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Abstract:

This paper analyses clusters from collaborative knowledge relations embedded in wider networks in a particular technological field. Focusing on the interface of clusters and networks contributes to a better understanding of collaboration, within and across places and cognitive domains. We propose an empirical analysis of the Midi-Pyrenean GNSS (Global Navigation Satellite Systems) cluster based on a relational database constructed from collaborative R&D projects funded at the European, national and regional levels. Using Social Network Analysis tools we discuss the results according to (i) the structural, technological and geographical dimensions of knowledge flows, (ii) the influence of particular organizations in the structure and (iii) the heterogeneity and complementarities of their position and role. We conclude by showing that our findings provide new opportunities for cluster theories.

Keywords: Knowledge, Networks, Economic Geography, Cluster, GNSS

JEL classification: O32, R12

1. Introduction

In the Economics of Knowledge, clusters and networks are subject to a growing interest due to the increased observation of collective knowledge processes (Cooke, 2002) and their spatial concentration (Porter, 1998) in many technological fields. Nowadays knowledge processes are composite ones, i.e. they combine many interacting pieces of knowledge coming from different cognitive domains. In this paper we propose that knowledge networks and clusters come from the complex aggregation of relational strategies (Powell, Grodal, 2005; Cowan, Jonard, Zimmermann, 2007) between organizations embedded in Composite Knowledge Processes (CKPs). The second assumption of this work is that space matters even if it does not signify that geographical proximity between organizations is the *panacea* for knowledge creation and diffusion. We follow thus an emerging literature which is cautious about the univocal role of geographical proximity in collective knowledge processes (Breschi, Lissoni, 2001; Bathelt, Malmberg, Maskell, 2004; Rychen, Zimmermann, 2008; Crevoisier, Jeannerat, 2009). If firms combine internal and external knowledge, they also combine local and distant interactions according to a set of critical parameters related to their place in the knowledge value chain, the extent of their geographical market and the respective absorptive capabilities of their partners. In order to propose a better understanding of collective knowledge processes, within and across places, and within and across cognitive domains, the paper focuses on the interface of clusters and networks.

Network analysis tools (Borgatti et al., 2002) are well suited to identifying clusters and networks in Regional Science (Ter Wal, Boschma, 2008; Rychen, Zimmermann, 2008), in particular when their structural features are coupled with non-structural ones (Owen-Smith, Powell, 2004). Indeed, the geographical location and technological features of the "players" can have an influence on the structural form of the "web" of knowledge flows. This paper contributes to these developments, with an empirical focus on a particular CKP: the GNSS (Global Navigation Satellite Systems) technological field. GNSS cross several knowledge segments - from orbital infrastructure to a wide set of on-ground applications, and also traverse several industrial sectors such as telecommunications, tourism, security, transport and so on. This technological field is thus a composite one (Antonelli, 2006) due to the extent of knowledge combinations such technologies generally require before their potential diffusion. We use an emerging methodology which initially consists of publicly funded collaborative R&D projects, hence providing a wide view of knowledge relations, especially in emerging technological fields (Autant Bernard et al., 2007). This data collecting process aims to identify how a local cluster could be embedded (or not) in a technological field. Therefore we only consider collaborative GNSS R&D projects including "players" from one of the GNSS industry's major European regions: the Midi-Pyrenees Region (MP). The MP is not a random choice. This French Region is an important European region for the space and aeronautics industry that nowadays combines its cumulative knowledge process in this sector with moves towards the emerging civil mobility, positioning and navigation technologies which are supported by the EGNOS and GALILEO European Programs.

The paper is organized as follows: Section 2 summarizes the main issues that concern the links between collaboration networks and economic geography. In so doing we discuss how network analysis helps show that clusters are embedded in larger networks. We propose a set of theoretical arguments that combine structural, geographical and technological properties in the identification of a particular cluster. Section 3 presents the technological field of GNSS, the relational data with the variables (attributes of the nodes) and the selection routine for knowledge relations (the ties between the nodes). In particular, we focus especially on the relevant network boundaries. In order to do this we follow the same protocol as Owen-Smith and Powell (2004), emphasizing how a cluster is embedded in a technological field. Our starting network focuses on collaborative R&D projects in the GNSS technological field and thus aggregates the organizations located in the MP, the relations among them and all organizations in any location that have a network tie with MP-based organizations. Section 4 discusses the visualization of our particular network and of two relevant sub-networks (the local cluster and the cluster/pipeline structure). Section 5 investigates a set of quantitative results that relate to some descriptive statistics and traditional indexes from network analysis. Section 6 discusses the results in a more qualitative way according to three main focuses: (i) the structural and geographical organization of knowledge flows, (ii) the influence particular nodes have within the structure and (iii) the heterogeneity and complementarities of their position and role in the network.

2. Networks and clusters as a web of Composite Knowledge Processes (CKP)

2.1. Starting from CKP and collaboration networks rather than places **per se**

Since the development of Porter's ideas on clusters [Porter defined clusters as *"geographic concentrations of interconnected companies and institutions in a particular field"* (Porter, 1998)], several bodies of work have stressed the coexistence of different types of clusters (Markusen, 1996; Iammarino, McCann, 2006). We suggest that clusters, as the aggregation of interacting organizations in the same geographical location, have to be studied from the perspective of a larger network. Places and networks are meso-structures which do not necessarily link together every time. However, they can intersect when we assume that they are the "locus" of the dynamics of a peculiar technological field (White et al., 2004).

Technological fields are more or less coherent structures representing CKPs, i.e. processes in which dispersed and fragmented inputs of knowledge are combined for the purpose of the production of knowledge outputs (Antonelli, 2006). At the microeconomic level, organizations produce new knowledge merging internal and external knowledge, and they combine arm's length and network relations (Uzzi, 1997) in order to manage both their knowledge appropriation and accessibility. At the meso-economic level, the aggregation of these knowledge relations gives rise to a network which features a set of structural properties (Powell, Grodal, 2005). For instance, if a technological field features strong arm's length relations and strong competing pressure the network density will be weak; on the contrary, organizations that improve their conditions of knowledge accessibility by multiplying knowledge partnerships will appear more central than other organizations in the network. Starting from a CKP and gaining access to its network is thus a relevant approach if one wishes to dispute the notion that knowledge would escape 'into the atmosphere'. Knowledge spreads via networks and via the intended effort by agents to connect fragmented bits of knowledge (Breschi, Lissoni, 2001).

2.2. ***Structural/geographical/technological features of networks and clusters***

Because the structural features of networks can vary according to the technological field, it is not surprising that local clusters similarly vary in their structural form, but it is necessary to understand why networks can have a local dimension which is stronger or weaker and how this local element is structurally connected with its outside environment.

Literature on economic geography and economics of knowledge has produced interesting results. The basic idea is that clustering processes occur when the composite knowledge process requires the combination of cognitively distant but related pieces of knowledge (Nooteboom, 2005; Boschma, 2005). Between high specialization and high diversification, fragmented pieces of knowledge coming from more or less distant knowledge domains can be interconnected around an emerging technological window or standard (Vicente, Suire, 2007). Since knowledge spillovers can be both intended (the intentional effort to share knowledge) and unintended, geographical proximity causes ambivalent effects on innovation. When cognitive distance is large enough and knowledge assets are complementary, geographical proximity favours intended knowledge spillovers as long as organizations are involved in a relation. The gap between their respective knowledge bases which can impede accessibility is reduced by the potentiality of frequent meetings, whereas their different respective core activities moderate the risk of under-appropriation. Inversely, the co-location of firms endowed with close knowledge capabilities, even if it is in their mutual interest to cooperate, can engender unintended knowledge spillovers and a climate of mistrust. For this situation, Bathelt, Malmberg, Maskell (2004) and Torre (2008) showed that pipeline structures and temporary proximity correspond better to this kind of relation.

The question is how do we include these issues in the classic structural approach for networks? In line with Owen Smith and Powell (2004), we suggest adding non-structural dimensions, i.e. geographical and technological dimensions. Indeed, the introduction of non-structural dimensions leads to a more complete view on (i) how the compositeness of the knowledge process affects the structural properties of the network and their resulting geography and (ii) how the knowledge flows in the structure are conditional on the heterogeneous and complementary roles and positions that organizations achieve through their relational strategies.

2.3. *Social Network Analysis and localized collaboration networks*

Social Network Analysis (SNA) (Wasserman, Faust, 1994) is particularly suited to the examination of such issues. Among others, the work of Owen-Smith & Powell (2004) on the Boston Biotech cluster, Guiliani & Bell (2005) on the Chilean wine cluster, Boschma & Ter Wal (2007) on the South Italian footwear district, and Morrison (2008) on the Murge sofa district, constitute the first attempts in improving knowledge of the interaction mechanisms at work in clusters.

SNA provides concepts and tools that highlight the structural properties of localized collaboration networks. First of all, at the meso-economic level the basic SNA density measures outline the existence or the non existence of a cluster and how the latter is embedded in a technological field. A firm's agglomeration that displays a weak density of local knowledge relations will be more of a "satellite platform" (Markusen, 1996) than a cluster *per se*, i.e. a local structure which is more or less cohesive. On the contrary, an excessive density of local relations in a cluster can engender redundancies and, because relations mean costs, a slump in efficiency for organizations. Moreover, the study of network densities can be refined by matching the location and the knowledge base of the organizations. These measures are thus suited to identifying how the different knowledge bases of the CKP are connected and give an overview of how cluster and pipeline relations coexist in the production and the diffusion of knowledge (Bathelt, Malmberg, Maskell, 2004).

In addition to densities, one of the most used structural properties is network cliquishness, i.e. groups of organizations that are more closely linked to each other than to other organizations. These properties can be "emergent" when they derive from the aggregation of *bi*-lateral relations, but they can also be "presupposed" when cliques strictly represent groups of *n*-lateral relations. The more the network is constructed from *n*-lateral relations, the more it has chance to display cliquishness properties, as in the studies of Autant-Bernard et al. (2007). In this case, the analysis can focus on nodes as in most network analysis, but due to the strong presupposed network cliquishness it would be pertinent to consider the bipartite (or bi-modal) network, i.e. a network that takes into account the ties between two sets of nodes at two different levels - the ties between organizations and projects[1]. In doing so, additional properties can be studied by exploring how collaborative projects rely on each other through affiliated actors and provide a particular structure of preferential interactions that influences knowledge diffusion. In particular, cliquishness properties, if they are salient, show that knowledge does not spread in a random way throughout the network but into sub-groups of organizations which can be more or less connected with each other if some of the organizations act as a bridge within the structure (Burt, 1992). Moreover, the existence of cliques in a network can be explained by the necessity for some organizations to protect themselves from the risks of knowledge under-appropriation. Because knowledge spills over via interaction structures rather than via a pure *corridor* effect (Breschi, Lissoni, 2001), organizations with close knowledge capabilities maintain a high level of knowledge accessibility by connecting to the network at the same time as they limit the risks of unintended knowledge spillovers by positioning themselves in cliques that are more or less disconnected. Conversely, other organizations such as public research organizations can employ an inverse relational strategy by connecting disconnected organizations, since they are naturally less affected by these risks.

These structural properties result from the role and position that organizations develop through their relational strategies. Knowledge relations in a network are not randomly distributed. First of all, as

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[1] In the following empirical analysis, the bi-modal network will be used for the study of cliques since it permits avoidance of the over-estimation of cliquishness that can occur when we consider collaborative projects in which many organizations are involved instead of bilateral relations.

corroborated by many monographs on clusters, organizations have very differentiated positions: in terms of influence and power, in the knowledge dynamics at work in a cluster and in a technological field. The "hub and spoke" structure of agglomerations observed by Markusen (1996) is a good example of such influence and power. In this type of structure, a very central firm is tied to all the others, while these others are poorly connected to each other so that the knowledge trajectory is strongly associated with the strategy of the main firm. SNA, by proposing a set of centrality indexes for organizations in a network, furnishes suitable tools for dealing with this topic. Moreover, in a knowledge network that traverses both a technological field and a geographical location, the knowledge dynamics can be driven from inside as well as outside the cluster, in particular when outside companies succeed in forming a limited number of, but very strategic, relations with "insiders". Lastly, in addition to their central position, organizations embedded in a network can adopt different roles according to the way in which they position themselves in relation to others. A network is generally represented by non-overlapping categories of organizations so that the influence and power of an organization depends on their centrality but also on their ability to broker relations between categories of organizations. In adherence with Gould and Fernandez (1989), we follow the notion that *"communication of resources that flows within groups should in general be distinguished from flows between groups"* (p. 91). For instance, as demonstrated by Rychen and Zimmermann (2008), if we consider cluster insiders and clusters outsiders as non overlapping groups, two central insiders will have a different role if one is mostly tied to insiders whereas the other is mostly tied to outsiders. In the first case, the organization will be considered as a "coordinator". As observed by Owen-Smith and Powell (2004) in the Boston biotech cluster, this role is typical of the one played by public research organizations. In the second case, the organization will be considered as a "gatekeeper" (Allen, 1977), i.e. an organization that derives its influence from its ability to act as an intermediate for knowledge between non-connected insiders and outsiders. Many cluster studies show that clusters take advantage of the existence of gatekeepers (Rychen, Zimmermann, 2008), i.e. the key organizations that ensure the embeddedness of the cluster into the technological field. If we extend these roles from geographical space to knowledge space, we can also assume that organizations differ in their ability to coordinate knowledge in a group of organizations having similar knowledge capabilities, for example, for the purposes of standardization, whilst other organizations will prefer to have a gatekeeper strategy by connecting non connected organizations developing complementary knowledge bases in order to position themselves as the missing link for the CKP.

3. Context, data and methodology: the GNSS technological field

This section summarizes the context, the data and the methodology. After an overview of the key role of the MP Region in the GNSS technological field, we present the relational dataset, constructed from an original aggregation of collective R&D projects. We thus discuss its representativeness and present the variables. Finally, we present the methodology of the empirical analysis, based on the identification of the structural properties and the key role and position of the main players using the standard UCINET tools (Borgatti et al., 2002).

3.1. The composite knowledge process

Fig.1 here

GNSS is a standard term for the systems that provide positioning and navigation solutions from signals transmitted by orbiting satellites. In the past decades these technologies were mainly developed by the defense industry (missile guidance) and the aircraft industry (air fleet management). The knowledge dynamics were cumulative, based on incremental innovations dedicated to the narrow aerospace industry market. Nowadays, these technological dynamics present the characteristics of a CKP. Indeed (Figure 1), in the technological and symbolic paradigm of mobility, GNSS represents technologies which find complementarities and integration opportunities in many other technological and socio-economic contexts.

The GNSS field is a worldwide technological field which combines clusters and pipelines. Indeed, considering the European level, Balland and Vicente (2009) have identified seven main GNSS clusters in the regions of Midi-Pyrenees, Upper Bavaria, Ile de France, Inner London, Community of Madrid, Tuscany, and Lazio. In this study we only focus on the knowledge relations starting from (and inside) the MP so as to explain how CKPs combine local and non local relations. The choice of the MP is not random. Indeed, the MP has a concentration of more than 12,000 jobs dedicated to spatial activities and was recently identified by the French government as being the worldwide “competitiveness cluster” in aerospace and on-board systems (Dupuy, Gilly, 1999; Zuliani, 2008). The MP is a historical leader in Europe for the design and creation of space systems and homes the main actors working on the two major GNSS European programs, Egnos and Galileo, such as the CNES (National Centre of Spatial Studies), EADS Astrium and Thales Alenia Space (TAS). In particular, the coexistence within the same place of the two major competing companies EADS Astrium and TAS is a remarkable point. It should be interesting to study how organizations that display a weak level of cognitive distance co-exist in the same place, and how each one manages the intended and unintended knowledge spillovers through its position in the relational structure of the cluster.

3.2. An aggregative method for Collaborative Knowledge Projects

- Data sources

An intensive amount of *deskwork* enabled us to list all the main regional organizations involved in the GNSS technological field, from space and ground infrastructures to applications and related services, and from large firms to SMEs and research units. In doing that we constructed a database of 30 collaborative projects in which these organizations are involved (see table 1), ensuring a "snowball effect" by bringing together other firms that consequently add complementary pieces of knowledge to the CKP, inside and outside the region, through these collaborative R&D projects. The data aggregation decision tree starts with two main sets of sources: regional sources[2] (through the review of websites dedicated to GNSS), and European sources[3], focusing only on projects that include "navigation" or "positioning" and Galileo or EGNOS. Once the collaborative projects were identified in a nested system of publicly funded collaborative projects[4], all the websites of the projects were visited in order to have a look at their work package organization and hence remove non relevant knowledge relations (see below).

Table 1 here

- Ties selection process

Our relational database brings together projects which differ in size. These depend greatly on the geographical scale of the funding, bearing in mind that regional and national projects bring together fewer units than European Projects (3 to 14 partners in regional and national projects, 18 to 57 partners in 4 of the European projects). Selecting the ties consists of cleaning up the relational database by removing pair-wise relations between partners who are not involved in the same work packages for the whole of the project, and maintaining pair-wise relations between the project leader and all the partners. Moreover, when the leader of the project is outside the region, we only consider the work packages in which MP organizations are involved.

- *Comments on the relational database*

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[2] http://www.navigation-satellites-toulouse.com/?lang=en, http://www.aerospace-valley.com/en/
[3] http://www.galileoju.com/, http://www.gsa.europa.eu/
[4] We would like to thank one of the referees for this conceptual suggestion

Such a methodology implies comments relating to both its advantages and its limitations. Firstly, starting from publicly funded projects is certainly a non-exhaustive way of capturing all the relations between firms, but the advantage is that our analysis thereby resides on a clear definition of what a knowledge relation is and avoids the vagueness of the nature of the relations we can perceive when we understand relations uniquely through interviews. In particular, the density of relations can be approximated objectively by using an index referring to the number of projects in which organizations are involved pair-wise. Nevertheless, our data can be perceived as being representative of the knowledge process of GNSS in (and from) the Midi-Pyrenees for the period 2005-2008[5]:

(i) GNSSs are emerging technologies which concern applications dedicated to public utilities such as transport security, environment observation, telecommunications and so on. In this way, GNSSs are among the priorities for policy makers, whatever their geographical scale.

(ii) Considering that public funding is conditional on "requests for tender", the organizations in our database are those which have succeeded in obtaining the funding due to their legitimacy in this technological field. This legitimacy results from their experience in past relations, so our relational database is strongly representative of the knowledge trends in the technological field.

Secondly, using projects as a starting point is dependent on the geographical scale of the public funding, which can be regional, national or European. Nevertheless, this limitation can be transformed into a convenient advantage since these three scales of funding are distinguished. The aggregation of these projects and their transformation into a unified network structure thus ensures a representative view of the embeddedness of regional organizations into the European GNSS field. Consequently, our protocol follows the multi-level governance system that typifies research funding in Europe and constitutes the current "circuitry of network policy" (Cooke, 2002). As a perfect exhaustiveness is difficult to reach, it is possible that marginal data are missing. Data concerning knowledge relations, in which local organizations are involved and that are supported or funded at the regional level, but by another region, could be missing. Nevertheless, a test conducted from the public information available on the organizations' websites confirmed that these missing data are marginal. Moreover, the results of one of the major Midi-Pyrenean requests for tender in Navigation Satellite Systems (VANS), which includes 5 collaborative R&D projects from within our database, show that the MP organizations represent 80% of the selected partners. Similarly, ULISS, the French requests for tender on EGNOS and Galileo applications, restricts the eligibility to organizations located in France.

Table 2 presents some basics statistics relating to the relational database, whereas figure 2 shows the degree distribution of ties in the network and takes the form of a quasi rectangular hyperbola, i.e. a few nodes concentrate a large part of the relations in the structure.

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[5] All the collaborative projects are included in this period, even if some of them started before and others finished after this base period.

Table 2 here

Figure 2 here

3.3. Spatial attributes and knowledge features

- Spatial node attributes

Each node is geographically labeled with a very simple binary feature, "inside" or "outside" the MP Region. Our protocol is thus similar to Owen-Smith and Powell's (2004), who considered the Boston cluster and the 'Boston+ cluster', i.e. the Boston cluster augmented with all organizations in any location that had a network tie with Boston-based organizations. We are thus only interested in one of the extremities of the pipelines. Interconnecting the clusters means gathering larger data of knowledge relations as tested by Autant-Bernard et al. (2007) and Balland and Vicente (2009) with data from the European Framework Programmes, but without any consideration of nationwide and region wide programs and funds.

- Knowledge attributes

Each node is labeled according to its main technological segment. This differentiation of nodes aims to highlight the composite dimension of the knowledge process. The deskwork undertaken on projects has led to the classification of each node according to four knowledge segments (KS):
(i) The infrastructure level with all the spatial and ground infrastructures; (ii) The hardware level, including all the materials and chipsets which receive, transmit or improve the satellite signal; (iii) The level of software, including all the software applications that use navigation and positioning data; (iv) The whole of the applications and services segment, which concerns many heterogeneous agents and socioeconomic activities where navigation and positioning technologies are introduced (or should be introduced in the future).

This attribute-based classification requires further comment. Obviously it would be more suitable to construct this classification from technological features, for example, patent codes, as the literature invites us to do (Nooteboom, 2000; Breschi, Lissoni, 2001). However, in our case this task is difficult and to some extent inappropriate because we want to take into account the whole of the knowledge value chain. Indeed, patenting activities primarily concern the major elements of the infrastructure segments and hardware segments. Software segments and "applications and services" segments cannot be patented, or at least only marginally. One reason is that this knowledge process is in an emergent phase. Other reasons are specific to each of these two last segments. The software segment is included in the copyright system and the "applications and services" segment contains various kinds of practical knowledge and specific professional expertise which are not patented.

Our classification is thus based on the standard classification of network industries (Shy, 1999). This classification is useful in the sense that it ensures a clear distinction between the knowledge capabilities developed in each segment, at least for the first three classes. It has also led to discussion on how the technological complementarities, the production of systemic goods and the standardization process are organized in this technological field.

3.4. Empirical methodology

We used UCINET 6 (Borgatti et al., 2002) and Netdraw visualization standard tools in order to study our network, its structural properties and the role and position of the key organizations in the network. The weighted relations matrix[6] (MP+ Network) was used to draw the network including geographical and knowledge attributes. From this matrix we were able to draw three other matrixes: the dichotomized matrix, the matrix of relations between local nodes (MP Network), and the bi-modal matrix that enabled us to draw the simplified MP+ Network.

4. Basic descriptive statistics and visualization of the GNSS network

Figure 2 displays the MP+ Network, while figures 3 and 4 focus on two distinctive zooms, the "MP network" and the "simplified MP+ network" which display cliques and the main pipelines between the insiders (triangles) and the outsiders (circles). Moreover, these images display (i) the tie strengths, corresponding to how many times two nodes are connected pair-wise and (ii) the four GNSS segments, from the infrastructure segment (black) to the applications and services segment (white).

4.1. The MP+ network

Figure 2 here

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[6] The cells C_{ij} are defined as follows:

- $C_{ij}=0$ if i and j do not collaborate in any GNSS project
- $C_{ij}=1$ if i and j collaborate in one GNSS project
- $C_{ij}=n$ if i and j collaborate in n GNSS projects

The MP+ network (figure 2) represents all the nodes and ties resulting from the aggregation of all the collaborative R&D projects. At first glance the network exhibits interesting meso-economic properties, such as cliques, and also visible key actors that seem to have a strong influence within the GNSS knowledge process. The density of the MP+ network is 0.0944, that is, 9.44% of all possible ties are activated out of the 8385 (130x129/2) non reflexive and undirected possible ties. This network is also highly clustered since its unweighted clustering coefficient is 0.844 while the weighted coefficient remains high (0.490). The average geodesic distance is 2.39 indicating that knowledge should circulate easily in the network. Generally, a short global separation between organizations and high local clustering define “small world” networks (Watts, 2009). Nevertheless, in our particular network this result should be interpreted cautiously; as previously stated, our network is a bipartite one according to Newman et al’s (2001) definition because the nodes are involved in collaborative projects that *de facto* create a strong cliquishness. If our network exhibits a “small world” effect we may be able to neutralize this natural cliquishness effect (see below).

4.2. Identification of the relevant sub-networks

Figure 3 here

Considering the size and the strong density of the MP+ network, it would be elucidative to extract relevant sub-networks in order to have a better view of the geographical and technological features of the network as a whole.

Figure 3 shows the MP network, i.e. all the geographical outsiders have been removed from the database. Cliquishness is also observable, and the centrality and influence of some nodes have been highlighted. At this stage the apparent density of ties in the local structure reveals the existence of a Midi-Pyrenean GNSS cluster with a particular web of knowledge flows. Obviously, the density of this network (16.45%) is higher than in the MP+ network and the geodesic distance between nodes decreases (2.22). These results are of little significance since all the local ties have been considered, while the ties between “outsiders” have not been taken into account for the MP+ network similarly to Owen-Smith and Powell (2004).

Figure 4 displays the “simplified” MP+ network. In order to avoid this bias in the cliquishness and in the clustering of the MP+ network it is thus more pertinent to consider the methodology employed in the analysis of bipartite networks (Robins, Alexander 2004), which consists of counting the diamonds[7] instead of the triangles[8]. In line with this methodology, two or more organizations form a

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[7] A diamond appears when two organizations connected to a project are also connected to another project

clique if they are connected pair-wise in at least two projects, and all the organizations that exhibit this feature are replaced within a new matrix. The network we obtain now displays cliquishness properties arising from preferential relations in the overall structure than from the collection of projects *per se*. The resulting graph in figure 4 has a noticeably smaller number of organizations (26) and displays interesting structural properties. At first glance, this figure suggests a strong cohesiveness for the local cluster and the beginnings of global pipelines that are concentrated on a small number of local nodes. To be more precise, the density of the network is 20% and the clustering coefficient is 0.818 while the weighted coefficient remains high (0.566). The average geodesic distance is 2.191. All these properties suggest that this simplified MP+ network, which neutralizes the natural cliquishness effect of the former, exhibits a "small world" structure (Watts, 1999) that combines a high level of network cohesiveness with a high level of knowledge accessibility.

Figure 4 here

5. Structure, role and position in the GNSS collaboration network: main results

5.1. Preferential interactions

It may be useful to assess whether or not the network reveals the presence of preferential interactions between organizations sharing similar or complementary knowledge. That is why we have computed the E-I index, which was proposed by Krackhardt and Stern (1988), to measure the group embedding on the basis of a comparison between the numbers of within-group ties and between-group ties. This E-I index is defined by the following formula:

$$-1 \leq E-I \equiv \frac{Nb-Nw}{N} \leq +1$$

Where,

$$Nb = \sum_i N_b^i \text{ and } Nw = \sum_i N_w^i$$

With N_b^i being the number of ties of group *i* members to outsiders and N_w^i the number of ties of group *i* members to other group *i* members, and *N* is the total number of ties in the network. The resulting index ranges from -1, when all ties are internal to the group (homophily assumption), to +1, when all ties are external to the group (heterophily assumption).

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[8] A triangle is a triad which appears each time three organizations participate in the same project, which happens very often in networks of events.

Table 4 here

If we restrict our attention to the network of local nodes – the MP Network – we see that organizations from the Midi-Pyrenees GNSS network have a marked preference for composite interactions between different knowledge segments (Table 4) and that this knowledge heterophily is statistically significant. This result confirms the concept of CKP which has been referred to above, in which pieces of knowledge coming from different knowledge environments are combined and managed in a dense network of co-localized organizations. The two knowledge segments which have the highest preference for outward interactions are the infrastructure and hardware segments. The cross-density matrix shows that infrastructure nodes have relations with all the other segments and that the hardware group interacts frequently with the infrastructure group. The CKP is thus a specific one - it is mainly driven by infrastructure firms involved in collaborative projects with firms and labs coming from the hardware, the software or the “applications and services” segments. This confirms the idea that the different partners in GNSS innovative projects are grouped around infrastructure (satellite and telecommunications) firms seeking to foster their technological standards by developing a wide range of applications for these standards. It is thus necessary to interact frequently with geographically close partners in order to bridge the cognitive gap. If we move from the local knowledge relations to the subset of knowledge relations between insiders (MP organizations) and outsiders (non-MP organizations) (table 5), the knowledge heterophily remains[9], but with a weaker degree, in particular because of the very low level of heterophily that features the relations of the organizations of the infrastructure knowledge segment at the European level[10]. Indeed, if the development of new applications and services requires local knowledge relations that span cognitive domains, these innovations will have more chance to be turned into tradable and mass-market products if the infrastructure platform rests on interoperable and interconnected infrastructures at the European level. The high level of internal relations in the infrastructure segment corresponds thus to the incentives built by the European Commission for the cooperation on standards.

Table 5 here

5.2. Actor similarities and equivalences

In the early stages of technological dynamics such as GNSS the problem is one of defining a standard and finding applications that will ensure its diffusion. This might generate an intense competition

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[9] but with a weaker degree of significance since the p-value of the permutation test is slightly superior to 10%.

[10] We would like to thank the referee who suggested us computing the E-I index for this particular type of knowledge relations, instead of the E-I index for the whole of the network.

between incumbent firms seeking to impose their standards, and geographical proximity might be a problem in this case because of the risk of unintended knowledge spillovers between rival firms. In the Midi-Pyrenees GNSS network we have two strong competitors in the infrastructure segment [Thales Alenia Space (TAS) and EADS Astrium] and in addition there is the French Spatial Agency (CNES) which is also a key player in the domain of satellite building. The way they position themselves in this context of intense competition is an important issue in the efficiency and stability of the GNSS cluster. Do they frequently interact or do they, on the contrary, try to avoid any contact by differentiating their neighborhood as much as possible? To answer this question it is necessary to analyze the cliques or quasi-cliques present in the network. The more organizations belong to the same clique, the more they will display a structural equivalence and the more the flows of knowledge between them will be dense. Obviously, as previously explained, the MP+ Network will display as many cliques as collaborative projects since naturally each project is a clique. This problem can be circumvented if we use the bipartite network in order to reconstruct the simplified MP+ Network. Note that a clique is defined as the biggest group of nodes having all possible ties present within the group. Using the basic cliquishness assessment (Table 6) we obtain 15 cliques.

Table 6 here

The biggest clique, clearly observable in the simplified MP+ Network, is composed of a set of local SMEs that interact frequently. It is worth noticing that TAS appears frequently in cliques composed of local organizations (CNES, TESA, Rockwell Collins, M3 System, Skylab, …) while EADS Astrium has in preference chosen to interact with non local actors (Infoterra, Nottingham sc. Ltd). Here we obtain an answer to our question about the networking strategies chosen by these two rivals; in spite of their geographical proximity they have chosen not to interact with the same pools of actors. TAS has preferred a local interaction strategy while EADS Astrium has chosen an outward-oriented strategy. Nevertheless, it is worth noticing that TAS and EADS Astrium belong to the same clique along with the CNES, the French National Spatial Agency, which is central in the standardization process of GNSS. This situation is typical of the “co-opetition process” observed in many network industries; while companies try to avoid competition and unintended knowledge spillovers by limiting knowledge flows between them as much as possible, they need to cooperate on standardization since the extent of the potential market depends strongly on users’ and consumers’ preferences for standards (Shy, 1999). This “battle of standards” is resolved by research units and public agencies which take on the role of intermediaries in the standard setting process (Katz, Shapiro, 1994).

5.3. Role and position: centrality, efficiency and brokerage

In both geographical and relational dimensions an efficient location is a critical parameter of the modern innovative firm because it is the best way to gain access to new pieces of knowledge and to ensure, at the same time, a good level of knowledge appropriation.

Since the GNSS technological field is a composite one, the choice of relational and geographical localizations is determined by a twofold challenge; there is a need to understand that organizations endowed with different knowledge bases must interact but, at the same time, they need to design their innovations around a common technological standard. This implies that some central organizations will develop a special kind of absorptive capacity allowing them to detect complementary blocks of knowledge and to integrate them. It also means that a GNSS network should be structured in such a way that ensures (i) a good circulation of knowledge between the MP and other places, (ii) a good circulation of knowledge between the different knowledge segments and (iii) a central role for some organizations endowed with a knowledge integration capacity.

- *Centrality and power: which actors influence the knowledge dynamics and where are they located?*

SNA proposes three main methods for understanding an organization's centrality: degree centrality, closeness centrality and betweenness centrality. We compute these centrality indexes with a focus on the twenty most central organizations within the MP+ Network[11].

Table 7 here

The left side of Table 7 presents the results relating to the closeness centrality index based on path distances, i.e. the index that measures how close an agent is to others in terms of average geodesic distance. The higher the index, the shorter the average geodesic distance from the node to all the other nodes. Here a central agent is one that has knowledge accessibility because this agent is able to reach other agents on shorter path lengths. It is not surprising that TAS displays the greater index of closeness centrality. This influential position is due to the fact that TAS is involved in many collective projects. TESA and the CNES, two research institutes, are also very central, followed by a group of local GNSS SMEs. EADS Astrium, another major worldwide company in the space and satellite industry located in Toulouse, presents a smaller closeness centrality index.

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[11] Note that the computation of the centrality indexes for the simplified MP+ Network gives close results that concern the ranking of the more central organizations, and so are not displayed here.

While closeness centrality has allowed us to measure the knowledge accessibility of an actor by the latter's average (geodesic) distance to the knowledge of other actors, degree centrality, in the middle part of the table, gives us another concept of knowledge accessibility which is based on the number of opportunities for access to external knowledge. Indeed, the degree centrality index is just the total of each actor *i*'s number of ties with the other actors. The results are close to the previous ones, but it is worth noting EADS Astrium's climb to seven steps higher in the ranking.

On the right side of Table 7 we compute the betweenness centrality index. In this case the relational influence and the capacity to absorb new knowledge is drawn from the position of a node as an intermediary between the other nodes, allowing this node to be influential by brokering knowledge diffusion between other nodes or by becoming established as a "leading" intermediary. In this vision of influence, TAS keeps its place as "leader", but one can observe the increasing influence of EADS Astrium, its direct local competitor.

Finally, some actors (TAS and the CNES) seek to access external knowledge by shortening the distance to other actors, by multiplying the opportunities of contacts and by positioning themselves as intermediaries. Others (EADS, Actia, France Telecom R&D) seem to have more specific networking strategies focused on the search for betweenness centrality. Moreover, it is worth noting that, whatever the centrality measure is, 20-25% of the top twenty most central organizations is made up of non local nodes, which means that some external organizations are well positioned in the network. By supposing "embedded clusters" rather than clusters *per se*, it becomes possible to show the pathways of knowledge and the organizations that play a central role in these pathways, even if some of them can be located outside the cluster. In our particular case, this result is interesting, because by construction of the relational database, local organizations are more likely to be central than external ones. It shows clearly that the Midi-Pyrenees GNSS cluster is strongly embedded in a wider European network. It is mainly explained by the geography of the space industry, which has for long time developed research collaborations in Europe. It is especially true for the GNSS industry, because research collaborations between organizations coming from different countries are a strategic issue for the European Union, in order to develop its own global navigation satellite system (Galileo) and become independent from the American GPS. Thus it is not surprising that outside organizations display a certain degree of influence in the MP network, due to the European pipelines that support the development of the European infrastructure.

- *Brokerage*

The above results provide an initial view of the position of the organizations in the MP+ Network, but there is no consideration of the particular role these organizations have within the structure. The basic geographical and knowledge attributes of the nodes can help us to understand their so-called “broker” role (Gould, Fernandez, 1989). The different brokering strategies we can analyze are particularly suited to studying the consequences of the trade-off between knowledge accessibility and appropriation. Gould and Fernandez (1989) provide a set of measures for these brokering profiles. Here we will undertake an initial analysis to distinguish the group of local and the group of non local nodes, and a second analysis that differentiates the four technological segments as outlined above. According to the Gould and Fernandez’ definitions (1989), nodes exhibit a high “coordination” score when they act as intermediaries for relations between members of their own group. They obtain a high “gatekeeping/representative” score when they allow members of their group to contact members of another group. They obtain a high “consultant” score when they broker relations between the members of the same group but when they themselves are not members of that group. Finally, they exhibit a high “liaison” score when they broker relations between different groups and yet they themselves are not part of any group.

Table 8 here

Table 8 displays a census of the highest (raw and normalized) brokerage scores[12] concerning the relations between local and non local nodes[13]. We can observe that even if logically, the two main worldwide companies, TAS and EADS Astrium, exhibit high gatekeeper scores when the un-normalized measure is used, the normalized measures indicate that they have a stronger preference for “consultant” roles that lead them to broker relations between non local organizations. On the contrary, a group of local innovative SMEs (M3 System, Pole Star, Navocap) seem to play an important coordination role among local organizations in parallel with the public research organization TESA. The spatial research agency CNES exhibits a high level of all types of brokerage because it is involved in many collaborative projects, but it seems to have a slight preference for the gatekeeper role, chiefly because of its historical involvement in the European Space research network.

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[12] The scores are normalized since a node endowed with more relations than the others will automatically obtain higher scores for any of the brokerage types. Moreover, depending on the number and size of the attributes group, some types of brokerage will automatically be more frequent than others, even if they are chosen at random. It is thus necessary to compare actual brokerage ties to the expected ones obtained from a random sampling. The normalized brokerage scores are then defined as the ratios of actual scores to expected scores

[13] We only computed the raw and normalized scores of the main brokers who had a total brokerage score of at least 150. This is justified by the fact that random sampling may not converge towards the true distribution of ties when nodes have few ties.

These results show that it would be irrelevant nowadays to analyze clusters independently of the technological field; firstly, firms embedded in local networks are also involved in larger ones and secondly, non local firms bring knowledge from outside and capture knowledge from inside through gatekeeping strategies. Consequently, even if we have identified a GNSS cluster in the Midi-Pyrenees Region, the aggregate efficiency of this local structure does not only depend on the internal relations, but also on the way the cluster connects itself to larger pipelines through a subset of nodes.

Table 9 brings supplementary information on why the MP+ Network is typical of the current GNSS CKP. Here we use the same Gould and Fernandez indexes, but this time on the GNSS knowledge segment. There is now a “liaison” role since we have more than two groups. We also specify the size of the nodes in terms of number of employees and we indicate whether the agents are local or non local.

Table 9 here

If we firstly focus our attention on the raw (un-normalized) scores we can observe that the biggest organizations belong to the infrastructure segment and that they naturally have high raw brokerage scores. TAS, Telespazio, the CNES and EADS Astrium are big coordinators inside the infrastructure segment, but they also act as intermediaries for many relations between nodes from the different knowledge segments. There is no coordination brokerage in the hardware group, which means that outward relations are the priority for these firms.

If we now focus on the relative (normalized) scores, the first striking result is that all the organizations from the hardware and software segments have a marked preference for “consulting” or “liaison” roles. This means that they prefer to interact with partners from other knowledge segments. Gatekeeping strategies are more frequently chosen (in comparison to random assignments) in the infrastructure segment, so that technological standardization in the GNSS technological field is conducted by organizations from the infrastructure segment rather than from the hardware and software segments. Moreover, we see that CKPs are sustained by the two important research organizations from the MP Network, TESA and the CNES; even though they are members of the infrastructure group, they have a preference for “consultant” and “liaison” roles over gatekeeping. This may be explained by their neutrality in the knowledge appropriation conflict and also by their special absorptive capacity allowing them to manage relations between cognitively distant partners, as clearly demonstrated by Owen Smith and Powell (2004) in their Boston Biotech Cluster.

6. Discussion and concluding remarks

The starting point of this contribution was to consider clusters as particular interaction structures that are embedded in technological fields and different locations. With regard to this we consider that the relations between cluster insiders (the MP Network), and between insiders and those outsiders that have a relation with the former (the MP+ Network), constitute an appropriate boundary. SNA fits particularly well with this kind of empirical study where many interacting organizations, by their relational strategies, give rise to a particular structure. This methodological contribution to cluster empirical identification does not provide a normative approach for the analysis of cluster aggregate efficiency. Nevertheless, this approach leads to an understanding of the complex geographical and technological organization of a particular cluster. From the overall meso-properties of the aggregate structure to the role and position of the organizations in the network, the findings raise both discussion points on cluster theories and a research agenda.

Firstly, our MP+ Network displays a weak geodesic distance and a particular clique structure. In particular, we observe that cliques overlap owing to the position of central organizations that act as bridges between cliques, so that knowledge created in dense cliques can diffuse efficiently into the structure by way of these bridges. If we compare these structural properties to the main typologies of clusters or localized industrial systems (Markusen, 1996; Iammarino, McCann, 2006), it can be noted that our GNSS network, in its “MP” or “MP+” form, traverses different forms of structure. On the one hand, the strong cohesiveness of the structure consisting of the local hardware and software SMEs recalls the structure observed in the “Marshallian districts”, while on the other hand several large companies (TAS, EADS Astrium), public research organizations and agencies (TESA, CNES) exhibit a hub position typical of the one observed in the “hub and spoke districts”. A more systematic quantitative analysis of different clusters in different technological fields will be necessary to confirm this coexistence of different patterns of clustering processes.

Secondly, the methodology, consisting of the construction of a nested system of public funded collective projects, gives some interesting empirical perspectives. In particular, by coupling knowledge and geographical features with structural ones, and by matching local and local/non local relations, it offers an interactions-based approach for the industrial organization of clusters and networks. Indeed, one of the major issues for the organizations working in network industries is the need to set up standards. For GNSS, as for the Internet and telecommunication industries, and in particular when the emergent technologies and services display the economic properties of public utilities (Shy, 1999), their diffusion depends both on the ability of the organizations to reach an agreement on a standard, and on the variety of new applications and services this new technology will potentially engender. When taking this into consideration, the structural properties of our GNSS network seem to confirm the strong position of the MP in the European GNSS technological field. The first stake is observable in the MP+ Network as well as in the simplified MP+ Network. These graphs show, firstly, that the main competitors, EADS Astrium and TAS in the infrastructure segment, are tied directly or by the intermediary of the CNES which plays the role of a standardization agency. Secondly, they show that pipelines have been built between these local organizations and the German (Infoterra Ltd, Nottingham Scientific Ltd mainly) and Italian (Telespazio, GMV mainly) GNSS infrastructure companies. Obviously, this noteworthy structure is based on the strong incentives from the European Commission for cooperation on standards, through the Framework Programs Policies. The second stake is observable in the MP Network. The diffusion of a GNSS standard will depend on its compatibility and convergence with existing systems, such as telecommunication systems (Wi-Fi in particular) and transport systems, and with a large as possible set of software-based applications and services in traditional sectors (tourism, agriculture, transport, security, earth observation, and so on). The knowledge heterophily we have discovered in the quantitative analysis of the MP network is illustrative of this CKP and is organized around a knowledge platform (Cooke, 2006; Antonelli, 2006), where geographical proximity between cognitively distant organizations favors learning processes and research coordination with a limited risk of unintended knowledge spillovers (Boschma, 2005). This platform organization will help the GNSS companies to find new opportunities to impose their standards in the economy, while the other companies can improve their market position by exploring and developing new services in their own sector. The study of the structural properties of clusters is thus a relevant and original way to understand the part played by a location in the industrial organization of a technological field, in particular if we consider that the long term viability of clusters depends on their ability to impose and maintain technological standards (Suire, Vicente, 2009)

Thirdly, a cluster aggregates heterogeneous and complementary knowledge profiles. By knowledge profiles we mean not only the cognitive base and technological segment pertaining to each of the organizations, but also their strategic positioning in knowledge networks. Obviously, the position of each organization depends on their size and market power, but also on their particular broker roles in composite and geographical knowledge dynamics. By indexing these broker roles, we see an interesting possibility for further theoretical and empirical research. Indeed, the literature stresses that the co-location of firms which are cognitively and technologically close can be collectively under efficient (Boschma, 2005; Nooteboom, Woolthuis, 2005). Our results confirm this outcome since the simplified MP+ Network shows that the majority of satellite companies are located in different places. They are connected via pipelines in European projects; the proximity between their knowledge bases facilitates long distance interactions and reduces the risk of unintended knowledge spillovers (Torre, 2008). Nevertheless, we have emphasized the fact that two of the major satellite companies, TAS and EADS Astrium, are located in the same place, so that this theoretical argument suggests that their co-location might be inefficient. Nevertheless, by analyzing the cliquishness properties and broker role, it does not appear to be so obvious. Indeed, they belong to a small number of overlapping cliques and thus differentiate to some extent their neighborhoods and minimize their structural equivalence. Moreover, their broker roles differentiate their geographical strategies, the former having a stronger strategy of local coordination than the latter. Ultimately, this structural complementarity renders their co-location not as risky. This result confirms that the level of knowledge spillovers does not depend only on the geographical proximity between organizations, but also on their intended effort to connect knowledge between them (Breschi, Lissoni, 2001).

Fourthly, our empirical identification of the GNSS technological field in the Midi-Pyrenees demonstrates the particular role and position of public research organizations in the aggregate structure. Our findings confirm the result obtained by Owen-Smith and Powell in their study of the Boston biotech cluster. Since public research organizations (TESA here) or research and standardization agencies (CNES here) do not face the same knowledge accessibility/appropriation trade-off, they position themselves within the structure in a very different way than private organizations. The very significant index of local coordination computed for TESA can be understood as the willingness of this group to connect disconnected local organizations, whatever their knowledge segment, in order to “water down” the whole of the local structure. The geographical gatekeeper role of CNES marks its willingness to impose standards in the technological field by ensuring the knowledge accessibility and flow in the whole of the MP+ Network. Once again, introducing non-structural features to the network nodes – here, the geographical and knowledge attributes – highlights the differentiated and complementary roles organizations develop in the network.

Lastly, firms external to the local GNSS cluster can play a key role in the CKP as well as in the structuring of the local relations. The “outsiders” from our top twenty central organizations and, to a lesser extent, their geographical gatekeeper roles, give a clear illustration of this finding. Since clusters are more or less embedded in technological fields, they cannot be analyzed without a focus on the structure of knowledge flows between the cluster and the technological environment to which it is connected. In consideration of this, the [cluster/cluster+] protocol of data collection initiated by Owen-Smith and Powell (1994) and used in this contribution is a promising methodology for understanding clusters and pipelines structures, and how particular places reach efficiency from their outside connections.

The results we obtained on the structural properties and the role and position of the organizations in the structure, along the lines of the methodological and theoretical framework begun by Ter Wal and Boschma (2008), bring new research perspectives on cluster theories in knowledge-based economies. Obviously these results should be re-assessed in the future through theoretical research on knowledge clusters and aggregate efficiency within networks, as well through more systematic empirical research on various CKPs. Moreover, one of the future issues for further research will be to collect relational data spanning over a longer period in order to highlight, as suggested by Boschma and Frenken (2009) and Suire and Vicente (2009), how clusters grow and decline along the cycles of the technological field.

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Fig.1: the composite knowledge process in GNSS

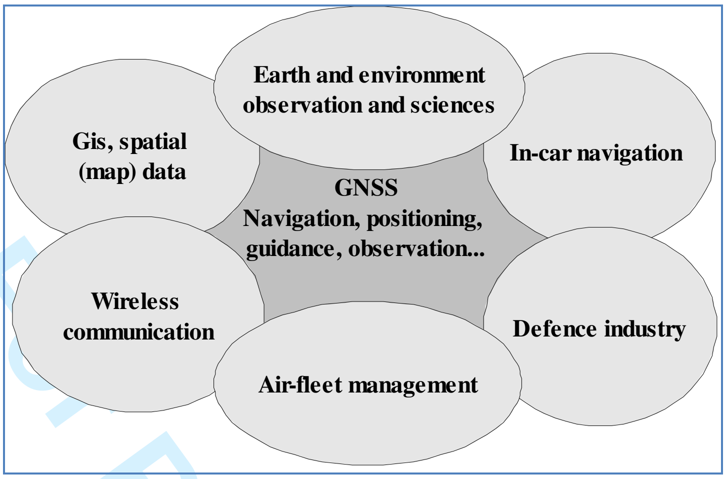


Table 1: GNSS collaborative projects

Project name	Number of partners	Geographic scale
SITEEG	14	MP
SSA-CAPYTOL	9	MP
TRANSCONSTROL	4	MP
TELEMED-AERO	9	MP
TSARS	2	MP
OURSES	9	F
FILONAS SDIS 31	10	MP
Géo Marathon	3	MP
SPSA	3	F
LIAISON	32 (17)	EU
Sinergit	8	F
CityNav	7	MP
WI AERO	3	MP
AIR NET	4	EU
CIVITAS MOBILIS	9	MP
AVANTAGE	4	MP
BINAUR	5	MP
Egnos bus	2	MP
Terranoos	2	MP
TONICité	3	MP
Fil Vert 2006	4	MP
Astro +	21	EU
ACRUSS	4	MP
Geo-urgences	4	MP
CTS-SAT	4	MP
Safespot (WP2)	57 (11)	EU
Harmless	10	EU
M-Trade	10	EU
Agile (WP 4, 5, 6, 7)	18 (13)	EU
GIROADS	13	EU

Collaborative projects		Organizations	
Number of projects	30	Number of organizations	130
Number of organizations by project	7	Number of project by organizations	1.67
Standard error	4.1	Standard error	1.66
Minimum	2	Minimum	1
Maximum	17	Maximum	12

Table 2 : Basic descriptive statistics of collaborative projects and organizations

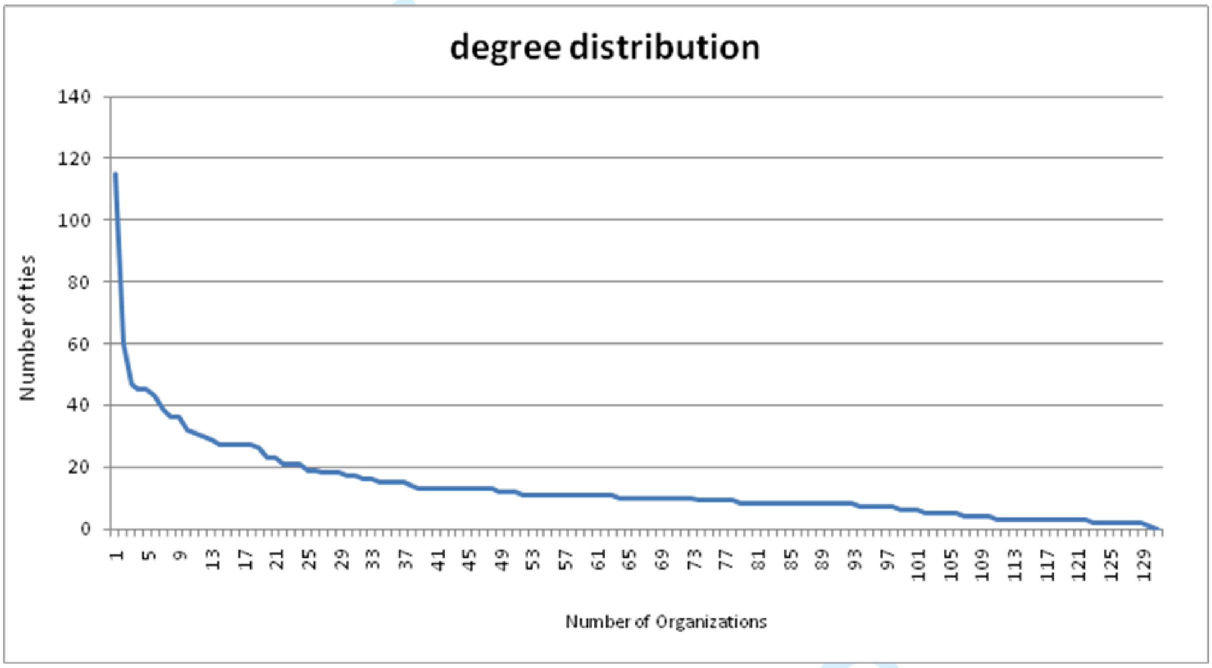


Figure 2: Degree distribution

Descriptive statistics of the MP+ Network	
Number of nodes	130
Number of links (dichotomized)	1584
Internal links	544
Internal-External links	294
External-External links	746
Density (dichotomized)	0.0944
Mean degree	1.135
Minimum degree	1
Maximum degree	115

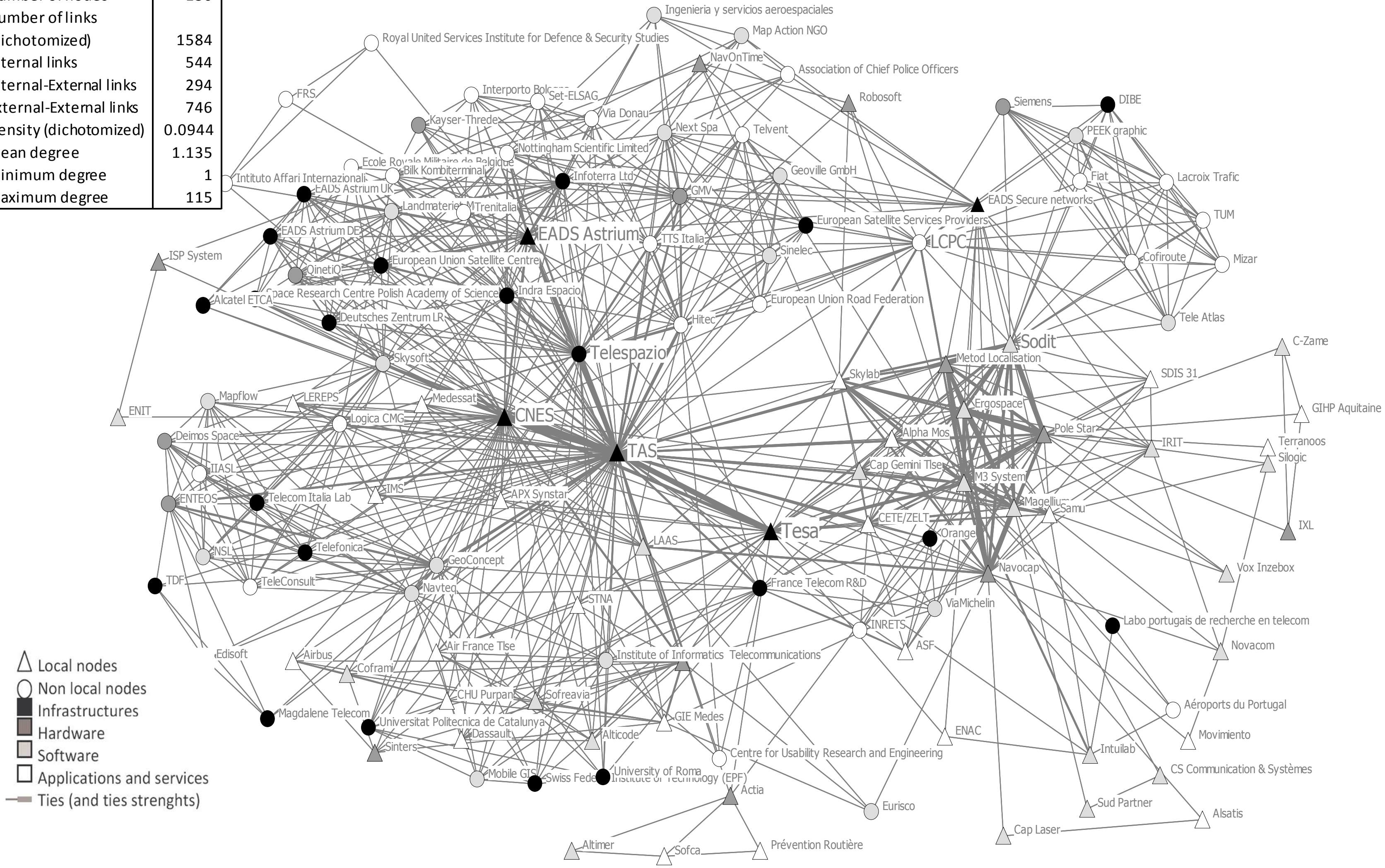


Figure 2: MP+ Network

Descriptive statistics of the MP Network	
Number of nodes	58
Number of links (dichotomized)	544
Density (dichotomized)	0.1645
Mean degree	12.07
Minimum degree	1
Maximum degree	47

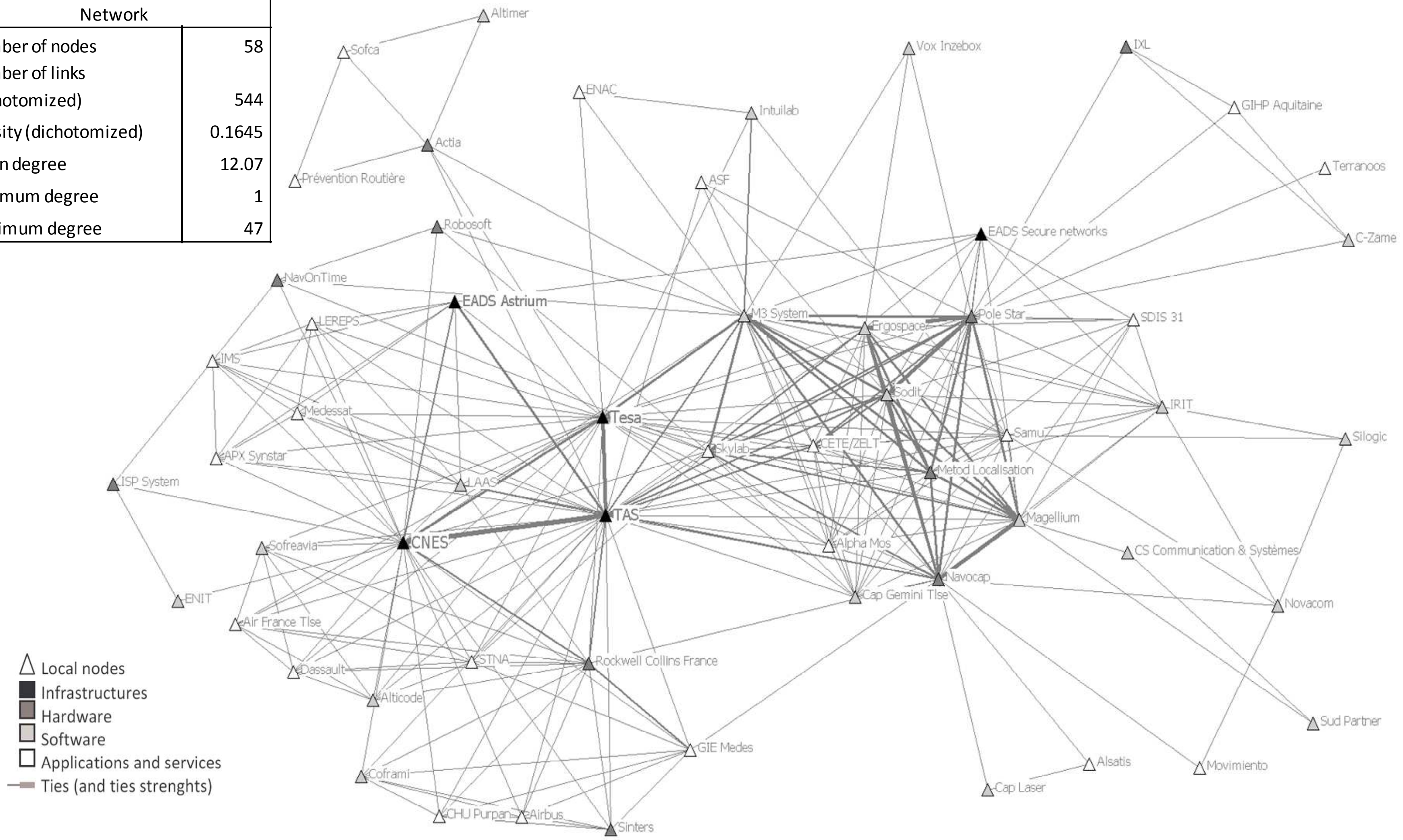
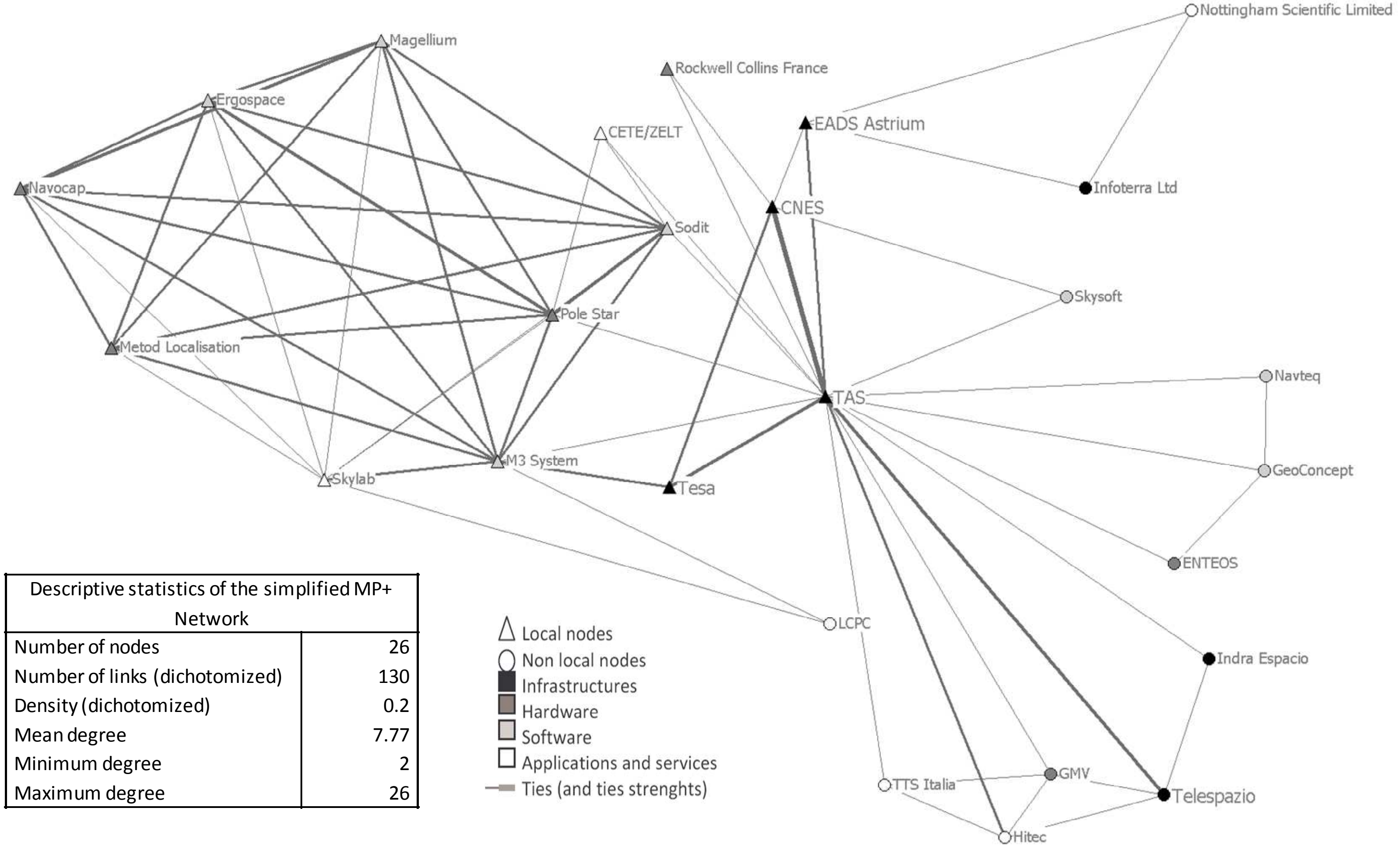


Figure 3: MP Network



Descriptive statistics of the simplified MP+ Network	
Number of nodes	26
Number of links (dichotomized)	130
Density (dichotomized)	0.2
Mean degree	7.77
Minimum degree	2
Maximum degree	26

Figure 4:Simplified MP+ Network

Table 4 : E-I Index for groups defined by KS membership
Network of local nodes

	Frequence	Percentage	Possible	Density
Internal……………………………………	122	0.225	996	0.122
External……………………………………..	420	0.775	2310	0.182
E-I………………………………………………	298	0.550	1314	0.397

E-I Index: ………………………………………………	0.550		Infrastructure…..	0.736
Expected value for E-I index:…………………	0.397		Hardware…………	0.692
Re-scaled E-I index: ……………………………	0.550	**Group level E-I Index :**	Software………….	0.404
Permutation Test :			A. & services……………	0.485
Number of iterations:……………………………	5000			

		Infrastructure	Hardware	Software	A & services
	Infrastructure	1.900	0.440	0.340	0.383
	Hardware	0.440	0.311	0.310	0.174
density matrix	Software	0.340	0.310	0.195	0.120
	A & services	0.383	0.174	0.120	0.087

	Obs	Min	Avg	Max	SD	P >= Ob	P <= Ob
Internal…………………………………………	0.225	0.196	0.302	0.446	0.031	0.998	0.003
External…………………………………………	0.775	0.554	0.698	0.804	0.031	0.003	0.998
E-I…………………………………………………	0.550	0.107	0.397	0.609	0.062	0.003	0.998

E-I Index is significant (p<0.05)

Table 5 : E-I Index for groups defined by KS membership
Network of relations between MP and non MP organizations

	Frequence	Percentage	Possible	Density
Internal………………………………	92	0.313	4746	0.019
External……………………………….	202	0.687	12024	0.017
E-I…………………………………………	110	0.374	7278	0.434

E-I Index: …………………………………………	0.374	**Group level E-I Index :**	Infrastructure…..	0.019
Expected value for E-I index:…………………	0.434		Hardware………..	1.000
Re-scaled E-I index: …………………………….	0.374		Software………….	0.719
Permutation Test :			A. & services……………	0.793
Number of iterations:…………………………….	5000			

		Infrastructure	Hardware	Software	A & services
density matrix	Infrastructure	0.138	0.036	0.036	0.032
	Hardware	0.036	0.000	0.007	0.004
	Software	0.036	0.007	0.006	0.007
	A & services	0.032	0.004	0.007	0.003

	Obs	Min	Avg	Max	SD	P >= Ob	P <= Ob
Internal…………………………………………	0.313	0.095	0.283	0.483	0.051	0.310	0.736
External………………………………………	0.687	0.517	0.717	0.905	0.051	0.736	0.310
E-I……………………………………………	0.374	0.034	0.434	0.810	0.102	0.736	0.310

E-I Index is hardly significant ($p \cong 0.10$)

1: TAS Tesa CNES
2: TAS Rockwell Collins France CNES
3: TAS CNES EADS Astrium
4: TAS CNES Skysoft
5: TAS Pole Star Sodit CETE/ZELT
6: TAS M3 System Pole Star Sodit
7: TAS M3 System Tesa
8: TAS Hitec Telespazio GMV
9: TAS Hitec GMV TTS Italia
10: TAS Navteq GeoConcept
11: TAS Telespazio Indra Espacio
12: TAS GeoConcept ENTEOS
13: Ergospace M3 System Pole Star Metod Localisation Magellium Navocap Skylab Sodit
14: M3 System Skylab LCPC
15: EADS Astrium Infoterra Ltd Nottingham Scientific Limited

Table 6 : the cliques of the simplified MP+ network

Table 7 : the 20 most central nodes

Normalized Closeness Centrality		Normalized Degree Centrality		Normalized Betweenness Centrality	
	------------		------------		-----------
TAS	75.439	TAS	17.829	TAS	46.129
CNES	58.371	CNES	9.302	CNES	11.778
Tesa	56.332	Sodit	7.287	LCPC	7.402
M3 System	55.128	Telespazio	6.977	Sodit	7.376
Sodit	54.894	M3 System	6.977	Pole Star	7.241
Pole Star	53.750	Pole Star	6.667	M3 System	6.921
Navocap	53.306	Navocap	6.047	Navocap	6.637
Telespazio	53.086	Tesa	5.581	EADS Astrium	4.981
Skylab	52.016	EADS Astrium	5.581	Tesa	4.852
Magellium	52.016	Magellium	4.961	Actia	4.585
Ergospace	51.807	Ergospace	4.806	Magellium	3.289
Metod Localisation	51.600	GMV	4.651	Telespazio	3.240
LCPC	51.600	Metod Localisation	4.496	EADS Secure networks	2.395
CETE/ZELT	51.394	Skylab	4.186	Samu	2.120
Samu	51.190	LCPC	4.186	GMV	1.572
EADS Astrium	50.988	Skysoft	4.186	France Telecom R&D	0.992
GMV	50.588	Indra Espacio	4.186	Skylab	0.792
Alpha Mos	50.391	Hitec	4.186	Nottingham Scientific Limited	0.708
Cap Gemini Tlse	50.391	GeoConcept	4.031	Infoterra Ltd	0.689
Hitec	49.049	Nottingham Scientific Limited	3.566	GeoConcept	0.669
Indra Espacio	48.864	Infoterra Ltd	3.566	Hitec	0.661

Table 8:Egonet analysis		geographical brokerage scores of main brokers					
		un-normalized brokerage			relative (normalized) brokerage		
		Coordinator	Gatekeeper	Consultant	Coordinator	Gatekeeper	Consultant
non local nodes	Nottingham Scientific Ltd	120	20	4	2.893	0.490	0.098
	Skysoft	238	10	0	3.647	0.156	0
	Infoterra Ltd	106	20	4	2.794	0.535	0.107
	Indra Espacio	232	18	0	3.422	0.270	0
	Hitec	214	0	0	3.953	0	0
	Telespazio	850	22	0	3.759	0.099	0
	LCPC	162	72	10	2.027	0.915	0.127
	France Telecom R&D	86	40	0	2.048	0.968	0
	GeoConcept	218	10	0	3.621	0.169	0
	GMV	210	25	0	3.193	0.386	0
local nodes	M3 System	130	26	0	2.824	0.574	0
	Pole Star	130	48	0	2.274	0.853	0
	CNES	340	521	376	0.765	1.190	0.859
	Tesa	468	0	0	3.953	0	0
	TAS	476	1071	1564	0.450	1.028	1.502
	Navocap	156	13	0	3.389	0.287	0
	Sodit	36	108	80	0.429	1.306	0.968
	EADS Astrium	12	135	236	0.092	1.047	1.830

Table 9: Ego-network analysis: knowledge segments brokerage scores of main brokers

Knowledge segments	Nodes (number of employees;L(ocal)/NL(ocal))	un-normalized brokerage				relative brokerage			
		Coord	Gatekeep	Consult	Liaison	Coord	Gatekeep	Consult	Liaison
Infrastructure	TAS (2200,L)	196	781	982	1442	0.537	0.954	1.199	1.060
	Telespazio (1700,NL)	78	218	138	242	1.001	1.245	0.788	0.832
	CNES (1896,L)	42	314	400	688	0.274	0.912	1.162	1.203
	Infoterra Ltd (70,NL)	20	45	16	24	1.529	1.532	0.545	0.492
	Indra Espacio (210,NL)	0	79	46	64	0	1.505	0.877	0.734
	Tesa (25,L)	0	20	154	274	0	0.218	1.681	1.799
	EADS Astrium (1788,L)	44	130	78	136	0.974	1.282	0.769	0.807
	France Telecom R&D (80,NL)	8	37	28	56	0.553	1.138	0.861	1.037
Hard-ware	Pole Star (9,L)	0	14	68	130	0	0.316	1.537	1.768
	Navocap (30,L)	0	11	58	102	0	0.309	1.628	1.722
	GMV (600,NL)	0	13	80	154	0	0.255	1.571	1.820
Software	Skysoft (70,NL)	6	42	52	116	0.267	0.831	1.029	1.382
	GeoConcept (90,NL)	22	50	62	54	1.060	1.073	1.330	0.697
	M3 System (22,L)	6	30	34	82	0.378	0.842	0.954	1.385
	Sodit (8,L)	18	59	94	102	0.622	0.908	1.446	0.944
Applica-tions & services	LCPC (550,NL)	40	77	34	88	1.452	1.244	0.549	0.856
	Nottingham Sc. Ltd (210,NL)	2	18	42	84	0.140	0.561	1.308	1.574
	Hitec (100,NL)	62	56	12	28	3.323	1.336	0.286	0.402

Cris: for this paper the French abstract is included already

Getting into networks and clusters: Evidence from the Midi-Pyrenean GNSS collaboration network

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Abstract:

This paper analyses clusters from collaborative knowledge relations embedded in wider networks in a particular technological field. Focusing on the interface of clusters and networks contributes to a better understanding of collaboration, within and across places and cognitive domains. We propose an empirical analysis of the Midi-Pyrenean GNSS (Global Navigation Satellite Systems) cluster based on a relational database constructed from collaborative R&D projects funded at the European, national and regional levels. Using Social Network Analysis tools we discuss the results according to (i) the structural, technological and geographical dimensions of knowledge flows, (ii) the influence of particular organizations in the structure and (iii) the heterogeneity and complementarities of their position and role. We conclude by showing that our findings provide new opportunities for cluster theories.

Keywords: Knowledge, Networks, Economic Geography, Cluster, GNSS
JEL classification: O32, R12

Entrer au cœur des réseaux et des clusters : Le cas du réseau de collaboration dans les GNSS en Midi-Pyrénées

Résumé

L'article analyse les clusters à partir des relations collaboratives d'innovation encastrées dans des réseaux plus larges dans un domaine technologique donné. Se positionner à l'interface des réseaux et des clusters permet d'avoir une meilleure compréhension des collaborations, dans et entre espaces géographiques et domaines cognitifs. Nous proposons une analyse empirique basée sur le cluster GNSS (Systèmes Globaux de Navigation par Satellite) en Midi-Pyrénées, à partir d'une base de données relationnelles issue de l'agrégation de projets collaboratifs de R&D régionaux, nationaux et Européens. A l'aide des outils de l'analyse sociale des réseaux, nous discutons les résultats selon (i) les dimensions structurelle, technologique et géographique des flux de connaissances, (ii) l'influence de certaines organisations dans la structure, et (iii) l'hétérogénéité et la complémentarité de leur position et rôle. Nous concluons en montrant que nos résultats fournissent de nouvelles perspectives pour la théorie des clusters.

Mots-clefs : Connaissance, Réseaux, Economie géographique, Cluster, GNSS
Classification JEL : O32, R12

1. Introduction

In the Economics of Knowledge, clusters and networks are subject to a growing interest due to the increased observation of collective knowledge processes (Cooke, 2002) and their spatial concentration (Porter, 1998) in many technological fields. Nowadays knowledge processes are composite ones, i.e. they combine many interacting pieces of knowledge coming from different cognitive domains. In this paper we propose that knowledge networks and clusters come from the complex aggregation of relational strategies (Powell, Grodal, 2005; Cowan, Jonard, Zimmermann, 2007) between organizations embedded in Composite Knowledge Processes (CKPs). The second assumption of this work is that space matters even if it does not signify that geographical proximity between organizations is the *panacea* for knowledge creation and diffusion. We follow thus an emerging literature which is cautious about the univocal role of geographical proximity in collective knowledge processes (Breschi, Lissoni, 2001; Bathelt, Malmberg, Maskell, 2004; Rychen, Zimmermann, 2008; Crevoisier, Jeannerat, 2009). If firms combine internal and external knowledge, they also combine local and distant interactions according to a set of critical parameters related to their place in the knowledge value chain, the extent of their geographical market and the respective absorptive capabilities of their partners. In order to propose a better understanding of collective knowledge processes, within and across places, and within and across cognitive domains, the paper focuses on the interface of clusters and networks.

Network analysis tools (Borgatti et al., 2002) are well suited to identifying clusters and networks in Regional Science (Ter Wal, Boschma, 2009; Rychen, Zimmermann, 2008), in particular when their structural features are coupled with non-structural ones (Owen-Smith, Powell, 2004). Indeed, the geographical location and technological features of the "players" can have an influence on the structural form of the "web" of knowledge flows. This paper contributes to these developments, with an empirical focus on a particular CKP: the GNSS (Global Navigation Satellite Systems) technological field. GNSS cross several knowledge segments - from orbital infrastructure to a wide set of on-ground applications, and also traverse several industrial sectors such as telecommunications, tourism, security, transport and so on. This technological field is thus a composite one (Antonelli, 2006) due to the extent of knowledge combinations such technologies generally require before their potential diffusion. We use an emerging methodology which initially consists of publicly funded collaborative R&D projects, hence providing a wide view of knowledge relations, especially in emerging technological fields (Autant Bernard et al., 2007). This data collecting process aims to identify how a local cluster could be embedded (or not) in a technological field. Therefore we only consider collaborative GNSS R&D projects including "players" from one of the GNSS industry's major European regions: the Midi-Pyrenees Region (MP). The MP is not a random choice. This French Region is an important European region for the space and aeronautics industry that nowadays combines its cumulative knowledge process in this sector with moves towards the emerging civil mobility, positioning and navigation technologies which are supported by the EGNOS and GALILEO European Programs.

The paper is organized as follows: Section 2 summarizes the main issues that concern the links between collaboration networks and economic geography. In so doing we discuss how network analysis helps show that clusters are embedded in larger networks. We propose a set of theoretical arguments that combine structural, geographical and technological properties in the identification of a particular cluster. Section 3 presents the technological field of GNSS, the relational data with the variables (attributes of the nodes) and the selection routine for knowledge relations (the ties between the nodes). In particular, we focus especially on the relevant network boundaries. In order to do this we follow the same protocol as Owen-Smith and Powell (2004), emphasizing how a cluster is embedded in a technological field. Our starting network focuses on collaborative R&D projects in the GNSS technological field and thus aggregates the organizations located in the MP, the relations among them and all organizations in any location that have a network tie with MP-based organizations. Section 4 discusses the visualization of our particular network and of two relevant sub-networks (the local cluster and the cluster/pipeline structure). Section 5 investigates a set of quantitative results that relate to some descriptive statistics and traditional indexes from network analysis. Section 6 discusses the results in a more qualitative way according to three main focuses: (i) the structural and geographical organization of knowledge flows, (ii) the influence particular nodes have within the structure and (iii) the heterogeneity and complementarities of their position and role in the network.

2. Networks and clusters as a web of Composite Knowledge Processes (CKP)

2.1. Starting from CKP and collaboration networks rather than places **per se**

Since the development of Porter's ideas on clusters [Porter defined clusters as *"geographic concentrations of interconnected companies and institutions in a particular field"* (Porter, 1998)], several bodies of work have stressed the coexistence of different types of clusters (Markusen, 1996; Iammarino, McCann, 2006). We suggest that clusters, as the aggregation of interacting organizations in the same geographical location, have to be studied from the perspective of a larger network. Places and networks are meso-structures which do not necessarily link together every time. However, they can intersect when we assume that they are the “locus” of the dynamics of a peculiar technological field (White et al., 2004).

Technological fields are more or less coherent structures representing CKPs, i.e. processes in which dispersed and fragmented inputs of knowledge are combined for the purpose of the production of knowledge outputs (Antonelli, 2006). At the microeconomic level, organizations produce new knowledge merging internal and external knowledge, and they combine arm’s length and network relations (Uzzi, 1997) in order to manage both their knowledge appropriation and accessibility. At the meso-economic level, the aggregation of these knowledge relations gives rise to a network which features a set of structural properties (Powell, Grodal, 2005). For instance, if a technological field features strong arm’s length relations and strong competing pressure the network density will be weak; on the contrary, organizations that improve their conditions of knowledge accessibility by multiplying knowledge partnerships will appear more central than other organizations in the network. Starting from a CKP and gaining access to its network is thus a relevant approach if one wishes to dispute the notion that knowledge would escape ‘into the atmosphere’. Knowledge spreads via networks and via the intended effort by agents to connect fragmented bits of knowledge (Breschi, Lissoni, 2001).

2.2. *Structural/geographical/technological features of networks and clusters*

Because the structural features of networks can vary according to the technological field, it is not surprising that local clusters similarly vary in their structural form, but it is necessary to understand why networks can have a local dimension which is stronger or weaker and how this local element is structurally connected with its outside environment.

Literature on economic geography and economics of knowledge has produced interesting results. The basic idea is that clustering processes occur when the composite knowledge process requires the combination of cognitively distant but related pieces of knowledge (Nooteboom, 2005; Boschma, 2005). Between high specialization and high diversification, fragmented pieces of knowledge coming from more or less distant knowledge domains can be interconnected around an emerging technological window or standard (Vicente, Suire, 2007). Since knowledge spillovers can be both intended (the intentional effort to share knowledge) and unintended, geographical proximity causes ambivalent effects on innovation. When cognitive distance is large enough and knowledge assets are complementary, geographical proximity favours intended knowledge spillovers as long as organizations are involved in a relation. The gap between their respective knowledge bases which can impede accessibility is reduced by the potentiality of frequent meetings, whereas their different respective core activities moderate the risk of under-appropriation. Inversely, the co-location of firms endowed with close knowledge capabilities, even if it is in their mutual interest to cooperate, can engender unintended knowledge spillovers and a climate of mistrust. For this situation, Bathelt, Malmberg, Maskell (2004) and Torre (2008) showed that pipeline structures and temporary proximity correspond better to this kind of relation.

The question is how do we include these issues in the classic structural approach for networks? In line with Owen Smith and Powell (2004), we suggest adding non-structural dimensions, i.e. geographical and technological dimensions. Indeed, the introduction of non-structural dimensions leads to a more complete view on (i) how the compositeness of the knowledge process affects the structural properties of the network and their resulting geography and (ii) how the knowledge flows in the structure are conditional on the heterogeneous and complementary roles and positions that organizations achieve through their relational strategies.

2.3. *Social Network Analysis and localized collaboration networks*

Social Network Analysis (SNA) (Wasserman, Faust, 1994) is particularly suited to the examination of such issues. Among others, the work of Owen-Smith & Powell (2004) on the Boston Biotech cluster, Guiliani & Bell (2005) on the Chilean wine cluster, Boschma & Ter Wal (2007) on the South Italian footwear district, and Morrison (2008) on the Murge sofa district, constitute the first attempts in improving knowledge of the interaction mechanisms at work in clusters.

SNA provides concepts and tools that highlight the structural properties of localized collaboration networks. First of all, at the meso-economic level the basic SNA density measures outline the existence or the non existence of a cluster and how the latter is embedded in a technological field. A firm's agglomeration that displays a weak density of local knowledge relations will be more of a “satellite platform” (Markusen, 1996) than a cluster *per se*, i.e. a local structure which is more or less cohesive. On the contrary, an excessive density of local relations in a cluster can engender redundancies and, because relations mean costs, a slump in efficiency for organizations. Moreover, the study of network densities can be refined by matching the location and the knowledge base of the organizations. These measures are thus suited to identifying how the different knowledge bases of the CKP are connected and give an overview of how cluster and pipeline relations coexist in the production and the diffusion of knowledge (Bathelt, Malmberg, Maskell, 2004).

In addition to densities, one of the most used structural properties is network cliquishness, i.e. groups of organizations that are more closely linked to each other than to other organizations. These properties can be "emergent" when they derive from the aggregation of *bi*-lateral relations, but they can also be "presupposed" when cliques strictly represent groups of *n*-lateral relations. The more the network is constructed from *n*-lateral relations, the more it has chance to display cliquishness properties, as in the studies of Autant-Bernard et al. (2007). In this case, the analysis can focus on nodes as in most network analysis, but due to the strong presupposed network cliquishness it would be pertinent to consider the bipartite (or bi-modal) network, i.e. a network that takes into account the ties between two sets of nodes at two different levels - the ties between organizations and projects[i]. In doing so, additional properties can be studied by exploring how collaborative projects rely on each other through affiliated actors and provide a particular structure of preferential interactions that influences knowledge diffusion. In particular, cliquishness properties, if they are salient, show that knowledge does not spread in a random way throughout the network but into sub-groups of organizations which can be more or less connected with each other if some of the organizations act as a bridge within the structure (Burt, 1992). Moreover, the existence of cliques in a network can be explained by the necessity for some organizations to protect themselves from the risks of knowledge under-appropriation. Because knowledge spills over via interaction structures rather than via a pure *corridor* effect (Breschi, Lissoni, 2001), organizations with close knowledge capabilities maintain a high level of knowledge accessibility by connecting to the network at the same time as they limit the risks of unintended knowledge spillovers by positioning themselves in cliques that are more or less disconnected. Conversely, other organizations such as public research organizations can employ an inverse relational strategy by connecting disconnected organizations, since they are naturally less affected by these risks.

These structural properties result from the role and position that organizations develop through their relational strategies. Knowledge relations in a network are not randomly distributed. First of all, as corroborated by many monographs on clusters, organizations have very differentiated positions: in terms of influence and power, in the knowledge dynamics at work in a cluster and in a technological field. The “hub and spoke” structure of agglomerations observed by Markusen (1996) is a good example of such influence and power. In this type of structure, a very central firm is tied to all the others, while these others are poorly connected to each other so that the knowledge trajectory is strongly associated with the strategy of the main firm. SNA, by proposing a set of centrality indexes for organizations in a network, furnishes suitable tools for dealing with this topic. Moreover, in a knowledge network that traverses both a technological field and a geographical location, the knowledge dynamics can be driven from inside as well as outside the cluster, in particular when outside companies succeed in forming a limited number of, but very strategic, relations with “insiders”. Lastly, in addition to their central position, organizations embedded in a network can adopt different roles according to the way in which they position themselves in relation to others. A network is generally represented by non-overlapping categories of organizations so that the influence and power of an organization depends on their centrality but also on their ability to broker relations between categories of organizations. In adherence with Gould and Fernandez (1989), we follow the notion that *“communication of resources that flows within groups should in general be distinguished from flows between groups”* (p. 91). For instance, as demonstrated by Rychen and Zimmermann (2008), if we consider cluster insiders and clusters outsiders as non overlapping groups, two central insiders will have a different role if one is mostly tied to insiders whereas the other is mostly tied to outsiders. In the first case, the organization will be considered as a “coordinator”. As observed by Owen-Smith and Powell

(2004) in the Boston biotech cluster, this role is typical of the one played by public research organizations. In the second case, the organization will be considered as a “gatekeeper” (Allen, 1977), i.e. an organization that derives its influence from its ability to act as an intermediate for knowledge between non-connected insiders and outsiders. Many cluster studies show that clusters take advantage of the existence of gatekeepers (Rychen, Zimmermann, 2008), i.e. the key organizations that ensure the embeddedness of the cluster into the technological field. If we extend these roles from geographical space to knowledge space, we can also assume that organizations differ in their ability to coordinate knowledge in a group of organizations having similar knowledge capabilities, for example, for the purposes of standardization, whilst other organizations will prefer to have a gatekeeper strategy by connecting non connected organizations developing complementary knowledge bases in order to position themselves as the missing link for the CKP.

3. Context, data and methodology: the GNSS technological field

This section summarizes the context, the data and the methodology. After an overview of the key role of the MP Region in the GNSS technological field, we present the relational dataset, constructed from an original aggregation of collective R&D projects. We thus discuss its representativeness and present the variables. Finally, we present the methodology of the empirical analysis, based on the identification of the structural properties and the key role and position of the main players using the standard UCINET tools (Borgatti et al., 2002).

3.1. The composite knowledge process

Fig.1 here

GNSS is a standard term for the systems that provide positioning and navigation solutions from signals transmitted by orbiting satellites. In the past decades these technologies were mainly developed by the defense industry (missile guidance) and the aircraft industry (air fleet management). The knowledge dynamics were cumulative, based on incremental innovations dedicated to the narrow aerospace industry market. Nowadays, these technological dynamics present the characteristics of a CKP. Indeed (Figure 1), in the technological and symbolic paradigm of mobility, GNSS represents technologies which find complementarities and integration opportunities in many other technological and socio-economic contexts.

The GNSS field is a worldwide technological field which combines clusters and pipelines. Indeed, considering the European level, Balland and Vicente (2009) have identified seven main GNSS clusters in the regions of Midi-Pyrenees, Upper Bavaria, Ile de France, Inner London, Community of Madrid, Tuscany, and Lazio. In this study we only focus on the knowledge relations starting from (and inside) the MP so as to explain how CKPs combine local and non local relations. The choice of the MP is not random. Indeed, the MP has a concentration of more than 12,000 jobs dedicated to spatial activities and was recently identified by the French government as being the worldwide "competitiveness cluster" in aerospace and on-board systems (Dupuy, Gilly, 1999; Zuliani, 2008). The MP is a historical leader in Europe for the design and creation of space systems and homes the main actors working on the two major GNSS European programs, Egnos and Galileo, such as the CNES (National Centre of Spatial Studies), EADS Astrium and Thales Alenia Space (TAS). In particular, the coexistence within the same place of the two major competing companies EADS Astrium and TAS is a remarkable point. It should be interesting to study how organizations that display a weak level of cognitive distance co-exist in the same place, and how each one manages the intended and unintended knowledge spillovers through its position in the relational structure of the cluster.

3.2. An aggregative method for Collaborative Knowledge Projects

- *Data sources*

An intensive amount of *deskwork* enabled us to list all the main regional organizations involved in the GNSS technological field, from space and ground infrastructures to applications and related services, and from large firms to SMEs and research units. In doing that we constructed a database of 30 collaborative projects in which these organizations are involved (see table 1), ensuring a "snowball effect" by bringing together other firms that consequently add complementary pieces of knowledge to the CKP, inside and outside the region, through these collaborative R&D projects. The data aggregation decision tree starts with two main sets of sources: regional sources[ii] (through the review of websites dedicated to GNSS), and European sources[iii], focusing only on projects that include "navigation" or "positioning" and Galileo or EGNOS. Once the collaborative projects were identified in a nested system of publicly funded collaborative projects[iv], all the websites of the projects were visited in order to have a look at their work package organization and hence remove non relevant knowledge relations (see below).

Table 1 here

- *Ties selection process*

Our relational database brings together projects which differ in size. These depend greatly on the geographical scale of the funding, bearing in mind that regional and national projects bring together fewer units than European Projects (3 to 14 partners in regional and national projects, 18 to 57 partners in 4 of the European projects). Selecting the ties consists of cleaning up the relational database by removing pair-wise relations between partners who are not involved in the same work packages for the whole of the project, and maintaining pair-wise relations between the project leader and all the partners. Moreover, when the leader of the project is outside the region, we only consider the work packages in which MP organizations are involved.

- *Comments on the relational database*

Such a methodology implies comments relating to both its advantages and its limitations. Firstly, starting from publicly funded projects is certainly a non-exhaustive way of capturing all the relations between firms, but the advantage is that our analysis thereby resides on a clear definition of what a knowledge relation is and avoids the vagueness of the nature of the relations we can perceive when we understand relations uniquely through interviews. In particular, the density of relations can be approximated objectively by using an index referring to the number of projects in which organizations are involved pair-wise. Nevertheless, our data can be perceived as being representative of the knowledge process of GNSS in (and from) the Midi-Pyrenees for the period 2005-2008[v]:

(i) GNSSs are emerging technologies which concern applications dedicated to public utilities such as transport security, environment observation, telecommunications and so on. In this way, GNSSs are among the priorities for policy makers, whatever their geographical scale.

(ii) Considering that public funding is conditional on “requests for tender”, the organizations in our database are those which have succeeded in obtaining the funding due to their legitimacy in this technological field. This legitimacy results from their experience in past relations, so our relational database is strongly representative of the knowledge trends in the technological field.

Secondly, using projects as a starting point is dependent on the geographical scale of the public funding, which can be regional, national or European. Nevertheless, this limitation can be transformed into a convenient advantage since these three scales of funding are distinguished. The aggregation of these projects and their transformation into a unified network structure thus ensures a representative view of the embeddedness of regional organizations into the European GNSS field. Consequently, our protocol follows the multi-level governance system that typifies research funding in Europe and constitutes the current “circuitry of network policy” (Cooke, 2002). As a perfect exhaustiveness is difficult to reach, it is possible that marginal data are missing. Data concerning knowledge relations, in which local organizations are involved and that are supported or funded at the regional level, but by another region, could be missing. Nevertheless, a test conducted from the public information available on the organizations’ websites confirmed that these missing data are marginal. Moreover, the results of one of the major Midi-Pyrenean requests for tender in Navigation Satellite Systems (VANS), which includes 5 collaborative R&D projects from within our database, show that the MP organizations represent 80% of the selected partners. Similarly, ULISS, the French requests for tender on EGNOS and Galileo applications, restricts the eligibility to organizations located in France.

Table 2 presents some basics statistics relating to the relational database, whereas figure 2 shows the degree distribution of ties in the network and takes the form of a quasi rectangular hyperbola, i.e. a few nodes concentrate a large part of the relations in the structure.

Table 2 here

Figure 2 here

3.3. Spatial attributes and knowledge features

- Spatial node attributes

Each node is geographically labeled with a very simple binary feature, “inside” or “outside” the MP Region. Our protocol is thus similar to Owen-Smith and Powell’s (2004), who considered the Boston cluster and the ‘Boston+ cluster’, i.e. the Boston cluster augmented with all organizations in any location that had a network tie with Boston-based organizations. We are thus only interested in one of the extremities of the pipelines. Interconnecting the clusters means gathering larger data of knowledge relations as tested by Autant-Bernard et al. (2007) and Balland and Vicente (2009) with data from the European Framework Programmes, but without any consideration of nationwide and region wide programs and funds.

- Knowledge attributes

Each node is labeled according to its main technological segment. This differentiation of nodes aims to highlight the composite dimension of the knowledge process. The deskwork undertaken on projects has led to the classification of each node according to four knowledge segments (KS):

(i) The infrastructure level with all the spatial and ground infrastructures; (ii) The hardware level, including all the materials and chipsets which receive, transmit or improve the satellite signal; (iii) The level of software, including all the software applications that use navigation and positioning data; (iv) The whole of the applications and services segment, which concerns many heterogeneous agents and socioeconomic activities where navigation and positioning technologies are introduced (or should be introduced in the future).

This attribute-based classification requires further comment. Obviously it would be more suitable to construct this classification from technological features, for example, patent codes, as the literature invites us to do (Nooteboom, 2000; Breschi, Lissoni, 2001). However, in our case this task is difficult and to some extent inappropriate because we want to take into account the whole of the knowledge value chain. Indeed, patenting activities primarily concern the major elements of the infrastructure segments and hardware segments. Software segments and "applications and services" segments cannot be patented, or at least only marginally. One reason is that this knowledge process is in an emergent phase. Other reasons are specific to each of these two last segments. The software segment is included in the copyright system and the "applications and services" segment contains various kinds of practical knowledge and specific professional expertise which are not patented.

Our classification is thus based on the standard classification of network industries (Shy, 1999). This classification is useful in the sense that it ensures a clear distinction between the knowledge capabilities developed in each segment, at least for the first three classes. It has also led to discussion on how the technological complementarities, the production of systemic goods and the standardization process are organized in this technological field.

3.4. Empirical methodology

We used UCINET 6 (Borgatti et al., 2002) and Netdraw visualization standard tools in order to study our network, its structural properties and the role and position of the key organizations in the network. The weighted relations matrix[vi] (MP+ Network) was used to draw the network including geographical and knowledge attributes. From this matrix we were able to draw three other matrixes: the dichotomized matrix, the matrix of relations between local nodes (MP Network), and the bi-modal matrix that enabled us to draw the simplified MP+ Network.

4. Basic descriptive statistics and visualization of the GNSS network

Figure 2 displays the MP+ Network, while figures 3 and 4 focus on two distinctive zooms, the "MP network" and the "simplified MP+ network" which display cliques and the main pipelines between the insiders (triangles) and the outsiders (circles). Moreover, these images display (i) the tie strengths, corresponding to how many times two nodes are connected pair-wise and (ii) the four GNSS segments, from the infrastructure segment (black) to the applications and services segment (white).

4.1. The MP+ network

Figure 2 here

The MP+ network (figure 2) represents all the nodes and ties resulting from the aggregation of all the collaborative R&D projects. At first glance the network exhibits interesting meso-economic properties, such as cliques, and also visible key actors that seem to have a strong influence within the GNSS knowledge process. The density of the MP+ network is 0.0944, that is, 9.44% of all possible ties are activated out of the 8385 (130x129/2) non reflexive and undirected possible ties. This network is also highly clustered since its unweighted clustering coefficient is 0.844 while the weighted coefficient remains high (0.490). The average geodesic distance is 2.39 indicating that knowledge should circulate easily in the network. Generally, a short global separation between organizations and high local clustering define “small world” networks (Watts, 2009). Nevertheless, in our particular network this result should be interpreted cautiously; as previously stated, our network is a bipartite one according to Newman et al’s (2001) definition because the nodes are involved in collaborative projects that *de facto* create a strong cliquishness. If our network exhibits a “small world” effect we may be able to neutralize this natural cliquishness effect (see below).

4.2. Identification of the relevant sub-networks

Figure 3 here

Considering the size and the strong density of the MP+ network, it would be elucidative to extract relevant sub-networks in order to have a better view of the geographical and technological features of the network as a whole.

Figure 3 shows the MP network, i.e. all the geographical outsiders have been removed from the database. Cliquishness is also observable, and the centrality and influence of some nodes have been highlighted. At this stage the apparent density of ties in the local structure reveals the existence of a Midi-Pyrenean GNSS cluster with a particular web of knowledge flows. Obviously, the density of this network (16.45%) is higher than in the MP+ network and the geodesic distance between nodes decreases (2.22). These results are of little significance since all the local ties have been considered, while the ties between “outsiders” have not been taken into account for the MP+ network similarly to Owen-Smith and Powell (2004).

Figure 4 displays the “simplified” MP+ network. In order to avoid this bias in the cliquishness and in the clustering of the MP+ network it is thus more pertinent to consider the methodology employed in the analysis of bipartite networks (Robins, Alexander 2004), which consists of counting the diamonds[vii] instead of the triangles[viii]. In line with this methodology, two or more organizations form a clique if they are connected pair-wise in at least two projects, and all the organizations that exhibit this feature are replaced within a new matrix. The network we obtain now displays cliquishness properties arising from preferential relations in the overall structure than from the collection of projects *per se*. The resulting graph in figure 4 has a noticeably smaller number of organizations (26) and displays interesting structural properties. At first glance, this figure suggests a strong cohesiveness for the local cluster and the beginnings of global pipelines that are concentrated on a small number of local nodes. To be more precise, the density of the network is 20% and the clustering coefficient is 0.818 while the weighted coefficient remains high (0.566). The average geodesic distance is 2.191. All these properties suggest that this simplified MP+ network, which neutralizes the natural cliquishness effect of the former, exhibits a "small world" structure (Watts, 1999) that combines a high level of network cohesiveness with a high level of knowledge accessibility.

Figure 4 here

5. Structure, role and position in the GNSS collaboration network: main results

5.1. Preferential interactions

It may be useful to assess whether or not the network reveals the presence of preferential interactions between organizations sharing similar or complementary knowledge. That is why we have computed the E-I index, which was proposed by Krackhardt and Stern (1988), to measure the group embedding on the basis of a comparison between the numbers of within-group ties and between-group ties. This E-I index is defined by the following formula:

$$-1 \leq E - I \equiv \frac{Nb - Nw}{N} \leq +1$$

Where,

$$Nb = \sum_i N_b^i \text{ and } Nw = \sum_i N_w^i$$

With N_b^i being the number of ties of group *i* members to outsiders and N_w^i the number of ties of group *i* members to other group *i* members, and *N* is the total number of ties in the network. The resulting index ranges from -1, when all ties are internal to the group (homophily assumption), to +1, when all ties are external to the group (heterophily assumption).

Table 4 here

If we restrict our attention to the network of local nodes – the MP Network – we see that organizations from the Midi-Pyrenees GNSS network have a marked preference for composite interactions between different knowledge segments (Table 4) and that this knowledge heterophily is statistically significant. This result confirms the concept of CKP which has been referred to above, in which pieces of knowledge coming from different knowledge environments are combined and managed in a dense network of co-localized organizations. The two knowledge segments which have the highest preference for outward interactions are the infrastructure and hardware segments. The cross-density matrix shows that infrastructure nodes have relations with all the other segments and that the hardware group interacts frequently with the infrastructure group. The CKP is thus a specific one - it is mainly driven by infrastructure firms involved in collaborative projects with firms and labs coming from the hardware, the software or the “applications and services” segments. This confirms the idea that the different partners in GNSS innovative projects are grouped around infrastructure (satellite and telecommunications) firms seeking to foster their technological standards by developing a wide range of applications for these standards. It is thus necessary to interact frequently with geographically close partners in order to bridge the cognitive gap. If we move from the local knowledge relations to the subset of knowledge relations between insiders (MP organizations) and outsiders (non-MP organizations) (table 5), the knowledge heterophily remains[ix], but with a weaker degree, in particular because of the very low level of heterophily that features the relations of the organizations of the infrastructure knowledge segment at the European level[x]. Indeed, if the development of new applications and services requires local knowledge relations that span cognitive domains, these innovations will have more chance to be turned into tradable and mass-market products if the infrastructure platform rests on interoperable and interconnected infrastructures at the European level. The high level of internal relations in the infrastructure segment corresponds thus to the incentives built by the European Commission for the cooperation on standards.

Table 5 here

5.2. Actor similarities and equivalences

In the early stages of technological dynamics such as GNSS the problem is one of defining a standard and finding applications that will ensure its diffusion. This might generate an intense competition between incumbent firms seeking to impose their standards, and geographical proximity might be a problem in this case because of the risk of unintended knowledge spillovers between rival firms. In the Midi-Pyrenees GNSS network we have two strong competitors in the infrastructure segment [Thales Alenia Space (TAS) and EADS Astrium] and in addition there is the French Spatial Agency (CNES) which is also a key player in the domain of satellite building. The way they position themselves in this context of intense competition is an important issue in the efficiency and stability of the GNSS cluster. Do they frequently interact or do they, on the contrary, try to avoid any contact by differentiating their neighborhood as much as possible? To answer this question it is necessary to analyze the cliques or quasi-cliques present in the network. The more organizations belong to the same clique, the more they will display a structural equivalence and the more the flows of knowledge between them will be dense. Obviously, as previously explained, the MP+ Network will display as many cliques as collaborative projects since naturally each project is a clique. This problem can be circumvented if we use the bipartite network in order to reconstruct the simplified MP+ Network. Note that a clique is defined as the biggest group of nodes having all possible ties present within the group. Using the basic cliquishness assessment (Table 6) we obtain 15 cliques.

Table 6 here

The biggest clique, clearly observable in the simplified MP+ Network, is composed of a set of local SMEs that interact frequently. It is worth noticing that TAS appears frequently in cliques composed of local organizations (CNES, TESA, Rockwell Collins, M3 System, Skylab, …) while EADS Astrium has in preference chosen to interact with non local actors (Infoterra, Nottingham sc. Ltd). Here we obtain an answer to our question about the networking strategies chosen by these two rivals; in spite of their geographical proximity they have chosen not to interact with the same pools of actors. TAS has preferred a local interaction strategy while EADS Astrium has chosen an outward-oriented strategy. Nevertheless, it is worth noticing that TAS and EADS Astrium belong to the same clique along with the CNES, the French National Spatial Agency, which is central in the standardization process of GNSS. This situation is typical of the “co-opetition process” observed in many network industries; while companies try to avoid competition and unintended knowledge spillovers by limiting knowledge flows between them as much as possible, they need to cooperate on standardization since the extent of the potential market depends strongly on users’ and consumers’ preferences for standards (Shy, 1999). This “battle of standards” is resolved by research units and public agencies which take on the role of intermediaries in the standard setting process (Katz, Shapiro, 1994).

5.3. Role and position: centrality, efficiency and brokerage

In both geographical and relational dimensions an efficient location is a critical parameter of the modern innovative firm because it is the best way to gain access to new pieces of knowledge and to ensure, at the same time, a good level of knowledge appropriation.

Since the GNSS technological field is a composite one, the choice of relational and geographical localizations is determined by a twofold challenge; there is a need to understand that organizations endowed with different knowledge bases must interact but, at the same time, they need to design their innovations around a common technological standard. This implies that some central organizations will develop a special kind of absorptive capacity allowing them to detect complementary blocks of knowledge and to integrate them. It also means that a GNSS network should be structured in such a way that ensures (i) a good circulation of knowledge between the MP and other places, (ii) a good circulation of knowledge between the different knowledge segments and (iii) a central role for some organizations endowed with a knowledge integration capacity.

- *Centrality and power: which actors influence the knowledge dynamics and where are they located?*

SNA proposes three main methods for understanding an organization's centrality: degree centrality, closeness centrality and betweenness centrality. We compute these centrality indexes with a focus on the twenty most central organizations within the MP+ Network[xi].

Table 7 here

The left side of Table 7 presents the results relating to the closeness centrality index based on path distances, i.e. the index that measures how close an agent is to others in terms of average geodesic distance. The higher the index, the shorter the average geodesic distance from the node to all the other nodes. Here a central agent is one that has knowledge accessibility because this agent is able to reach other agents on shorter path lengths. It is not surprising that TAS displays the greater index of closeness centrality. This influential position is due to the fact that TAS is involved in many collective projects. TESA and the CNES, two research institutes, are also very central, followed by a group of local GNSS SMEs. EADS Astrium, another major worldwide company in the space and satellite industry located in Toulouse, presents a smaller closeness centrality index.

While closeness centrality has allowed us to measure the knowledge accessibility of an actor by the latter's average (geodesic) distance to the knowledge of other actors, degree centrality, in the middle part of the table, gives us another concept of knowledge accessibility which is based on the number of opportunities for access to external knowledge. Indeed, the degree centrality index is just the total of each actor *i*'s number of ties with the other actors. The results are close to the previous ones, but it is worth noting EADS Astrium's climb to seven steps higher in the ranking.

On the right side of Table 7 we compute the betweenness centrality index. In this case the relational influence and the capacity to absorb new knowledge is drawn from the position of a node as an intermediary between the other nodes, allowing this node to be influential by brokering knowledge diffusion between other nodes or by becoming established as a "leading" intermediary. In this vision of influence, TAS keeps its place as "leader", but one can observe the increasing influence of EADS Astrium, its direct local competitor.

Finally, some actors (TAS and the CNES) seek to access external knowledge by shortening the distance to other actors, by multiplying the opportunities of contacts and by positioning themselves as intermediaries. Others (EADS, Actia, France Telecom R&D) seem to have more specific networking strategies focused on the search for betweenness centrality. Moreover, it is worth noting that, whatever the centrality measure is, 20-25% of the top twenty most central organizations is made up of non local nodes, which means that some external organizations are well positioned in the network. By supposing "embedded clusters" rather than clusters *per se*, it becomes possible to show the pathways of knowledge and the organizations that play a central role in these pathways, even if some of them can be located outside the cluster. In our particular case, this result is interesting, because by construction of the relational database, local organizations are more likely to be central than external ones. It shows clearly that the Midi-Pyrenees GNSS cluster is strongly embedded in a wider European network. It is mainly explained by the geography of the space industry, which has for long time developed research collaborations in Europe. It is especially true for the GNSS industry, because research collaborations between organizations coming from different countries are a strategic issue for the European Union, in order to develop its own global navigation satellite system (Galileo) and become independent from the American GPS. Thus it is not surprising that outside organizations display a certain degree of influence in the MP network, due to the European pipelines that support the development of the European infrastructure.

- *Brokerage*

The above results provide an initial view of the position of the organizations in the MP+ Network, but there is no consideration of the particular role these organizations have within the structure. The basic geographical and knowledge attributes of the nodes can help us to understand their so-called "broker" role (Gould, Fernandez, 1989). The different brokering strategies we can analyze are particularly suited to studying the consequences of the trade-off between knowledge accessibility and appropriation. Gould and Fernandez (1989) provide a set of measures for these brokering profiles. Here we will undertake an initial analysis to distinguish the group of local and the group of non local nodes, and a second analysis that differentiates the four technological segments as outlined above. According to the Gould and Fernandez' definitions (1989), nodes exhibit a high "coordination" score when they act as intermediaries for relations between members of their own group. They obtain a high "gatekeeping/representative" score when they allow members of their group to contact members of another group. They obtain a high "consultant" score when they broker relations between the members of the same group but when they themselves are not members of that group. Finally, they exhibit a high "liaison" score when they broker relations between different groups and yet they themselves are not part of any group.

Table 8 here

Table 8 displays a census of the highest (raw and normalized) brokerage scores[xii] concerning the relations between local and non local nodes[xiii]. We can observe that even if logically, the two main worldwide companies, TAS and EADS Astrium, exhibit high gatekeeper scores when the un-normalized measure is used, the normalized measures indicate that they have a stronger preference for "consultant" roles that lead them to broker relations between non local organizations. On the contrary, a group of local innovative SMEs (M3 System, Pole Star, Navocap) seem to play an important coordination role among local organizations in parallel with the public research organization TESA. The spatial research agency CNES exhibits a high level of all types of brokerage because it is involved in many collaborative projects, but it seems to have a slight preference for the gatekeeper role, chiefly because of its historical involvement in the European Space research network.

These results show that it would be irrelevant nowadays to analyze clusters independently of the technological field; firstly, firms embedded in local networks are also involved in larger ones and secondly, non local firms bring knowledge from outside and capture knowledge from inside through gatekeeping strategies. Consequently, even if we have identified a GNSS cluster in the Midi-Pyrenees Region, the aggregate efficiency of this local structure does not only depend on the internal relations, but also on the way the cluster connects itself to larger pipelines through a subset of nodes.

Table 9 brings supplementary information on why the MP+ Network is typical of the current GNSS CKP. Here we use the same Gould and Fernandez indexes, but this time on the GNSS knowledge segment. There is now a "liaison" role since we have more than two groups. We also specify the size of the nodes in terms of number of employees and we indicate whether the agents are local or non local.

Table 9 here

If we firstly focus our attention on the raw (un-normalized) scores we can observe that the biggest organizations belong to the infrastructure segment and that they naturally have high raw brokerage scores. TAS, Telespazio, the CNES and EADS Astrium are big coordinators inside the infrastructure segment, but they also act as intermediaries for many relations between nodes from the different knowledge segments. There is no coordination brokerage in the hardware group, which means that outward relations are the priority for these firms.

If we now focus on the relative (normalized) scores, the first striking result is that all the organizations from the hardware and software segments have a marked preference for "consulting" or "liaison" roles. This means that they prefer to interact with partners from other knowledge segments. Gatekeeping strategies are more frequently chosen (in comparison to random assignments) in the infrastructure segment, so that technological standardization in the GNSS technological field is conducted by organizations from the infrastructure segment rather than from the hardware and software segments. Moreover, we see that CKPs are sustained by the two important research organizations from the MP Network, TESA and the CNES; even though they are members of the infrastructure group, they have a preference for "consultant" and "liaison" roles over gatekeeping. This may be explained by their neutrality in the knowledge appropriation conflict and also by their special absorptive capacity allowing them to manage relations between cognitively distant partners, as clearly demonstrated by Owen Smith and Powell (2004) in their Boston Biotech Cluster.

6. Discussion and concluding remarks

The starting point of this contribution was to consider clusters as particular interaction structures that are embedded in technological fields and different locations. With regard to this we consider that the relations between cluster insiders (the MP Network), and between insiders and those outsiders that have a relation with the former (the MP+ Network), constitute an appropriate boundary. SNA fits particularly well with this kind of empirical study where many interacting organizations, by their relational strategies, give rise to a particular structure. This methodological contribution to cluster empirical identification does not provide a normative approach for the analysis of cluster aggregate efficiency. Nevertheless, this approach leads to an understanding of the complex geographical and technological organization of a particular cluster. From the overall meso-properties of the aggregate structure to the role and position of the organizations in the network, the findings raise both discussion points on cluster theories and a research agenda.

Firstly, our MP+ Network displays a weak geodesic distance and a particular clique structure. In particular, we observe that cliques overlap owing to the position of central organizations that act as bridges between cliques, so that knowledge created in dense cliques can diffuse efficiently into the structure by way of these bridges. If we compare these structural properties to the main typologies of clusters or localized industrial systems (Markusen, 1996; Iammarino, McCann, 2006), it can be noted that our GNSS network, in its “MP” or “MP+” form, traverses different forms of structure. On the one hand, the strong cohesiveness of the structure consisting of the local hardware and software SMEs recalls the structure observed in the “Marshallian districts”, while on the other hand several large companies (TAS, EADS Astrium), public research organizations and agencies (TESA, CNES) exhibit a hub position typical of the one observed in the “hub and spoke districts”. A more systematic quantitative analysis of different clusters in different technological fields will be necessary to confirm this coexistence of different patterns of clustering processes.

Secondly, the methodology, consisting of the construction of a nested system of public funded collective projects, gives some interesting empirical perspectives. In particular, by coupling knowledge and geographical features with structural ones, and by matching local and local/non local relations, it offers an interactions-based approach for the industrial organization of clusters and networks. Indeed, one of the major issues for the organizations working in network industries is the need to set up standards. For GNSS, as for the Internet and telecommunication industries, and in particular when the emergent technologies and services display the economic properties of public utilities (Shy, 1999), their diffusion depends both on the ability of the organizations to reach an agreement on a standard, and on the variety of new applications and services this new technology will potentially engender. When taking this into consideration, the structural properties of our GNSS network seem to confirm the strong position of the MP in the European GNSS technological field. The first stake is observable in the MP+ Network as well as in the simplified MP+ Network. These graphs show, firstly, that the main competitors, EADS Astrium and TAS in the infrastructure segment, are tied directly or by the intermediary of the CNES which plays the role of a standardization agency. Secondly, they show that pipelines have been built between these local organizations and the German (Infoterra Ltd, Nottingham Scientific Ltd mainly) and Italian (Telespazio, GMV mainly) GNSS infrastructure companies. Obviously, this noteworthy structure is based on the strong incentives from the European Commission for cooperation on standards, through the Framework Programs Policies. The second stake is observable in the MP Network. The diffusion of a GNSS standard will depend on its compatibility and convergence with existing systems, such as telecommunication systems (Wi-Fi in particular) and transport systems, and with a large as possible set of software-based applications and services in traditional sectors (tourism, agriculture, transport, security, earth observation, and so on). The knowledge heterophily we have discovered in the quantitative analysis of the MP network is illustrative of this CKP and is organized around a knowledge platform (Cooke, 2006; Antonelli, 2006), where geographical proximity between cognitively distant organizations favors learning processes and research coordination with a limited risk of unintended knowledge spillovers (Boschma, 2005). This platform organization will help the GNSS companies to find new opportunities to impose their standards in the economy, while the other companies can improve their market position by exploring and developing new services in their own sector. The study of the structural properties of clusters is thus a relevant and original way to understand the part played by a location in the industrial organization of a technological field, in particular if we consider that the long term viability of clusters depends on their ability to impose and maintain technological standards (Suire, Vicente, 2009)

Thirdly, a cluster aggregates heterogeneous and complementary knowledge profiles. By knowledge profiles we mean not only the cognitive base and technological segment pertaining to each of the organizations, but also their strategic positioning in knowledge networks. Obviously, the position of each organization depends on their size and market power, but also on their particular broker roles in composite and geographical knowledge dynamics. By indexing these broker roles, we see an interesting possibility for further theoretical and empirical research. Indeed, the literature stresses that the co-location of firms which are cognitively and technologically close can be collectively under efficient (Boschma, 2005; Nooteboom, Woolthuis, 2005). Our results confirm this outcome since the simplified MP+

Network shows that the majority of satellite companies are located in different places. They are connected via pipelines in European projects; the proximity between their knowledge bases facilitates long distance interactions and reduces the risk of unintended knowledge spillovers (Torre, 2008). Nevertheless, we have emphasized the fact that two of the major satellite companies, TAS and EADS Astrium, are located in the same place, so that this theoretical argument suggests that their co-location might be inefficient. Nevertheless, by analyzing the cliquishness properties and broker role, it does not appear to be so obvious. Indeed, they belong to a small number of overlapping cliques and thus differentiate to some extent their neighborhoods and minimize their structural equivalence. Moreover, their broker roles differentiate their geographical strategies, the former having a stronger strategy of local coordination than the latter. Ultimately, this structural complementarity renders their co-location not as risky. This result confirms that the level of knowledge spillovers does not depend only on the geographical proximity between organizations, but also on their intended effort to connect knowledge between them (Breschi, Lissoni, 2001).

Fourthly, our empirical identification of the GNSS technological field in the Midi-Pyrenees demonstrates the particular role and position of public research organizations in the aggregate structure. Our findings confirm the result obtained by Owen-Smith and Powell in their study of the Boston biotech cluster. Since public research organizations (TESA here) or research and standardization agencies (CNES here) do not face the same knowledge accessibility/appropriation trade-off, they position themselves within the structure in a very different way than private organizations. The very significant index of local coordination computed for TESA can be understood as the willingness of this group to connect disconnected local organizations, whatever their knowledge segment, in order to "water down" the whole of the local structure. The geographical gatekeeper role of CNES marks its willingness to impose standards in the technological field by ensuring the knowledge accessibility and flow in the whole of the MP+ Network. Once again, introducing non-structural features to the network nodes – here, the geographical and knowledge attributes – highlights the differentiated and complementary roles organizations develop in the network.

Lastly, firms external to the local GNSS cluster can play a key role in the CKP as well as in the structuring of the local relations. The "outsiders" from our top twenty central organizations and, to a lesser extent, their geographical gatekeeper roles, give a clear illustration of this finding. Since clusters are more or less embedded in technological fields, they cannot be analyzed without a focus on the structure of knowledge flows between the cluster and the technological environment to which it is connected. In consideration of this, the [cluster/cluster+] protocol of data collection initiated by Owen-Smith and Powell (1994) and used in this contribution is a promising methodology for understanding clusters and pipelines structures, and how particular places reach efficiency from their outside connections.

The results we obtained on the structural properties and the role and position of the organizations in the structure, along the lines of the methodological and theoretical framework begun by Ter Wal and Boschma (2009), bring new research perspectives on cluster theories in knowledge-based economies. Obviously these results should be re-assessed in the future through theoretical research on knowledge clusters and aggregate efficiency within networks, as well through more systematic empirical research on various CKPs. Moreover, one of the future issues for further research will be to collect relational data spanning over a longer period in order to highlight, as suggested by Boschma and Frenken (2009) and Suire and Vicente (2009), how clusters grow and decline along the cycles of the technological field.

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Fig.1: the composite knowledge process in GNSS

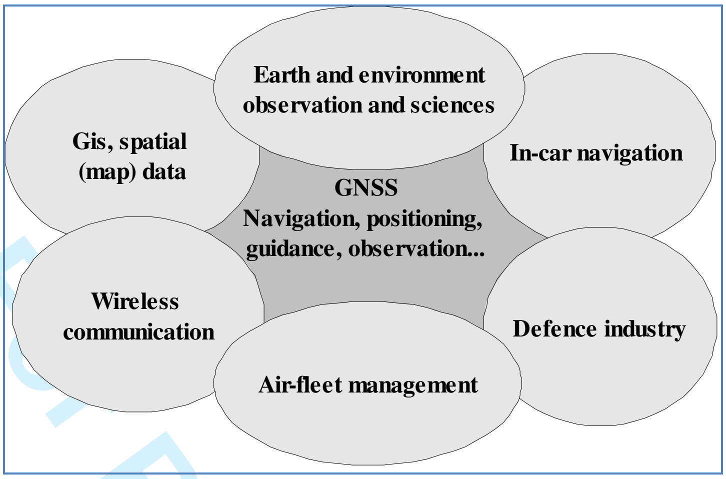


Table 1: GNSS collaborative projects

Project name	Number of partners	Geographic scale
SITEEG	14	MP
SSA-CAPYTOL	9	MP
TRANSCONSTROL	4	MP
TELEMED-AERO	9	MP
TSARS	2	MP
OURSES	9	F
FILONAS SDIS 31	10	MP
Géo Marathon	3	MP
SPSA	3	F
LIAISON	32 (17)	EU
Sinergit	8	F
CityNav	7	MP
WI AERO	3	MP
AIR NET	4	EU
CIVITAS MOBILIS	9	MP
AVANTAGE	4	MP
BINAUR	5	MP
Egnos bus	2	MP
Terranoos	2	MP
TONICité	3	MP
Fil Vert 2006	4	MP
Astro +	21	EU
ACRUSS	4	MP
Geo-urgences	4	MP
CTS-SAT	4	MP
Safespot (WP2)	57 (11)	EU
Harmless	10	EU
M-Trade	10	EU
Agile (WP 4, 5, 6, 7)	18 (13)	EU
GIROADS	13	EU

Collaborative projects		Organizations	
Number of projects	30	Number of organizations	130
Number of organizations by project	7	Number of project by organizations	1.67
Standard error	4.1	Standard error	1.66
Minimum	2	Minimum	1
Maximum	17	Maximum	12

Table 2 : Basic descriptive statistics of collaborative projects and organizations

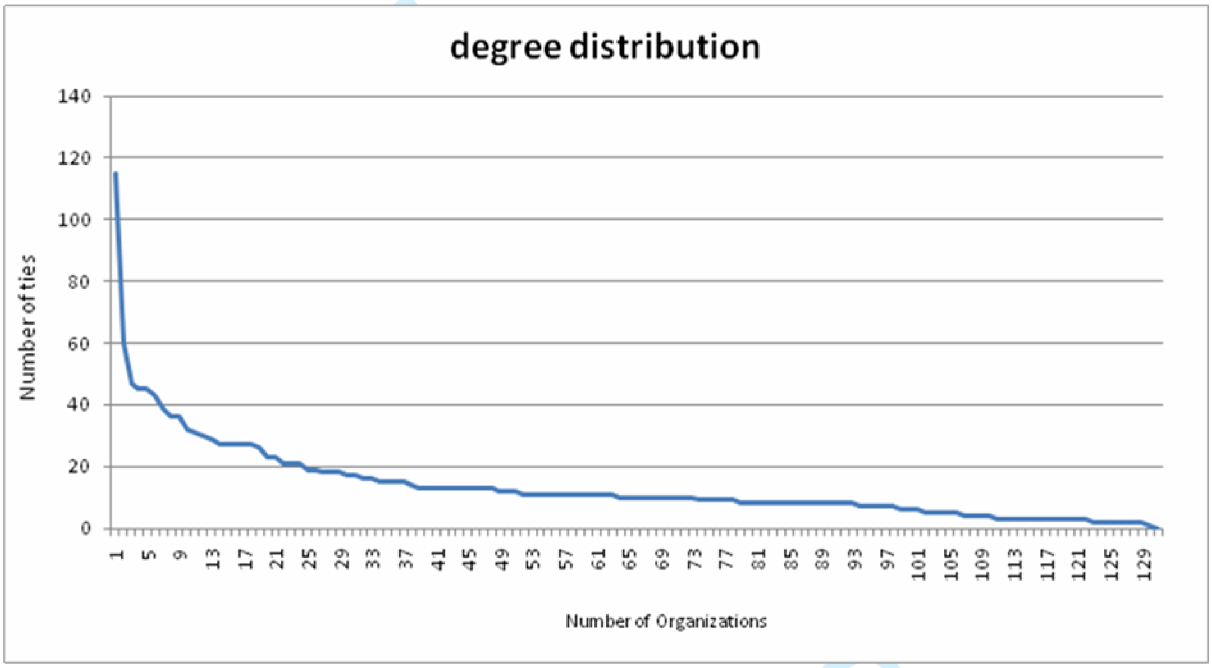


Figure 2: Degree distribution

Descriptive statistics of the MP+ Network	
Number of nodes	130
Number of links (dichotomized)	1584
Internal links	544
Internal-External links	294
External-External links	746
Density (dichotomized)	0.0944
Mean degree	1.135
Minimum degree	1
Maximum degree	115

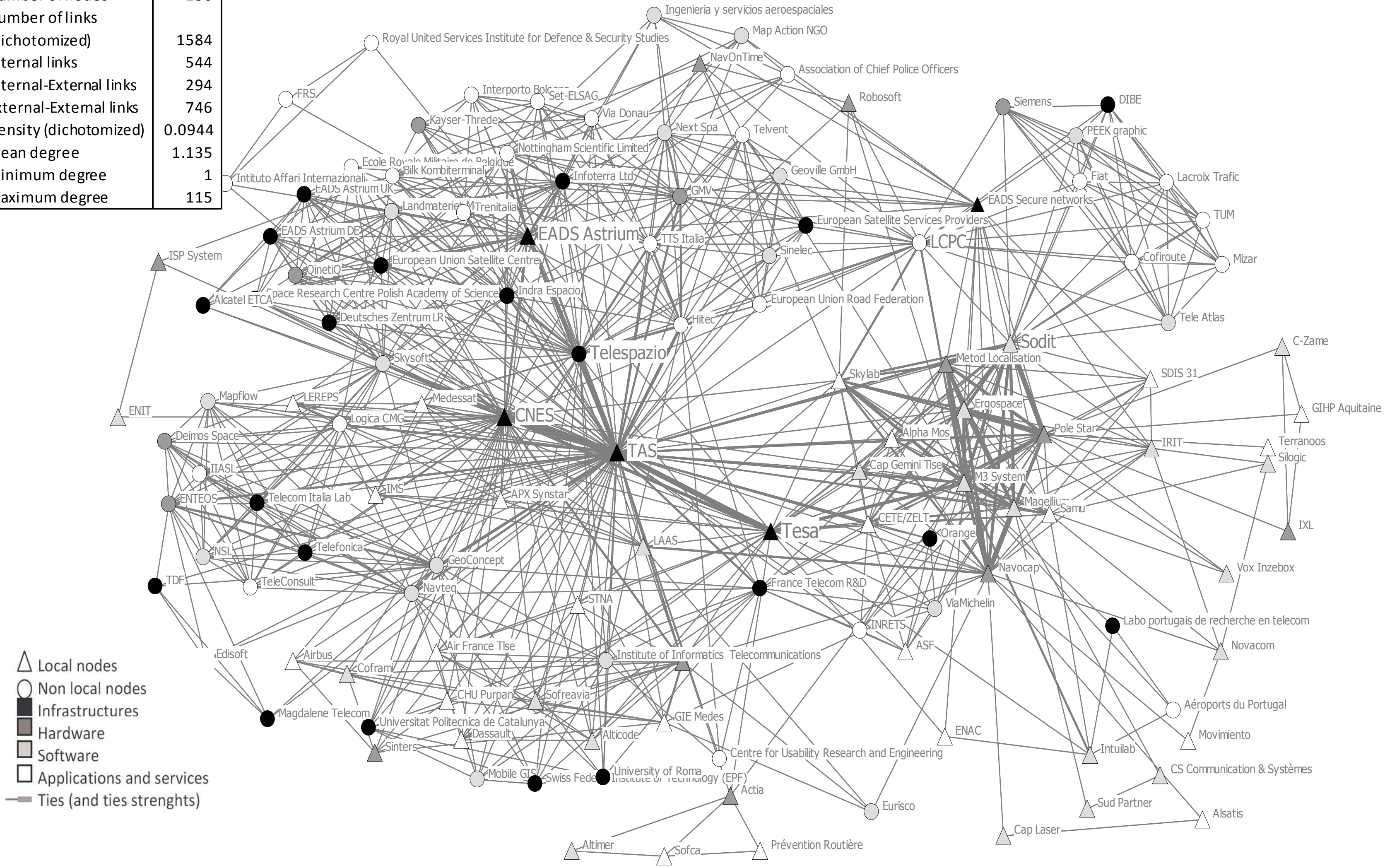
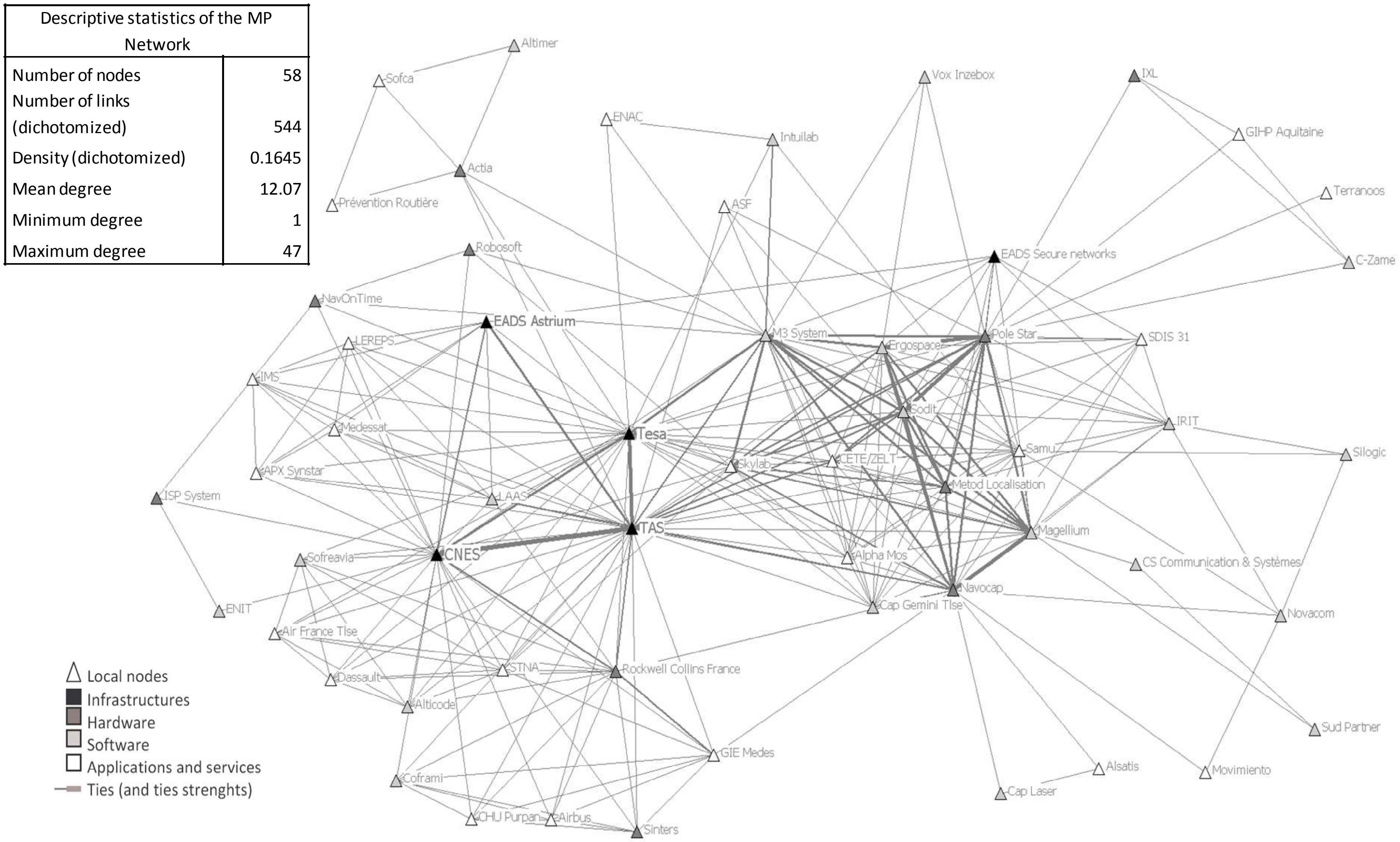
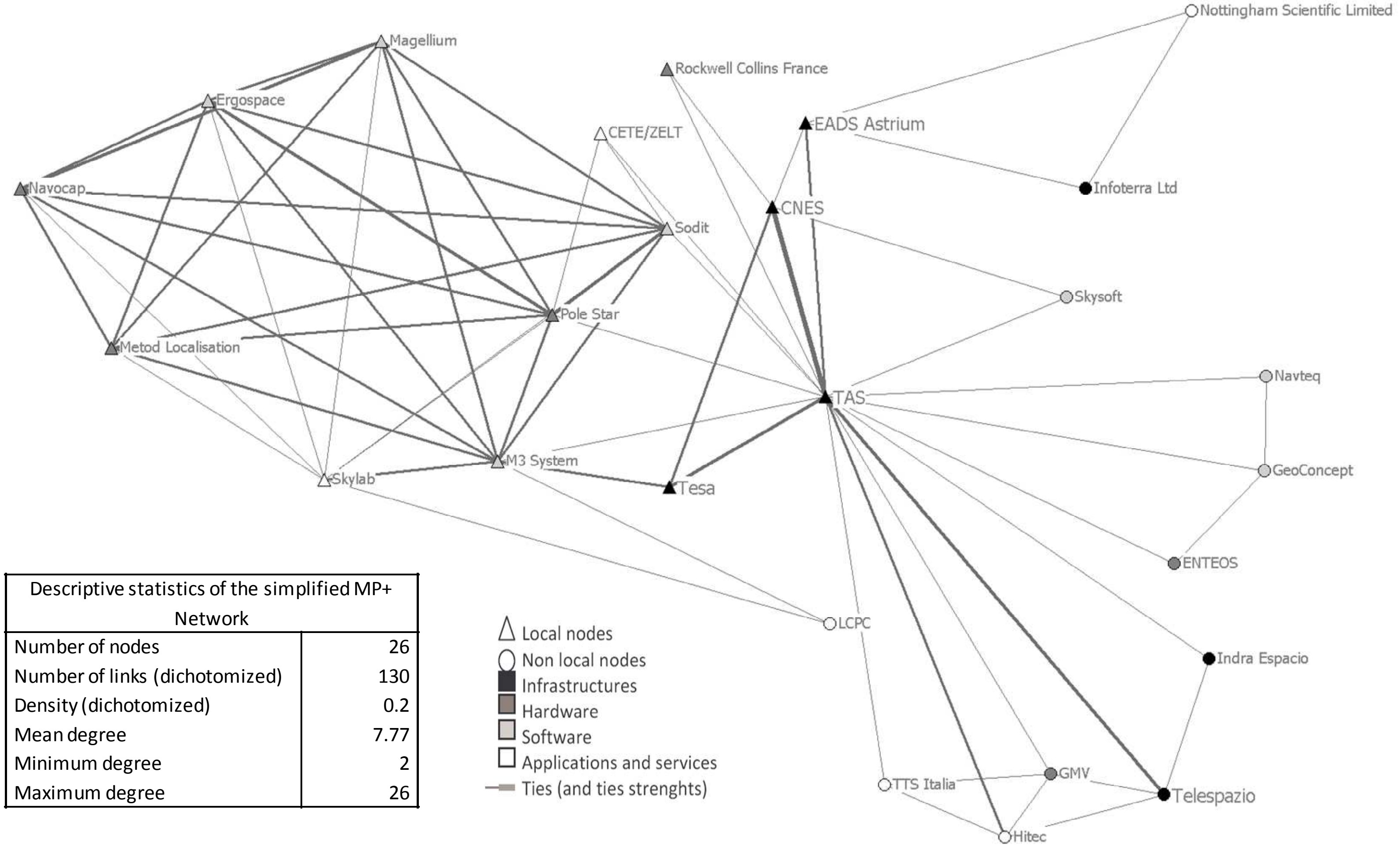


Figure 2: MP+ Network



Descriptive statistics of the MP Network	
Number of nodes	58
Number of links (dichotomized)	544
Density (dichotomized)	0.1645
Mean degree	12.07
Minimum degree	1
Maximum degree	47

Figure 3: MP Network



Descriptive statistics of the simplified MP+ Network	
Number of nodes	26
Number of links (dichotomized)	130
Density (dichotomized)	0.2
Mean degree	7.77
Minimum degree	2
Maximum degree	26

Figure 4:Simplified MP+ Network

Table 4 : E-I Index for groups defined by KS membership
Network of local nodes

	Frequence	Percentage	Possible	Density
Internal…………………………………	122	0.225	996	0.122
External…………………………………..	420	0.775	2310	0.182
E-I……………………………………………	298	0.550	1314	0.397

E-I Index: ………………………………………………	0.550		Infrastructure…..	0.736
Expected value for E-I index:…………………	0.397		Hardware………..	0.692
Re-scaled E-I index: ……………………………..	0.550	**Group level E-I Index :**	Software………….	0.404
Permutation Test :			A. & services……………	0.485
Number of iterations:…………………………….	5000			

		Infrastructure	Hardware	Software	A & services
	Infrastructure	1.900	0.440	0.340	0.383
	Hardware	0.440	0.311	0.310	0.174
density matrix	Software	0.340	0.310	0.195	0.120
	A & services	0.383	0.174	0.120	0.087

	Obs	Min	Avg	Max	SD	P >= Ob	P <= Ob
Internal…………………………………………	0.225	0.196	0.302	0.446	0.031	0.998	0.003
External………………………………………	0.775	0.554	0.698	0.804	0.031	0.003	0.998
E-I……………………………………………….	0.550	0.107	0.397	0.609	0.062	0.003	0.998

E-I Index is significant (p<0.05)

Table 5 : E-I Index for groups defined by KS membership
Network of relations between MP and non MP organizations

	Frequence	Percentage	Possible	Density
Internal………………………………	92	0.313	4746	0.019
External……………………………….	202	0.687	12024	0.017
E-I…………………………………………	110	0.374	7278	0.434

E-I Index: …………………………………………….	0.374		Infrastructure…..	0.019
Expected value for E-I index:………………….	0.434		Hardware………..	1.000
Re-scaled E-I index: …………………………….	0.374	**Group level E-I Index :**	Software………….	0.719
Permutation Test :			A. & services…………….	0.793
Number of iterations:…………………………….	5000			

		Infrastructure	Hardware	Software	A & services
	Infrastructure	0.138	0.036	0.036	0.032
	Hardware	0.036	0.000	0.007	0.004
density matrix	Software	0.036	0.007	0.006	0.007
	A & services	0.032	0.004	0.007	0.003

	Obs	Min	Avg	Max	SD	P >= Ob	P <= Ob
Internal………………………………………	0.313	0.095	0.283	0.483	0.051	0.310	0.736
External………………………………………	0.687	0.517	0.717	0.905	0.051	0.736	0.310
E-I……………………………………………	0.374	0.034	0.434	0.810	0.102	0.736	0.310

E-I Index is hardly significant ($p \cong 0.10$)

1: TAS Tesa CNES
2: TAS Rockwell Collins France CNES
3: TAS CNES EADS Astrium
4: TAS CNES Skysoft
5: TAS Pole Star Sodit CETE/ZELT
6: TAS M3 System Pole Star Sodit
7: TAS M3 System Tesa
8: TAS Hitec Telespazio GMV
9: TAS Hitec GMV TTS Italia
10: TAS Navteq GeoConcept
11: TAS Telespazio Indra Espacio
12: TAS GeoConcept ENTEOS
13: Ergospace M3 System Pole Star Metod Localisation Magellium Navocap Skylab Sodit
14: M3 System Skylab LCPC
15: EADS Astrium Infoterra Ltd Nottingham Scientific Limited

Table 6 : the cliques of the simplified MP+ network

Table 7 : the 20 most central nodes

Normalized Closeness Centrality		Normalized Degree Centrality		Normalized Betweenness Centrality	
	------------		------------		-----------
TAS	75.439	TAS	17.829	TAS	46.129
CNES	58.371	CNES	9.302	CNES	11.778
Tesa	56.332	Sodit	7.287	LCPC	7.402
M3 System	55.128	Telespazio	6.977	Sodit	7.376
Sodit	54.894	M3 System	6.977	Pole Star	7.241
Pole Star	53.750	Pole Star	6.667	M3 System	6.921
Navocap	53.306	Navocap	6.047	Navocap	6.637
Telespazio	53.086	Tesa	5.581	EADS Astrium	4.981
Skylab	52.016	EADS Astrium	5.581	Tesa	4.852
Magellium	52.016	Magellium	4.961	Actia	4.585
Ergospace	51.807	Ergospace	4.806	Magellium	3.289
Metod Localisation	51.600	GMV	4.651	Telespazio	3.240
LCPC	51.600	Metod Localisation	4.496	EADS Secure networks	2.395
CETE/ZELT	51.394	Skylab	4.186	Samu	2.120
Samu	51.190	LCPC	4.186	GMV	1.572
EADS Astrium	50.988	Skysoft	4.186	France Telecom R&D	0.992
GMV	50.588	Indra Espacio	4.186	Skylab	0.792
Alpha Mos	50.391	Hitec	4.186	Nottingham Scientific Limited	0.708
Cap Gemini Tlse	50.391	GeoConcept	4.031	Infoterra Ltd	0.689
Hitec	49.049	Nottingham Scientific Limited	3.566	GeoConcept	0.669
Indra Espacio	48.864	Infoterra Ltd	3.566	Hitec	0.661

Table 8:Egonet analysis		geographical brokerage scores of main brokers					
		un-normalized brokerage			relative (normalized) brokerage		
		Coordinator	Gatekeeper	Consultant	Coordinator	Gatekeeper	Consultant
non local nodes	Nottingham Scientific Ltd	120	20	4	2.893	0.490	0.098
	Skysoft	238	10	0	3.647	0.156	0
	Infoterra Ltd	106	20	4	2.794	0.535	0.107
	Indra Espacio	232	18	0	3.422	0.270	0
	Hitec	214	0	0	3.953	0	0
	Telespazio	850	22	0	3.759	0.099	0
	LCPC	162	72	10	2.027	0.915	0.127
	France Telecom R&D	86	40	0	2.048	0.968	0
	GeoConcept	218	10	0	3.621	0.169	0
	GMV	210	25	0	3.193	0.386	0
local nodes	M3 System	130	26	0	2.824	0.574	0
	Pole Star	130	48	0	2.274	0.853	0
	CNES	340	521	376	0.765	1.190	0.859
	Tesa	468	0	0	3.953	0	0
	TAS	476	1071	1564	0.450	1.028	1.502
	Navocap	156	13	0	3.389	0.287	0
	Sodit	36	108	80	0.429	1.306	0.968
	EADS Astrium	12	135	236	0.092	1.047	1.830

Table 9: Ego-network analysis: knowledge segments brokerage scores of main brokers

Knowledge segments	Nodes (number of employees;L(ocal)/NL(ocal))	un-normalized brokerage				relative brokerage			
		Coord	Gatekeep	Consult	Liaison	Coord	Gatekeep	Consult	Liaison
Infrastructure	TAS (2200,L)	196	781	982	1442	0.537	0.954	1.199	1.060
	Telespazio (1700,NL)	78	218	138	242	1.001	1.245	0.788	0.832
	CNES (1896,L)	42	314	400	688	0.274	0.912	1.162	1.203
	Infoterra Ltd (70,NL)	20	45	16	24	1.529	1.532	0.545	0.492
	Indra Espacio (210,NL)	0	79	46	64	0	1.505	0.877	0.734
	Tesa (25,L)	0	20	154	274	0	0.218	1.681	1.799
	EADS Astrium (1788,L)	44	130	78	136	0.974	1.282	0.769	0.807
	France Telecom R&D (80,NL)	8	37	28	56	0.553	1.138	0.861	1.037
Hard-ware	Pole Star (9,L)	0	14	68	130	0	0.316	1.537	1.768
	Navocap (30,L)	0	11	58	102	0	0.309	1.628	1.722
	GMV (600,NL)	0	13	80	154	0	0.255	1.571	1.820
Software	Skysoft (70,NL)	6	42	52	116	0.267	0.831	1.029	1.382
	GeoConcept (90,NL)	22	50	62	54	1.060	1.073	1.330	0.697
	M3 System (22,L)	6	30	34	82	0.378	0.842	0.954	1.385
	Sodit (8,L)	18	59	94	102	0.622	0.908	1.446	0.944
Applica-tions & services	LCPC (550,NL)	40	77	34	88	1.452	1.244	0.549	0.856
	Nottingham Sc. Ltd (210,NL)	2	18	42	84	0.140	0.561	1.308	1.574
	Hitec (100,NL)	62	56	12	28	3.323	1.336	0.286	0.402

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[i] In the following empirical analysis, the bi-modal network will be used for the study of cliques since it permits avoidance of the over-estimation of cliquishness that can occur when we consider collaborative projects in which many organizations are involved instead of bilateral relations.

[ii] http://www.navigation-satellites-toulouse.com/?lang=en, http://www.aerospace-valley.com/en/

[iii] http://www.galileoju.com/, http://www.gsa.europa.eu/

[iv] We would like to thank one of the referees for this conceptual suggestion

[v] All the collaborative projects are included in this period, even if some of them started before and others finished after this base period.

[vi] The cells C_{ij} are defined as follows:

- $C_{ij}=0$ if i and j do not collaborate in any GNSS project
- $C_{ij}=1$ if i and j collaborate in one GNSS project
- $C_{ij}=n$ if i and j collaborate in n GNSS projects

[vii] A diamond appears when two organizations connected to a project are also connected to another project

[viii] A triangle is a triad which appears each time three organizations participate in the same project, which happens very often in networks of events.

[ix] but with a weaker degree of significance since the p-value of the permutation test is slightly superior to 10%.

[x] We would like to thank the referee who suggested us computing the E-I index for this particular type of knowledge relations, instead of the E-I index for the whole of the network.

[xi] Note that the computation of the centrality indexes for the simplified MP+ Network gives close results that concern the ranking of the more central organizations, and so are not displayed here.

[xii] The scores are normalized since a node endowed with more relations than the others will automatically obtain higher scores for any of the brokerage types. Moreover, depending on the number and size of the attributes group, some types of brokerage will automatically be more frequent than others, even if they are chosen at random. It is thus necessary to compare actual brokerage ties to the expected ones obtained from a random sampling. The normalized brokerage scores are then defined as the ratios of actual scores to expected scores

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[xiii] We only computed the raw and normalized scores of the main brokers who had a total brokerage score of at least 150. This is justified by the fact that random sampling may not converge towards the true distribution of ties when nodes have few ties.