Forschungszentrum Jülich
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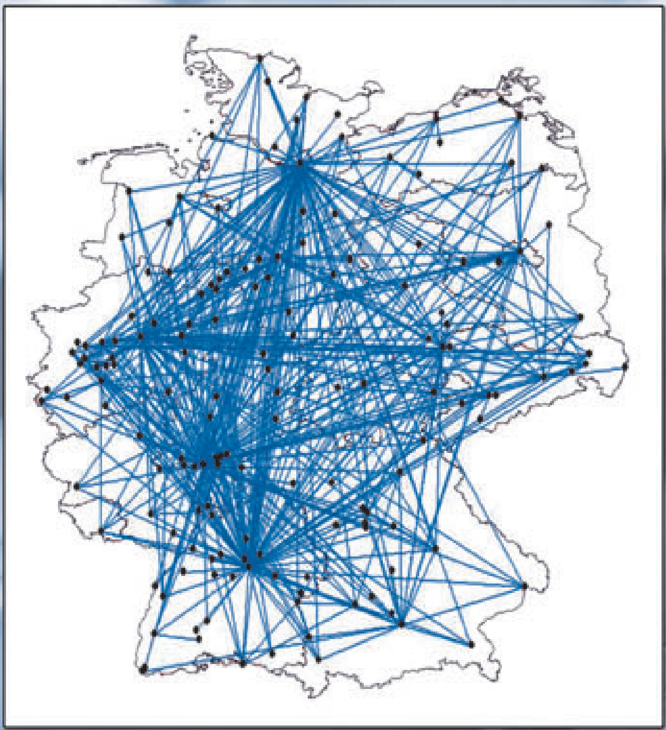
The Internet in Germany

Atlas of Providers and Regions

N. Lepperhoff, W. Fischer



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THE INTERNET IN GERMANY
ATLAS OF PROVIDERS AND REGIONS

Niels Lepperhoff, Wolfgang Fischer

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1 Introduction

The Internet is a new infrastructure for information transmission, storage and retrieval. Ever more societal, economic, cultural etc. activities are Internet-based, and a well-developed Internet-infrastructure is regarded as a prerequisite for a knowledge-based society.

The term Internet suggests a homogeneous network. But it is in fact a combination of private provider networks with their own management and often using – to some extent – different technologies. Only because well-established standards and norms are shared are these networks linked and a public Internet thus emerges, ensuring that data packets travel through the different networks to their destinations.

These provider networks, consisting among other things of cables and small boxes (routers), directing the data packet traffic through the Internet have their own peculiarities and span different nets with different topologies over the globe. Some are small but focused on a particular region, others are dense and have a medium coverage or are wide area networks connecting different parts of the world. What these networks look like is, to a large extent, unknown. Provider networks are often confidential, because they are the basis of the provider's business. Therefore, there is neither an official repository of network maps for all important providers nor a map for particular countries, regions or cities showing how good their connection to the Internet is. But Internet connectivity is important in a competitive world. And knowing how many providers own these connections gives an indication of the degree of competition between providers in a particular region or city.

To close the information gap a common approach is to interview providers about their networks. To a large extent the reports of Telegeography [2000, 2001, 2001b, 2002a, 2002b, 2002c, 2003] are based on interviews. Because providers know their own network best the data collected could be accurate and reliable. But the method has two disadvantages:

- The quality of data depends on the willingness of the providers to offer complete and exact information.
- The method is time-consuming, therefore data are outdated at time of publication.

Until 9/11 it was, at least in the USA, possible to get a lot of information about provider networks partly from publicly available network maps, which were published for marketing reasons, of an unknown quality. Furthermore, with some investigative competence, further knowledge could be gathered. Gorman and Mallecki [2000] used both methods. The situation in Germany is different because only a few network maps are publicly available.

To overcome such disadvantages and obstacles we have developed and used a software-system ("IMS") to map providers' networks. IMS was programmed by Jochen Leinen, Manfred Krings and Jürgen Rombey. We would like to thank them for their work. Our mapping approach allows automatic processing, enabling timely data collection. Furthermore, the application of IMS is cheap and independent of companies' policies regarding the publication of information. It can be used in principle to map the entire worldwide Internet or the Internet in particular regions of the globe.

The main objective of this Atlas is to map the Internet in Germany from three perspectives to show the networks of the most important *providers*, the combined network for *Germany* and the network in *regions*. The results of our efforts are presented in this Atlas. Our publication follows the shining example of the Atlas of Cyberspace [Dodge/Kitchen 2001].

But we have to make general reservations: Firstly, IMS does not determine the capacities of connections and networks. Secondly, the completeness and accuracy of the generated maps is difficult to assess, because there is no overall "correct" map available that we can use to compare IMS-results with reality. Nevertheless, our Atlas, even with incomplete maps, is a first step to making comprehensive information about the Internet topology in Germany publicly available.

Section 2 describes the method behind IMS. In Section 3 maps and some statistical measurements are given for each provider's network. Section 4 compares the networks. Afterwards the providers' networks are combined from a German and regional perspective. Section 5 analyses the combined network in Germany and Section 6 presents a first, tentative illustration of the combined networks with particular reference to the USA, Europe and Germany.

2 Method of measurement

A research group at the University of Southern California developed the Mercator software [Govindan/Tangmunarunkit 2000], which maps the routers and their connections. Their methods served as the basis for the Rocketfuel project, developed by the University of Washington [Spring/Andersen 2003; Spring et al. 2002]. Rocketfuel has two merits, exploited by our software system IMS: First, it combines all known techniques for data gathering and analysis, and the source code has been published. Second, Neil Spring developed and deployed an easily accessible infrastructure of servers around the globe, which can be used to execute remote measurements. These servers are called Scriptroute Servers.

2.1 Data gathering in general

To transport data packets on the Internet several pieces of software (protocols) have to work together. One protocol is the Internet Control Message Protocol (ICMP), which facilitates the management of networks. Therefore, it provides a service called traceroute, measuring the path that a packet takes from sender to receiver. Traceroute was developed as a network management tool revealing the paths packets take and thereby identifying each router on the path. By combining several traceroute measurements, a map of the network emerges.

The completeness of such a map depends on the locations of the senders and receivers of data packets. An analogy explains the fundamental problem: Imagine an elephant standing in a dark room. A person carrying a flashlight tries to identify this "big object". The flashlight illuminates only a small part of the elephant, and the person cannot move the flashlight. Standing in front of the elephant, the person would see the trunk not knowing what the rest of the elephant looks like. A second person with a flashlight stands in a distance illuminating another part of the elephant. Only if the two persons combine their views can they describe more parts of the animal. Traceroute plays the role of a flashlight. The location from where a traceroute is executed defines which part of the network is discovered. Similar to the elephant analogy, we use several locations around Germany, which is the focus of our analysis. Because a complete map of the Internet does not exist, an optimal number of these locations could not be calculated.

Practical problems limit the explanatory power of traceroute. Backup links, multiple IP links over the same fibre and multi-access links are impossible to detect with traceroute. Some providers block the response of traceroute requests. Therefore, some connections cannot be identified and parts of networks remain invisible.

We do not only have to select a sender but also a receiver of a traceroute. Selecting routers located in the network we want to map ensures that the traceroute probably covers the most important parts of the network targeted. The challenge is to identify these routers. Our approach is as follows: Each device connected to the Internet carries a unique number, called the IP-number. The IP-number addresses the device, enabling routers to guide packets from a sender to a receiver. Routers have IP-numbers as well. IP-numbers are sold to the providers in blocks. Therefore, we have to identify these IP-blocks and their owners. But probing each IP-number is generally too time consuming because there are often more than 65,000 IP-numbers in a block. So IMS selects its target from the providers' range of IP-numbers. As a consequence IMS reveals the *main* connections and cities because most packets travel through them, but some parts at the "edge" of the network remain mostly undetected: It is unlikely that IMS probes these "remote" connections. Our methods produce better results for small networks. Because they usually have a smaller IP range, IMS probing covers more parts of the IP range, therefore these maps are usually more complete than large network maps.

To gather data about a network, IMS executes several traceroutes from different locations around Germany to several randomly chosen routers within the target network. Traceroute reveals the path packets take between sender and receiver. Combining different paths reveals most parts of the target network. After data gathering IMS starts the data analysis, which is described in the following section. All data were obtained in Spring 2004.

2.2 Data analysing in general

After having collected routers and their connections, it is necessary to locate these routers geographically. Only if their location is known can we map the connections between cities and link the geography of the Internet with the geography of cities and states.

To localize routers IMS analyses its Domain Name. Providers often encode the city's name where a router is located into the domain name. Therefore, the quality of geographical localization depends on the naming policy of the telecommunication companies. In some cases the names are not found or could not be decoded. After IMS has identified the provider to which a router belongs, the domain name is matched against known keys of the provider to identify the city. IMS uses the keys provided by the University of Washington Scriptroute project and additional keys we have compiled ourselves.

This method has two shortcomings: First, sometimes there is no key matching the domain name, e.g. IMS does not know how to localize this router. Second, some routers do not have any domain name. In both cases, a second method is used. IMS measures the time a packet takes to reach the router, which has to be localized. This time is called Round Trip Time (RTT). Additionally, IMS measures the RTT to each router whose location is known and which has a direct connection to the router to be localized. If the RTT from the router and one of its neighbours differs by less than five milliseconds, IMS assume that both routers are located within the same city. If after several replications no new location is found we regard the city-location as confirmed. Nevertheless, some routers remain without location.

Some devices investigated are not routers but customer access devices (e.g. modem ports, DLS router). Such devices have no detectable location. Therefore, our analysis focuses on successfully localized routers. The number of access devices found varies from provider to provider. Providers with many devices show a lower localization success rate. *Figure 1* shows the ratio of successfully localized devices for all providers analysed.

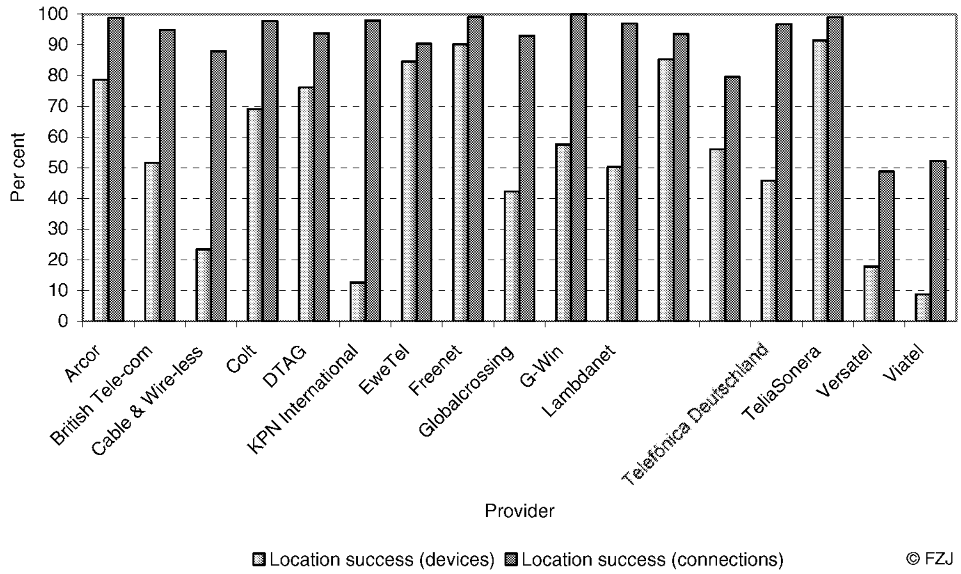

Figure 1: Ratio of localized devices.

After the localization of routers, IMS reduces the complexity of a provider's network map. Routers located in the same city are combined into one router. The result is a map of connected cities with fewer (local) details, which nevertheless preserves the core features of the provider's network identified by IMS. In a second synthesis, all the providers' networks are combined into a national or regional network. Thus, cities and connections of different providers´ networks are merged.

2.3 Mapping German providers

Our map is about Germany. Therefore we concentrate on providers in Germany who are members of the German Association of Companies Providing Telecommunication and Added-Value Services (Verband der Anbieter von Telekommunikations- und Mehrwertdiensten [vatm.de]). Providers who are resellers only and do not operate a network are excluded from our analysis. The formerly state-owned monopolist Deutsche Telekom (DTAG) and the German research network G-Win do not belong to VATM. Due to their importance for the Internet in Germany they are included in our analysis as well as some other important providers outside the association.

The traceroute senders are located around Germany to spotlight the networks in Germany from many directions. IMS relies on Scriptroute-servers. Therefore, we chose countries housing at least two Scriptroute-servers.[1] We start in the following countries: USA, Israel, Germany, United Kingdom, Italy, France, Russia, Hong Kong and South Korea. In addition, a traceroute to each target starts at Forschungszentrum Jülich.

2.4 Quality of method

Even if our method has several shortcomings we are confident that it produces useful results. Furthermore, there is no alternative to a mapping approach as long as the detailed provider maps are not publicly available. To demonstrate the quality of our method we compare the known topology of the German research network G-Win with our map. The official topology lists 28 cities and 38 connections. We found one city not mentioned in the official map (Potsdam) and three more connections (between Cologne and Essen, Berlin and Potsdam, Frankfurt and Munich). On the other hand, IMS missed seven connections and five cities. Therefore the IMS success rate is 82% for both the official connections and cities. This seems to be a quite impressive coverage. The cities IMS missed are located at the edge of the network (*Figure 2*), which is, as stated, often outside the "reach" of IMS, which has a better chance of identifying core cities and connections.

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[1] We have a threshold of two scriptroute-servers to assure load balancing in order to avoid abuse of network resources.

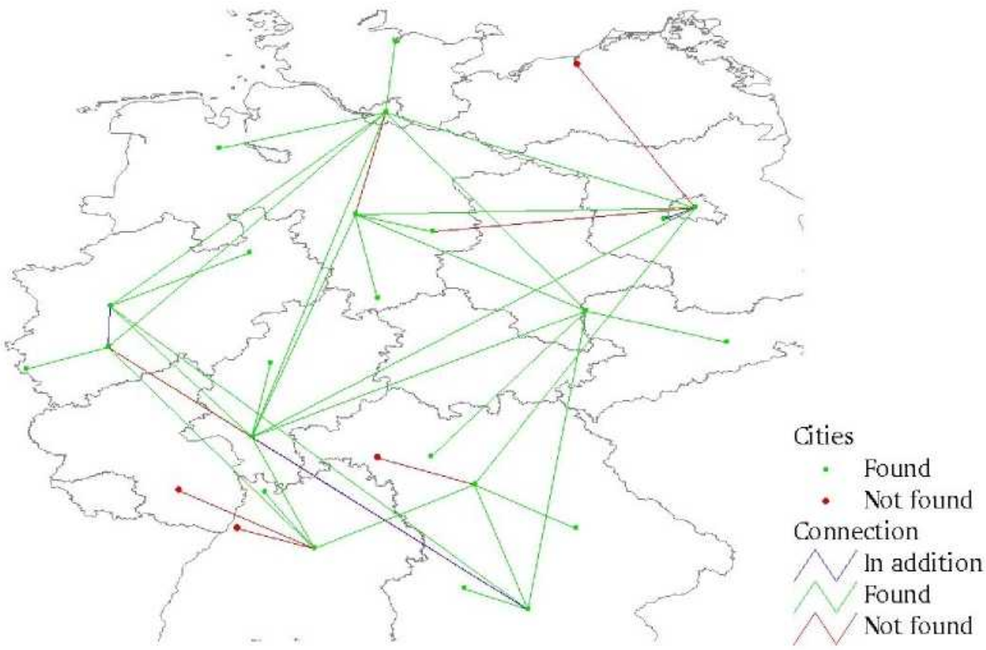

Figure 2: Comparing official G-Win topology with topology discovered by IMS.

3 Providers' networks

We have mapped 17 providers, of which 12 belong to the provider association (marked with *):

- Arcor [arcor.de] (owned by Vodafone)*
- British Telecom [bt.com]*
- Cable & Wireless [cw.com/de]*
- Colt [colt-telecom.de]*
- DTAG [dtag.de; telekom3.de]
- KPN International [kpn-wholsesale.com]
- EWE TEL [ewetel.de]*
- freenet.de [freenet-ad.de]*
- Global Crossing [globalcrossing.com]
- G-Win [dfn.de]
- LambdaNet Communications [lambdanet.net]*
- Level 3 [level3.de]*
- MCI Worldcom [wcom.de]*
- Telefónica Deutschland [telefonica.de] (owned by Telefónica)*
- TeliaSonera [teliasonera.com/carrier]*
- Versatel Germany [versatel.de]*
- Viatel [viatel.com]

Our maps give a visual impression of the shape and size of the network.[2] Because some networks, such as German Telekom, are too complex to recognize their shape only visually, we add some measurements describing the provider's network shape in more detail (see the following tables). These measurements are explained in the following using the Arcor network as an illustration.

The number of cities and the number of connections together describe the network size, which is a business indicator. Arcor´s network links 18 cities with 29 connections. Even if two networks have the same size, they could have different shapes. Therefore, more measurements are necessary to describe such a network "topology". Topology is the term used for the shape of a network, which can take the form of a "circle", a "star" or "mesh". Stars and meshes are the extreme topologies with respect to connectivity in networks.

The *out degree* of a city counts the number of connections this city has. The number of connections found is divided by the maximum number of connections a city could have. Out degree makes it possible to compare cities in networks with different sizes. For example, Frankfurt has an out degree of 0.53 and Berlin of 0.35 in Arcor's network. Thus, Frankfurt directly links 53% of all other cities and is the hub of Arcor's network. (In star-like topology one city, often called the hub, links all other cities.) Berlin has direct connections to only 35% of the cities.

[2] The geographic localizations provided by Washington University do not always reflect the real geographical positions of cities. Therefore, our maps do not always reproduce the exact geographical position of cities.

In a circle each city has two connections to its neighbours. A mesh directly links each city with the others. Creating a mesh needs much more connections than forming a circle, and no network could have more connections than a mesh. A star has the minimum number of connections. Real-world networks that rarely have these theoretical topologies are mostly characterized by a mixture of topologies. Nevertheless, the *density* indicates whether a network is more like a star or a mesh or is in between. The value of density ranges from (theoretically) zero to one. A meshed network shows a density of one, because each city is linked directly to all others. The density of Arcor's network is 0.19 indicating that the topology is more star-like.

A connection is the direct route between two neighbouring cities, e.g. C - B. A path is the way a packet has to travel from sender to receiver, including all the cities it passes (A - B via C). The number of cities on a path through the network measures the length of that path. *Figure 3* shows the path A - C- B between city A and city B consisting of two connections A - C and C - B. The term connection is reserved for a direct linkage of two cities (A - C or C - B).

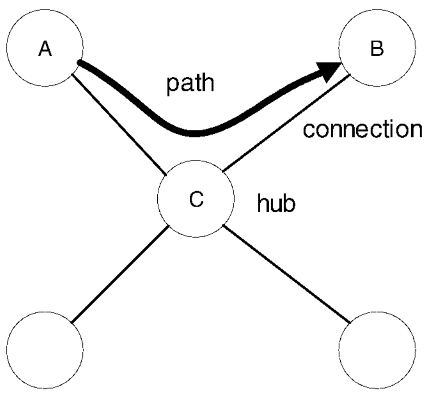

Figure 3: Path and connections in a star topology.

The path between neighbour cities (which is, because they are neighbours, also a connection) has a length of two. The *diameter* gives the length of the path which is the shortest between two cities and the longest of all shortest paths. A meshed network has a diameter of two, because each city has a connection to all the other cities without intermediate cities. The diameter of a star is three, and the diameter of Arcor's network is four, therefore the shortest way between each pair of cities is four.

The star topology has a centre (hub city), which is connected to all the other cities. Two measurements describe the centrality of a network. The *closeness* of a city measures how long the mean path length is from this city to another city. A value of one indicates that a city is a hub and zero that it is positioned in a circle. All other positions are in between. Frankfurt (closeness 0.68) is an important hub of the Arcor network. Berlin and Hanover, having the same closeness, are hubs, too, and have the same position in the network.

Whereas closeness describes a city's position in a network, *mean closeness* measures whether an entire network has a centre or not. The variance from the mean closeness describes the heterogeneity of the network. Arcor's network has a mean closeness of 0.44 indicating there are some centres and a variance of the mean closeness of less than 0.01, which is quite small.

3.1 Arcor

Table 1: Network characteristics of Arcor.

Measurement	Figure
Number of linked cities	18
Number of connections	29
Density	0.19
Diameter	4
Mean closeness	0.44
Variance of mean closeness	0.01

Table 2: Top five cities with most connections in the Arcor network.

City	Out degree
Frankfurt, Germany	0.53
Berlin, Germany	0.35
Hanover, Germany	0.29
Essen, Germany	0.24
Leipzig, Germany	0.24

Table 3: Top five cities with shortest paths in the Arcor network.

City	Closeness
Frankfurt, Germany	0.68
Berlin, Germany	0.53
Hanover, Germany	0.53
Essen, Germany	0.50
Cologne, Germany	0.49

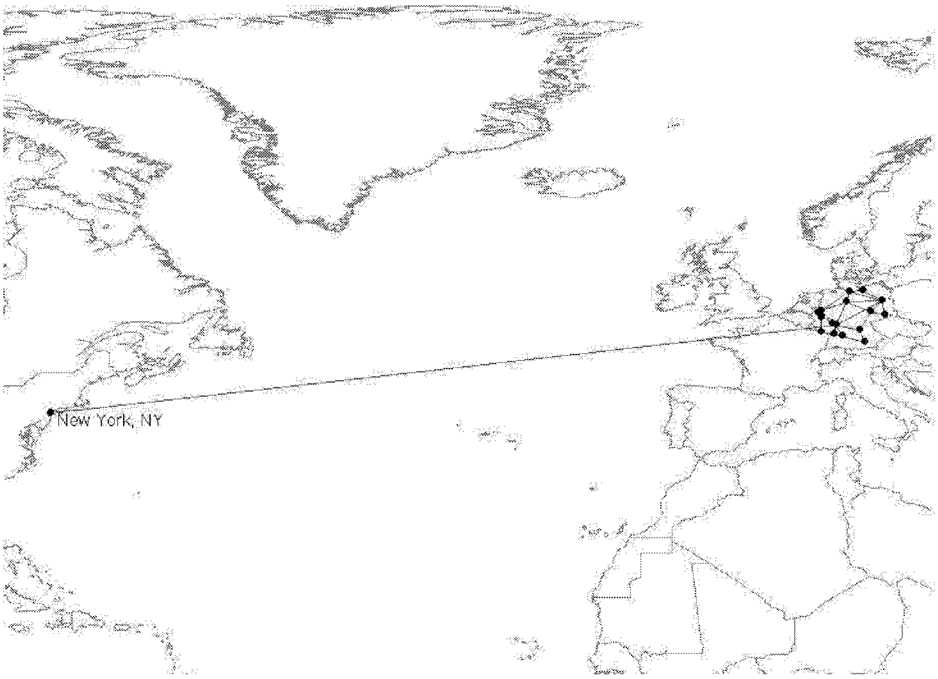

Figure 4: Worldview of the Arcor network discovered by IMS.

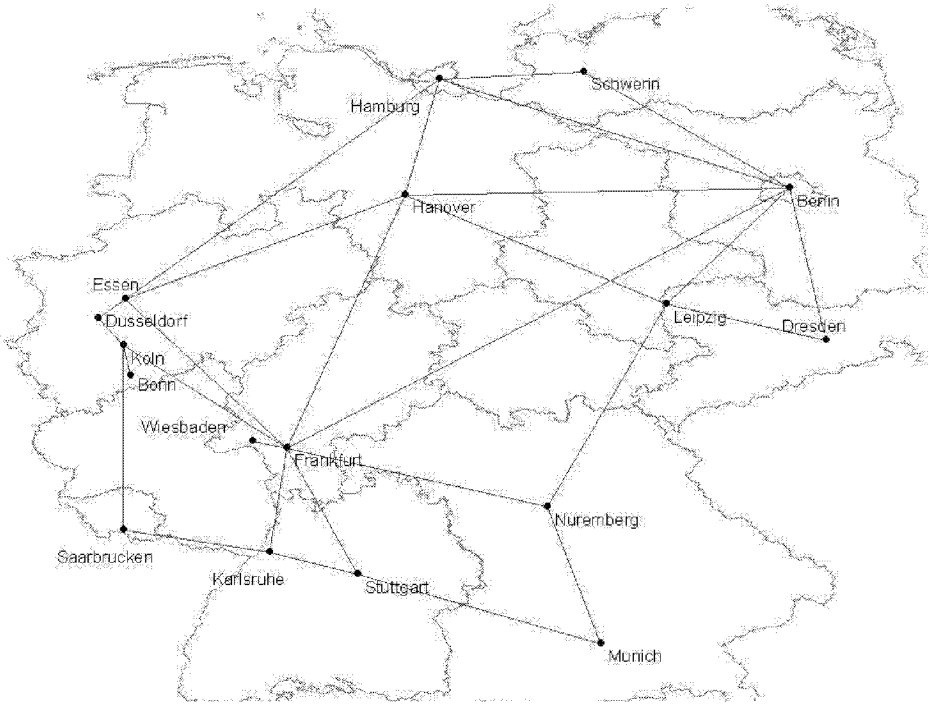

Figure 5: German part of the Arcor network discovered by IMS.

3.2 British Telecom

Table 4: Network characteristics of British Telecom.

Measurement	Figure
Number of linked cities	36
Number of connections	60
Density	0.10
Diameter	6
Mean closeness	0.38
Variance of mean closeness	0.01

Table 5: Top five cities with most connections in the British Telecom network.

City	Out degree
London, United Kingdom	0.4
Ealing, United Kingdom	0.34
Amsterdam, Netherlands	0.31
Frankfurt, Germany	0.26
Ilford, United Kingdom	0.23

Table 6: Top five cities with shortest paths in the British Telecom network.

City	Closeness
London, United Kingdom	0.57
Ealing, United Kingdom	0.57
Amsterdam, Netherlands	0.52
Ilford, United Kingdom	0.50
Frankfurt, Germany	0.44

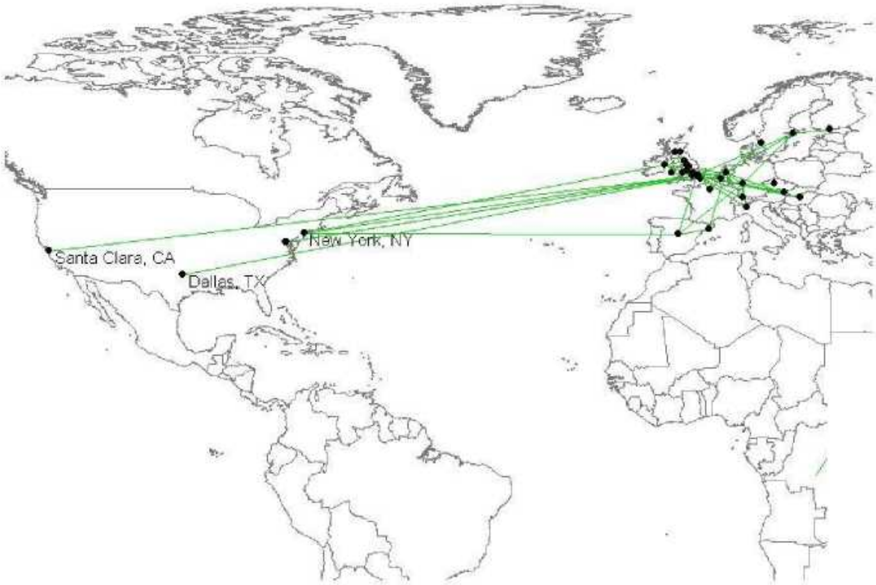

Figure 6: Worldview of the British Telecom network discovered by IMS.

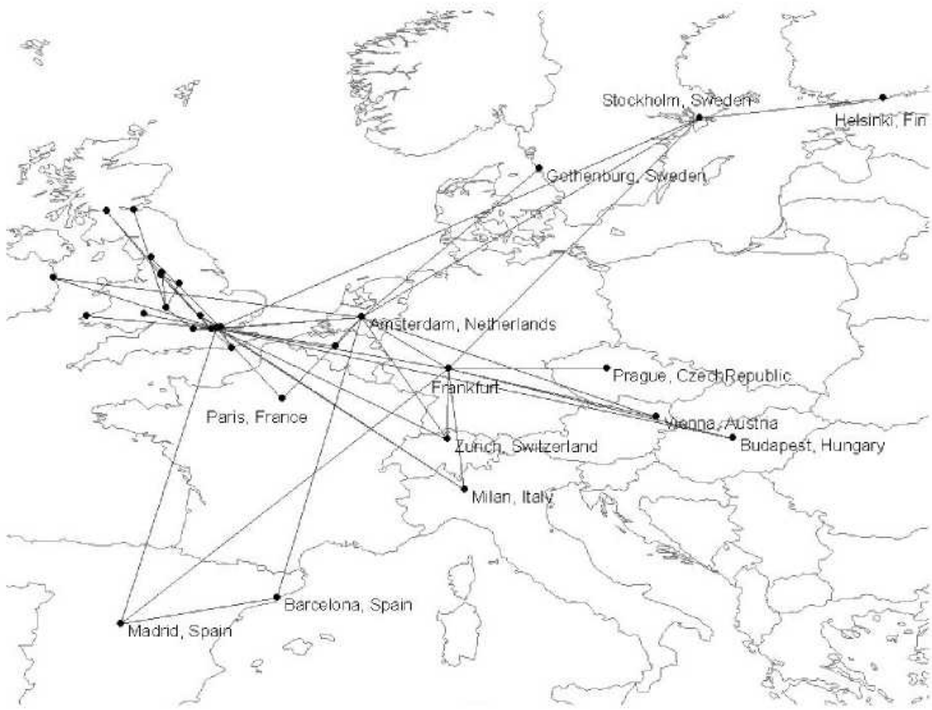

Figure 7: European part of the British Telecom network discovered by IMS.

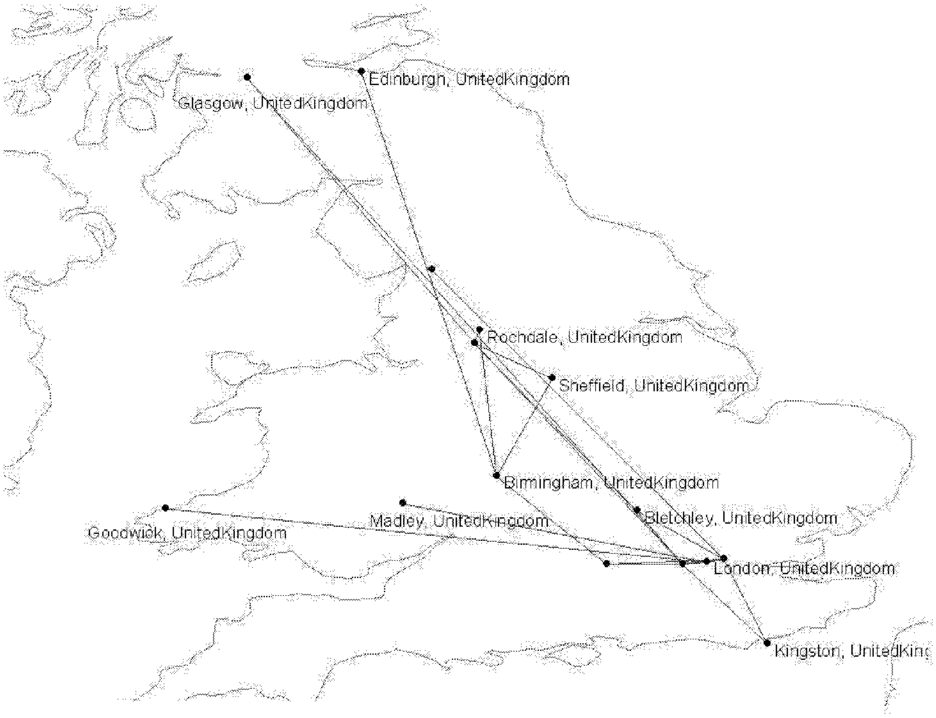

Figure 8: UK part of the British Telecom network discovered by IMS.

3.3 Cable & Wireless

Table 7: Network characteristics of Cable & Wireless.

Measurement	Figure
Number of linked cities	32
Number of connections	108
Density	0.22
Diameter	5
Mean closeness	0.49
Variance of mean closeness	0.01

Table 8: Top five cities with most connections in the Cable & Wireless network.

City	Out degree
Amsterdam, Netherlands	0.71
Paris, France	0.58
Washington, DC	0.48
Santa Clara, CA	0.45
Chicago, IL	0.45

Table 9: Top five cities with shortest paths in the Cable & Wireless network.

City	Closeness
Amsterdam, Netherlands	0.76
Paris, France	0.69
Washington, DC	0.62
Chicago, IL	0.58
Santa Clara, CA	0.57

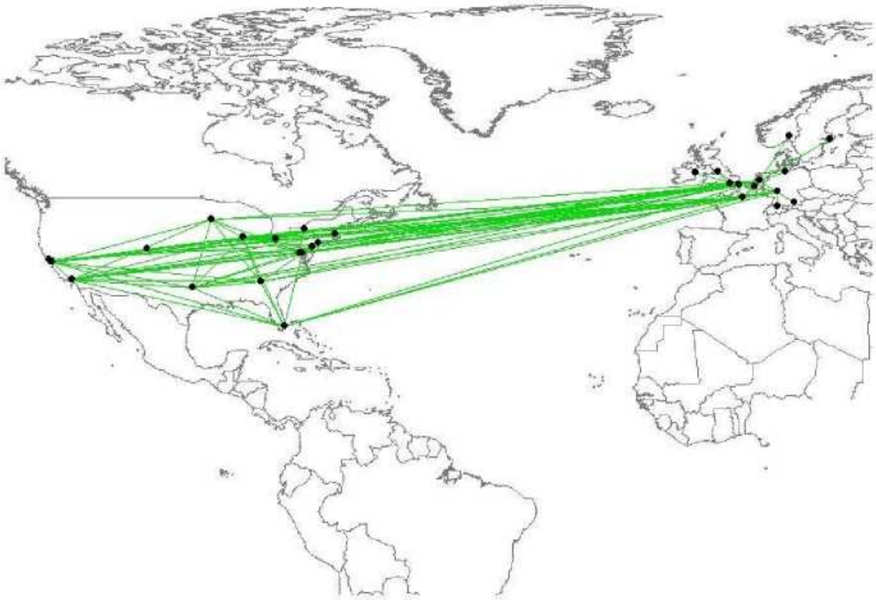

Figure 9: Worldview of the Cable & Wireless network discovered by IMS.

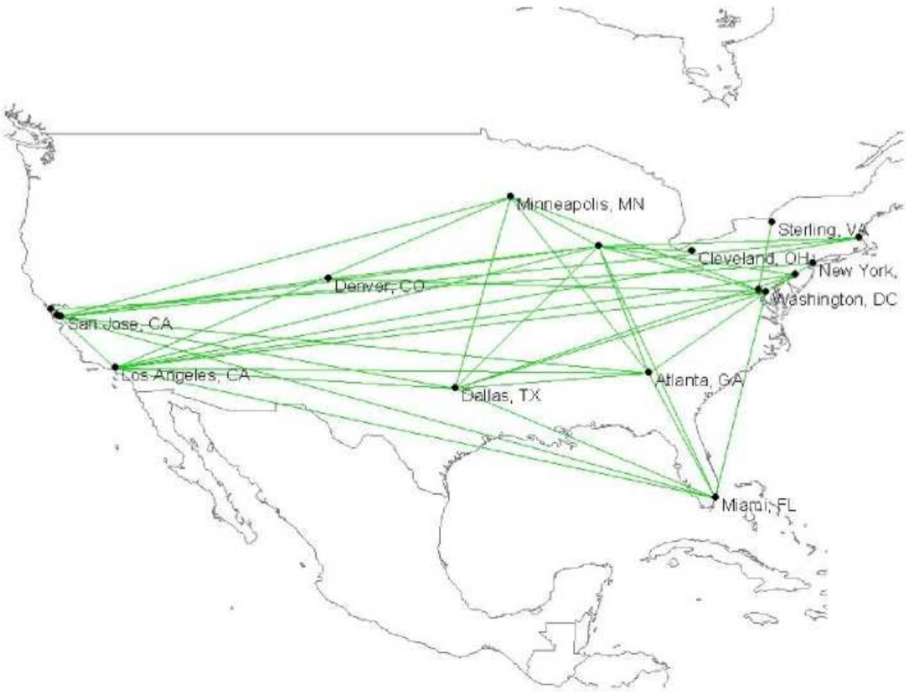

Figure 10: US part of the Cable & Wireless network discovered by IMS.

Figure 11: European part of the Cable & Wireless network discovered by IMS.

3.4 Colt

Table 10: Network characteristics of Colt.

Measurement	Figure
Number of linked cities	20
Number of connections	27
Density	0.14
Diameter	5
Mean closeness	0.42
Variance of mean closeness	0.01

Table 11: Top five cities with most connections in the Colt network.

City	Out degree
London, United Kingdom	0.42
Frankfurt, Germany	0.42
Paris, France	0.32
Berlin, Germany	0.21
Dublin, Ireland	0.16

Table 12: Top five cities with shortest paths in the Colt network.

City	Closeness
Frankfurt, Germany	0.61
London, United Kingdom	0.59
Paris, France	0.58
Berlin, Germany	0.46
Dublin, Ireland	0.44

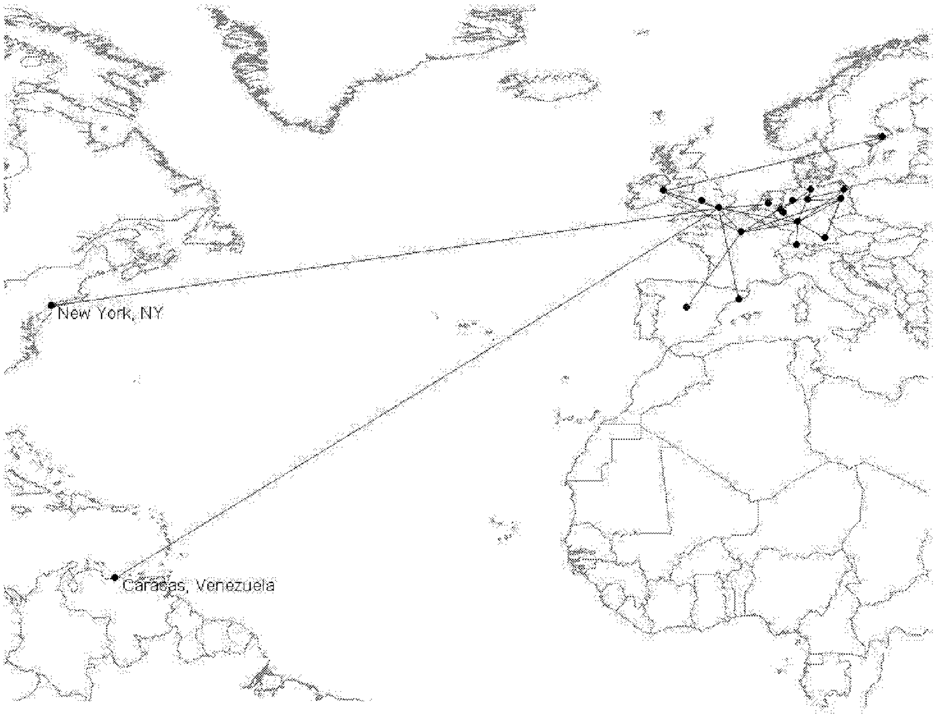

Figure 12: Worldview of the Colt network discovered by IMS.

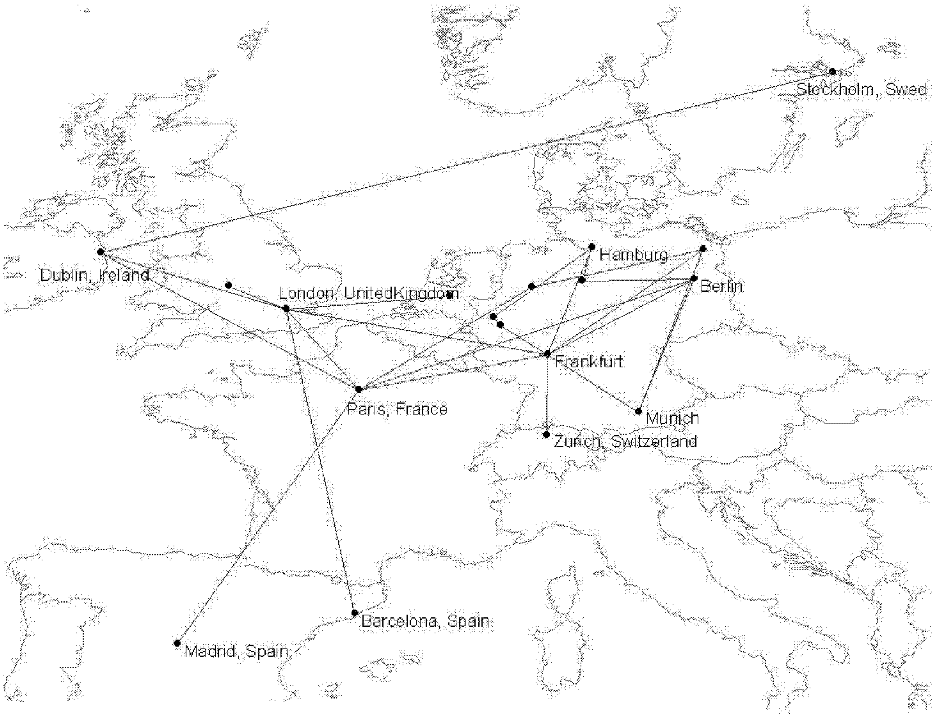

Figure 13: European part of the Colt network discovered by IMS.

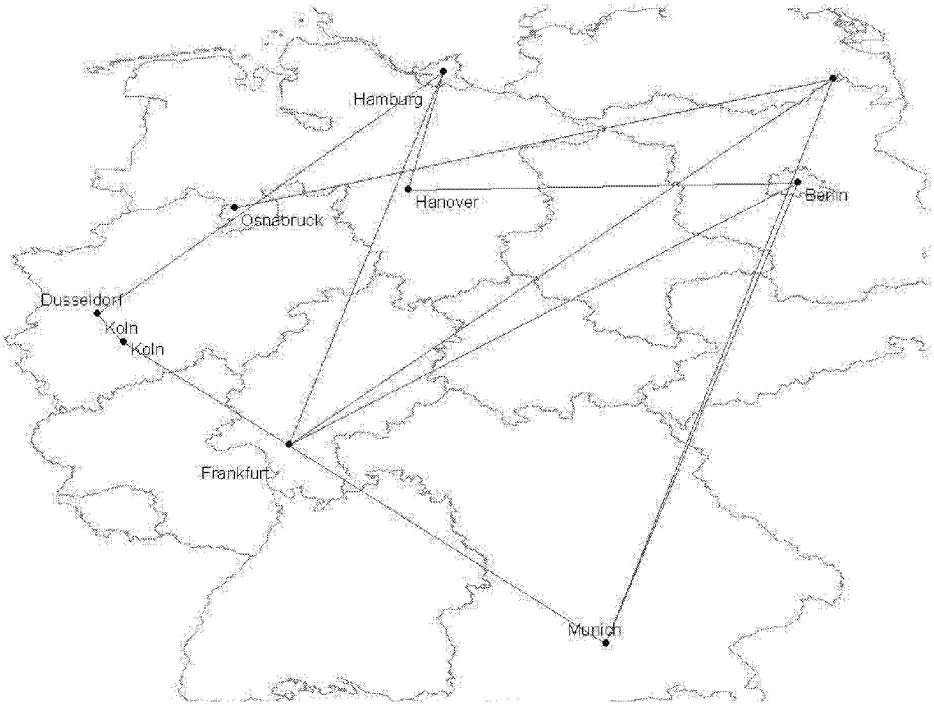

Figure 14: German part of the Colt network discovered by IMS.

3.5 German Telekom

Table 13: Network characteristics of German Telekom (DTAG).

Measurement	Figure
Number of linked cities	100
Number of connections	625
Density	0.13
Diameter	3
Mean closeness	0.54
Variance of mean closeness	0.01

Table 14: Top five cities with most connections in the German Telekom network.

City	Out degree
Stuttgart, Germany	0.99
Frankfurt, Germany	0.99
New York, NY	0.98
Washington, DC	0.95
Hamburg, Germany	0.83

Table 15: Top five cities with shortest paths in the German Telekom network.

City	Closeness
Stuttgart, Germany	0.99
Frankfurt, Germany	0.99
New York, NY	0.98
Washington, DC	0.95
Hamburg, Germany	0.85

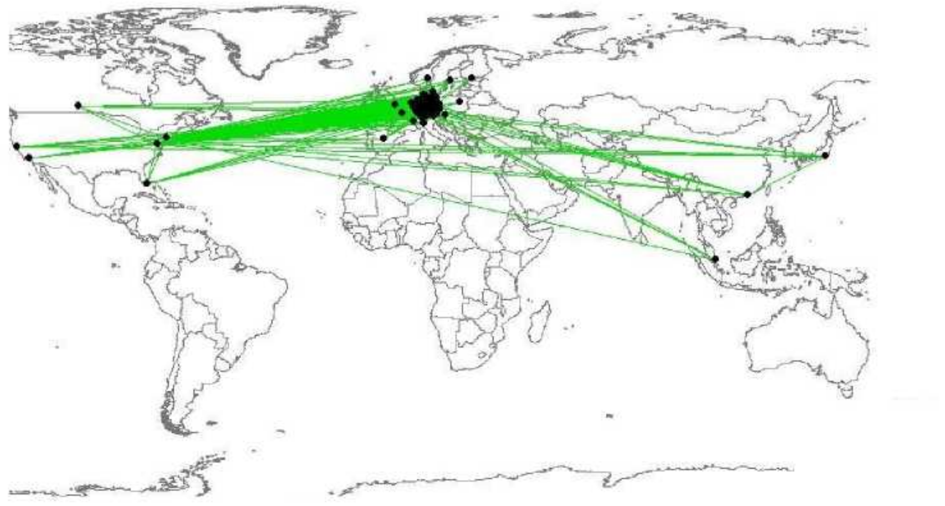

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Figure 15: Worldview of the German Telekom network discovered by IMS.

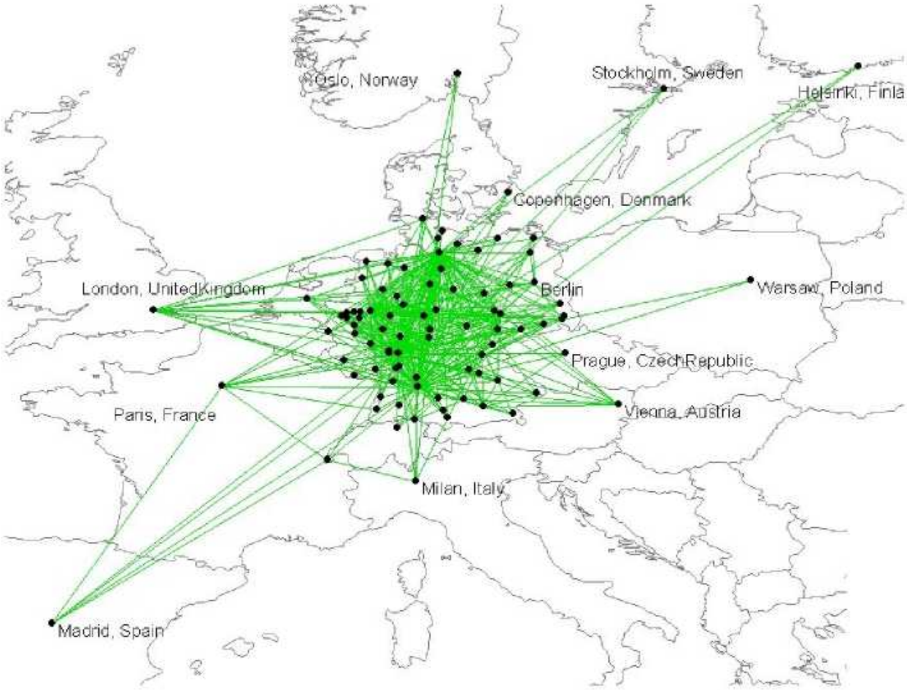

Figure 16: European part of the German Telekom network discovered by IMS.

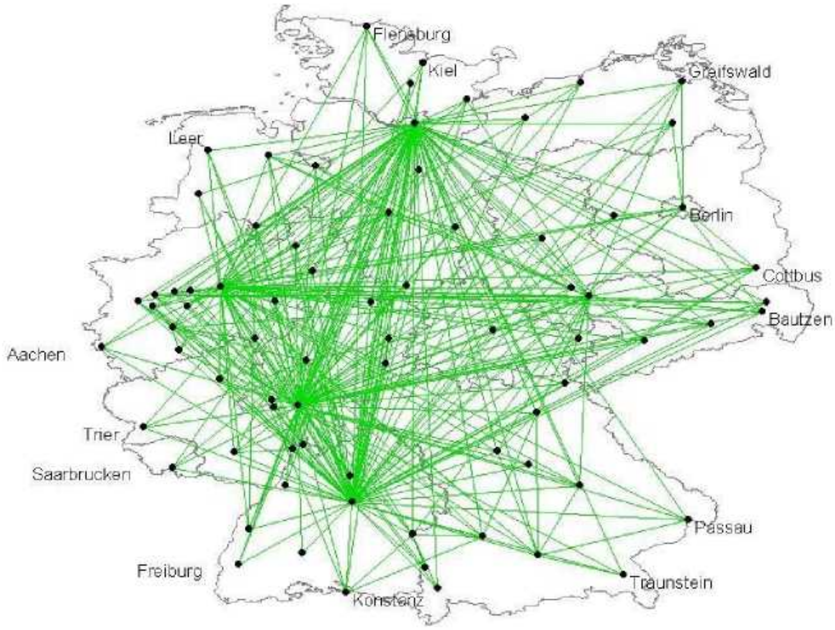

Figure 17: German part of the German Telekom network discovered by IMS.

3.6 KPN International

Table 16: Network characteristics of KPN International.

Measurement	Figure
Number of linked cities	24
Number of connections	33
Density	0.12
Diameter	5
Mean closeness	0.39
Variance of mean closeness	0.01

Table 17: Top five cities with most connections in the KPN International network.

City	Out degree
Frankfurt, Germany	0.48
Leiden, Netherlands	0.30
Amsterdam, Netherlands	0.26
Düsseldorf, Germany	0.26
Hamburg, Germany	0.22

Table 18: Top five cities with shortest paths in the KPN International network.

City	Closeness
Frankfurt, Germany	0.62
Leiden, Netherlands	0.52
Amsterdam, Netherlands	0.51
Düsseldorf, Germany	0.50
Nanterre, France	0.47

Figure 18: Worldview of the KPN International network discovered by IMS.

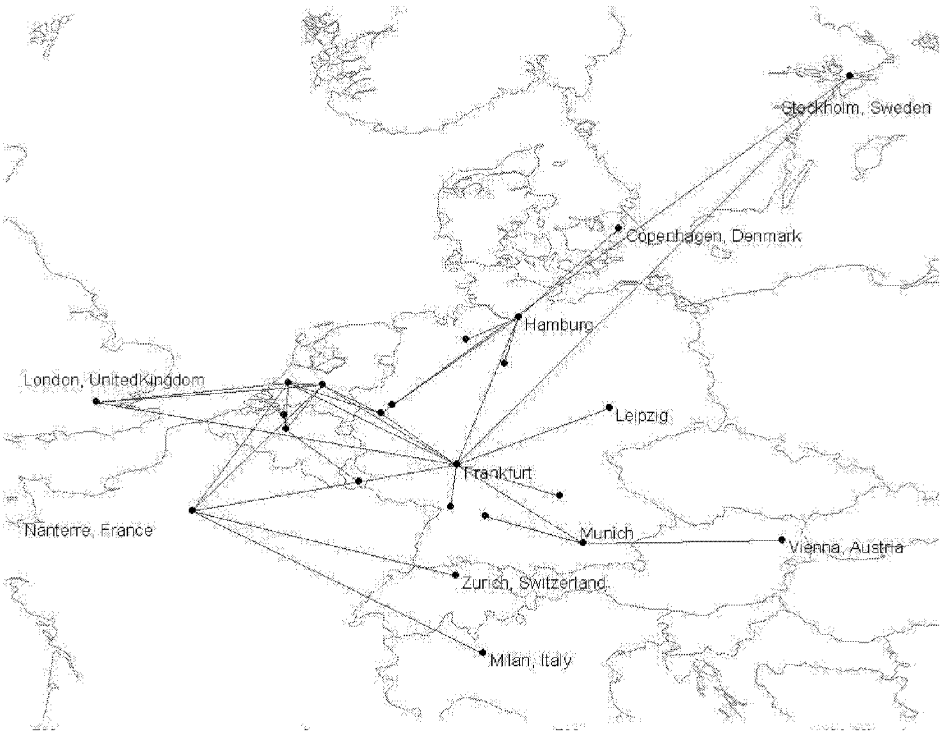

Figure 19: European part of the KPN International network discovered by IMS.

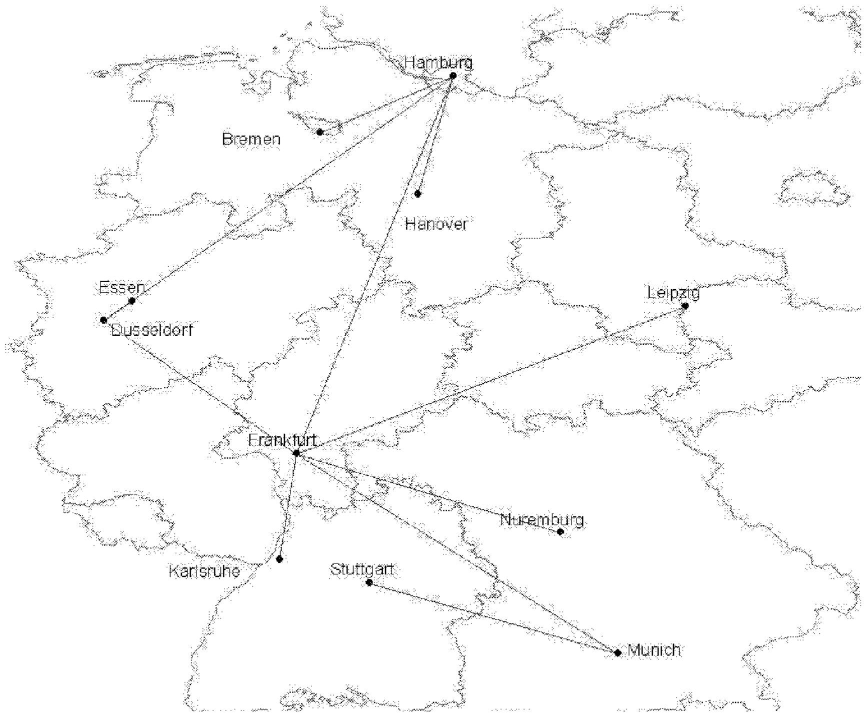

Figure 20: German part of the KPN International network discovered by IMS.

3.7 EWE TEL

Table 19: Network characteristics of EWE TEL.

Measurement	Figure
Number of linked cities	3
Number of connections	2
Density	0.67
Diameter	2
Mean closeness	0.78
Variance of mean closeness	0.02

Table 20: Cities with most connections in the EWE TEL network.

City	Out degree
Oldenburg, Germany	1
Cloppenburg, Germany	0.5
Frankfurt, Germany	0.5

Table 21: Cities with shortest paths in the EWE TEL network.

City	Closeness
Oldenburg, Germany	1.00
Cloppenburg, Germany	0.67
Frankfurt, Germany	0.67

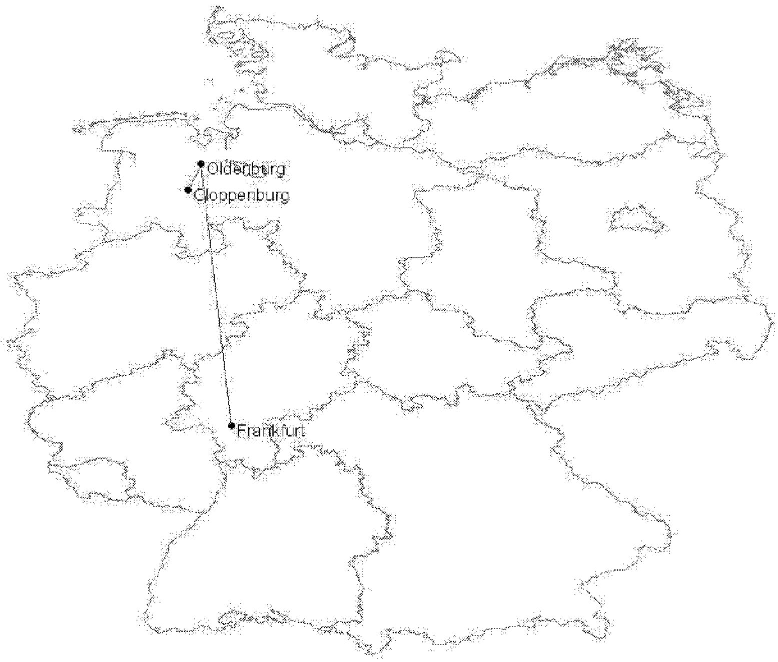

Figure 21: EWE TEL network discovered by IMS.

3.8 Freenet.de

Table 22: Network characteristics of Freenet.de.

Measurement	Figure
Number of linked cities	22
Number of connections	25
Density	0.11
Diameter	8
Mean closeness	0.28
Variance of mean closeness	0.002

Table 23: Top five cities with most connections in the Freenet.de network.

City	Out degree
Frankfurt, Germany	0.33
Hamburg, Germany	0.19
Düsseldorf, Germany	0.14
Nuremberg, Germany	0.14
Stuttgart, Germany	0.14

Table 24: Top five cities with shortest paths in the Freenet.de network.

City	Closeness
Frankfurt, Germany	0.37
Nuremberg, Germany	0.35
Düsseldorf, Germany	0.34
Erfurt, Germany	0.34
Leipzig, Germany	0.32

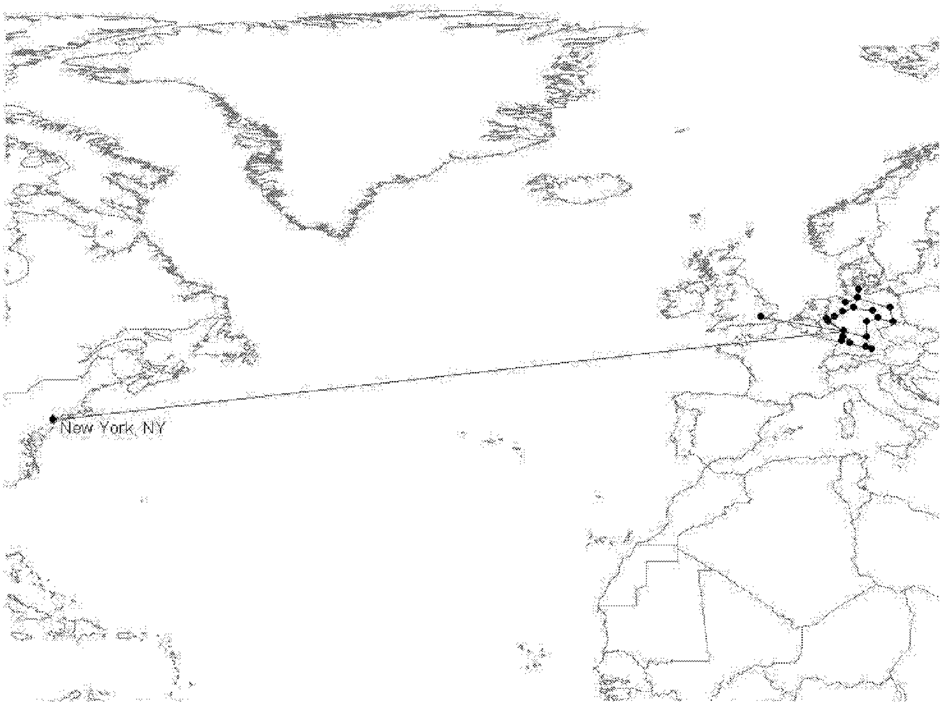

Figure 22: Worldview of the Freenet network discovered by IMS.

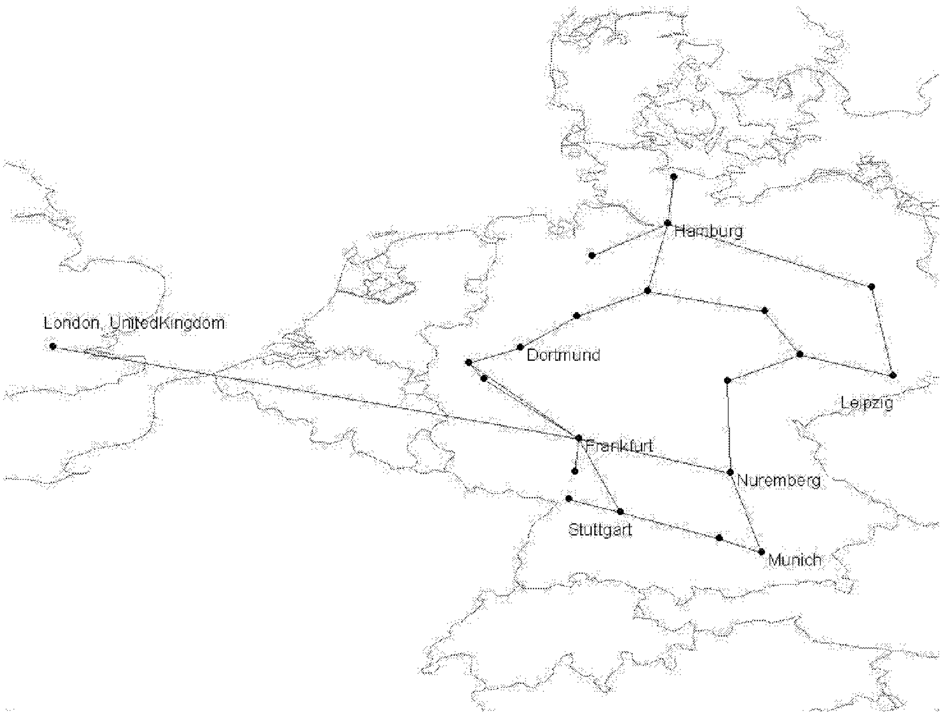

Figure 23: European part of the Freenet network discovered by IMS.

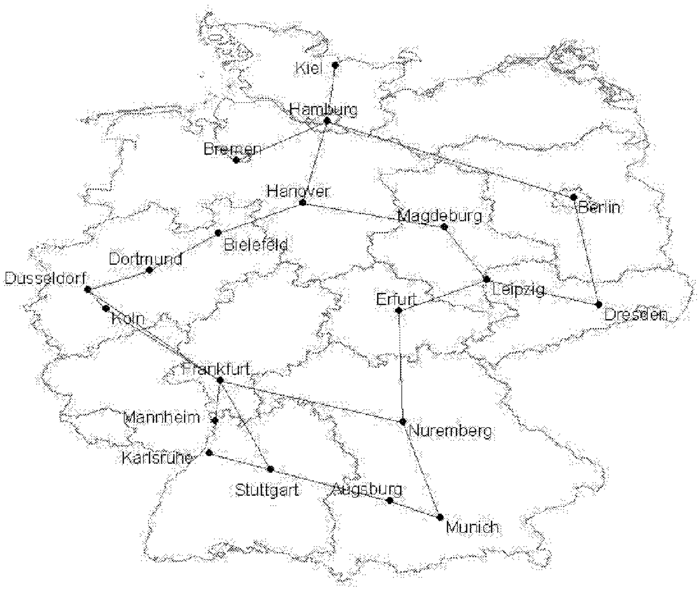

Figure 24: German part of the Freenet network discovered by IMS.

3.9 Global Crossing

Table 25: Network characteristics of Global Crossing.

Measurement	Figure
Number of linked cities	58
Number of connections	490
Density	0.30
Diameter	4
Mean closeness	0.56
Variance of mean closeness	0.02

Table 26: Top five cities with most connections in the Global Crossing network.

City	Out degree
London, United Kingdom	0.84
Frankfurt, Germany	0.81
Chicago, IL	0.81
Hong Kong	0.81
Milan, Italy	0.75

Table 27: Top five cities with shortest paths in the Global Crossing network.

City	Closeness
London, United Kingdom	0.85
Hong Kong	0.84
Frankfurt, Germany	0.83
Chicago, IL	0.83
Milan, Italy	0.79

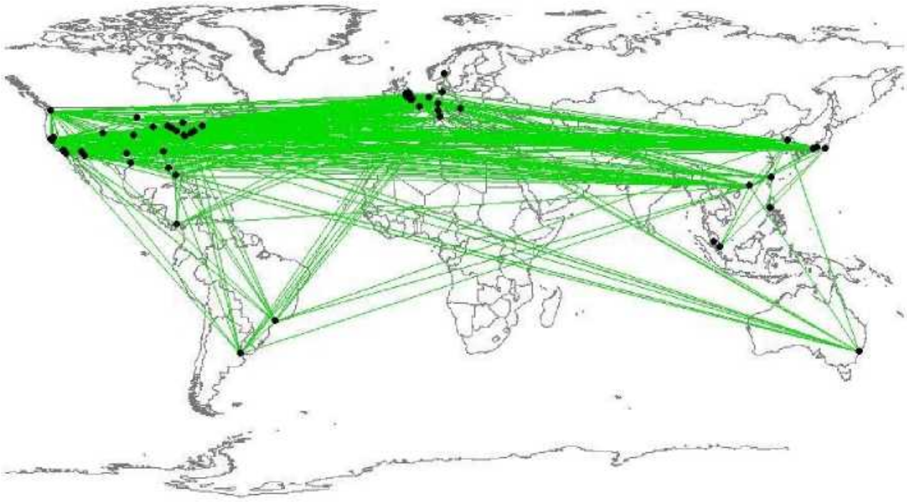

Figure 25: Worldview of the Global Crossing network discovered by IMS.

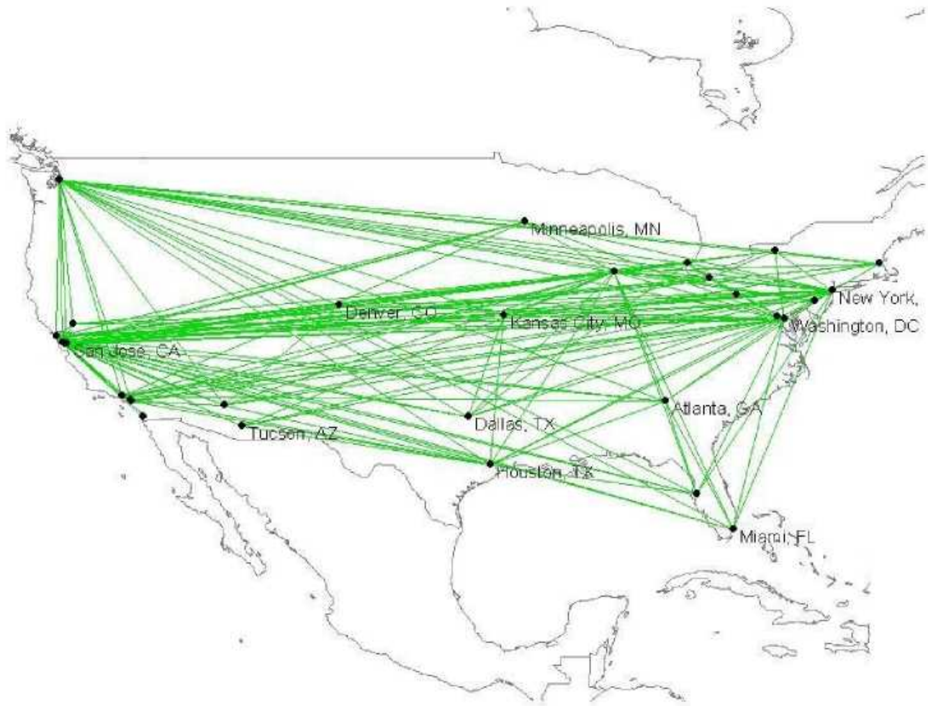

Figure 26: US part of the Global Crossing network discovered by IMS.

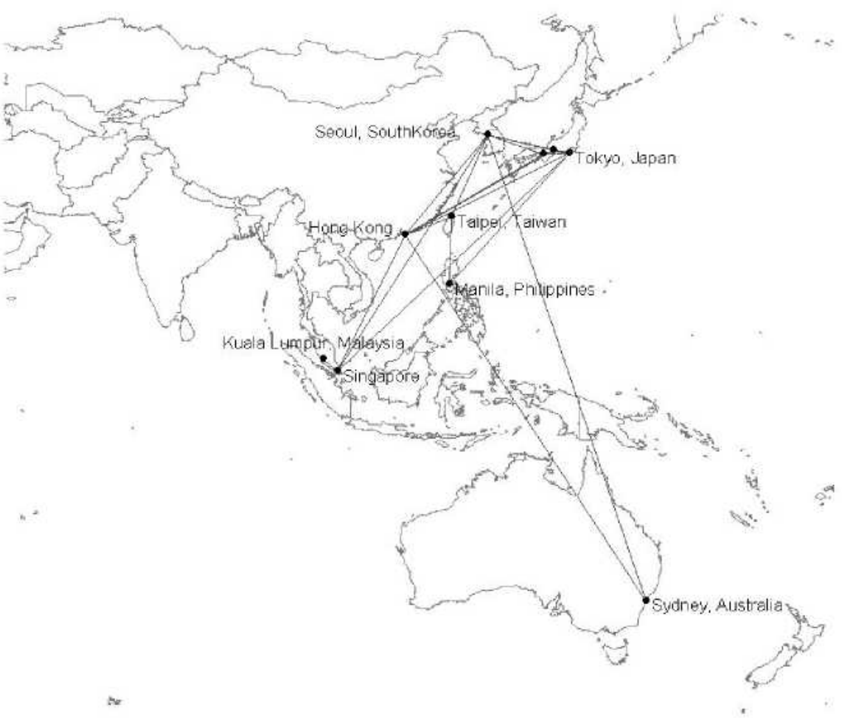

Figure 27: Asian part of the Global Crossing network discovered by IMS.

Figure 28: European part of the Global Crossing network discovered by IMS.

3.10 G-Win

Table 28: Network characteristics of G-Win.

Measurement	Figure
Number of linked cities	24
Number of connections	35
Density	0.13
Diameter	5
Mean closeness	0.39
Variance of mean closeness	0.01

Table 29: Top five cities with most connections in the G-Win network.

City	Out degree
Frankfurt, Germany	0.39
Hamburg, Germany	0.30
Leipzig, Germany	0.26
Cologne, Germany	0.22
Munich, Germany	0.22

Table 30: Top five cities with shortest paths in the G-Win network.

City	Closeness
Frankfurt, Germany	0.59
Hamburg, Germany	0.50
Leipzig, Germany	0.50
Berlin, Germany	0.48
Hanover, Germany	0.48

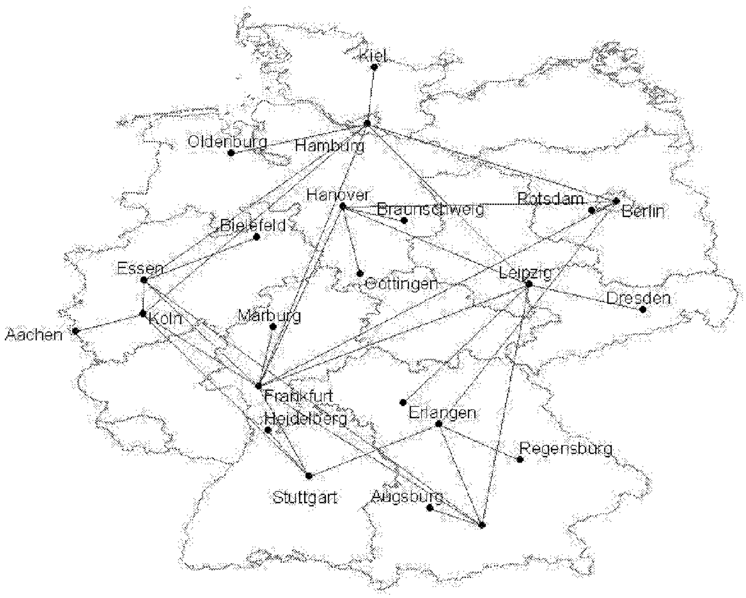

Figure 29: View of the G-Win network discovered by IMS.

3.11 LambdaNet Communications

Table 31: Network characteristics of LambdaNet Communications.

Measurement	Figure
Number of linked cities	28
Number of connections	53
Density	0.14
Diameter	4
Mean closeness	0.43
Variance of mean closeness	0.01

Table 32: Top five cities with most connections in the LambdaNet Communications network.

City	Out degree
Paris, France	0.52
Frankfurt, Germany	0.44
Düsseldorf, Germany	0.33
Hanover, Germany	0.26
Berlin, Germany	0.22

Table 33: Top five cities with shortest paths in the LambdaNet Communications network.

City	Closeness
Frankfurt, Germany	0.64
Paris, France	0.61
Düsseldorf, Germany	0.57
Berlin, Germany	0.53
London, United Kingdom	0.52

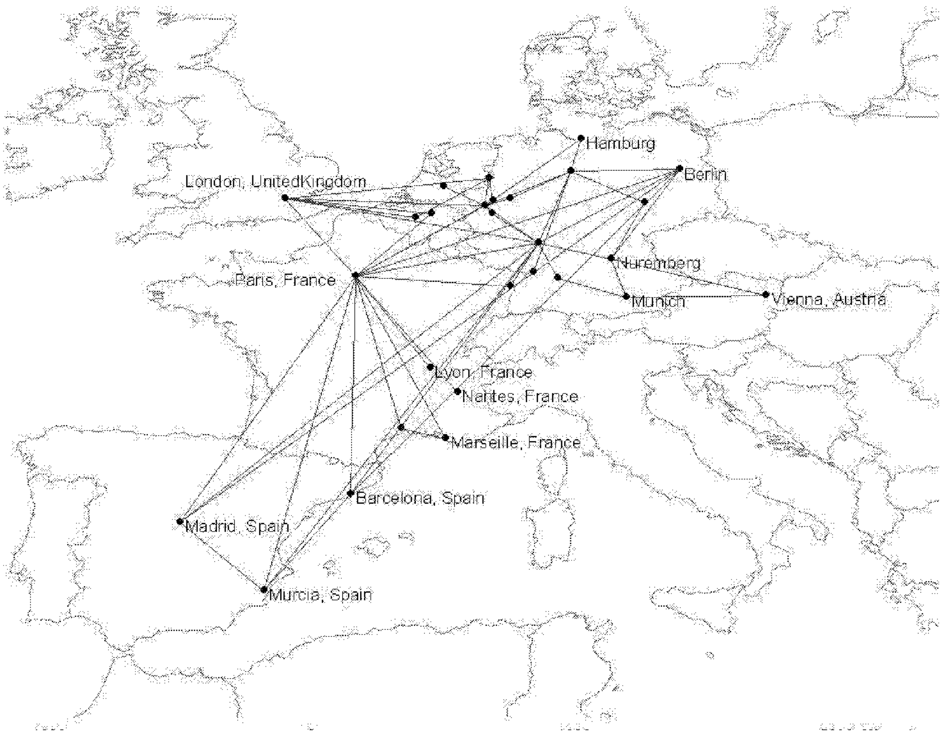

Figure 30: Worldview of the LambdaNet network discovered by IMS.

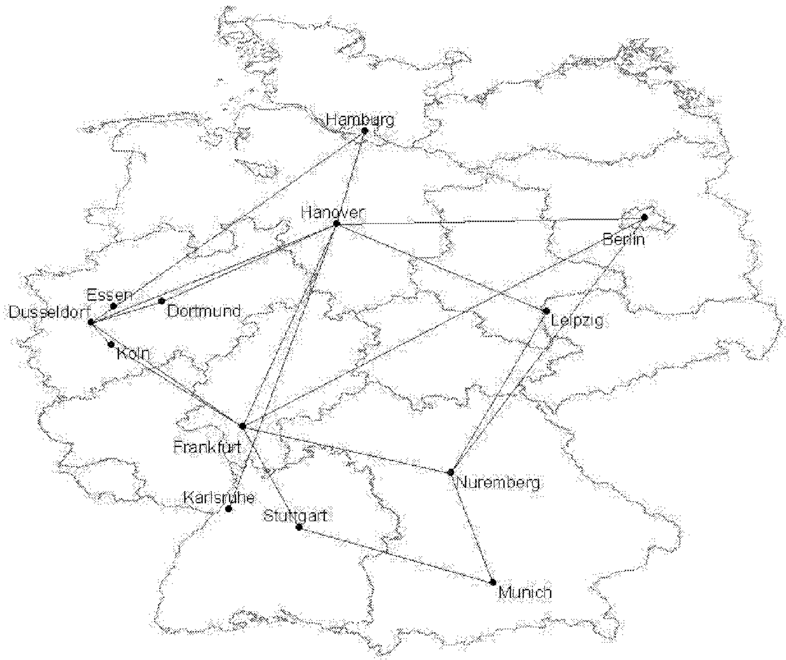

Figure 31: German part of the LambdaNet network discovered by IMS.

3.12 Level 3

Table 34: Network characteristics of Level 3.

Measurement	Figure
Number of linked cities	53
Number of connections	219
Density	0.16
Diameter	4
Mean closeness	0.46
Variance of mean closeness	0.01

Table 35: Top five cities with most connections in the Level 3 network.

City	Out degree
New York, NY	0.56
San Jose, CA	0.54
Chicago, IL	0.54
Seattle, WA	0.52
Washington, DC	0.52

Table 36: Top five cities with shortest paths in the Level 3 network.

City	Closeness
New York, NY	0.69
San Jose, CA	0.68
Chicago, IL	0.68
Washington, DC	0.68
Seattle, WA	0.67

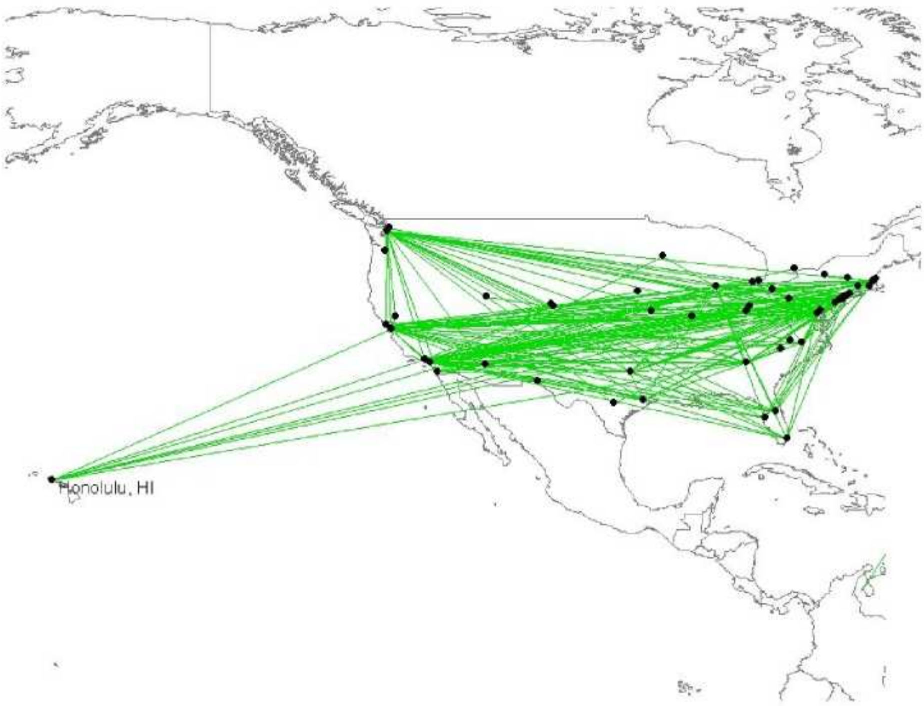

Figure 32: Worldview of the Level 3 network. IMS did not identify a European or German network.

3.13 MCI Worldcom

Table 37: Network characteristics of MCI Worldcom.

Measurement	Figure
Number of linked cities	98
Number of connections	233
Density	0.05
Diameter	8
Mean closeness	0.32
Variance of mean closeness	0.004

Table 38: Top five cities with most connections in the MCI Worldcom network.

City	Out degree
Washington, DC	0.36
New York, NY	0.29
Frankfurt, Germany	0.22
Chicago, IL	0.18
Santa Clara, CA	0.16

Table 39: Top five cities with shortest paths in the MCI Worldcom network.

City	Closeness
Washington, DC	0.53
New York, NY	0.49
Frankfurt, Germany	0.46
Hilden, Germany	0.44
London, United Kingdom	0.42

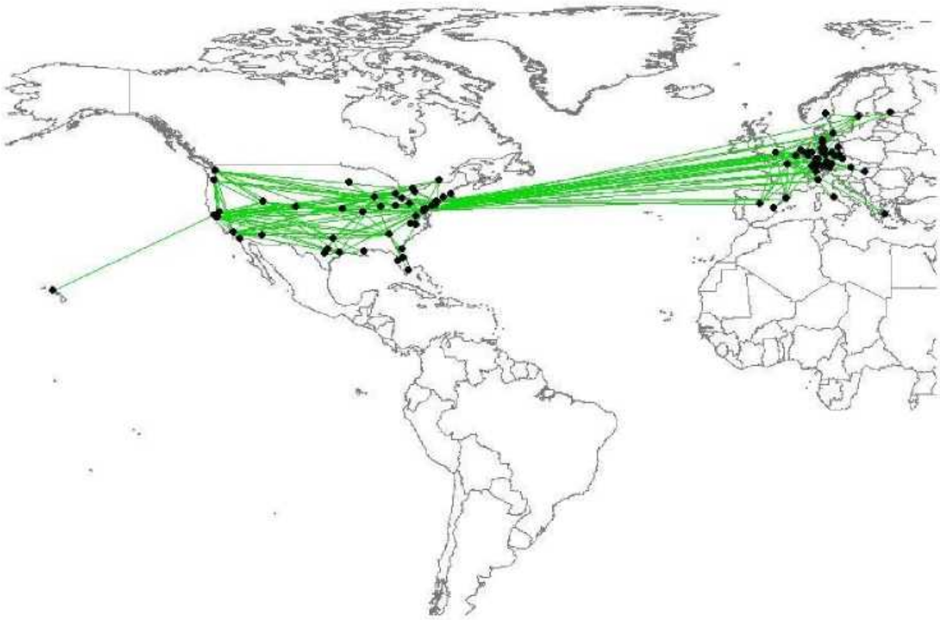

Figure 33: Worldview of the MCI Worldcom network discovered by IMS.

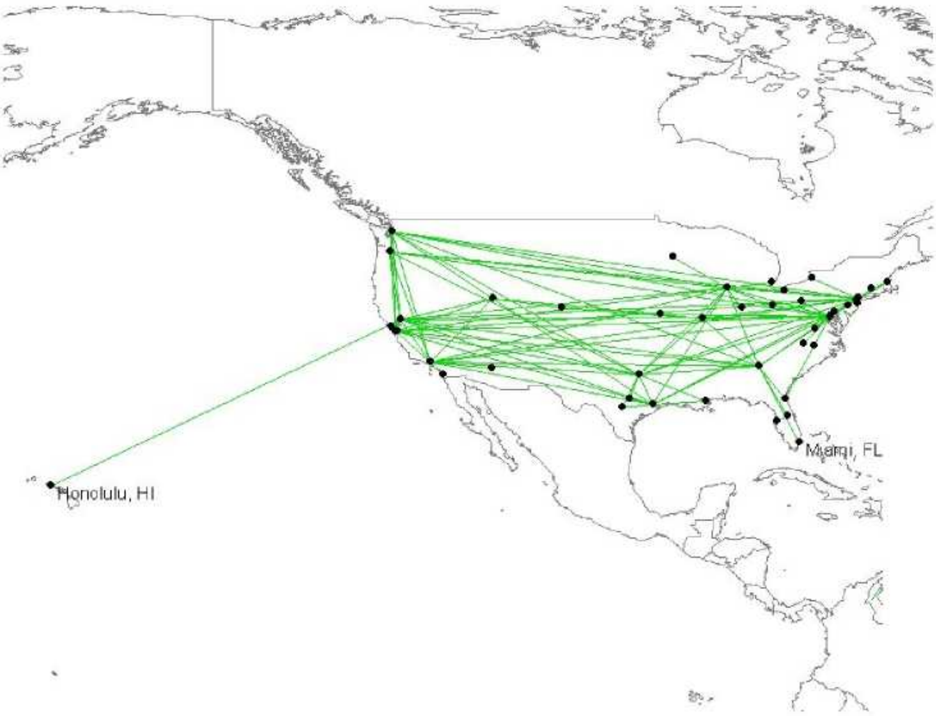

Figure 34: US part of the MCI Worldcom network discovered by IMS.

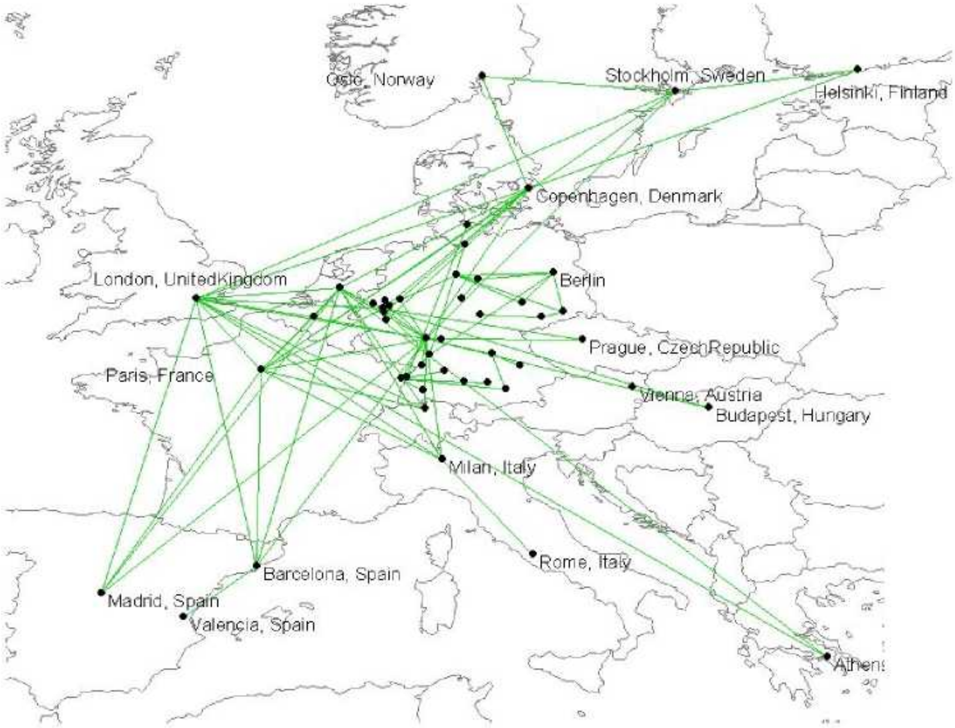

Figure 35: European part of the MCI Worldcom network discovered by IMS.

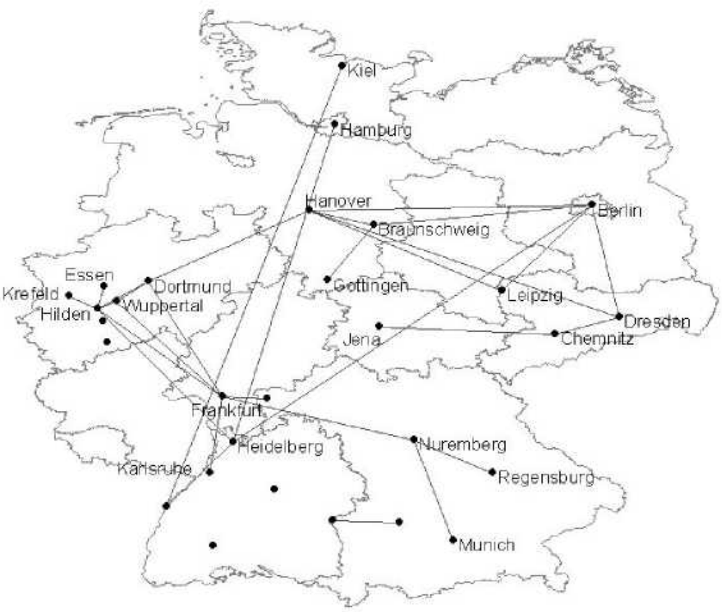

Figure 36: German part of MCI Worldcom network discovered by IMS. Other cities have connections via France.

3.14 Telefónica Deutschland

Table 40: Network characteristics of Telefónica Deutschland.

Measurement	Figure
Number of linked cities	134
Number of connections	151
Density	0.02
Diameter	7
Mean closeness	0.26
Variance of mean closeness	0.002

Table 41: Top five cities with most connections in the Telefónica Deutschland network.

City	Out degree
Frankfurt, Germany	0.17
Stuttgart, Germany	0.16
Munich, Germany	0.11
Gütersloh, Germany	0.10
Hamburg, Germany	0.08

Table 42: Top five cities with shortest paths in the Telefónica Deutschland network.

City	Closeness
Frankfurt, Germany	0.45
Berlin, Germany	0.39
Gütersloh, Germany	0.37
Munich, Germany	0.36
London, United Kingdom	0.35

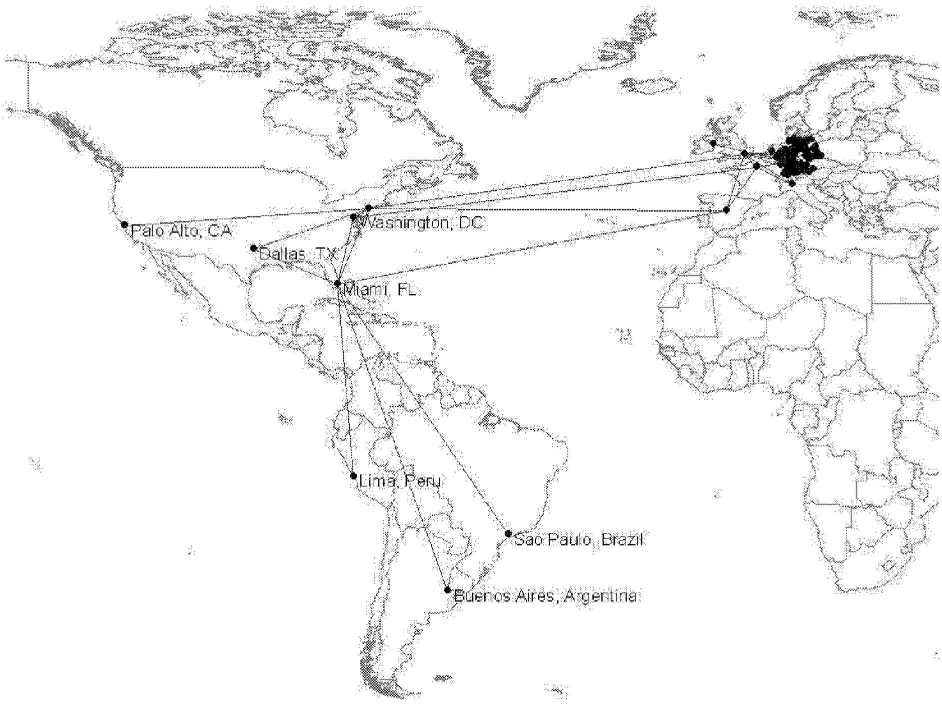

Figure 37: Worldview of the Telefónica Deutschland network discovered by IMS.

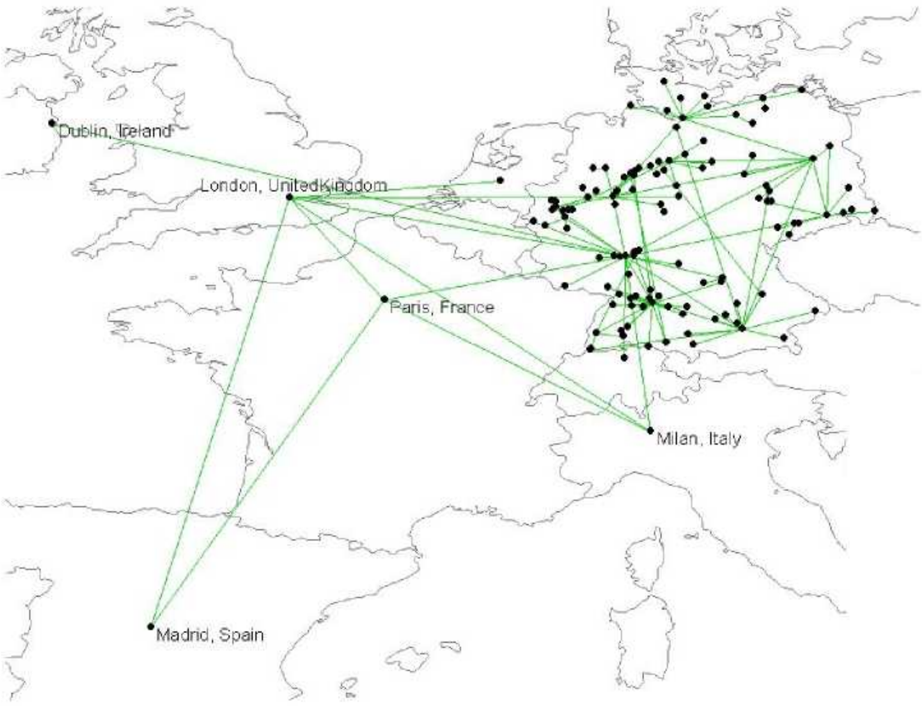

Figure 38: European part of the Telefónica Deutschland network discovered by IMS.

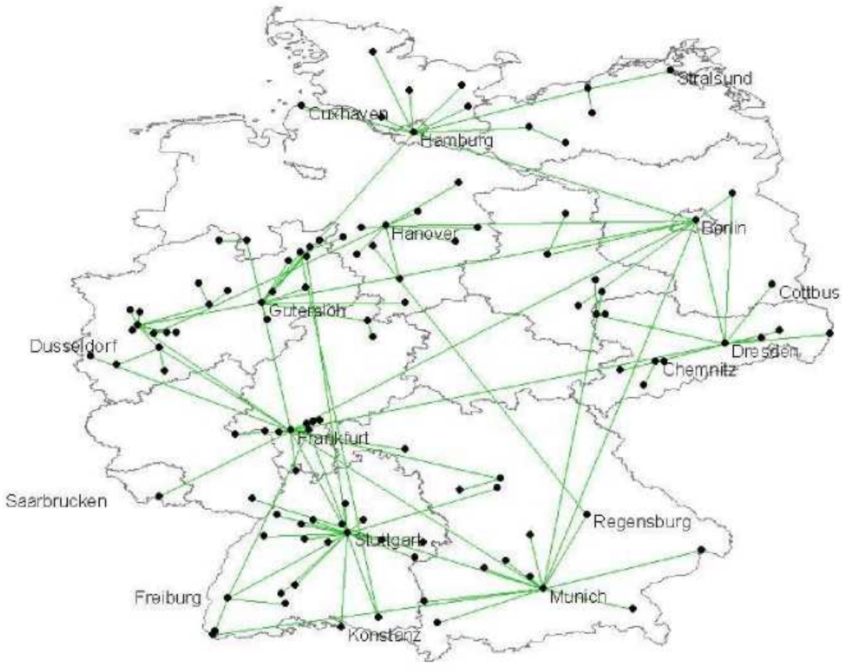

Figure 39: German part of the Telefónica Deutschland network discovered by IMS.

3.15 TeliaSonera

Table 43: Network characteristics of TeliaSonera.

Measurement	Figure
Number of linked cities	34
Number of connections	58
Density	0.10
Diameter	7
Mean closeness	0.35
Variance of mean closeness	0.004

Table 44: Top five cities with most connections in the TeliaSonera network.

City	Out degree
Frankfurt, Germany	0.42
Hamburg, Germany	0.33
Stockholm, Sweden	0.30
London, United Kingdom	0.18
Copenhagen, Denmark	0.15

Table 45: Top five cities with shortest paths in the TeliaSonera network.

City	Closeness
Frankfurt, Germany	0.49
Stockholm, Sweden	0.48
Hamburg, Germany	0.46
London, United Kingdom	0.45
Copenhagen, Denmark	0.43

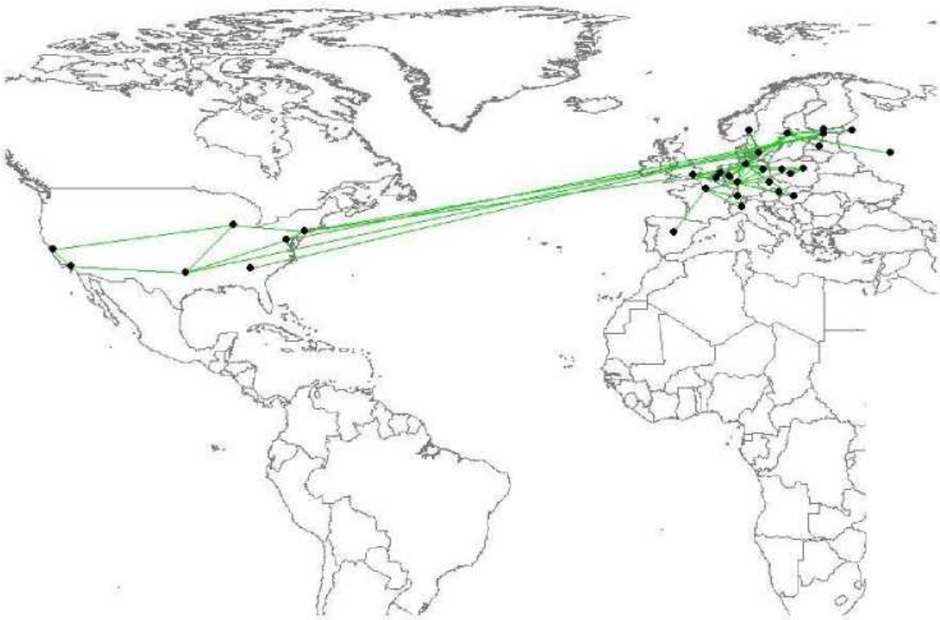

Figure 40: Worldview of the TeliaSonera network discovered by IMS.

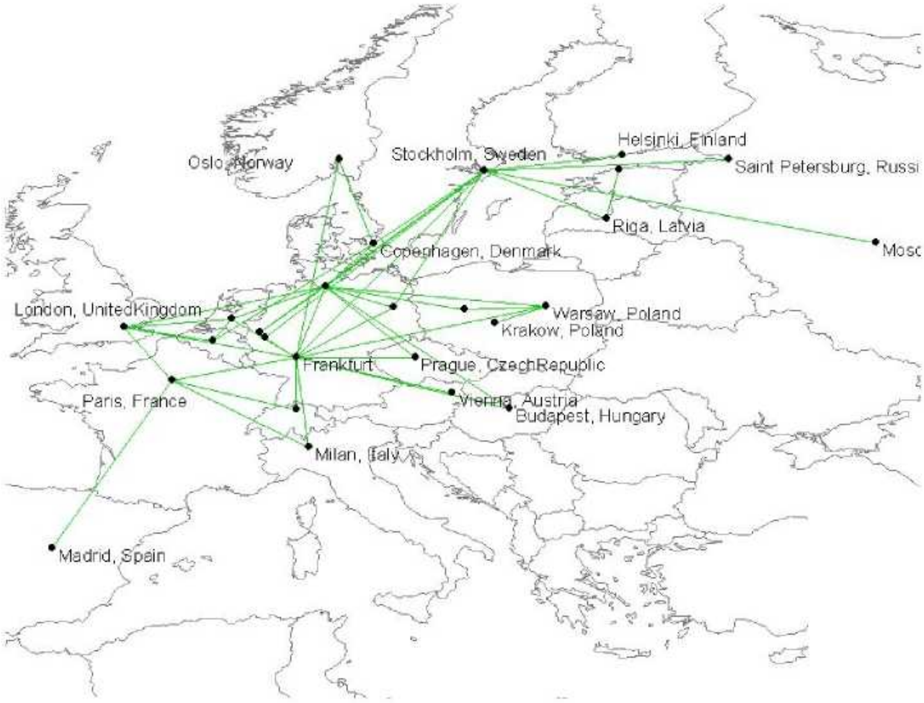

Figure 41: European part of the TeliaSonera network discovered by IMS.

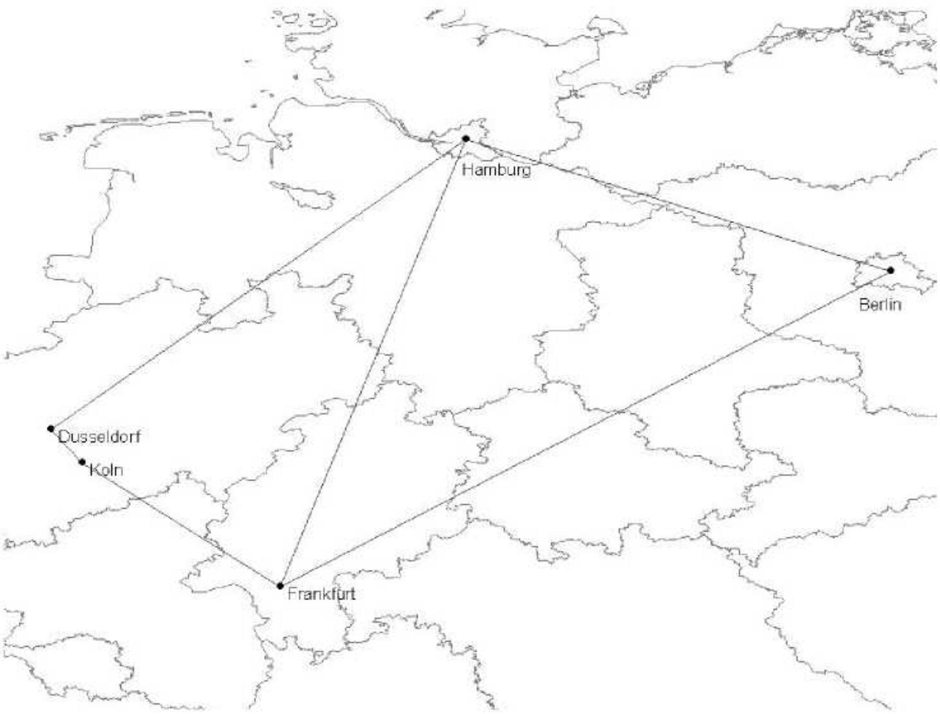

Figure 42: German part of the TeliaSonera network discovered by IMS.

3.16 Versatel Germany

Table 46: Network characteristics of Versatel Germany.

Measurement	Figure
Number of linked cities	8
Number of connections	16
Density	0.57
Diameter	3
Mean closeness	0.66
Variance of mean closeness	0.02

Table 47: Top five cities with most connections in the Versatel Germany network.

City	Out degree
Dortmund, Germany	0.86
Essen, Germany	0.71
Hamburg, Germany	0.71
Flensburg, Germany	0.57
Berlin, Germany	0.57

Table 48: Top five cities with shortest paths in the Versatel Germany network.

City	Closeness
Dortmund, Germany	0.88
Essen, Germany	0.78
Hamburg, Germany	0.70
Flensburg, Germany	0.64
Berlin, Germany	0.64

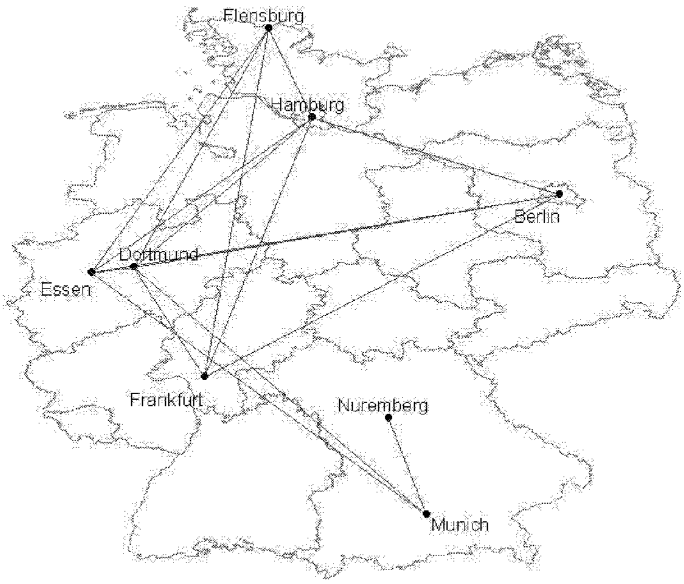

Figure 43: View of the Versatel Germany network discovered by IMS.

3.17 Viatel

Table 49: Network characteristics of Viatel.

Measurement	Figure
Number of linked cities	7
Number of connections	9
Density	0.43
Diameter	3
Mean closeness	0.59
Variance of mean closeness	0.004

Table 50: Top five cities with most connections in the Viatel network.

City	Out degree
Paris, France	0.50
London, United Kingdom	0.50
Egham, United Kingdom	0.50
Frankfurt, Germany	0.50
Zurich, Switzerland	0.33

Table 51: Top five cities with shortest paths in the Viatel network.

City	Closeness
Paris, France	0.67
Egham, United Kingdom	0.67
London, United Kingdom	0.60
Frankfurt, Germany	0.60
Amsterdam, Netherlands	0.60

Figure 44: Worldview of the Viatel network discovered by IMS.

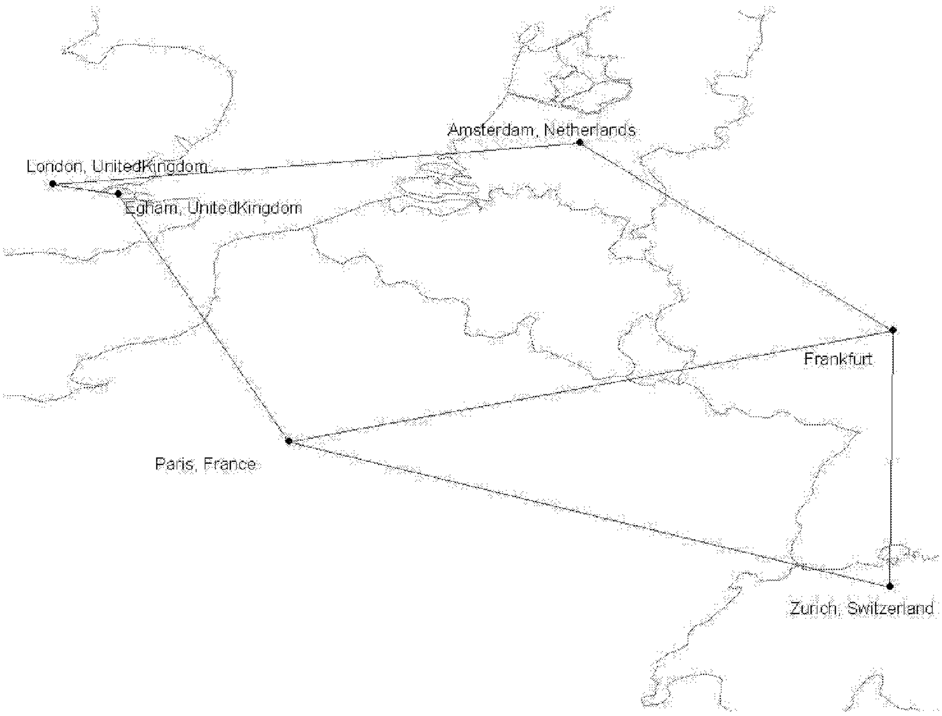

Figure 45: European part of the Viatel network discovered by IMS.

4 Comparing networks

A glance through the network characterization in section 3 reveals that the providers build networks with varying topological features. This section compares the network features of size, density and diameter.

The networks differ in size. The largest network IMS found connects 134 cities (Telefónica Deutschland), followed by DTAG (100) and MCI Worldcom (98), and the smallest, according to IMS, three (Ewe Tel). These numbers refer to the size of a networks. But due to the methodological limitations of IMS we have undoubtedly missed (some) cities in every network. Therefore the numbers given are at the lower bound of a network's size. *Figure 46* compares the providers by the number of linked cities.

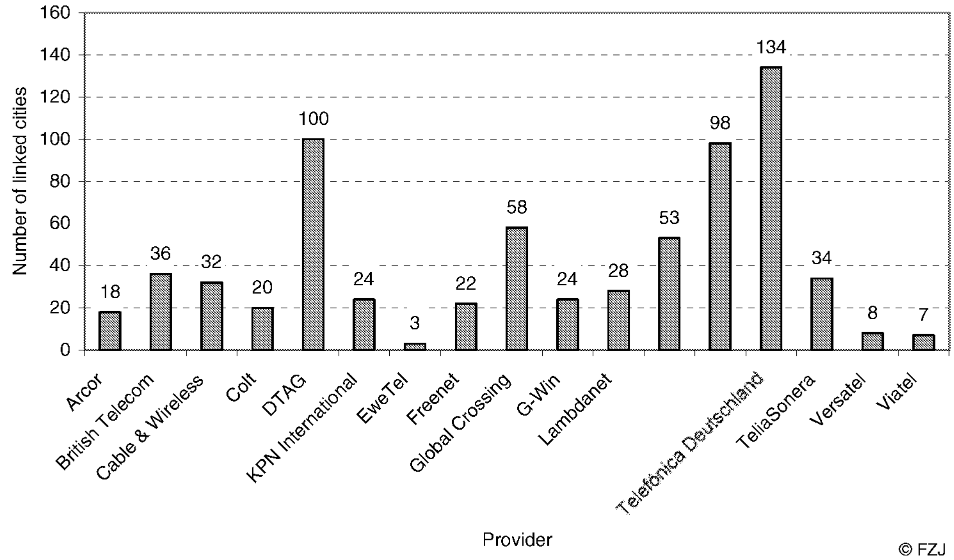

Figure 46: Number of linked cities by provider.

The number of linked cities is a measure for the area covered by the provider's network. As shown in section 3 providers have different topologies that cities belong to. Analysing topology is not a purely academic exercise. Network security is another reason. If, for example, the hub in a star topology fails, the network is disconnected. A mesh does not have such a centre, therefore its vulnerability is lower. On the other hand, a mesh needs more connections than a star, increasing the construction costs, especially for large networks, because the number of cities connected determines the required number of connections. Therefore, each provider has to consider a trade off between the risk of vulnerabilities and, on the other hand, the degree of redundancy and construction costs. *Figure 47* compares the network` densities, which describes the position of a particular topology between the two extremes of star and mesh.

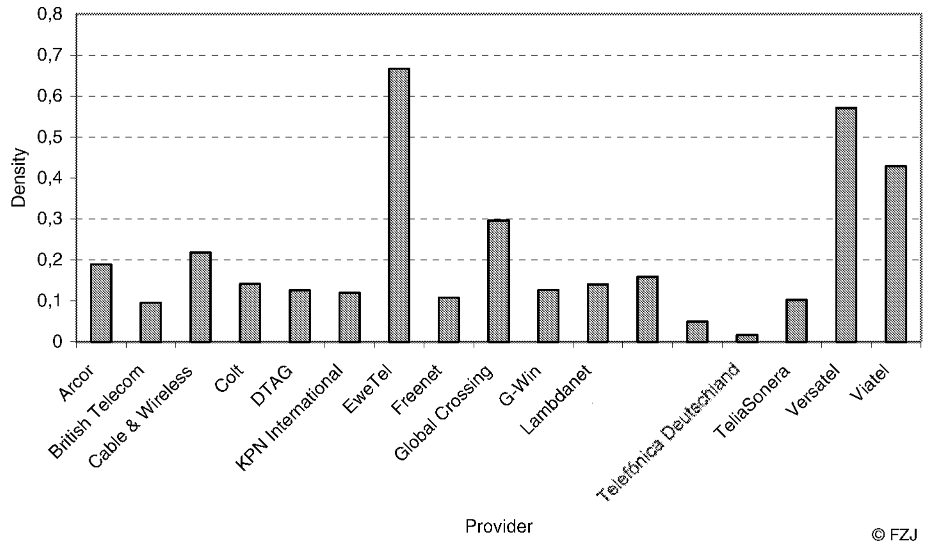

Figure 47: Network density by provider.

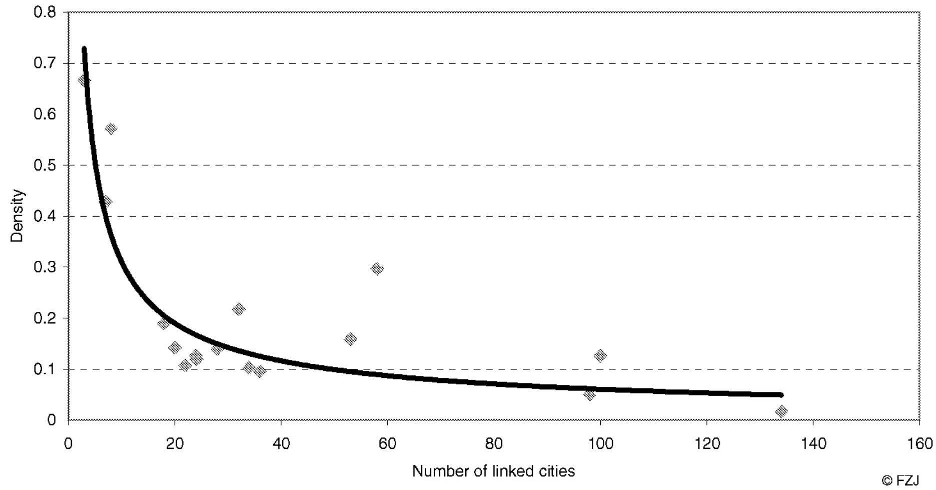

Figure 48: Comparing density and network size.

The network of Ewe Tel has the highest density because the network is tiny. Thus, the number of possible connections is very small. Ewe Tel links three cities. Thus, the minimal number of connections to link the cities is two and the density is 2/3. Adding one additional connection and the mesh is complete increasing the density to one. The number of possible connections increases exponentially by the number of linked cities. A network with 100 cities needs at least 99 connections. The density would be 99/9900, because the maximal possible number of connections is

9900. *Figure 48* shows the density in relation to the number of linked cities. Networks with many cities connected therefore tend to have a lower density than small networks. Maintaining a distinct density for reasons of redundancy and quality increases the number of connections required and the investment necessary to build and operate the network.

The challenge of network construction is to maintain a certain level of quality and redundancy without using too many connections even if the network grows. A common approach is to build into a network hub cities for particular regions. Cities in such a region are connected in a star-type topology. The network of Telefónica Deutschland (see Figure 39) illustrates such a topology.

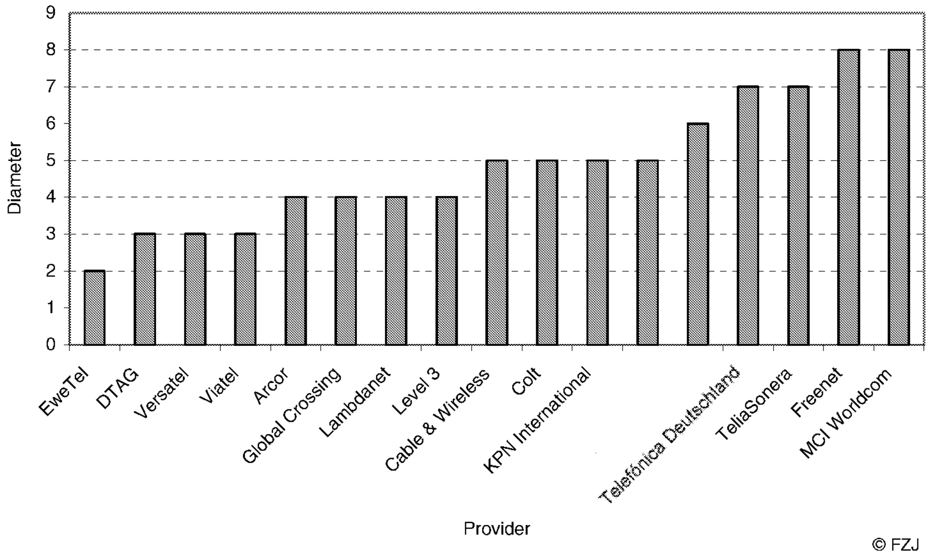

Figure 49: Classification of providers by diameter of their networks.

In a well-designed network paths are short. Each additional intermediate city increases the transmission time thus reducing the quality of service. The diameter measures the length of the longest path of all the shortest paths between the cities. In a network with a diameter of two, each city is directly connected with every other city (mesh topology). The transmission time is minimal because no intermediate city is required. *Figure 49* classifies the providers by the diameter of their networks. The network of Ewe Tel has a diameter of two, but the network of three cities is much smaller than the other networks. The DTAG operates one of the largest networks. Its diameter is three, which is a very low figure for such a large network, demonstrating the high connectivity DTAG has implemented. The other providers with comparable network sizes have higher diameters, revealing that these providers use different criteria than DTAG for the network construction. A possible reason is that DTAG, as the former state-owned monopolist built an expensive network, which has a short transmission time and high redundancy. The other providers are more or less "newcomers", entering the German market after deregulation. Economic considerations probably had a higher impact on network construction. An example is Telefónica Deutschland, having a strategy of access with minimal costs. *Table 52* classifies the providers by network size and diameter.

Table 52: Comparing networks size with diameter.

	Small network (<21)	**Medium network**	**Large network (>51)**
Low diameter (2 - 3)	Ewe Tel Versatel Viatel		DTAG
Medium diameter (4 - 6)	Arcor Colt	British Telecom Cable & Wireless KPN International G-Win Lambdanet	Global Crossing Level 3
Large diameter (7 - 8)		Freenet TeliaSonera	MCI Worldcom Telefónica Deutschland

From a user's perspective, which provider owns a network it is of no importance as long as at least the desired connections are available. This section investigates the connectivity in Germany and focuses on connections within Germany. Because we ignore paths between German cities via foreign cities, some cities actually have more connections than shown here. Therefore, we present the lower bound of connectivity in Germany.

Figure 53 shows the German part of the combined providers' network. Within Germany 483 connections link 160 cities resulting in a density of 0.038. Thus, 3.8% of possible connections are linked. Each city has a mean of six connections (variance: 162.7). The high variance indicates that the network is very heterogeneous regarding the number of connections. The diameter is five indicating that each pair of cities is linked via three additional German cities. *Figure 54* to *Figure 57* shows the combined network in regions of Germany.

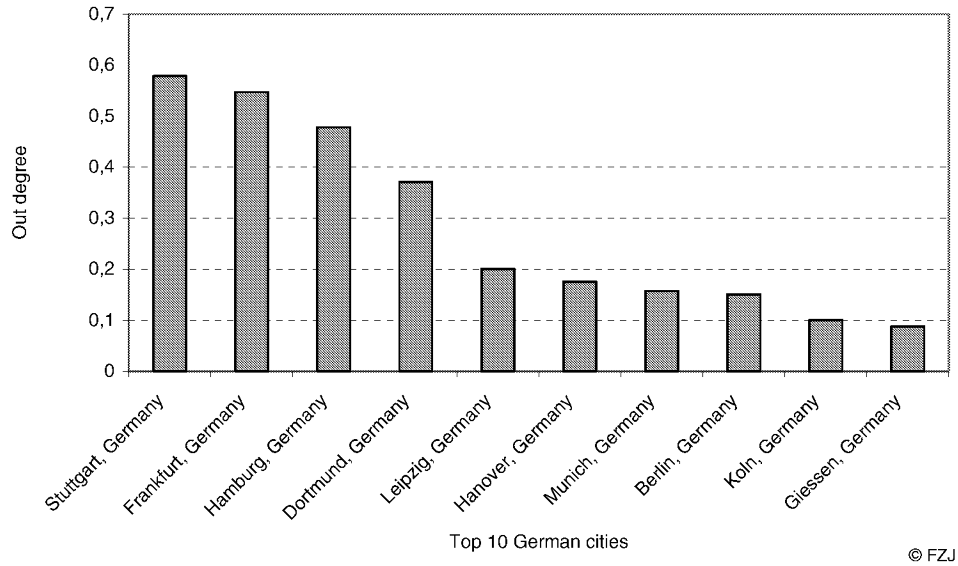

Figure 50: Top 10 German cities sorted by out degree.

Stuttgart, Frankfurt, Hamburg, Dortmund, Leipzig, Hanover, Munich, Berlin, Cologne and Gießen have the highest number of connections (*Figure 50*). Stuttgart, Frankfurt, Hamburg and Dortmund are hub cities in Germany, linking the other cities like spokes. They shape the topology of the German network, consisting of four stars, linking all cities. Within this topology Frankfurt and Stuttgart are the main hub cities, among other factors a consequence of the history of regulation. The former monopoly provider German Telekom constructed the network around Stuttgart. The new competitors chose Frankfurt as the centre of their networks. Thus, two hub cities have emerged in a geographically short distance. Probably economic competition and not a crafted design shaped this Internet topology, which has centres in the middle and south west of Germany. A crafted topology would be a more balanced one, e.g. with one main hub in the North and one in the South.

Stuttgart, Frankfurt, Hamburg, Dortmund and Leipzig have also the shortest path to other cities (*Figure 51*). Thus, their closeness is high and the order remains the same as in Figure 50.

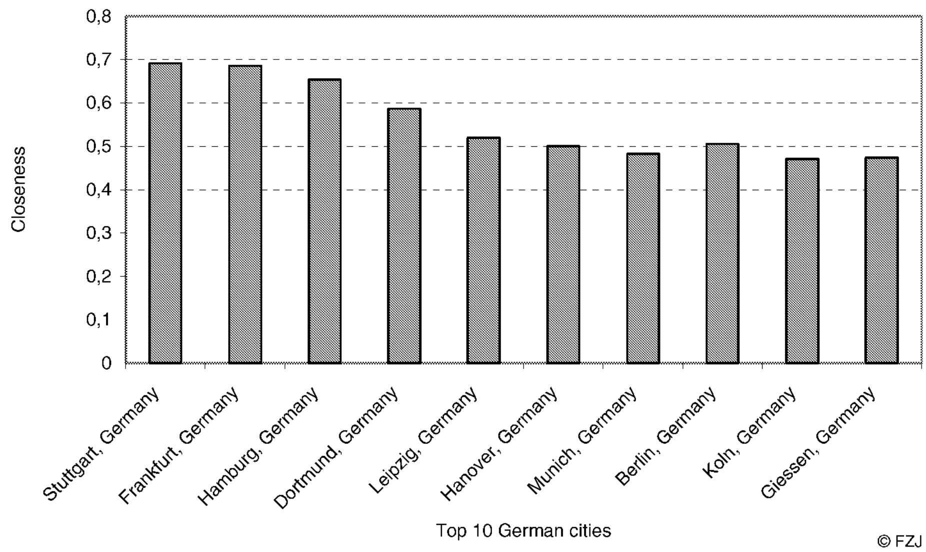

Figure 51: Top 10 German cities sorted by closeness.

A focus on the important connections and cities highlights the star topology. “Importance” depends on how often IMS found a connection. *Figure 58* shows connections only if IMS found them at least 10 times. Again the hubs Stuttgart and Frankfurt dominate the network topology.

The providers have to cooperate in some way to establish the German part of the Internet. Nevertheless, they compete on some “valuable” connections. IMS found two connections involving competition from eight providers: Cologne to Frankfurt and Frankfurt to Berlin. As *Figure 52* shows, according to IMS, 408 connections are exclusively operated by one provider. These are “monopoly connections”. (Of course these connections are not owned by one but different providers). Competition is concentrated on a few connections promising high turnover and profit. As shown in Figure 52, there are only a few connections involving strong competition. For example there is only one city where 16 providers compete. For 32 cities and 41 connections there is minimal competition (or an oligopoly situation): two providers operate competitive connections.

The situation is similar if we focus on cities. Frankfurt has 16 providers, Hamburg 13, Munich 12, Berlin and Hanover 10, Cologne 9 and Düsseldorf, Leipzig and Stuttgart have 8. Ninety-nine cities are “monopoly” cites, connected by only one provider each. Section 3 shows that the providers operated networks of different sizes. Therefore, cities with many providers are not necessarily hub cities, and cities with few providers are not necessarily unimportant from a topology perspective. The following figures show the number of providers in cities. *Figure 60* presents the results for Germany as a whole, *Figure 61* to *Figure 72* for each Federal State (without City-States).

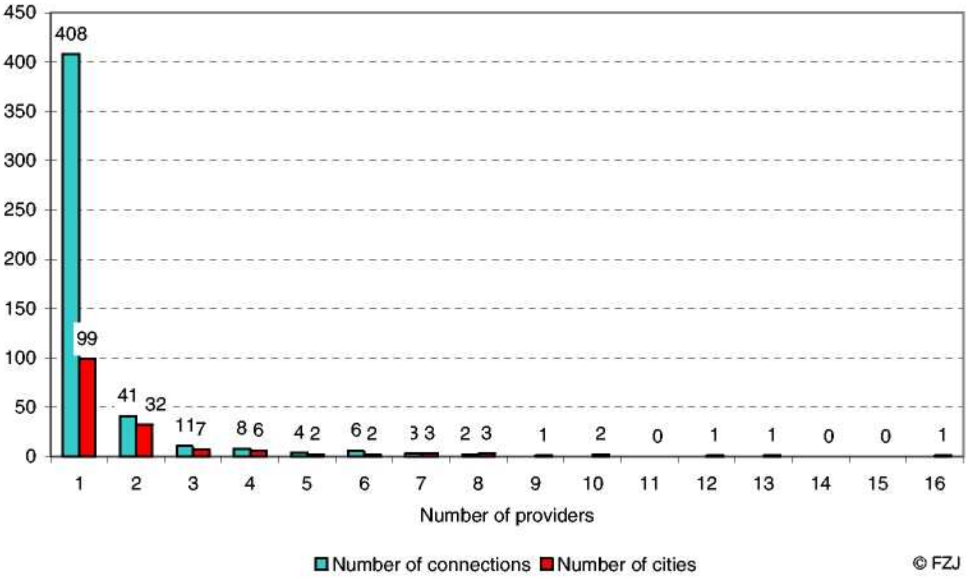

Figure 52: Number of connections and cities differentiated according to the number of operating providers.

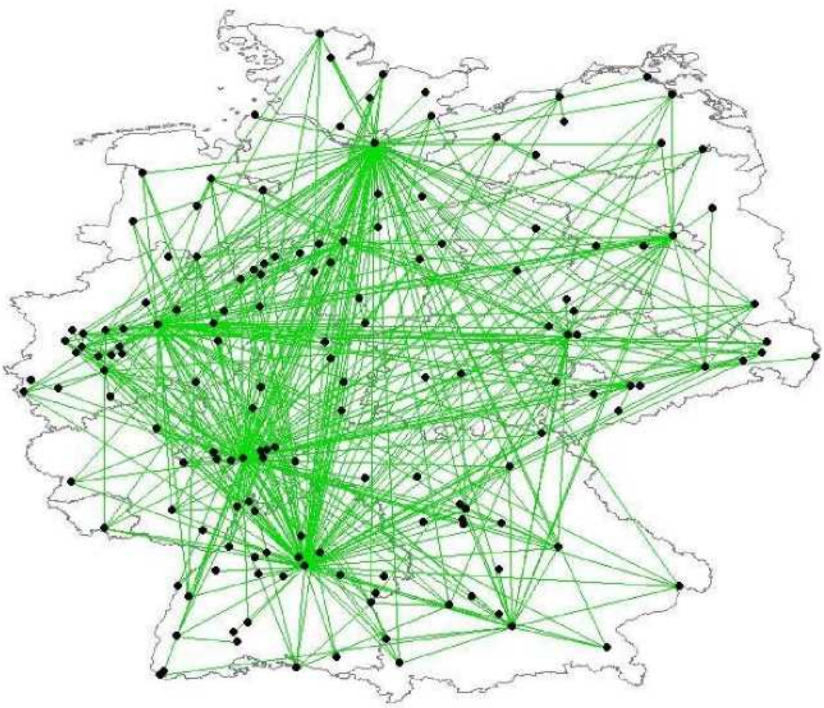

Figure 53: German part of the combined network.

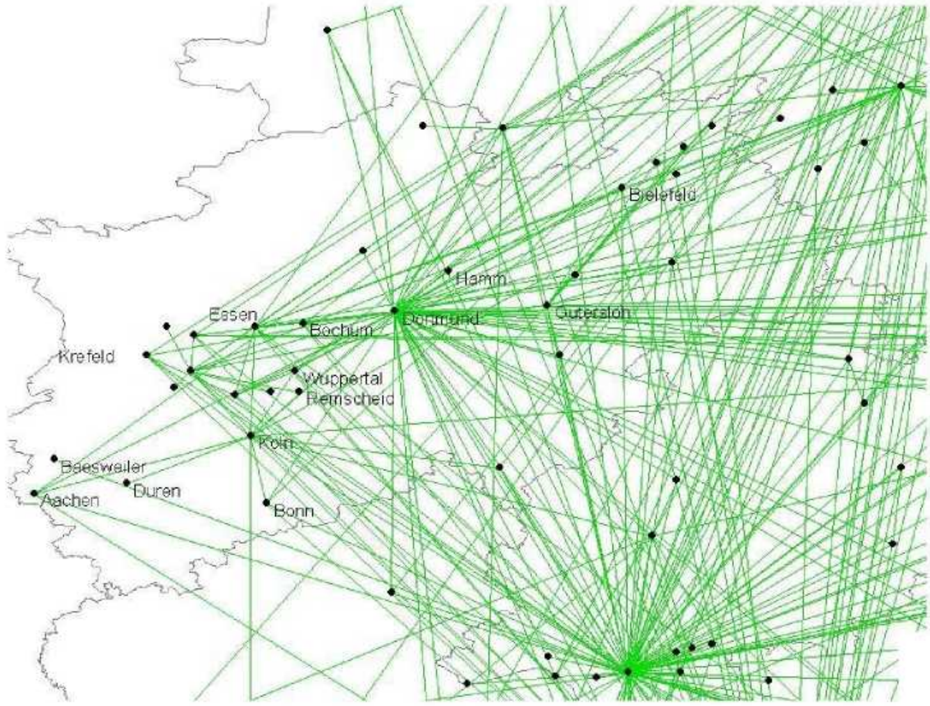

Figure 54: The combined network in the West.

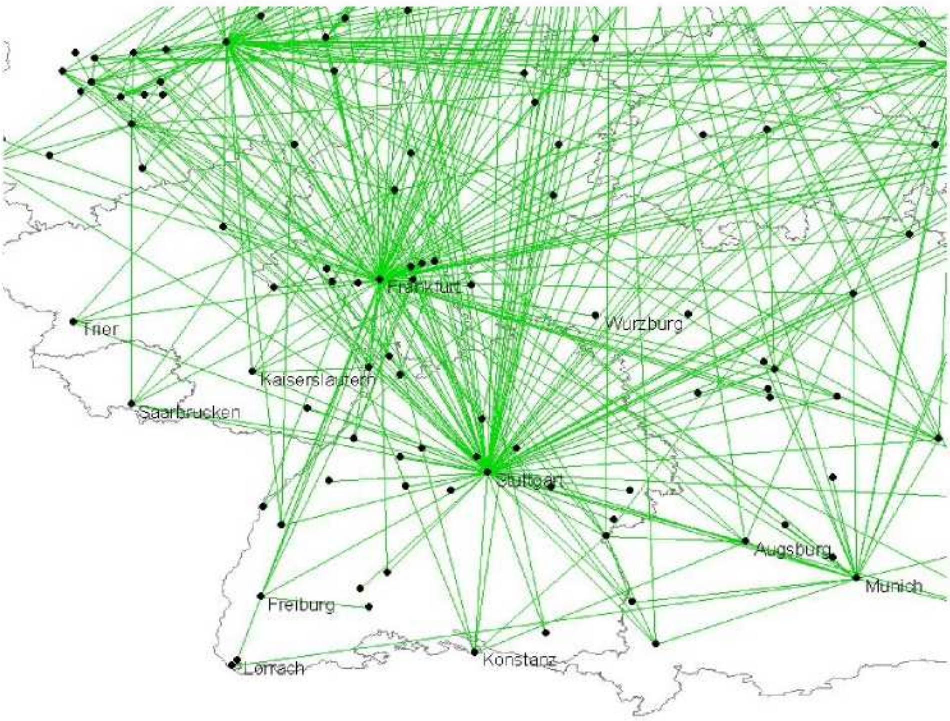

Figure 55: The combined network in the South (with the major hub cities Stuttgart and Frankfurt).

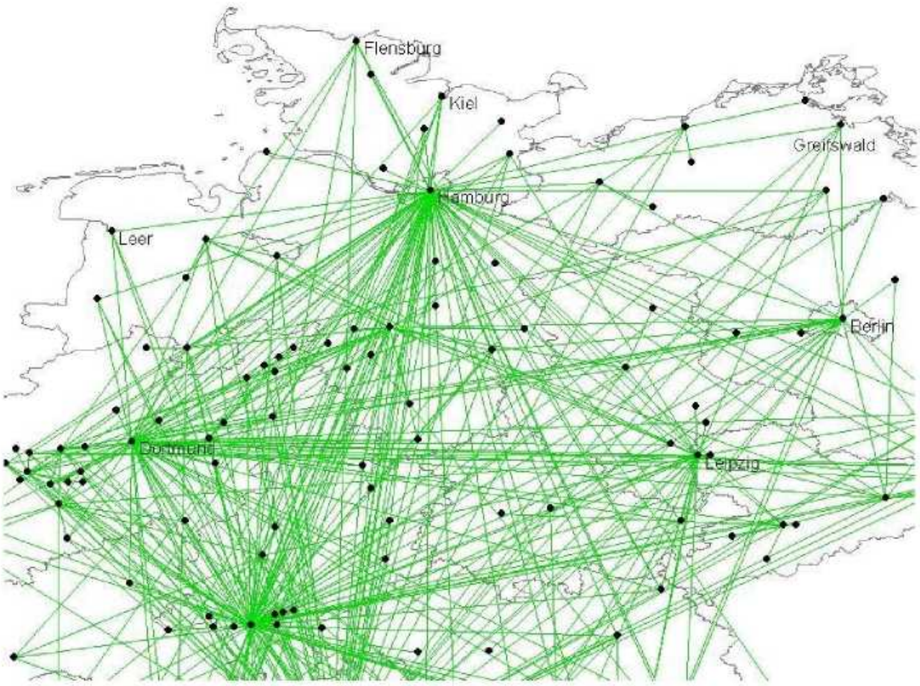

Figure 56: The combined network in central and northern Germany.

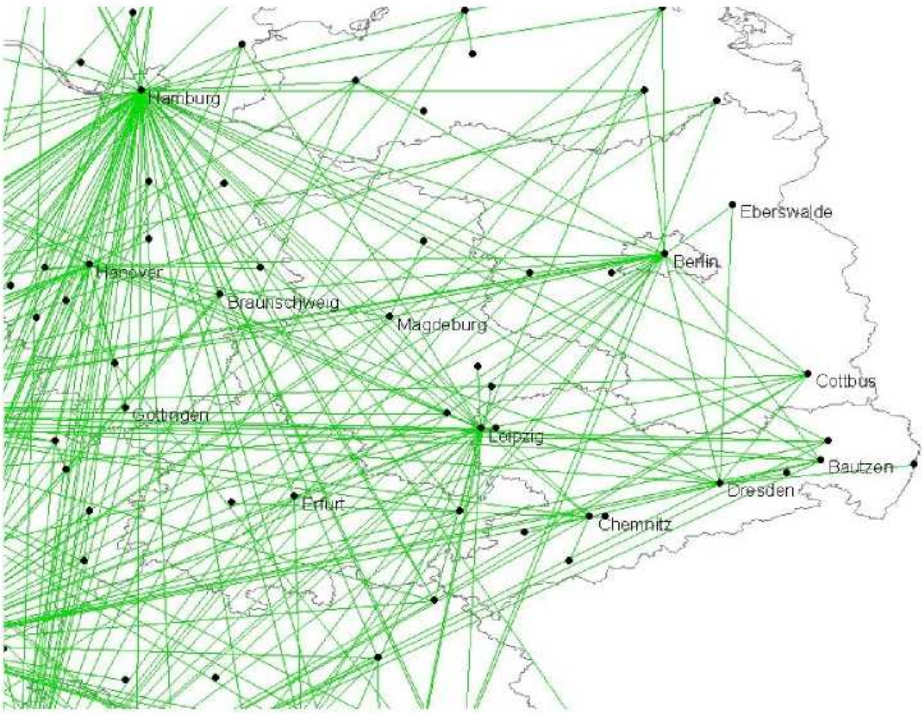

Figure 57: The combined network in the East.

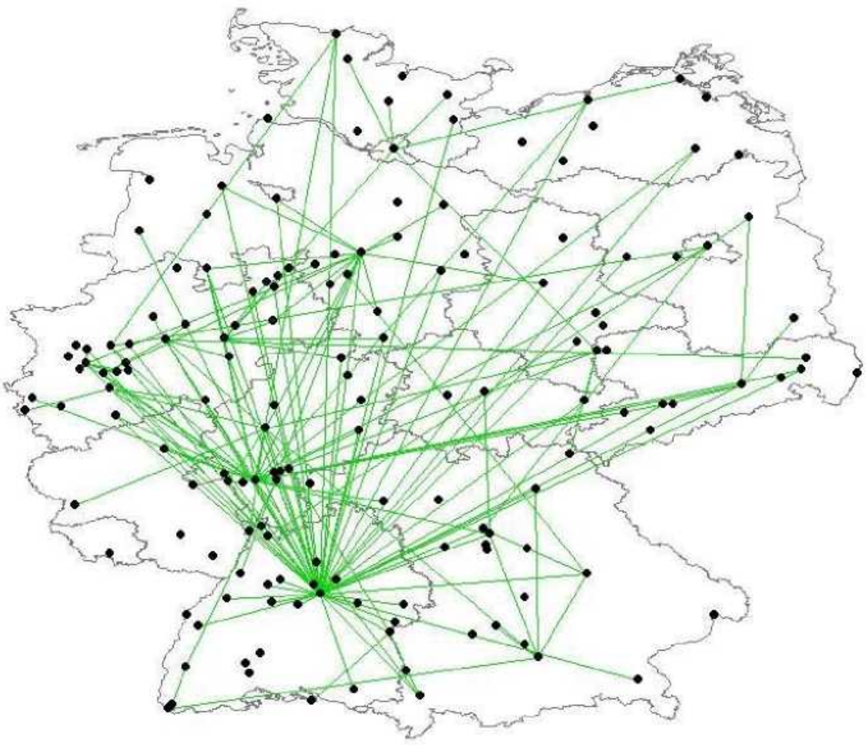

Figure 58: German connections of the combined network, which are found at least 10 times.

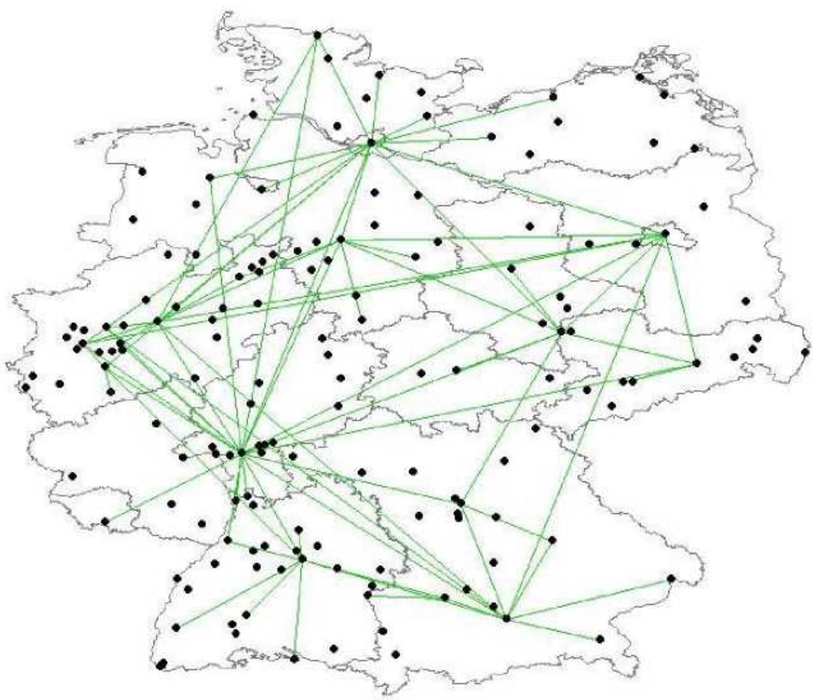

Figure 59: Connections in Germany facing competition.

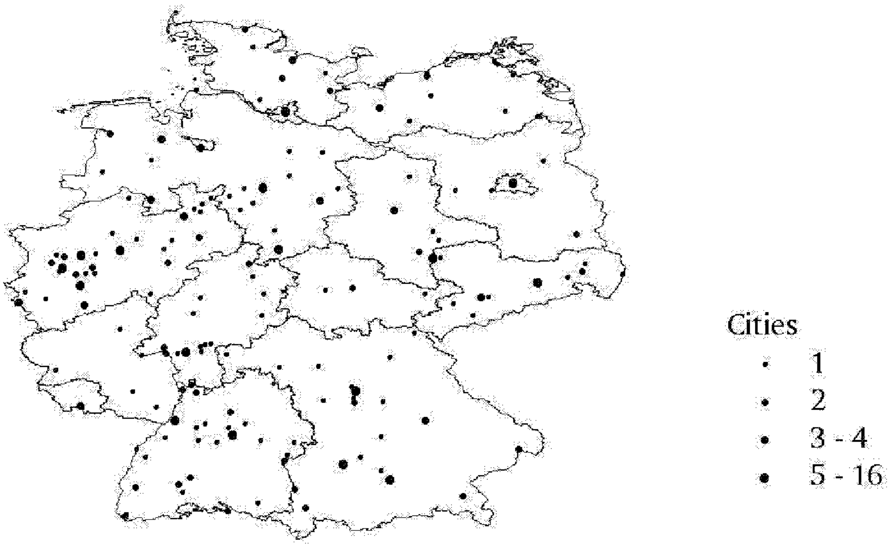

Figure 60: Cities differentiated according to the number of providers.

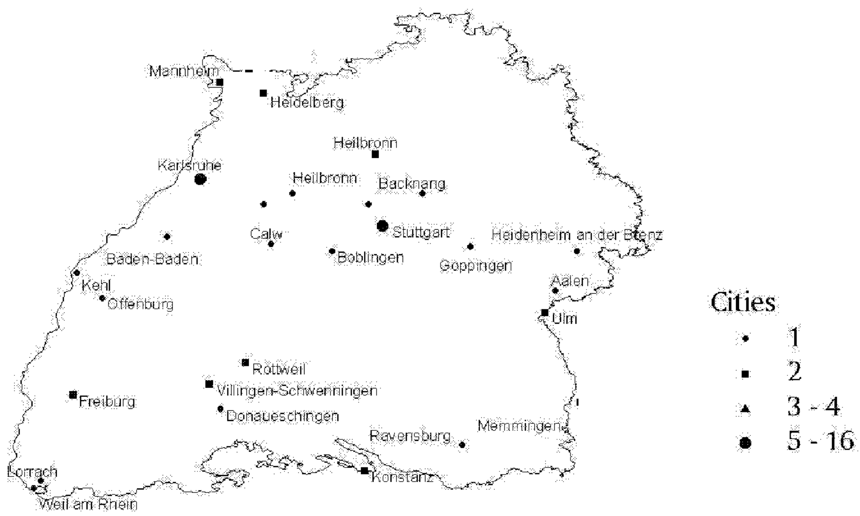

Figure 61: Cities in Baden-Württemberg differentiated according to the number of providers.

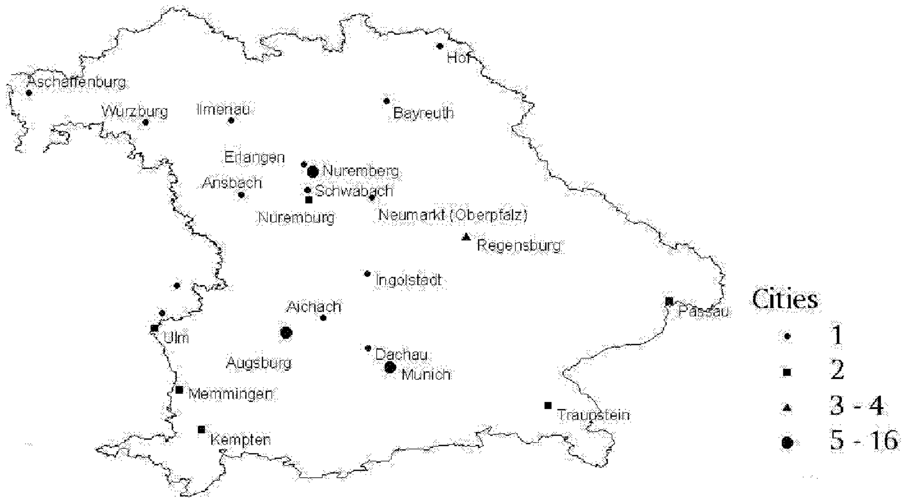

Figure 62: Cities in Bavaria differentiated according to the number of providers.

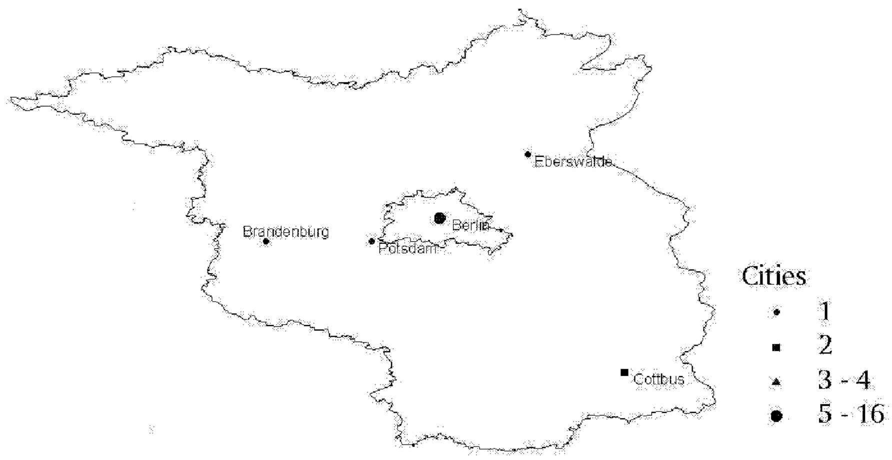

Figure 63: Cities in Brandenburg differentiated according to the number of providers.

Figure 64: Cities in Hesse differentiated according to the number of providers.

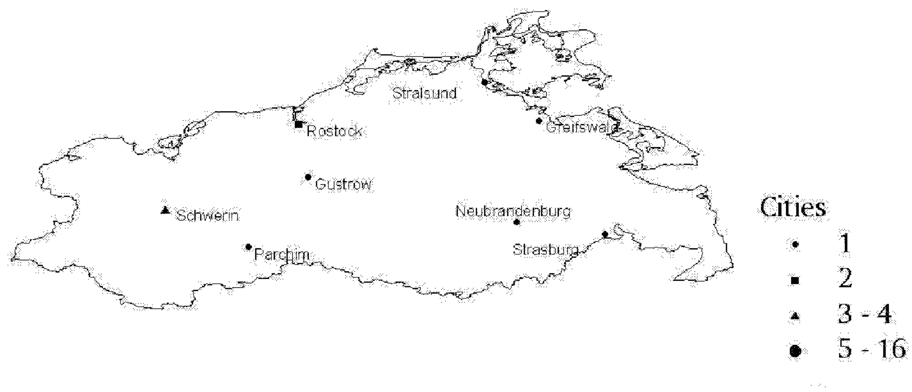

Figure 65: Cities in Mecklenburg-West Pomerania differentiated according to the number of providers.

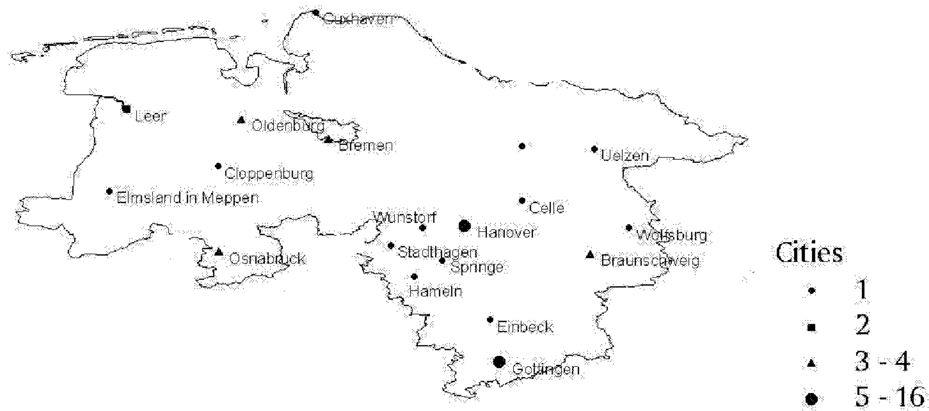

Figure 66: Cities in Lower Saxony differentiated according to the number of providers.

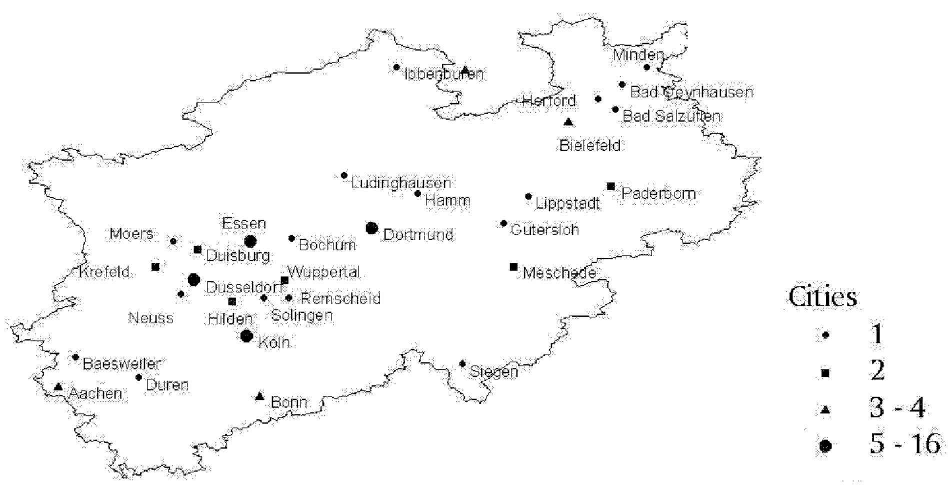

Figure 67: Cities in North Rhine-Westphalia differentiated according to the number of providers.

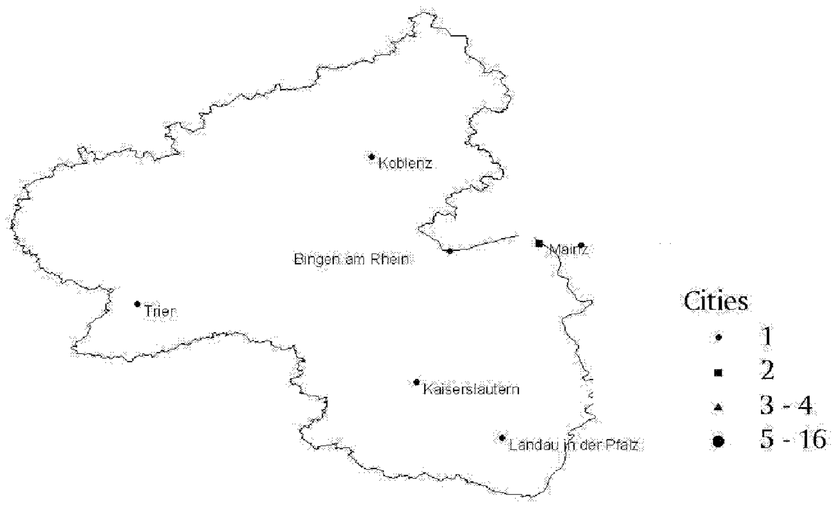

Figure 68: Cities in Rhineland-Palatinate differentiated according to the number of providers.

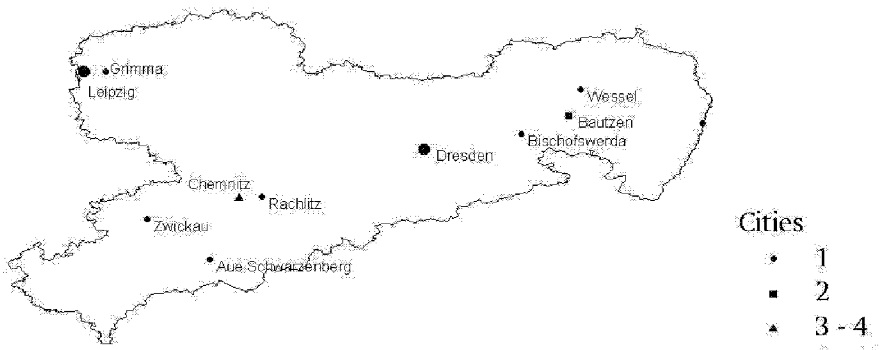

Figure 69: Cities in Saxony differentiated according to the number of providers.

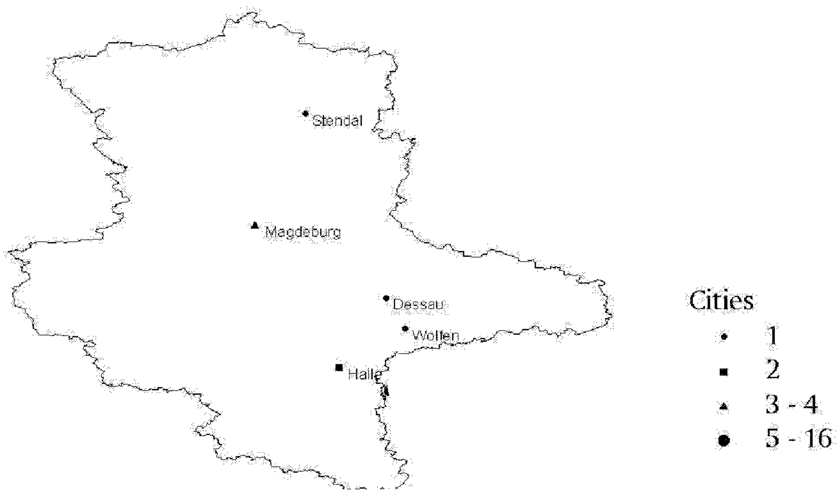

Figure 70: Cities in Saxony-Anhalt differentiated according to the number of providers.

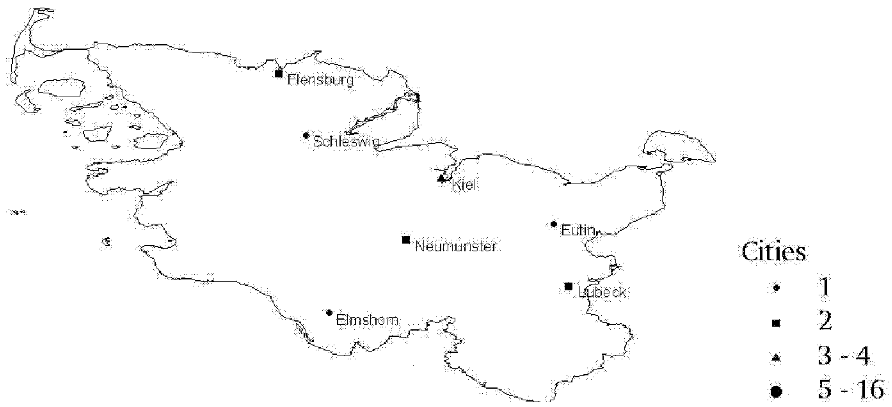

Figure 71: Cities in Schleswig-Holstein differentiated according to the number of providers.

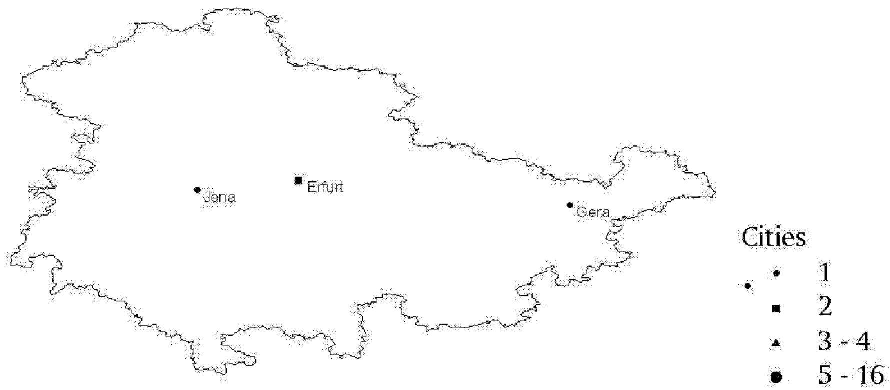

Figure 72: Cities in Thuringia differentiated according to the number of providers.

6 The German network in the European and Transatlantic context

The Internet in Germany is an integral part of the whole world-wide network. It is closely integrated into the European and the transatlantic network, linking Europe and the USA, the "home" of the Internet. Even if our focus was on Germany, IMS also collected data about the other parts of the Internet. This section presents a *first* illustration of the combined networks with particular reference to the USA, Europe and Germany. However, due to our methodology, our data about the USA, the European network and the rest of the world is *incomplete*. Therefore the connections shown in the figures represent only a *part* of the "real-world" connections (a figure we do not know). Therefore, all the following figures offer only a glimpse of the word-wide net. Nevertheless, we are pretty sure that we have identified *important* connections. Again in the figures, connections between the combined regional networks are omitted as in Section 5.

The providers' networks discovered by IMS are merged into one network consisting of 322 cities and 1633 connections world-wide. *Figure 73* gives an impression of that "world"-network. The Internet has two world-centres: the USA and Europe. Japan is a second-order world-centre. *Figure 74* shows the US-network discovered by IMS consisting of 73 cities and 382 connections. The European network consisting of 222 cities and 713 connections is shown in *Figure 75*.

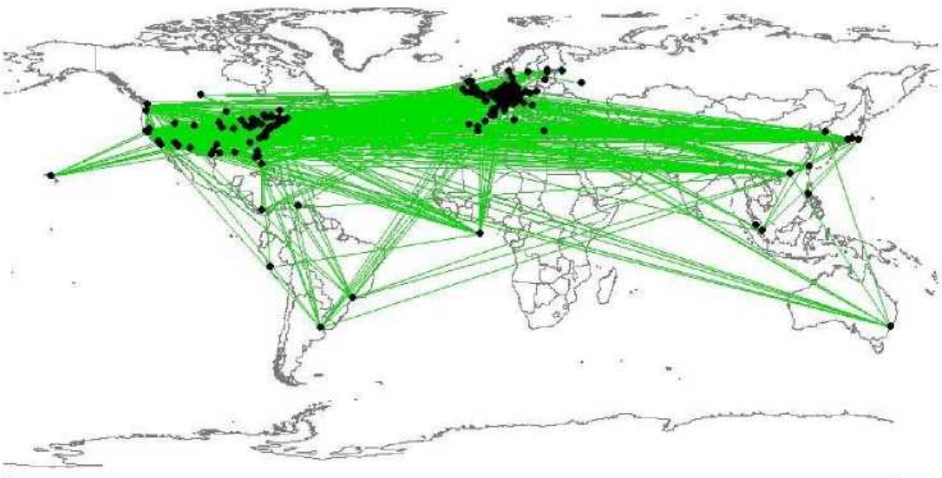

Figure 73: Global view of combined network.

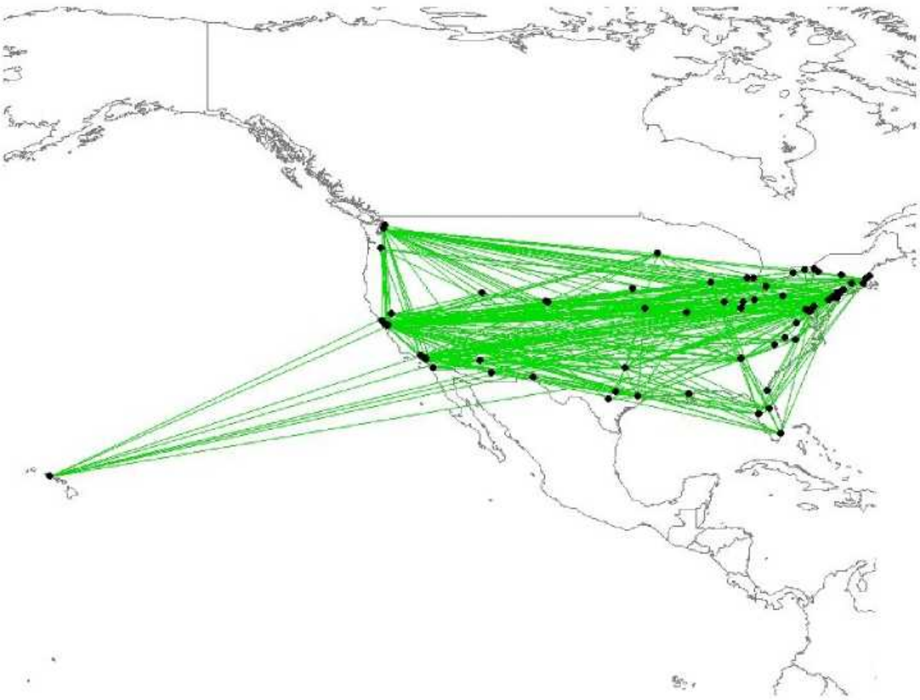

Figure 74: Combined US network.

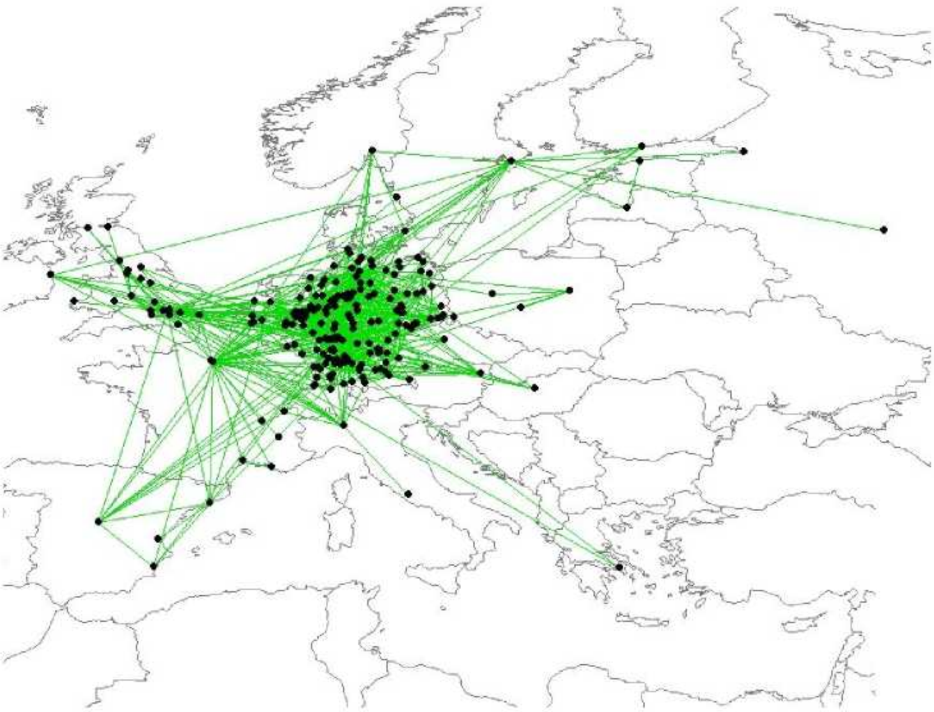

Figure 75: Combined European network.

7 References

Dodge , Martin; Kitchin , Rob (2001): Atlas of cyberspace Harlow: Addison-Wesley.

Gorman, Sean P.; Malecki, Edward J. (2000): The networks of the Internet: an analysis of provider networks in the USA. Telecommunications Policy, Vol. 24, No. 2., pp. 113-134.

Govindan, Ramesh; Tangmunarunkit, Hongsuda (2000): Heuristics for Internet Map Discovery. IEEE INFOCOM 2000. www.ieee-infocom.org/.

Spring, Neil; Wetherall David; Anderson, Tom (2003): Scriptroute: A Public Internet Measurement Facility. www.usenix.org/events/usits03/tech/spring.html.

Spring, Neil; Mahajan, Ratul; Wetherall, David (2002): ACM SIGCOMM. www.acm.org/sigs/sigcomm/.

Telegeography (2000): Hubs and Spokes. Telegeography Internet Reader. Washington: Telegeography. www.telegeography.com/.

Telegeography (2001): International Bandwidth 2001. CD-ROM. Washington: Telegeography.

Telegeography (2001b): Packet Geography 2002. Washington: Telegeography.

Telegeography (2002a): US Internet Geography 2003. CD-ROM. Washington: Telegeography.

Telegeography (2002b): Terrestrial Bandwidth 2003. CD-ROM. Washington: Telegeography.

Telegeography (2002c): Global Internet Geography 2003. CD-ROM. Washington: Telegeography.

Telegeography (2003): Global Geographic Internet Database and Report 2004. Washington: Telegeography.

Wasserman, Stanley; Faust, Katherine (1999): Social Network Analysis: Methods and Applications. 5th edition. New York et al. Cambridge University Press.

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It is to a large extent unknown how the topology of the German part of the world-wide Internet looks like. This Atlas is a first step to close that information gap. It shows the networks of the most important providers in Germany, the combined network for Germany and its regions and the German Internet as an integral part of the world-wide network.

Many of the issues at the centre of public attention can only be dealt with by an interdisciplinary systems analysis. Scientific, economic and ecological subsystems which interact with each other often have to be investigated simultaneously. The Programme Group Systems Analysis and Technology Evaluation (STE) takes up this approach and concentrates its work on issues concerning the long-term orientation of the energy economy, on selected economically or ecologically relevant material flows in the technosphere and geosphere as well as on electronic information processing and communications and the changes in society brought about by these technologies. In these fields, STE analyses the consequences of technical developments and provides scientific aids to decision making for politics and industry. This work is based on the further methodological development of systems analysis tools and their application as well as cooperation between scientists from different disciplines.

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