DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES E INFORMÁTICA

MESTRADO EM ENGENHARIA DE COMPUTADORES E TELEMÁTICA

ANO 2025/2026

MODELAÇÃO E DESEMPENHO DE REDES E SERVIÇOS

MINI-PROJECT 2:

TRAFFIC ENGINEERING OF TELECOMMUNICATION NETWORKS

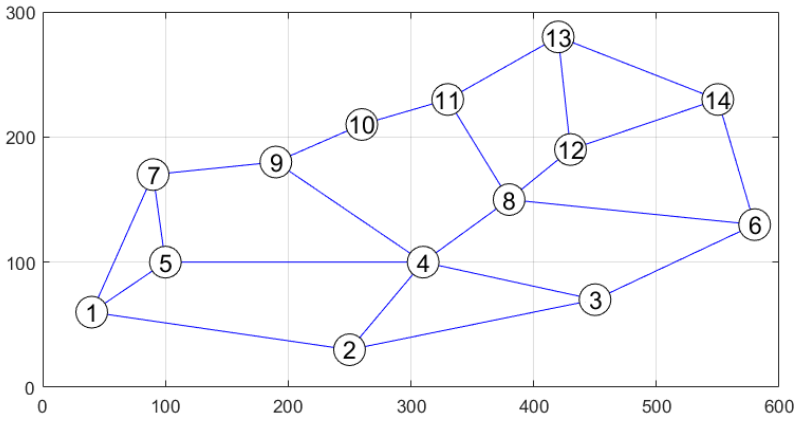
Mini-Project 2

Assignment Rules

- Develop this mini-project in a group of 2 students.
- Implement all tasks using MATLAB to obtain all requested results.
- Write a report containing all results together with their analysis and conclusions as complete as possible.
- When requested, include in the report the developed MATLAB codes duly explained.
- The report must identify the elements of the group (names and student numbers) and must include at the first page an auto-evaluation of the percentage of the work done by each element.
- In the classes of 17th of December (TP1) and 18th of December (TP2), both elements of each group must attend the class and demonstrate what have already developed.
- The report must be sent in PDF format to asou@ua.pt **until 23:59 of 23rd of December**.

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 14 nodes and 22 links and defined over a rectangle with 600 Km by 300 Km:



The length of all links is provided (in Km) by the square matrix *L*. The network supports a unicast service whose flows characteristics are given by matrix *Tu*. This matrix has a 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.

The network also supports an anycast service whose flows characteristics are given by matrix *Ta*. This matrix has a 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 upstream throughput (in Gbps) of the flow,
- third column defines the source downstream throughput (in Gbps) of the flow.

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

Mini-Project 2

Consider in all tasks that the anycast flows are always routed through the shortest path towards the closest anycast node.

Consider that each router has a capacity of 500 Gbps and its energy consumption is $E_n = 10 + 90 \times t^2$, where t is given by the total traffic load supported by the router divided by its capacity.

When a link is in operation, consider 2 link capacity cases:

- when the link has capacity of 50 Gbps, its energy consumption is $E_l = 6 + 0.2 \times l$ (where l is the length of the link, in Km)
- when the link has capacity of 100 Gbps, its energy consumption is $E_l = 8 + 0.3 \times l$.

On the other hand, when a link is in sleeping mode, its energy consumption is $E_l = 2$, whatever the link capacity is.

Task 1

In Task 1, consider that all links have a capacity of 50 Gbps and that the anycast nodes of the anycast service are network nodes 5 and 12.

1.a. **(Evaluation weight: 5%)** Determine the link loads of all links when the traffic flows of the unicast service are also routed through the shortest path provided by the network (using the lengths of the links). Determine the resulting worst link load.

1.b. **(Evaluation weight: 5%)** Determine the network energy consumption of the previous solution and the links that are put in sleeping mode. Include in the report the developed MATLAB code to compute the network energy consumption duly explained.

1.c. **(Evaluation weight: 10%)** Consider the optimization problem aiming to compute a symmetrical single path routing solution which minimizes 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 unicast flow. Develop a Multi Start Hill Climbing algorithm with initial Greedy Randomized solutions to solve this optimization problem. Output also the running time at which the algorithm has obtained its best solution. Include in the report the developed MATLAB code of the algorithm duly explained.

1.d. **(Evaluation weight: 10%)** Run the algorithm developed in task **1.c** for 30 seconds with $k = 6$. Register the worst link load, the network energy consumption and the links in sleeping mode of the best obtained solution. Register also the running time at which the algorithm has obtained its best solution. Compare these results with the results of **1.a** and **1.b**, justify the differences and draw conclusions.

Task 2

Like in Task1, consider in Task 2 that all links have a capacity of 50 Gbps and that the anycast nodes of the anycast service are network nodes 5 and 12.

Consider the optimization problem aiming to compute a symmetrical single path routing solution which minimizes the energy consumption of the network. Note that the solutions mst guarantee that the load of the links cannot be higher than 100%.

2.a. **(Evaluation weight: 10%)** Use a *k*-shortest path algorithm to determine the candidate routing paths for each unicast flow. Develop a Multi Start Hill Climbing algorithm with

initial Greedy Randomized solutions to solve this optimization problem. Output also the running time at which the algorithm has obtained its best solution. Include in the report the developed MATLAB code of the algorithm duly explained.

2.b. (Evaluation weight: 10%) Run the algorithm developed in task **2.a** for 30 seconds with $k = 6$. Register the worst link load, the network energy consumption and the links in sleeping mode of the best obtained solution. Register also the running time at which the algorithm has obtained its best solution.

2.c. (Evaluation weight: 10%) Repeat task **2.b** but now with all possible candidate routing paths. Compare these results with the results of tasks **1.d** and **2.b**, justify the differences and draw conclusions.

Task 3

In Task 3, consider that the capacity of each link can remain as 50 Gbps or can be upgraded to 100 Gbps. Like in the previous tasks, start by considering that the anycast nodes of the anycast service are network nodes 5 and 12.

Note that the capacity upgrade of a link consumes more energy when it is fully operational but might enable more other links to change to sleeping mode. So, the network consumption of the network might be less with some upgraded links.

Consider the optimization problem aiming to compute the links that should be upgraded and the symmetrical single path routing solution to support both services so that the resulting network energy consumption is minimized.

3.a. (Evaluation weight: 10%) Use a *k*-shortest path algorithm to determine the candidate routing paths for each unicast flow. Develop a Multi Start Hill Climbing algorithm with initial Greedy Randomized solutions to solve this optimization problem. Output also the running time at which the algorithm has obtained its best solution. Include in the report the developed MATLAB code of the algorithm duly explained.

3.b. (Evaluation weight: 10%) Run the algorithm developed in task **3.a** for 60 seconds with $k = 6$. Register the worst link load, the network energy consumption, the links in sleeping mode and the upgraded links of the best solution, and the running time at which the algorithm has obtained the best solution. Compare these results with the results of tasks **2.b** and **2.c**, explain the differences and draw conclusions.

Consider now that you can select two anycast nodes among network nodes 4, 5, 6, 12 and 13 (nodes connected to Data Centers that can host servers of the anycast service).

3.c. (Evaluation weight: 10%) Develop a MATLAB script that computes all possible combinations of two nodes and selects the combination that obtains the best solution of the optimization problem addressed in this Task 3. For each combination, the script must run the algorithm developed in task **3.a** for 60 seconds with $k = 6$. Include in the report the developed MATLAB script duly explained.

3.d. (Evaluation weight: 10%) Run the script developed in **3.c**. Register the two selected anycast nodes, the worst link load, the network energy consumption, the links in sleeping mode and the upgraded links of the best solution. Compare these results with the results obtained in task **3.b**, explain the differences and draw conclusions.