Supporting Bottleneck Structure Graphs in ALTO: Use Cases and Requirements

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IETF Plenary 113
ALTO WG Session
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- Introducing Bottleneck Structures in the IETF ALTO WG: Requirements
Brief Introduction to Bottleneck Structures
Framework and Implementation Details in the Following Papers


Conventional View: Single Bottleneck Model

Figure 1: Window Flow Control ‘Self-clocking’

Problem Positioning: The Hiding Root Cause of System-Wide Performance

Analogy:

- Structure of the congestion problem in data networks:
  - The single-bottleneck problem is the tip of the iceberg (the symptom)
  - The bottleneck structure is the submerged portion (determines system-wide performance)
Simple Example of Bottleneck Structure

Communication Network:

```
<table>
<thead>
<tr>
<th>f1</th>
<th>f2</th>
<th>f6</th>
<th>f5</th>
</tr>
</thead>
<tbody>
<tr>
<td>l1</td>
<td>l2</td>
<td>l3</td>
<td>l4</td>
</tr>
<tr>
<td>c1=25</td>
<td>c2=50</td>
<td>c3=100</td>
<td>c4=75</td>
</tr>
</tbody>
</table>
```

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Simple Example of Bottleneck Structure

Communication Network:

Bottleneck Structure:
Simple Example of Bottleneck Structure

Communication Network:

Bottleneck Structure:

perturbation
Simple Example of Bottleneck Structure

Communication Network:

Bottleneck Structure:
Simple Example of Bottleneck Structure

Communication Network:

Bottleneck Structure:

Flow bandwidth allocation: \[ r = [8.3, 16.6, 8.3, 16.6, 75, 8.3] \]
Propagation Lemmas

**Propagation Lemma:** A flow $f$ can influence the performance of another flow $f'$ iff the bottleneck structure has a directed path from $f$ to $f'$. (Same lemma exists for bottleneck links.)

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![Diagram](image)

**Propagation Lemma:** A flow $f$ can influence the performance of another flow $f'$ iff the bottleneck structure has a directed path from $f$ to $f'$. (Same lemma exists for bottleneck links.)

Propagation Equations

Link and flow equations:

(a) Link equation:

\[
\Delta_I = - \sum_{1 \leq i \leq m} \frac{\Delta f_i}{n}
\]

(b) Flow equation:

\[
\Delta_f = \min\{\Delta_I, 1 \leq i \leq m\}
\]

Propagation Equations

Link and flow equations:

(a) Link equation:
\[ \Delta f_i = \ldots \]
\[ \Delta f_m \]
\[ \sum_{1 \leq i \leq m} \frac{\Delta f_i}{n} \]
\[ \Delta f = \min\{\Delta f_i, 1 \leq i \leq m\} \]

(b) Flow equation:
\[ \Delta f = \ldots \]
\[ \Delta f \]
\[ 1 \]
\[ n \]

Example:

(c) Link gradient:
\[ f_1 \]
\[ l_1 \]
\[ l_2 \]
\[ -\delta \]
\[ 0 \]
\[ \delta \]

(d) Flow gradient:
\[ f_1 \]
\[ f_2 \]
\[ f_3 \]
\[ f_4 \]
\[ l_1 \]
\[ l_2 \]
\[ l_3 \]

Propagation Equations

Link and flow equations:

(a) Link equation:
\[ \Delta_l = - \sum_{i=1}^{m} \frac{\Delta f_i}{n} \]
(b) Flow equation:
\[ \Delta f = \min\{\Delta_l, 1 \leq i \leq m\} \]

Example:

(c) Link gradient:
\[ \nabla_{l_1}(f_2) = \frac{\partial r_{f_2}}{\partial c_{l_1}} = \frac{\Delta f_2}{(-\delta)} = \frac{\delta/2}{-\delta} = -1/2 \]

(d) Flow gradient:
\[ \nabla_{f_1}(f_4) = \frac{\partial r_{f_4}}{\partial r_{f_1}} = \frac{\Delta f_4}{(-\delta)} = -2\delta/(-\delta) = 2 \]

Optimal Flow Throughput Reduction

Communication Network:

\[ r = [8.3, 16.6, 8.3, 16.6, 75, 8.3] \]

Bottleneck Structure:
Optimal Flow Throughput Reduction

\[ \mathbf{r} = [8.3, 16.6, 8.3, 16.6, 75, 8.3] \]

- \( F \) : Total network flow
- \( \frac{\partial F}{\partial r_1^-} = 1 \)
- \( \frac{\partial F}{\partial r_2^-} = 1 \)
- \( \frac{\partial F}{\partial r_3^-} = 1/4 \)
- \( \frac{\partial F}{\partial r_4^-} = 0 \)
- \( \frac{\partial F}{\partial r_5^-} = 1 \)
- \( \frac{\partial F}{\partial r_6^-} = -1/2 \)
Optimal Flow Throughput Reduction

Table 3: As predicted by the theory of bottleneck ordering, flow $f_6$ is a significantly higher impact flow than flow $f_5$.

<table>
<thead>
<tr>
<th>Comp. time (secs)</th>
<th>$f_1$</th>
<th>$f_2$</th>
<th>$f_3$</th>
<th>$f_4$</th>
<th>$f_5$</th>
<th>$f_6$</th>
<th>Slowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>With all flows</td>
<td>664</td>
<td>340</td>
<td>679</td>
<td>331</td>
<td>77</td>
<td>636</td>
<td>679</td>
</tr>
<tr>
<td>Without flow $f_5$</td>
<td>678</td>
<td>350</td>
<td>671</td>
<td>317</td>
<td>—</td>
<td>611</td>
<td>678</td>
</tr>
<tr>
<td>Without flow $f_6$</td>
<td>416</td>
<td>295</td>
<td>457</td>
<td>288</td>
<td>75</td>
<td>—</td>
<td>457</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg rate (Mbps)</th>
<th>$f_1$</th>
<th>$f_2$</th>
<th>$f_3$</th>
<th>$f_4$</th>
<th>$f_5$</th>
<th>$f_6$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>With all flows</td>
<td>7.7</td>
<td>15.1</td>
<td>7.5</td>
<td>15.4</td>
<td>65.8</td>
<td>8.1</td>
<td>119.6</td>
</tr>
<tr>
<td>Without flow $f_5$</td>
<td>7.5</td>
<td>14.5</td>
<td>7.6</td>
<td>16.1</td>
<td>—</td>
<td>8.3</td>
<td>54</td>
</tr>
<tr>
<td>Without flow $f_6$</td>
<td>12.2</td>
<td>17.2</td>
<td>11.1</td>
<td>17.7</td>
<td>68.1</td>
<td>—</td>
<td>126.3</td>
</tr>
</tbody>
</table>
Types of Perturbations (derivatives) Supported by the Bottleneck Structure Graph

- Flow routing
- Traffic shaping (BW enforcement)
- Link capacity upgrades
- Link capacity fluctuations (e.g., SNR in a wireless channel)
- Path shortcuts
- Flow scheduling
- Flow completion
- Job mapping
- Multi-job scheduling
Bottleneck Structure Graph (BSG) Service: ALTO Use Cases
Bottleneck Structure Graphs (BSG): Use Cases

Potential WGs collaborations with ALTO

- PANRG
- PCE
- TEAS
- CDNI
- COINRG
- NETMOD
- CAN (BOF)
- Others...
Bottleneck Structure Graphs (BSG): Use Cases Documented in the I-Draft

- Application Rate Limiting for CDN and Edge Cloud Applications
- Time-bound Constrained Flow Acceleration for Large Data Set Transfers
- Application Performance Optimization Through AI Modeling
- Optimized Joint Routing and Congestion Control
- Service Placement for Edge Computing
- Training Neural Networks and AI Inference for Edge Clouds, Data Centers and Planet-Scale Networks
- 5G Network Slicing
We will focus on “Optimized Joint Routing and Congestion Control”. For details on all other use cases, see the I-Draft:

https://datatracker.ietf.org/doc/html/draft-giraltyellamraju-alto-bsg-requirements-00
BSG Use Cases: Optimizing Joint Routing and Congestion Control

Assume Google’s B4 Network from [B4-SIGCOM]:

Figure 4: Google's B4 network introduced in [B4-SIGCOMM].

<table>
<thead>
<tr>
<th>Link</th>
<th>Adjacent data centers</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>DC1, DC2</td>
</tr>
<tr>
<td>12</td>
<td>DC1, DC3</td>
</tr>
<tr>
<td>13</td>
<td>DC3, DC4</td>
</tr>
<tr>
<td>14</td>
<td>DC2, DC5</td>
</tr>
<tr>
<td>15</td>
<td>DC3, DC6</td>
</tr>
<tr>
<td>16</td>
<td>DC6, DC7</td>
</tr>
<tr>
<td>17</td>
<td>DC7, DC8</td>
</tr>
<tr>
<td>18</td>
<td>DC8, DC10</td>
</tr>
<tr>
<td>19</td>
<td>DC9, DC10</td>
</tr>
<tr>
<td>110</td>
<td>DC7, DC11</td>
</tr>
</tbody>
</table>

Table 1: Link connectivity (adjacency matrix) in the B4 network.
BSG Use Cases: Optimizing Joint Routing and Congestion Control

Assume Google’s B4 Network from [B4-SIGCOM] (human friendly version):
BSG Use Cases: Optimizing Joint Routing and Congestion Control

- Assume a simple configuration with a pair of flows (one for each direction) connecting every data center in the US with every data center in Europe.

- All links are assumed to have a capacity of 10 Gbps except for the transatlantic links (DC7-DC11 and DC8-DC10), which are configured at 25 Gbps.

- Then the bottleneck structure is the graph shown on the right.

Figure 4: Google’s B4 network introduced in [B4-SIGCOMM].

Figure 5: Bottleneck structure of Google’s B4 network example.
BSG Use Cases: Optimizing Joint Routing and Congestion Control

Network

Bottleneck structure

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BSG Use Cases: Optimizing Joint Routing and Congestion Control
BSG Use Cases: Optimizing Joint Routing and Congestion Control

Suppose that an application needs to place a new flow on Google's B4 network to transfer a large data set from data center 11 (DC11) to data center 4 (DC4). There are multiple path choices:
BSG Use Cases: Optimizing Joint Routing and Congestion Control

• Using bottleneck structures, we can compute in $O(V+E*\log(V))$ the path that will yield maximal throughput while considering the reaction of the congestion control algorithm (See [G2-TREP]).

• The optimal path corresponds to DC11 $\rightarrow$ I19 $\rightarrow$ DC10 $\rightarrow$ I8 $\rightarrow$ DC8 $\rightarrow$ I16 $\rightarrow$ DC4 yielding a throughput of 2.5 Gbps.

• Note that this is higher than the shortest path DC11 $\rightarrow$ I10 $\rightarrow$ DC7 $\rightarrow$ I15 $\rightarrow$ DC4, which yields a throughput of 1.429 Gbps.

• SLA management: Bottleneck structures can also be used to qualify and quantify the ripple effects produced on all other flows when placing the new flow to ensure their SLAs are preserved. See next slide.
BSG Use Cases: Optimizing Joint Routing and Congestion Control
BSG Use Cases: Optimizing Joint Routing and Congestion Control

Routing on shortest path

Routing on maximal throughput path

Flows affected when placing flow on shortest path

Flows affected when placing flow on maximal throughput path
BSG Use Cases: Optimizing Joint Routing and Congestion Control

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BSG Use Cases: Optimizing Joint Routing and Congestion Control

Routing on shortest path

Negatively affects the most poorly treated flows

Preserves the most poorly treated flows

Routing on maximal throughput path

Flows affected when placing flow on shortest path

Flows affected when placing flow on maximal throughput path
Routing on shortest path

Negatively affects the most poorly treated flows

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Flows affected when placing flow on shortest path

Flows affected when placing flow on maximal throughput path

BSG Use Cases: Optimizing Joint Routing and Congestion Control
Introducing Bottleneck Structures in the IETF ALTO WG: Requirements
ALTO Requirements to Support Bottleneck Structures

Requirement 1: Bottleneck Structure Graph (BSG) Abstraction

- **Requirement 1A (R1A).** The ALTO server MUST compute the bottleneck structure graph to allow applications optimize their performance using the BSG service.

- **Requirement 1B (R1B).** The ALTO server MUST at least support the computation of one bottleneck structure type from Section 3.7. Depending on the network information available (e.g., presence of QoS class information), the ALTO server MAY support all the three bottleneck structure types, in which case the ALTO client MAY be able to choose the bottleneck structure type for retrieval. Also, it is RECOMMENDED that the ALTO server supports the computation of the path gradient graph (PGG) as the default bottleneck structure implementation for retrieval by the ALTO clients.
ALTO Requirements to Support Bottleneck Structures

Requirement 2: Information Received from the Network

• **Topology Object (T).** The T Object is a data structure that includes:
  (1) A Topology Graph \((V, E)\), where \(V\) is the set of routers and \(E\) is the set of links connecting the routers in the network.
  (2) A Capacity Dictionary \((C)\), a key-value table mapping each link with its capacity (in bps).

• **Flow Dictionary (F).** The F Dictionary is a key-value table mapping every flow with the set of links it traverses.

• **Requirement 2A (R2A).** The ALTO server MUST collect information about (1) the set of routers and links in a network, (2) the capacity of each link and (3) the set of links traversed by each flow.
ALTO Requirements to Support Bottleneck Structures

Requirement 3: Information Passed to the Application

• **Requirement 3A (R3A).** The ALTO client MUST be able to query the ALTO server to obtain the current bottleneck structure of the network, represented as a digraph.

• **Requirement 3B (R3B).** One or more ALTO services (the Network Map, the Cost Map, the Entity Property Map or the Endpoint Cost Map) MUST support reporting to ALTO clients additional network state information derived from the bottleneck structure to the ALTO client.
ALTO Requirements to Support Bottleneck Structures

Requirement 4: Features Needed to Support the Use Cases

- **Requirement 4A (R4A).** The ALTO BSG service MUST be able to compute the effect of network reconfigurations using bottleneck structure analysis and according to the types described in Section 3.9.

- **Requirement 4B (R4B).** The BSG service MUST be able to update the bottleneck structure graph in near-real time, at least once a minute or less.
References

Discussion Q&A

Thank you