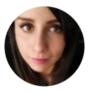
Local layered algorithmic model for topological design of rural telecommunications networks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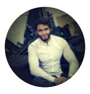
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Abstract

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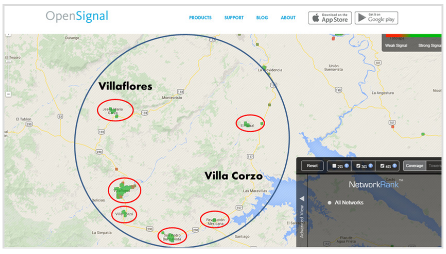
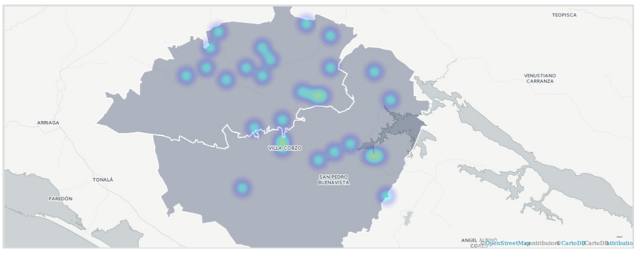
Figures





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Local layered algorithmic model for topological design of rural telecommunications networks

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Abstract

This paper aims to present a *local layered algorithmic* model for the topological design of rural telecommunications networks, which can be used to estimate the infrastructure requirements and associated costs that are necessary to deliver broadband coverage to unconnected rural communities in Mexico. The approach that is presented takes advantage of the geographical proximity to already connected towns (nodes of an existing primary network) to determine by means of a Voronoi tessellation areas to be covered with new *local networks*. For each cell of the tessellation we considered a *layered architecture*: primary and secondary network, the latter being an expansion of the first. In order to deploy the local network of each segment, actual road distances were taken into consideration, hence, increasing the applicability of the model. We applied our methodology on two municipalities of the Mexican state of Chiapas and we found satisfactory results that take advantage of the two fundamental benefits of our approach: design simplification and modular deployment.

Keywords

Telecommunications network design, topological network design, algorithmic network design, rural community, digitalization, broadband service coverage.

I. Introduction

Internet penetration has been growing at an almost exponential rate since the year 2000, scoring a total of nearly 3 billion worldwide users in July 2014, which represents more than 40% of the global population [20]. More impressive perhaps are mobile phone penetration statistics. By the end of 2015 there are expected to be nearly 4.5 billion users around the globe [16].

Increasing access to digital technologies is just part of an important rising phenomena: *digitalization*. According to Katz et al. [9] digitalization is defined as the social transformation triggered by the massive adoption of digital technologies to generate, process,

the corresponding infrastructure. Such connectivity networks generate positive externalities making the impact of telecommunications infrastructure on economic growth higher than linear. Röller et al. [15] found that when levels of infrastructure approach universal service, increasing returns on growth are reached.

Under this scenario the design and deployment of effective telecommunications networks has become a major demand for most countries around the world, which is particularly important for developing countries. Yet, to bring telecommunications to rural communities remains to be a difficult problem to solve.

While urban telecommunications networks are relatively inexpensive and comparatively easier to deploy and maintain, rural networks are the opposite (expensive and difficult to deploy and maintain), thus leading to a low development of the telecommunications networks in rural communities [10]. According to the National Census of Population and Housing performed by

INEGI in 2010 [7], 23% of the total population in Mexico live in rural communities, many of which lack of telecommunications services like mobile telephony or broadband access.

It is well known that network design is a very complex process, and that inadequate designs can result in unnecessary investment costs and poor service performance. This is why different optimization problems in the field of operations research arise naturally to support telecommunications networks design. As Prytz [14] pointed out, a good network design is difficult to characterize exactly because it depends on too many factors. A network design engineer typically has to evaluate tradeoffs between several design parameters. Despite the multiple factors involved, Prytz [14] says that the main design objectives of telecommunications networks can be summarized as follows:

- *Performance:* application response time and availability. This frequently translates into requirements on the data transmission rate and the percentage of data that has to be present; or on the probability that an application runs without failures due to congestion.

- *Redundancy, resiliency & survivability :* network ability to rest available under component failures (like router, switch or network link interruptions). These objectives translate into requirements on network resources, such as the need for alternative paths to reroute traffic.

- *Economic viability :* the returns on investment (including the cost of equipment, capacity leasing, labor, support, etc.) need to be attractive enough to justify the deployment of the network.

Network design problems usually consist on *designs-from-scratch* or *expansion/change of existing networks* [14]. As Prytz shows, there are complex interactions and natural conflicts between the design-objectives explained before; therefore, network designs are frequently broken into smaller subproblems that are easier to deal with. Furthermore, networks are usually subdivided into different segments that obey different functionality and topology, and are often treated separately according to their own architectures. Such segments of a network can be grouped into tiers or layers that are arranged hierarchically. In such manner, the top layer of a network is often referred as the *primary*, *backbone* or *core*, and the subsequent layers known as secondary or tertiary networks. A top-down approach is often used to satisfy each layer's particular criteria.

To satisfy the design objectives, according to Penttinen [11] a common network planning and design methodology encompasses several steps that are performed iteratively. Among such steps, the *topological design* concerns about the selection of the network nodes, the definition of their location, the definition of the mechanisms to connect them (such as fiber or point-to-point links), and the calculation of the bandwidth capacity of the network branches (that is, the links between the nodes). The topological design frequently uses optimization methods like *graph theory* or *linear programming* to find the optimum cost for data transmission.

This paper presents a model to develop the *topological design* of the expansion of an existing network (a primary network), to explore the possibilities to increase its reach into local rural communities that lack of telecommunications services. Assuming the availability of the primary network (which already satisfies redundancy, resiliency and survivability), this paper focuses on the secondary networks that need to be deployed. The approach that is presented allows the simplified and automatic design of local network extensions under a diversity of scenarios, which are useful for the analysis of the implications of the different alternatives to extend the penetration of the primary network. In such sense, the rest of the paper is organized as follows: section II describes the different steps of the proposed methodology, and explores its advantages; section III covers the implementation

II. METHODOLOGY

To design possible expansions of a backbone network laid over a given geographic area, which already connects several localities but not all of them, the proposed methodology accounts for the following steps:

1) Identify localities with telecommunications services (already connected to the backbone network) and the unconnected localities to connect.
2) Use a tessellation technique to exploit the notion of geographic proximity by grouping unconnected localities around their closest connected town.
3) Use spanning tree techniques to determine the expansion branches of the secondary network by connecting neighboring localities along existing roads and trails.

Considering the complexity to design a network that covers all the localities within a geographic area, our methodology addresses the different aspects of the network design in a hierarchical manner: from a *local layered algorithmic approach*.

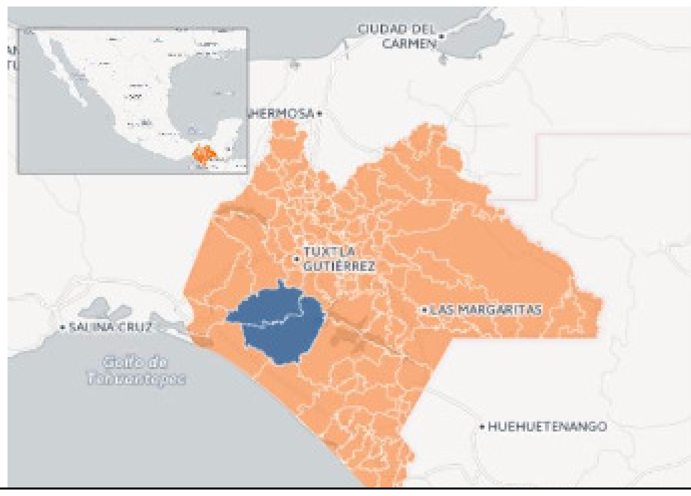
Since most of the graph problems regarding the design of a whole connectivity network fall in the category of *NP* or *NP-complete* problems, an optimal solution may be computationally intractable [8]. Our approach is considered to be *local* as we segment every instance of the problem into much smaller subinstances that are more graciously treated. We use the notion of locality and proximity at every design step, hence reducing the complex problem of designing a whole network to connect tens of thousands of localities, into several easier and more tractable subproblems. The tool we used to carry out the segmentation is a Voronoi tessellation (also called Voronoi diagram).

In view of primary and secondary types of network explained before, each requiring different levels of redundancy and capacity, our approach is considered to be *layered* as we consider two different layers: the already existing core network, and its possible expansion into secondary networks. While the core network is the most important, as it connects the main cities of the region and has a greater degree of redundancy and capacity, the secondary networks are necessary to reach localities with less population and little economic activity. We designed these secondary networks using the minimum cost spanning tree approach (MCST), through the Prim's algorithm. We point out that the cost of an edge is not the Euclidian distance between two localities, but the road distance between them, increasing the applicability and relevance of the model.

Computational algorithms have been developed to implement all three proposed steps of our methodology (to identify connected and unconnected towns, tessellate and group towns, and build local networks along roads and trails). Therefore, all the proposed procedure can be performed automatically with a computer, and repeated iteratively to analyze different regions and/or scenarios. Thus the proposed approach is considered *algorithmic*.

We used Google's API *Directions* to obtain roads and trails distances. The degree of connectivity in the different localities, on the other hand, was found with the OpenSignal API *NetworkStats*.

As mentioned before the proposed methodology was tested analyzing two neighboring Mexican municipalities in the state of Chiapas: *Villaflores* and *Villa Corzo* (see Fig. 1). The total population in the chosen region is around 154,000 citizens living in 105 localities with 100 to 16,000 residents each.



There are three main factors that support the chosen region:

- **Urgency:** If we consider the state of digitalization in Latin America, Mexico is in the tenth position, below Chile, Uruguay, Panama, Costa Rica, Argentina, T&T, Ecuador, Colombia and Brazil [9]; thus, Mexico has an immediate need to improve digitalization to capture its benefits. The chosen region in Chiapas has a large percentage of uncovered population, characteristic of several rural areas in Mexico that could be connected to increase broadband penetration and thus the overall national digitalization index.

- **Impact:** Chiapas is a state rich in natural resources with a privileged strategic geographic position, which lacks of basic connectivity infrastructure and ICT services. If such infrastructure and services could be deployed a substantial impact

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A model to estimate the broadband and Internet access demand for typical Mexican rural communities

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