DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES
E INFORMÁTICA

MESTRADO EM ENGENHARIA DE COMPUTADORES E TELEMÁTICA

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# MODELAÇÃO E DESEMPENHO DE REDES E SERVIÇOS

# MINI-PROJECT 2:

# TRAFFIC ENGINEERING OF TELECOMMUNICATION NETWORKS

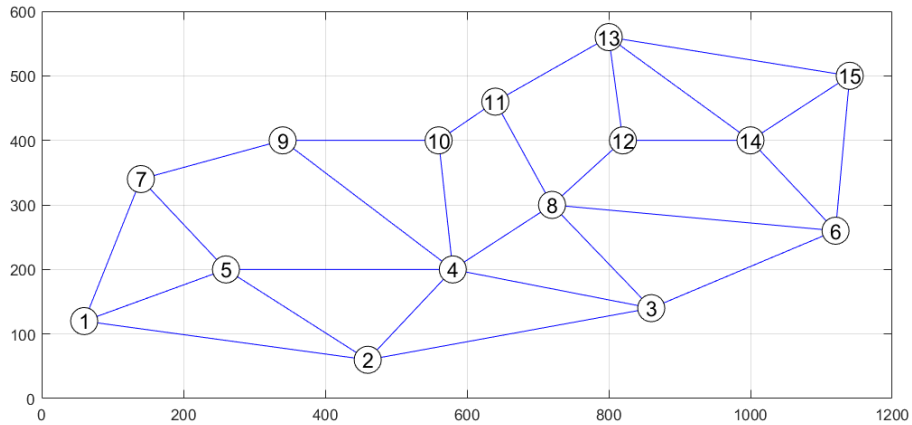
Mini-Project 2

## 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 be sent in PDF format to asou@ua.pt until the end of 22nd of December of 2023.

## Description of the network, supported services and energy consumption models

Consider the MPLS (Multi-Protocol Label Switching) network of an ISP (Internet Service Provider) with the following topology composed by 15 nodes and 28 links and defined over a rectangle with 1200 Km by 600 Km:




The length of all links is provided (in Km) by the square matrix $L$.

The network supports two unicast services whose flows characteristics are given by matrices $T1$ (for Service 1) and $T2$ (for Service 2). Each of these matrices has the number of rows equal to the number of flows (one row per unicast flow) and 4 columns:

- first column defines the source node of the flow,
- second column defines the destination node of the flow,
- third column defines the throughput (in Gbps) of the flow from source to destination,
- fourth column defines the throughput (in Gbps) of the flow from destination to source.

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

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. Start by computing a matrix $D$ with the propagation delay on each direction of each link as $D = L / v$.
- Each router has a throughput capacity of 1 Tbps (=1000 Gbps) and its energy consumption is $20 + 80 \times \sqrt{t}$, (where $t$ is the total throughput traffic supported by the router divided by its total capacity).
- Each link has a capacity of 100 Gbps in each direction and its energy consumption is $9 + 0.3 \times l$ (where $l$ is the length of the link, in Km) when the link is operational and is 2 when the link is in sleeping mode.

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## Task 1 (evaluation: 6.0 values)

**1.a.** Consider the solution where all flows are routed through the path with the minimum propagation delay of the network. Is this a feasible solution? Justify your answer.

**1.b.** Consider the optimization problem of computing a symmetrical single path routing solution to support both services which aims to minimize the resulting worst link load. Use a *k*-shortest path algorithm (using the lengths of the links) to determine the candidate routing paths for each flow of each service. To solve this problem, develop a Multi Start Hill Climbing algorithm with initial Greedy Randomized solutions and with a stopping criterion defined by a given running time.

**1.c.** Run the algorithm developed in task **1.b** for 60 seconds with $k = 2$. Concerning the best obtained solution, register the following values:

- the worst link load of the solution,
- the average link load of the solution,
- the network energy consumption of the solution,
- the average round-trip propagation delay of each service,
- the number (and list) of links not supporting any traffic flow,
- the number of cycles run by the algorithm,
- the running time at which the algorithm has obtained the best solution.

**1.d.** Run again the algorithm developed in task **1.b** for 60 seconds but now with $k = 6$. Concerning the best obtained solution, register the same values that were also requested in task **1.c**.

**1.e.** Compare the values associated with the solutions obtained in tasks **1.c** and **1.d** and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the algorithm.

## Task 2 (evaluation: 6.0 values)

**2.a.** Consider now the optimization problem of computing a symmetrical single path routing solution to support both services which aims to minimize the energy consumption of the network. Adapt the algorithm developed in task **1.b** to address this optimization problem.

**2.b.** Run the algorithm developed in task **2.a** for 60 seconds with $k = 2$. Concerning the best obtained solution, register the same values that were also requested before.

**2.c.** Run again the algorithm developed in task **2.a** for 60 seconds but now with $k = 6$. Concerning the best obtained solution, register the same values that were also requested before.

**2.d.** Compare the values associated with the solutions obtained in tasks **2.b** and **2.c** and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the algorithm.

**2.e.** Compare the values associated with the solutions obtained in tasks **1.d** and **2.c** and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the two algorithms.

## Task 3 (evaluation: 4.0 values)

**3.a.** Consider now the optimization problem of computing a symmetrical single path routing solution to support both services which aims to minimize the average round-trip propagation delay of the service with the worst average round-trip delay and then the average round-trip propagation delay of the other service. Adapt the algorithm developed in task **1.b** to address this optimization problem.

**3.b.** Run the algorithm developed in task **3.a** for 60 seconds with $k$ = 2. Concerning the best obtained solution, register the same values that were also requested before.

**3.c.** Run again the algorithm developed in task **3.a** for 60 seconds but now with $k$ = 6. Concerning the best obtained solution, register the same values that were also requested before.

**3.d.** Compare the values associated with the solutions obtained in tasks **3.b** and **3.c** and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the algorithm.

**3.e.** Compare the values associated with the solutions obtained in tasks **1.d**, **2.c** and **3.c** and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the two algorithms.

## Task 4 (evaluation: 4.0 values)

Besides the two unicast services, consider that the network also supports one anycast service whose flows characteristics are given by matrix $T3$. This matrix has the number of rows equal to the number of flows (one row per anycast flow) and 3 columns:

- first column defines the source node of the flow,
- second column defines the source upload throughput (in Gbps) of the flow,
- third column defines the source download throughput (in Gbps) of the flow.

Assume that each anycast flow is routed from its source node to the closest anycast node (in terms of round-trip propagation delay) and through the routing path providing the shortest round-trip propagation delay. Consider initially that the anycast nodes of this anycast service are network nodes 3 and 10.

**4.a.** Consider the optimization problem of computing a symmetrical single path routing solution to support all services which aims to minimize the energy consumption of the network (this problem is similar with the one addressed in Task 2 but now the network also supports the anycast service). Adapt the algorithm developed in task **2.a** to address this optimization problem.

**4.b.** Run the algorithm developed in task **4.a** for 60 seconds with $k$ = 6 for the unicast flows. Concerning the best obtained solution, register the same values that were also requested before (in the case of the average round-trip propagation delay, you now need to register this value for each of the 3 services).

**4.c.** Consider now that you can freely select the 2 anycast nodes of the anycast service. Try all possible combinations of 2 nodes and register the combination that minimizes the average round-trip propagation delay of the anycast service.

**4.d.** Repeat task **4.b** but now considering as anycast nodes the combination computed in the previous task **4.c**. Concerning the best obtained solution, register the same values that were also requested before.

**4.e.** Compare the values associated with the solutions obtained in tasks **4.b** and **4.d** and draw all meaningful conclusions both concerning the differences between the solutions and the differences between the performance of the algorithm.