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Optical Communication Networks

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Abstract.

Two closely related protocols are the standard technology for information transmission in broadband optical networks: the Synchronous Digital Hierarchy (SDH) and its North American equivalent SONET. Unlike systems with unplanned growth, such as those of natural origin or the Internet, these telecommunication networks are strictly planned as rings, meshes, stars or tree-branches structures designed to connect different equipments. In spite of this planification, we have found that the SDH network operated by Telefónica in Spain shares remarkable topological properties with other complex networks with different origin. In particular, the telecommunication network displays power-law scaling in the degree distribution of SDH equipments and small-world networks properties.

In this work, the complexity observed in the Spanish SDH system is reproduced by two complex networks models. One of them, the *ad hoc* model, considers real planning directives that take into account geographical and technological variables with the aim to predict the growth of the system or generates policies for future sytem designs. The other model has a completely different philosophy. Based on a single evolutive rule, named compatibility, the Compatibility Attachment Model (CAM) is a generic approach to the complexity of the networks, included the one observed in the SDH system.

Keywords: complex networks, communication networks, optical communications, SDH network, model
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1. Introduction

During the last decade many complex systems have been studied from a network theoretical perspective. The results of these studies have shown the presence of particular, common and non intuitive statistical properties in these systems when they are abstracted to a network [1]. The so-called complex networks display interesting topological properties such as scale-free character (i.e., scaling in the distribution of connectivities), properties of small-world networks [2] and modularity.

Under this perspective we have studied the Spanish Synchronous Digital Hierarchy (SDH) telecommunication network operated by Telefónica España. This system is a multiplexing protocol for transferring multiple digital bit streams over the same optical fiber [3]. Structurally is a end-to-end circuit strictly designed as ring, mesh, bus and other motifs connecting equipments with different link capacities (Mbps/Gbps). In our research, the telecommunication system, introduced in Spain in 1992, was abstracted to a graph $G = (E, S)$ composed by a set E of nodes corresponding to SDH Equipments (as well as any equipment belonging to other technologies connected by optical systems to SDH equipments) and a set S of links corresponding to Synchronous Transport Module (STM-N) optical system that interconnects two SDH equipments or SDH equipments with others belonging to other technologies.

Our results [4] have shown that the Spanish SDH system is a scale-free network that displays properties of small-world networks. With the aim to understand the origin of that complexity two network models were proposed: the *ad hoc* model and the *compatibility attachment model* (CAM).

2. Modeling the Topology of SDH Systems

The *ad hoc* model [4] takes into account real planning directives used by Telefónica España in order to simulate the network growth. Through a stochastic process, in each iteration a new node (equipment) with particular characteristics is added to the network. The new added node will be linked to existing ones depending on technical and engineering rules. In this way, the *ad hoc* model works according to the following general characteristics of the real system. Assumes that the SDH network is built as hierarchical networks of equipments interconnected through bidirectional links. In this way, adopts the hierarchy of the real SDH system: a lower layer that corresponds to the Access Network and three upper layers that correspond to the Carrier Network. Based on this hierarchy the model distinguishs five SDH equipment classes: A (equipment at national level), B (equipment at regional level), C (equipment at interconnection level), D (equipment at access level) and E (client equipment connected to SDH equipment by SDH connections). In real SDH networks each equipment is characterized by a number of installed ports that serve to establish SDH connections, as well as by a maximum number of ports that can be installed. In the *ad hoc* model all the equipments belonging to a given class are equivalent in these respects, thus the model characterizes each equipment class by a number of initially installed ports and a number

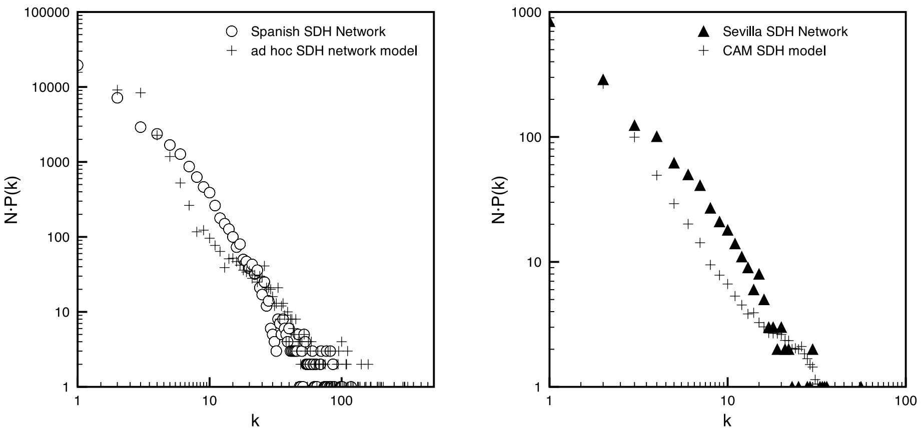

Figure 1: Distribution of the number of nodes with k connections, $N \cdot P(k)$, obtained from the entire Spanish SDH network (left) and from the Sevilla province (right) in comparison with the distributions generated by the models.

of maximally supported ports. Concerning geographical location, each equipment in real SDH systems posses an ID that signals its address. In the *ad hoc* model the region where the network is deployed is divided into territorial units denominated *provinces*, and each province is divided into lower-level territorial units called *sectors*. Although traffic demand is an important factor behind the growth of real SDH networks the model considers, for simplicity, that the Spanish territory has a uniform demand and therefore the probability that an equipment is added to any region will be considered uniformly distributed.

The other model, CAM [5], is a generic proposal completely different. The model also simulates the network growth through a stochastic process similar to the *ad hoc* model. However, the link between the added equipment and those already present is goberned by a single evolutive rule named *compatibility* that indicates the compatibility between their *characters* defined by a certain probability density function (PDF). Thus, the new added equipment is compatible with others when the difference between their characters is less than the compatibility threshold $C_m(\tau) = \frac{d}{\tau}$, where d is a constant called *compatibility distance* and τ represents the time of arrival of the new added equipment.

3. Results and Discussions

Fig. 1 provides the degree distribution $N \cdot P(k)$ obtained from the networks generated by the the *ad hoc* model (left) and CAM (right) compared to the real SDH systems. Remarkably, both models reproduce the distribution observed in real networks. Moreover, the models reproduce the small-world properties of the real system. The *ad hoc* model generates networks with values of the mean clustering $\langle C \rangle = 0.08$ and the average path lenght $\langle l \rangle = 10.4$ similar to the ones obtained empirically in entire SDH network (0.004 and 11.3 respectively). Values of $\langle C \rangle = 0.07$ and $\langle l \rangle = 4.3$ obtained by the CAM are close to the ones obtained from the province of Sevilla (0.07 and 6.2 respectively).

The complexity found in the Spanish SDH network depends on a strict planning, but also on factors such as user demand, costs associated to the connections of a new equipment and complex intrinsic constrictions. The fact that the *ad hoc* model reproduces the empirically observed properties of the real SDH network evidences the possibility to generate an algorithm that captures the events associated to the network evolution and predicts the future of the system. However, all these events can be "compressed" into the compatibility concept. Our results suggest that compatibility between two SDH equipments is sufficient to generate the complex topology observed.

Acknowledgments

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