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Complexity in Spanish optical fiber and SDH transport networks

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ABSTRACT

Complex networks are important instances of technology-related complex systems. In this work we apply tools from complexity science to characterise two Telefónica España transport network systems: the optical fiber network and the SDH transport network. We compare both cases and derive its most important properties. Remarkably, our results show that in both cases several features of heterogeneous, hierarchical complex networks arise.

Networks are a ubiquitous part of everyday life, and most of them can be considered as being complex networks. Research associated to these kind of nontrivial networks is attracting ever more attention. In the last few years, the study of complex networks has unveiled interesting properties in natural and man-made systems, e.g., genetic networks, ecological networks, social networks, scientific collaboration networks, WWW, Internet, peer-to-peer networks, power grids, etc. [1]. The mathematical framework provided by complexity science allows for a novel theoretical approach to describe complex networks as an aggregation of simple units interacting through a nontrivial topology [2]. The task to understand the properties of such networks is arduous and challenging. In order to achieve this, complexity science offers several analytical tools to characterise and classify them suitably.

An interesting example of real complex networks are communication networks. In particular, two examples of such networks used for advanced communications are the optical fiber (OF) network and the Synchronous Digital Hierarchy (SDH) network. In this work, we analyse real data on these networks from Spain's largest telecommunication operator, Telefónica España (TE). The conclusions obtained from our results can be easily applied to elsewhere similar networks, since the design and installation criteria are similar for most telecommunication operators.

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1. Optical fiber network

Optical fiber networks provide physical support for transmission networks such as SONET/SDH or Wavelength Division Multiplexing (WDM), among others. Optical fibers compose most networks, from core to long-haul, to metropolitan networks. Nowadays, optical fiber is also deployed in the access network: Fiber To The Node (FTTN), Fiber To The Building (FTTB) and Fiber To The Home (FTTH). Optical fiber is commonly used not only by telecommunication operators but also by other entities in order to have a high capacity network for their own operations. The unused bandwidth can be negotiated to third parties as well. Additionally, telecommunication operators typically project an important amount of unused fiber to be deployed for future growth.

Optical fiber networks are channeled by means of ducts between the different geographical points where it is deployed. To connect different optical fibers, vaults and distribution frames are used, which in turn determine administrative units. In order to transliterate the optical fiber network to an abstract representation of it, we define it to consist in a set of nodes and links, the nodes being the end terminations (vaults and distribution frames) and the links, simply the actual optical fibers connecting them (note that in practice, links can contain several optical fibers, i.e. optical bundles of fiber). Note that these networks are purely physical and have an infrastructural purpose; they are part of the physical layer that supports communication, and are associated with actual geographical locations.

2. SDH/SONET transport network

Synchronous Digital Hierarchy (SDH) is a multiplexing protocol, devised to transport large amounts of data traffic over the same fiber simultaneously. It is the successor of Plesiochronous Digital Hierarchy (PDH) and refers to an international standard from ITU-T, which determines common architectures definitions for telecommunications services around the world. It is Europe's equivalent of North-American Synchronous Optical Networking (SONET). Both provide multiplexing protocols to transfer multiple digital bits over the same optical fiber [3]. For twenty years, SDH and SONET have been the standard technology to transmit information in broadband optical networks. The transmitted streams accept different traffic types, such as voice, video, multimedia and data packets, as well as those generated by IP, and they travel in a synchronised manner through the same optical fibers. Moreover, both protocols owe their success to built-in design properties such as robust protection and restoration, proven operation administration management, bandwidth and infrastructure scalability and provision functionality [4].

The SDH network is composed by SDH equipments that perform multiplexing and routing tasks. This type of equipment permit the combination of flux of traffic which is aggregated in various levels. The fundamental units can be mainly three kinds of equipment [3]: terminal multiplexers, add-drop multiplexers and digital cross-connects. For our purposes, a node will be any of these SDH equipments, as well as any other equipments belonging to other technologies connected by optical systems to an SDH equipment. Additionally, SDH equipment is connected at each other by optical fibers, forming circuits. End-to-end circuits may be designed as ring, mesh, bus and other structures with various link capacities (i.e. speeds). Synchronous Transport Module (STM-N) optical systems interconnect any two of these SDH equipments (or SDH equipments with other technology equipments). These will be consider the links of the network.

In a sense, the optical fiber network is the underlying physical network which sustains SDH networks (and others). In the other hand, the SDH network can be considered a logical network, in the sense that a connection is made whenever two SDH nodes are activated to detect each other. Interestingly enough, there is much work in SDH/SONET adaptability to new scenarios and SDH equipment capability [5]. However, few studies [6] have analysed SDH transport networks through complex networks theory. In this work, we apply these concepts to real complex network examples.

3. TE network analysis

TE's optical fiber network is a fairly large network consisting of 89 738 nodes and 101 499 links, which undergoes daily changes. The network can be split into 50 subnetworks, which resemble the 50 Spanish provinces, plus some additional links to abroad, that are abstracted as another province. This administrative division imposed on the network represents an important geographical constraint, since up to 66% of the nodes are located in the 10 most populated provinces. On the other hand, the SDH transport network consists in 38 739 nodes and 57 140 links, grouped in four different layers, three belonging to the carrier network and one to the access network.

We are interested to look at different network parameters that describe the topology. The degree probability distribution, $P(k)$, where k is the degree (i.e., the number of links) of a node, describes, by means of a local variable (the degree k) a global, statistical quality. Indeed, it is well known that the information contained in $P(k)$ can yield important information about the network structure, as well as other properties. Another interesting quantity that we focused in is the average shortest path l. This is simply defined as the minimum number links to travel from one node to another. Furthermore, we also studied the average clustering coefficient (i.e. how much neighbours of a node are connected between them), and the average shortest path, which is simply how many links there are, in average, between two nodes in the network.

Table 1
Network parameters for TE SDH and OF networks.

	OF	SDH
Number of nodes N	89738	38739
Number of links M	101499	57140
Average degree $\langle k\rangle$	2.27	2.95
Average clustering coefficient C	0.05	0.04
Average shortest path l	57.72	11.35
Degree pdf exponent γ	−3.3	−2.45

4. Results

We analysed a number of network properties from both the SDH and the optical fiber networks. Our results are summarised in Table 1.

As is readily apparent, both systems share similarities but show also differences. Particularly, the average clustering coefficient is quite similar, indicating an equivalence to a certain extent. But on the other hand, there is a large difference in the average shortest path, approximating the SDH network to a small-world type of structure [8,9], whereas it is not the case for the optical fiber network. Indeed, similar studies have shown that the Spanish SDH network presents such properties at various scales [7].

Finally, we studied the degree probability distribution functions and extracted the respective power-law exponent γ. The aggregated results for Spain are shown in Fig. 1. As one can see, the distributions are quite well described by a power-law approximation, with a range that covers at least four orders of magnitude in both cases. The exponents are different; in both cases are larger than $\gamma = 2$ in magnitude. Finally, the average degree is also rather similar, approximately 2 and 3 for the OF and SDH network respectively.

We also performed the same analysis for the subnetworks corresponding to the two largest cities, Madrid and Barcelona. Results are shown in Figs. 2 and 3 respectively. In all cases, the power-law exponent γ was larger for the OF networks and consistent with global Spanish values, namely, $\gamma = 3.5$ for Madrid, and $\gamma = 3.0$ for Barcelona, whereas the exponents for the SDH counterparts were $\gamma = 2.0$ for both Madrid and Barcelona.

Interestingly, in all cases the OF networks show exponents larger than 3, while the SDH networks reflect exponents smaller than 3. This may imply that these networks belong to different classes with their own growth dynamics which in turn could have different impacts in their stability [1]. This possibility is currently under study.

5. Conclusions

In this work we analysed and compared two real cases of complex networks: the Spanish SDH transport and optical fiber networks. We measured various properties that characterise these systems, such as clustering coefficients, average degree, and average shortest path. Additionally, we observed the degree probability distributions.

Remarkably enough, even though these complex networks are both planned and rigidly designed in order to seek economical benefit and functional optimisation as main goals, the networks reveal a scale-free structure, indicating a strong hierarchical component inherent in their structure. This could indicate that the growing mechanism [10] (possibly, a local mechanism) is similar

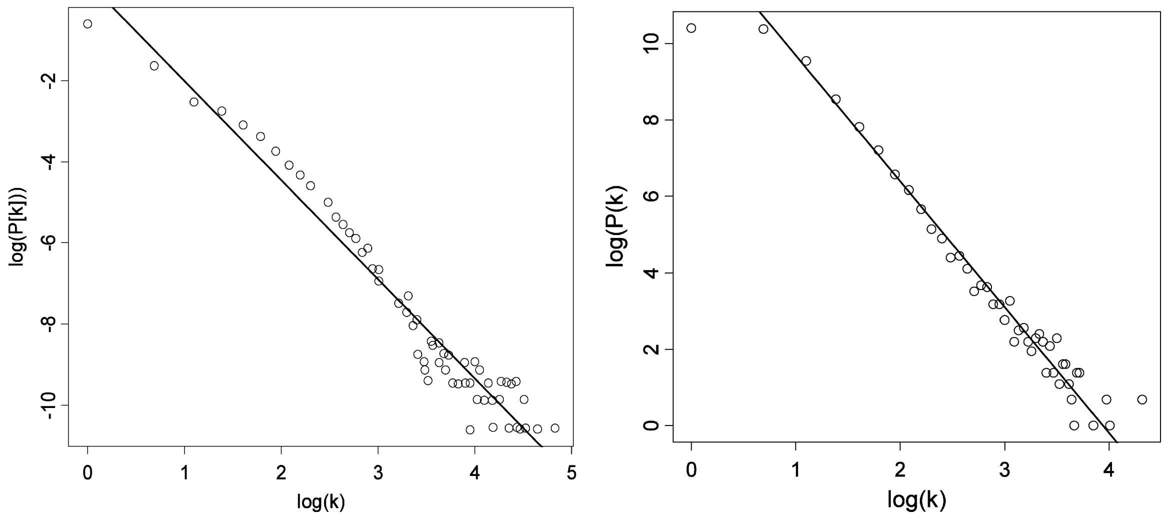

Fig. 1. Degree probability distributions. Left: Spanish SDH transport network. Right: optical fiber network. Both x is represent logarithms of the respective quantities. The linear regressions show a slope corresponding to $\gamma = -2.45$ (SDH) and $\gamma = -3.3$ (OF).

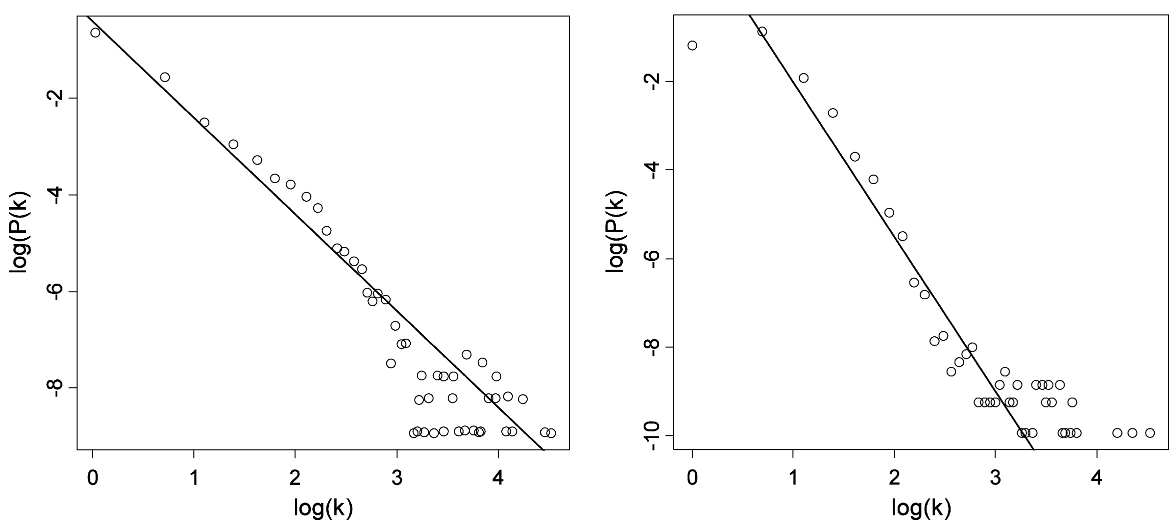

Fig. 2. Same as Fig. 1 for Madrid. The linear regressions show a slope corresponding to $\gamma = -2$ (SDH) and $\gamma = -3.5$ (OF).

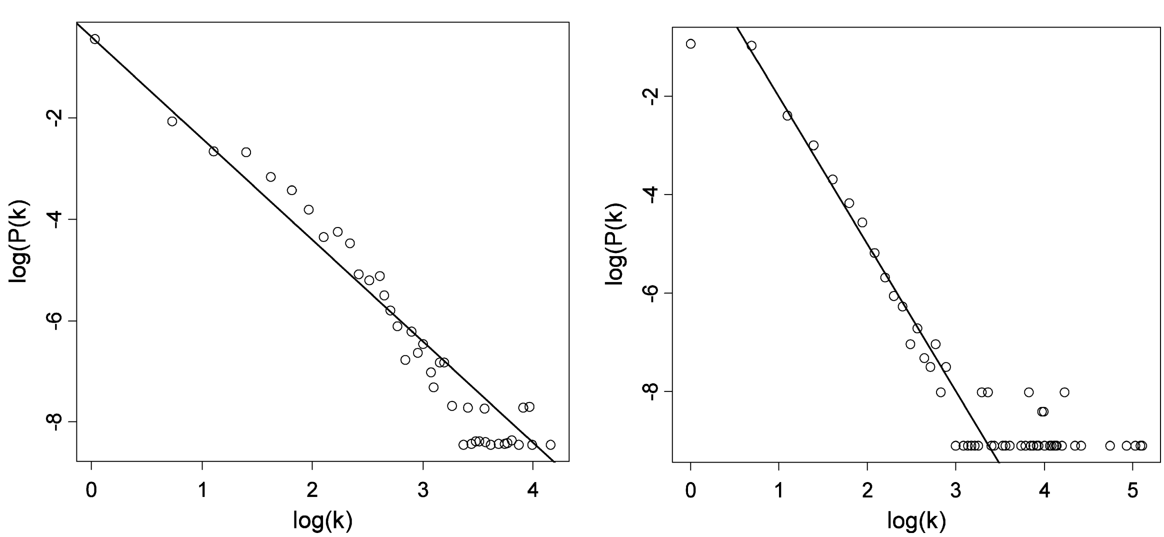

Fig. 3. Same as Fig. 1 for Barcelona. The linear regressions show a slope corresponding to $\gamma = -2$ (SDH) and $\gamma = -3$ (OF).

and, despite being largely dependent on a strict planning, also depends on user demand, the costs associated to the connections of a new node and complex intrinsic constrictions. This combination of planning and unpredictable events could give rise to the global complex properties observed. The results of this work may probably apply to other optical fiber network, as most telecommunication operators shear similar design and installation criteria. This possibility is an interesting extension of the present work and is currently undergoing work.

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References

[1] M.E.J. Newman, The structure and functions of complex networks, SIAM Review 2 (2003) 167.

[2] A. Santiago, R.M. Benito, Emergence of multi-scaling in heterogeneous complex networks, Int. J. Mod. Phys. C 18 (2007) 1591;
An extended formalism for preferential attachment in heterogeneous complex networks, Europhys. Lett. 82 (2008) 58004.

[3] H.G. Perros, Connection-Oriented Networks: SONET/SDH, ATM, MPLS and Optical Networks, John Wiley and Sons, 2005.

[4] L. Choy, Virtual concatenation tutorial: enhancing SONET/SDH networks for data transport, Journal of Optical Networking 1 (2002) 18.

[5] Cavendish, et al., New transport services for next-generation SONET/SDH systems, IEEE Communications Magazine (2002) 80.

[6] J. Spencer, L. Sacks, On power-laws in SDH transport networks, in: Communications, 2003, ICC '03, IEEE International Conference on Communications, vol. 3, 2003, p. 1786;
J. Spencer, D. Johnson, A. Hastie, L. Sacks, Emergent properties of the BT SDH network, BT Technology Journal 21 (2003) 28.

[7] J.P. Cárdenas, A. Santiago, M.L. Mouronte, V. Feliú, R.M. Benito, Complexity in the SDH network, International Journal of Bifurcation and Chaos (2009), in press;
A. Santiago, J.P. Cárdenas, M.L. Mouronte, V. Feliú, R.M. Benito, Modeling the topology of SDH Networks, Journal of Modern Physics C 19 (2008) 1809.

[8] M. Faloutsos, P. Faloutsos, C. Faloutsos, On power-law relationships of the Internet topology, in: Proceedings of SIGCOMM: Conference on Communication, IEEE, 1999.

[9] S. Strogatz, Exploring complex networks, Nature 410 (2001).

[10] S.N. Dorogovtsev, J.F.F. Mendes, Evolution of Networks. From Biological Nets to the Internet and WWW, Oxford University Press, 2003.