## Exercise 1

The graph **network1.gml** represents a set of points (graph nodes) that must be connected by a communication network. Each potential link has an activation cost that is stored in the attribute 'cost' of the graph (in Euro).

## Questions

- 1. Find the set of links that connects all nodes at minimum cost.
- 2. Suppose that you can install in node 3 a hub (<a href="https://en.wikipedia.org/wiki/Ethernet\_hub">https://en.wikipedia.org/wiki/Ethernet\_hub</a>) with the following features:
  - a. If the hub is installed, the cost of a link cost from node 3 to any other node decreases by a factor of 10;
  - b. The hub accepts a maximum of 4 connections;
  - c. An adapter (cost: 10 Euro) must be installed in each node directly connected to the hub;
  - d. Hub installation costs 100 Euro.

Is it convenient to install the device in node 3?

[**Hint**: use the multicommodity flow formulation in the notebook MST-multi.ipynb and add extra constraints to solve #2. Edges cost can be manipulated with networkx methods]

## Exercise 2

The graph **network2.gml** represents a set of points (graph nodes) that must be connected by a communication network. Each potential link has an activation cost that is stored in the attribute 'cost' of the graph (in Euro).

To realize the network, in each node a hub **must** be installed among different available types. Each hub type is characterized by a cost (in Euro) and by a maximum number of connections that it can accommodate (see table 1).

Hub	Cost	Max Connections
1	15	2
2	20	4
3	50	8

Realize the network of minimum cost.

[**Hint**: Starting from the multicommodity flow formulation in the notebook MST-multi.ipynb add extra an extra binary variable  $z_i^k$  equal to 1 if a hub of type k is installed in node i]