URANIUM PROJECT

Directed Graph Modeling for GAS Distribution Infrastructure

Engineering Department
University of «Roma TRE»
Via della Vasca Navale, 79
00146, Rome - Italy

URANIUM - Unified Risk Assessment Negotiation via Interoperability Using Multi-sensory data

SPEAKER: Luca Faramondi
MAIL: luca.faramondi@uniroma3.it

OVERVIEW

- GAS Distribution Network Model
  - Pipes and Measurement and Regulation Stations
- Types of pipelines
- Proposed Model
- Digraph
- Spectral Clustering
- Line Graph
- Proposed Solution

MCIPLab.it

WITH THE FINANCIAL SUPPORT OF THE PREVENTION, PREPAREDNESS AND CONSEQUENCE
MANAGEMENT OF TERRORISM AND OTHER SECURITY-RELATED RISKS PROGRAMME
EUROPEAN COMMISION – DIRECTORATE-GENERAL HOME AFFAIRS

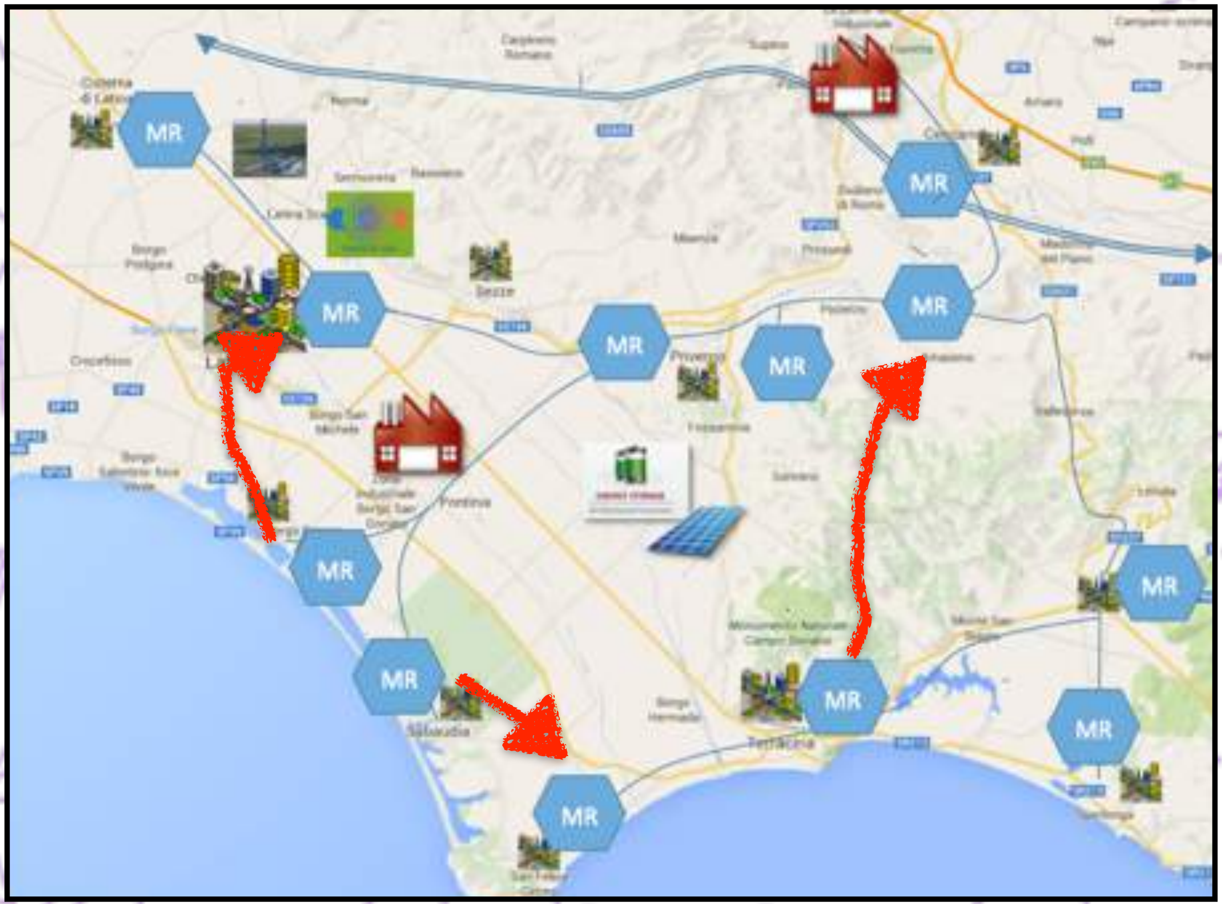
GAS DISTRIBUTION NETWORK MODEL

MEDIUM PRESSURE PIPELINE (Gas Distribution)

- **Type 4:** Pipeline with a pressure between 1,5 bar and 5 bar
- **Type 5**: Pipeline with a pressure between 0,5 bar and 1,5 bar
- **Type 6**: Pipeline with a pressure between 0,04 bar and 0,5 bar

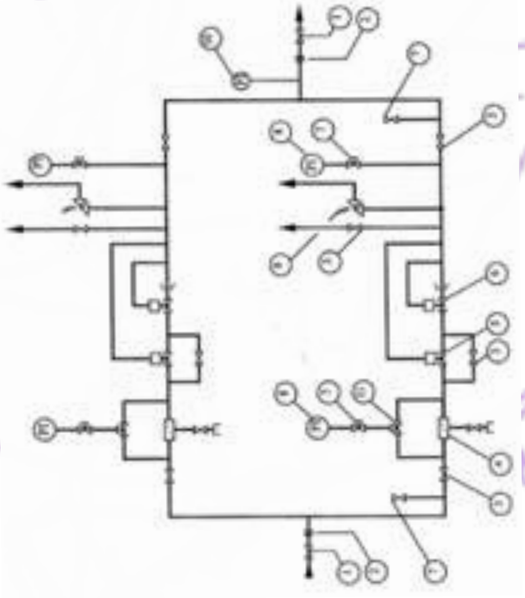
LOW PRESSURE PIPELINE (City Centre)

- **Type 7**: Pipeline with a maximum pressure 0,04 bar



MR STATIONS

Regulating stations contain equipment for pressure **regulation** and for quick switching off of gas supply with associated pipes. The equipment consists of **two complete lines**, of which one is standby, which will automatically take over operation in case of malfunction.



- How to modelize the **network topology** ?
- How to modelize the different **pipe** topology ?
- How to modelize the Measurement and **Regulation Stations** ?

With the financial support of the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme
European Commision – Directorate-General Home Affairs

MCIPLab.it

PIPES AND MR-STATIONS

- **How to modelize the network topology ?**

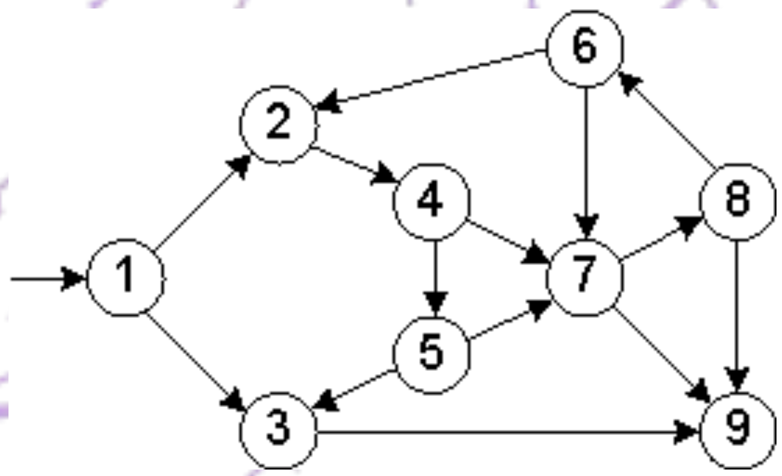
The system is composed by a set of points of measure interconnected by pipes. Each node provides the pressure measure.
The proposed model associates a node to each MR-Station and a directed edge for each pipe.
In the obtained directed graph, two MR-Stations i and j are connected by the edge (i,j) if and exists a pipe between the MR-Stations associated to the node i and j. The edge orientation depends by the gas flow.

- **How to modelize the different pipe topology ?**

The pipe topology is modelled as constraint on the measure value.

Directed Graph (Digraph)

In mathematics, and more specifically in graph theory, a **directed graph** (or **digraph**) is a graph, or **set of vertices connected by edges**, where the edges have a **direction** associated with them.
In formal terms, a directed graph is an ordered pair G = (V, E) with:
V a set whose elements are called vertices, nodes, or points.
E a set of ordered pairs of vertices, called arrows, directed edges, directed arcs, or directed lines.



With the financial support of the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme
European Commision – Directorate-General Home Affairs

MCIPLab.it

ADVANTAGES OF THE PROPOSED SOLUTION

- Interdependencies are easy to identify
- Useful well known algorithms are applicable on the modelled scenario
- Based on the graph theory, more precisely, on the **line graph** and **spectral clustering** we are able to provide a measure about the importance of a node (MR-Station) in the infrastructure.

An index associated to the MR-Station because:

- MR-Stations are more vulnerable than the pipeline network.
- Big part of the gas pipeline network is underground.
- MR Stations are often remotely controlled and internet connected.
- MR Stations contain the control algorithms to regulate the gas pressure in the connected pipes.

With the financial support of the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme
European Commision – Directorate-General Home Affairs

LINE GRAPH

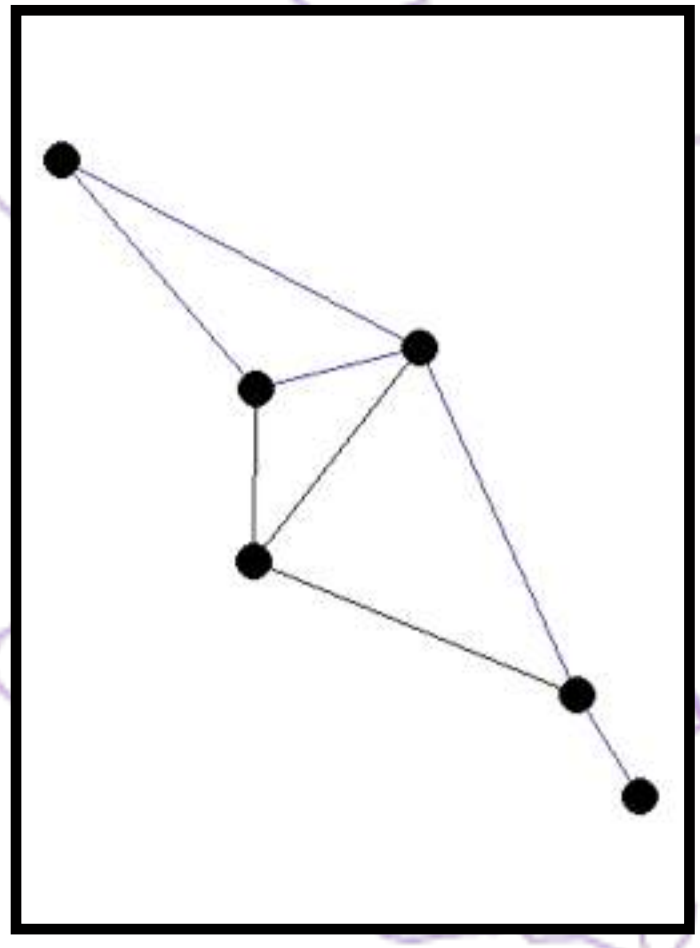
A line graph L(G) (also called an adjoint, conjugate, covering, derivative, derived, edge, edge-to-vertex dual, interchange, representative, or theta-obrazom graph) of a simple graph G is obtained by associating a vertex with each edge of the graph and connecting two vertices with an edge iff the corresponding edges of G have a vertex in common.

The algorithm used to generate the Line Graph is usually applied on undirected graph but also exists a version for digraph case.

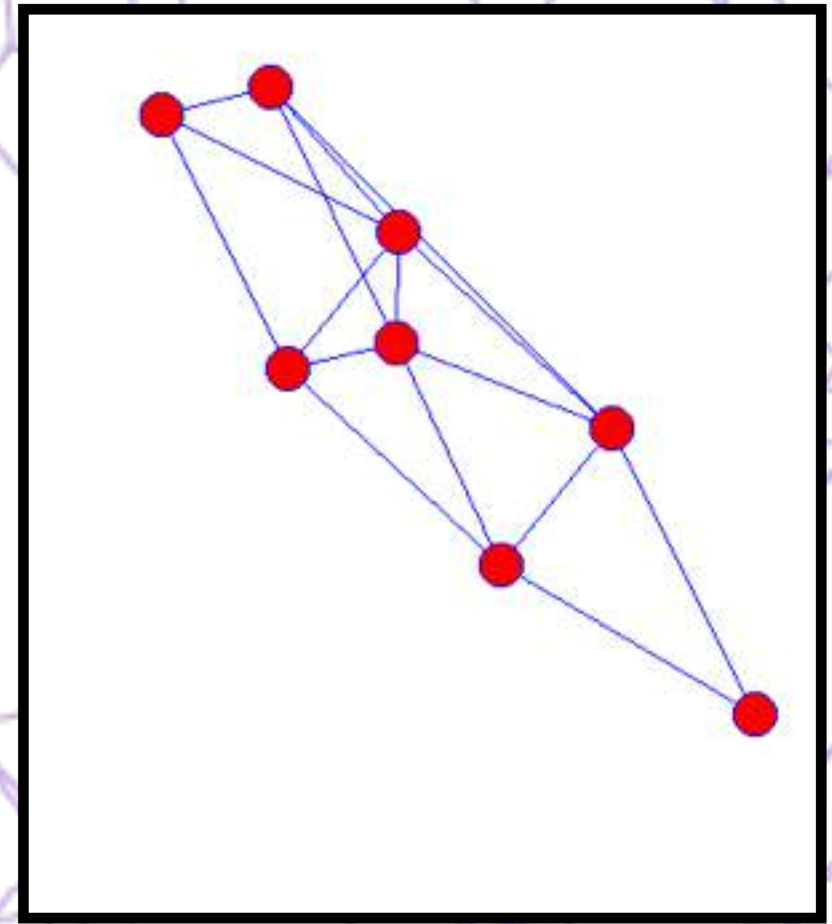
MCIPLab.it
With the financial support of the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme
European Commision – Directorate-General Home Affairs

LINE GRAPH

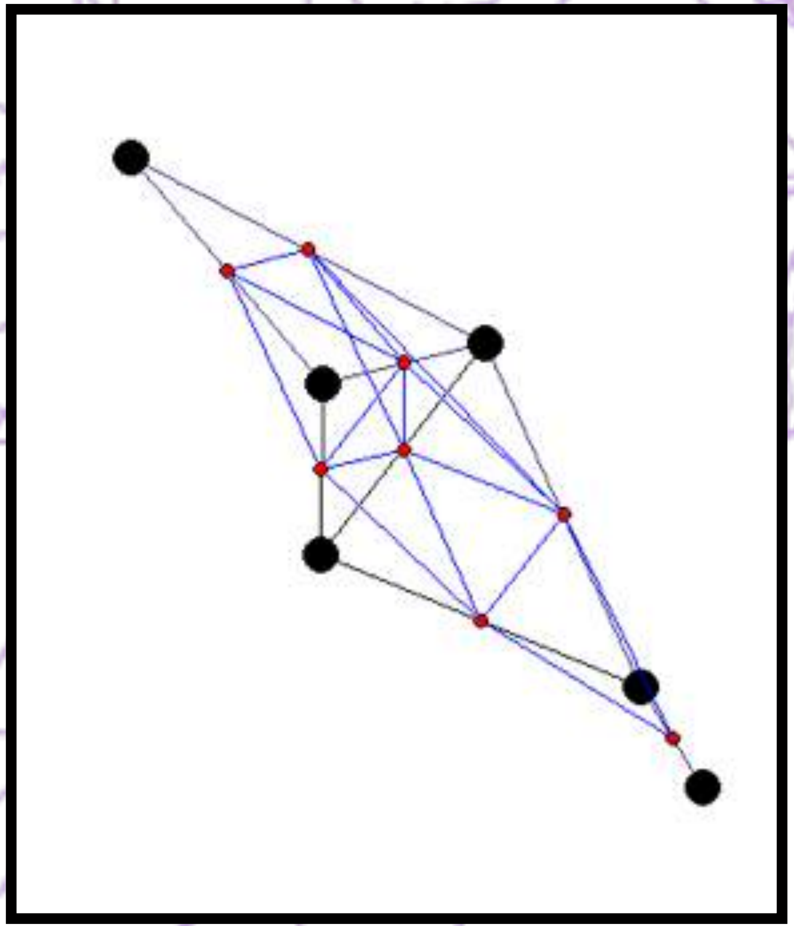
Original Graph: G



Line Graph: L = L(G)



G and L



WITH THE FINANCIAL SUPPORT OF THE PREVENTION, PREPAREDNESS AND CONSEQUENCE
MANAGEMENT OF TERRORISM AND OTHER SECURITY-RELATED RISKS PROGRAMME
EUROPEAN COMMISION – DIRECTORATE-GENERAL HOME AFFAIRS

SPECTRAL CLUSTERING

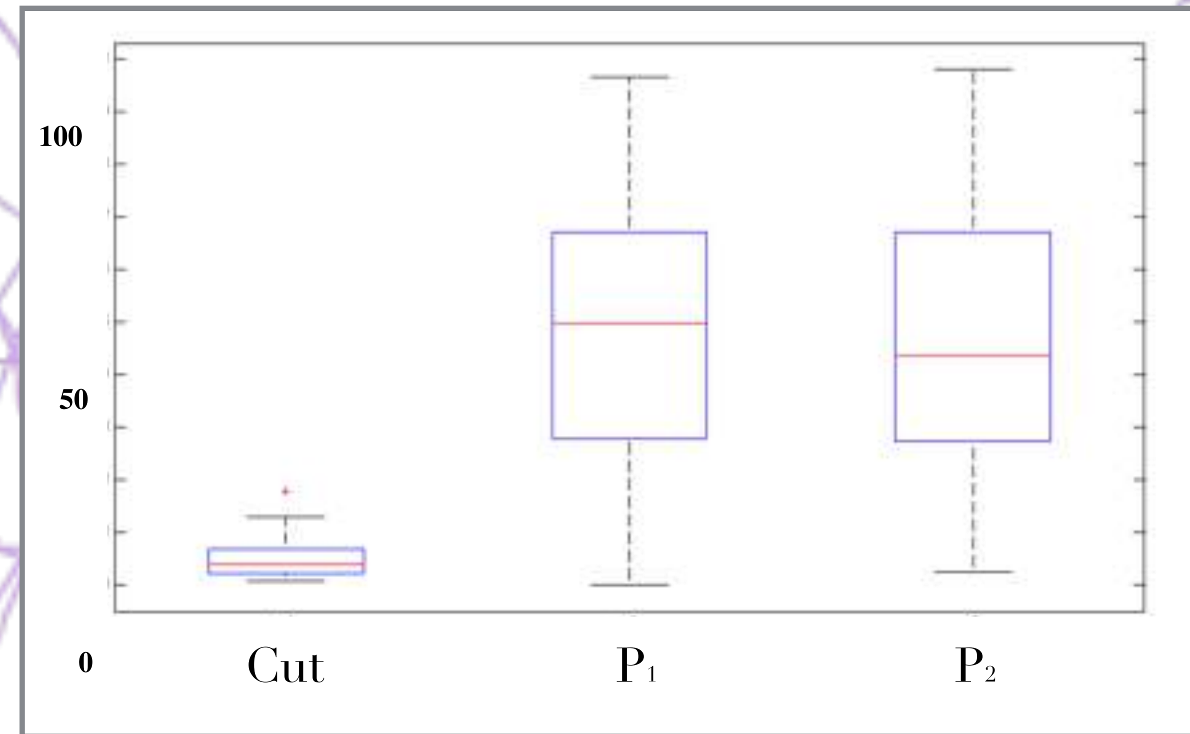
Partition a weighted graph in **k** groups

The sum of the weights within each group must be "big"

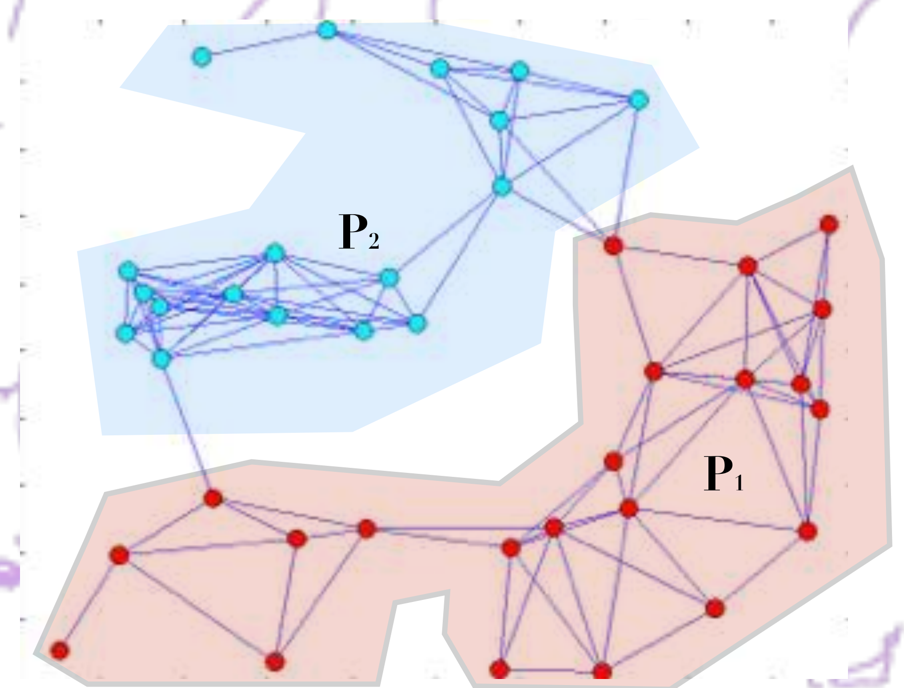
The sum of the weights that connect the groups is "small".

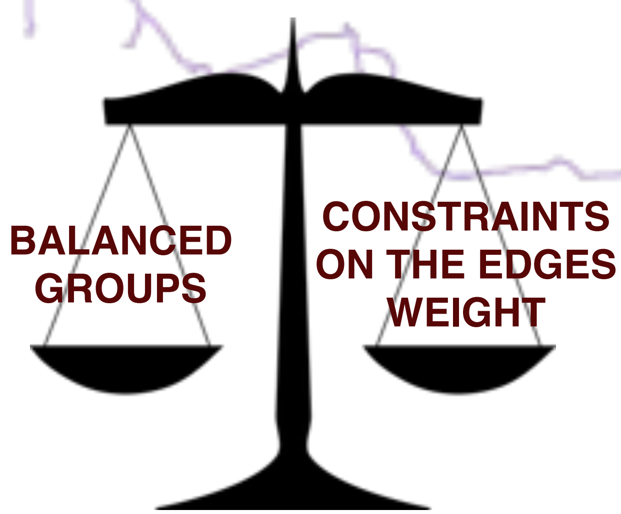
The number of nodes in each group must be "balanced".

In the proposed solution each weight associated to each edge is set at 1.
In this way, the spectral clustering, aims to divide the node set in k partitions, minimizing the number of the edges such that connect nodes in different partitions.



Number of edges in the two partitions and in the cut. Results computed on 1000 instances composed by graph with N = 40.





WITH THE FINANCIAL SUPPORT OF THE PREVENTION, PREPAREDNESS AND CONSEQUENCE MANAGEMENT OF TERRORISM AND OTHER SECURITY-RELATED RISKS PROGRAMME
EUROPEAN COMMISION – DIRECTORATE-GENERAL HOME AFFAIRS

THE PROPOSED APROACH IN 5 PHASES

1 The graph is obtained based on the MR-Station and the pipes

2 The spectral clustering is computed on the associated line graph

3 The results are applied on the original graph

4 Stations connected to pipes belonging to different partitions are considered critical stations.

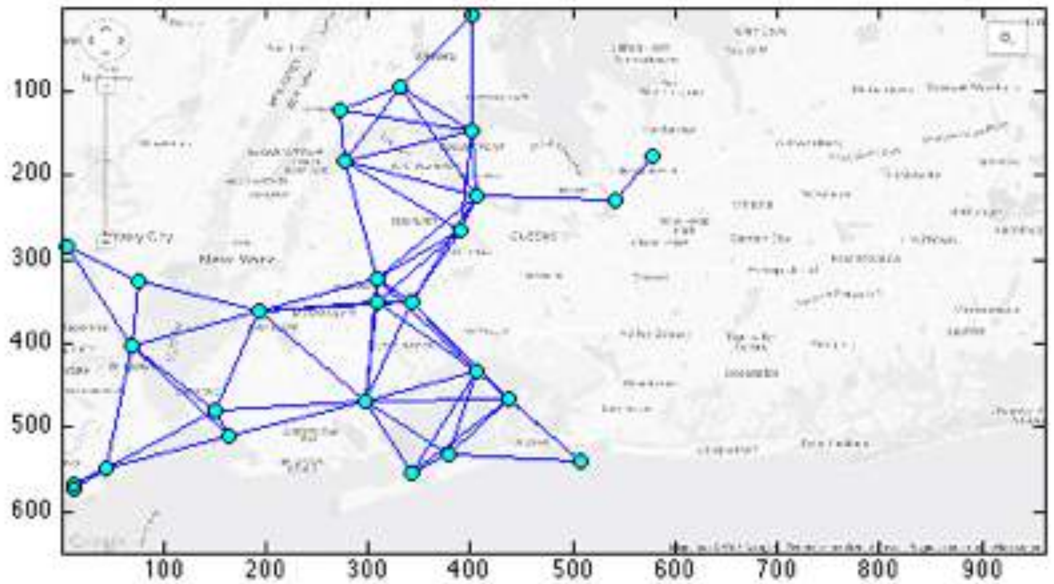
5 Starting from the critical nodes, a critical level is associated alsto to the other nodes in the network.

MCIPLab.it

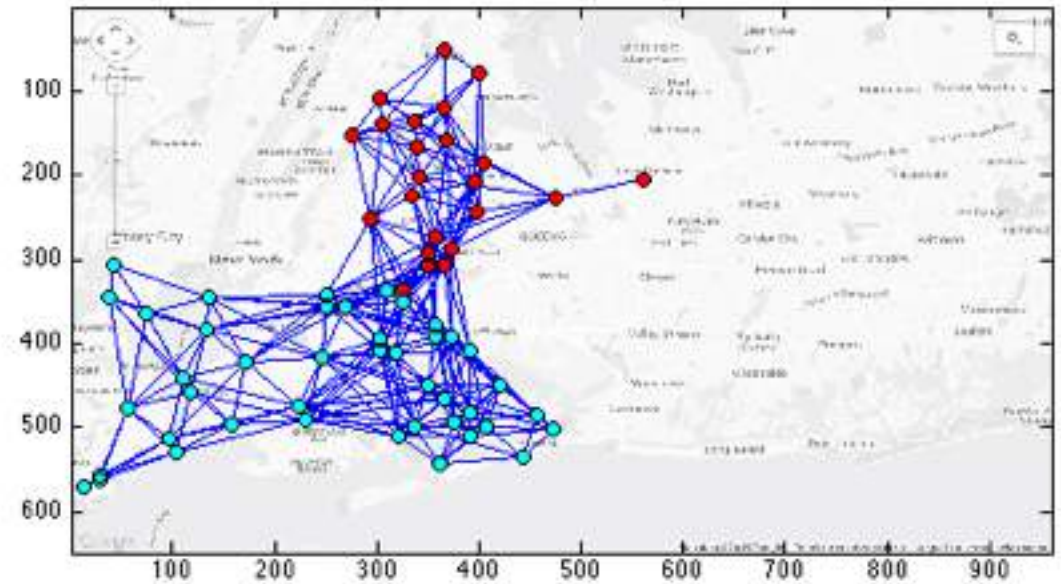
WITH THE FINANCIAL SUPPORT OF THE PREVENTION, PREPAREDNESS AND CONSEQUENCE MANAGEMENT OF TERRORISM AND OTHER SECURITY-RELATED RISKS PROGRAMME
EUROPEAN COMMISION – DIRECTORATE-GENERAL HOME AFFAIRS

RESULTS

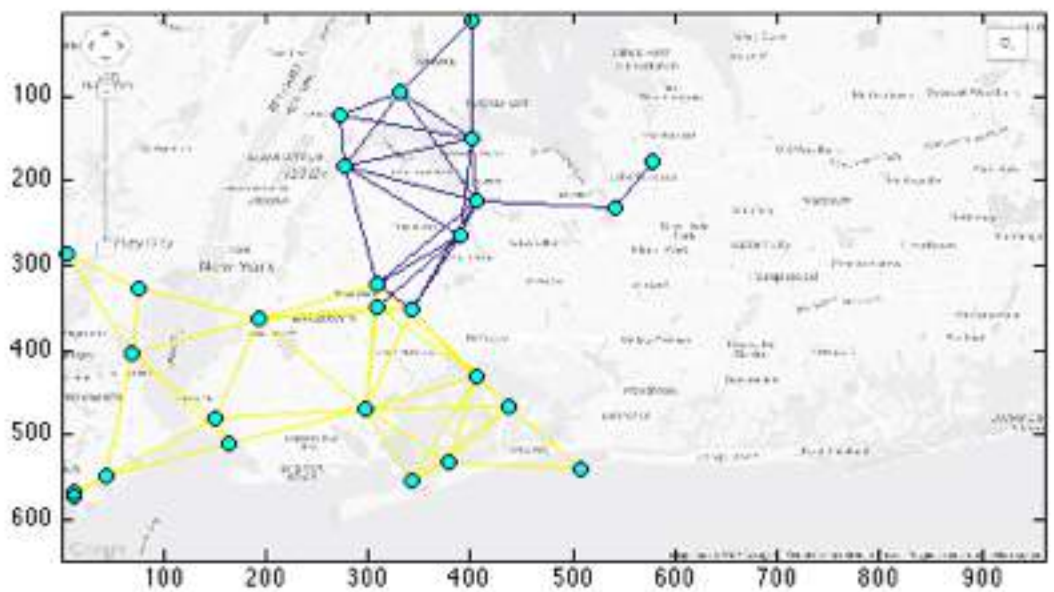
Phase 1 - Gas distribution network



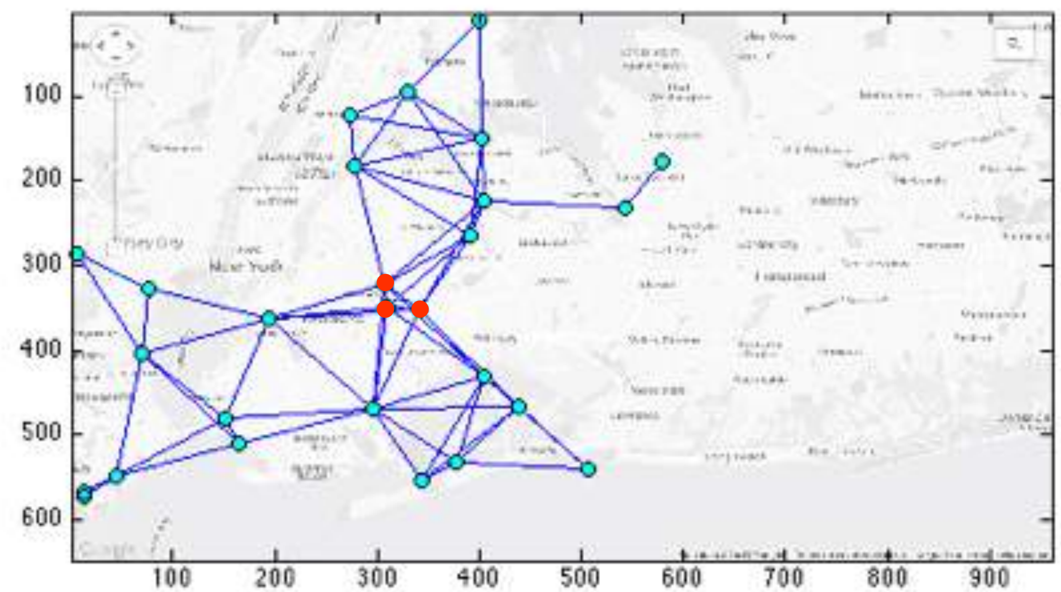
Phase 2 - Spectral Clustering on Line Graph



Phase 3 - Clustering results applied to the original graph



Phase 4 - Identification of critical MR - Stations

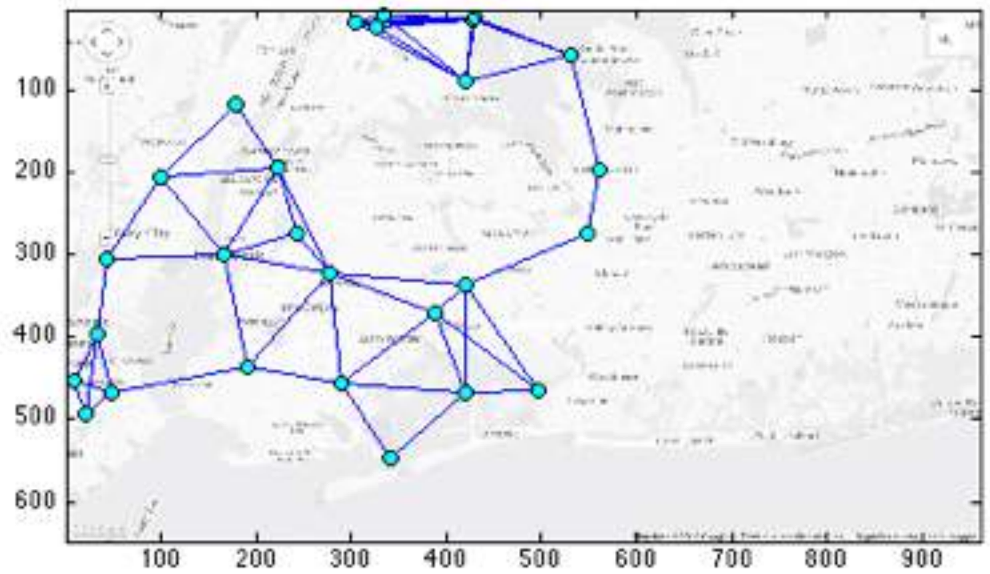


MCIPLab.it

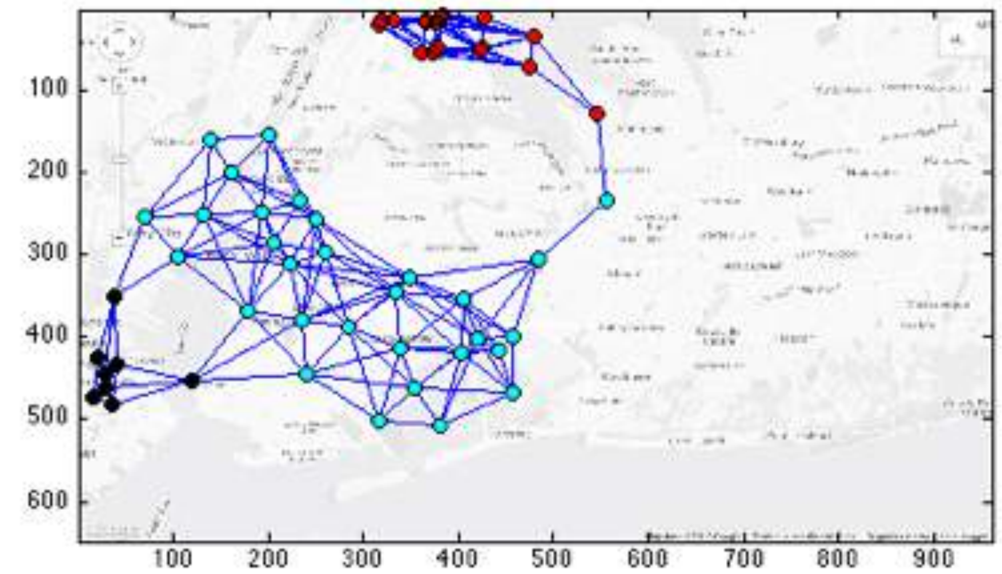
WITH THE FINANCIAL SUPPORT OF THE PREVENTION, PREPAREDNESS AND CONSEQUENCE MANAGEMENT OF TERRORISM AND OTHER SECURITY-RELATED RISKS PROGRAMME
EUROPEAN COMMISION – DIRECTORATE-GENERAL HOME AFFAIRS

RESULTS - AUTOMATIC PARTITIONS

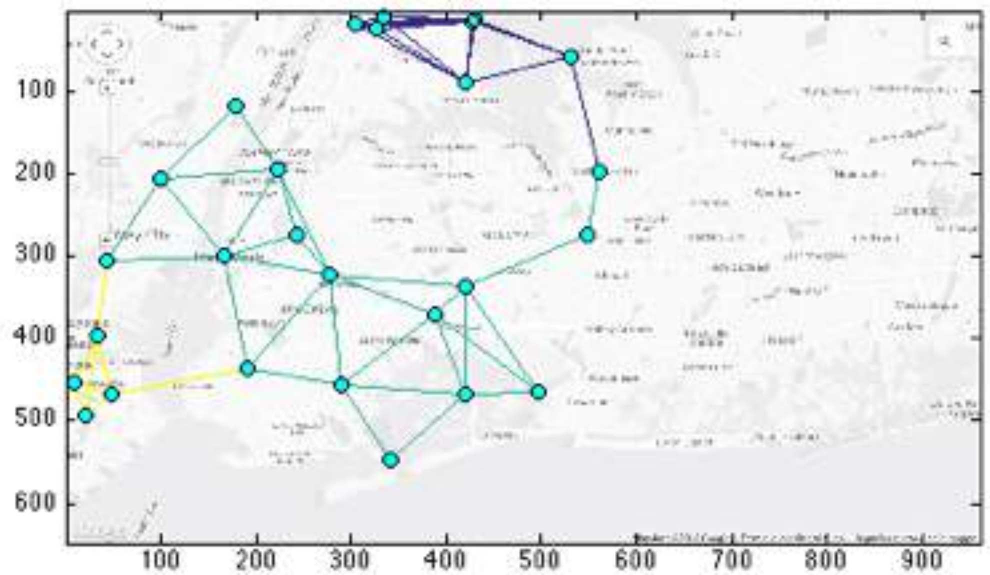
Phase 1 - Gas distribution network



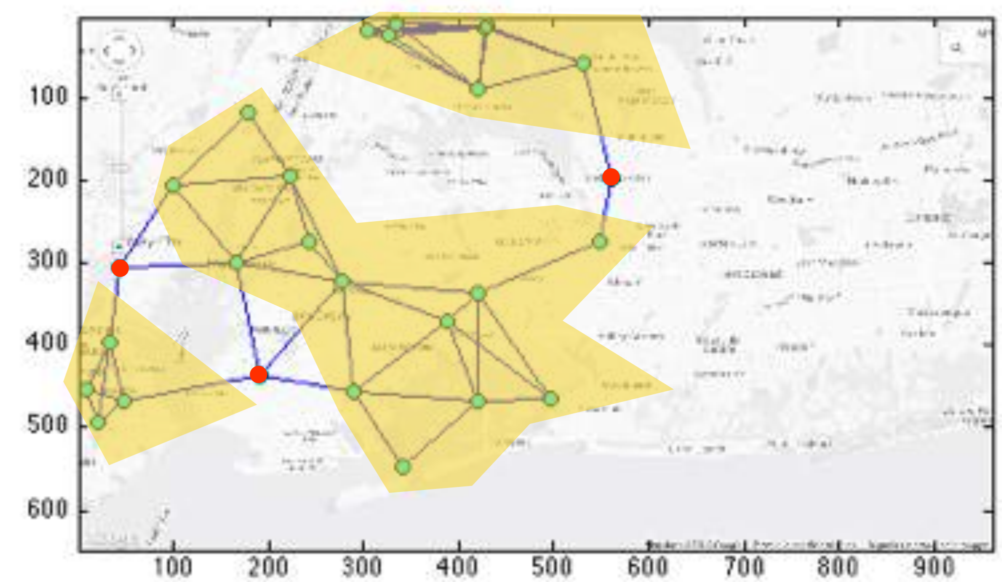
Phase 2 - Spectral Clustering on Line Graph



Phase 3 - Clustering results applied to the original graph

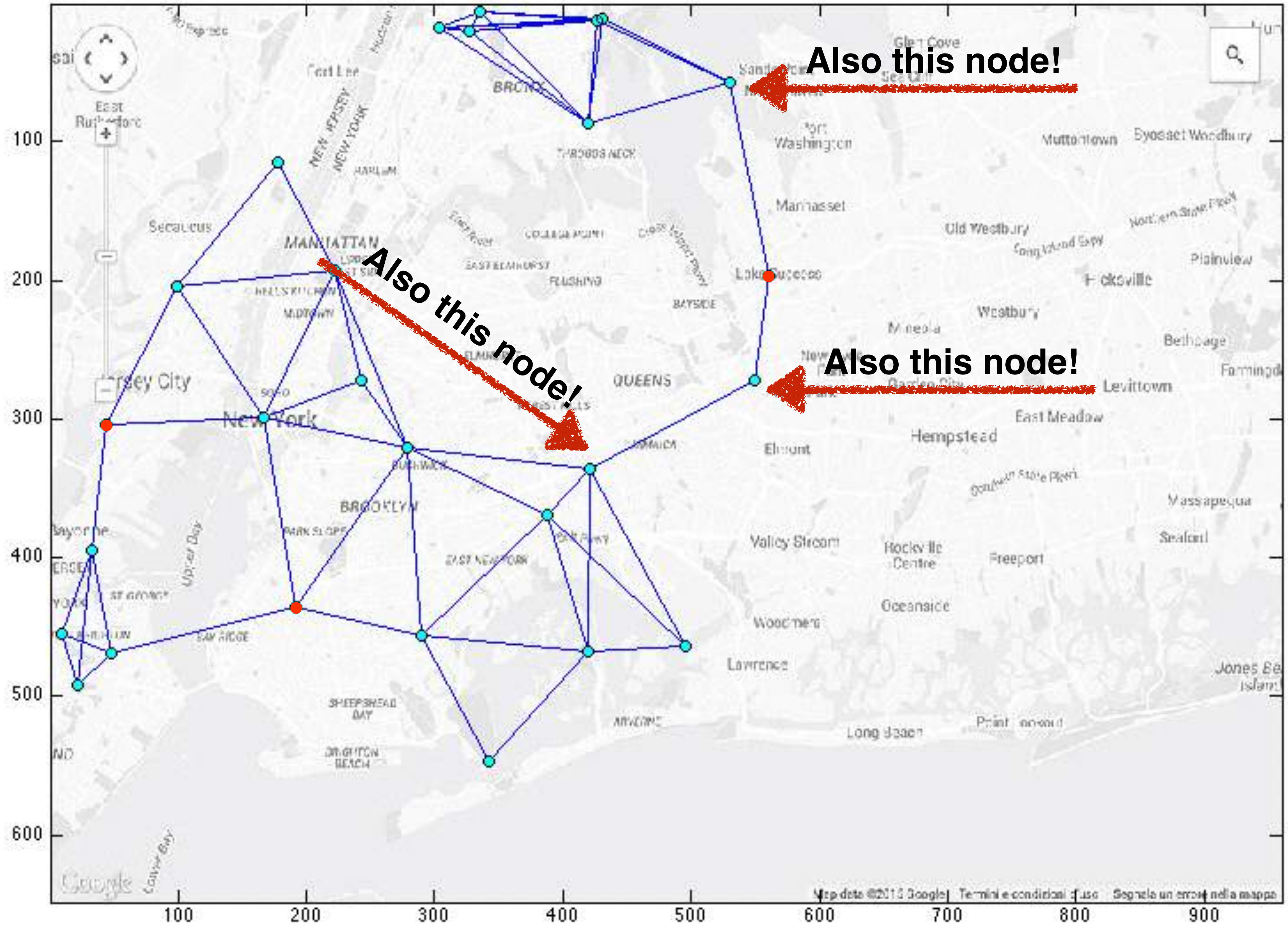


Phase 4 - Identification of critical MR - Stations



WITH THE FINANCIAL SUPPORT OF THE PREVENTION, PREPAREDNESS AND CONSEQUENCE MANAGEMENT OF TERRORISM AND OTHER SECURITY-RELATED RISKS PROGRAMME
EUROPEAN COMMISION – DIRECTORATE-GENERAL HOME AFFAIRS

RESULTS



Also other nodes could be considered critical.

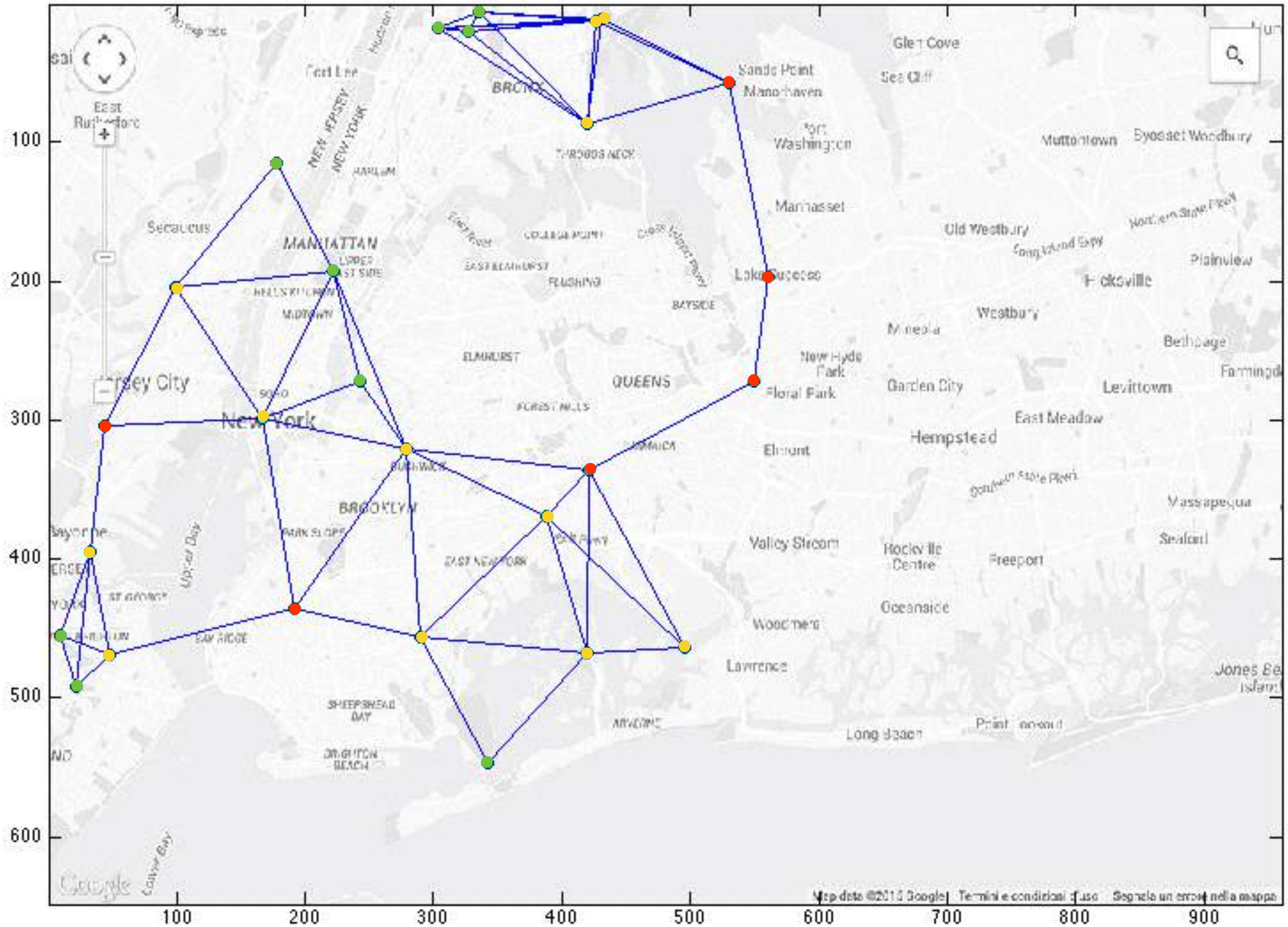
Another phase is necessary to consider other critical nodes.

Other estimations are provided looking at the flow orientation and the neighborhood of the stations.

MCIPLab.it

With the financial support of the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme
European Commision – Directorate-General Home Affairs

FINAL RESULTS



The biggest number of partitions is identified corrupting the lowest number of nodes.

The number of partitions is automatically computed.

Different levels of criticality are automatically defined.

With the financial support of the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme
European Commision – Directorate-General Home Affairs

MCIPLab.it

THANK YOU FOR ATTENTION!

Thanks to Gabriele Oliva (Campus Bio-Medico di Roma) for the collaboration.

With the financial support of the Prevention, Preparedness and Consequence
Management of Terrorism and other Security-related Risks Programme
European Commision – Directorate-General Home Affairs