Routing State Abstraction
Algorithms for Compressing Path Vectors

`draft-gao-alto-routing-state-abstraction-07`

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What is RSA?

- *Routing State Abstraction* is a set of algorithms to provide the information for a set of correlated flows, encoded as the ALTO path vector extension.

How is RSA related to ALTO WG items?

- RSA provides a concrete implementation of the path vector extension.
- RSA can be used to 1) **compress** and 2) **improve the privacy of** an existing path vector response, **without loss of information**.

Changes since -06

- Improve the clarity of the algorithms
  - Split the algorithms into small pieces
  - Add an example for each piece
  - Include the algorithms to interact with the path vector extension (encoding/decoding)
- Remove some extensions (i.e., client side bandwidth constraints) that are specific to the algorithms

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Example

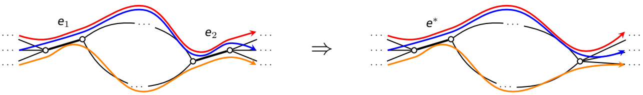
```
PID1 +-----+                                    +-----+  PID2
eh1__|     |_                               ____|     |__eh2
     | sw1 | \   +------+         +------+ /    | sw2 |
     +-----+  \  |      |         |      |/     +-----+
               \_| sw5  +---------+ sw6  |
PID3 +-----+   / |      |         |      |\     +-----+  PID4
eh3__|     |__/  +------+         +------+ \____|     |__eh4
     | sw3 |                                    | sw4 |
     +-----+                                    +-----+
```

Link	Description
l1	sw1 <==> sw5
l2	sw2 <==> sw6
l3	sw3 <==> sw5
l4	sw4 <==> sw6
l5	sw5 <==> sw6

```
path vectors:
    eh1: [ eh2: [ane:l1, ane:l5, ane:l2]]
    eh3: [ eh4: [ane:l3, ane:l5, ane:l4]]

abstract network element property map:
    ane:l1 : 100 Mbps, 1
    ane:l2 : 100 Mbps, 2
    ane:l3 : 100 Mbps, 1
    ane:l4 : 100 Mbps, 1
    ane:l5 : 100 Mbps, 1
```

Equivalent Aggregation

Merge the links which have the same set of source-destination pairs.



To guarantee "no loss of information": properties of the resultant link are calculated by "summing" the properties using UPDATE function.

metric	UPDATE(x, y)	default
hopcount	x + y	0
routingcost	x + y	0
bandwidth	min(x, y)	+infinity
loss rate	1 - (1 - x) * (1 - y)	0

Example 1

Original:

```
set of pairs:
    ane:l1 : { eh1->eh2 }
    ane:l2 : { eh1->eh2 }
    ane:l3 : { eh3->eh4 }
    ane:l4 : { eh3->eh4 }
    ane:l5 : { eh1->eh2, eh3->eh4 }

properties:
    ane:l1 : 100 Mbps, 1
    ane:l2 : 100 Mbps, 2
    ane:l3 : 100 Mbps, 1
    ane:l4 : 100 Mbps, 1
    ane:l5 : 100 Mbps, 1
```

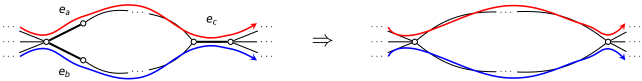
Merge ane:l1 and ane:l2 as ane:a, merge ane:l3 and ane:l4 as ane:b.

```
set of pairs:
    ane:a  : { eh1->eh2 } (same as ane:l1 and ane:l2)
    ane:b  : { eh3->eh4 } (same as ane:l3 and ane:l4)
    ane:l5 : { eh1->eh2, eh3->eh4 }

properties:
    ane:a  : 100 Mbps, 3 (100 = min(100, 100), 3 = 1 + 2)
    ane:b  : 100 Mbps, 2 (100 = min(100, 100), 2 = 1 + 1)
    ane:l5 : 100 Mbps, 1
```

Redundant Constraint Identification

Each link represents a linear bandwidth constraint. `IS_REDUNDANT` is an algorithm to find all redundant bandwidth constraints.

(A direct use case) Consider the bandwidth-only requests, if a constraint is redundant, the corresponding link can be removed too.



To guarantee "no loss of information": bandwidth-only requests

Example 2

```
bw(eh1->eh2)                    <= 100 Mbps (ane:a)
                  bw(eh3->eh4)  <= 100 Mbps (ane:b)
bw(eh1->eh2) + bw(eh3->eh4)     <= 100 Mbps (ane:l5)
```

The first two constraints are redundant.

```
bw(eh1->eh2) + bw(eh3->eh4) <= 100 Mbps (ane:l5)
```

The corresponding PV result:

```
set of pairs:
    ane:l5 : { eh1-> eh2, eh3->eh4 }

properties:
    ane:l5 : 100 Mbps
```

Limitations

Before:

```
set of pairs:
    ane:a   : { eh1->eh2 }
    ane:b   : { eh3->eh4 }
    ane:l5 : { eh1->eh2, eh3->eh4 }

properties:
    ane:a   : 100 Mbps, 3 <- redundant
    ane:b   : 100 Mbps, 2 <- redundant
    ane:l5 : 100 Mbps, 1
```

After removing links with redundant constraints (ane:a and ane:b):

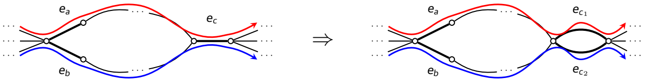
```
set of pairs:
    ane:l5 : { eh1->eh2, eh3->eh4 }

properties:
    ane:l5 : 100 Mbps, 1
```

Routing cost information is "lost".

Equivalent Decomposition

In general cases links with redundant constraints cannot be removed, but can be *decomposed* (which can be further aggregated).

Decomposition: split the set of pairs on a link, and treat the link as multiple links traversed by different subsets of pairs.



To guarantee "no loss of information":

- Let P be the original set of pairs, P_i be the set of pairs of the i-th subset. The subsets should be disjoint ($P_i \cap P_j = \emptyset$ if $i \neq j$) and complete ($\cup P_i = P$).
- The properties of each **decomposed link** are the same as the properties of the original link.

Example 3

Before (bw for ane:l5 is changed for demonstration purpose):

```
set of pairs:
    ane:a  : { eh1->eh2 }
    ane:b  : { eh3->eh4 }
    ane:l5 : { eh1->eh2, eh3->eh4 }

properties:
    ane:a  : 100 Mbps, 3
    ane:b  : 100 Mbps, 2
    ane:l5 : 200 Mbps, 1 <- redundant
```

After decomposing ane:l5 to ane:c and ane:d:

```
set of pairs:
    ane:a  : { eh1->eh2 }
    ane:b  : { eh3->eh4 }
    ane:c  : { eh1->eh2 }
    ane:d  : { eh3->eh4 }

properties:
    ane:a  : 100 Mbps, 3
    ane:b  : 100 Mbps, 2
    ane:c  : 200 Mbps, 1 (same as ane:l5)
    ane:d  : 200 Mbps, 1 (same as ane:l5)
```

Notes

- Equivalent aggregation and decomposition are discussed in our IWQoS paper[1] but this document uses a new algorithm for decomposition (included in an extended version). Various algorithms exist to find redundant constraints in a set of constraints. The one mentioned in the document is first proposed by Telgen[2] (Benefits: simple and multiprocessing-friendly).
- Since we always aggregate after decomposing a link. The algorithm actually combines the aggregation step to reduce the overhead of storing temporary results.
- "Perfect" decomposition which minimizes the number of links is NP-hard (binary matrix factorization[3]) so the one proposed in the document is actually a greedy algorithm.

Should such information (or part of it) be included in the draft?

[1] Kai Gao et al. "NOVA: Towards on-demand equivalent network view abstraction for network optimization". In: *2017 IEEE/ACM 25th International Symposium on Quality of Service (IWQoS)*. 2017.

[2] Jan Telgen. "Identifying redundant constraints and implicit equalities in systems of linear constraints". In: *Management Science* 29.10 (1983).

[3] Stephen A. Vavasis. "On the Complexity of Nonnegative Matrix Factorization". en. In: *SIAM Journal on Optimization* 20.3 (2010).

Decoding & Encoding

The transformation between the internal link-oriented data structure and the PV format. Please refer to the draft for more details.

```
path vectors (PV):
    eh1: [ eh2: [ane:l1, ane:l5, ane:l2]]
    eh3: [ eh4: [ane:l3, ane:l5, ane:l4]]

set of pairs (P):
    ane:l1 : { eh1->eh2 }
    ane:l2 : { eh1->eh2 }
    ane:l3 : { eh3->eh4 }
    ane:l4 : { eh3->eh4 }
    ane:l4 : { eh1->eh2, eh3->eh4 }

P = DECODE(PV)
PV = ENCODE(P)
```

Only extract the PV part so it is compatible with other extensions like multi-cost.

Summary

Current status:

- Clear target: supplement of the PV extension with referenced implementations.
- Better quality: cleaner descriptions and more examples.

Next steps:

- Adopt this document as a WG draft?
- Call for reviews from the WG

Q & A

Join the Discussion at `alto@ietf.org`!

Questions and Comments are Welcome!