DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES
E INFORMÁTICA

MESTRADO EM ENGENHARIA DE COMPUTADORES E TELEMÁTICA

ANO 2024/2025

MODELAÇÃO E DESEMPENHO DE REDES E SERVIÇOS

MINI-PROJECT 2:

TRAFFIC ENGINEERING OF TELECOMMUNICATION NETWORKS

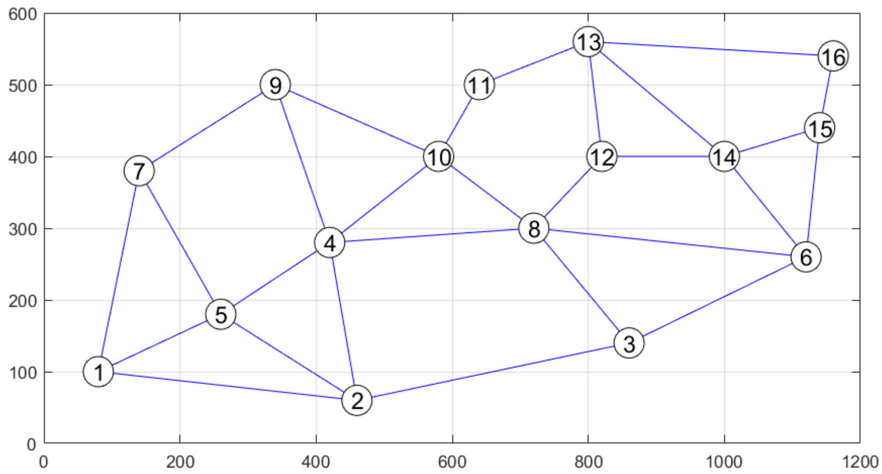
Mini-Project 2

Assignment Description

Develop this mini-project in a group of 2 students. Implement all tasks using MATLAB to obtain the requested results. Justify all obtained results and draw all conclusions as complete as possible. Write a report with all results together with their analysis and conclusions. Include in the report all developed MATLAB codes duly explained. The report must identify the elements of the group (names and Student Numbers) and must include an auto-evaluation of the percentage of the work done by each member. The report must be sent in PDF format to asou@ua.pt until the end of 17^{th} of December of 2024.

Description of the network and supported services

Consider the MPLS network of an ISP (Internet Service Provider) with the following topology composed by 16 nodes and 28 links and defined over a rectangle with 1200 Km by 600 Km:



The capacity of all links is 100 Gbps in each direction. The length of all links is provided (in Km) by the square matrix L.

The network supports two unicast services (s = 1 and s = 2) and one anycast service (s = 3), whose traffic flows characteristics are given by matrix T with one row per traffic flow and 5 columns with the following information:

- The first column is the service s at which the traffic flow belongs (its value is 1, 2 or 3)
- The second column defines the source node of the traffic flow
- The third column defines the destination node of the traffic flow (if it is a unicast flow) or is equal to 0 (if it is an anycast flow)
- The fourth column defines the throughput (in Gbps) of the traffic flow from the source node to the destination node
- The fifth column defines the throughput (in Gbps) of the traffic flow from the destination node to the source node

To load all input matrices, run on your script: `load('InputDataProject2.mat')`

In all tasks, the anycast flows are always routed through the shortest propagation delay path towards the closest anycast node (in terms of propagation delay). Consider that the propagation delay on each direction of each link is given by the speed of light on fibers $v = 2\times10^5$ km/sec (compute a matrix D with the propagation delay on each direction of each link as $D = L / v$).

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Task 1 (evaluation: 6.0 values)

In Task 1, consider the solutions where all traffic flows of both unicast services (s = 1 and s = 2) are routed through the shortest propagation delay path.

1.a. Compute the worst round-trip delay and the average round trip delay of each of the 3 services (presenting all values in milliseconds) if the anycast nodes of the anycast service (s = 3) are network nodes 3 and 10.

1.b. Determine the link loads of all links and the worst link load of the network of the previous solution.

1.c. Consider that you can freely select the anycast nodes of the anycast service. Try all possible combinations of 2 nodes and select the one that minimizes the worst link load. Indicate the two selected nodes, the worst round-trip delay and the average round trip delay of each service.

1.d. Again, consider that you can freely select the anycast nodes of the anycast service. Try all possible combinations of 2 nodes and select the one that minimizes the worst round-trip delay of the anycast service. Indicate the two selected nodes, the worst round-trip delay and the average round trip delay of each service.

1.e. Again, consider that you can freely select the anycast nodes of the anycast service. Try all possible combinations of 2 nodes and select the one that minimizes the average round-trip delay of the anycast service. Indicate the two selected nodes, the worst round-trip delay and the average round trip delay of each service.

1.f. Compare the results obtained in all experiments of Task 1 and draw all possible conclusions.

Task 2 (evaluation: 8.0 values)

Consider the optimization problem of computing a single routing path to each traffic flow of both unicast services, aiming to minimize the worst link load of the network. Use a k-shortest path algorithm (using the propagation delays of the links) to determine the candidate routing paths for each flow of each unicast service.

To solve this problem, use a Multi Start Hill Climbing algorithm with initial Greedy Randomized solutions and with a stopping criterion defined by a given running time. Besides the found best solution, the algorithm must also output the following performance parameters:

- (i) total number of cycles run
- (ii) the running time at which the algorithm obtains its best solution
- (iii) the number of cycles at which the algorithm obtains its best solution.

2.a. Run the algorithm for 30 seconds with k = 6 candidate paths for each unicast flow when the anycast nodes of the anycast service are network nodes 3 and 10. Indicate the worst round-trip delay and the average round trip delay of each service (presenting all values in milliseconds) and the worst link load of the network. Indicate also the algorithm performance parameters.

2.b. Repeat experiment **2.a** with the anycast nodes selected in experiment **1.c**.

2.c. Repeat experiment **2.a** with the anycast nodes selected in experiment **1.d**.

2.d. Repeat experiment **2.a** with the anycast nodes selected in experiment **1.e**.

2.e. Compare the results obtained in all experiments of this Task 2 and of the previous Task 1 and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the algorithm.

Task 3 (evaluation: 6.0 values)

Consider now that the traffic flows of the unicast service s = 2 must be protected by a 1:1 protection mechanism based on a pair of link disjoint routing paths (like before, the traffic flows of the unicast service s = 1 must be assigned with a single routing path). To generate the candidate pairs of link disjoint paths, use the provided MATLAB function with the `costMatrix` defined by the propagation delays of the links (consider the first path of each pair as a candidate working path and the second path of each pair as a candidate protection paths):

```
>> help kShortestPathPairs
  [firstPaths,secondPaths,totalPairCosts] = kShortestPathPairs(costMatrix,source,destination,K)

  - Returns K pairs of link disjoint paths from source to destination node
    in a network of N nodes represented by the NxN matrix costMatrix.
  - In matrix costMatrix, cost of 'inf' represents the 'absence' of a link.
  - On each pair of paths, the cost of the first path is always less or equal
    than the cost of the second path.

  Outputs:
  [firstPaths]    : the list of K first paths of each pair (in cell array 1 x K)
  [secondPaths]   : the list of K second paths of each pair (in cell array 1 x K)
  [totalPairCosts]: costs of the K pairs of paths (in array 1 x K)
```

To solve this problem, use a Multi Start Hill Climbing algorithm with initial Greedy Randomized solutions and with a stopping criterion defined by a given running time. Besides the found best solution, the algorithm must also output the same performance parameters as defined in Task 2.

3.a. Run the algorithm for 60 seconds with k = 12 candidate paths for each traffic flow of unicast service s = 1 and with k = 12 candidate pairs of link disjoint paths for each traffic flow of unicast service s = 2. Consider that the anycast nodes of the anycast service are network nodes 3 and 10. Indicate the worst round-trip delay and the average round trip delay of each service[1] (presenting all values in milliseconds) and the worst link load of the network. Indicate also the algorithm performance parameters.

3.b. Repeat experiment **3.a** with the anycast nodes selected in experiment **1.c**.

3.c. Repeat experiment **3.a** with the anycast nodes selected in experiment **1.d**.

3.d. Repeat experiment **3.a** with the anycast nodes selected in experiment **1.e**.

3.e. Compare the results obtained in all experiments of this Task 3 and of the previous Task 2 and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the algorithm.

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[1] In the unicast service s = 2, the worst round-trip delay and the average round-trip delay should be only computed over the working paths of the flows (the paths supporting the traffic when there are no link failures).