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I. Nishioka
NEC Corp.
D. King
Old Dog Consulting
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Use of the Synchronization VECTOR (SVEC) List for Synchronized Dependent Path Computations

Abstract

A Path Computation Element (PCE) may be required to perform dependent path computations. Dependent path computations are requests that need to be synchronized in order to meet specific objectives. An example of a dependent request would be a PCE computing a set of services that are required to be diverse (disjointed) from each other. When a PCE computes sets of dependent path computation requests concurrently, use of the Synchronization VECTOR (SVEC) list is required for association among the sets of dependent path computation requests. The SVEC object is optional and carried within the Path Computation Element Communication Protocol (PCEP) PCRequest (PCReq) message.

This document does not specify the PCEP SVEC object or procedure. This informational document clarifies the use of the SVEC list for synchronized path computations when computing dependent requests. The document also describes a number of usage scenarios for SVEC lists within single-domain and multi-domain environments.

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1. Introduction

[RFC5440] describes the specifications for the Path Computation Element Communication Protocol (PCEP). PCEP specifies the communication between a Path Computation Client (PCC) and a Path Computation Element (PCE), or between two PCEs based on the PCE architecture [RFC4655]. PCEP interactions include path computation requests and path computation replies.

The PCE may be required to compute independent and dependent path requests. Path computation requests are said to be independent if they are not related to each other and therefore not required to be

synchronized. Conversely, a set of dependent path computation requests is such that their computations cannot be performed independently of each other, and the requests must be synchronized. The Synchronization VECTOR (SVEC) with a list of the path computation request identifiers carried within the request message allows the PCC or PCE to specify a list of multiple path computation requests that must be synchronized. Section 1.1 ("SVEC Object") describes the SVEC object. Section 1.2 ("Application of SVEC Lists") describes the application of SVEC lists in certain scenarios.

This informational document clarifies the handling of dependent and synchronized path computation requests, using the SVEC list, based on the PCE architecture [RFC4655] and PCEP [RFC5440]. The document also describes a number of usage scenarios for SVEC lists within single-domain and multi-domain environments. This document is not intended to specify the procedure when using SVEC lists for dependent and synchronized path computation requests.

1.1. SVEC Object

When a PCC or PCE sends path computation requests to a PCE, a PCEP Path Computation Request (PCReq) message may carry multiple requests, each of which has a unique path computation request identifier. The SVEC with a list of the path computation request identifiers carried within the request message allows the PCC or PCE to specify a list of multiple path computation requests that must be synchronized, and also allows the specification of any dependency relationships between the paths. The path computation requests listed in the SVEC must be handled in a specific relation to each other (i.e., synchronized).

[RFC5440] defines two synchronous path computation modes for dependent or independent path computation requests specified by the dependency flags (i.e., Node, Link, or Shared Risk Link Group (SRLG) diverse flags) in the SVEC:

- o A set of independent and synchronized path computation requests.
- o A set of dependent and synchronized path computation requests.

See [RFC5440] for more details on dependent, independent, and synchronous path computation.

These computation modes are exclusive to each other in a single SVEC. If one of the dependency flags in a SVEC is set, it indicates that a set of synchronous path computation requests has a dependency and does not allow any other path computation requests. In order to be synchronized with other path computation requests with a dependency, it is necessary to associate them.

The aim of the SVEC object carried within a PCReq message is to request the synchronization of M path computation requests. Each path computation request is uniquely identified by the Request-ID-number carried within the respective Request Parameters (RP) object. The SVEC object also contains a set of flags that specify the synchronization type. The SVEC object is defined in Section 7.13 ("SVEC Object") of [RFC5440].

1.2. Application of SVEC Lists

It is important for the PCE, when performing path computations, to synchronize any path computation requests with a dependency. For example, consider two protected end-to-end services:

- o It would be beneficial for each back-up path to be disjointed so they do not share the same links and nodes as the working path.
- o Two diverse path computation requests would be needed to compute the working and disjointed protected paths.

If the diverse path requests are computed sequentially, fulfillment of the initial diverse path computation without consideration of the second diverse path computation and disjoint constraint may result in the PCE either providing sub-optimal path disjoint results for the protected path or failing to meet the end-to-end disjoint requirement altogether.

Additionally, SVEC can be applied to end-to-end diverse path computations that traverse multiple domains. [RFC5441] describes two approaches, synchronous (i.e., simultaneous) and 2-step approaches, for end-to-end diverse path computation across a chain of domains. The path computation procedure is specified for the 2-step approaches in [RFC5521], but no guidelines are provided for the synchronous approach described in this document.

The following scenarios are specifically described within this document:

- o Single-domain, single-PCE, dependent and synchronized path computation request.
- o Single-domain, multi-PCE, dependent and synchronized path request.
- o Multi-domain, dependent and synchronized path computation request, including end-to-end diverse path computation.

The association among multiple SVECs for multiple sets of synchronized dependent path computations is also described in this document, as well as the disjoint Virtual Shortest Path Tree (VSPT) encoding rule for end-to-end diverse path computation across domains. Path computation algorithms for these path computation scenarios are out of the scope of this document.

The clarifications and use cases in this document are applicable to the Global Concurrent Optimization (GCO) path computation mechanism specified in [RFC5557]. The GCO application provides the capability to optimize a set of services within the network, in order to maximize efficient use of network resources. A single objective function (OF) or a set of OFs can be applied to a GCO. To compute a set of such traffic-engineered paths for the GCO application, PCEP supports the synchronous and dependent path computation requests required in [RFC4657].

The SVEC association and the disjoint VSPT described in this document do not require any extension to PCEP messages and object formats, when computing a GCO for multiple or end-to-end diverse paths. In addition, the use of multiple SVECs is not restricted to only SRLG, node, and link diversity currently defined in the SVEC object [RFC5440], but is also available for other dependent path computation requests.

The SVEC association and disjoint VSPT are available to both single-PCE path computation and multi-PCE path computation.

2. Terminology

This document uses PCE terminology defined in [RFC4655], [RFC4875], and [RFC5440].

Associated SVECs: A group of multiple SVECs (Synchronization VECTors), defined in this document, to indicate a set of synchronized or concurrent path computations.

Disjoint VSPT: A set of VSPTs, defined in this document, to indicate a set of virtual diverse path trees.

GCO (Global Concurrent Optimization): A concurrent path computation application, defined in [RFC5557], where a set of traffic engineered (TE) paths is computed concurrently in order to efficiently utilize network resources.

Synchronized: Describes a set of path computation requests that the PCE associates and that the PCE does not compute independently of each other.

VSPT: Virtual Shortest Path Tree, defined in [RFC5441].

3. SVEC Association Scenarios

This section clarifies several path computation scenarios in which SVEC association can be applied. Also, any combination of scenarios described in this section could be applicable.

3.1. Synchronized Computation for Diverse Path Requests

A PCE may compute two or more point-to-point diverse paths concurrently, in order to increase the probability of meeting primary and secondary path diversity (or disjointness) objectives and network resource optimization objectives.

Two scenarios can be considered for the SVEC association of point-to-point diverse paths.

- o Two or more end-to-end diverse paths

When concurrent path computation of two or more end-to-end diverse paths is requested, SVEC association is needed among diverse path requests. Note here that each diverse path request consists of primary, secondary, and tertiary (and beyond) path requests, in which all path requests are grouped with one SVEC association.

Consider two end-to-end services that are to be kept separate by using diverse paths. The path computation requests would need to be associated so that diversity could be assured. Consider further that each of these services requires a backup path that can protect against any failure in the primary path. These backup paths must be computed using requests that are associated with the primary paths, giving rise to a set of four associated requests.

- o End-to-end primary path and its segmented secondary paths

When concurrent path computation for segment recovery paths, as shown in Figure 1, is requested, SVEC association is needed between a primary path and several segmented secondary paths.

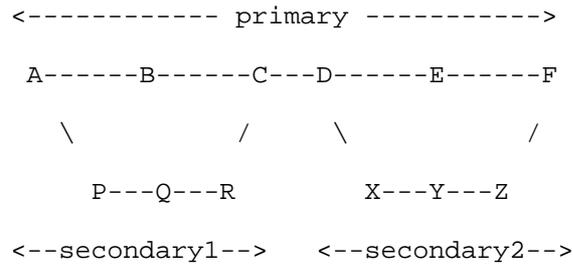


Figure 1. Segment Recovery Paths

In this scenario, we assume that the primary path may be pre-computed and used for specifying the segment for secondary paths. Otherwise, the segment for secondary path requests is specified in advance, by using Exclude Route Object (XRO) and/or Include Route Object (IRO) constraints in the primary request.

3.2. Synchronized Computation for Point-to-Multipoint Path Requests

For point-to-multipoint path requests, SVEC association can be applied.

- o Two or more point-to-multipoint paths

If a point-to-multipoint path computation request is represented as a set of point-to-point paths [RFC6006], two or more point-to-multipoint path computation requests can be associated for concurrent path computation, in order to optimize network resources.

- o Point-to-multipoint paths and their secondary paths

When concurrent path computation of a point-to-multipoint path and its point-to-point secondary paths [RFC4875], or a point-to-multipoint path and its point-to-multipoint secondary paths is requested, SVEC association is needed among these requests. In this scenario, we use the same assumption as the "end-to-end primary path and its segmented secondary paths" scenario in Section 3.1.

4. SVEC Association

This section describes the associations among SVECs in a SVEC list.

4.1. SVEC List

PCEP provides the capability to carry one or more SVEC objects in a PCReq message, and this set of SVEC objects within the PCReq message is termed a SVEC list. Each SVEC object in the SVEC list contains a distinct group of path computation requests. When requesting association among such distinct groups, associated SVECs described in this document are used.

4.2. Associated SVECs

"Associated SVECs" means that there are relationships among multiple SVECs in a SVEC list. Note that there is no automatic association in [RFC5440] between the members of one SVEC and the members of another SVEC in the same SVEC list. The associated SVEC is introduced to associate these SVECs, especially for correlating among SVECs with dependency flags.

Request identifiers in the SVEC objects are used to indicate the association among SVEC objects. If the same request-IDs exist in SVEC objects, this indicates these SVEC objects are associated. When associating among SVEC objects, at least one request identifier must be shared between associated SVECs. The SVEC objects can be associated regardless of the dependency flags in each SVEC object, but it is recommended to use a single SVEC if the dependency flags are not set in all SVEC objects. Similarly, when associating among SVEC objects with dependency flags, it is recommended to construct them using a minimum set of associated SVECs, thus avoiding complex relational associations.

Below is an example of associated SVECs. In this example, the first SVEC is associated with the other SVECs, and all of the path computation requests contained in the associated SVECs (i.e., Request-IDs #1, #2, #3, #4, #X, #Y, and #Z) must be synchronized.

<SVEC-list>

<SVEC> without dependency flags

Request-ID #1, Request-ID #3, Request-ID #X

<SVEC> with one or more dependency flags

Request-ID #1, Request-ID #2

<SVEC> with one or more dependency flags

Request-ID #3, Request-ID #4

<SVEC> without dependency flag

Request-ID #X, Request-ID #Y, Request-ID #Z

4.3. Non-Associated SVECs

"Non-associated SVECs" means that there are no relationships among SVECs. If none of the SVEC objects in the SVEC list on a PCReq message contains a common request-ID, there is no association between the SVECs and so no association between the requests in one SVEC and the requests in another SVEC.

Below is an example of non-associated SVECs that do not contain any common request-IDs.

<SVEC-list>

<SVEC> with one or more dependency flags

Request-ID #1, Request-ID #2

<SVEC> with one or more dependency flags

Request-ID #3, Request-ID #4

<SVEC> without dependency flags

Request-ID #X, Request-ID #Y, Request-ID #Z

5. Processing of SVEC List

5.1. Single-PCE, Single-Domain Environments

In this environment, there is a single PCE within the domain.

When a PCE receives PCReq messages with more than one SVEC object in the SVEC list, PCEP has to first check the request-IDs in all SVEC objects in order to identify any associations among them.

If there are no matching request-IDs in the different SVEC objects, these SVEC objects are not associated, and then each set of path computation requests in the non-associated SVEC objects has to be computed separately.

If there are matching request-IDs in the different SVEC objects, these SVEC objects are associated, and then all path computation requests in the associated SVEC objects are treated in a synchronous manner for GCO application.

If a PCE that is unable to handle the associated SVEC finds the common request-IDs in multiple SVEC objects, the PCE should cancel the path computation request and respond to the PCC with the PCErr message `Error-Type="Capability not supported"`.

In the case that M path computation requests are sent across multiple PCReq messages, the PCE may start a SyncTimer as recommended in Section 7.13.3 ("Handling of the SVEC Object") of [RFC5440]. In this case, the associated SVECs should also be handled as described in [RFC5440], i.e., after receiving the entire set of M path computation requests associated by SVECs, the computation should start at one. If the SyncTimer has expired or the subsequent PCReq messages are malformed, the PCE should cancel the path computation request and respond to the PCC with the relevant PCErr message.

5.2. Multi-PCE, Single-Domain Environments

There are multiple PCEs in a domain, to which PCCs can communicate directly, and PCCs can choose an appropriate PCE for load-balanced path computation requests. In this environment, it is possible that dependent path computation requests are sent to different PCEs.

However, if a PCC sends path computation requests to a PCE, and then sends a further path computation request to a different PCE using the SVEC list to show that the further request is dependent on the first requests, there is no method for the PCE to correlate the dependent requests sent to different PCEs. No SVEC object correlation function between the PCEs is specified in [RFC5440]. No mechanism exists to resolve this problem, and the issue is open for future study. Therefore, a PCC must not send dependent path computation requests associated by SVECs to different PCEs.

5.3. Multi-PCE, Multi-Domain Environments

In this environment, there are multiple domains in which PCEs are located in each domain, and end-to-end dependent paths (i.e., diverse paths) are computed using multiple PCEs. Note that we assume a chain of PCEs is predetermined and the Backward-Recursive PCE-Based Computation (BRPC) procedure [RFC5441] is in use.

The SVECs can be applied to end-to-end diverse path computations that traverse multiple domains. [RFC5441] describes two approaches, synchronous (i.e., simultaneous) and 2-step approaches, for

end-to-end diverse path computation across a chain of domains. In the 2-step approaches described in [RFC5521], it is not necessary to use the associated SVECs if any of the dependency flags in a SVEC object are not set. On the other hand, the simultaneous approach may require the associated SVEC because at least one of the dependency flags is required to be set in a SVEC object. Thus, a use case of the simultaneous approach is described in this environment.

When a chain of PCEs located in separate domains is used for simultaneous path computations, additional path computation processing is required, as described in Section 6 of this document.

If the PCReq message contains multiple associated SVEC objects and these SVEC objects contain path computation requests that will be sent to the next PCE along the path computation chain, the following procedures are applied.

When a chain of PCEs is a unique sequence for all of the path computation requests in a PCReq message, it is not necessary to reconstruct associations among SVEC objects. Thus, the PCReq message is passed to the tail-end PCE. When a PCReq message contains more than one SVEC object with the dependency flag set, the contained SVECs may then be associated. PCEs receiving the associated SVECs must maintain their association and must consider their relationship when performing path computations after receiving a corresponding PCReply (PCRep) message.

When a chain of PCEs is different, it is required that intermediate PCEs receiving such PCReq messages may reconstruct associations among SVEC objects, and then send PCReq messages to corresponding PCEs located in neighboring domains. If the associated SVECs are reconstructed at the intermediate PCE, the PCE must not start its path computation until all PCRep messages have been received from all neighbor PCEs. However, a complex PCE implementation is required for SVEC reconstruction, and waiting mechanisms must be implemented. Therefore, it is not recommended to associate path computation requests with different PCE chains. This is an open issue and is currently being discussed in [H-PCE], which proposes a hierarchical PCE architecture.

6. End-to-End Diverse Path Computation

In this section, the synchronous approach is provided to compute primary and secondary paths simultaneously.

6.1. Disjoint VSPT

The BRPC procedure constructs a VSPT to inform the enquiring PCE of potential paths to the destination node.

In the end-to-end diverse path computation, diversity (or disjointness) information among the potential paths must be preserved in the VSPT to ensure an end-to-end disjoint path. In order to preserve diversity (or disjointness) information, disjoint VSPTs are sent in the PCEP PCRep message. The PCReq containing a SVEC object with the appropriate diverse flag set would signal that the PCE should compute a disjoint VSPT.

A definition of the disjoint VSPT is a collection of VSPTs, in which each VSPT contains a potential set of primary and secondary paths.

Figure 2 shows an example network. Here, transit nodes in domains are not depicted, and PCE1 and PCE2 may be located in border nodes. In this network, there are three VSPTs for the potential set of diverse paths, shown in Figure 3, when the primary path and secondary path are requested from S1 to D1. These VSPTs consist of a disjoint VSPT, which is indicated in a PCRep to PCE1. When receiving the disjoint VSPT, PCE1 recognizes the disjoint request and disjoint VSPT information. PCE1 will then continue to process the request and compute the diverse path using the BRPC procedure [RFC5441]. Encoding for the disjoint VSPT is described in Section 6.2.

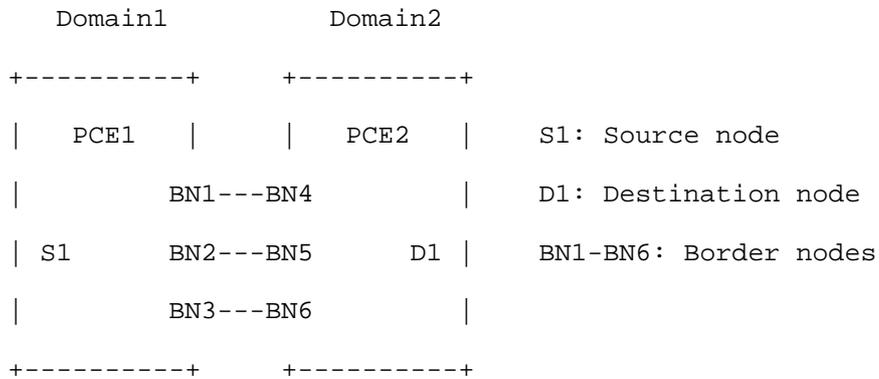


Figure 2. Example Network for Diverse Path Computation

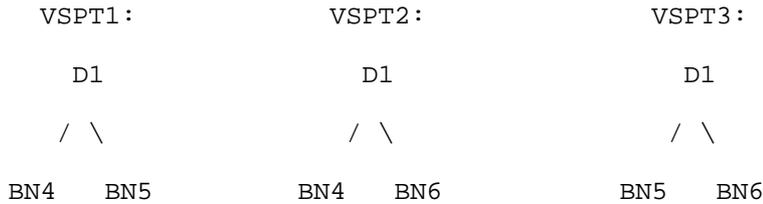


Figure 3. Disjoint VSPTs from PCE2 to PCE1

6.2. Disjoint VSPT Encoding

Encoding for the disjoint VSPT follows the definition of PCEP message encoding in [RFC5440].

The PCEP PCRep message returns a disjoint VSPT as <path list> for each RP object (Request Parameter object). The order of <path> in <path list> among <responses> implies a set of primary Explicit Route Objects (EROs) and secondary EROs.

A PCE sending a PCRep with a disjoint VSPT can reply with a partial disjoint VSPT based on its network operation policy, but the order of <path> in <path list> must be aligned correctly.

If confidentiality is required between domains, the path key mechanism defined in [RFC5520] is used for a disjoint VSPT.

Below are the details of the disjoint VSPT encoding (in Figure 3), when a primary path and a secondary path are requested from S1 to D1.

- o Request ID #1 (Primary)
 - ERO1 BN4(TE route ID)- ...-D1(TE-Router ID) [for VSPT1]
 - ERO2 BN4(TE route ID)- ...-D1(TE-Router ID) [for VSPT2]
 - ERO3 BN5(TE route ID)- ...-D1(TE-Router ID) [for VSPT3]
- o Request ID #2 (Secondary)
 - ERO4 BN5(TE route ID)- ...-D1(TE-Router ID) [for VSPT1]
 - ERO5 BN6(TE route ID)- ...-D1(TE-Router ID) [for VSPT2]
 - ERO6 BN6(TE route ID)- ...-D1(TE-Router ID) [for VSPT3]

6.3. Path Computation Procedure

For end-to-end diverse path computation, the same mode of operation as that of the BRPC procedure can be applied (i.e., Step 1 to Step n in Section 4.2 of [RFC5441]). A question that must be considered is how to recognize disjoint VSPTs.

The recognition of disjoint VSPTs is achieved by the PCE sending a PCReq to its neighbor PCE, which maintains the path computation request (PCReq) information. If the PCReq has one or more SVEC object(s) with the appropriate dependency flags, the received PCRep will contain the disjoint VSPT. If not, the received VSPT is a normal VSPT based on the shortest path computation.

Note that the PCE will apply a suitable algorithm for computing requests with disjoint VSPTs. The selection and application of the appropriate algorithm is out of scope in this document.

7. Manageability Considerations

This section describes manageability considerations specified in [PCE-MNG-REQS].

7.1. Control of Function and Policy

In addition to [RFC5440], PCEP implementations should allow the PCC to be responsible for mapping the requested paths to computation requests. The PCC should construct the SVECs to identify and associate SVEC relationships.

7.2. Information and Data Models (MIB Modules)

There are currently no additional parameters for MIB modules. There would be value in a MIB module that details the SVEC association. This work is currently out of scope of this document.

7.3. Liveness Detection and Monitoring

The associated SVEC in this document allows PCEs to compute optimal sets of diverse paths. This type of path computation may require more time to obtain its results. Therefore, it is recommended for PCEP to support the PCE monitoring mechanism specified in [RFC5886].

7.4. Verifying Correct Operation

[RFC5440] provides a sufficient description for this document. There are no additional considerations.

7.5. Requirements on Other Protocols and Functional Components

This document does not require any other protocol and functional components.

7.6. Impact on Network Operation

[RFC5440] provides descriptions for the mechanisms discussed in this document. There is value in considering that large associated SVECs will require greater PCE resources, compared to non-associated SVECs. Additionally, the sending of large associated SVECs within multiple PCReq messages will require more network resources. Solving these specific issues is out of scope of this document.

8. Security Considerations

This document describes the usage of the SVEC list, and does not have any extensions for PCEP. The security of the procedures described in this document depends on PCEP [RFC5440]. However, a PCE that supports associated SVECs may be open to Denial-of-Service (DoS) attacks from a rogue PCC. A PCE may be made to queue large numbers of requests waiting for other requests that will never arrive. Additionally, a PCE might be made to compute exceedingly complex associated SVEC computations. These DoS attacks may be mitigated with the use of practical SVEC list limits, as well as:

- o Applying provisioning to PCEs, e.g., for a given number of simultaneous services (recommended).
- o Using a priority-based multi-queuing mechanism in which path computation requests with a smaller SVEC list are prioritized for path computation processing.
- o Specifying which PCCs may request large SVEC associations through PCE access policy control.

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Authors' Addresses

Itaru Nishioka
NEC Corp.
1753 Shimonumabe,
Kawasaki, 211-8666,
Japan

Phone: +81 44 396 3287
EMail: i-nishioka@cb.jp.nec.com

Daniel King
Old Dog Consulting
United Kingdom

Phone: +44 7790 775187
EMail: daniel@olddog.co.uk

