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Optimization Challenges in Telecommunications Networks

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ABSTRACT

In this paper, we employed graph theory to solve optimization problems in telecommunication networks. For instance, if two antennas simultaneously transmit, on the same frequency, different signals to a receiver, the latter will have difficulty in interpreting them correctly (a bit like if two people are talking to you at the same time, it is difficult to follow the two conversations simultaneously). To overcome this problem, it is necessary to assign different frequencies to two antennas whose signals are likely to be received by the same receiver (think of FM radios). One could consider assigning different frequencies to each antenna, but for material reasons (limited number of frequencies, price etc.) this is not possible. For example, RMC radio, which has become one of the most listened to radio stations in France, still does not have a frequency assigned to Strasbourg. We employed graph theory to solve these optimization problems

Keywords: Network optimization, IoT, resource optimization.

1. Introduction

Many optimization problems arise in telecommunications networks. To solve them, we often use the tools of graph theory. A graph consists of a set of vertices which model the nodes and a set of edges which model the links of the network. Nodes can be network subscribers or users but also equipment such as computers, servers, routers, antennas, web pages. Links can be physical links (cables, fibers), radio links or even virtual links like hyperlinks.

The role of telecommunications networks is notably to exchange information. For example, an email between two people, the loading of a video from a server or the access to a web page are called requests between two nodes of a network. Routing a request consists in finding in the graph representing the network a path between the two communicating nodes. For example, in Figure 3(a), a query between nodes s and t is routed by the shortest path of length 2 (via vertex a). Finding a path is one of the so-called "easy" problems. They can be solved in polynomial time in the size of the network (see the article “TRANSPORT, FLOWS AND CUTS” (ref)). In reality, several requests must be routed simultaneously, satisfying many constraints (limited capacity or bandwidth, interference, information processing, etc.). This makes the problems much more complicated. We present network design and management problems through various examples, focusing on their applications, description, and modeling as graph problems.

2. Methodology

Interference in wireless networks. If two antennas simultaneously transmit, on the same frequency, different signals to a receiver, the latter will have difficulty in interpreting them correctly (a bit like if two people are talking to you at the same time, it is difficult to follow the two conversations simultaneously) . To overcome this problem, it is necessary to assign different frequencies to two antennas whose signals are likely to be received by the same receiver (think of FM radios). One could consider assigning different frequencies to each antenna, but for material reasons (limited number of frequencies, price...) this is not possible. For example, RMC radio, which has become one of the most listened to radio stations in France, still does not have a frequency assigned to Strasbourg.

It is therefore necessary to minimize the total number of frequencies used. To solve this problem, we use graph coloring. Each antenna is modeled by a vertex of the graph and two vertices are linked by an edge if the associated antennas must receive different frequencies. The frequency assignment problem amounts to assigning each vertex of the graph G a color (modeling the frequency) so that two neighboring vertices receive different colors (Figure 1). Minimizing the total number of frequencies used amounts to determining the minimum number of colors of the graph, noted X(G).

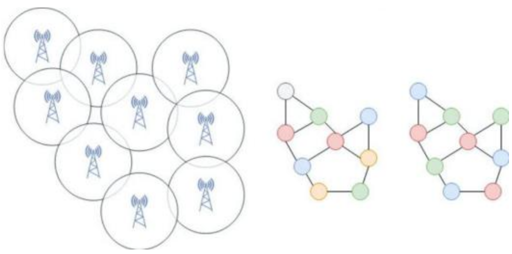

Figure 1. The figure on the left represents an array of 9 antennas as well as the range of their emissions. Different frequencies must be assigned to two antennas whose spans intersect. This network is modeled by a graph of which we propose two valid colorings, one using 5 colors (in the center) and the other 3 colors (on the right) which is optimal in this case.

One way to solve the problem is to test all possible colorings with one color (there is only one), then all colorings with two colors, and so in succession until finding a proper coloring (where two neighboring vertices have different colors). However, this algorithm requires testing X(G)^(n+1) colorations, that is to say an exponential execution time in the number of vertices, which is prohibitive. For example, if X(G)=4 and n=135, this involves testing about 10^81colorings, as much as the number of atoms in the universe.

Unfortunately, this problem is NP-complete and it is currently not known how to solve it in a significantly better way (other than in exponential time in n). Fortunately, in practice, engineers and researchers know how to solve the problem in decent times either by using generic methods such as linear programming or by taking into account the particularities of real networks. For example, deciding whether 2 colors are sufficient can be effectively resolved by testing whether the graph contains cycles (a cycle is a path looping back to its starting point) of odd length or not. Another well-known example is planar graphs (which can be drawn in the plane without crossing edges).

3. Modeling, Analysis and Results

In 1852, mathematician and botanist Francis Guthrie asked how many colors a geographer should use to color a map of countries so that two countries with a common border were given different colors. He conjectures that 4 colors are always sufficient. This question is equivalent to whether X(G)≤4for any planar graph G. This question was only answered affirmatively in 1976 by Appel and Haken (with the use of the computer) and is the first famous mathematical result to have been proven using the power of computers. This result caused controversy (is a proof made with the help of computers valid?) until the computer part of the proof was formally certified by Gonthier and Werner in2005.

Applications in wired networks and link with flows. The problem of interference also arises in other contexts of telecommunication’s networks. Let's take an “Internet” type network where the vertices are the computers, or the routers and the edges are the optical fibers between the various elements of the network. Two separate signals using the same fiber must have different wavelengths (frequencies) to avoid interference. Consider a set of queries and assume that for each query the associated path is predefined. To assign a wavelength to each request, we define the following conflict graph. A vertex is assigned to each query and two vertices are adjacent if the paths of the associated queries share the same link. Minimizing the number of wavelengths amounts to determining a proper coloration of having as few colors as possible (Figure 2).

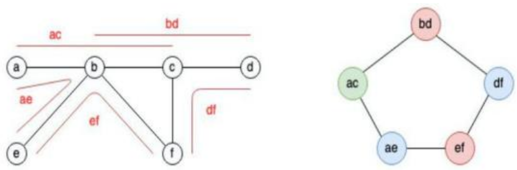

Figure 2: The figure on the left represents a network with 6 vertices and 5 queries: ac (query between a and c), bd, df, ef, and ae. The figure on the right is the conflict graph of these queries. While there are at most two requests per link, 3 wavelengths are required to satisfy the request.

In reality, the problem faced by operators is to simultaneously calculate a multiflow (the paths that requests must follow) that is feasible while minimizing the number of wavelengths to be used. The combination of these two problems which are, by themselves, already difficult makes the problem extremely complicated mathematically and in practice... To set up a network service in the networks of new generations.

Preamble: Imagine that you have reserved an evening for a long time to finally be able to watch the last episode of your favorite series and that your neighbors have also chosen that evening to download the complete version of their favorite filmmaker using all the bandwidth of the network. . In the near future, you will be able to purchase a network service that reserves part of the bandwidth exclusively for you. Such network services will allow emergency calls to always be prioritized or a telemedicine operation to always have low network delay by reserving network slots.

Remember that traditionally in telecommunications networks, “routing” a request amounts to finding a path between its source and its destination (for example, see Figure 3(a)). Once the path has been chosen, the network must then be configured to route the traffic. that is, to indicate to each node of the network which link must be taken to reach its destination. In existing networks, this operation is very complex because each piece of equipment must be configured by hand and the configurations are specific to it. Finally, it may need to be reconfigured to respond to outages and traffic dynamics.

In addition, certain traffic flows must be processed by network functions, whether to guarantee network security (for example with a firewall function which filters abnormal traffic to avoid attacks), to improve the speed (compression function) or improve a video stream (video optimization function). A network service corresponds to a sequence of functions, called a service chain, which must be applied to a stream of data. For example, a video network service may consist of a firewall function, then a compression function and finally a video optimization function (Figure 3 (b)). Traditionally, network functions are run on expensive dedicated hardware called a middlebox. To provide a network service, a request must therefore first be routed to the hardware dedicated to the first function, then to that dedicated to the second function, and so on. to the destination, following the shortest paths. An example is given in Figure 3(b) where the video service is provided by going first to node e containing a firewall, then to node d with the compressor and to node c (via a) with the video optimizer, then finally in t. Setting up a network service is therefore complicated and costly.

Fortunately, the new generation networks that are beginning to be installed, in particular networks 5G and loT, have seen the emergence of two major revolutions: software networks and network virtualization. In a software network, the operator remotely controls the nodes of the network to automatically change their configurations, for example the links to be taken. Network virtualization, and in particular network functions virtualization (NFV), is an approach in which network functions are no longer executed on dedicated hardware, but on generic servers located in small data centers. One of the main advantages of this approach is that virtual network functions can be launched on demand without the need to install new equipment. The model of virtualized programmable networks therefore allows operators to offer complex and flexible network services.

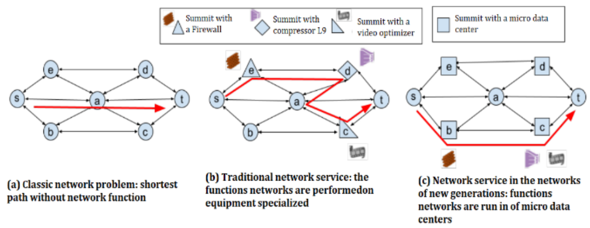

Figure 3: Typical request routing (a). Routing of a network service in a traditional network (b), in a new generation network (c).

In next-generation networks, virtual network functions can be performed on any of the micro data centers available. For example, in Figure 3(c), they are respectively on b(firewall) then c(compression and optimization). A new algorithmic problem then arises is how to route the requests while choosing where the virtual network functions of the service chains are executed.

-Summit with a micro data center

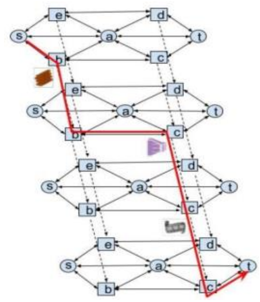

Figure 4: The layered graph associated with the network of Figure 1(c) and the demand between s and twith the realization of 3 virtual functions.

This new algorithmic problem can be reduced to a shortest path problem in a multi-layer graph. To realize an ordered sequence of m virtual functions, we use a graph formed by m+1copies of the original network Organized in layers, see Figure 4. The vertical links (in dotted lines) make it possible to go from a node to a micro-data center at the same node in the neighboring layer. Finding a path for a query with the nodes where the functions of the chain are executed is equivalent to finding a path from the source on the first layer to the destination on the last layer. The execution of the virtual function is performed on layer i and if it has been executed in a node, the same node of layer i+1 is passed through the associated vertical link.

The problem presented is a simplified version of the real problem where we must also take into account the capacity constraints of the links and the micro-data centers, which amounts in the case of a single service chain to solving a flow problem. in the layered graph. Moreover, it is often necessary to deal with a set of service chains, which gives rise to difficult multi-flow problems. One can also use the multi-layered approach to decide on the placement of micro data centers.

One of the major advantages of 5Gis the ability to define network slices, i.e. to be able to reserve for a specific application or particular customers (see preamble) a subnet: a set of bandwidth resources and computational ability. The applications envisaged are, for example, to reserve independent sub-networks for emergency services (SAMU, etc.), tele-medicine or autonomous cars. If a service chain is a path of network functions, these slices are more generally defined as a graph in which the nodes are network functions which must be connected according to the links (Figure 5).

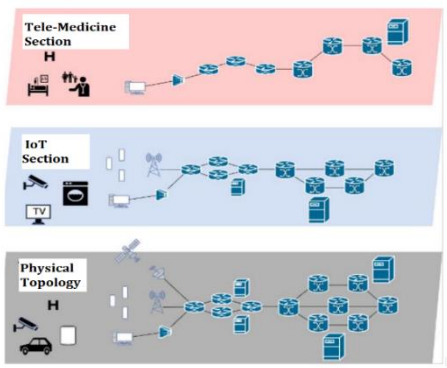

Figure 5: Network slices 5G.

4. Conclusion

Graph theory and virtualization can solve optimization problems in networks. But there are hazards that the theory cannot take into account. Thus, in the 1980s, the French telephone network was designed to satisfy multiple requests via separate routers: but to facilitate management, several routers were installed in a single location in Lyon. The network graph was well designed, but a fire ravaged the premises in 1981, depriving millions of users of telephone services. This type of incident happened again recently, in March 2021, with the fire on web servers in Strasbourg.

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