Telecommunications Network Planning and Maintenance

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***Abstract*—Telecommunications network operators are on a constant challenge to provide new services which require ubiquitous broadband access. In an attempt to do so, they are faced with many problems such as the network coverage or providing the guaranteed Quality of Service (QoS). Network planning is a multi-objective optimization problem which involves clustering the area of interest by minimizing a cost function which includes relevant parameters, such as installation cost, distance between user and base station, supported traffic, quality of received signal, etc. On the other hand, service assurance deals with the disorders that occur in hardware or software of the managed network. This paper presents a large number of multicriteria techniques that have been developed to deal with different kinds of problems regarding network planning and service assurance. The state of the art presented will help the reader to develop a broader understanding of the problems in the domain.**

***Index Terms*—Network Planning, Network Maintenance, Service Assurance.**

I. INTRODUCTION

Broadband Internet access, often shortened to just "broadband", is high speed Internet access that provides download speeds equal to or faster than 256 kbit/s. Speeds are defined in terms of maximum download because several common consumer broadband technologies support much slower upload speeds than download, such as Asymmetric Digital Subscriber Line (ADSL).

The population demand for the broadband services has not stopped rising in the last couple of years. Not only that the number of users is getting higher, but they extensively use the newly offered services. As an example, the growth of the number of Internet users' in the region of Spain is shown in Fig. 1.

The standard broadband technologies in most areas are Digital Subscriber Line (DSL) and cable modems [1]. Newer technologies in use include VDSL (Very High Speed DSL) and pushing optical fiber connections closer to the subscriber in both telephone and cable plants [2]. For more detailed overview of DSL technologies see [3]. As an example, Fig. 2 shows the growing demand of DSL services in Spain.

Fiber-optic communication has played a crucial role in enabling Broadband Internet access by making transmission of information over larger distances much more cost-effective than copper wire technology. A detailed overview of fixed access network technologies is given in [4]. The authors gave an insight to the challenges that telecommunication operators face in providing ubiquitous broadband access, when trying to cut costs radically and to invest heavily in new technologies.

In a few areas not served by cable or ADSL, community organizations have begun to install Wi-Fi networks, and in some cities and towns local governments are installing municipal Wi-Fi networks. As of 2006, high speed mobile Internet access has become available at the consumer level in some countries, using the High-Speed Downlink Packet Access (HSDPA) and Evolution-Data Optimized (EV-DO) technologies. The newest technology being deployed for mobile and stationary broadband access is Worldwide Interoperability for Microwave Access (WiMAX) based on the IEEE 802.16 standard, which is also called WirelessMAN.

A Digital Subscriber Line Access Multiplexer (DSLAM) is a network device, located near the customer's location that connects multiple customer DSLs to a high-speed Internet backbone line using multiplexing techniques. By locating DSLAMs at locations remote to the telephone company central office (CO), telephone companies are now providing DSL service to consumers who previously did not live close enough for the technology to work. The ability to provide high speed Internet service from a central location is attractive but the issues of equipment and operational costs exist [5]. To achieve

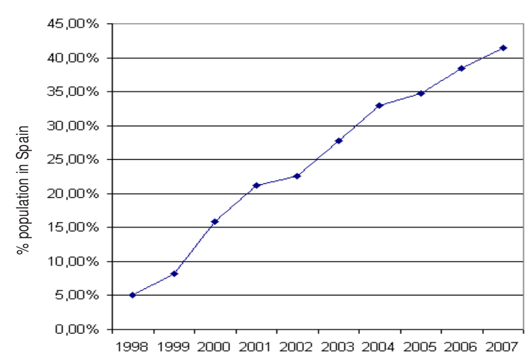

Fig. 1. Growth of the Internet services demand in Spain.

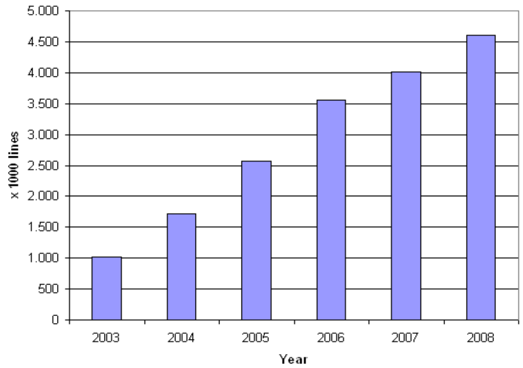

Fig. 2. Growth of DSL connections installed in Spain by Telefónica S.A.

the high data rates DSLAMs must be deployed deep into the network as close as possible to the costumer. Customers connect to the DSLAM through ADSL modems or DSL routers, which are connected to the public switched telephone network (PSTN) via typical unshielded twisted pair telephone lines. Each DSLAM has multiple aggregation cards, and each such card can have multiple ports (typically 24 ports) to which the customers' lines are connected.

Traditional 20th century DSLAM used Asynchronous Transfer Mode (ATM) technology to connect to upstream ATM routers/switches. These devices then extract the IP traffic and pass it on to an IP network. Internet Protocol DSLAMs, or IP-DSLAMs, extract the IP traffic at the DSLAM itself. Advantage of IP-DSLAM over a traditional ATM DSLAM is in terms of lower capital expenditure and operational expenditure and a richer set of features and functionality. A statistical analysis of the traffic variability measurements in broadband access networks especially for ADSL broadband access platforms was presented in [6] and [7]. An increasing population of residential users with ADSL access generates most of the aggregated traffic on IP platforms due to the peer-to-peer connections.

Next Generation Networking (NGN) [8] is a broad term used to describe some key architectural evolutions in telecommunication core and access networks. A Next Generation Network (NGN) is a packet-based network that uses Internet technologies such as Internet Protocol (IP) and Multiprotocol Label Switching (MPLS). It offers unrestricted access by users to different service providers, "from anywhere to anywhere", and it supports generalized mobility which will allow consistent and ubiquitous provision of services to users.

Telecommunication operators are under constant pressure and obligation to extend and improve their facilities in order to cover the users' growing demand. In the next period, a big deployment of a fiber optics network is expected that will provide the users with a very high bandwidth network access, over 30Mbps. However, high costs that an operator faces in order to install the new infrastructure are a problem which can be solved by Network Planning.

II. Network planning

Network planning is an iterative process, involving topological design, network-synthesis, and network-realization, and is aimed at ensuring that a new network or service meets the needs of the subscriber and operator. This is an extremely important process which must be performed before the establishment of a new telecommunications network or service. In the process of network planning many parameters (depending on the type of network) have to be taken into account. These parameters can be technological, economical or demographical, and since the result of the network planning process is heavily dependent on the values of parameters taken, thorough preceding study is needed. Network planning involves clustering the area of interest by minimizing a cost function which includes relevant parameters, such as installation cost, distance between user and base station, supported traffic, quality of received signal, etc. To find a set of candidate sites, with which the cost function achieves the minimum, is the task of optimization algorithms. Network planning is a multi-objective optimization problem, which can be solved as a single-objective problem by assigning different weighting factors to different objective terms.

Carpenter et al. [9] used dynamic programming (DP) to optimize the placement of network nodes. The algorithm was implemented as the design engine for ™Telcordia's Network Planner - a prototype software tool for xDSL network planning over an existing copper network.

Experimental results and analysis indicated that the CWSP-PAM-ANT (Clustering with Shortest Path-PAM Ant-Colony-Based) algorithm [10] was effective, and leaded to minimum costs for network construction in an urban area where accuracy is needed and the network is complex due to the large number of streets and intersections. The CWSP-PAM-ANT algorithm is based mainly on the idea of Partioning Around Medoids (PAM) where the Ant-Colony-Based algorithm is used to compute the shortest distances, or paths, from all data points to the cluster medoid. The proposed algorithm is applied to a map representing the examined area. The streets are converted into linkages between data points that represent intersections. The number of subscribers determines the weights of a linkage. The output is a map divided in clusters where positions of the switches are determined.

A genetic optimization system GenOSys, developed at British Telecom, can generate different network configurations and evaluate them rapidly to arrive at an optimal or near-optimal solution [11]. The system is based on a genetic algorithm with the optimization objective of determining the best locations for distribution points and identifying geographically advantageous tree-structure sub-networks to aggregate cables from customers to a primary connection point via distribution points. The authors showed that short computational time was required to solve a 240-node problem.

Amaldi et al. [12] proposed an optimization model based on linear mathematical programming whose objective function is the minimization of the overall Wireless Mesh Network

(WMN) installation cost while taking into account the coverage of the end users, the wireless connectivity in the wireless distribution system and the management of the traffic flows. Technology dependent issues such as rate adaptation and interference effect have been considered in the implementation of the model as well.

A well planned and optimized WCDMA radio network can provide some 30% extra capacities under the same infrastructure cost. Hence, network planning and optimization plays a vital role for the deployment and maintenance of this type of network. Zhang et al. [13] developed a static simulator for WCDMA network to test four heuristic algorithms, namely Tabu Search (TS), Evolutionary Simulated Annealing (ESA), Genetic Algorithm (GA) and a hill climbing local search (Greedy) in order to obtain optimized network configurations. The constraints considered in optimization of the cost function were different from the ones used in case of public switched telephone network (PSTN), but the same method could easily be applied.

In [14], Liu and Worrall gave a theoretical overview of 3G network planning. The goal of network planning is not only to define the initial network, but to keep it optimized as well. Finally, network optimization is a process used to improve overall quality as experienced by the subscribers, to ensure that network resources are used efficiently.

A genetic type algorithm used to optimize the number and locations of base stations for cellular network was proposed in [15]. Total cost of the system which links to the total number of base stations deployed in an area is used as the primarily targeted objective to optimize. The authors proposed a second stage optimizer (such as self-organizing map) that has a capability of selective extraction of information from the environment to optimize the results generated by the traditional planning tool. An accurate determination of subscriber patterns and preferences is considered the key to a network operator obtaining effective ARPUs (average revenue per user). Another similar approach in determining the optimum positions and number of base stations in a radio network planning, using genetic type algorithm, was introduced by Park et al. [16].

In [17] the authors proposed a Particle Swarm Optimization (PSO) algorithm for the cell planning problem in cellular radio networks. The optimization objectives were minimization of the number of sites, maximization of the number of handover areas (overlap areas between cells), minimization of the noise level and maximization of the amount of traffic.

Though one only optimization method cannot be the best for each problem, the solutions presented in this section surely brought improved results on the issue they addressed. The addressed issues of Network Planning and the algorithms used to solve them are presented in Table I.

This section shows that Network Planning can be applied in various types of telecommunications networks. The problem of network configuration comes down to the placement of nodes which may refer to DSLAMs for fixed access networks, or cell base stations for cellular networks. This is an optimization problem which can be redefined to suit the appropriate solution only by changing the relevant input parameters.

TABLE I
COMMON NETWORK PLANNING PROBLEMS AND ALGORITHMS APPLIED.

Optimization problem	Applied algorithm
Network configuration User-node optimal path	Dynamic Programming (DP) Genetic Algorithm (GA) Tabu Search (TS) Evolutionary Simulated Annealing (ESA) Hill Climbing Particle Swarm Optimization (PSO) CWSP-PAM-ANT algorithm Linear mathematical models

III. SERVICE ASSURANCE

Novel network architectures allow users to get specific performance guarantees which are defined in a Service Level Agreement (SLA) document [18]. SLA represents a formal high level definition (user view) of characteristics for a communication service whereas low level specification (network view) is obtained translating the SLA in a different document named Service Level Specification (SLS).

Telecommunication equipment and the links between them suffer incidences on a daily bases, and they have to be solved in order to maintain the Quality of Service (QoS) guaranteed to the customers. The upgrade of network infrastructure, physical damage of transmission cables, etc., causes deterioration of the QoS, and the telecommunication company's resources available to solve its network problems are limited. Disorders occurring in the hardware or software of the managed network are referred to as faults. The external manifestations of faults are referred to as alarms, which are defined by equipment vendors and observable by network operators.

A. *Alarm detection and alarm correlation*

Modern telecommunication networks may produce thousands of alarms per day, making the task of real-time network surveillance and fault management difficult. The alarms may be overlooked or misinterpreted. The concept of alarm correlation [19] tries to interpret the multiple alarms such that a new meaning is assigned to their occurrences. Various tasks are part of the alarm correlation process, such as: compression - the reduction of multiple occurrences of an alarm into a single alarm, count - the substitution of a specified number of occurrences of alarms with a new alarm, suppression - inhibiting a low-priority alarm in the presence of a higher-priority alarm, Boolean - substitution of a set of alarms satisfying a Boolean pattern with a new alarm, and generalization - reference to an alarm by its superclass. Alarm correlation may be used for network fault isolation and diagnosis, selecting corrective actions, proactive maintenance, and trend analysis.

B. Trend analysis

Data mining techniques can be applied to recognize the patterns in alarm occurrences. Trend analysis requires finding long-term, rather frequently alarm occurring dependencies. Klemettinen et al. [20] described the knowledge discovery system Telecommunication Network Alarm Sequence Analyzer (TASA), in which data mining techniques were applied for telecommunication networks alarm data analysis. The system consisted of the set of rules. First, a large database of alarms was analyzed off-line in order to discover the temporal connections and relationships between those alarms. The initial set of rules was created and then analyzed by network management specialists who selected the interesting ones. The selected rules were then converted into correlation rules and applied in real-time fault identification.

Another approach was described in [21], where the authors proposed the Frequent Temporal Patterns of Data Streams (FT-DPS) algorithm to mine frequent temporal patterns for data streams. The algorithm was applied in data mining with variable time intervals but also to perform trend detection.

C. Fault tolerance

The development of more efficient routing protocols results in better fault tolerance. The routing protocols need to be optimal, simple, robust, scalable, etc. and able to provide the earlier mentioned QoS. Detailed overview of the nature inspired routing protocols for fixed telecommunication networks is provided in [22]. The routing protocols were based on widely used algorithms such as Ant Colony Optimization (ACO), Evolutionary Algorithms (EA) and BeeHive algorithm, among others.

D. Corrective actions

Detection of faults and alarm filtering and correlation lead to the next stage of telecommunication network maintenance which is the selection of corrective actions. Alarcón et al. [23] explained how ELECTRE I method can be used in an effective manner to take correct decisions about the maintenance actions in a telecommunication network. The authors applied a multicriteria decision-making method to define the order of restoration of transport paths, circuits and cables. Parameters, such as customer category, level of QoS, bit rate, customer's fee among others have been used in the decision matrix.

For the professionals in telecommunications companies whose work is dedicated to decision-making, ELECTRE I method is easy to understand and apply, moreover it guaranties that their opinions are taken into account in all the stages of the process. They are involved, that much in determining the values of the initial decision matrix, as in assigning the weights and importance factors to the applied criteria. These characteristics facilitate the method's acceptance and implementation, knowing how hard a "manual" decision-making can be.

E. Other approaches

Service Assurance is a complex problem that can be tackled with using different approaches. Tsai et al. [24] proposed a method to measure the availability of Internet service and an approach to predict the availability of IP-VPN end-to-end service for the broadband IP network in Taiwan. In the model, eighteen Access switches and two out of seven Edge switches are directly connected to Hinet (ISP) through ATM switches in Data Communication Business Group on one side. The above Access switches and Edge switches are connected to three types of DSLAMs with different amount of ATU-Rs (users) on the other side. According to the availability analysis and prediction, the results obtained show if an IP network meets the requirement of SLA.

The heterogeneity of a network is a problem to cope with but also an opportunity to exploit. Botta et al. [25] described the heterogeneity with respect to terminals, networks, and services, and introduced the concept called "Service Condition". Terminal heterogeneity refers to various terminal devices subscribers use to connect to the network, such as high-performance workstations, Personal Digital Assistants (PDAs), advanced mobile phones, etc. Regarding the network heterogeneity, even if we consider as dynamically variable only the part that is closest to the user (access or edge network), we have a quite large number of options to deal with, i.e. wired (LAN, xDSL,...), wireless (WLAN, Bluetooth,...), mobile networks (GPRS, EDGE, UMTS,...), among others that could be taken into account. Services may have different characteristics in terms of media involved (audio, video,...), of their format (coding, compression,...), and of their typology (synchronous, asynchronous, transactional,...) which is referred to as service heterogeneity. The Service Condition concept was introduced as a precise framework in which different service conditions were related to QoS parameters for easier network performance evaluation.

In the highly competitive market, telecommunications operators tend to protect the secrets of their products and algorithms behind them that are being used in the processes of Network Planning and Service Assurance. For that reason, it is hard to find the references to their practical implementations.

CONCLUSIONS

In this paper, we presented a detailed overview of the solutions for telecommunications network planning and network maintenance, namely service assurance. Network planning is a process that leads to the optimized network design which as a result provides the users with the ubiquitous access to network and the guaranteed level of service. As it is an optimization problem, the solutions presented in this paper usually involved widely used optimization techniques such as genetic algorithms, decision theory, ant colony optimization, particle swarm optimization, among others. Even though these tools proved useful, the expert knowledge in the management of telecommunications networks is required to adequately define the network planning problem and to set the important optimization parameters.

Service assurance deals with the faults in the network equipment and software, and the external manifestations of faults that are referred to as alarms. When alarms are detected, alarm filtering and correlation are applied in order to find the real source of the fault, and prioritize the faults, i.e. decide which part of equipment or software comes first under repair.

This state-of-the-art shows that telecommunications network planning and maintenance are complex issues that are in constant demand for better solutions. With the evolution of telecommunications networks, which carries heavy investments in new technologies, the research is directed to cutting the costs while providing the users with the guaranteed level of service.

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