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Optimizing the Cellular Network Planning Process for In-Building Coverage using Simulation

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ABSTRACT
The global scenario of mobile telecommunications networks suggests that the next years the number of mobile users will continue growing as well as the services demand. The biggest growth is expected mainly in Asiatic and developing countries. Particularly, the Mexican telecommunications market suggests that if the number of mobile users will continue growing in Mexico as in the last years, then the mobile networks operators should increment the network capacity and the in-building coverage in order to maximize the quality of service. Also, network operators should offer attractive plans to users in order to maximize their economic benefits. Therefore, this research study aims to develop a simulation model to analyze the services transmission in a Third Generation mobile network and maximize the network coverage and the theoretical economic benefit of network operators. The delivered services included are voice, data and video. Using this simulation model we obtained the optimal cost-effective network design in a scenario of a Mexican airport. This design consisted of six cells, each one configured with an Omni-directional antenna and capacity of seven traffic channels. Through the traffic channels were delivered the services: sound, multimedia, narrow band and wide band, with a data rate of 12 kb/s, 128kb/s, 384 kb/s, and 1920 kb/s, respectively. The maximum economic benefit was 46.6% using the optimal network design. We propose this simulation model as a tool for decision-making support of mobile network operators in Mexico.

Keywords: mobile network, telecommunication services, simulation model, optimization.

RESUMEN
El escenario global de las redes móviles de telecomunicaciones sugiere que en los próximos años el número de usuarios y la demanda de servicios continuarán creciendo, sobre todo en países asiáticos y en desarrollo. Particularmente, el mercado mexicano sugiere que si el número de usuarios en México continua creciendo como en los últimos años, entonces los operadores de las redes deberán incrementar la capacidad de red y la cobertura en interiores para maximizar la calidad del servicio. Además, deberán ofrecer planes atractivos de renta a los usuarios a fin de maximizar sus beneficios económicos. Por lo tanto, el objetivo de este estudio de investigación es el desarrollo de un modelo de simulación para analizar la transmisión de servicios en una red móvil de tercera generación y en consecuencia, maximizar los beneficios económicos teóricos de los operadores y la cobertura de red, para la distribución de servicios de voz, datos y video. Utilizando modelo de simulación, se obtuvo el diseño de red óptimo basado en costo-beneficio en el escenario de un aeropuerto mexicano. Este diseño consistió de seis celdas, cada una configurada con una antena omni-direccional, y con una capacidad de siete canales de tráfico, resultando un beneficio económico máximo de 46.6%. Así, este modelo de simulación se propone como una herramienta para el apoyo en la toma de decisiones de los operadores de redes móviles en México.

1. Introduction

Since the late 1970s, when the cellular era started, mobile communications have gone through an evolutionary change every decade in terms of technology and usage. At the beginning, Japan took the lead in the development of cellular technology, which resulted in the deployment of the first cellular networks in Tokyo [1]. The First Generation Mobile Systems (1G) permitted the distribution of speech services and were based mainly on analogue transmission techniques. In the early 1990, the Second Generation Mobile System (2G) appeared in the market when the digital transmission technology came into force. Then, the distribution of services such as the voice mail, text messages, and call waiting, apart from just calls, was available. One of the advantages for users using the Second Generation Mobile System was the low cost alternatives to making call, such as the text messages and one of the advantages for operators was the ability to deploy equipment from different vendors because the open standards allowed easy interoperability. In contrast, the disadvantages in the Second Generation Mobile Systems were the lack of capacity, global roaming, and quality as well as the minimum amount of data that could be sent. The Third Generation Cellular Networks (3G) was developed mainly to cover the weakness of the second generation in terms of high speed data and multimedia connectivity. The Third Generation standards such CDMA (Code Division Multiple Access), UMTS (Universal Mobile Telecommunications System), and EDGE (Enhanced Data Rates for GSM Evolution), were able to support high speed data ranges from 144 kbps to greater 2Mbps.

In the last 10 years, the global mobile subscribers and the mobile subscriptions have growth vertiginously. In 2011 reached a total around 3.9 billion subscribers and 5.8 billion subscriptions. China and India have accounted for approximately 40 percent of the estimated [3]. It is important to note that the number of subscribers and subscriptions are not equal due to the fact that actually many subscribers have more than one subscription. Particularly, in Mexico the subscriptions grew from 64 thousand in 1990 to 95 million in 2011, near to 1500% of growth in this period, with the maximum tendency since 1998. In terms of the network traffic, in Mexico the annual minutes (voice) were near to the 220 thousand million in 2011. The Figure 3 depicts an exponential trend of voice traffic growth since year 2000 with some seasonal variations. It can be appreciated the correlation between the voice traffic growth and the strong increase in mobile subscriptions.

In order to continue being competitive in the attractive Mexican telecommunication market, mobile network operators, nationals and internationals, need to optimize the network design in terms of cost-effective satisfying the user requirements of coverage and quality of service. It is important to outline that the in-building coverage is a determinant factor in the experience of the users with mobile networks, especially in meeting points, airports, commercial centers, restaurants, convention centers, train stations, theatres, and offices, where users access the network for specific voice and data services and therefore, the coverage needs to be guaranteed.

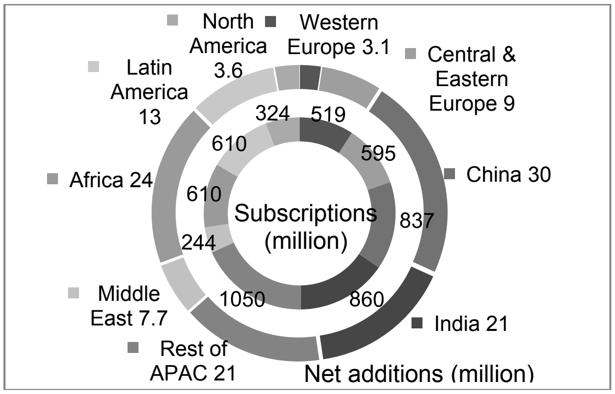

Figure 1. Global telecommunications mobile subscriptions by region [3]

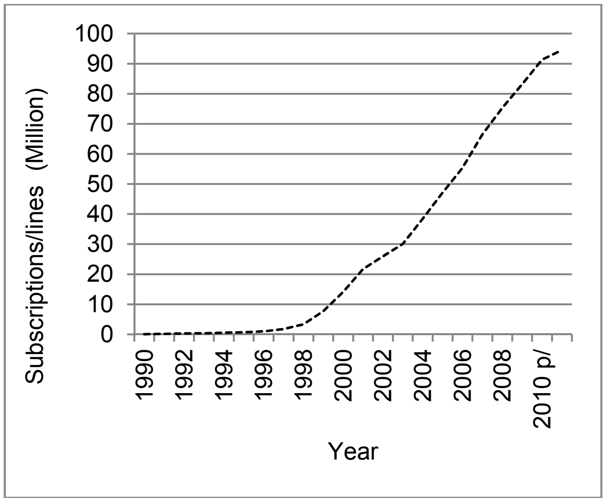

Figure 2. Mexican annual subscription to mobile telephones, adopted from [4]

In this direction, we developed a simulation model in order to analyze the services transmission in a Third Generation mobile network and optimize the cellular network planning process for in-building coverage purposes.

The paper has six main sections and is organized as follows. Firstly, the cellular network planning process is introduced in Section 2. Section 3 provides a brief review of the discrete-event simulation approach. The Third Generation mobile network´s simulation model is described in Section

4. Section 5 presents some initial results, and the model validation and optimization. The conclusions are outlined in Section 6.

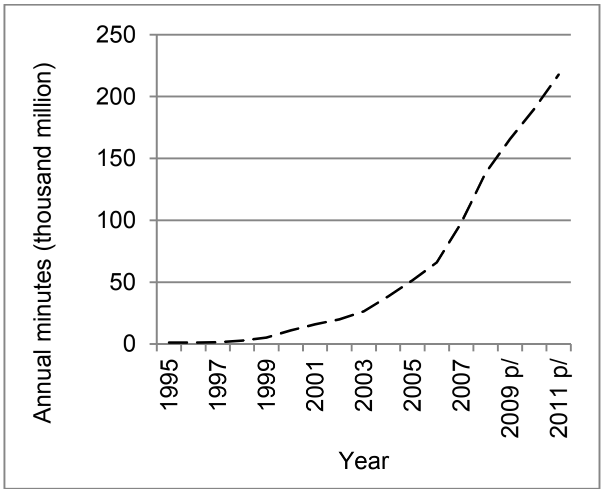

Figure 3. Mexican annual minutes from mobile telephones, adopted from [4]

2. Cellular network planning

Network planning is a process that consists of several activities whose final target is to define an optimal cost-effective network design, which is then built as a mobile cellular network [1]. One of the basic requirements for cellular network planning process is the coverage, which is related to how the end-user experiences the mobile network in a specific geographic area. Therefore, the target for coverage planning process is to find the optimal geographical locations for radio frequency antennas and determine the number of these in order to build a continuous coverage between them. The traditional theoretical model of mobile cellular networks is formed by hexagons (cells) where each hexagon represents the ideal coverage of a tri-sector antenna. However, the model also can be formed by circles (cells) where each circle represents the ideal coverage of an Omni-directional antenna. The cells can be macro, micro or pico as is shown in Fig. 4, depending on the size of the geographical area to cover. On the one hand, macro cells are characterized by a big transmission power and can reach a geographical coverage radius of 2000 meters. On the other hand, micro cells are characterized by a small transmission power and are used mainly to service big buildings such as shopping malls and business centers, where the macro cells can not satisfy the indoor coverage requirements or the network traffic is very high in peak hours. By contrast, pico cells have been designed mainly to coverage within big buildings where macro and micro cells can not satisfy the service requirements to users.

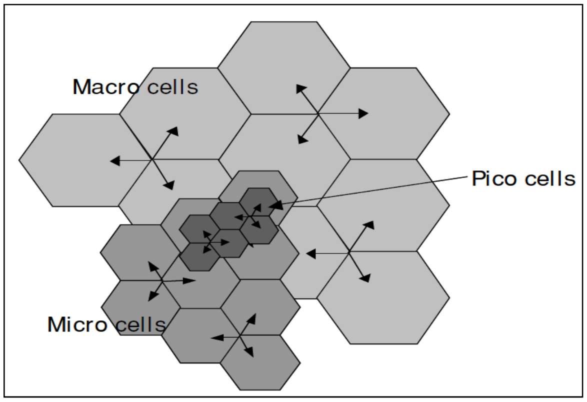

Figure 4. Theoretical macro, micro and pico cells of a mobile telecommunications network [1]

3. Discrete-event simulation

Discrete-Event Simulation (DES) is one of the most common simulation modeling paradigms to analyze the complex systems behaviors [2]. In this simulation approach, the system state variables change only at a discrete set of points in time. Using DES, a network of queues and activities are developed to model the system behavior. The DES models are stochastic in nature with randomness incorporated because of the use of statistical distributions. Therefore, within DES models, the concepts of time and state are of paramount importance while event, activity and process form the basis of three primary conceptual frameworks within discrete event. The modeling cycle of DES models is illustrated in Fig. 5.

The real world problem is the system (real or proposed), idea, situation, policy, or phenomena to be modeled; the conceptual model is the mathematical/logical/verbal representation of the real world problem for a particular study; and the computer problem is the conceptual model implemented on a computer [5]. The conceptual model is developed through a computer modeling phase, the computer model is developed through a model coding phase, inferences about the real world problem are obtained by conducting computer experiments on the computerized model in the experimentation phase, and solutions and understanding are used through an implementation phase. The set of steps followed in this simulation study were based on those suggested in the literature (see [6] to [9]) using DES.

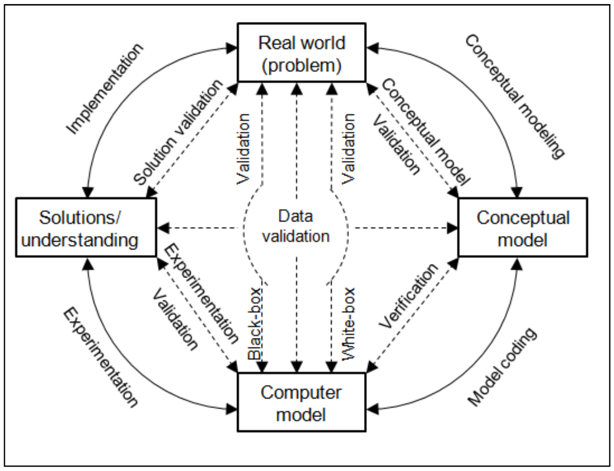

Figure 5. The DES modeling cycle [5]

4. Simulation model development

Particularly, an optimal cost-effective network design depends on two main factors: one, the traffic generated in the network as consequence of the demand on services by end users and second, the offered price of the services by network operators. In order to quantify and describe the network traffic generated in a Third Generation mobile network, first, we developed a simulation model. Then, the network traffic generated in the simulation model is used to calculate the percentage of the annual benefit, of network operators, as function of the number of cells in the optimal network configuration. The maximum annual profit of network operators corresponds with the optimal cost-effective network design.

The simulation model is developed using the discrete-event simulation approach. The user's calls are the entities while their generation and their processing are the activities.

4.1 Input data analysis

In the last years, four services have been assumed as the most demanded in a Third Generation mobile network [10] by end users: sound, multimedia, narrow band and wide band. Figure 6 shows the service demand proposed in this research study. In this case, each service is processed with an exponential probability distribution whose duration is based on Eq. 1.

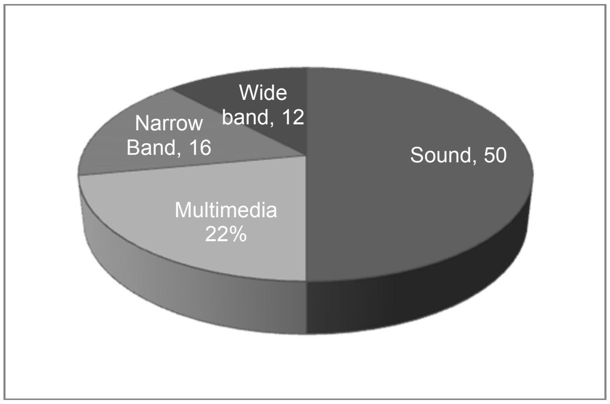

Figure 6. The demand of 3G telecommunication services

$$f(x,\lambda) = \begin{cases} \lambda e^{-\lambda x}, & x \geq 0 \\ 0, & x < 0 \end{cases} \quad (1)$$

It was considered λ=3 minutes (see Fig. 7) for the sound and multimedia services, λ=0.1 minutes (see Fig. 8) for the narrow band service, and λ= 30 minutes (see Fig. 9) for the wide band service.

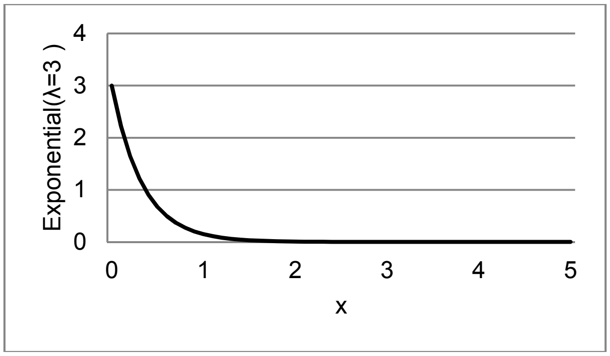

Figure 7. Duration of sound and multimedia services

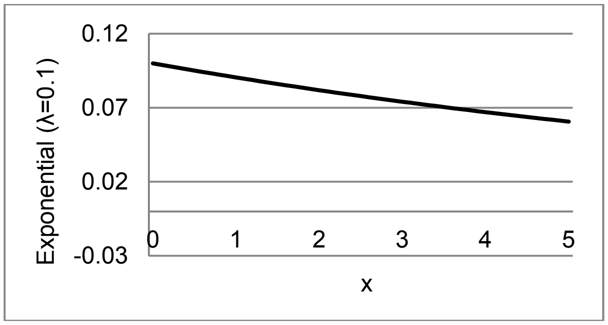

Figure 8. Duration of narrow band services

Figure 9. Duration of wide band services

The simulated environment was a small Mexican airport located in Los Cabos, Baja California Sur. This airport is ranked as the seventh most important in Mexico. With an internal area of 8500 square meters (see Fig. 10), this airport receives annually a total of 2,466,733 passengers, but in average 730 passengers at peak hours every day (see Fig. 11). We propose to use of Omni-directional antennas whose theoretical coverage is a direct quadratic function of their radius, and the capacity is fixed on seven traffic channels. With respect to the implementation, a commercial discrete-event simulation package known as ARENA™ was used.

Figure 10. Mexican airport located in Los Cabos, BCS

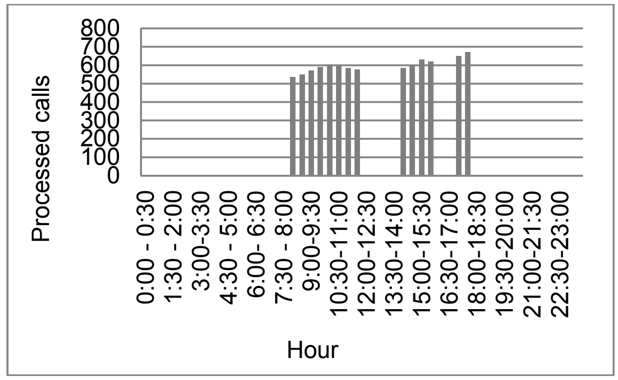

Figure 11. Daily processed calls in the airport

5. Simulation model results

It is important to stress that the simulation model of a telecommunication network is a non-terminating system, it means that the duration of the simulation run is not finite [11]. As the objective in simulating a no terminating system is to understand the long-run behavior, the simulation runs were executed incrementing its duration from t=0 in steps of 5 days. In order to eliminate the effects of the initial conditions, we analyzed the Mean Square Pure Error (MSpE). From the simulation theory, the MSpE represents the experimental error that arises from variation that is uncontrolled and generally unavoidable, during the execution of the simulation [12][13]. The analysis starts defining the performance measurements to use in the MSpE analysis and then, the simulations runs are executed. Finally, the simulation results are used to know the evolution of the MSpE in order to establish the optimal simulation run length. The number of users that access to the mobile network was proposed as the performance measure to analyze in this research study. Figure 12 shows that the MSpE, correspondent to the users in the mobile network, reached an appropriate stabilization phase after 80 days. Therefore, the optimal simulation run length was 80 days for the model proposed. At this simulation time, the effect of the initial conditions was eliminated significantly.

5.1 Simulation model validation

A simulation model is considered valid for a set of experimental conditions if the model's accuracy is within its acceptable range of accuracy, required for the model's intended purpose [14]. Several validation techniques have been developed in DES and an extensive list of them is presented in [14] [15].

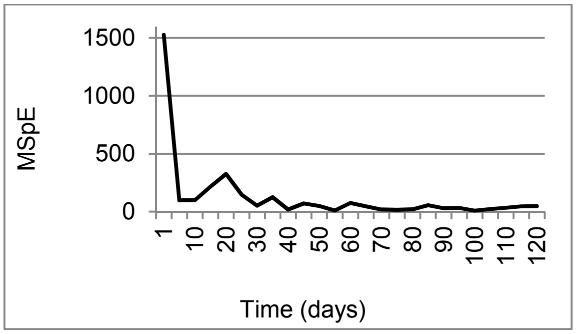

Figure 12. MSpE analysis for the users in the network

We validated the model using the known extreme–condition test that consist on test the model structure and the output under extreme input conditions. In the first scenario tested, we considered the minimum network capacity in terms of transmission channels and as a consequence, the number of users rejected by the network in the model was maximized. In the second scenario tested, we considered the maximum network capacity in terms of transmission channels, so the number of users rejected by the network in the model was practically zero. The results of these scenarios tested were according to the logic followed in a real mobile telecommunication network. Figure 13 presents the test results.

5.2 Scenario analysis

The weekly users attended by the simulated mobile network, demanding one of the four service classes were obtained as the output of the simulation model and as function of the numbers of cells and are reported in the Table 1. Each service had an average data rate (kb/s) which varied according to the duration for which the average was taken. In this case the average data rates for the services under study were: sound services: 12 kb/s; multimedia service: 128 kb/s; narrow band service: 384 kb/s; and wide band service 1920 kb/s.

5.3 Optimization

Once we knew the number of users accessing the different mobile network configurations for each type of service, as well as the data rate generated by each service, we were in a position to calculate the percent of the annual profit as function of the network configuration. First, the percent of the annual profit was calculated as function of the net profit and the cost as is indicated in Eq. 2.

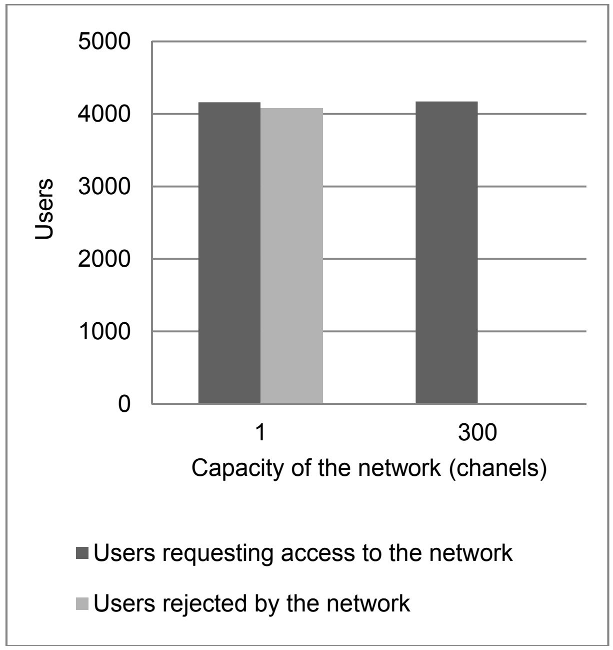

Figure 13. Results of the extreme-condition test

Cells	Sound service	Multimedia service	Narrow band service	Wide band service
22	2082	927	665	498
20	2082	927	665	498
16	2082	927	665	498
14	2082	927	665	498
12	2082	923	667	501
10	2076	915	660	493
7	1755	778	558	415
6	1579	695	506	378
3	827	366	263	199

Table 1. Weekly users attended as outputs of the simulation model

$$Annual\ profit\ (\%) = \frac{Annual\ net\ profit\ (\$)}{Anual\ cost\ (\$)} \quad (2)$$

Then, the annual net profit was defined as is shown in Eq. 3, as well as the annual cost as is shown in Eq. 4.

$$Net\ profit(\$) = Net\ income\ (\$) - cost(\$) \quad (3)$$

$$Cost(\$) = Fixed\ cost\ (\$) + (cell\ cost) * (cells) \quad (4)$$

Generally, the fixed costs include the cost of an official permit that network operators need to pay to Mexican government for the transmission of the services. While the cell cost, corresponds to the installation cost plus operation cost plus maintenance cost as is presented in Eq. 5.

$$Cell\ cost(\$) = Operation\ and\ maintenance\ cost\ (\$) + \frac{Equipment\ cost(\$) + instalation\cos t(\$)}{life\ time\ of\ cells} \quad (5)$$

The net income was defined as function of the traffic days that were taken in account.

$$Net\ income(\$) = daily\ income(\$) * number\ of\ traffic\ days\ in\ teh\ network \quad (6)$$

Finally, the daily income (di) was defined as function of the cell load, the peak hours, the channel income and the channel data rate as follows in Eq. 7:

$$di(\$) = \frac{cell\ load\left(\frac{kb}{s}\right) * peak\ hours * channel\ income(\frac{\$}{min})}{channel\ data\ rate\ (\frac{kb}{s})} \quad (7)$$

Using all equations from (2) to (7) presented before, and the outputs of the simulation model, we calculated the percent of the annual benefit in the network for network operators with data assumed in a Mexican scenario. The minimum annual benefit obtained for an operator was 20% that corresponds to the network configuration of twenty-two cells. And the maximum annual benefit obtained was of 46.6%, when the network configuration used six cells.

6. Conclusions

The aim of the present research paper was to develop a simulation model to analyze the services transmission in a Third Generation mobile network and maximize the network coverage and the theoretical economic benefit of network operators.

This paper has clearly shown that based on a simulation model, the optimal cost-effective network design, that satisfy the requirements of in-building coverage of users in an scenario of a Mexican airport, correspond to a network with 6 omnidirectional cells, each one with a capacity of seven traffic channels able to deliver the sound, multimedia, narrow band and wide band services with a data rate of 12, 128, 384 and 1920 (kb/s), respectively. Using this configuration, the network operator would be able to get annual benefit of 46.6%.

From the research that has been carried out, we can conclude that many challenges are presented in mobile telecommunication network design process and our proposal can be used as a first approximation to these challenges. The simulation model developed is able to model other different mobile services so other interesting scenarios can be built to analyze their impact on the economic benefit of operators.

The results of this research could assist decision makers of mobile network operators in Mexico.

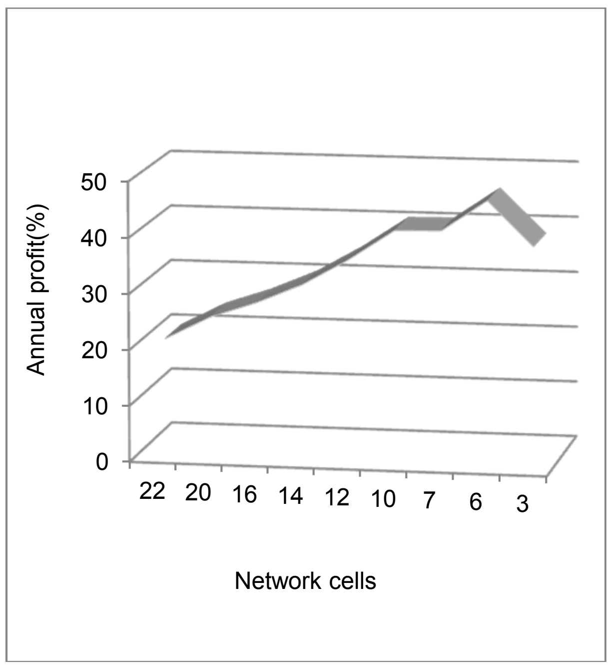

Figure 14. Percentage of the annual profit

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