Data Communications: The First 2500 Years*

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It is usually assumed that data−networks are a 20th Century phenomenon. Evidence of efforts to build data communications systems, however, can be found throughout history. Before the electrical telegraph was introduced, many countries in Europe already had fully operational nationwide data−networks in place. We briefly recount the long history of pre−electric communication methods and devices.

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1. INTRODUCTION

Modern data communications techniques rely on many concepts and ideas that all seem to have evolved in a relatively short span of time. When, in the mid 19th Century, the electrical telegraph was introduced, a system of message relaying and encoding had to be developed virtually on the spot. Or so it seems.

It is of course well−known that it was always possible to communicate very important signals over long distances with comparatively primitive means, e.g. by sounding church bells, giving smoke or fire signals, or by waving flags. It is clear that all these methods are limited in their possible uses: they are all relatively crude *broadcast* methods, that cannot but give a small set of pre−defined messages. It would be interesting to see, therefore, what historical record there is of methods and techniques that make point−to−point signaling of arbitrary messages possible. For this, a number of enabling techniques had to be developed first. These include:

- Methods for *relaying messages* point to point, instead of broadcasting them.
- Methods for *encoding* arbitrary information, e.g. in an alphabet, or in a vocabulary that has been optimized for a particular type of signaling.

Assuming that we have some type of rudimentary signaling link, the problem of controlling that link itself also has to be solved. To be able to do this at all, one has to be able to make the distinction between *control information* and *message data*, even when both types of signals travel on the same link. Furthermore, explicit control procedures have to be formulated and agreed upon between the senders and receivers of a data link. It is interesting to see when we can find the first evidence of explicit:

- Distinctions being made between control information and message data, and
- Methods being developed for error control, flow control, and rate control.

Before reading the remainder of this paper, it may be worthwhile to pause here for a while and imagine how early each of the four bullet items could possibly have been first realized and documented.

2. BROADCOAST METHODS

Signs of victory or alarm are readily given with a simple fire beacon. The size of the fire, or the number of fires lit, can be used as an indication of the significance of the event that is being communicated. We can imagine that this must have been one of the earliest forms of communication that was practiced, although there are of course no written records to substantiate this claim.

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* For a more detailed description of the material presented here see *The Early History of Data Networks*, by Gerard J. Holzmann, Björn Pehrson, IEEE Computer Society Press, 1994.

We can find many references to this basic broadcast technique even in, relatively speaking, recent documents. In 1455 AD, for instance, it was recorded that the Scottish Parliament issued the following ordinance:

> One bale of faggot shall be the notice of the approach of the English in any manner; two bales that they are ‘coming indeed;’ and four bales blazing beside each other, to say that they are ‘coming in earnest.’

The range of a single fire, however, has its limits. Had one wanted, for instance, to signal the fall of Troy in approximately 1200 BC, to Agamemnon’s palace in Mycenea, the distance to be bridged would have been more than 600 km. This is clearly impossible. Or is it? In fact, the opening acts of the play *Agamemnon* [278−285], written by Aeschylus, describing the siege of Troy, includes a detailed record of a line of ten signal beacons, that was used for precisely this purpose. Similar references to lines of beacons occur in many other sources. Homer’s *Iliad*, written in approximately 700 BC, for instance, contains the passage:

> Thus, from some far−away beleaguered island, where all day long the men have fought a desperate battle from their city walls, the smoke goes up to heaven; but no sooner has the sun gone down than the light from the line of beacons blazes up and shoots into the sky to warn the neighbouring islanders and bring them to the rescue in their ships. [XVIII, 210−213]

Where, though, did the basic method of relaying messages from one station to another come from? Was it invented just for fire beacons or is it older still?

3. MESSAGE RELAYS

To find the origin of message relay methods we have to go back still further in time. We can imagine that throughout most of history any more substantial type of message could only be transferred with the help of messengers. Courier posts can be dated back in written records to at least 2900 BC. We have records of royal messengers, or professional runners, traveling the roads between the main cities of the ancient empires, carrying letters, deeds, challenges, gifts, or just idle chatter between kings. The safety of these messengers was of course by no means guaranteed. They were often attacked or even killed by robbers.

For the kings, the safety of the messenger was probably of lesser concern than the safety of the messages that were carried. Since it could take many days, or weeks, for a message to reach its destination, simply waiting twice the round−trip delay before concluding that a messenger had been killed was not very practical. The solution adopted by King Sargon of Akkad, who lived circa 2350 BC in Mesopotamia, was to have all his messengers carry a homing pigeon. If the messenger was attacked on route, he would release the pigeon. The return of the pigeon to the palace was then taken as a warning that the original message had been ‘lost,’ and that a new messenger should be sent, presumably via another route. This is perhaps the earliest form of the use of a *negative acknowledgement* signal, and, with a little more imagination, also an early example of the use of a distinct encoding of control information and message data (one of our four bullet items).

Another method to reduce the probability of message (i.e., messenger) loss was the installation of guard posts at regular distances on the royal roads through the ancient empires. This seems to have been done first by the Babylonian kings. Though this was initially done only for the protection of travelers, the presence of the guard posts led quite naturally to two significant changes in the method of communication:

1. It first led to the establishment of the *relay* system, where a message was passed from guard station to guard station, each time carried by a new runner.
2. Next it led to the decision to equip each guard post with a permanent fire beacon, so that a simple alarm or warning sign could be passed quickly from station to station, without the need for the human runners.

Herodotus (484−424 BC), describes in *The History* [VIII, 98] with admiration how the relay system functioned at the time that Xerxes ruled Persia, in the 5th Century BC. Another historian, Xenophon (430−355 BC), dates the system back further still, to the reign of Cyrus in the

6th Century BC. He writes, for instance, in *Cyropaedia*:

> They say, moreover, that sometimes this express does not stop all night, but the night−messengers succeed the day messengers in relays, and when this is the case, this express, some say, gets over the ground faster than the cranes. If their story is not literally true, it is at all events undeniable that this is the fastest overland traveling on earth; and it is a fine thing to have immediate intelligence of everything, in order to attend to it as quickly as possible. [VIII, 6.17−18]

Referring to the list of four bullet items that we started with: we can date the invention of ad hoc methods for relaying messages to circa 1200 BC (the fall of Troy), and the more systematic relay methods along permanent chains of signaling stations to at least 600 BC.

Next, let is consider the earliest methods for encoding message data.

4. MESSAGE ENCODING

One of the oldest, and most remarkable, descriptions of a telegraphic device appears in *The Histories* by Polybius. Polybius was a Greek historian, who lived circa 200−118 BC. In his early thirties he was taken to Rome as a hostage, and he spent the remainder of his life documenting the history of the Roman empire. In book X of *The Histories*, Polybius comments on the obvious restrictions of signaling by means of (chains of) beacon fires:

> I think that as regards the system of signaling by fire, which is now of the greatest possible service in war but was formerly underdeveloped, it will be of use not to pass it over but to give it a proper discussion. It is evident to all that in every matter, and especially in warfare, the power of acting at the right time contributes very much to the success of enterprises, and fire−signals are the most efficient of all the devices which aid us to do this. [X:43]

Polybius notes that another method of signaling had become popular around 350 BC; a method that he credits to Aeneas (an author of works on strategy). To use this method, sender and receiver are to be provided each with one earthenware vessel of the same dimension. In preparation for communication, the vessels are filled with water, to precisely the same level, and a graduated rod attached to a piece of cork is floated in the water. In Polybius's description, the rod is marked in up to 30 sections, each 3 finger−breadths wide. Polybius explains:

> In each section should be written the most evident and ordinary events that occur in war, e.g., on the first 'Cavalry arrived in the country,' on the second 'Heavy infantry,' on the third 'Light−armed infantry,' next 'Infantry and cavalry,' next 'Ships,' next 'Corn,' and so on until we have entered in all the sections the chief contingencies of which, at the present time, there is a reasonable probability in war time.

To initiate communication, the sender raises a torch. Upon the acknowledgement of that signal by the receiver (who also raises a torch), both sender and receiver pull a plug from the bottom of the vessel, and allow the water to escape. When the correct message lines up with the top of the vessel, the sender stops the flow of water by raising his torch. The receiver acknowledges the signal, quickly also reseals his vessel, and reads the message.

Note that in Aeneas's system control signals (given with torches) are neatly separated from data signals (marked on the rod). A rudimentary data encoding method is also used: words and phrases are represented by the positions of a rod (or more generously interpreted: by the numerals from 1 to 30). The beginnings of a flow control procedure can also be recognized, with explicit signals for *synchronization* and *positive acknowledgement*.

It is not clear what the effective speed of the vessel method would be, but presumably it would have required several minutes for each signal. Polybius gives an eloquent critique of the method, noting that it generally will not be possible to foresee precisely what one will later need to communicate. The predefined markings of the rod thus become a serious limitation. Polybius does not mention it, but in principle one could of course write the alphabet on the sections of the graduated rod, and spell out any message. But, clearly, at several minutes per letter, this would have required an enormous amount of time for even the simplest of messages.

To solve that problem, Polybius proposes a different method. He first divides the letters of the alphabet (24 characters at the time) into five groups. There are five letters each in the first four groups, and the remaining 4 letters are the the last group. Any character from the set can now be encoded into two numbers, between 1 and 5. If we think of the groups as pages, and place the characters on separate lines, each character can now be encoded as a pair of small numbers. The first number of a pair encodes the page, and the second gives the line number of a character. To transmit the codes more quickly than Aneas's method allowed, Polybius sets up two groups of five torches. When not in use, the torches are hidden behind a screen: one to the left of the sender, and one to the right. By raising between one and five torches above the left screen, the sender transmits a page number; similarly, by raising between one and five torches above the right screen, he transmits a line number. We again need methods for synchronization and positive acknowledgements, but they remain virtually unchanged from Aneas's earlier system.

It appears that several competing methods for spelling messages with fire signals were in use at the time. Polybius refers to methods by Cleoxenus and Democleitus, but apparently no independent descriptions of their devices have survived. There does exist an independent description of a method that was used by Sextus Julius Africanus, with three groups of eight characters each, using the repeated raising and lowering of a single torch to encode the numbers from each code pair.

All these competing methods contain very specific methods of encoding the alpabet, and are sufficient to construct completely general telegraphic systems that appear to have been used for several centuries. Very likely, they were never used on a large scale, for instance to build national networks, but they did serve a purpose of providing rapid long distance communications at times of war.

Based on the above, we can now date the earliest general method for encoding arbitrary message data for long distance communications to circa 350 BC. Next, let us consider the explicit formulation of protocol control flow procedures.

5. CONTROL FLOW PROCEDURES

It would be a long time indeed before the next step in the evolution of long distance communication methods was made. Was it because better communication methods were simply not needed, or was it because the enabling technologies to make the next logical steps in their development were not available? A convincing case could be made for each of these propositions.

The one critical enabling technology that allowed the next step to be finally made appears to have been the invention of the telescope. The first telescope was build in 1608 by the Dutch spectacle maker Hans Lippershey. News of his discovery traveled quickly through Europe. Galileo learned about it through a letter from a colleague and was able to reproduce the device. With the 30−power telescope he built, Galileo discovered the moons of Jupiter. He described his discovery, and the telescope, in his *Nuncius Siderius* in 1609. Almost immediately inventors set out to explore the new powers of vision by inventing and re−inventing telegraphic devices of all sorts.

In 1616, someone named Franz Kessler (circa 1580 − circa 1650) published a booklet in Oppenheim, named *Unterschiedliche bisshero mehrern Theils Secreta oder Verborgene, Geheime Kunste* ('Various until now mostly hidden, secret arts'), in which he describes a system of signaling, that operates with the help of telescopes. Kessler reduced the alphabet to fifteen letters, and randomly assigned a number between 1 and 15 to each letter (to make it harder for an outsider to decode his messages). The sender sets up a barrel, covered with inflammable material on the inside, and containing a burning torch. The barrel is closed with a shutter on the side that is turned towards the receiver. By flashing the shutter between 1 and 15 times (sic) any character from the alphabet can be signaled. The receiver observes, and counts, the flashes with the help of the telescope.

Kessler's description does not yet contain any mention of a more sophisticated method for flow control, but that would soon change. In 1684, the Englishman Robert Hooke (1635−1703) held a lecture for the Royal Academy of Sciences. In his talk, titled *On Showing A*

Way How To Communicate One's Mind At Great Distances, he describes a device that also works with the help of telescopes, but this time with some extra explanations on how to operate telegraphic devices in general.

Hooke's device is a simple framework from which large cut−out symbols can be displayed to represent codes. Several things are novel, and quite important, in his description. First, the symbols proposed by Hooke do not represent characters from the alphabet but abstract codes of which the meaning is defined in a vocabulary. Second, Hooke uses separate symbols for control and data, and even displays them in distinct locations on the framework. Thirdly, and most importantly, Hooke for the first time ever proposes explicit rules of protocol for the transmissions. This is how Hooke explained the last two points in 1684:

> There will also requisite several other characters, which may, for expedition, express a whole sentence, to be continually made use of, whilst the correspondents are attentive and communicating. The sentences to be expressed by one character [symbol] may be such as these [...].
> I am ready to communicate [synchronization]. I am ready to observe [idem]. I shall be ready presently [delay]. I see plainly what you shew [acknowledgement]. Shew the last again [an error code]. Not too fast [rate control]. Shew faster [idem]. Answer me presently. Dixi [I have spoken, i.e., end−of−text]. Make haste to communicate this to the next correspondent [priority]. I stay for an answer; and the like. All which may be expressed by several single characters, to be exposed on the top of the poles [instead of suspended below them, like the characters for message data], by themselves [...] so as no confusion may be created thereby.

And with this we have now also dated our last bullet item, the first description of explicit protocol control procedures, to 1684 AD.

The sceptic may object that, even if we grant that all the building blocks for the construction and operation of data networks were in place by the end of the 17th Century, surely this wasn't actually done until fairly recently. Let's consider that point in a little more detail and see if we can find an earlier reference also there.

6. NATIONAL DATA NETWORKS

The builder of the first data network that spanned a country was born in a little French town named Brûlon in 1763. At this time, the word ''telegraph'' had not yet entered the language (that happened in 1793 as a result of the work that we will describe here), but work on devices for long distance communications was a popular pastime. We can speculate that the interest in these devices was triggered by the rather significant improvements in telescope design of that period. The first telescopes of the early 17th Century suffered from flaws such as chromatic and spherical aberration, which limited their usefulness. In 1747 Leonhard Euler had discovered that the flaws of one lens could be used to cancel those of another. Three years later, the Swede Samuel Klingenstjerna made an extensive study of the color separation properties of different types of glass. Using all this new knowledge, the Englishman John Dollond succeeded in building a telescope that would become the standard for many years to come.

The hero of this part of our story, Claude Chappe, was originally raised for the church. When the French Revolution started in 1789, he lost the religious benefices he had obtained only a few years earlier, and he had to find other employ. Together with his four brothers he decided to perform experiments with telegraphic devices. In the yard of the parental house in Brûlon Chappe constructed several versions of simple telegraphs, based on visual and acoustical signals.

In March of 1791, Chappe succeeded to establish a signaling link of circa 10 km, between the towns of Brûlon and Parcé. He used, what is in retrospect, a remarkably crude device: two pendulum clocks, with the numbers from 1 to 10 written on the face plate, two large flip−boards, one side white and one side black, and two Dollond telescopes. The flip−boards were used for synchronization; first to synchronize the two clocks, and next to identify the numbers that were to be transmitted. The sender would flip the board each time the clock would point to the number he wanted to signal next; the receiver would observe the sender's board through his telescope, and read the matching number from his local clock when the board changed. The number sequences transmitted encoded the words and phrases in a dictionary.

Chappe successfully transmitted several sentences between Brûlon and Parcé, and he was careful enough to have the results recorded in notarized affedavits. In 1792, Claude Chappe moved to Paris, to offer his invention to the new Legislative Assembly. His proposals were delegated from one committee to the next, though, while the Legislative Assembly was otherwise occupied with, if nothing else, the survival of the state itself. Not until the Legislative Assembly had converted itself into a National Convention, was Chappe granted permission to conduct an official experiment to prove his claims.

For the experiment, Claude Chappe built a line of three stations: the first on the outskirts of Paris in Belleville, the next in Ecouen, and the last in the town of Saint−Martin−du−Tertre, a total distance of circa 25 km. Chappe had by now developed a new design that consisted of a large horizontal beam with two small wings attached to the ends, seemingly mimicking a man with outstretched arms, holding a signal flag in each hand. The beam (called a 'regulator') and the wings (called the 'indicators') could all rotate on an axis. The regulator could be set in one of four positions (horizontal, vertical, and tilted left or right) and each indicator could be set in one of 8 positions. The maximum number of different symbols that could be encoded in one position of the semaphore was therefore $4 \times 8 \times 8 = 256$. In practice, only 192 of the possible combinations were used, to avoid confusion.

Chappe assigned numeric values to (a subset of) the semaphore combinations. He then used a method similar to the one he had applied for the pendulum system, something that had in fact never been done before: he developed a special dictionary of common words and phrases (containing individual letters from the alphabet as special cases) and he numbered the pages of the dictionary, and the lines of each page. Using his semaphore, he could now send any letter, word, or phrase from his dictionary with the minimum number of signals. A message on his system could thus typically be encoded in fewer signals than there were words in a sentence: a substantial improvement over all earlier attempts.

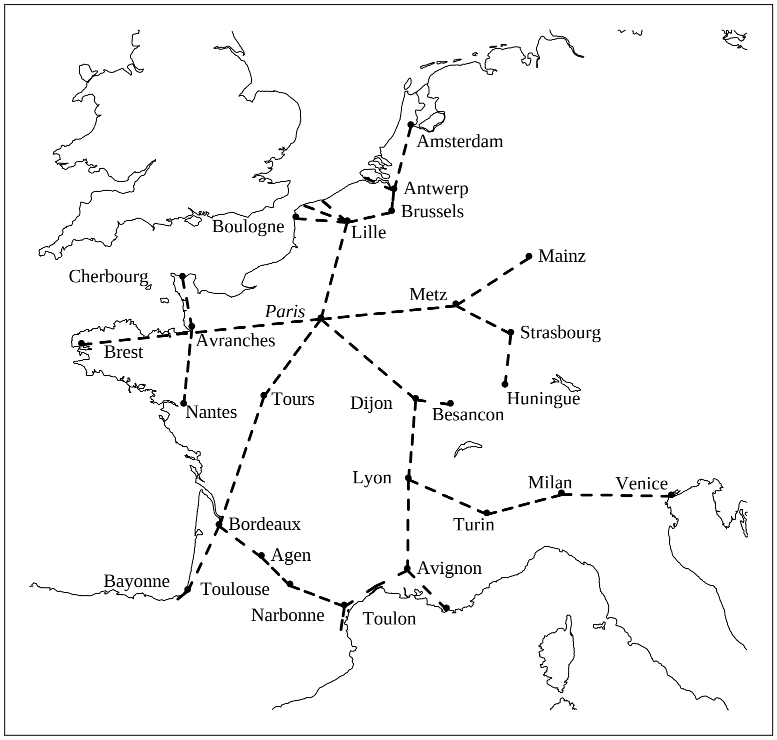
The experiment was held on 12 July 1793. Meanwhile Chappe had to invent a complete set of protocol procedure rules for his new system, including all the controls for recovering from errors, temporary suspensions (fog...), repetitions, positive and negative acknowledgements etc. Although Chappe was familiar with the work of Robert Hooke, he had to take the state of the art a step further to be able to establish a true synchronous communication between the two posts that formed the endpoints of his experimental line, through the intermediary station at Ecouen. As far as we know, no−one had done that before.

Claude Chappe's older brother Ignace described the events in a book *Histoire de la télégraphie*, published in 1824. He ridiculed those who thought they could design a telegraph without ever considering the subtleties of the protocol rules:

> Those who think they have invented a telegraph that can be used without preliminary instructions for the telegraph operators, are mistaken; they have probably never performed experiments with more than two or three stations.

Fortunately, Chappe passed the test with flying colors. On 26 July 1793, just two weeks after the experiment was held, the National Convention decided to institute a *French State Telegraph*. Claude Chappe was given the title of Ingénieur Télégraphe, and the permanent use of a government horse. The term *Télégraphe* had been suggested to Ignace Chappe by Count Miot de Mélito, who was then Chef de Division a l'Interieur in Paris. Until then, Chappe had toyed with the term *Tachygraphe* (or 'fast writer'). The new term *Télégraphe* ('far writer') was instantly adopted. Curiously, in the first few months after its introduction it was frequently misspelled as *Thélégraphe*, including in the official state documents that gave Chappe his prestigious new title.

As a first assignment, Chappe was commissioned on 4 August 1793 to establish a telegraphic connection between Paris and Lille, a distance of circa 190 km. It took Chappe nine months to complete this assignment. On 30 April 1794, fifteen stations along the line had been constructed, operators for the telegraph had been trained, and a complete set of operating instructions prepared (and, we may assume, debugged). Early log−books reveal that the telegraph line was transmitting the text of decrees from the National Convention from Paris to Lille,



The French Optical Telegraph Network – Circa 1846

probably to test out the line, as early as 17 May 1794, starting at 4:30 am. On 16 July 1794 the tests were complete, and the line was officially declared open. Among the first messages were two of exceptional importance to revolutionary France. On August 15 the line reported that the city of Le Quesnoy had been retaken by the French troops. Two weeks later, 30 August 1794, it announced the recapture of the city of Condé. Both messages were delivered to the convention within hours after the event had taken place: something that did not fail to impress the delegates. The future of the French network was virtually guaranteed at this point. New lines were commissioned, adding hundreds of telegraph stations to the net.

By 1852, the French network of optical telegraphs had grown to 556 telegraph stations, covering a total distance of circa 4800 km. The network connected 29 of France's largest cities to Paris. With up to six operators per station, working in three shifts with two operators on duty at each station at all times, the French State Telegraph employed well over 3,000 people.

It would be a mistake to assume, though, that any of this development was easy or automatic. In the wake of the French revolution, Napoleon's rise and fall, and a series of violent wars, it was a constant struggle for Chappe to keep his system alive. Money for new constructions was usually more easily promised than actually payed, and it was up to Claude Chappe to explain to the workers he hired that they had to stay on the job for weeks on end with only vague promises that, perhaps eventually, they would be reimbursed. Sadly, Claude Chappe did not live to see his network expand to its final size. In 1805 he committed suicide, for reasons that have never been fully explained. His four brothers took over the administration of the State Telegraph, and secured its continued growth.

The success of the French network almost immediately led to similar attempts to build telegraph lines in the other countries of Europe. In 1794, for instance, only months after the first reports of the opening of the telegraphic connection between Paris and Lille had been reported, Abraham N. Edelcrantz started construction of a Swedish network of shutter telegraphs. In 1796, Edelcrantz's shutter design in turn inspired the Englishman Sir George Murray. Murray's design was adopted by the British Admiralty and installed on several lines connecting London to the fleet in Portsmouth and Yarmouth. By the 1840's virtually every country in Europe, and several outside, had one or more optical telegraph lines, be it all of a slightly different type.

The first countries to switch from optical to electromagnetic systems were England and the U.S., starting in 1837. To the countries with larger optical telegraph networks, however, it was not immediately clear that the change would be an improvement. In 1840, for instance, one of the staunchest defenders of optical telegraphy, the Frenchman Dr. Jules Guyot, traveled to England to study the electrical novelties. Upon his return he published an article in the *Courier Francais* that appeared 5 July 1841. He argues convincingly:

> Every sensible person will agree that a single man in a single day could, without interference, cut all the electrical wires terminating in Paris; it is obvious that a single man could sever, in ten places, in the course of a day, the electrical wires of a particular line of communication, without being stopped or even recognized.

Clearly, he stated, no serious competition could be expected from ‘‘a few wretched wires.’’

As a result, the French optical telegraph network managed to hold its own until 1846. In that year the French government decided to finally replace the oldest line in its network, the historical line from Paris to Lille, after 52 years of service. The first electrical lines in France were operated with a curious telegraphic device, designed by Alphonse Foy and Louis Bréguet, that could reproduce the positions of the Chappe semaphore on its controls. The Foy−Bréguet telegraph was discarded in 1855, and replaced with the simpler telegraph designed by Samuel Morse.

In Sweden, a study on the replacement of the optical telegraphs was not initiated until 1852. For more than ten years, both electrical and optical telegraph stations were in use side by side; the optical telegraphs reaching where the electrical cables initially could not easily lead. In 1864, there were 174 electromagnetic telegraph stations, with 250 operators, but also still 24 optical telegraph stations with 66 operators. In 1867, the number of optical telegraphs had fallen to 18, employing 42 people. Not until 1881 were the last three optical telegraphs replaced in Sweden, later than in any other country in Europe.

7. CONCLUSION

Data communications has a much longer history than most of us realize. If we consider the crucial steps that made it possible to even begin the construction of our modern communications networks, we find to our surprise that they were all discovered (and documented) centuries ago.

Even the construction of the first nation−wide data networks has a much longer history than is commonly known. For more than half a century, the governments of several countries in Europe operated remarkably sophisticated networks of optical telegraphs. The achievements of people such as Claude Chappe and Abraham Edelcrantz are largely forgotten, having been superseded by developments they could not have imagined in their most ambitious moments. They were, however, the true pioneers of data networking. What characterized them was not luck, but a strong vision and a dedication to perfection, even under adversity. They both had to overcome major obstacles before they could be successful, only some of which were technical. As Edelcrantz noted in his book *Treatise on Telegraphs*, published in 1796:

> It often happens, with regard to new inventions, that one part of the general public finds them useless and another part considers them to be impossible. When it becomes clear that the possibility and the usefulness can no longer be denied, most agree that the whole thing was fairly easy to discover and that they knew about it all along.

The German author J.L. Bockmann summed it up differently. His commentary on the first reports on the French optical telegraph, written in 1794, carried the following caption:

> Der irrt, wer alles schon für aufgefunden hällt! Der nummt den Horizont für Gränzen einer Welt.
> [Those who think that everything has already been invented, are mistaken! They let the horizon define the boundaries of their world.]

It is as true today as it was two hundred years ago.