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Getting Into Networks and Clusters:
Evidence on the GNSS composite knowledge process in (and from) Midi-Pyrénées

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GETTING INTO NETWORKS AND CLUSTERS[†]

Evidence on the GNSS composite knowledge process in (and from) Midi-Pyrénées

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Abstract:
This paper aims to contribute to the empirical identification of clusters by proposing methodological issues based on network analysis. We start with the detection of a composite knowledge process rather than a territorial one stricto sensu. *Such a consideration allows us to avoid the overestimation of the role played by geographical proximity between agents, and grasp its ambivalence in knowledge relations. Networks and clusters correspond to the complex aggregation process of bi or n-lateral relations in which agents can play heterogeneous structural roles. Their empirical reconstitution requires thus to gather located relational data, whereas their structural properties analysis requires to compute a set of indexes developed in the field of the social network analysis. Our theoretical considerations are tested in the technological field of GNSS (Global Satellite Navigation Systems). We propose a sample of knowledge relations based on collaborative R&D projects and discuss how this sample is shaped and why we can assume its representativeness. The network we obtain allows us to show how the composite knowledge process gives rise to a structure with a peculiar combination of local and distant relations. Descriptive statistics and structural properties show the influence or the centrality of certain agents in the aggregate structure, and permit to discuss the complementarities between their heterogeneous knowledge profiles. Quantitative results are completed and confirmed by an interpretative discussion based on a run of semi-structured interviews. Concluding remarks provide theoretical feedbacks.*

Key-words: Knowledge, Networks, Economic Geography, Cluster, GNSS
JEL classification: O32, R12

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This paper aims to contribute to the empirical identification of clusters by proposing methodological issues based on network analysis. We start with the detection of a composite knowledge process rather than a territorial one stricto sensu. *Such a consideration allows us to avoid the overestimation of the role played by geographical proximity between agents, and grasp its ambivalence in knowledge relations. Networks and clusters correspond to the complex aggregation process of bi or n-lateral relations in which agents can play heterogeneous structural roles. Their empirical reconstitution requires thus to gather located relational data, whereas their structural properties analysis requires to compute a set of indexes developed in the field of the social network analysis. Our theoretical considerations are tested in the technological field of GNSS (Global Satellite Navigation Systems). We propose a sample of knowledge relations based on collaborative R&D projects and discuss how this sample is shaped and why we can assume its representativeness. The network we obtain allows us to show how the composite knowledge process gives rise to a structure with a peculiar combination of local and distant relations. Descriptive statistics and structural properties show the influence or the centrality of certain agents in the aggregate structure, and permit to discuss the complementarities between their heterogeneous knowledge profiles. Quantitative results are completed and confirmed by an interpretative discussion based on a run of semi-structured interviews. Concluding remarks provide theoretical feedbacks.*

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1. Introduction

Clusters and networks can be viewed as peculiar meso or macro structures coming from the complex aggregation of bi or n-lateral relations between firms or institutions (Powell, Grodal, 2005; Cowan, Jonard, Zimmermann, 2007). In the Economics of Knowledge, clusters and networks are subject to a growing attention due to the increasing observation of collective (or at least interactive) knowledge processes in many technological fields (Cooke, 2002). Several theoretical justifications can be provided to explain this trend. In this paper, we suppose that knowledge networks and clusters come from the complex aggregation of relational strategies between firms (and other institutions) embedded in a composite knowledge processes. Knowledge processes are nowadays composite ones, that is to say that they combine many interacting pieces of knowledge coming from different areas. Firms have thus to combine internal and external knowledge by forming partnerships in order to assure good conditions of accessibility, or to integer their internal knowledge in larger technological systems.

The second significant assumption of this work is that space matters in knowledge interactions. This is not an astounding assumption. Nevertheless, the fact that space matters does not signify that geographical proximity between firms is the *panacea* of their innovative and market performances; or at least that local knowledge relation are exclusive of distant ones. Saying that, we follow an emerging literature which takes with caution the univocally role of geographical proximity in collective knowledge processes (Boschma, 2005), the excessive weight associated to local knowledge spillovers (Breschi, Lissoni, 2001), the local clusters instability or life cycle (Vicente, Suire, 2007; Menzel, Fornahl, 2007), the role of distant knowledge interactions (Bathelt, Malmberg, Maskell, 2004), and the role of gatekeeper (Allen, 1977) firms play at the interface of local and global knowledge networks (Zimmermann, Rychen, 2008; Graf, 2007). If firms combine internal and external knowledge, they combine also local and distant interactions according to a set of critical parameters related to their place in the knowledge value chain, their market geographical scale, and the respective absorptive capabilities of partners.

Network visualization and analysis tools (Borgatti & alii, 2002) are well-suited to identify and study clusters and networks in Regional Science (Giuliani, Bell, 2005; Boschma, Ter Wal, 2007; Graf, 2007), in particular when their structural features are coupled with nonstructural ones (Owen-Smith, Powell, 2004). Indeed, geographical location and technological features of the “players” (the nodes of the aggregate structure) can have an influence on the structural form of the “web” of knowledge flows. This paper aims to contribute to these developments, with a empirical focus on a peculiar composite knowledge process: the GNSS (Global Navigation Satellite Systems) technological field. In preference to the major part of the literature on knowledge networks which reconstructs networks from the aggregation of bi-lateral relations (R&D agreements, joint ventures, patent citations, co-patents, …), we use an emerging sampling methodology consisting to start by collaborative R&D projects, partly public funded or sponsored, and which give a large view of knowledge relations, in particular in emerging technological fields (Autant Bernard & alii, 2007). This data collecting process aiming to identify how a local cluster could be embedded (or not) in global networks, we consider and aggregate only GNSS collaborative R&D projects including “players” from one on the major European region of the GNSS industry: the Midi-Pyrénées Region. Doing that, our empirical network analysis is based on a peculiar GNSS network: the in (and from) Midi-Pyrénées GNSS network.

Section 2 summarizes the main questions on the links between composite knowledge processes and economic geography. We put forward the idea that the overestimation of geographical proximity in knowledge relations can be avoided if one starts with a located composite knowledge process rather than places in a strict sense. Network analysis permits to show how clusters could be embedded in larger networks since their structural features are coupled with geographical and technological ones. Section 3 presents the technological field of GNSS, the relational data sample of the “in (and from)

Midi-Pyrénées (IFM) GNSS network" with the variables (attributes of the nodes) and the routine of knowledge relation selection (the ties between the nodes). Section 4 presents the visualization of the IFM networks and of two relevant sub-networks, in order to have a first look on the structural properties of the cluster and pipeline structures. Section 5 investigates a set of quantitative results concerning some descriptive statistics of the IFM networks and traditional (meso and micro) indexes of networks analysis matched with the geographical and technological features of the network. Section 6 confronts the results to a monographic and more qualitative approach of the IFM GNSS composite process, while the conclusion suggests perspectives and theoretical backgrounds

2. Networks and clusters as the web of composite knowledge processes (CKP)

2.1. Starting from CKP rather than places stricto sensu

Since the development of the Porter' ideas on clusters, several works have stressed the coexistence of different types of clusters (Storper, Harrison, 1991; Markusen, 1996; Iammarino, McCann, 2006). This means that an attentive observation, helped by a collection of monographic works, displays a variety of clusters structural forms and evolutionary pathways, so that it would be illusive to draw an optimal and excludable form of cluster. Nevertheless, some clusters succeed when others decline (Vicente, Suire, 2007), so that this coexistence of structural forms is at least conditional to a set of critical parameters of stability and aggregate performance, such as the historical contingencies, the collective management of intended (and unintended) knowledge spillovers, the technology maturity, the complexity degree of the knowledge value chain, the competitive pressure, or the links between the knowledge generation and the market opportunities. Obviously, the list is not exhaustive and the correlations between these parameters could be strong.

Considering this variety of structural forms of clusters and its critical parameters, we put forward that clusters, as the aggregation of (more or less) interacting organizations in the same place, have to be studied as in a larger network perspective, in order to study local clusters as meso-structures embedded in a technological environment. Places and networks are meso-structures which do not match every time. However, they can intersect when we suppose that they are the "locus" of the dynamics of a peculiar technological field (White & alii, 2004). That is why we suggest to analyze clusters by starting by the composite knowledge process at work in a technological field. The intersection of a place and a knowledge network could thus give rise to a peculiar knowledge. This later is thus particularly well-suited for the analysis of how geography and knowledge play together.

Technological fields are more or less cohesive structures representing composite knowledge processes, 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, firms produce new knowledge mixing internal and external knowledge so that they combine arm length and network relations (Uzzi, 1997) in order to manage both their knowledge appropriability and accessibility conditions. At the meso-economic level, the complex aggregation of these *bi* or *n*-lateral knowledge relations gives rise to a network which is featured by a set of structural properties (Powell, Grodal, 2005), such as density, centrality, structural holes and so on… For instance, if a technological field is featured by a strong weight of arm length relations and a strong competing pressure, the network density will be weak, and if not, organizations which improve their conditions of knowledge accessibility multiplying knowledge partnerships will appear more central than others in the network. Starting from CKP is thus particularly appropriate to break down the idea that knowledge spills only over an "ether". Knowledge spreads through networks and thus from the intended effort of agents to connect fragmented knowledge. Knowledge does not diffuse at random, but through the peculiar structure of the network and the place some peculiar agents occupy in the structure (Breschi, Lissoni, 2001).

2.2. Structural/geographical/technological features of networks and clusters: the related variety assumption

Because the structural features of networks can vary according to the very nature of the composite knowledge process at work in the technological field, it is not surprising that local clusters vary likewise in their structural forms, if we suppose, as we did, that local clusters are embedded in larger knowledge networks. But it is necessary moreover to understand why networks can have a more or less strong local dimension and how this local part 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). Related variety is thus one of the critical parameters of clusters' cohesion and performance (Frenken & alii, 2007; Boschma, Iammarino, 2007). Between high specialization and high diversification – the debate between MAR and Jabobs' externalities in growth theories – knowledge variety is "related" when the fragmented pieces of knowledge can be interconnected around an emerging technological window or standard (Vicente, Suire, 2007). Related variety refers thus to a certain amount of cognitive distance between organizations (Nooteboom, 2000), or at least between their core knowledge activities. Since knowledge spillovers can be intended (the intentional effort to share knowledge) and unintended (through the local labor market for instance), geographical proximity exhibits thus 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 absorption capabilities which can impede the accessibility is reduced by the potentiality of frequent meetings, whereas their different respective core activities moderate the risk of under appropriation. At the opposite, the co-location of firms endowed with close knowledge capabilities, even if they could have a common interest to cooperate (in a risk reduction purpose for instance), can engender unintended knowledge spillovers and a mistrust climate. In this case, as Bathelt, Malmberg, Maskell (2004) showed, pipeline structures are more suited.

How to introduce these questions in the classic structural approach of networks? Following Owen Smith and Powell (2004), we suggest to bridge the gap between geographic and structural approaches of networks bringing technological and knowledge features in the web (i.e the graph) of relations. Such a methodological complement could be appropriate to capture how related variety influences the geography of knowledge relations in a peculiar technological field. Indeed, the introduction of nonstructural dimensions permits to have a more complete view on (i) how the compositeness of the knowledge process affects the structural properties of the network, and (ii) how the knowledge flows in the structure are conditional to the heterogeneous and complementary roles and positions organizations succeed to obtain by their relational strategies.

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

This section summarizes the context, the data and the methodology. Stressing the key role of the Midi-Pyrénées Region in the composite dimension of innovation in the GNSS technological field, we present the relational dataset we use in order to understand this knowledge dynamics. The sample is constructed from an original aggregation of collective R&D projects which is particularly suitable for the study of the structural properties of networks, since an appropriate ties selection routine is constructed. We discuss thus the representativeness of the sample, present the variables and the selection routine of knowledge relations. Finally, we present the methodology of the empirical analysis, based on the identification of the meso structural properties and the key role of the main players of our GNSS network, using the standard UCINET tools (Borgatti & alii, 2002).

3.1. The GNSS technological field: a composite knowledge process in (and from) Midi-Pyrénées

Fig.1 here

GNSS (Global Navigation Satellite Systems) is a standard term for the systems that provide positioning and navigation solutions from signals transmitted from orbiting satellites. In the past decades, these technologies were mainly used and developed in defense industry (missile guidance) and aircraft industry (air fleet management). The knowledge dynamics was cumulative, based on incremental innovations dedicated to the narrow market of the aerospace industry. Nowadays, this technological dynamics presents the characteristics of a composite knowledge process. Indeed (Figure 1), in the technological and symbolic paradigm of mobility (and sustainable development to a lesser extent), GNSS are technologies which find complementarities and integration opportunities in many other technological and socio-economic contexts. GNSS is thus a technological field combining satellite systems, integrated sensors, chipsets, additional infrastructure technologies and some advanced positioning techniques. It thus requires interactions between at least four levels: The infrastructure level, the hardware level, the software level, and all the applications and services segment (see below).

The GNSS field is a world-wide technological field which combines clusters and pipelines, gathers a limited number of firms in the satellite and spatial infrastructure segment, several actors in the hardware and software segment, and a plethora of application-based firms. The Silicon Valley in the US, the Bavarian cluster, the Roma cluster and the Midi-Pyrénées cluster are the main identified endowed with an high density of GNSS firms. In this study, we focus only on the knowledge relations starting from (and inside) Midi-Pyrénées Region, in order to explain how composite knowledge processes combine local and non local relations. The Midi-Pyrénées case is not a random choice for at least one reason. Indeed, The Midi-Pyrenees region concentrates more than 12 000 jobs dedicated to spatial activities and had been recently identified by the French government as the world wide "competitiveness cluster" in aerospace and on-board systems (Zuliani, 2008). Midi Pyrenees is an historical leader in Europe for the design and the realization of space systems, mainly through the structural role played since the 1980s by Matra-Marconi Space Company (now EADS Astrium) and the CNES (National Centre of Spatial Studies) (Dupuy, Gilly, 1999), which has conducted local actors to work on the two major GNSS European programs Egnos and Galileo, defined as priorities in the European Framework Program dedicated to transport. Galileo is a global navigation satellite system, which aims to be an alternative and a complement to the American GPS, providing more precise measurements, better positioning services and, above all, an independent system, able to work even if GPS does not. The first step to Galileo has already been realized, with the European Geostationary Navigation Overlay Service (EGNOS).

3.2. The sample (1): an aggregative method of collaborative knowledge projects

Data for the construction of the knowledge network come from a peculiar matching of several sources, a sequential process of data aggregation, and selection routine of knowledge relations:

- *Data sources*

Firstly, an intensive *deskwork* had permitted to list all the main regional firms involved in the GNSS technological field, from space and ground infrastructures to applications and related services, and from big firms to SMEs and research units. In doing that, we have thereby constructed a sample of 30 collective projects in which these firms are involved (see table 1), which permitted by a "snow-ball effect" to gather other firms which bring complementary pieces of knowledge in the composite knowledge dynamics, inside and outside the region, through these collaborative R&D projects. The arborescence of data aggregation has started by two main sets of sources, regional ones[1] (through the review of websites dedicated to GNSS), and European ones[2], focusing only on projects including "navigation" or "positioning" and Galileo or EGNOS. Once the collaborative projects have been indentified, all the websites of the projects have been visited in order to have a look at their work package organization, in order to remove non relevant knowledge relations (see below). All these projects are partly public funded, at the regional, national and European level. The choice of (partly or not) public funded or labeled collective projects is obviously convenient because information is available for each project. The matching of these sources gives rise to the initial sample of relational data.

Secondly, we have completed this methodology by making *semi-structured interviews* (about 15 interviews of entrepreneurs and policy makers) in order to complete our information on the knowledge dynamics at work, and to have a better understanding of the knowledge value chain of this composite knowledge process. It is important to notice that the original network has not been constructed directly from the interviews, but from the formal aggregation of collective projects identified thanks to the intensive deskwork. Nevertheless, these interviews are crucial and are particularly well-suited for qualitative assessments. Indeed, the results we obtain using network analysis give us a first relevant understanding of the structural properties of the network, and of the heterogeneity and complementarities of "players" concerning their network and knowledge strategies. Nevertheless, such an "quantitative assessment" can exhibit small "shadow zones" in the set of results that an interpretative discussion based on semi-structured interviews can highlight.

[1] http://www.navigation-satellites-toulouse.com/?lang=en, http://www.aerospace-valley.com/en/
[2] http://www.galileoju.com/, http://www.gsa.europa.eu/

Table 1 here

- *Ties selection routine*

Our sample of collaborative R&D gathers projects which differ in size. The latter depends strongly on the geographical scale of the funding, regional and national projects gathering less units than European Projects (from 3 to 14 partners in regional and national projects, from 18 to 57 partners in 4 of the European projects of the sample). The interviews have clearly displayed the necessity not to select all the possible ties between partners in European Projects due to the standard "work package segmentation" of these large-scale projects. The interviews have consequently moved us to set a particular criteria of ties selection in order to avoid the overestimation of distant interactions on local ones. The ties selection routine consists in cleaning up the relational database by removing pair wised relations between partners who are not involved in the same work packages of the whole of the project, and maintaining pair wised relations between the project leader and all the partners. Moreover, when the leader of the project is outside the region, we consider only the work packages in which actors of Midi-Pyrénées are involved. As previously said, interviews have lead us to apply this selection routine over a certain threshold of the number of partners involved in the same projects. If we state this threshold at 15 partners, the ties selection criteria is applied only for European integrated projects.

- *Comments on the sample*

Such a methodology implies comments relating to its limitations and advantages. First, starting from projects is certainly on one side a non exhaustive way to capture the relations between firms. More or less formal bi-lateral relations can be forgotten, but the advantage is that our analysis rests thereby 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 capture relations only through interviews. In particular, the density of relations can be approximated with objectivity by using an index referring to the number of projects in which firms are pair wise involved, rather than a density of relation captured by a "weak, medium, strong" indicator in questionnaires which can be subject to caution due to the heterogeneous perception and subjectivity of interviewed entrepreneurs on what a knowledge relation is. Moreover, our sample pushes aside the partnerships of the defense industry which are difficult to capture. Nevertheless, our sample can be perceived as representative of the knowledge dynamics of GNSS in (and from) Midi-Pyrénées in the period 2005-2008 for at least two reasons. On the one hand, the GNSS are emerging technologies which concern emerging applications dedicated to public utilities such as transport security, environment observation, telecommunications and so on. In that way, as for many emerging technologies, GNSS are among the priorities of policy makers, whatever their geographical scale. On the other hand, considering that public funding or labels are conditional to "calls for tender", the firms and institutions of our sample, and their relations, are the ones who have succeeded to obtain the funding due to their legitimacy and experience in this technological field, and so, due to the experience from past relations.

Secondly, starting from projects is strongly dependent to the geographical scale of the public funding, which can be regional, national, European, and thus implies a funding dependant geographical scale of projects. Nevertheless, this limitation can be transformed into a convenient advantage since all these three scales of funding are present in our sample of projects in the GNSS industry. The aggregation of these projects and their transformation into a unified network structure permit thus to have a representative view of the embeddedness of regional firms into to the European GNSS knowledge dynamics and avoids to over-focus on the regional dimension as in most clusters analysis. .

3.3. the sample (2): spatial attributes and knowledge features

Our sample is consequently composed by 130 nodes and 898 ties between them. In order to complete the findings on the structural properties of the network by the technological and geographical features, we give two sets of attributes at each node of the network.

- *Spatial nodes attributes*

First, each node of the sample is geographically labeled in a very simple binary feature, "inside" or "outside" the Midi-Pyrénées Region. A more complex vector approach could be used if the purpose was to measure the geographical extent of knowledge spillovers. But our purpose does not reach this ambition, and settles for a clear distinction between local and non local knowledge relations, in order to distinguish geographical clustering effects from pipelines effects.

- *Knowledge attributes*

Second, each node of the sample is labeled according to the technological segment of the knowledge value chain. This differentiation of nodes has for goal to enrich the analysis by adding technological features in the geographical organization of the network, and thus highlight the composite dimension of the knowledge process at work. As said before, the interviews of firms and institutions, and the deskwork on projects, have permitted to classify each node according to four technological segments. : (i) The infrastructure level with all the spatial and ground infrastructures. (ii) The hardware level, including all the materials, devices and chipsets which receive, diffuse or improve the satellite signal. (iii) The software level, which concerns all the software applications using navigation and positioning data and Geographical Information Systems (GIS), and (iv) all the applications and services segment, which concerns many heterogeneous agents and socioeconomic activities in which navigation and positioning technologies are introduced.

This attribute-based classification calls further comments: Obviously, it would be more suitable to construct this classification on scientific and technological characteristics such as patent codes, as the literature invites to do (Breschi, Lissoni, 2001), in order to construct a robust index of cognitive distance (Nooteboom, 2000). However, in our case, this task is difficult, and in some extent inappropriate, because we ambition to take into account all the knowledge value chain. Indeed, the patent activities concerns essentially the nodes of the majors of the infrastructures segments and hardware segments of the sample. Software segment and "applications and services" segments do not patent, or in a marginal level. One of the reason is that this knowledge process is in a phase of emergence. Other reasons are specific to each of the two last segments. The nodes of software segment are included in the copyright system, and the nodes of the last segment bring various kinds of practical knowledge and specific professional expertise which are not patented.

Our classification is thus based both on the role each node plays in the collaborative projects and the standard classification of network industries (Shy, 1999). This classification is useful in the sense that it permits to have a clear distinction between the knowledge capabilities developed in each segment, at least for the three first classes. It permits moreover to display the so-called "related variety" (Boschma, Iammarino, 2007) of the knowledge process, and embraces all the analytic, synthetic, symbolic dimensions of the knowledge value chain (Asheim, Gertler, 2005).

All these attributes are summarized and crossed in the following table (Table 2), including the distinction between firms and public research and standardization institution

Table 2 here

3.4. Empirical methodology

We use UCINET 6 (Borgatti & alii, 2002) and Netdraw visualization tools in order to draw and study our network and its structural properties. We proceed in three steps. First, the weighted relations matrix[3] is used to draw the network including geographical and knowledge attributes. From this matrix, we draw two other matrixes, the dichotomized matrix and the matrix of relations between local

[3] 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

nodes. Second, we present a set of quantitative results concerning descriptive statistics and all the relevant and interpretable meso properties of the network and ego-network properties. These characteristics describe mainly the cohesion and accessibility of the network, and the centrality, efficiency and brokerage of its nodes. Third, we complete these results with an interpretative discussion based on interviews.

4. The visualisation of the GNSS network

The image of the "in and from Midi-Pyrénées GNSS (IFM) network" (Figure 2) permits to have a first highlight on its structural properties, while figure 3 et 4 focus on two distinctive zooms, the Midi-Pyrénées GNSS cluster 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 pair-wised connected, and (ii) the four segments of the GNNS value chain, from the infrastructure segment (black) to the applications and services segment (white).

4.1. In (and from) Midi-Pyrénées GNSS network

Figure 2 here

The IFM network (figure 2) represents all the nodes and ties resulting from the aggregation of all the collaborative R&D projects of our sample. Obviously, this network appears as a denser web of ties than other networks studied in the literature, which consider only the aggregation of bi-lateral relations. At first glance, the IFM network exhibits interesting meso economic properties, such as density hierarchy, cliques and core-periphery structures, but also visible key actors which seem to have a strong influence in the GNSS knowledge process. These general observations will be improved by formal and interpretative network analysis in the following sections, with a peculiar attention to the coupling between the traditional structural features of networks and the geographical and technological features of our sample.

4.2. identification of the relevant sub-networks

Figure 3 here

Before doing that, and considering the size and the strong density of the IFM network, it would be clarifying to extract relevant sub-networks in order to have a better view of the geographical features of the IFM network.

Figure 3 shows the Midi-Pyrénées GNSS cluster, i.e when all the geographical outsiders are removed from the sample. Density hierarchy, cliqueness and core-periphery structure are as well observable in this sub-network, and the centrality and the influence of some nodes are highlighted.. Once again, these observations have to be improved by formal results, in order to study with more precision the role of these key actors in the knowledge process. But at this stage, the apparent density of ties in the local structure reveals the existence of a Midi-Pyrenean GNSS cluster, with a peculiar structural form and thus a peculiar web of knowledge flows.

Figure 4 displays the "cluster-pipelines" structure of the IFM network by removing ties between nodes which are only once connected and focusing on the main components. At first glance, this figure suggests a strong cohesion of the local cluster and the starts of global pipelines, which permit the accessibility, are concentrated on few local nodes. Notice that insiders are on the right and outsiders on the left of the figure, and all the segments of the GNSS value chain are present in this sub-network[4].

Figure 4 here

5. Results

5.1. Meso properties of the network

The IFM GNSS network we observe is characterized by a rather low density of 10.7 percent: 898 undirected ties are activated out of the 8385 (=130×129/2) non reflexive and undirected possible ties. When we focus on the local network of nodes located in Midi-Pyrénées, the density is much higher (21.1 percent), which suggest that local/local relations are more frequent than local/non local[5]. This network is also highly clusterized since its unweighted clustering coefficient is 0.844 while the weighted coefficient remains high (0.490). Neighborhoods are thus markedly denser than the global network. Moreover, the average geodesic distance in the full network is 2.39, and it is 2.22 on the local network. Thus, this network is globally sparse but highly clusterized and with a low average geodesic distance. Watts (1999) showed that short global separation and high local clustering define "small world" networks. Nevertheless, our network is a bipartite one in the sense of Newman et al. (2001) because the nodes are associated in teams defined by the collaborative projects we observed. Newman et al. showed that these kinds of networks have a special property: all members on the same team (project) form a fully linked clique. It implies that the observation of a high clustering coefficient and a low average geodesic distance in our network must be interpreted cautiously: it is created partly because the nodes share membership in project groups and because some nodes belong to several

[4] The weak interrelatedness of outsiders is not significant and is due to our sample construction which focuses only on projects including insiders.
[5] "non local/non local" relations are not relevant due to the sample construction

projects. Since the small world issue is not the core of the paper, we do not implement here the methodology proposed by Newman and al. to correct these artifacts. All we can conclude here is that knowledge might circulate quickly in this network because it is highly clusterized and with short average path length, even if these 'small world' properties are mainly the result of collaborative project membership.

- *Preferential interactions*

Since we want to understand the respective roles of proximity and distant knowledge interactions, it may be useful to assess whether the meso-structure of our GNSS network reveals the presence of preferential interactions between nearby partners as well as favored meetings between actors sharing common knowledge. That is why we compute 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:

$$-1 \leq E\text{-}I \equiv \frac{N_b - N_w}{N} \leq +1$$

Where :

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

With N_b^i 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 of the network.

We compute this index for two definitions of group membership. The first one is the distinction between local nodes (from the Midi-Pyrénées region) and non local ones. The resulting figures are displayed below. In table 3 we can see that the E-I index is -0.628, which results from the fact that group-internal ties are much more numerous than group-external ties. Furthermore, this E-I index based on the observed distribution of ties is clearly different from the one which is obtained using the maximum number of possible internal and external ties (-0.004). Once the E-I index has been computed it is necessary to assess whether it is significantly different from what would be expected by random choice of their ties by group members. This is done performing the Ucinet permutation test which compares the actual distribution of ties within and between groups to a sampling distribution where they are randomly distributed. The permutation test confirms that this difference is not random since 100% of the E-I indexes obtained after random permutations are bigger than the observed one. We can thus conclude that, in our observed network, there is a clear preference for within geographical group interactions (local/local and non local/non local) and that this deviation from randomness is significant. This result supports the idea that geographical proximity facilitates contacts and knowledge relations, which imply that the GNSS network is not a random structure but rather a cohesive one typical of knowledge clusters. Nevertheless, we will also show below that despite this characteristic, some organizations perform brokerage networking between distant ones.

Table 3 here

The second category of within/between group interactions we want to study concerns the technological layers and their related knowledge, that we label the KS (Knowledge Segment). We have distinguished four technological segments: infrastructure, hardware, software and applications/services. These groups of activities are characterized by common pieces of knowledge, common know-how and common technologies but, if there is a composite knowledge dynamic, we should observe interactions between these different technological layers. If we examine the E-I index of the whole GNSS network we have constructed, this is not really obvious. Indeed, the observed E-I index is 0.413 which suggests that there are more ties between KS groups than within KS groups. Nevertheless, this figure is not significantly different from the average E-I index that would be obtained from random draws (0.434), meaning that the observed preference for interactions with other KS groups is simply due to the number of groups and the density of the network.

Nevertheless, if we now restrict our attention to the network of local nodes[6], we see that organizations and firms from the Midi-Pyrénées GNSS network have a marked preference for composite interactions between different segments of the knowledge value chain (Table 4) and that this heterophily is statistically significant. This result confirms the idea which has been stressed in section 2.2: related variety implies a certain amount of cognitive distance which is more easily managed in a dense network of co-localized organizations. The two techno-sectoral layers which have the highest preference for outward interactions are the infrastructure and hardware ones. Cross tables on these KS interactions (not displayed here) show that infrastructure nodes have relations with all the other layers and that the hardware group is frequently interacting with the infrastructure group. The composite knowledge dynamic is thus a particular one in the Midi-Pyrénées GNSS sector: it is mainly driven by infrastructure firms involving themselves in collaborative projects with firms and labs coming either from the hardware, the sofware or the applications & services group. This confirms the idea of a GNSS cluster based on related variety: the different partners in GNSS innovative projects are gathered 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 nearby partners in order to fill the cognitive gap.

[6] We should bear in mind that the local network is more since it is exhaustive

Table 4 here

- *Similarities and equivalences of actors*

In the early stage of a technological dynamic such as the GNSS one, the problem is to stabilize the infrastructures' standards and to find applications that will ensure the diffusion of the standard. 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-Pyrénées GNSS network, we have two strong competitors in the infrastructure sector (Thales Alenia Space and EADS Astrium) and there is also a public national research agency (CNES) which is a key player as well in the domain of satellite building. The way they position themselves in this context of intense competition is an important question for the efficiency and stability of the GNSS cluster. Do they frequently interact or do they, on the contrary, try to avoid any contact? To answer this question, it is necessary to analyze the cliques or quasi-cliques present in the network and to observe the way these key organizations position themselves in the different cliques.

A clique is defined as a biggest ensemble of nodes having all possible ties present among themselves. It is also possible to define N-cliques, N-clans and K-plexes, which are all clique-like measures of the density of relations inside some groups of nodes using less restrictive definitions of the clique membership. We have implemented all these measures on our GNSS network and they give very convergent results. That is why we only display here the most restrictive one, that is to say the census of the cliques present in our GNSS network (Table 5). If we set the minimum size of the clique to four, there are 50 cliques in our network, some of them containing up to 15 fully connected actors.

Table 5 here

To assess the frequency of interactions of the different nodes, we used the clique overlap matrix which counts the number of times that pairs of nodes are present in the same cliques. In table 5, we present the five groups of nodes who are co-members of at list 3 cliques. We see that the most frequently co-cliqued actors are Thales Alenia Space (TAS) and the CNES, which appear together in 14 cliques. This means that the different completely connected networks they belong are the same 14 times. Moreover, it is worth noticing that TAS appears frequently in cliques made of local actors (CNES, TESA, Rockwell Collins, M3 System and Skylab) while EADS Astrium has obviously chosen to interact rather with non local actors (Infoterra, Nottingham sc. Ltd , etc.). We get there an answer to our question about the networking strategies chosen by these two rivals: in spite of their geographical proximity, they chose not to interact with the same pools of actors. TAS has preferred a local interaction strategy while EADS Astrium, probably because of its strong linkages with the German GNSS cluster, has chosen an outward-oriented strategy.

5.2. Centrality, efficiency and brokerage

Both in the 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, that knowledge spillovers are coming in rather than coming out.

Since the GNSS technological context is characterized by related variety (see section 2), the choice of relational and geographical localizations is determined by a twofold challenge: there is a need for variety meaning that actors endowed with different sorts of knowledge must interact but, at the same time, these actors need to design their innovations around a common technological window or standard. This implies that some central actors will develop a special kind of absorptive capacity allowing them to detect complementary bricks of knowledge and to integrate them in the common technological standard. It also means that the GNSS network should be structured in a way that ensures (i) a good circulation of knowledge between Midi-Pyrénées and the other key regions of the GNSS sector; (ii) a good circulation of knowledge between the different KS of the GNSS sector (Infrastructure, hardware, software, applications and services); (iii) a central role for some actors endowed with a knowledge integration capacity.

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

Many empirical analyses of clusters stressed the role some central firms play in local knowledge dynamics. Good examples are the structuring role of Hewlett-Packard in the Silicon Valley (Saxenian, 1994), the existence of hubs in technological districts (Markusen, 1996), or the role played by "fashion leaders" in clusters (Vicente, Suire, 2007).

Network analysis proposes three main methods to capture the centrality of nodes in an aggregate network structure: degree centrality, closeness centrality and betweenness centrality. For the sake of clarity, we only present for each method the twenty most central nodes of our GNSS network.

The left part of Table 6 presents the results concerning the closeness centrality index based on path distances, that is to say the index that measures how close an agent is to others in terms of average geodesic distance. The higher is the index, the shorter is the average geodesic distance of the node to all the other nodes. A central agent here is a one who has knowledge accessibility because he is able to reach other agents at shorter path lengths. Without any surprise, TAS (Thales Alenia Space) displays the stronger index of closeness centrality. This influential position is due to the fact that TAS is involved in many collective projects of the sample. Tesa and the CNES, two research institutes, are also very central, followed by a set of GNSS SMEs located in Toulouse. Another major world-wide company of the space and satellite industry located in Toulouse, EADS Astrium, presents a weaker closeness centrality index.

In the middle part of Table 6, the figures concern the degree centrality index (normalized). While closeness centrality allowed us to measure the knowledge accessibility of an actor by his average (geodesic) distance to other actors' knowledge, degree centrality gives us another concept of knowledge accessibility based on the number of opportunities of access to external knowledge. Indeed, the degree centrality index is just a count of each actor *i*'s number of ties with the other actors. The results are close to the previous ones for the most central actors but it is worth signaling the rising of EADS Astrium which is now seven steps higher in the ranking.

Table 6 here

In the last part of Table 6, 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 him to be influential by broking knowledge diffusion between other nodes or by establishing himself as a "leading" intermediary of the composite knowledge process. In this vision of influence and centrality, TAS keeps its "leader" place but one can observe the increasing influence of its direct local competitor, EADS Astrium, compared to the closeness and degree approaches.

Finally, some actors (TAS and the CNES) seek to access external knowledge both 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 noticing that, whatever the centrality measure is, 20-25% of the top twenty most central actors is made up of non local nodes, which means that some external organizations are well positioned in the IFM GNSS network.

Nonetheless, it is difficult to evaluate these strategies without an indicator of their efficiency: what is the return of the relational investment in terms of power, control and access to knowledge? Burt's concept of structural hole (Burt, 1992) is particularly useful to tackle this problem. A structural hole is a missing tie in a triad giving more power to one of the considered ties because the others are constrained to go through the central node to stay in contact. In big networks, they are many missing ties and the uneven repartition of these holes gives power to some actors while it raises constraints for some others. One method for capturing structural holes of an ego network consists in counting the number of redundant ties. If A is linked to B and C and B is linked to C, then the direct tie between A and C is redundant since A can go through B to get in contact with C. The more an ego has redundant ties, the less he benefits from structural holes, and the less is networking strategy is efficient since he invests a lot in relationships while he could obtain the same effective network (but with longer geodesic distance nonetheless) with a smaller amount of relational investment. Table 7 gives a ranking of the most powerful GNSS actors in terms of these criteria of network efficiency.

Table 7 here

The effective size of an ego's network is the number of alters he has, minus the average number of ties that each alter has to other alters. The efficiency indicator is the ratio of the effective size to the actual size of ego's network. It consequently measures the return on relational investment. The most efficient nodes are roughly the same as the most central ones identified in table 7. To some extent, it confirms the rationality of network positioning strategies: when a firm invests a lot in relational effort, it also seeks to render this investment as efficient as possible and the choice of ties is strictly controlled to avoid random connections. Nevertheless it is worth underpinning that some firms are more efficient than there are central (EADS Astrium and France Telecom R&D for example) and, furthermore, that some firms that did not score in the top twenties for the centrality indexes now appear in the top twenties in terms of efficiency of their ego network (ISP System, Intuilab, Rockwell Collins France, Novacom and Sofca). These firms clearly prefer to avoid redundant ties that would imply a loss of their control over the flow of circulating knowledge.

- *Brokerage*

The above results have given a first view on the agents playing a critical role in the composite knowledge process of the Midi-Pyrénées GNSS network, but without any consideration for the nodes' attributes. Nevertheless, the basic spatial and knowledge attributes of the nodes can help us to understand the so-called "broker" role some agents play in the network. The different brokering strategies we can analyze (Coordination, Gatekeeping, Consultance and Liaison) are particularly well suited to study the consequences of the trade-off between knowledge accessibility and appropriation. Firms or research units develop strategies of network embeddedness in accordance with their knowledge management strategies. These strategic choices depend on several factors: 1) their place in the knowledge value chain; 2) the main segment in which they operate; 3) their location and 4) their absorptive capabilities. All of these critical parameters determine the way agents position themselves in networks in order to increase their accessibility to external knowledge while maintaining at the same time proper conditions of internal knowledge appropriation. These knowledge management strategies can be captured by identifying the agents' brokerage strategies. Gould and Fernandez (1989) provided a set of measures of these brokering profiles. To implement these measures, a first step is to group agents according to their attributes. Here we will implement a first analysis distinguishing the group of local and the group of non local nodes and a second analysis differentiating the four KS groups already introduced above. According to the definitions of Gould and Fernandez (1989), nodes exhibit a high "coordination" score when they intermediate relations between members of their own group. They obtain a high "gatekeeping/representative" score when they allow members of their group to get in contact with members of another group. They obtain a high "consultant" score when they broker relations between the members of a same group but are not themselves members of that group. And finally, they exhibit a high "liaison" score when they broker relations between different groups and are not part of any of them. The scores can be weighted to account for the fact that a given brokerage role may be played by several actors. In this case, two nodes gatekeeping the relation between A and B would not receive a gatekeeping score of 1 but of ½. Nevertheless, this weighting is not relevant when one desires to compare the brokerage scores of egos because it gives too much weight to actors that do not broker a lot of relations but are the sole to broker these relations. That is why we chose not to weight the brokerage scores. Nevertheless we had to do another type of bias correction: the normalization of the scores. Indeed, 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[7].

Table 8 here

Table 8 displays a census of the highest (raw and normalized) brokerage scores concerning the relations between local and non local nodes. We can observe that even if the two main worldwide companies TAS and EADS Astrium exhibit logically high gatekeeper scores when the un-normalized measure is used, the normalized measures indicate that they have a stronger preference for "consultant" roles leading them to broker relations between non local organizations. On the contrary, a group of innovative SMEs (M3 System, Pole Star, Navocap) seem to play an important coordination role among local organizations, in parallel to the small local research center TESA. The important

[7] We only computed the raw and normalized scores of the main brokers having a total brokerage score of at list 150. This is justified by the fact that random sampling may not converge towards the true distribution of ties when the node has too few of them.

space research unit "CNES" exhibits a high level of any type of brokerage because it is involved in many collaborative projects, but it seems to prefer slightly the gatekeeper role, chiefly because of its historical involvement in the Space European research network.

These results clearly show that it would be irrelevant nowadays to analyze clusters independently of the technological and organizational environment, for at least two main reasons. Firstly, firms embedded in local networks are also involved in larger ones: knowledge flows rely on these two connected dimensions. Secondly, non local firms bring knowledge from outside and capture knowledge from inside, using "gatekeepers" to do so, but they also exchange knowledge between themselves thanks to local "consultants". Consequently, even if we have identified a GNSS cluster in the Midi-Pyrénées Region, the aggregate efficiency of this local structure does not depend only on the internal relations, but also on the way the cluster connects itself through a subset of nodes to geographically larger pipelines.

Table 9 brings supplementary information on why the singular cluster-pipeline structure is typical of the current GNSS composite knowledge dynamics. We use here the same Gould and Fernandez indexes, but this time on groupings defined by the KS membership. There is now a "liaison" role since we have more than two groups. We also precise the size of the nodes in terms of number of employees and we indicate whether the agents are local or non local ones.

Table 9 here

If we firstly focus our attention on the raw (un-normalized) scores, we can observe that the biggest actors belong to the infrastructure layer and that they naturally have high raw brokerage scores. TAS, Telespazio, the CNES and EADS Astrium are big coordinators inside the infrastructure layer, but they also intermediate many relations between nodes belonging to the different technological layers of the GNSS industry. There is no coordination brokerage in the hardware group, which means that outward relations are the priority for these firms. It is also interesting to notice that the main brokers of the applications & services layer are non local firms.

If we now focus on the relative (normalized) scores, a first striking result is that all the actors from the hardware and software segments have a marked preference for 'consulting' or 'liaison' roles. This means that they prefer to work with partners from other KS and this is easy to understand if we bear in mind the related variety and composite knowledge argument. Gatekeeping strategies are more frequently chosen (in comparison to a random assignment) in the infrastructure segment, which confirms that the GNSS technological dynamic is oriented towards related variety: to build up the technological standard requires coordination between infrastructure firms in projects which are also involving innovators from the hardware, software and applications segments. We can thus conclude that the technological standardization in the GNSS industry is conducted by firms and labs from the infrastructure segment rather than from the hardware and software segments[8]. Moreover, we see that the composite knowledge dynamic is sustained by the two important research centers of the Midi-Pyrénées GNSS cluster, 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 displayed by Owen Smith and Powell (2004) in their Boston Biotech Cluster.

6. Interpretative discussion

The previous part furnishes as representative a view as possible both on the structural properties and the strategic knowledge profiles of central organizations of our in (and from) Midi-Pyrénées GNSS cluster. This section aims to complete this empirical methodology by explaining some coordination mechanisms at work in the morphogenesis of the network (Cohendet, Kirman and Zimmermann 2003), and by highlighting by a qualitative assessment some oF the main results of the previous quantitative analysis. Semi-structured interviews are thus particularly well-suited for that purpose, since they permit to capture peculiar aspects of knowledge relations which are not directly apparent in the R&D projects sample. This qualitative approach brings supplementary explanations of the structure of the Midi-Pyrénées GNSS cluster, but moreover allows to understand why the pipelines of the cluster are directed towards certain countries or clusters rather than others. Furthermore, interviews highlight the fact that research units are at the heart of the composite knowledge process, by ensuring the fluidness of knowledge flows and exchanges. Finally, it also reveals the reasons of the existence of a clique of SMEs, and the way these latter manage the risk of local knowledge spillovers, but also the reasons why TAS is a geographical gatekeeper while EADS is an external star.

6.1. The structure of the Midi-Pyrénées GNSS cluster

The previous results on relation densities have clearly displayed the existence of the Midi-Pyrénées GNSS cluster. The cluster is made up of the two European majors firms of the satellite construction, EADS Astrium and Thales Alenia Space. EADS Astrium is a unit of the European group of *EADS*, a worldwide leader in aerospace, defence and related services, including for example the aircraft manufacturer Airbus and the world's largest helicopter manufacturer, Eurocopter (Dupuy, Gilly, 1999). Thales Alenia Space is the European leader of satellite manufacturing and a major player in the field of

[8] TAS seems to be a weaker gatekeeper than EADS Astrium but this observation must be moderated since Telespazio, a TAS subsidiary, has a marked gatekeeping strategy.

orbital infrastructure. TAS was born in 2006 when Thales (ex Thomson) acquired Alcatel Alenia Space, and is held by Thales for the two-thirds and by the Italian company Finmeccanica for one-third. These two companies are competing ones and are cognitively close in their core knowledge activities. The French spatial agencies (CNES) and a collaborative research unit (Tesa), are the two key players of research in the cluster, connecting university, engineering schools, institutions and firms. Finally, we can observe a clique of eight local SMEs, recently born, which develop GNSS applications and are organized around complementary competencies.

In order to realize an efficient knowledge matching, firms must have access to information about the other sources of knowledge, firm's strategies or the projects they are engaged on. This kind of information seems to flow easily between organizations thanks to the efficiency of the Toulousian social network. The service manager of EADS said: *"it's very easy to make R&D cooperation in Toulouse, everyone knows everyone"*. This local social network is composed of formal or informal meetings, animated by some "networks men" we have identified. Exhibition and business meetings are usually organized by local development agencies (Midi Pyrénées Expansion), the agglomeration community (Grand Toulouse[9]), or policy makers of the regional council (Région Midi Pyrénées). Conferences are more under the initiative of research centers (CNES, Tesa)[10]. Moreover, informal meetings are also an important part of the Toulousian social network, and a relevant source of information flows where firms signal their knowledge bases and the external knowledge sources they are looking for. The efficiency of these common informal meetings can be found in the professional background of the GNSS actors. A large part of them have had previous experience in GNSS toulousian large companies like Thales, Alcatel, Matra, Astrium, or the CNES and are coming from the same engineering schools, which is very helpful for the building of lasting professional relations, as shown by Grossetti (2005) and Zuliani (2008).

6.2. The pipelines

Even if we can notice a stronger density of interactions between local organizations, the cluster is also opened on its technological worldwide environment, through the building of global pipelines (Maskell et alii 2004). These pipelines are directed to many other European organizations, located in France (Navteq), Spain (GMV), Portugal (Edisoft), Italy (Telespazio), UK (Nottingham scientific limited) and Germany (EADS Astrium Gmbh, *Deutsche Zentrum* für Luft- und Raumfahrt). However, the two biggest pipelines we can observe are oriented towards Italy and Germany. A said before, TAS belongs

[9] An agglomeration community is a metropolitan government structure created to increase economic development of an urban area.
[10] The last event of this nature was the Toulouse Space Show, the biggest GNSS meeting in Europe, hosting two major conferences, "the European Navigation Conference on Global Navigation Satellite Systems" and the "European Frequency and Time Forum", and a business meeting covering all application domains.

for a big part to the Italian group Finmeccanica, since Telespazio is held for the one-third by the Thalès French parent company. These financial links are a strong determinant of the links with Italy, because many Italian firms are already linked to Telespazio, or Finmeccanica. ("*We receive strong incentives to collaborate with our Italian colleagues of Telespazio*", TAS public contact of LIAISON European project). In the same time, relations of the Midi Pyrénées cluster with Germany can be explained by the strong implantation of the EADS group in this country, but also by the strong links between CNES, the French spatial agency, and the *Deutsche Zentrum* für Luft- und Raumfahrt (DLR), the German one. In 2005, CNES and DLR have decided to coordinate their R&D efforts and create together a GNSS Competence Center, located in Munich, Toulouse, and Paris.

6.3. Research institutions as "leaky" intermediaries

The particular broker roles of Tesa and CNES displayed in the previous part have been confirmed by the run of semi-structured interviews. Local coordinators could be seen as organizations which play the tricky role of linking the different segments of the GNSS knowledge value chain, but also ensuring an efficient knowledge matching between more or less cognitively distant partners. Our interviews confirm that TESA and CNES play partly similar and partly complementary roles.

- Tesa is a very local, and central, research structure bringing together several academic research laboratories, industry and institutions working on the development of hybrid systems combining telecommunications and GNSS. Tesa wants to be the "*missing link between research and the development of services and applications for users*"[11]. Tesa appears thus as a "leaky" (Owen Smith, Powell 2004) interface, diffusing knowledge between the different segments, at a Midi-Pyrenean level. That is why its brokerage score of liaison between knowledge segments is high, while its geographical brokerage score of gatekeeper is zero.

- The CNES is the government agency responsible for shaping French space research and policy. CNES is also a critical player in Europe's space program, and holds with the European Space Agency the role of European coordinators, justifying thus its high brokerage score of geographical gatekeeper.

6.4. Knowledge accessibility and appropriation between SMEs

The figures 3 and 4 givs a good representation of a core group of local SMEs which are more connected than others, as also confirmed by the cliques analysis (see table 5). This core group of firms

[11] Journal of Tesa, n°2, feb 2008.

is composed by eight toulousian SMEs of the hardware and software GNSS segment. Interviews show that strong geographical proximity between these firms increases their accessibility to knowledge. Composite knowledge in this technological dynamic supposes relations aiming to solve interoperability and compatibility constraints, with many face to face contacts, all the more that distant interactions costs are often more difficult to manage for SMEs than for large firms (Torre, 2008). Nevertheless, the GNSS downstream business, with hardware, software applications and value added services is a growing market, with high risks of unintended knowledge spillovers. These firms always start claiming that they are complementary. But at the same time, they have not enough cognitive distance to avoid the risk of unintended knowledge spillovers. In order to avoid this risk, they have decided to create an association: the Cecile group, and recently a GIE[12] (TAMS), based on a competency matrix. This tool delimitates cognitive fields for each firms on the basis of their capabilities. The control of the respect of this matrix is made by another firm, which makes audit control. An actor said*: "Cecile is an open collaborative structure, new members can arrive, but they have to improve the knowledge base of the group providing new competencies."*

6.5. Why big similar firms became geographical gatekeepers or external stars?

One of the particularity of the Midi-Pyrénées GNSS cluster, as previously said, is that it gathers in a same place two competing big companies. Nevertheless, formal results on cliquishness have shown that these latter differentiate themselves by their relational strategies. A geographical gatekeeper, as previously defined, have strong links with local firms and also strong links with external firms, joining global and local organizations. So, we could talk about geographical gatekeeper when an organization has an active role on bringing knowledge inside the cluster and sharing knowledge outside the cluster. Visual inspection of the overall network (Fig 2) helps us to identify Thales Alenia Space (TAS) as the major geographical gatekeeper of the cluster, in the un-normalized approach. Strong external relations can be explained by European based big projects, like Egnos yesterday, or Galileo today. This project aims to be an alternative and a complement of the American GPS. Geo-political issues, but also technological changes provided by this European project, engage all big European actors of the GNSS infrastructure segment. EADS Astrium, which has a very similar knowledge base, size and financial capacities than TAS, has got quite strong external links, but at the opposite very weak local relations. We have seen that EADS Astrium and TAS develop close strategies of network positioning, but in different cliques and in a different geographical extent. In fact, our analysis shows that EADS Astrium is not a geographical gatekeeper but an "external star" (Allen 1977). Cluster immersion and interviews help us to explain why TAS combines local and distant relations while EADS Astrium focuses mainly on distant ones, so that their structural profile differs.

[12] A GIE (Groupement d'intérêt économique) is a formal consortium with legal status.

Strong local relations of TAS can be explained by its local partnership development strategy. TAS aims to make the Midi Pyrenean cluster a bigger and more competitive one. This strategy was revealed by many interviews and its formal recognition strategy of the local GNSS cluster : *Navigation Valley*. *Navigation Valley* aims to structure the GNSS cluster in Toulouse, to be able to support the competition with BavAIRia, the GNSS cluster of Munich, in which EADS Astrium is involved through the organizational matrix or the parent company EADS. *Navigation Valley* was a big project which aims to set up a platform for development and innovation in order to promote and enhance coordination between Toulousian organizations belonging to each segment of the knowledge process. This knowledge platform in which TAS is more involved than EADS is the illustration of the will of TAS to improve the conditions of the collective upstream knowledge phase and improve thus the conditions of integration and interoperability of more or less distant but complementary pieces of knowledge locally developed. EADS Astrium seems to be less involved in this project, displaying a wider relational strategy with worldwide satellite companies. In spite of their proximity in their knowledge bases and the risks of uncontrolled knowledge spillovers (and a mistrust climate perceived during the interviews), these two competing companies succeed to co-exist in the same place thanks to a strategic differentiation on the geographical extent and the nature of their knowledge relations.

7. Concluding remarks

The starting point of this contribution was to consider that local clusters are cohesive structures which are embedded in technological fields and places, and thus argue in favour of a coupling between structural and nonstructural features of knowledge networks. This methodological contribution to cluster empirical identification does not provide a normative approach of the analysis of cluster aggregate efficiency. Nevertheless, by focusing on knowledge processes rather than on places *stricto sensu*, and by stressing on the knowledge profiles and the structural roles of clustered agents, this approach leads to perceive the complex geographical and technological organization of a particular cluster. These empirical results strengthen recent theoretical researches on clusters which take with caution the overestimation of the role played by geographical proximity in collective innovation (Breschi, Lissoni, 2001; Boschma, 2005; among many others). These empirical results concerning our particular case confirm that:

- *The knowledge dynamics is organized according to a complex matching of local/non local relations and inter/intra technological segments relations*. The methodology consisting in the aggregation of partly publicly supported or sponsored collective projects gives in that way some interesting empirical perspectives. First, it permits to gather relational data with a representative share of local and non local relations. Second, by knowing the role of each organization in the projects, it gives a more or less complete view of the role of each of them in the composite knowledge process. Third, by coupling knowledge features and structural ones, it offers an interactions-based approach of clusters related variety.

- *The cluster aggregates heterogeneous and complementary knowledge profiles*. By knowledge profiles, we mean not only the cognitive bases and technological segment of each organizations, but either their strategic positioning in knowledge networks. Obviously, the respective position of each organization, and in particular their centrality, depends on their size and market power, but also on their particular broker roles in the composite and geographical knowledge dynamics. By indexing these broker roles, we find out an interesting result for further theoretical and empirical researches. Indeed, the literature has stressed that the co-location of firms which are cognitively and technologically close can be collectively under efficient (Boschma, 2005; Nooteboom, Woolthuis, 2005; Suire, Vicente, 2008). Our results do not infirm this outcome, but show that their complementary broker roles differentiate their network and knowledge strategies, and render their co-location not so risky. More generally, these results confirm, with other works in this field (Guiliani, Bell, 2005; Boschma, Ter Wal, 2007), the relevance of empirical methodologies based on social network analysis, in particular when the study of the network structural properties are matched with knowledge and geographical nonstructural ones.
- *Lastly, external firms of the local GNSS cluster can play a key role in the composite knowledge dynamics as well as in the structuring of the local relations*. The "outsiders" found out in our top twenty central organizations and, to a less extent, their geographical gatekeeper roles, give a clear illustration of this finding. Once again, both the sample methodology and the network analysis, in spite of their intrinsic limits, appear as promising routines for capturing clusters and pipelines structures.

Obviously, the results we obtain must be confronted in the future with (i) theoretical researches on knowledge clusters and networks aggregate efficiency, and (ii) to more systematic empirical researches on various composite knowledge processes.

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Fig.1: the composite knowledge process in GNSS

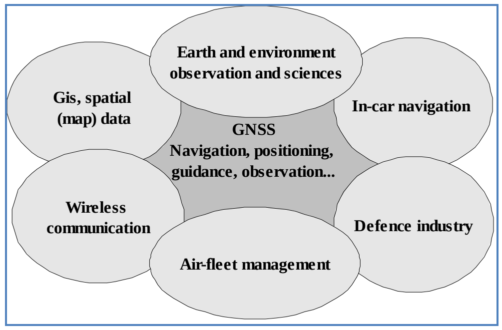

Table 1: GNSS collective projects of the sample

Project name	Number of partners	Geographic scale	Content of the project
SITEEG	14	MP	Collect real-time information on traffic and pollution.
SSA-CAPYTOL	9	MP	The applications ground / board for aeronautics
TRANSCONSTROL	4	MP	Control the transport of dangerous materials.
TELEMED-AERO	9	MP	Telemedicine in air transport
TSARS	2	MP	Application of satellite transmission technology in risk management.
OURSES	9	F	Development of the ICT in rural and mountainous areas by setting up new satellite technologies.
FILONAS SDIS 31	10	MP	Location system & communication for fire-fighters
Géo Marathon	3	MP	GNSS application to track runners
SPSA	3	F	Supervision and GPS positioning for watering systems
LIAISON	32 (17)	EU	Localization solutions using A-GPS technology combined with Telecom networks
Sinergit	8	F	Provide traffic information in real time for motorists, professionals and managers of the road
CityNav	7	MP	In car Navigation solutions
WI AERO	3	MP	Tracking and management of mobile equipment used in major industrial centres.
AIR NET	4	EU	Location system, identification and management of airport vehicles
CIVITAS MOBILIS	9	MP	Using satellite navigation for reducing pollution in public transport
AVANTAGE	4	MP	Guider disabled people to a specific destination with an optimal way.
BINAUR	5	MP	Facilitate the mobility of visually impaired person with satellite navigation systems
Egnos bus	2	MP	modelling multipath GPS in urban areas
Terranoos	2	MP	Geo-referencing of the flora in the Pyrenees using the GPS and Egnos signal
TONICité	3	MP	Digital guide for tourism in the city
Fil Vert 2006	4	MP	Location of bike in a bike-cycling
Astro +	21	EU	Using telecommunications, Earth observation and satellite navigation for rescue missions.
ACRUSS	4	MP	Analyse the behaviour of drivers with GNSS signal.
Geo-urgences	4	MP	Optimize supervision in real time Hospital Mobile Units
CTS-SAT	4	MP	Develop a new automatic transport module for person, guided by satellite
Safespot (WP2)	57 (11)	EU	Communication between vehicles and road infrastructure for road safety
Harmless	10	EU	Humanitarian Aid, Emergency Management and Law enforcement Support Applications
M-Trade	10	EU	Multimodal Transportation supported by EGNOS
Agile (WP 4, 5, 6, 7)	18 (13)	EU	Application of Galileo in the LBS Environment
GIROADS	13	EU	GNSS introduction in the road sector

Table 2 : basic characteristics of the sample

	firms		*total*	public research or standardization institutions		*total*	**total**
	local	non-local		local	non local		
Infrastructure (satellite, telecommunications)	3	12	*15*	2	9	*11*	**26**
Hardware (material, semi-conductors, chipsets, sensors, …)	10	7	*17*	0	0	*0*	**17**
Software (GIS, maps and all natigation and positionning software)	17	16	*33*	3	2	*5*	**38**
Applications and services	20	22	*42*	3	4	*7*	**49**
total	**50**	**57**	***107***	**8**	**15**	***23***	**130**

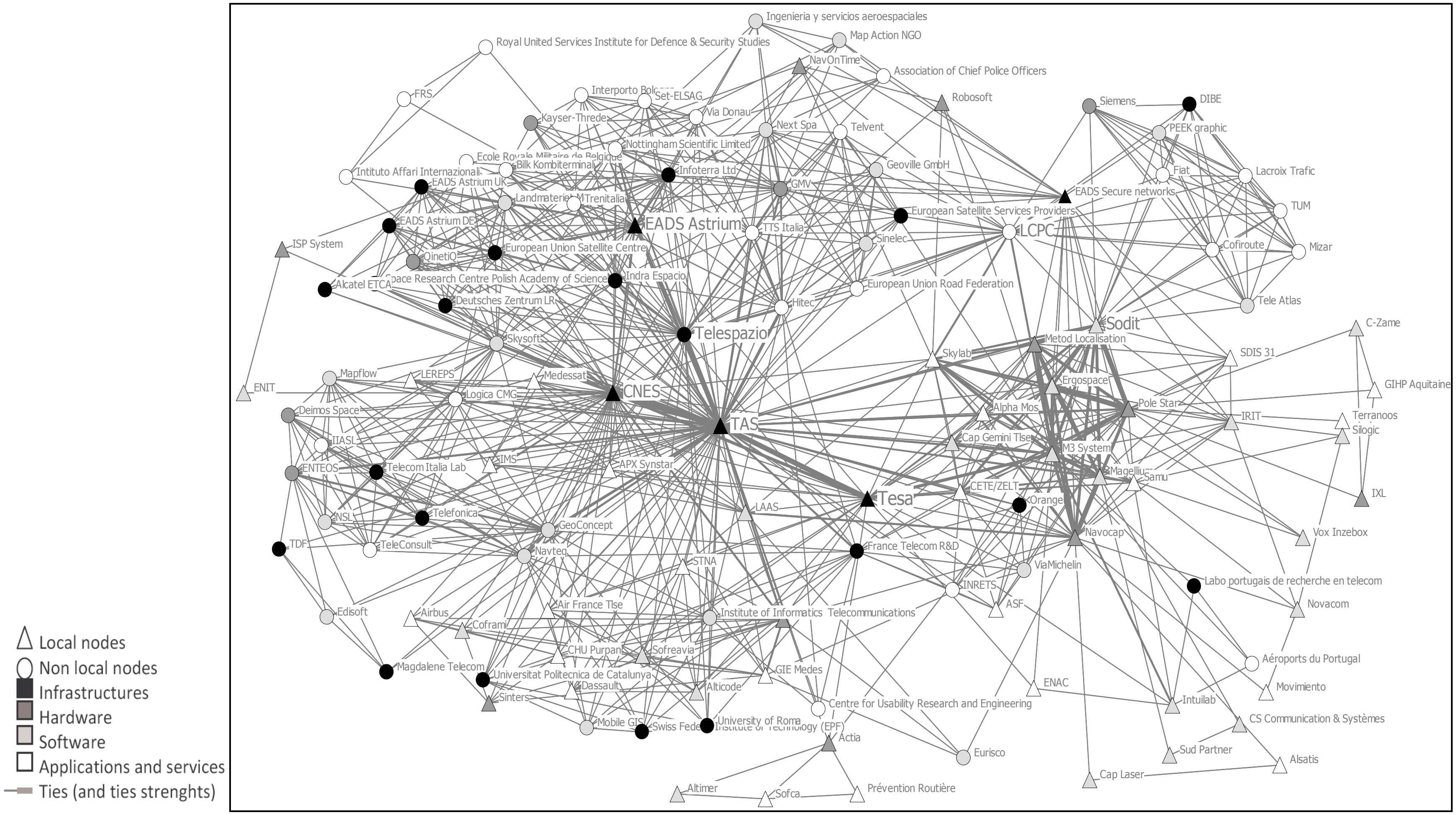

Figure 2: In (and from) Midi-Pyrénées GNSS network

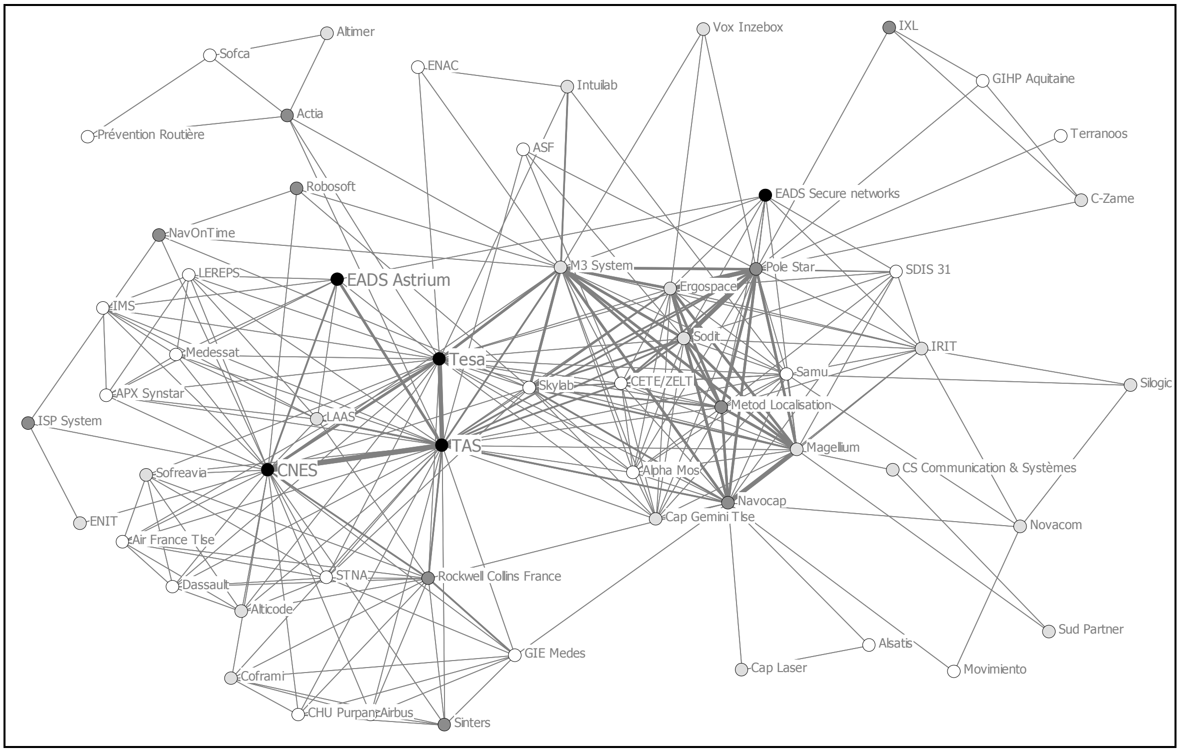

Figure 3: The Midi-Pyrénées cluster

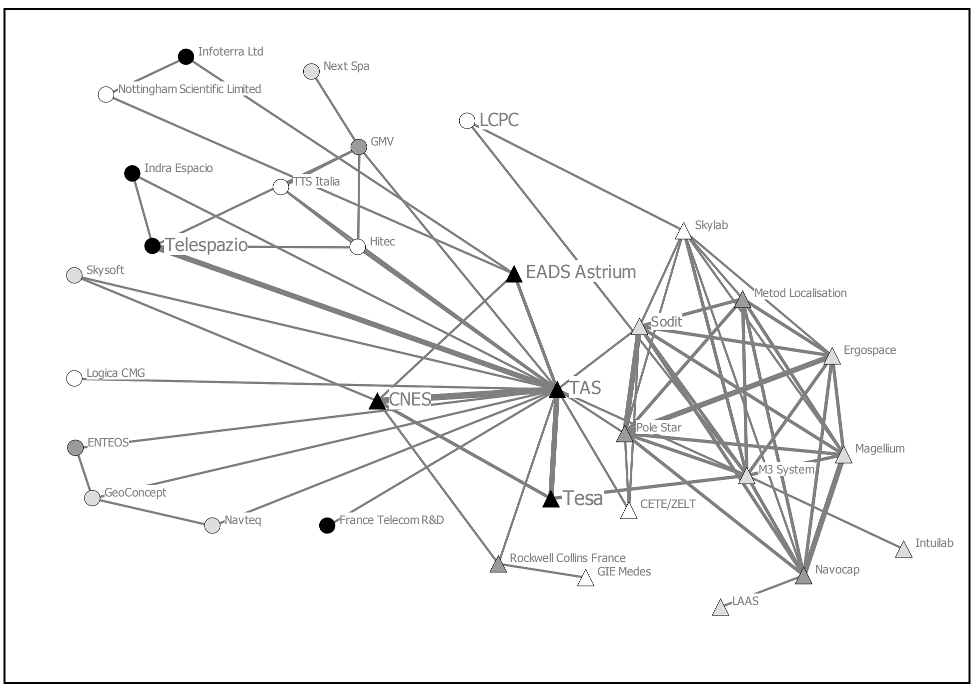

Figure 4: The cluster-pipeline structure (with ties ≥2)

Table 3 : E-I Index for groups defined by geographical membership
Groupe 1 : entities from the Midi-Pyrénées region; groupe 2 : entities external to the Midi-Pyrénées région

	Frequence	Percentage	Possible	Density
Internal……………………………………	1288	0.814	8418	0.153
External…………………………………	294	0.186	8352	0.035
E-I……………………………………………	-994	-0.628	-66	-0.004

E-I Index: ………………………………………………	-0.628
Expected value for E-I index:…………………	-0.004
Re-scaled E-I index: ………………………………	-0.628
Permutation Test :	
Number of iterations:……………………………	5000

	Obs	Min	Avg	Max	SD	P >= Ob	P <= Ob
Internal………………………………………	0.814	0.448	0.502	0.583	0.018	0.000	1.000
External………………………………………	0.186	0.417	0.498	0.552	0.018	1.000	0.000
E-I…………………………………………………	-0.628	-0.166	-0.003	0.105	0.035	1.000	0.000

E-I Index is significant (p<0.05)

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			

	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: Cliques and clique co-membership

<table>
<tr><th>Actors (nodes)</th><th colspan="6">Number of times the actors are co-members of the same cliques</th></tr>
<tr><td>TAS</td><td rowspan="2">14</td><td></td><td rowspan="3">6</td><td></td><td rowspan="4">4</td><td rowspan="6">3</td></tr>
<tr><td>CNES</td><td></td><td></td></tr>
<tr><td>TESA</td><td></td><td></td><td></td></tr>
<tr><td>Rockwell Collins</td><td></td><td></td><td></td><td></td></tr>
<tr><td>M3 system</td><td></td><td></td><td></td><td rowspan="2">5</td><td></td></tr>
<tr><td>Skylab</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Landmateriet Metria</td><td></td><td></td><td></td><td></td><td rowspan="9">4</td><td rowspan="12">3</td></tr>
<tr><td>Deutscht Zentrum</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Eur. Union Satellite Center</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ac. Royale Mil. de Belgique</td><td></td><td></td><td></td><td></td></tr>
<tr><td>EADS UK</td><td></td><td></td><td></td><td></td></tr>
<tr><td>EADS DE</td><td></td><td></td><td></td><td></td></tr>
<tr><td>EADS Astrium</td><td></td><td rowspan="2">7</td><td></td><td rowspan="3">5</td></tr>
<tr><td>Infoterra</td><td></td><td></td></tr>
<tr><td>Nottingham scientific ltd</td><td></td><td></td><td></td></tr>
<tr><td>Telespazio</td><td></td><td></td><td rowspan="2">6</td><td rowspan="3">5</td><td></td></tr>
<tr><td>Indra espacio</td><td></td><td></td><td></td></tr>
<tr><td>Skysoft</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ergospace</td><td></td><td></td><td></td><td></td><td rowspan="2">4</td><td rowspan="5">3</td></tr>
<tr><td>Pole Star</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Navocap</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Magellium</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Method Localization</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Geoconcept</td><td></td><td></td><td></td><td></td><td rowspan="3">4</td><td></td></tr>
<tr><td>Logica CMG</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Geospace</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>France Telecom R&D</td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">3</td></tr>
<tr><td>Institute of Informatics Telecom</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 6 : 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 7 : Structural Hole Measures: the twenty most efficient ego networks

	Effective Size	Efficiency
	-------	-------
TAS…………………………………………………………………..	74.701	0.859
CNES………………………………………………………………..	40.569	0.795
Actia………………………………………………………………..	4.333	0.722
Telespazio………………………………………………………..	26.538	0.680
LCPC………………………………………………………………..	16.520	0.661
Tesa…………………………………………………………………	19.000	0.655
EADS Astrium…………………………………………………….	20.032	0.646
Sodit…………………………………………………………………	19.839	0.640
M3 System………………………………………………………..	16.385	0.630
Pole Star……………………………………………………………	16.000	0.615
Navocap…………………………………………………………….	14.500	0.604
France Telecom R&D………………………………………..	10.222	0.568
EADS Secure networks………………………………………	9.471	0.557
ISP System………………………………………………………..	1.667	0.556
Intuilab……………………………………………………………..	3.333	0.556
Sofca…………………………………………………………………	1.667	0.556
GMV………………………………………………………………….	13.800	0.552
Rockwell Collins France…………………………………….	8.625	0.539
GeoConcept……………………………………………………….	12.304	0.535
Hitec………………………………………………………………….	11.545	0.525
Novacom…………………………………………………………….	2.600	0.520

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