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Computing Energy Consumption Path in Segment Routing Networks

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Abstract

This document elaborates on the method for calculating energy consumption paths in Segment Routing (SR) networks, aiming to evaluate and optimize traffic-related metrics on network paths, including energy consumption and carbon emissions.

Status of This Memo

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1. Introduction

With the accelerated global digital transformation, the scale and complexity of network infrastructure have grown exponentially. The accompanying energy consumption and carbon emission issues have become key bottlenecks restricting the sustainable development of the industry. Building a green, low-carbon, and efficient network operation system is no longer merely a means of cost control, but has evolved into a crucial core research direction in the field of information and communication technology. How to achieve energy conservation and emission reduction through intelligent resource scheduling and path optimization while ensuring network service quality has become a common focus.

Existing research and practices mainly focus on two scenarios:

First, the dynamic sleep mechanism based on the traffic tidal effect. Given that network traffic exhibits significant periodic fluctuations in temporal and spatial distribution (i.e., the "tidal phenomenon"), this strategy can, during off-peak business periods (trough periods), use the network controller to accurately identify idle links, dynamically shut down some network devices, line cards, or ports, putting them into a deep sleep state. This directly reduces the number of active devices at the physical level and significantly lowers basic energy consumption.

Second, the green routing algorithm strategy integrating carbon emission intensity. In the process of establishing or re-optimizing paths for private line users, real-time or predicted "carbon emission intensity" is introduced as a key metric, giving priority to low-carbon paths powered by clean energy or with higher energy efficiency ratios. This mechanism not only reduces the carbon footprint in a single connection but also gradually forces old nodes with high carbon emission factors to exit the core forwarding plane through long-term traffic guidance, accelerating the iteration and update of network infrastructure to high-energy-efficiency nodes.

The existing relevant research content in the IETF includes:

[I-D.many-lsr-power-group-02] proposes a mechanism for advertising and managing power-groups using the IS-IS routing protocol. Its core is to enable the controller to perceive the power consumption dependencies of network hardware, support more intelligent traffic engineering, and thereby achieve network energy conservation. This mechanism can be well combined with the traffic tidal phenomenon, concentrating traffic into several power groups and putting unloaded components into sleep.

[I-D.petra-path-energy-api-02] defines a PETRA API that provides a standardized network energy consumption query interface, allowing users to send queries to the network to retrieve traffic-related energy consumption and environment-derived metrics for specified network paths. These metrics are computed by the network infrastructure devices dynamically involved in the path. Through the API, users can query and select forwarding paths with lower carbon emissions.

[I-D.belmq-green-framework-10] proposes an architecture for energy consumption collection and monitoring. The draft mentions an API that enables external systems— such as upper-layer energy management systems, carbon accounting platforms, and operational dashboards—to query and retrieve energy consumption, energy efficiency metrics, and associated metadata for devices or networks.

[I-D.ietf-green-terminology-01] specifies the metrics applicable to energy consumption assessment and provides a reference for terms and parameters related to energy-efficient routing. Among these, the Energy Efficiency Ratio (EER) is a key metric for evaluating the energy conversion efficiency of networks, devices, or components, which is fundamentally defined as the ratio of useful output to energy input in an energy conversion process. The energy efficiency ratio is a key parameter for private line energy consumption and carbon emission intensity assessment.

[RFC9252] defines the fundamental architecture and operational principles of Segment Routing (SR) and describes the SR network programming model, which enables flexible network path control through the definition of Segment Identifiers (SIDs). This document focuses on path computation based on energy consumption information and utilizes SR to implement energy-aware path control.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119] (Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997) and [RFC8174] (Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017).

1.2. Terminology

Energy Efficiency/Energy Efficiency Ratio (EER): The energy efficiency is expressed as the ratio between the useful output and input of an energy conversion process of a network, device, or component[I-D.ietf-green- terminology-01].

This ratio (i.e., Energy Efficiency Ratio, EER) is the throughput forwarded by 1 watt (e.g., [I-D.cprjgf-bmwg-powerbench]).

2. Background

In the modern digital era, driven by the demand for sustainable development and the need to reduce operational costs, network energy consumption has become a core concern. Networks consume substantial energy, leading to carbon emissions and environmental impacts. Optimizing energy usage helps reduce their carbon footprint and supports global efforts to combat climate change. Energy is a major operational expense for network operators, and improving efficiency directly lowers electricity costs, especially in large-scale networks, resulting in significant financial savings. As network traffic grows exponentially, energy-efficient designs ensure sustainable scalability without proportional increases in energy consumption, which is essential for supporting future technologies such as 5G, IoT, and cloud computing.

The source routing characteristics of SR make it a flexible, scalable, and efficient networking technology. SR simplifies network control, enables explicit path definition, and ensures compatibility with existing technologies, which can meet the demands of modern networks for traffic engineering, fault recovery, and scalability while reducing complexity and overhead. Additionally, SR networks support network slicing, allowing the creation of independent paths for different service types.

SR networks can be utilized for energy-efficient path optimization in large-scale networks and seamlessly integrate with existing IPv4/IPv6 infrastructures. By collecting energy consumption data from each node and link, SR can plan energy-efficient paths based on routing policies, thereby achieving the goal of reducing overall network energy consumption.

The motivations for addressing energy consumption in SR networks include, but are not limited to:

1. Through SR TE, traffic can be concentrated into a few device components, providing a foundation for dynamic shutdown based on traffic tides.

2. SR networks enable deterministic evaluation of energy consumption and carbon emissions across different paths from source to destination. Due to variations in the geographical locations and construction timelines of Core Network Rooms housing forwarding devices, there are significant differences in device energy efficiency levels and the proportion of renewable (green) electricity used. Leveraging the capabilities of SR networks, it becomes possible to directly compare and assess the energy cost and carbon footprint of alternative forwarding paths.

3. Energy consumption parameters

Energy consumption parameters include Energy Efficiency Ratio (EER), renewable electricity usage ratio, carbon emission factor, etc.

3.1. Energy Efficiency:

The energy efficiency metric EER is expressed in megabits per watt (Mbit/W), representing the actual forwarding throughput achieved per watt of power consumed. A higher value indicates better device energy efficiency. This metric is typically derived from laboratory testing and is distributed in the network as a static value.

For more details on the EER metric, please refer to [I-D.ietf-green-terminology-01].

3.2. Renewable electricity usage ratio & carbon emission factor:

For carbon emission estimation of traffic traversing multi-hop, multi-site paths with varying renewable electricity usage ratios across different facilities, a per-segment accounting method SHOULD be employed. For each segment corresponding to a facility along the traffic path, carbon emissions associated with fossil fuel-based electricity MUST be calculated by deducting the portion covered by renewable energy.

The carbon emission calculation formula for a single segment is as follows:

Cn = En x Fn x (1 - Rn)

where: Cn is the carbon emission of segment n (t CO2e), En is the electricity consumption allocated to the traffic on segment n (kWh), Fn is the grid average carbon emission factor for the region where segment n is located (t CO2e/kWh), Rn is the renewable energy ratio consumed at the facility of segment n.

The grid average carbon emission factor Fn indicates the carbon intensity of the local power grid. A higher value of Fn implies a higher share of fossil fuel-based electricity, a lower share of renewable energy, and a higher environmental cost associated with power consumption.

The grid carbon emission factor Fn is obtained from official regional grid emission databases, and updated periodically (e.g., annually).

The renewable energy ratio Rn is provided per site/facility by the operator’s energy management system or carbon management platform, based on actual renewable energy consumption and credible energy attribute certificates. The network controller does not generate these parameters but retrieves them via northbound interfaces or local configuration.

4. Private Line Carbon Accounting Mechanism

The computation framework for carbon accounting in SR networks proposed in this document is as follows: A centralized controller collects EER parameters from all nodes in the SR domain, and retrieves the renewable energy ratio and carbon emission factor per node from the energy management system and other related platforms.

When a path query is triggered via an external API (e.g., PETRA API), the controller calculates the end-to-end energy consumption and carbon emissions for candidate paths according to the source, destination, and traffic volume. After the optimal path is selected by the API caller, the controller deploys the selected path as an SR Policy to the head-end node.

```
                             +-------------------+
                             |Carbon Management |
                             +-------/|\ |-------+
                                     |  | API(PETRA API)-Energy Consumption Information Q
uery
                  Carbon Emissions   |  |
                  Energy Consumption |  |
                             +--------| \|/------+
                    +--------|Network Controller| Energy Consumption and Carbon Emissions
 Calculation
                    |        +------/|\ |-------+
         SR-Policy  |  Power metrics |  | Energy-aware Forwarding Path Optimization
                    |  Collection    |  |
                    |                |  |
                 +-\|/-+   +---------| \|/---------+   +-----+
       Handling  |Head |---|    Segment Routing    |---|End  |
       behaviors |Point|   |    Network Domain     |   |Point|
                 |     |   |  PE ----- P ------ PE |   |     |
                 +-----+   +-----------------------+   +-----+
```

Figure 1: Framework of Computing Energy Consumption path in SR network

4.1. Energy Consumption Collection

The Energy Efficiency Ratio (EER) is distributed and collected within the SR network domain through IGP protocol extensions. In cross-domain scenarios, it can be advertised and collected using BGP-LS (BGP Link-State) extensions.

The collection of energy consumption information between the SR network domain and the network controller adopts standardized methods, such as YANG, NETCONF, and SNMP.

The renewable electricity usage ratio and carbon emission factor are obtained by the controller from the carbon management platform.

4.2. Path Calculation Based on Energy Consumption

The network controller selects network paths based on the collected energy consumption information and performs path computation according to a specified policy. First, calculate N candidate paths using traditional metrics such as bandwidth, delay, and packet loss rate.

Then, evaluate the energy consumption and carbon emissions of each path.

Finally, the controller returns the computed results—including both energy and carbon metrics—to the upper-layer application via an API.

It is important to emphasize that carbon emission assessment is critical, as the total power consumption of a path—derived from traffic volume and device energy efficiency ratio (EER)—may not accurately reflect its true environmental impact.

For example: Suppose the controller receives an API request specifying a source address, destination address, and traffic volume, and computes two candidate paths. Path A has a higher total power consumption than Path B. However, because the data centers or nodes along Path A use a significantly higher proportion of renewable (green) electricity, the resulting carbon emissions—obtained by converting the electricity consumed into CO_2 equivalents using location- and time-specific emission factors—are substantially lower for Path A. In this case, despite its higher power draw, Path A represents the environmentally preferable option with a lower overall carbon footprint.

4.3. Issuance of Path

The network controller distributes the path to the head-end node. This distribution can be performed using standard mechanisms such as YANG, BGP, or PCEP.

The head-end node conducts network forwarding based on the distributed SR Policy.

When using YANG, BGP, or PCEP, necessary expansions for the energy consumption metric should be made.

5. Use Case

5.1. Dynamic link shutdown

```
                             +------------------+
                    +--------|Network Controller|
                    |        +------/|\ |-------+
         SR-Policy  |  Power metrics |  | Energy-aware Forwarding Path Optimization
                    |  Collection    |  |
                    |                | \|/
                 +-\|/-+     +----P1----P2----P3----+        +-----+
                 |     |     |          |           |        |     |
                 |Head |--- PE1         |          PE2-------|End  |
                 |Point|     |          |           |        |Point|
                 +-----+     +----P4----P5----P6----+        +-----+
```

   Figure 2: Leveraging traffic tide patterns for dynamic shutdown
                         of network elements

   As shown in the figure, there are multiple reachable forwarding paths
   from the head node to the end node:

   PE1-P4-P5-P6-PE2 and PE1-P1-P2-P3-PE2.

   When night falls and the traffic proportion gradually decreases, TE
   technology can be used to concentrate traffic onto one path and put
   the other into deep sleep to reduce energy consumption.

5.2. Network Path Carbon Emission Assessment

```
                             +------------------+
                             |Carbon Management |
                             +------/|\ |-------+
                                     |  | API(PETRA API)-Energy Consumption Information Q
uery
                  Carbon Emissions   |  |
                  Energy Consumption |  |
                             +-------| \|/------+
                    +--------|Network Controller| Energy Consumption and Carbon Emissions
 Calculation
                    |        +------/|\ |-------+
         SR-Policy  |  Power metrics |  | Energy-aware Forwarding Path Optimization
                    |  Collection    |  |
                    |                | \|/
                    |            EER:100 Mbits/W
                 +-\|/-+     +---------P1-------+    +-----+
                 |     |  100|                  |100 |     |
                 |Head |--- PE1                PE2---|End  |
                 |Point|     |    200 Mbits/W   |    |Point|
                 +-----+     +---------P2-------+    +-----+
```

          Figure 3: Network Path Carbon Emission Assessment

As shown in the figure above, there are two paths from the head node to the tail node: PE1 -> P1 -> PE2 and PE1 -> P2 -> PE2.

Among them, PE1, PE2, and P1 have the same energy efficiency parameter of 100 Mbits/W, with a green power usage ratio of 50%. Device P2 has an energy efficiency ratio (EER) of 200 Mbits/W and a green power usage ratio of 10%.

At this time, an upper-layer application queries the optional paths from the head node to the tail node, as well as their power consumption and carbon emission costs, via an API.

The calculation process is as follows:

1. After the router devices distribute the parameters via IGP, they synchronize the energy efficiency ratio parameter EER to the network controller through BGP-LS (since EER is a static parameter, it does not need to be flooded repeatedly).

2. The controller obtains the local power grid carbon emission factor Fn of each node and the green power usage ratio Rn of the core network equipment room where the node is located from the carbon management platform.

3. The controller parses the source address, destination address, and traffic volume from the parameters input via the API. Assume the traffic volume is 2000 Mbits.

4. The controller calculates the optional paths:

    * Path 1: PE1 -> P1 -> PE2

    * Path 2: PE1 -> P2 -> PE2

5. The controller calculates the energy consumption and carbon emission level for each segment of the optional paths. In this example, the emission levels of Path 1 and Path 2 differ due to P1 and P2:

    * P1 has an energy efficiency ratio of 100 Mbits/W, so the power consumption for 2000 Mbits traffic is 0.02 kW.The corresponding carbon emission is: Cn = 0.02 x Fn x (1 - 0.5) = 0.01Fn

    * P2 has an energy efficiency ratio of 200 Mbits/W, so the power consumption for 2000 Mbits traffic is 0.01 kW.The corresponding carbon emission is: Cn = 0.01 x Fn x (1 - 0.1) = 0.009Fn

It can be seen from the above that even though P2 has better energy efficiency at the device level, Path 1 has lower carbon emissions due to its higher green power usage ratio.

6. IANA Considerations

The Flow Monitor Option Type should be assigned in IANA.

7. Security Considerations

TBD.

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