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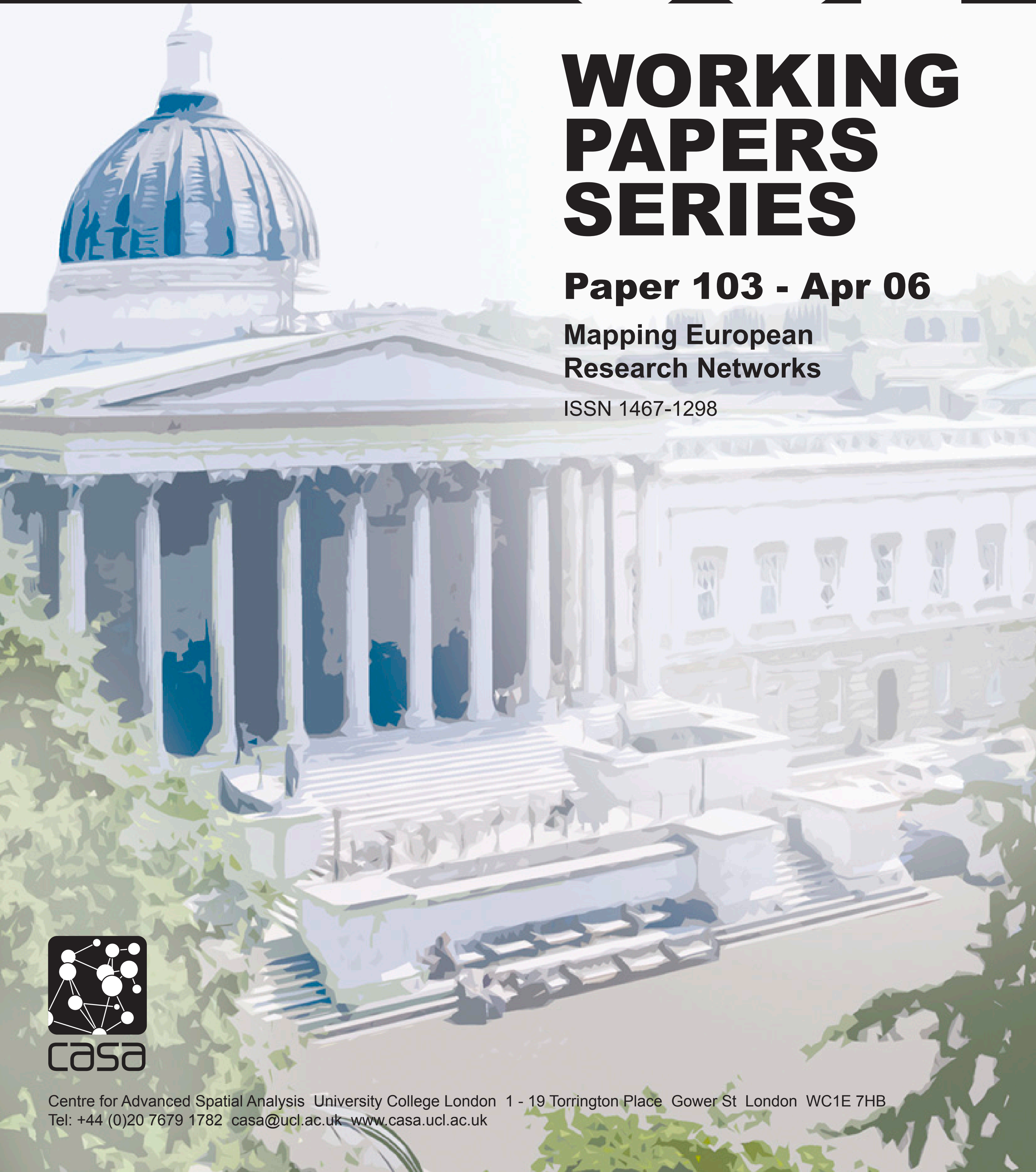

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Mapping European Research Networks

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Mapping European Research Networks

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Abstract: This paper proposes a framework for measuring the performance and mapping the geography of the European Research Area (ERA) based on the analysis of existing research and knowledge networks. The objective is to provide insights into the spatial structure of the European space from the perspective of the distribution of excellence in research. Starting from the debate on European spatial development, key issues such as polycentricity, the *territorial dimension* and impact of European policies, the role of research investments as an engine of urban and regional development, the paper explores the potential use of integrating social network analysis and GIS in the evaluation of the spatial-relational structure of the European Research Area. The research uses data on the participation of academic and business research actors into research projects funded by the European Commission under the Sixth Framework Programme.

Keywords: polycentrism, networks, evaluation, European spatial structure

Mapping European Research Networks

1 Settings

1.1 The role of research networks in Europe

In the last twenty years the European Union has developed and maintained policies to support scientific and technology research, mainly through its four-yearly Research Framework Programmes. These policies aim at encouraging cooperation between all the actors of research in Europe: universities, industry, and private agencies. Despite these efforts, at the beginning of the 21st century, research in Europe was facing a constant decline in human and financial resources, especially in comparison with the US and Japan. Acknowledging this gap and the importance of research for the economic and social development of the Union, in January 2000 the Commission signed up to the strategic document “Towards a European Research Area” (Commission of the European Communities, 2000), immediately ratified by the Lisbon Summit of the European Council. This document, today part of the so-called Lisbon Agenda on European Competitiveness lays the foundations for a common policy for research and technological development and sets, among the key objectives, the coordination of national research policies and the integration of resources. The strategy to achieve these objectives includes, among others, the “networking of excellence”, that is the development of material and immaterial infrastructures for the circulation of knowledge and more operational tools such the Network of Excellence, today one of the key financial instruments of the Sixth Framework Programme.

Parallel to the definition of these strategies, the Commission has also set up a protocol for mapping and evaluating excellence and identifying highly performing research units in scientific and technology research (Commission of the European Communities, 2001). The protocol, applied to the three pilot areas of biosciences, nanotechnologies and economics

(EC Directorate General for Research, 2001, 2002, 2004), identifies bibliometric analysis and citation rates as a possible approach. However, in order to avoid the constraints of the international databases, which collect mainly English-speaking literature and publications, the protocol suggests that the analysis of participation in the Research Framework Programme, could provide an alternative approach to measuring excellence.

«*For the bibliometric analysis, citation rates should be applied as a proxy for scientific quality. […] Another indicator might also be the participation in the Framework Programme. It would indicate some formalised or structured networking.»* (Commission of the European Communities, 2001, p8)

The same methodologies have been applied also in the analysis of innovation networks (Balconi, Breschi et al., 2004; Besussi and Chapman, 2005; Jaffe and Trajtenberg, 2002).

These official documents can be interpreted as evidence of the Commission's interests in the concept of the network both as an analytical tool and a normative agenda: the network is the prescriptive formula that should be promoted in order to increase the competitiveness of European research and the analysis of networks is one of the fundamental tools to evaluate competitiveness and excellence.

1.2 The territorial dimension of the European Research Area

The integration of the ERA development strategy into the Lisbon Agenda, extends its remit and potentially exposes it to the evaluation criteria applied others European policies for the economic and social development of the Union such as Transport, Agricultural and Regional Policies. Within this framework, the strategy must or should comply to the recommendations that the Commission has set for the development of the European territory. These recommendations are anchored to the spatial principles outlined in the ESDP (polycentric development, parity of access to knowledge and infrastructures, protection of the natural and cultural heritage) and in the Third Cohesion Report, which has introduced the new pillar of territorial cohesion and territorial capital (Waterhout, 2003) to complement those of economic and social cohesion.

The shift of focus towards the territorial impact of European policies, it doesn't seem appropriate, as suggested by the Commission to evaluate excellence in research only by means of a-spatial indicators of the level of cooperation and integration of research networks.

This paper discusses the exploratory stage of a methodology to integrate the territorial dimension into the analysis of research networks. The scope is to give some evidence of the potential benefits of providing a geographical support to the representations of traditionally non-geographical information.

A further objective, not explored at this stage, is the design of new indicators of spatial-relational centrality, which could provide useful insights into the monocentric or polycentric territorial structures of the European space. This new information could prove useful in evaluating the hypothesis that different territorial structures support different models of knowledge diffusion and technology transfers, but also of other skills, such as organisational capacity and project management skills, all considered crucial for the entry and permanence in the research network system and in the ERA.

The paper is exploratory in nature and therefore no hypotheses have been formulated regarding the structure of the network, or its territorial impacts.

2 Methodology

2.1 Individuals, relations and networks

The main rationale behind Social Network Analysis (SNA) methods is that social structures can be described not only in terms of individual attributes but also in terms of relations. «In our view […] traditional social science studies attributes of INDIVIDUALS (call these monadic attributes) whereas network analysis studies attributes of PAIR OF INDIVIDUALS (call these dyadic attributes). Social relations are just one type of dyadic attribute. Other members of this set are distances (such as miles between cities), and similarities (such as correlations among respondents' responses across a set of questionnaire items).» Borgatti and Everett, 1997

The distinction between the two approaches is both theoretical and methodological. Individual attributes and intrinsic characteristics of individuals, objects, events or, in spatial and geographic analysis, places, spatial objects.

These characteristics are, by their own nature, independent from the relations between the units themselves and from the context of observation. The individual attribute persists across the various contexts. A person's age doesn't change whether it is measured at home or at the workplace; a region's GDP doesn't change whether this is compared with the national or European average. Dyadic attributes, instead, are not intrinsic of either party taken in isolation but they describe an emergent property of and in the relation between these units and they change or disappear if one of the two units on either side of the relation is removed. They are, differently from individual attributes, dependent on the context: a teacher – student relationship does not exist outside the classroom and relations between regions based on economic flows are not the same as those based in migration.

Each network is defined by a specific type of relation that links a set of persons, objects, events or more abstractly nodes. Different types of relations generate different types of networks even when imposed on the same set of nodes. The network of a hierarchical decisional structure in an organisation is different from the network of advice-giving relations in the same organisation (Knoke and Kuklinski, 1982).

The structure of a network is given by the configuration of the present and absent relations between the nodes and can vary from an isolated structure where no node is connected to a saturated, fully connected network. Real cases lay in the continuum between these two extreme structures and SNA methods have focussed especially on the possibility to measure the variations in these structures, in the hypothesis that different structures and structural properties can influence or even determine the behaviour and the performance of the individual nodes and of the whole network

2.2 Centrality Measures in Social Network Analysis

Social network analysis owes much of its quantitative tools to graph theory from which it takes the statistical measures to describe the structural properties of networks. Social sciences have adopted these measures and embedded them within their own epistemological and explanatory domains. In these contexts, structural measures can be used to describe different social phenomena: the role of kinship in the diffusion of life styles, processes of centralisation and decentralisation in decision network, the emergence and life cycle of fashionable ideas within networks of scientific citations, the role of institutions, individual or even cities as brokers and gatekeepers of information flows.

In the context of this analysis, I have selected those structural indicators, which seems better designed to measure and evaluate the relation and the territorial dimensions of European research networks.

The measures selected from the tool box of network analysis, all describe in different ways the concept of centrality: degree centrality (or local centrality), closeness centrality (or global centrality) and betweenness centrality (or dependency).

The concept of centrality is one of the oldest in network analysis (Freeman, 1978). Measures of centrality are designed to evaluate the actors' position in the network and can be interpreted as the prominence of an actor in the social group (Brandes, Kenis et al., 2003; Freeman, 1978). It is because of this common view on the interpretation of centrality that I have consider it the most appropriate measure to represent spatial patterns of polycentricty in the European space.

2.2.1 Degree centrality

Considering a matrix G = (V;E), where V is the set of nodes (vertices), and E is a set of undirected edges, degree centrality (Freeman, 1978) is the simplest form of centrality and it is defined as the number of edges incident upon a node. It corresponds to the cardinality of the vertex set:

$$N(v) = \{i \in V(G) : (i,v) \in E(G)\} \qquad (1)$$

and it is usually normalised by the total number of possible incident edges. It can be interpreted as the “size” of each actor’s individual network or as its social capital.

Bonacich, 1987) has proposed a modification of the Freeman’s degree centrality, which questions the original proposition that actors with more connections are also the more “powerful”. Bonacich’s idea is that both centrality and power are a function of the connections of the actors in one’s neighbourhood. According to this definition, a node is more central if it is connected to other well connected (central) nodes. By contrast being connected to poorly connected nodes, makes a node more powerful since its neighbouring nodes are dependent on it for their centrality.

2.2.2 Closeness Centrality

Degree centrality measures have been criticised because they only take into account the immediate ties that a node has, or the ties of the node’s neighbours, rather than indirect ties to all others. Closeness centrality approaches emphasize the distance of a node to all others in the network by focussing on the distance from each node to all others.

Closeness centrality therefore is:

$$C_c(v) = \frac{|V(G)| - 1}{\sum_{i:i \neq v} d(v,i)} \qquad (2)$$

where *d(v,i)* is the geodesic distance between *i* and *j*. The measure ranges from 0 to 1 where the highest value is to be found in the node at the centre of a star graph where one node is directly connected to all the remaining nodes. In this sense it can be interpreted and the measure of how much an actor is at the centre of a network and how accessible it is for the other actors.

2.2.3 Betweenness Centrality

Betweenness centrality describes a node as being in a favoured position if it lies on the geodesic path between a pair of other nodes. The more geodesics a node falls on, the more central it is.

Betweenness centrality can be written as:

$$C_B(v) = \sum_{i,j:i \neq j, i \neq v, j \neq v} \frac{g_{ivj}}{g_{ij}} \qquad (3)$$

where g_{ivj} is the number of shortest paths from *i* to *j* through *v*. It describes the role of broker or gateway of the node but also how much a network is dependent on that actor to connect different part of the network that would otherwise be isolated.

2.3 Centrality measures in spatial analysis: two-dimensional polycentricity

The hypothesis of measuring spatial polycentricity using centrality measures based on relational and not only individual attributes, has had a large resonance in a number of research environment that are working towards the design a normative definition of polycentricity. The concept was first developed within the framework of the Interreg IIIB ESPON (European Spatial Planning Observation Network) programme by Michael Wegener (ESPON-111, 2004; Figure 1). Findings from the programme agree that a normatively useful definition of polycentricity must take into account two dimensions: morphological and relational.

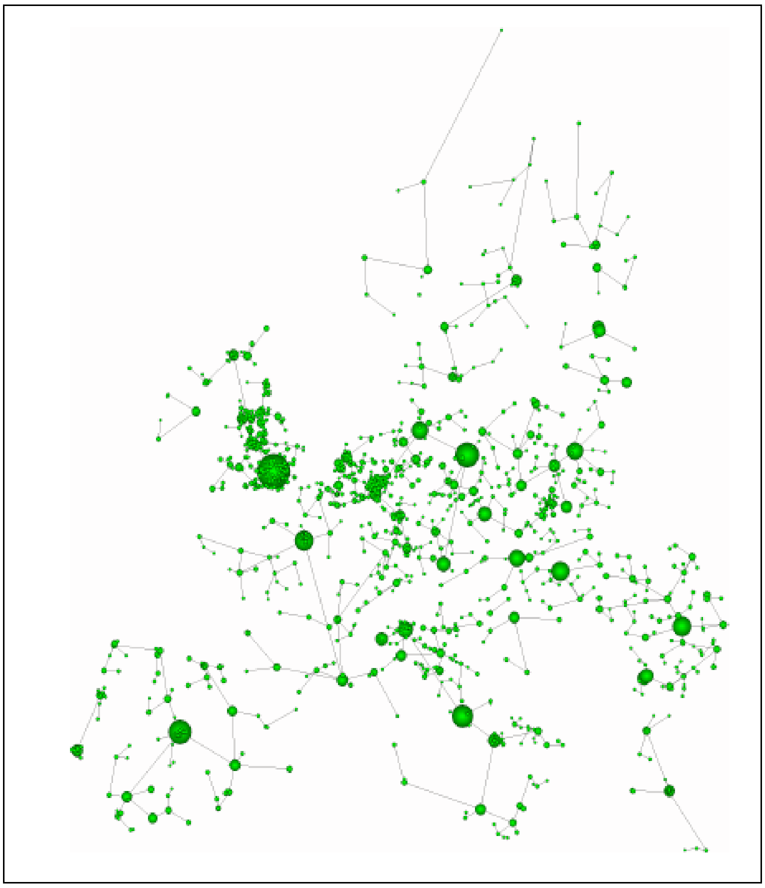

Fig. 1- Cities in Europe over 50,000 population connected to the nearest larger city (author: K. Spiekermann, ESPON 1.1.1)

Within the programme, the morphological approach looks at urban systems as the spatial arrangements of several nodes and centres. The urban systems is described in terms of hierarchy (strong or weak) and two extreme patterns can be identified: mono-nuclear with one dominant city and several dependent centres and polynuclear with no dominant city and centres of similar size where size can be demographic, economic or functional.

The relational approach takes into account the direction and intensity of flows or co-operations between centres. Two main patters are identified: mono-oriented where relations are preferentially directed towards the centre and multi-directional where relations have no clear orientation.

On the basis of this conceptual definition, the programme has developed an experimental indicator to measure the degree of polycentricity of the European space. This indicator aggregates three different dimensions of polycentricity: size of centres, location of centres (which refer to the morphological approach) and connectivity (measured as assumed flows based on proximity and size and representing the relational approach).

Whereas centres' size can be seen as reminiscent of rank-size approaches to measuring polycentricity, location reminds us of the Christaller's view of centrality and spatial tessellation.

Connectivity however is a much more problematic dimension, because often flows and relations are assumed (in the case of the ESPON programme, they are assumed from location and size) rather than surveyed.

This paper's contribution therefore adopts the concept of a relational dimension to polycentricity and applies it to real, existing connectivity patterns. The relations that we will investigate are derived from data on participation in research projects funded under the EC's 6th Framework Programme for Research (FP6).

3 Results

We have collected data on partnership to all the Networks of Excellence (NoEs) in the FP6 thematic area of Information Society Technologies. NoEs are a one of the financing instruments of the FP6 that specifically target the creation of permanent networks of research. The database includes 1549 partners and 133 projects. Partners are described by their geographical location (540 unique cities and 29 countries) securing in this way the possibility to visualise the data in a GIS environment. Projects are also described by the funds received from the FP6 programme. Even though NoEs have an internal hierarchy (lead partner, associate partners, consultants) we have treated all partners as equal, since information on the internal structure of each NoE is difficult to collect. In this sense, we have allocated funds to each partner as an equal share of the funds of the NoEs they are partners of. This new attribute for partners has been used to evaluate their performance in terms of units of funds per degree of centrality.

We have use the software packages Pajek (Batagelj and Mrvar, 2005) and UCINET (Borgatti *et al.*, 2005) for all the network analysis and visualisations.

3.1 Analysis of partners network

By using information on partnership and co-partnership in NoEs we have built an incidence matrix X (partners by NoE) in which $x_{i,j} = 1$ if partner *i* is in NoE *j* and $x_{i,j} = 0$ otherwise. Given this matrix X, it is possible to construct the product of matrix *X* and its transpose, *XX'*, whose *ijth* cell gives the number of NoEs both partners *i* and *j* are involved in. The result is an adjacency matrix both symmetric and valued and the value is an index of their social proximity.

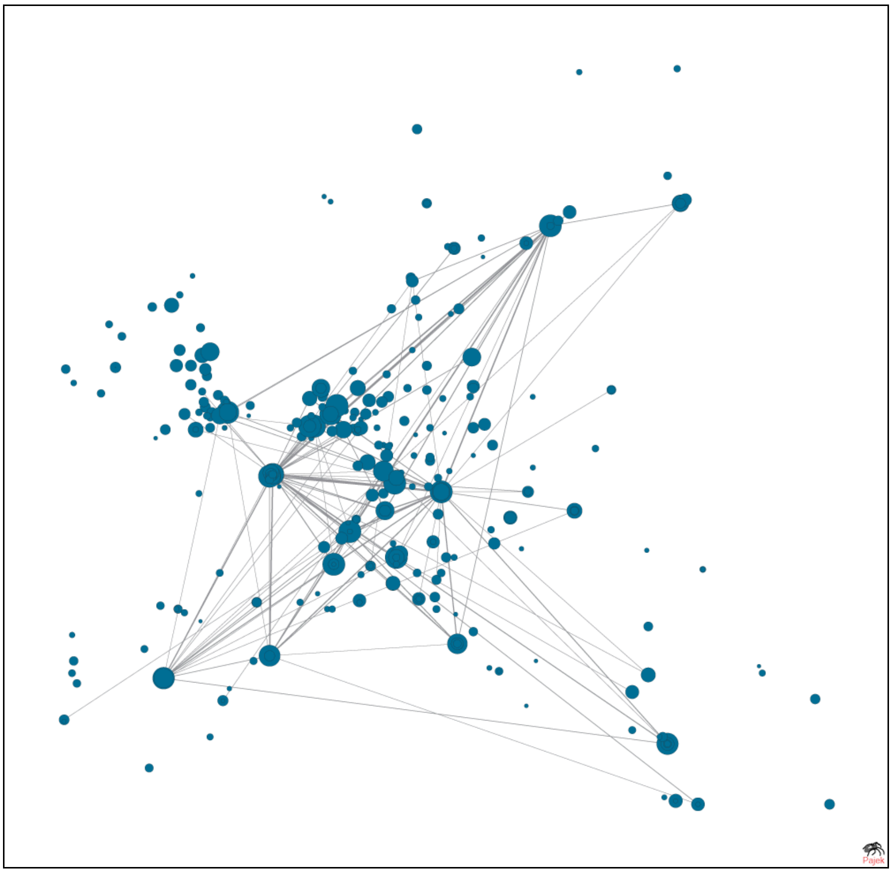

Fig. 2 – Partners in Europe connected by co-partnerships in NoEs (only connections with value 6 or more; size of nodes = amount of funds received)

The measures of centrality described, have been applied to a dychotomised subset of the matrix (433 by 433 partners, 3966 links with values ranging from 2 to 22) where all the partners who are involved in only 1 NoE have been removed (figure 2).

In figures 3 and 4 we show the rank-size distribution of the values of Freeman's degree and betweenness centrality and the relative fitted power law based on $C(v) \sim r^{-\alpha}$ where *C(v)* is the centrality values, *r* is the rank and α is related to the degree of concentration. This is sensibly higher for betweenness than for Freeman's degree centrality, which can be interpreted as a higher concentration for partners on which the network is dependent. Figures 5 and 6 show the geographical distribution of these two centrality measures where we can see partners located in the cities of Paris, Munich, Stockholm and Lausanne with the highest centrality scores.

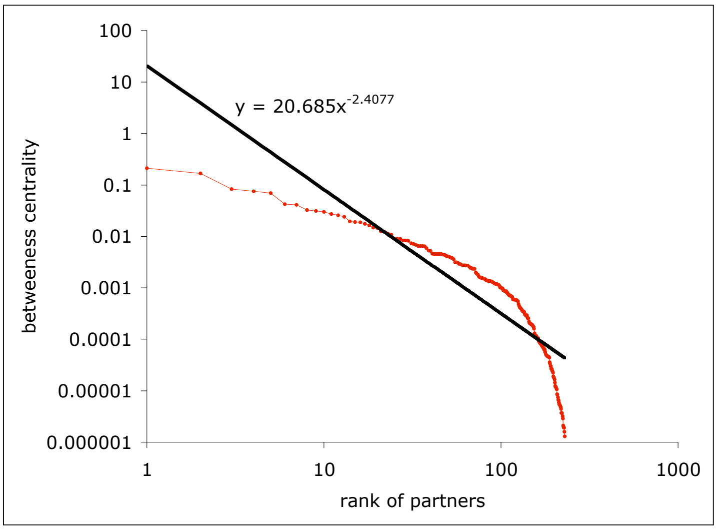

Fig. 3 Partners' betweenness Centrality and fitted power law distribution (a = 2.40)

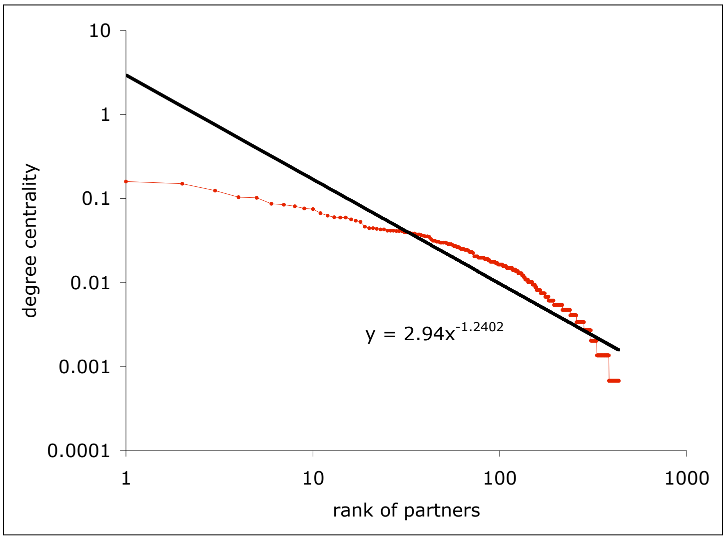

Fig. 4 Partners' degree centrality and fitted power law distribution (a = 1.24)

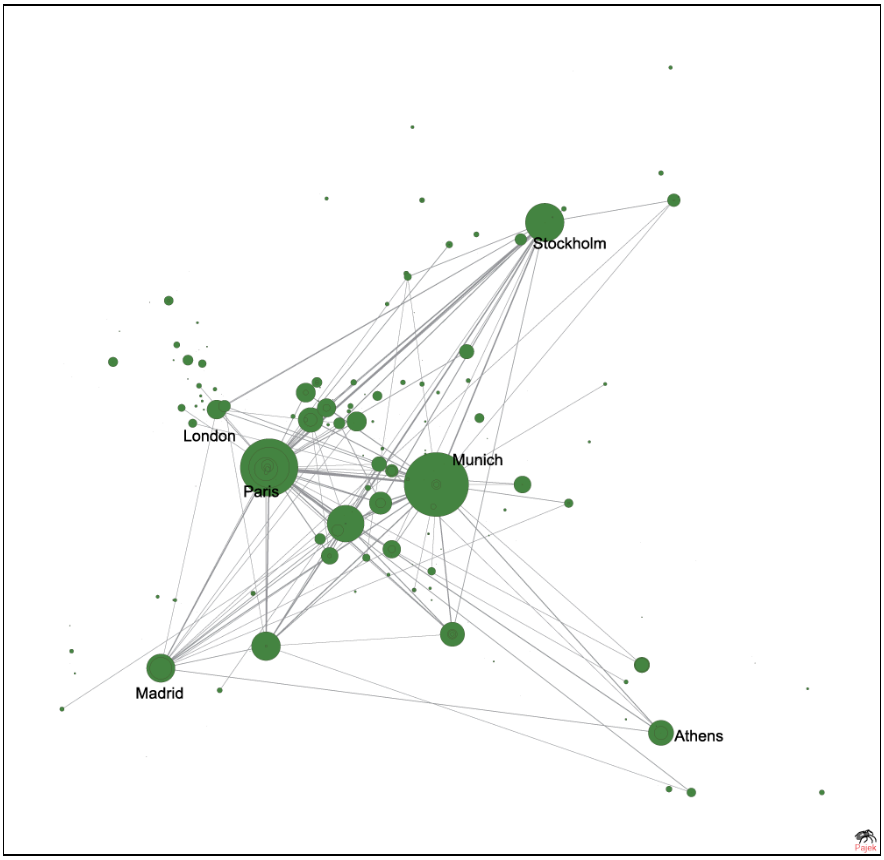

Fig. 5 Geographic distribution of partners' betweenness centrality

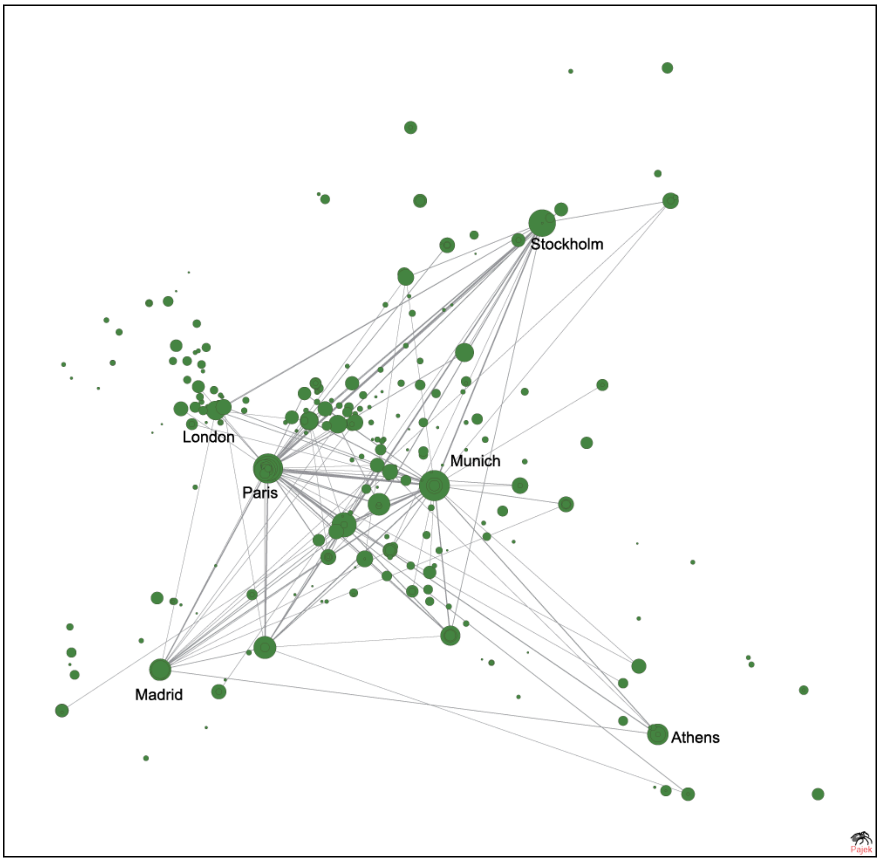

Fig. 6 Geographic distribution of partners' degree centrality

In the absence of a sound hypotheses regarding the structures, it would be too speculative to extend our interpretations of the polycentric patterns any further. We have however attempted a first step towards the evaluation of the performance by measuring the ratio of funds over degree centrality. Here lower values represent higher performance. This index is shown if figure 7.

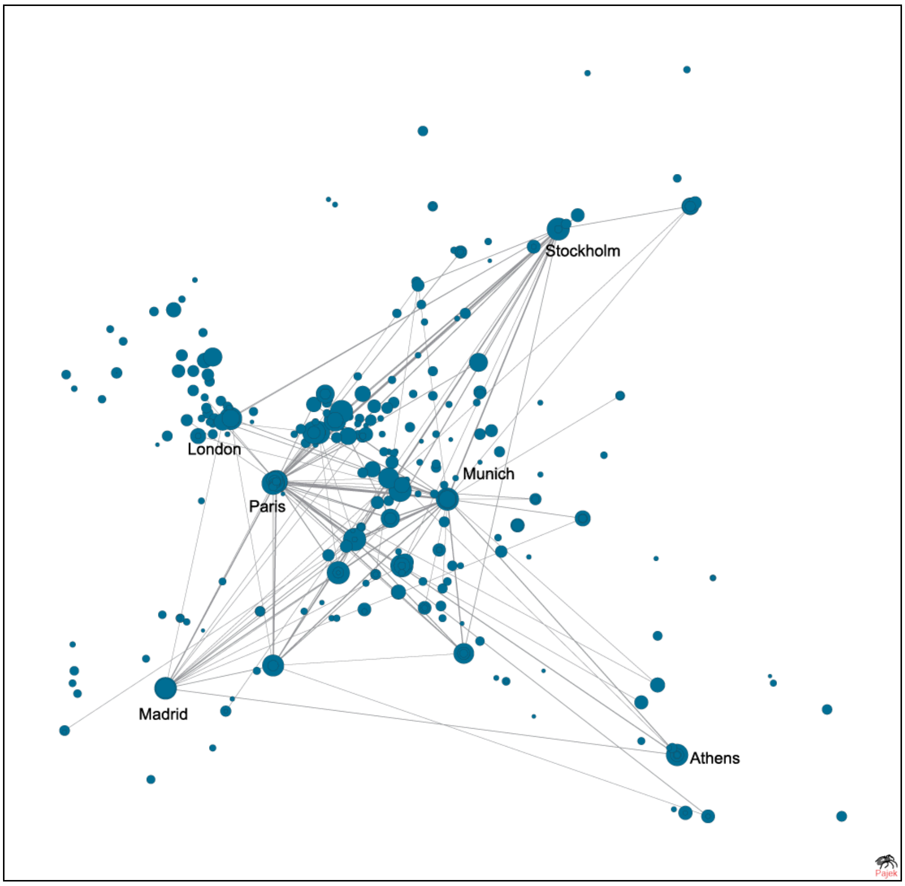

Fig. 7 Geographic distribution of partners' performance index (smaller size of node = higher performance of node)

1.2 Analysis of cities' network

The affiliation network of cities by projects was built by aggregating partners on the basis of their geographic location. The resulting matrix of 540 cities by 133 projects has been transformed into an adjacency matrix by applying the same procedure used for the partners' network. Centrality measures (Freeman's degree and betweenness) have been calculated for a dychotomised sub-network of 152 by 152 cities with edge values ranging from 10 to 200 (Figure 8).

Figures 9 and 10 show the spatial patterns of the degree and betweenness centrality respectively. Here we can see that, compared to the analysis of the network of partners, centralisations values are significantly higher. This is expected and is an effect of the aggregation that favours cities with many partners.

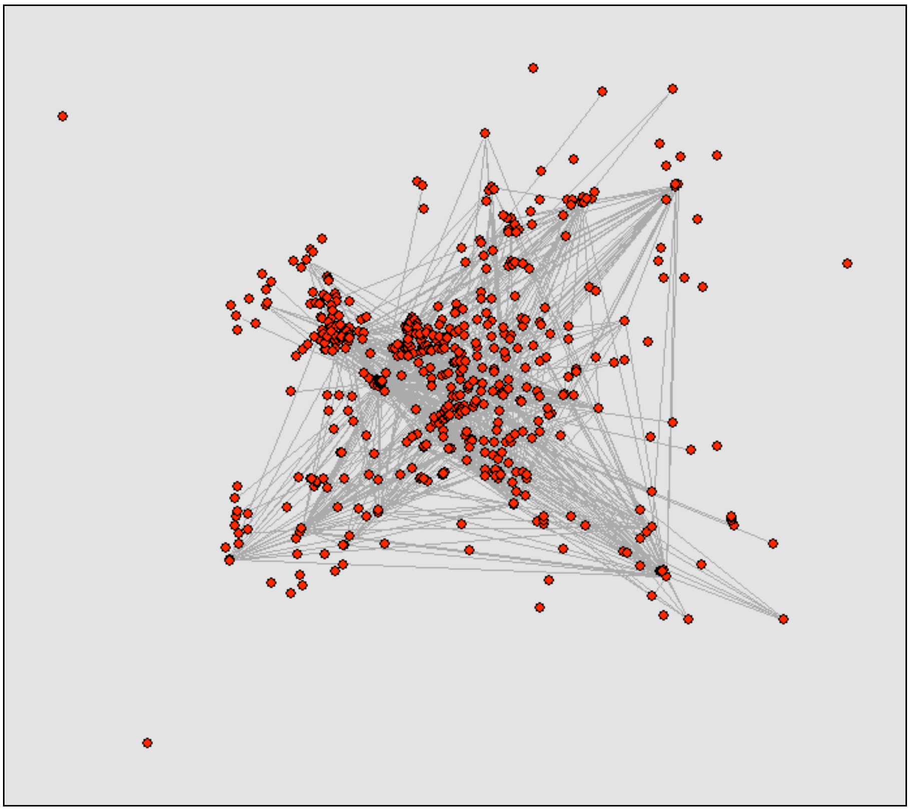

Fig. 8 Cities' network (M-core = 10)

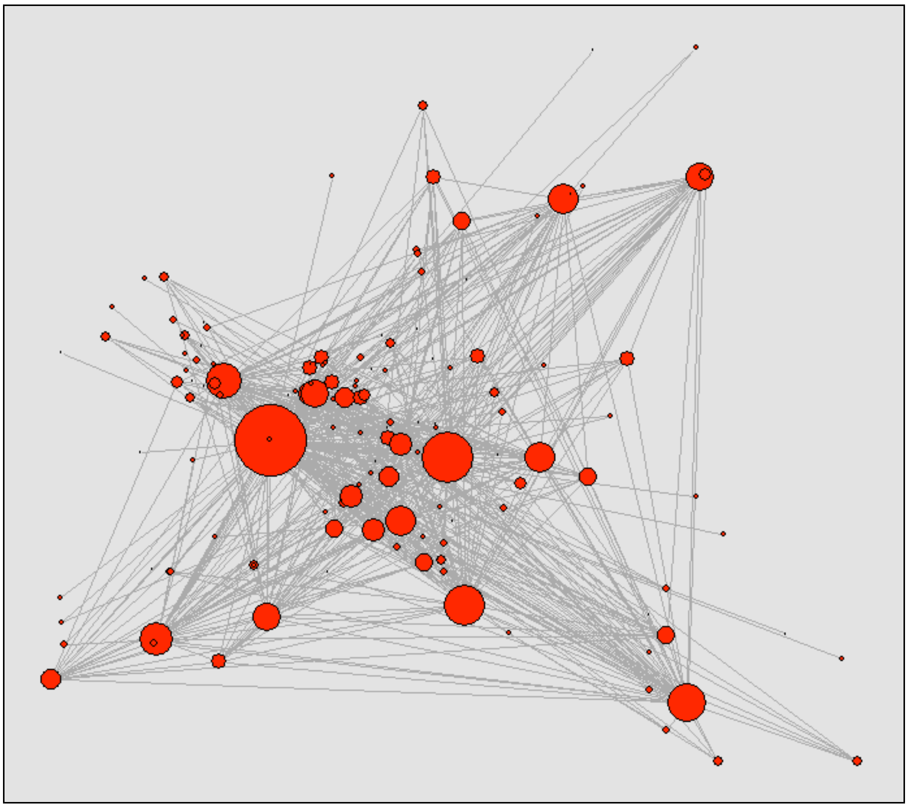

Fig. 9 Geographic distribution of cities' degree centrality

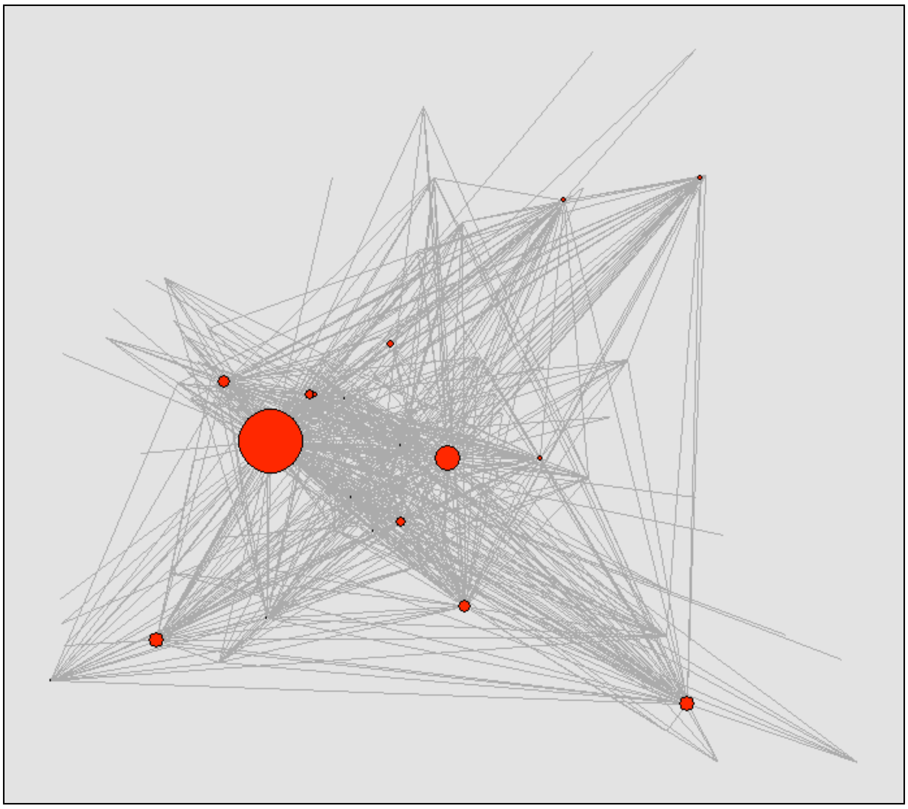

Fig. 10 Geographic distribution of cities' betweenness centrality

In addition to the centrality analysis, the structure of the network has been explored visually with the application of the Fruchterman-Reingold algorithm to the cities network. The Fruchterman-Reingold (Fruchterman and Reingold, 1991) layout algorithm attempts to simulate a system of mass particles where the vertices simulate mass points repelling each other while the edges simulate springs with attracting forces. It then tries to minimize the "energy" of this physical system.

The results in figure 11 for the cities' network of 152 nodes and figure 12 for a sub-network of 24 cities show two different structures embedded within the network: one group of cities all depending on the same hub (Paris) and isolated from each other; another group, also using Paris as a broker, but where cities are more interconnected.

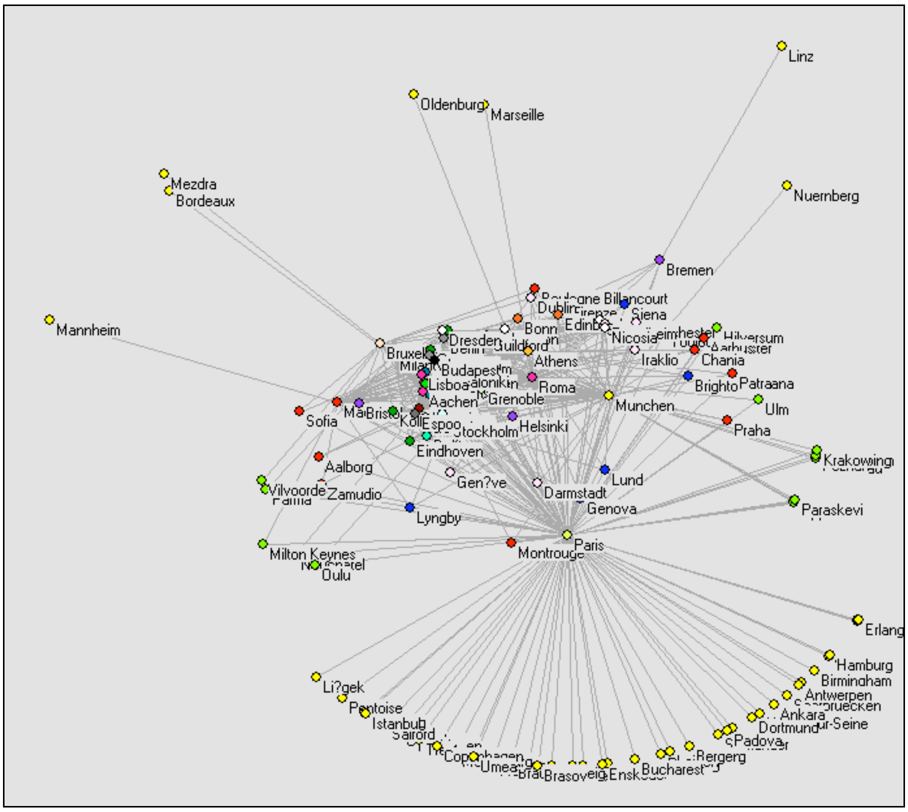

Fig. 11 Fruchterman-Reingold layout for cities network (152 nodes)

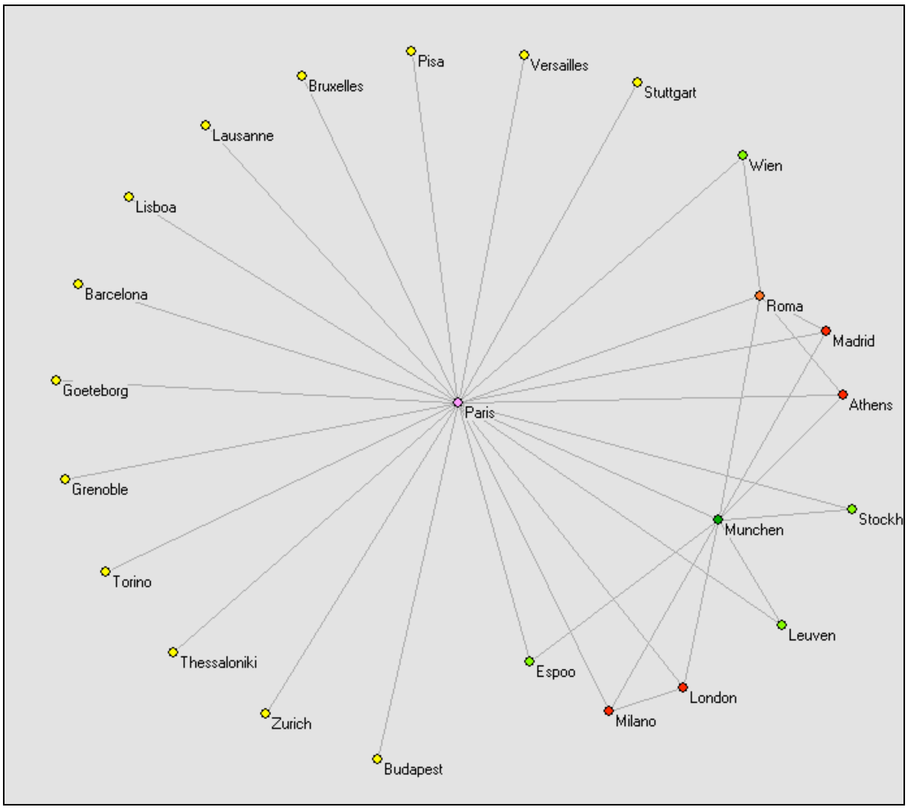

Fig. 12 Fruchterman-Reingold layout for cities network (24 nodes)

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