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Computer Networks on Copper Cables

From 'Promises to the Public' to 'Profits for Providers'

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Abstract
The history of computing often comes across as a history of fundamental social and economic transformation which culminated in the digital era. The literature usually presents computers and digital networks as innovations of an epoch-making character. The 1970s and 1980s, in particular, are judged to have been a period in which highly innovative engineers opened the way to the digital future. Packet-switching and protocols like X25 enabled electronic data interchange between computers and launched digital communication's triumphal march. Such stories often omit the role played by older technologies, which were hidden in a physical infrastructure that was underground. Computers, especially household computers, were interconnected by the physical infrastructure of the telephone network which, in the 1970s and 1980s, was often decades old. The double-core copper cables which were the backbone of telephone networks were the core element in the early 'information highways' in large public digital communication networks.
The aim of this paper is to discuss the role played by public telephone network twisted pair copper cable infrastructures in the history of large scale data communication networks for mass users in Europe. The paper raises a number of questions: what was the extent of copper cables' impact on the emergence of data and computer networks for the general public? Why was an old copper cable infrastructure chosen as the basis for such networks? How were investments in infrastructure justified? What role did 'analogue technologies' play in the transformation of societies and economies into the digital era?
I would argue that copper cables, and twisted pair cables in particular, were chosen as the basis for data networks for many and varying reasons. In the 1980s they constituted a promise to the public, which fully accorded with monopoly obligations. The telephone network was the only network capable of providing nationwide coverage within a short time frame and at acceptable costs for users. After the telecommunication markets were privatized and the internet had triumphed this changed completely. From then on copper cables on the 'last mile' meant profits for providers. The invention of DSL technologies allowed for high transmission rates without investment in fibre optic cables on

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this part of the network being required. Private companies and stake holders preferred to make profits from an old but inexpensive copper network rather than investing in expensive fibre optic cables. In the long run this turned out to be an obstacle to high speed connections as transmission rates are still very low as compared with those of networks consisting solely of fibre-optic cables.

The history of computing is often told as a story of fundamental social and economic transformation. The literature usually presents computers and digital networks as innovations of an epoch-making character, impacting on people's everyday lives (Balbi & Magaudda, 2018; O'Regan, 2016; Haigh, 2016; Albers, 2014; Ceruzzi, 2003; Abbate, 2000). The 1970s and 1980s, in particular, are judged to have been a period in which highly innovative engineers opened the way to the digital future (Castells, 2002). Data processing, packet-switching and protocols like X.25 enabled electronic data interchange between computers to take place and launched digital communication's triumphal march.[1] Such stories often omit the role of 'old' technologies, which were hidden in a physical infrastructure that was underground. This is unfortunate as the impact of this infrastructure on computer networks' transmission capacities and thus performance was highly significant. Household computers in particular were connected up by the telephone network's physical infrastructure which did not change in the 1970s and 1980s. The twisted pair copper cables which were the backbone of telephone networks were the core element in early 'information highways' in large public digital communication networks. Therefore, the roots of computer network development lie in the development of computers as well as in the development of the network infrastructures they use.

The aim of this paper is to discuss the role played by twisted pair copper cable infrastructures in the history of large scale mass user data communication networks in Europe. The focus is on the public telephone network because this was the most important mass communication network for the wider public. This paper zooms in on the household and its computer network connectedness. Of course, there were also other networks too, which served particular companies or paying customers (in large cities). These networks, however, will only be mentioned in passing.

The paper will raise a number of questions: what was the extent of copper cables' impact on the emergence of data and computer networks for the general public? Why was an old copper cable infrastructure chosen as the basis for such networks? How was investment in infrastructure

1 See, for example: Thematic Focus: Fundaments of Digitization, in: Media in Action, Issue 01/2017 (www001.zimt.uni-siegen.de/ojs/index.php/mia/issue/view/1).

justified? What role did 'analogue technologies' play in the social and economic transformation to the digital era?

To answer these questions this paper will begin by considering some of the basic characteristics of telephone networks and then move on to a discussion of what has determined and developed (trans-border) telephone networks from their 1970s origins to their digitization. Thirdly, the emergence of mass user data communication networks in the 1980s and their subsequent transmission capacity increases will be discussed. Finally, conclusions will be drawn.

It must be stressed that telephone networks for computer communication developed variously within Europe, however, within the same model (Noam, 2002). Here, my main reference is the German example because Germany played an important role in the development of data communication networks in Europe and even today its share of twisted pair copper cables in the overall European network is still the highest. Germany has the largest net technologies market in Europe and was the driving force behind the Integrated Services Digital Network (ISDN), which has played a key role in European development.

Some basic telephone network technical and institutional characteristics

What are the components of a telephone network? In terms of material parts, telephone networks consist of four major components: cables (local loops and trunk lines), switches, amplifiers and end devices. Of course, cables were supplemented by radio links as part of the overall network. In this paper, however, the focus is on the cables, which were the backbone of telephone networks.

National telephone networks usually consist of various network levels. In Germany, for example, the national network was made up of four levels in the 1970s: a supra-regional network, a medium regional level, a lower regional network and a local network. For users these four levels are a unit. Technically speaking, however, they are separate entities and switching between the various network levels is a crucial factor in transmissions—especially when different types of cables are involved. Significantly, it is the technically weakest link in the networks which determines transmission rates for end user (Hars, 1989).

Replacing a widely ramified network is a difficult matter and one which requires significant investment costs. Switches and amplifier relays have to be replaced as do the various cables. The bulk of this infrastructure is generally underground and this makes it even more difficult and

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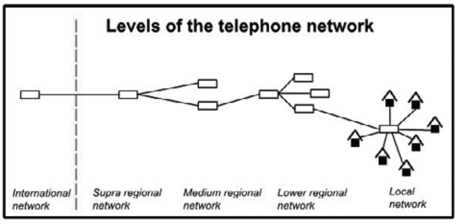

Graph 1: The various levels of a telephone network.

expensive to install. In particular, in densely populated areas, road surfaces needed to be dug up and lines into numerous households replaced. The 'last mile'—the distance between the last service area interface and the household—is often the weak link in a mass user network. Here, of course, the investment involved is much more critical as the cables etc. are much more ramified, much higher in number and frequently underneath a quantity of urban infrastructure and buildings. By contrast long distance regional network lines are multi-fibre cables on which a large number of transmissions are channelled via the same cable. These investment costs are labelled 'sunk costs' because they require large scale investments and lengthy time frames before investments pay off. Economically speaking, long term use of such networks is desirable for telecommunication service providers. Rapid technical development is usually regarded as a threat to sunk costs (Russel, 2018).

Telephone networks on copper cables, like infrastructure in general, are prone to path dependencies. Once a technical path and its system characteristics has been chosen, it is difficult to change track. Components need to be (backwards) compatible with other network elements—and also with the numerous end devices (Ambrosius, 2015).

Technology cannot alone tell the (home) computer networks on copper cables story. The market structure for telecommunication services in the 1970s was equally important. Across Europe national monopoly service providers operated all telecommunication networks but did so, however, under various types of public service rule constraints. In Germany, for example, the Bundespost owned all the equipment including home telephones themselves which were hired from the monopoly firm until the 1980s. As a public service institution the Bundespost was subject to legal restrictions in its investment decisions and technological policies. Statutory provisions required the Bundespost not to invest in risk capital and it was obliged to offer the same type of service for the same price nation-wide within the telephone network. Moreover, it had to offer reduced price services to the economically disadvantaged (Staab, 1980). Consequently, European monopoly firms in the telecommunication sector

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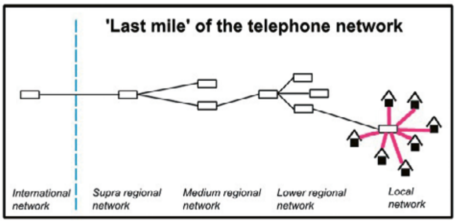
Graph 2: The 'last mile' of a telephone network.



had to 'think technology', technical change and technical innovations in terms of nation-wide function and affordability (Noam, 1992). Improving the existing infrastructure technically and economically was the paramount objective as compared to the introduction of new services and products. This was still the case when digital transmissions technologies entered the telecommunication equipment market in the 1970s and 1980s. This 'thinking technology' logic is the key to understanding developments surrounding copper cables. In this respect Europe differed remarkably from private service providers in the US, where 'public service' has never been such a powerful concept.

Telephone networks on copper cables

The origins and development of telephone networks

Telephone networks were first set up in the late 19th century as small local networks with limited numbers of subscribers. Cables were generally single line copper cables with a limited capacity. The interwar period saw the next step in network development, when long-distance cables were installed to connect up European regions and nations (Wheen, 2011). It was in the 1950s and 1960s, then, that the true breakthrough in the creation of wide ranging telephone networks took place across Europe. Automatic switching, duplex use of cables and other technical innovations increased networks' efficiency, reduced costs and thus enabled more and more people to be connected to and use telephone networks. Subscriber numbers exploded, reaching close to nation-wide coverage. Almost all households were connected to it, wherever they were (Ahr, 2013).

In the 1950s and 1960s the various telephone network lines were made up of twisted pair copper cables in the lower regional and local networks and coaxial cables in the upper regional and long distance networks. Transmissions were analogue and thus the switches and amplifiers processing analogue transmissions used in the networks were also analogue.

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It was a limited capacity system, sufficient for voice transmission but capable of hosting only very limited data communication volume at a low capacity (Chapuis & Joel, 1990).

Digitization of the telephone network

The introduction of the F1 transmission system by the Bell laboratories in 1962 was a milestone in the subsequent development of data communication networks on telephone lines. The F1 system allowed twisted pair copper cables to be used for digital transmissions for the first time and, therefore, took an important step closer to mass user data communication. For the transmission of signals, Pulse-Code-Modulation replaced frequency division multiplexing on analogue lines. The new technology promised numerous advantages: it was less prone to interference and was space-saving and labor intensive, making for faster link connections, increased capacities and thus reduced telephone network running costs by up to approximately 40%. Even better, only the switches needed to be renewed (Elias, 1977). 'Analogue technologies' like numerous telephones could be used even under digital transmission conditions. Analogue signals were simply switched to digital ones. Therefore, in the 1970s many European post and telecommunication administrations decided to digitize their telephone networks. At that time, however, hardly anyone had digital data communication networks in the back of their minds.[2]

Alongside switch digitization, a revolution in cable technology was also looming in the 1970s, with fibre optic cables containing a number of optical fibres capable of carrying light. The first generation of these was no better than copper cables in capacity terms (this was only the case later, in the 1980s) but reduced the space requirements and costs involved in running and maintaining a network. Fibre-optic cables promised economic efficiency and the European PTT administrations therefore began replacing copper cables in long-distance lines in the late 1970s. Europe's upper and the lower regional lines followed, in the 1980s and 1990s. In the local networks, however, many twisted pair copper cable lines remained—in particular the last part connecting up individual households. Renewing local networks was simply too expensive at that time.

To sum up, in the 1970s the European monopoly administrations decided to digitize their telephone networks solely for economic reasons. This decreased telephone service costs and was a promise to the public. Increasing the network's efficiency also fully complied with monopoly firm obligations.

2 See: CCITT documents, ITU archives (Geneva).

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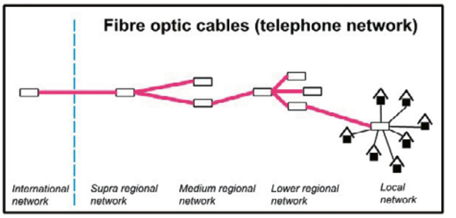
Graph 3: Fibre optics in the telephone network (1990s).



National telecommunication policies and data networks on copper cables

Closed data communication networks

When data communication network digitization was decided upon, in particular for text-messaging, data communication networks had co-existed alongside telephone networks for decades. Telex networks had been operational since the 1930s, when the German Reichspost had introduced the service, however telex had only a limited number of subscribers—mostly companies and local authorities. After WWII the service spread across Europe and the world for text-message transmission. Capable of delivering information at a rate of 50 bauds, the telex system later replaced 19th century telegraph systems. It was capable of transmitting 66 words per minute and was, at least up to 1970s, superior to any form of telephone network text sending system. Telex was not a nationwide service for end users however. It did not connect up private households but rather large companies and local authorities.

From the mid-1960s and early 1970s onwards data communication network development accelerated within two separate contexts. On the one hand, there were closed data communication networks for computers like ARPANET, which allowed for high transmission rates among a limited number of computers (Abbate, 2000; Schmitt, 2016). On the other hand, the national telecommunication administrations, their industries and a number of computer companies developed publicly available data networks under monopoly service conditions. These networks generally integrated older text messages forms and new data transmissions. Stepwise networks like Datex-L-net, which used the physical infrastructure of the former telex network and was thus separate from the telephone network, increased their transmission rates and converted to packet switching on the basis of the famous X.25 protocol. They enabled telex machines or memory typewriters to communicate with other forms of teleprinters, however international services were often impossible until 1984 (Hillebrand, 1978). A new development was mixed private and public systems like e-post or telefax which still used the old telex network at the outset but were subsequently made available on the public telephone network. In the 1980s numbers of integrated data networks offering even better services, up to 64kb/sec, exploded. Fibre optic cables allowed for broadband television and radio program transmission and broadband cable-TV networks emerged in the 1980s and 1990s using coaxial copper cables, especially in the BENELUX countries, which were transformed into broadband service networks in the long run.

Numerous data communication services appeared in the 1970s and 1980s whose aim was to improve office communication without prioritizing data communication for a mass audience. Some of these existed side by side, others competed with one other. They all had different technical characteristics and required different switches, cables and protocols. The majority were still closed networks that were not designed for mass use (Lernevall & Akeson, 1997).

Open data communication for the general public in the public telephone network

The early 1980s was a critical juncture for the future development of telecommunication networks in general and computer networks for mass use in particular. Two formerly separate developments—computer networks and telecommunication networks—now linked up. The key issue was the future development of networks for data communication. Should these networks be nationwide and open or closed networks for specific uses and users? Should there be plural networks for individual services or a limited number of networks integrating the various services? The answers to these questions were the basis for many future technological development decisions.

One of the key players deciding on such matters in Europe were the national telecommunication monopoly firms. Although deregulation and privatization of the telecommunication sector was already on the horizon, the monopoly firms were still a decisive power as they owned telecommunication networks and provided services on them (Heuermann, 1984). It was not until 1987 that the EC Commission put the topic on the agenda when it issued a green paper on telecommunication markets (Ungerer, 2013). And it still had to ‘think technology’ in monopoly firms’ terms, particularly regarding nation-wide services and equal prices. Therefore, the existing telephone network—the only one with nation-wide coverage—had to be the starting point for further consideration and research. The telephone network lent itself to an even greater extent to becoming the basis for mass data communication as its digitization was already under way. Twisted pair copper cables in the local networks thereby automatically became a key element in the data communication network future.

A number of services for data communication were already established or in the planning phase at this time and involved using the public telephone network as a carrier system. In the late 1970s the first telefax systems started operating as a picture and drawing transmission service. Services like 'Bildschirmtext' (BTX) and 'Médium interactif par numérisation d'information téléfonique' (Minitel) were additional data transmission options from the 1980s onwards, providing for simple services such as ticket purchase, message boards, etc. (Schafer & Thierry, 2017). They connected up household end devices with low transmission rates for digital data communication. The German BTX, for example, had 1200 Kbit download and 75 Kbit upload rates. These networks and services were—in the traditional European telecommunication technology design context—solely planned as national networks with limited cross-border facilities. New service subscriber numbers varied considerably. In Germany, for example, the interactive videotext system BTX had approximately 60,000 users in 1986, whereas the Bundespost originally calculated one million. In France, however, Minitel had one million subscribers in 1985 and this success led to it remaining in service even after the turn of the millennium. At the same time, when new data communication systems were developed by the national telecommunication administrations (and their industries) data communication using modems in the telephone network increased, especially with the dissemination of home computers such as Commodore C64 (Driscoll, 2014).

Many modem users circumvented the Bundespost monopoly over public telephone network transmissions and connected up their computers illicitly (Röhr, 2017). All these digital data communication services worked on low transmission rates, however, enabling households to connect to data networks on twisted pair copper cables and introducing a client-server model for home computer use. Equally important is the fact that data communication via computers (or comparable devices) became increasingly usual. TV teletexts were an example and brought data communication to the general public. People got used to home data communication.

In the 1980s it became clear that any future data communication market developments would depend on a more effective infrastructure enabling higher transmissions rates. To provide an increasing number of users with better services the telecommunication administrations worked hard to increase telephone network transmission capacity to 64 Kbit or 144 Kbit. Nevertheless, in the 1980s the telecommunication administrations were convinced that telephone communications would long remain the most important household service whereas telefax and computer connections would remain subordinate (Rosenbrock, 1984). Even the most

Table 1: Number of telephones in Europe (1978)

Europe	155,961,700
(West) Germany	22,931,683
Great Britain	23,182,239
France	17,518,813
Italy	16,125,204

enthusiastic exponents of digital data communication did not foresee a dramatic increase in the use of data networks by the wider public. For this reason, too, the twisted pair copper cables in the local networks were still regarded as a sustainable technology prior to 2000. In 1984, 82% of total telecommunication sector revenues came from phone calls. This led to the German post and telecommunication administration, for example, deciding to develop an Integrated Services Digital Network (ISDN) by replacing an analogue infrastructure stepwise with a digital one in 1987. ISDN continued and accelerated the ongoing process of digitizing the public telephone network. It promised public use of data communication networks for a variety of services to the general public. Nationwide end users were to be able to use their home computers for data communication purposes. No one anticipated the mass connectivity with home computers to the Internet over the same physical telephone network infrastructure which came to fruition in the 1990s (Irmer, 1982). Quite the contrary, in 1987 the German post and telecommunication administration estimated a maximum of two million households using data communication services at low transmission rates in the ISDN network (Schön, 1986).

To sum up, the 1980s were in many regards crucial for computer networks on copper cables as the monopoly telecommunication firms enabled households to connect up to data communication networks nationwide and get used to data communication.

High-speed on copper: households and the Internet

The 1990s began with the deregulation of telecommunication monopolies across Europe. National administrations—then the largest state owned companies across Europe—were privatized. Completely new legislation was subsequently introduced by the European Community and national governments (Bartosch & Braun, 2009). Instead of 'thinking technology' in monopoly terms, private operators now had to think profit-oriented.

This also meant attempting to avoid investing in cable infrastructure, for example, by rapidly introducing fibre optic or high capacity coaxial cables into local networks. They prioritized cheaper technologies to increase transmission rates, necessary to households in the internet age. Replacing twisted pair copper cables with fibre optics in the 'last mile' was downgraded as a priority in the late 1990s and early 2000s as private providers prioritized profits (Schneider, 2001). They were backed by the emergence of asymmetrical subscribers, which based wide-band signals above the analogue based signals and thus allowed for a breakthrough of transmission rates on twisted pair copper cables. Different standards within the Digital Subscriber Line (DSL) services subsequently allowed for ever higher transmission rates. When DSL technology prices dramatically declined in the early 2000s, it turned out to be a further obstacle to the installation of fibre optic cables on the 'last mile' (Golden, 2007). Nevertheless, in actual fact, twisted pair copper cables are technically limited as the pairs disturb one another, thus limiting potential transmission capacities. Without a new cable infrastructure, the different modulation and compression modes are simply second best solutions. DSL technologies cannot replace investment in fibre optic cable infrastructure if high transmission rates are to be made possible. The 'last mile' on copper remains a critical section of the network, although VDSL promised higher transmission rates up to 100 Mbit. Telecommunication providers and regulators in countries like Germany—which relied on copper cables for some time and did not invest in fibre optic technology at the local network level—lag behind in average transmission rates for household data communication (Bluschke, 2007).

Conclusion

Copper cables, and twisted pair cables in particular, were chosen as the basis for data networks for many and varying reasons. In the 1980s they were a promise to the public which fully accorded with monopoly obligations. The telephone network was the only network capable of nationwide coverage within a short time frame and at affordable user costs. After the telecommunication markets were privatized and the Internet triumphed, this changed completely. From then on copper cables on the 'last mile' promised profits for providers. The invention of DSL technologies allowed for high transmission rates without the need for investment in fibre optic cables on the part of the networks. Private companies and stake holders preferred to make profits with an old but inexpensive copper network rather than investing in expensive fibre optic cables. In the long run this turned out to be an obstacle to high speed connections as the transmission

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rates are still very low as compared with a network consisting solely of fibre-optic cables.

The advantages generated by new modulation and data compression modes enabled households to be supplied with ever higher transmissions rates and access to digital communication facilities. However, they cannot outweigh the disadvantages of a cable infrastructure that is still based on twisted pair copper cables, some of which are 50-60 years old, rather than fibre optic or high capacity coaxial cables.

Twisted pair copper cables may have survived social and economic transformation because they were not an 'analogue technology' but rather a technology from 'analogue times', a compromise solution in the early phase of the shift to the digital era. Their importance lay in their ability to disseminate data communication to larger parts of society and introduce a wider public to data communication.

Finally, copper cables, and twisted pair cables in particular, are a key element in the history of computing. The Internet was only able to develop into a mass home user network because technical innovations made the use of copper cables for advanced data communication possible. Without digital transmissions over 'analogue era' cables the Internet would either not have turned into a key technology for society as a whole or it would have taken much longer. Nevertheless, even if (twisted pair) copper cables can be used for high transmission rates, they were superior to fibre optics and thus limited potential transmission capacities. Despite being a key technology in the rapid dissemination of digital mass communication, copper cables have often been overlooked in historical research. Perhaps this is because they are so invisible.

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