Network Planning for Stochastic Traffic Demands using a Genetic Algorithm

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Basic network planning problem

**Given**
- Network information (topologies, link cost, etc.)
- Traffic demands

**Determine**
- Route for each demand
- Bandwidth allocated for each link

**Objective**
The total network cost subject to network constraints is minimized.
Problem

Traffic demands are not deterministic but stochastic.

How to handle the uncertainty?
Planning Approaches

- Mean-rate based
  - Pro: low cost
  - Con: high amount of traffic is discarded

- Peak-rate based
  - Pro: able to handle a large traffic demand variation
  - Con: very expensive

Statistical network planning

- Objective: minimize the cost
- Constraint: accept a violation probability for the link load
  (Grade of Service – GoS)
Mathematical model (1)

• Parameters:
  – Traffic demand distribution of a nodepair (sd) : \( t^{sd} \)
    (Traffic demands are statistically independent.)
  – Cost of a bandwidth unit on the link \( ij \): \( c_{ij} \)
  – GoS agreement: \( \varepsilon \)

• Variables:
  – Routing (binary) decision variable: \( f_{ij}^{sd} \)
  – Bandwidth assignment variable: \( b_{ij} \)
Mathematical model (2)

- Objective: minimize the total cost

$$\min \sum_{ij} c_{ij} \cdot b_{ij}$$

- Multi-commodity flow constraint

$$\sum_{j} f_{ij}^{sd} - \sum_{j} f_{ji}^{sd} = \begin{cases} 
1 & i = s \\
-1 & i = d \\
0 & i \neq s, d 
\end{cases} \quad \forall i$$
Mathematical model (3)

• Capacity constraint

Aggregated traffic distribution:

\[ t = t_{s_1d_1} \otimes t_{s_2d_2} \otimes t_{s_3d_3} \]

Probability that the aggregated traffic is lower than the capacity \( b \) of a link is: \( \int_0^b t(x)dx \)
Mathematical model (4)

- Capacity constraint

\[
\prod_{\{s,d : f_{ij}^{sd} = 1\}} \int_0^{b_{ij}} (f_{ij}^{s_1d_1} \cdot t_{s_1d_1} \otimes f_{ij}^{s_2d_2} \cdot t_{s_2d_2} \otimes \ldots \otimes f_{ij}^{s_n d_n} \cdot t_{s_n d_n}) \, dx \geq 1 - \varepsilon
\]

\forall i, j

\[
P\{\text{link (i,j) is overloaded}\} \leq \varepsilon
\]

\[
b_{ij} = ?
\]
Calculate the link bandwidth $b_{ij}$

$$F(b_{ij}) = \prod_{\{s,d; f_{sd}^{ij} = 1\}}^{b_{ij}} \int_0^{b_{ij}} f_{ij}^{sd} \cdot t^{sd}(x)dx \geq 1 - \varepsilon$$

- $F(b_{ij})$ is the CDF of the traffic distribution on the link
  - a monotone function
- bisection method can be used to find $b_{ij}$

Solution interval
Genetic algorithm (1)

Generate initial population of solutions

Create new solutions by cross-over or mutation

Evaluate the solution quality

Discard „bad“ solutions to form a new population

Terminate?

Yes

No

Store the best solution
Genetic algorithm (2)

• A set of routes for each nodepair is pre-selected.
• A solution is encoded in a chromosome
  
  | 1 | 3 | 2 | 3 | 1 | 1 |
  
  nodepair

  selected route for the corresponding nodepair

  → a chromosome represents a routing solution for the problem.

• Calculate the required bandwidth for each „chromosome“ to guarantee GoS
  
  → calculate the cost of each „chromosome“
Genetic algorithm (3)

- Cross-over

```
1 3 2 3 1 1
1 1 3 2 3 1
```

- Mutation

```
1 3 2 3 1 1
```

```
3 1 1 1 1 3 2
```
Performance Evaluation

- Traffic demands are taken from GEANT project*
- Link cost = 1 per Mbps
- GoS agreement: $\varepsilon = 5\%$

(*) http://www.geant.net/
Performance of the genetic algorithm

![Graph showing the performance of the genetic algorithm with total cost on the y-axis and number of iterations on the x-axis. The graph compares the best solution (red line) and the average solution (blue line).]
Results

<table>
<thead>
<tr>
<th></th>
<th>Mean rate</th>
<th>Peak rate</th>
<th>Statistical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized cost</td>
<td>0.42</td>
<td>1</td>
<td>0.53</td>
</tr>
<tr>
<td>Link overload probability</td>
<td>18% - 25%</td>
<td>0%</td>
<td>5% (ε)</td>
</tr>
</tbody>
</table>

- Peak rate planning: too expensive
- Mean rate planning: high link overload probability

→ Statistical planning is a good compromise
Link utilization

[Graph showing link utilization over time, with lines for Traffic demand 1, Traffic demand 2, and Aggregated traffic.]
Cost vs. GoS

Total cost vs. GoS - \( \varepsilon(\%) \)
Conclusion

• Proposal of a solution for network planning problem with stochastical traffic demands using a genetic algorithm.

• Limitation: guarantee the overload probability for each link only

• Future work: guarantee the GoS for each end-to-end flow