balancing and congestion prevention) [10]. Conventional routing protocols (IS-IS, OSPF) provide limited traffic control capabilities based on the metrics of the links that make up the network [11].

To provide load balancing using segment routing, it is possible to use dynamic engineering to redirect traffic through the nodes of various telecom operators using the UFP mechanism. Since a controller is needed to dynamically build routes, organize failure protection and management in such networks, organizing the simplest interaction between controllers in the networks of different telecom operators can allow traffic to be exchanged by sending simple requests for bandwidth allocation in communication channels with further packet encapsulation one operator into another operator's packet on the border routers of their networks. But when one packet is encapsulated in another, routing connectivity is lost, and the load on edge routers also increases, which leads to the loss of the essence of the flexibility of the segment routing mechanism. Instead, it is possible to exchange a minimum number of labels between edge devices, adding these labels to their own routing tables for use in all neighboring networks.

The segment routing mechanism in the exchange of information between networks of different telecom operators can provide another extremely useful function: without disclosing the physical or even approximate network architecture, a neighboring telecom operator can provide information about its available routes to external networks using label forwarding [12].

Figure 3 shows a possible way to organize a protection mechanism against failures that occur during data transmission by redirecting traffic to a third-party ISP based on segment routing.

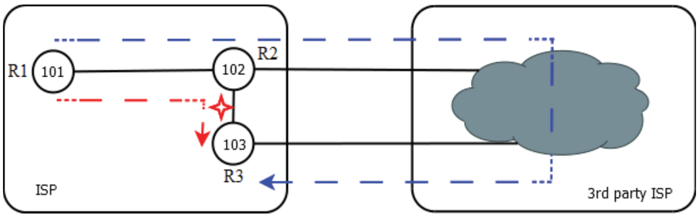


**Figure. 3.** Organization of a protection mechanism against failures that occur during data transmission by redirecting traffic to a third-party ISP based on segment routing

As can be seen from Figure 3, if the data transmission channel between nodes R2 and R3 in the network of the ISP is interrupted, it can be used the cloud infrastructure of a third-party ISP to ensure data transmission between nodes R1 and R3. To do this, it is absolutely not necessary to have information about the architecture of those network. The SR mechanism in the network of third-party ISP will take over all the work of switching traffic on its side. To do this, traffic from node R2 must be forwarded to a node in the network of a third-party ISP using the Topology-Independent Loop-Free Alternate (TI-LFA) protocol with the same stack of nodes. The TI-LFA protocol supports the protection of nodes and data links in any topology, compensating for the shortcomings of traditional tunnel protection technologies. The receiving party only needs to know the location of the ingress and egress forwarding points in its network. Even if there were intermediate nodes between nodes with a problem connection, thanks to the use of the TI-LFA protocol, these nodes can be ignored, thereby reassembling a new stack of route segments. If the stack is forwarded unchanged, then the nodes in the third-party ISP segment must forward traffic to the first known node in the stack, thereby discarding intermediate inaccessible nodes. Segment routing technology does not require in its use the use of notification mechanisms about the state of nodes and links between them. All routing decisions are made by the source using the internal gateway protocols, for example, OSPF or IS-IS, or the controller, specifying the available routes.

All available paths can be labelled (using, for example, the RGB label color scheme) according to their declared characteristics. By simply passing a color label with a route stack between controllers, it will be possible to ensure quality of service (QoS) performance even when traffic is redirected. The route exchange packet format proposed below will allow neighboring controllers to obtain the necessary information about their routes in an exhaustive way (Figure 4).

| ISP label | IP address of the ingress point | Route label stack | IP address of the egress point | Route marking | Route cost |
|---|---|---|---|---|---|
| | | | | | |

**Figure 4.** Possible format of the route information exchange package

The proposed exchange format provides the following data:

– ISP label – is a pointer to the ISP providing the route and is required for internal calculation of both billing (traffic accounting) and route cost calculation algorithms within the network of the recipient's ISP;

– IP address of the ingress point – required to add information about the adjacent segment on the boundary segment. Without this field, hosts simply do not know where the entry point of the route is;

– oute label stack – numbers of segments required for traffic switching in the network of another operator, these labels must be added to the stack or encapsulated by some mechanism at the edge nodes. For the mechanism described above to work, it is necessary to have at least the ingress and egress route points in a foreign network to eliminate re-encapsulation;

– IP ddress of the egress point – needed to find the segment closest to the output in the home network;

– oute marking – standard color marking of the route corresponding to one or another used QoS metric;

– oute cost – the original cost of the route as determined by the sender.

In view of all of the above, the stack can be considered as a vector of the direction of the packet through the network, its additional color label can serve as a “weight” metric, or be considered as another variable in the vector.

After receiving a packet with this data format, the controller needs to determine whether the route can be used according to the ISP label by any available mechanism, for example, OSPF or IS-IS, then find the nearest segment to the specified address of the input node and add the label to its global stack or configure the adjacency index to the specified node on the interface leading to this address.

By configuring the ingress point, the controller can add a route to its route matrix. At the same time, by internal mechanisms, based on the provided metric and label, he can calculate the new cost of the route, as well as compare the labels of characteristics. When adding such a route, the controller needs to determine known routes containing the closest points to the ingress and egress addresses and add routes with "embedded" received stacks.

Since the IPv6 addresses themselves are used as markers in the SRv6 networks being developed, the transmitted packet can get rid of the addresses of the input and output nodes.

Such an organization of interaction completely abstracts the ISP from thinking through the details of using classical routing mechanisms, and a simple exchange of labels of neighboring networks will increase the flexibility of traffic engineering and load balancing.

Figure 5 shows a scenario of possible interaction between data transmission networks of two ISPs based on segment routing technology.

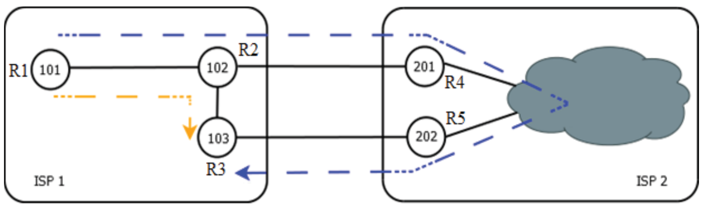


**Figure 5.** Scenario of interaction between data transmission networks of two ISPs based on segment routing technology

Figure 5 illustrates in detail what information two neighboring segment routing domains need to have. The interaction is based on the transmission of service information in the format described above. To build two routes to node R3, one of which runs through the network of a third-party ISP2, it is necessary to form a stack of route labels to node R3. Based on this information, SR controllers can integrate edge nodes into their network, knowledge of which will allow switching traffic simply by moving along the generated label stack of the route, no matter how complex and long it is. Figure 5 shows that in the case of data transfer between nodes R1 (SID 101) and R3 (SID 103) (the data transfer path is shown by a yellow arrow), if for some reason it is not possible to transfer data between nodes R2 (SID 102) and R3 (SID 103), traffic will be directed towards node R4 (SID 201). Two new labels, 201 and 202, will be added to the label stack. Traffic is then forwarded to the R4 router interface, and the route label stack will look like this: $\{101, 102, 201, 202, 103\}$.

Node R4 is a node of a neighboring carrier, and we are completely indifferent to the details of the routing process within this domain. The mere information that the next segments in the forwarding will be segments $\{201, 202\}$ is sufficient for the routing mechanism and ensuring that traffic enters the R5 node (SID 202) by any means. And the next label 103, which belongs to node R3, is the boundary for node R5 and is known to its domain due to the route data exchange format described above (the data transmission path is shown by the blue arrow).

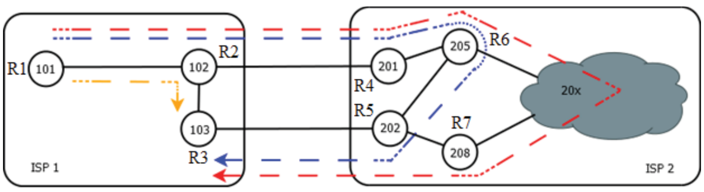


**Figure 6.** Traffic engineering within two adjacent data transmission networks based on segment routing

As can be seen from Figure 6, if ISP2 provides more detailed information about the number of SR nodes in its network, or at least provides individual nodes as transit waypoints, integrating this information into its SR controller and supporting interaction with these nodes, as well as building based on their routes, opportunities open up for traffic engineering in this network. For example, when transmitting data from node R1 (SID 101) to node R3 (SID 103), without additional information, there would be only one route 101-102-201-205-202-103 (blue arrow) alternative to route 101-102-103 (yellow arrow), but knowing at least one more node in the neighboring segment routing domain opens up the possibility of routing traffic through the new route 101-102-201-205-20x-208-202-103 (red arrow).

At the same time, having received information that there are several 20x nodes in the network, you can get and organize a group of routes, load balancing between which (neighboring hubs and intermediate nodes in the network of a third-party operator) is handled by the operator himself and his segment routing controller.

Knowing several intermediate segments, several data transfer routes are determined at once, requesting new routes and their color labels on these nodes, it is possible to organize load balancing and make a decision on traffic redirection to meet QoS characteristics.

In essence, segment routing has already implemented an approach to choosing a route based on the source through a matrix of routes and their metrics, however, in order to use the mechanisms described above for transmitting packets using segment routing in networks of different ISPs, it is necessary to implement a mechanism on the controller side, supplement the matrix again received routes from third-party controllers, ensure the introduction of a new label into the vector about belonging to a particular operator or, if necessary, even a real value label. All this will make it possible to optimally select routes even in the absence of critical situations, for example, to compensate for the previously transmitted traffic of another operator, choose its vectors as a priority to reduce costs in its own network.

## V. Conclusion

Segment routing replaces various IP/MPLS protocols and increases the flexibility of working with services. It allows to reduce the number of protocols in IP/MPLS networks, as well as simplify their operation and maintenance. With its help, it is possible to determine the optimal shortest paths for data transmission, provide fast rerouting, global resource prediction, optimization of traffic routes in transport networks, and the proposed method can help achieve these goals.

Segment routing is a flexible, scalable way to route sources. The source chooses a path and encodes it in the packet header as an ordered list of segments. Each segment is identified by a segment identifier (SID), which is a 32-bit integer.

Segment routing allows to simplify the level of network management, reduce the requirements for routers, achieve flexible expansion and network scalability. It provides an unprecedented level of traffic control. At the same time, it can be introduced into existing networks. All of this shows that the future of segment routing has so much potential to transform networks and the services they provide quickly and flexibly.

With segment routing, the network no longer needs to maintain state on a per-application, per-flow basis. Instead, it obeys the shipping instructions contained in the package. Segment routing is based on a small number of extensions to the IS-IS and OSPF protocols. It can work with MPLS or IPv6 data plane and integrates with MPLS multi-service capabilities including L3VPN, VPWS (Virtual Private Wire Service), VPLS (Virtual Private LAN Service), and EVPN (Ethernet VPN).

It is also important that segment routing is capable of supporting future services within 5G and IoT networks, and it can be considered as the foundation for building new generation transport data transmission networks, since in order to introduce innovative services, the transport network must support flexible programming of services, network segmentation (network slicing) and customization based on user needs.

Knowing several intermediate segments, it is possible to determine several routes for data injection at once. By requesting new routes and their color labels on the respective nodes, it is possible to organize load balancing and make a decision to redirect traffic to meet QoS characteristics.

## References


1. A.V. Alyoshintsev (2011). An overview of wireless systems with the ability to implement the principles of dynamic routing when transmitting signals and commands from one node to another in smart buildings. *T-Comm*. No9. S5. 2011, pp. 8-13. (In Russian)
2. A.V. Alyoshintsev (2017). Modeling of modems in conditions of multi-connected network topology with dynamic routing. *Methodological issues of teaching infocommunications in higher education*. 2017. V. 6. No. 3. pp. 4-6. (In Russian)
3. C. Filsfils, K. Michielsen, K. Talaulikar, “Segment Routing, Part I”. Cisco Systems, Inc., 2018.
4. A. V. Shvedov, D. V. Gadasin and O. G. Klygina, "Determining Shortest Paths between Two Arbitrary Nodes in a Composite Transport Network Using Segment Routing," *2021 Systems of Signals Generating and Processing in the Field of on Board Communications*, 2021, pp. 1-8, doi: 10.1109/IEEECONF51389.2021.9416072.
5. A. V. Shvedov, D. V. Gadasin and E. V. Pak, "Application of the Backman Model for the Distribution of Traffic Flows in Networks with Segment Routing," *2022 Systems of Signals Generating and Processing in the Field of on Board Communications*, 2022, pp. 1-5, doi: 10.1109/IEEECONF53456.2022.9744344.
6. A.V. Shvedov, D. V. Gadasin, O. G. Klygina (2022). Organization of interaction of fog computing and segment routing for the provision of IOT services in smart grid. *Synchronization systems, signal generation and processing*. 2022. Vol. 13. No. 3, pp. 40-49.
7. C. Filsfils, S. Previdi, L. Ginsberg, B. Decraene, S. Litkowski, R. Shakir, “Segment Routing Architecture”, document RFC 8402, 2018.
8. D. V. Gadasin, A.V. Shvedov, A.V. Koltsova (2021). Probabilistic assessment of virtual cluster construction. *Proceedings of the international symposium "Reliability and Quality"*. 2021. Vol. 1, pp. 87-92.
9. D. V. Gadasin, A. V. Shvedov, O. G. Klygina and I. V. Shulginov, "Routing Management System Formation for Machine-to-Machine Interaction in a Decentralized Environment," *2021 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF)*, 2021, pp. 1-7, doi: 10.1109/WECONF51603.2021.9470710.
10. D. V. Gadasin, A.V. Shvedov, O. G. Klygina, D. D. Gadasin (2021). Implementation of the fog computing platform for the provision of IoT services. *REDS: Telecommunication devices and systems*. 2021. Vol. 11. No. 2, pp. 65-75.
11. V. V. Maklachkova, A. V. Shvedov and S. Alyev, "Analysis of Resilience Indicators in Corporate Networks and Possible Ways to Improve It," *2022 Systems of Signals Generating and Processing in the Field of on Board Communications*, 2022, pp. 1-5, doi: 10.1109/IEEECONF53456.2022.9744353.
12. D. O. Marchenko, O. G. Klygina, D. V. Gadasin, A.V. Shvedov (2021). Ensuring load balancing mechanisms in networks with segment routing based on monitoring data. *Promising technologies in information transmission media: materials of the 14th International Scientific and Technical Conference*, Vladimir, October 06-07, 2021. Vladimir: Vladimir State University named after Alexander Grigoryevich and Nikolai Grigoryevich Stoletov, 2021, pp. 419-422.


## СЕГМЕНТНАЯ МАРШРУТИЗАЦИЯ В СЕТЯХ ПЕРЕДАЧИ ДАННЫХ


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**Аннотация**

Телекоммуникационная сеть является группой узлов и связей между ними, основная цель её организации заключается в передаче информации за определенный промежуток времени. Поскольку сеть является лишь инструментом, технологии применения этого инструмента к передаваемой информации могут варьироваться, т.е. алгоритмы передачи информации между узлами, выбор порядка передачи, построение маршрутов от одного узла к другому могут отличаться в зависимости от принципов организации сети и целей передачи информации. Одной из таких технологий является сегментная маршрутизация (Segment Routing, SR), созданная для того, чтобы усовершенствовать методы работы с сетью, ее видение и устранить проблемы, присущие ранее использовавшимся на данных сетях технологиям. Сегментная маршрутизация представляет собой важный эволюционный шаг вперед в области проектирования, управления и эксплуатации современных сетей передачи данных. Важным механизмом обеспечения оптимизации использования сетевых ресурсов является механизм балансировки нагрузки. Данные о состоянии узлов и каналов передачи данных в сети могут существенно облегчить задачу обеспечения балансировки нагрузки в сети. Данная статья посвящена обзору технологии сегментной маршрутизации, а также рассмотрению существующих предпосылок для более активного внедрения и использования данной технологии.



***Ключевые слова:*** *сегментная маршрутизация, маршрутизация, балансировка нагрузки, мониторинг сети, метки, стек меток, SID, Traffic Engineering.*

**Литература**


1. *Алёшинцев А.В.* Обзор беспроводных систем с возможностью реализации принципов динамической маршрутизации при передаче сигналов и команд от одного узла другому в интеллектуальных зданиях // T-Comm: Телекоммуникации и транспорт. 2011. Т. 5. № 9. С. 8-13.
2. *Алёшинцев А.В.* Моделирование модемов в условиях многосвязной сетевой топологии с динамической маршрутизацией // Методические вопросы преподавания инфокоммуникаций в высшей школе. 2017. Т. 6. № 3. С. 4-6.
3. *Filsfils C., Michielsen K., Talaulikar K.* Segment Routing, Part I. Cisco Systems, Inc., 2018.
4. *Shvedov A.V., Gadasin D.V., Klygina O.G.* Determining Shortest Paths between Two Arbitrary Nodes in a Composite Transport Network Using Segment Routing // 2021 Systems of Signals Generating and Processing in the Field of on Board Communications, 2021, pp. 1-8, doi: 10.1109/IEEECONF51389.2021.9416072.
5. *Shvedov A.V., Gadasin D.V., Pak E.V.* Application of the Backman Model for the Distribution of Traffic Flows in Networks with Segment Routing // 2022 Systems of Signals Generating and Processing in the Field of on Board Communications, 2022, pp. 1-5, doi: 10.1109/IEEECONF53456.2022.9744344.
6. *Шведов А.В., Гадасин Д.В., Клыгина О.Г.* Организация взаимодействия туманных вычислений и сегментной маршрутизации для предоставления сервисов IOT в smart grid // Системы синхронизации, формирования и обработки сигналов. 2022. Т. 13. № 3. С. 40-49. EDN TRRYZN.
7. *Filsfils C., Previdi S., Ginsberg L., Decraene B., Litkowski S., Shakir R.* Segment Routing Architecture, document RFC 8402, 2018.
8. *Гадасин Д.В., Шведов А.В., Кольцова А.В.* Вероятностная оценка построения виртуального кластера // Труды международного симпозиума "Надежность и качество". 2021. Т. 1. С. 87-92. EDN BCNSGB.
9. *Gadasin D.V., Shvedov A.V., Klygina O.G., Shulginov I.V.* Routing Management System Formation for Machine-to-Machine Interaction in a Decentralized Environment // 2021 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), 2021, pp. 1-7, doi: 10.1109/WECONF51603.2021.9470710.
10. *Гадасин Д.В., Шведов А.В., Клыгина О.Г., Гадасин Д.Д.* Реализация платформы туманных вычислений для предоставления сервисов IoT / // REDS: Телекоммуникационные устройства и системы. 2021. Т. 11. № 2. С. 65-75.
11. *Maklachkova V.V., Shvedov A.V., Alyev S.* Analysis of Resilience Indicators in Corporate Networks and Possible Ways to Improve It // 2022 Systems of Signals Generating and Processing in the Field of on Board Communications, 2022, pp. 1-5, doi: 10.1109/IEEECONF53456.2022.9744353.
12. *Марченко Д.О., Клыгина О.Г., Гадасин Д.В., Шведов А.В.* Обеспечение механизмов балансировки нагрузки в сетях с сегментной маршрутизацией на основе данных мониторинга // Перспективные технологии в средствах передачи информации : материалы 14-ой международной научно-технической конференции, Владимир, 06-07 октября 2021 года. Владимир: Владимирский государственный университет имени Александра Григорьевича и Николая Григорьевича Столетовых, 2021. С. 419-422. EDN ZSCNIR.