Analysis and Design of New Initial RAT Selection Strategies Based on Pricing and Path Loss for Heterogeneous Wireless Networks GSM/EDGE/UMTS

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Abstract—This document is the translation to English of my undergraduate research thesis, which was originally written in Catalan. At that point, writing it in Catalan seemed like a good idea but, eventually, I realized it was a very bad idea. This translation has been done automatically using Google Translate, so do not expect Shakespeare's English. Actually, it is quite terrible, but I am trying to make it decently understandable.

As I have to review every single line because the Catalan-English automatic translation is quite terrible (yet, quite impressive given that it was done automatically by Google Translate), this is work in progress. You will notice a mark within this document indicating where I have reached in reviewing the automatic translation. I am essentially trying to make the text readable, yet still not fully correct or grammatically accurate. After this first mark in the document, the text is probably impossible to be understood. I am working on it. Hopefully someday I will have reviewed the whole translation. There is another mark that indicates the part of the text where the formatting of the text and figures has not been done yet (mainly starting somewhere in the middle of Section 4.2.3).

Note that, when I review the text I just make sure that it can be more or less understood. I am leaving many things as Google translated them. They are understandable but not always grammatically correct. So, please, do not judge my English skills based on this document. You can find all my publications at my personal website: http://www.ee.columbia.edu/ roger/

Out of this thesis I published a paper that was originally written in English. It might help understand this document better. You can find it here: http://www.ee.columbia.edu/ roger/paper_pricing.pdf

If you speak Catalan and want to help me to finish this up once and for all, feel free to send me an email. I am planning to add an acknowledgements section.

By the way, this document was written originally during the first couple of months of 2006.

1 INTRODUCTION

In the mid 90's the telecommunications industry experienced a great market growth and this huge growth did not stop until well finished the 90s. This period was known initially as the telecom boom, and later also known as the telecom bubble. This bubble ended up exploding, though, and led to a significant decline in the telecommunications sector. The period of enormous growth, led by large companies such as AOL, which eventually was bought by Time Warner, as well as small business through the Internet world that grew quickly. It was also the period when online portals were very popular on the Internet, generating great expectation in the stock market.

After the collapse of this market, skeptics suggested that a full recovery would not come until after many years. What few people imagined is that all work carried out during those recession years in the telecommunications market would be extremely useful to the sector.

When the telecommunications bubble exploded, companies showed a drastic decrease or loss of profits in millions of dollars, forcing the closing of on-line small business that had grown significantly. However, while all this was happening, particularly in Spain but throughout Europe and the world more generally as well, the boom of mobile communications took place. In late 2004 the market penetration of mobile phones was 91.6% and it is expected to reach a market share of 100% during the year 2006. Spain now has 41.5 millions of phones for 44 million people, while the number of fixed lines is only 17.495 million. This data, extracted from the media, indicates that the bubble might not have exploded for this specific market.

Within this growing market it is difficult to take a position that ensures success. It is also quite demoralizing for innovation in this area (at least from the point of view of a future telecommunications engineer working on a research project about mobile communications) the fact that nowadays much of the revenue from this sector comes from companies dedicated to sell the latest musical hit as melody/tune for mobile terminals or providing the platform for voting the leading candidate to be expelled from one of the many cluttering reality shows on television today. Work has continued in the mobile communications environment and, although it seems difficult to deviate the hegemony of current GSM networks, it was necessary to take a step forward and the industry began working in the future 3G networks.

It is true that the development of this new technology was delayed and, while still not fully implemented, the beyond 3G systems are starting to appear at research level but not yet at a full level of implementation. It is also true that it is not that easy to introduce an entirely different system from the ground up in an environment where GSM is fully implemented.

In the development of 3G networks, the community began to think about the intermediate period between the onset of 3G technology and its full and final implementation, completely replacing GSM networks. During this period, which may take many years, both technologies will coexist and, why not, work together cooperatively. Thus, based on the existing radio resource management strategies (RRM) for GSM / GPRS, EDGE networks and those new strategies based on the standards developed for UMTS, the community is aiming to develop a new strategy that allows the management of all two networks together, which would lead to improved quality offered by both access technologies (RAT: Radio Access Technology). Thus were born the strategies of Common Radio Resource Management (CRRM) for heterogeneous networks, formed by GERAN (GSM Enhanced Radio Access Network), the GSM / GPRS network expanded to achieve higher speeds over EDGE, and UTRAN (Universal Terrestrial Radio Access Network).

Within this new study, tackling the management of both networks simultaneously to achieve a better quality, appeared new radio resource management strategies, the new CRRM algorithms. Two of the most important are vertical handover, which also allows to change the cell technology that is connected to the mobile terminal as it moves, and Initial RAT Selection. This second function determines, from the analysis of multiple network parameters and the place where the is physically located, the RAT through which the connection will be initiated depending on the type of user or service we want to use.

It is within the framework of this last CRRM strategy (Initial RAT Selection) in which this project is located, analyzing Initial RAT Selection based on different policies designed specifically and proposing new strategies and policies to improve the results in terms of quality on the network.

Moreover, researcher have been working for several years working on what could be the future of mobile networks and telecommunications networks in general. The pricing is analyzed nowadays with a focus away from a classic marketing strategy, seeking to maximize revenues and minimize expenses of mobile communications operators and all types of business. By the late 90s researchers began working specifically on the possibility of applying an economic task or business strategy, such as the pricing of services, from the point of view of radio resource management, and later from the point of view of quality management of the service offered by the network. Thus, the pricing of the service will also be thought from a standpoint of resource allocation and consistently as part of CRRM strategies. And it is clear that one of the key factors that determines the quality of the service is the price you will be paying for this service.

Thus, combining these two branches of study, we eventually seek to unite the two, both CRRM and pricing, and I developed an initial application of simple pricing strategy to perform the function of Initial RAT Selection.

1.1 Contents

This project is organized as follows. Chapter 2 develops a theoretical basic introduction of different heterogeneous networks and their related CRRM strategies, focusing particularly on the role of Initial RAT Selection. The next section, Chapter 3, focuses on a theoretical study of the concept of pricing of network provisioning QoS by analyzing some state of the art of pricing in such networks.

Chapter 4 is a study of the Initial RAT Selection Based on Policies (Policy-based Initial RAT Selection). I carried out a study of the politics of selection of RAT available in order to determine the optimum policy for each possible scenario. Moreover I identified potential weaknesses of these policies. This study is based on results obtained from multiple OPNET simulations. The results and shortcomings are analyzed in Chapter 5. New policies for selection of RAT based on measurements of propagation losses are proposed too in order to improve the results.

Finally, as a union of the two subjects studied, Chapter 6 develops a simple pricing strategy oriented to feature selection of RAT and also presents the results obtained through OPNET simulations. Chapter 7 summarizes the basic conclusions of the project and suggests new avenues of research to further improve the model especially designed in Chapter 6.

2 CRRM IN HETEROGENEOUS NETWORKS

It's been over 10 years since GSM mobile communications were introduced commercially. During this time the mobile phone market has grown unstoppably, seemingly so impervious to the crisis in the telecommunications market in the early years of this decade, to a point where there are more cell-phone users than traditional landline users. It is at this point that the number of mobile terminals in Spain exceeds the number of fixed terminals.

After many delays and problems, it seems that the new technology (3G) begins to break through into the market gradually, starting initially with a specialized market and devoting itself primarily to businesses. But now we are starting to see the first steps of the new technology towards the market of ”street users”. Finally

UMTS has become the new model of 3G technology standardized by 3GPP (Third Generation Partnership Project) designed to replace GSM in a decade. However, it is not entirely clear whether this substitution will actually occur. All the delays and problems encountered with he development of 3G technology gave time to another fourth generation strategy to be developed. One example of these new technologies that have appeared before the implant of UMTS is the WiMAX network, which is being studied based on heterogeneous mobile communication networks in South Korea, says an article from the Financial Times. However, these new technologies do not yet have such an implementation as UMTS and are far behind in this respect. The only network that you can consider if you are extending at a rate comparable to UMTS is WLAN.

During the delays of UMTS solutions, there have been developments in 2.5 G to increase the capacity of data transmission based on GSM networks in order to offer interactive services, email and other applications. This led to GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution), which combined form the access network GERAN (GSM / EDGE Radio Access Network).

It is also true that one of the licenses for 3G operators, specifically assigned to XFER has not been launched yet. However Telefonica and Vodafone have launched their UMTS network, currently working and offering 3G services such as video calling in many parts of Spain and Catalunya.

2.1 Heterogeneous networks

We are in the context of a fully installed GSM network access which, taking advantage of the delays in the appearance of the third generation and basically to solve the shortcomings produced by this delay, has been extended to higher data transmission capacities (GERAN). 3G technologies are beginning to take flight, starting with its introduction to the market, launch of the 3G access network and the sale of the first 3G handsets. Moreover, the growing popularity and unstoppable implementation of wireless networks WLAN lead us towards an environment in which the three main access technologies (GERAN, UTRAN and WLAN) are combined, performing similar functions and also offering similar services.

This environment will promote mixed solutions for resource allocation, based on the models of existing radio resource management for each access technology independently. Clearly, control and management of QoS in these networks should be applied to this heterogeneous environment in a common and organized way. In a model with multiple wireless access technologies, connected to the same transport network through a common control element, as stated in [1], one can obtain an open and flexible architecture that allows a variety and number of wireless technologies to manage a wide range of services with different QoS requirements.

The goal in this common architecture would be to transmit each service through the network connection that is used by the service more efficiently under the current network conditions, including the different access networks or RATS (Radio Access Technology). Another goal is to make this heterogeneous network transparent to the user, so that your mobile is able to transmit through any or several access networks, and this selection is done transparently, without user intervention.

So, in order to design joint strategies for radio resource management, control and QoS provisioning in these access technologies, talks about the concept of heterogeneous networks have to be had. Specifically, this project focuses on the analysis of radio resource management in heterogeneous networks consisting of GERAN and UTRAN.

2.2 CRRM

The concept of heterogeneous network facilitates the use of common management of resources in each RAT. Following the 3GPP specifications, CRRM (Common Radio Resource Management) strategies are designed to manage resources that belong to multiple radio access technologies in a coordinated manner and efficiently. In [2] the authors introduced the concept of CRRM in general and applicable to any combination of RATs, although the specific implementation and the level of coordination between these access networks depends on how much different the RATs are.

Before treating the joint management of resources, it is important to define which RRM (Radio Resource Management) allocations are applied individually for each access technology.

[2] and [3] define the concept of Radio Resource Unit (RRU) and the physical transmission parameters necessary for supporting the transmission of information. Thus, although the definition is common to all access networks, a RRU represents a different approach for each type of network. For example, if a network is FDMA, each RRU corresponds to a certain bandwidth on a certain carrier, and in the case of a network FDMA / TDMA (for example GSM) each RRU corresponds to a time slot and a carrier . In the case of CDMA, particularly in the UMTS network, an RRU is a carrier, a coding sequence and a certain level of power transmitted.

While these are the main physical parameters of the transmission depends on each network type, also consider other aspects such as modulation and coding system used. Obviously, each type of service requires a different amount of RRUs, whilst one service may need different RRUs for different users. That is, for example, if a user requires a high speed transmission, extra carriers may be necessary, ie, more bandwidth.

The goal of every operator is to install a network that can bear all the transmissions of its customers, always offering a guaranteed minimum QoS for these users, but at the same time minimizing the costs of the operator.

An easy way to guarantee the QoS provided to users is minimal overprovisioning of the network, providing it with more resources than initially required for all potential users. But the operator will always intend to provide the QoS minimizing the costs of installation of the network. The challenge is planning a network that allows us to have a sufficient amount of RRUs to guarantee QoS, but always minimizing the number of RRUs, which is directly proportional to the cost of the network.

Fig. 1. Relationship between network planning and RRM

The method allows us, from a provision of RRUs below what would be required in principle to offer and guaranteed QoS and minimum radio resource management, known as RRM (Radio Resource Management). The different RRM strategies are responsible for awarding each connection a certain amount of resources of all resources offered by the network after it has been planned.

In Figure 1, taken from [3], we see this model network planning to have a certain amount of RRUs to be managed through RRM strategies to be administered optimally, while guaranteeing a minimum QoS. The fact that mobile networks are very dynamic (propagation conditions, terms of generating traffic, interference, etc.) forces also to manage the network dynamically, forcing these RRM strategies to be also dynamic.

In the framework of heterogeneous networks, the aim is also to guarantee a minimum QoS from a minimum of RRUs, while minimizing the cost of the network. And the best way to do this is through a joint management of radio resources with CRRM. To do this you need to determine what degree of centralization of the different RRM functions in the network you need.

The main drawback is the complexity of CRRM strategies. To compute the RRUs for each connection, a large number of measurements must be performed and analyze many network parameters. On the other hand, one must also consider the number of users in the network, its powers and its transmitted bit rates, and many other parameters that must be measured. This makes clear that the RRM strategies will become more complex if applied commonly over the entire heterogeneous network, and suggests that it could be useful not to completely centralize the management and allocation of resources. However, the fact that the heterogeneous networks under study have access networks based on CDMA, which transmit on the same frequency and time instant differing only by code sequences that are never completely orthogonal, it is considered indispensable to have good resource allocation to achieve the most optimal point through CRRM.

Regarding the degree of centralization of management functions and allocation of radio resources we can find in many situations that they can be summarized in the following three categories: low centralization, centralization medium and high centralization. This classification is described in [2].

Case 1: Low centralization

Figure 2 shows a diagram of CRRM in which there is a low degree of interaction between the local authorities of each RAT and the RRM core, which performs the functions of CRRM. Actually some functions of this core module are delegated and it basically performs the task of PEP (Policy Enforcement Point) that translates and configures specific policies of each organization and RRM information sent between them and allows for the realization of different CRRM functions. It is important to note that this architecture also has CRRM functions, but they are held at each RAT independently or are based on data from other RATs received through the PEP.

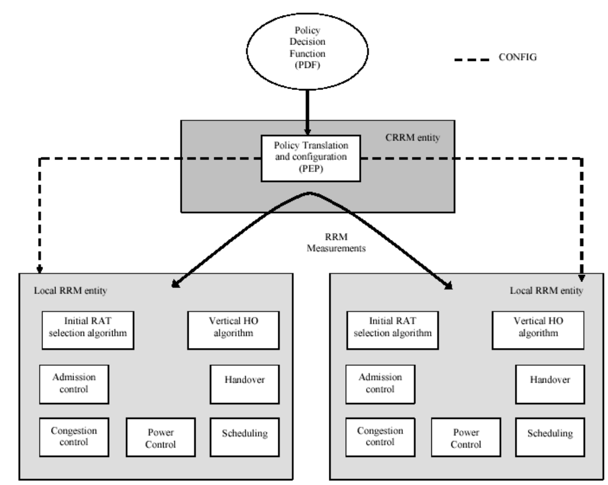

Fig. 2. Low interaction functions CRRM and local RRM functions

Case 2: Medium centralization

A medium level of interaction between RRM entities and the core CRRM is shown in Figure 3. The central module of this architecture has communication among different CRRM entities of each RAT and it sets the various policies and strategies for CRRM. In this case, it also performs other functions, so is this common resource management module to whom the task is delegated to performs also some specific functions such as Vertical Handover and Initial RAT Selection. Different RATs, through their RRM modules, send multiple measures of the state of each network module so that it can meet the available capacity of each network to perform different functions.

However, local authorities in RRM for each RAT continue taking care of tasks within their own, such as network handover, scheduling algorithms, and other basic functions of RRM. Thus, the interaction between the elements of RRM and CRRM occurs only at certain instants of time of the order of seconds or even minutes, so that RRM and CRRM functions are independent. The exchange measurements from different RATs for the correct application of CRRM algorithms are usually periodic or even petitioned by the CRRM entity when needed.

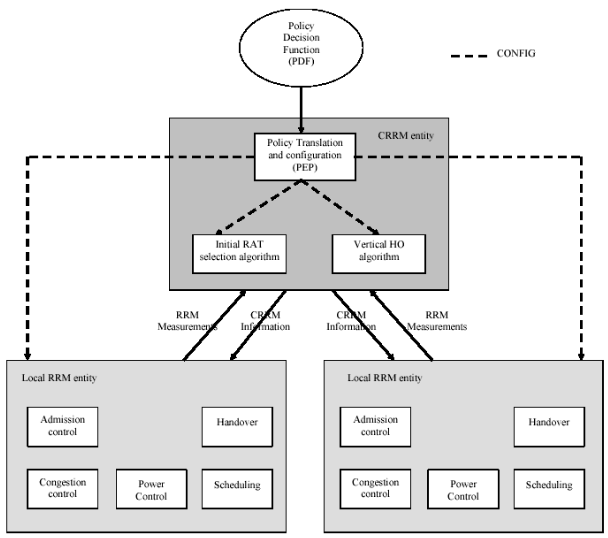

Fig. 3. Interaction between the functions of half CRRM and local RRM functions

High centralization

Finally, one can achieve much higher interaction degrees between the local RRM local entities and the CRRM module by delegating different RRM functions at a local level. This possibility is shown in Figure 4. In this case the RRM functionality will be reduced to a minimum, mainly the transfer of appropriate measures and certain functions of the technology of each RAT performed in very short periods of time, such as in UTRAN power control, made with a frequency of less than 1 ms.

The CRRM entity concentrates most of the functions of management and allocation of radio resources. All these functions are performed taking into account the state of all RATs in the network. This solution requires CRRM decisions to be taken in a very short time scale, on the order of milliseconds, with the ability to make changes to the same mobile terminal very often. This requires major reconfiguration capabilities of mobile terminals that are difficult to achieve with current technology.

Commonly to all three degrees of centralization of the resource allocation to different heterogeneous RATs in the network, one can find the same functions and strategies.

The basic functions of RRM are handover, admission control, congestion control, scheduling and power control for UTRAN. The handover function lets you change the base station connected to the mobile terminal as it

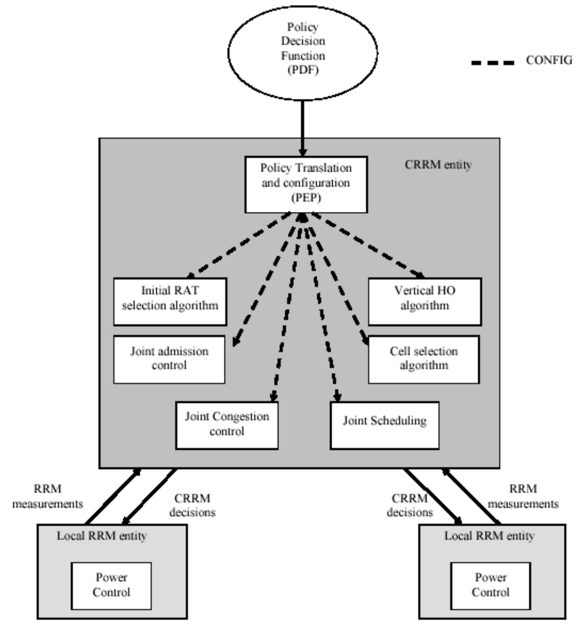

Fig. 4. High-interaction functions CRRM and local RRM functions

moves, resulting in the propagation losses to the base station to which it was connected before increasing. The admission control and congestion manage radio resources available and allocates them appropriately to the level of load present in the network, avoiding situations of mass saturation or congestion. Scheduling algorithms organize the allocation of resources over a connection and finally the UTRAN power control ensures sufficiently low levels of interference as to ensure a minimum QoS for all connections.

On top of that, the basic functions of the CRRM are Vertical Handover and Initial RAT Selection, both described in the next section that focuses especially on the second.

These strategies are applied in order to optimally manage different RRUs and radio resources available from the network planning, always aiming to maximize and optimize the QoS offered by the network. A common indicator of the QoS is the BLER (Block Error Rate), especially for voice traffic, and the traffic delay for interactive online sessions. Another indicator of the QoS can be the total throughput, which indicates the amount of data transmitted by the network.

2.3 Initial RAT Selection

As already mentioned, within the strategies and functions of CRRM there are two that are major. These two, which are actually equivalent, are the Vertical Handover and Initial RAT Selection. In both cases these algorithms are based on multiple measures of the state of the network and the knowledge of other variables, such as the number of users and the throughput of each user, and they decide through which RAT data is transmitted.

In the case of Vertical Handover, this function is performed throughout the duration of the connection. It is an extension of the Handover function, which, as mentioned above, allows changing the base station to which we are connected as we move away and there is an increase in propagation loss. In the case of Vertical HO, in addition to a possible change of base station, the connection can also change to another access network if, for whatever reason, the current network is saturated and offers low QoS. You can also carry out a Vertical HO for many reasons, such as a load balancing between different RATs.

On the other hand, the function Initial RAT Selection function is equivalent to Vertical HO, but in this case it is done only at the start of the connection. At the time that a user starts a new transmission, it is decided through which RAT it is optimal to initiate the data transmission given the QoS offered by the network. To carry out this decision will take into account a lot of parameters and measures of the network, which can make this selection substantially complicated. For this reason, unlike in Vertical HO which is always based on measurements, the initial RAT selection is carried out generally based on policies, as discussed in [1] and [3]. These Initial RAT Selection policies determine which RAT starts the connection, and this is made based on a few parameters and both objective and subjective criteria, and may even depend on the preferences of the operator or user.

Some of the most common parameters used by policy-based Initial RAT Selection are related to the type of service that is transmitted and certain characteristics of users, such as indoor or outdoor. A new feature in this project is also applied, the estimated propagation losses that each user has to the serving base station.

[1]introduced two different criteria that are based on various policies. These criteria depend on two parameters, which are the type of service standards and criteria for indoor users.

Criteria for the type of service:

In analyzes of Initial RAT Selection made in [1] and [3], the type of service is considered as the basic criterion for designing policies. The focus is specifically on two types of service: voice traffic and interactive www data. In this case, the authors propose an approach based on transmitting www data basically UTRAN, which achieves lower delays and, in general, a higher QoS. Moreover, voice traffic is diverted mainly to GERAN

Criteria on the nature of indoor users:

Another criterion defined in the sources is based on the indoor/outdoor nature of users. It is proposed to divert indoor traffic through GERAN, preserving UTRAN from an increased interference and QoS degradation, due to the high power to be transmitted by the users that are indoors.

So, working on polcity-based initial RAT selection, what must be determined beforehand, based on multiple measures of the state of the network and a large number of parameters, is which policy is more suitable for each environment or network status.

This project mainly focuses on the study of this second CRRM function, the initial RAT selection based on policies. Among other things, it focuses on in-depth analysis of this function and different possible policies and criteria to determine which are most appropriate for each environment in order to maximize various aspects of QoS. Thus, in analyzing the role of Initial RAT Selection, the aim is to define strategies that maximize BLER for voice traffic, minimize the delay for interactive traffic and maximize the total throughput for both traffic, thus setting the criteria of maximizing the QoS that we rely on. Moreover, we also present a new approach to policy-based Initial RAT selection incorporating concepts of pricing in wireless networks.

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3 PRICING ON CRRM

3.1 Introduction / Motivation

The current project is framed by the development and analysis of CRRM strategies for heterogeneous networks. Specifically, the project focuses on the simulation and analysis of policies selection of RAT in many different scenarios. One goal is to define suitable policies for each scenario given its features. In this case, as introduced in the previous chapter, the "suitability" of each policy is analyzed based on different QoS parameters such as delay for interactive traffic or BLER for voice traffic.

In this study we aim to add a new variable to analyze the policies, the price or pricing strategy. This price is specified in different ways, always setting an individual tariff for each type of service taken into account in the analysis. We define, for example a price in /min for voice traffic and /bit for data traffic.

This new variable is studied from the point of view of the operator, and extending the analysis of the suitability of each policy, seeking to maximize the revenue generated by the network, thereby contributing to the goals of maximizing the total throughput, minimize delay for interactive traffic and minimize also the BLER for voice traffic. However the price, because it sets a cost for the service, becomes a variable of QoS for the user, who will not perceive the same quality of the Internet connection, for example, if it is very expensive or very cheap. So if you are paying a very low price, you will not have such a sense of poor quality if the delay is not too low, or in the contrary, if you are paying a lot, the user will be very sensible to small delays and latencies.

But the study of the pricing of services, pricing, there is nothing to come back. Previously, telecommunications networks were designed with a "philosophy" best effort of avoiding the resource reservation for each connection and completely untapped benefits of statistical multiplexing. Under this philosophy created one of the most commonly used protocols, the IP protocol used on the Internet and many different types of networks. However, over time they have developed more complex networks and to allow bear a much higher quality services and more dynamic. It was from here when it has evolved into a new philosophy in which the network must ensure a minimum quality of service to the user, thus speaking of networks with QoS provisioning. The network, and to ensure the correct transmission of all data, also guarantees a minimum QoS.

This should guarantee minimum QoS network not ever depend on the behavior of the network operator. The behavior of the users in the form of transfers that models the QoS provided by the network, a certain fixed infrastructure.Thus, QoS is the performance variables as quality of transmission, such as BLER, which has a fixed network working with a number of users.Who receives this QoS is the end user, so it will depend on who should be the behavior network. This shows that the concept of QoS is the key aspect to be taken into account to design the network operator. Based on this fact is demonstrated the great importance for the study of CRRM networks we work with the current project as it is from good CRRM techniques to reach the levels achieved QoS the user expects, while optimizing the use of radio resources.

It is also obvious that the user perceived QoS depends not only on the network.We have already discussed how this depends very much on the quality of service pricing, and therefore the price. Thus, it is clear that the price is a very important part of QoS, and hence QoS is closely tied to the price. We also know that the QoS depends heavily CRRM policies. Therefore, the study of pricing and pricing is closely related to the current project is focused on the study of CRRM policies.

3.2 QoS perceived by the user: Utility

We talked about how, in the current telecommunication networks, QoS is to apply a philosophy in which the operator guarantees a minimum quality of service to end users. It also highlighted a very important fact, that quality of service does not value the network or the operator. It's the end user that the QoS values, and what it will mark the minimum quality that the network has to offer.

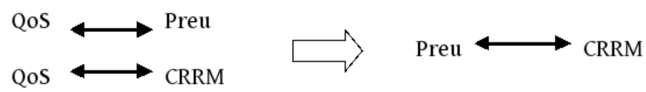

Fig. 5. Justification of the analysis of pricing in a project on CRRM policies

That is why it is very important to know how the user assesses the perceived quality. For this reason, many studies have been made and many models have been proposed to represent this behavior, as perceived by the end-user quality. And given the importance of price as a fundamental part of QoS, has begun to talk about the usefulness or utility function. Utility models have been proposed are based on aspects other than price, but we are focusing on in this chapter.

The utility is the way the user perceives the QoS offered by the network and its behavior with respect to the variation in the form of QoS maximum price you are willing to pay for the service. The variation of the maximum price you are willing to pay for a certain QoS is modeled by the utility function. Basically, in most studies (eg [4], [5] and [6]), we analyze the utility and pricing based on the utilization of the network. That is, the user behavior is modeled as the price variation utilization your network traffic or offered. Thus, variations modeled by the utility function is displayed as variations in user traffic offered to the network. As we discuss below, this model has been extended in recent years to reach replacement services and consider more complicated models.

Basically all pricing models can outline as shown in Figure 6. It is considered that the user perceives a QoS network, and an external variable is price. From these two variables determines the amount of information to transmit. That is, depending on the user's QoS has a maximum price you're willing to pay, and then decide based on the price the amount of information (? T) that is ready to transmit, for example in the form of packets/second. On the other hand we have predefined network infrastructure that reacts to the total charge received by the users, and their reaction is the QoS offered to these users, in the form of delay, throughput, speed, BLER, etc.

Actually we use comes directly from the load transmitting each user, or what would be the same as the behavior of data transmitted according to price. In the first proposed models [4], the utility function is defined as an expression that sets the maximum price the user is willing to pay based on the QoS offered by the network. Thus, to t user is willing to pay a higher price than it

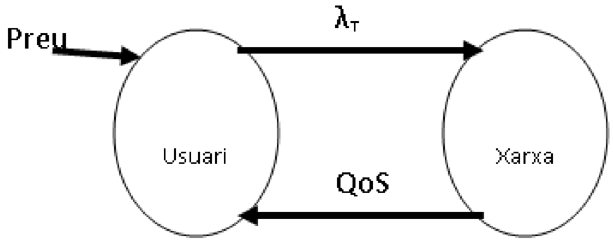

Fig. 6. Pricing model

is in force shall, while a willingness to pay a price not less than the current broadcast. This forces the change in value of ? and for each user based on the price set by the operator with a fixed QoS, is a step function (Figure 7).

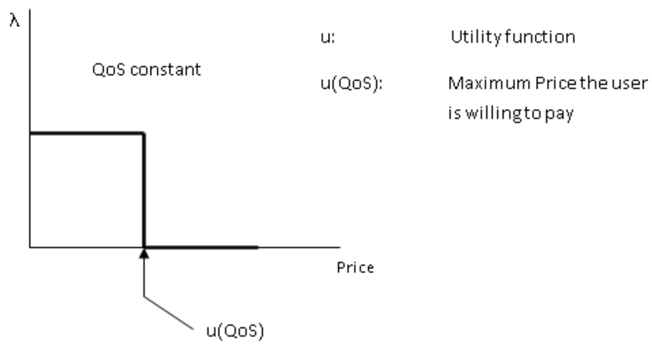

Fig. 7. Pricing model

However, new studies have been expanding and improving the utility function model, adding for example the possibility to resort to an alternative service. So speaks Paschalidis [7] replacement demand and its effects. Extending the model to the fact that when the price goes up for a service, users spend to make it serve as a substitute for another imperfect. Thus, a user demand model is extended so that the demand for a service is based on the price of this, but the price of other services imperfect substitutes. This can lead to consider other possible models of extended use, where additional services instead, or in addition to these services, replacement model rats, considering GERAN and UTRAN. This would be a model already clearly oriented towards heterogeneous networks operating under CRRM strategies.

Returning to the basic model of utility function, as mentioned above, one of the first studies, in particular for networks with heterogeneous user population, is the Steigliz Honig and [4]. The model proposed by the authors is based on a private network with K users, where each user transmits at different speeds. To model QoS, the authors use the delay (δ), which is a function of the total load (Δ). Therefore, they use $\delta = D(\Lambda)$, where $\Lambda = \sum_{k \in activeusers} \lambda k$ and $D()$ is the function that defines the value of the delay with the load as input.

This way, the utility function is defined as $u_k(\delta)$, characterized for being always positive, monotonously decreasing and with a limit of 0:

- $u_k(\delta)$: price that user k is willing to pay for a QoS δ.
- $u_k(\delta)$: monotonously decreasing
- $lim(u_k(\delta)) = 0$ when $\delta \to \infty$

Specifically, the model the authors propose for the utility function is:

$$u_k(\delta) = \frac{U_{0,k}}{1 + (\frac{\delta}{\delta_{0,k}})} \tag{1}$$

where $U_{0,k} = u_k(0)$ and $u_k(\delta_{0,k}) = \frac{1}{2} u_k(0)$.

This utility function is more or less abrupt depending on the parameter n, and when this value approaches infinity, the function converges to a step function, returning to the initial model we saw earlier in Figure 7.

Most models of user behavior have been studied before the price based on the utility model, all based on a utility function similar to that mentioned above and taken from [4]. With respect to these models, the QoS is an estimate of the quality we have at one point or can be a prediction of the value of this quality in the network. In other cases it may also be the amount of resources allocated to the connection. Thus, [8] speaks of a utility function to allocate these resources to each connection, and explain how the utility function does not have to be the same for all services. Nor should always be the same for all users, could distinguish between classes of users, such as standard users and professional users.

It is in this context where introduced concept elasticity of utility, very similar to the elasticity of demand for market research. A user voice traffic or video in real time, using a constant bit rate and therefore require a certain bandwidth of constant to achieve QoS is modeled by a utility function very inelastic. Moreover, users of data services, email or www, tend to be more tolerant to small variations of the delay, so that the utility will be more elastic with respect to bandwidth, which is what this If QoS is considered. Other services are in an intermediate case and discuss useful and partially elastic. An example of this flexibility is shown in Figure 8.

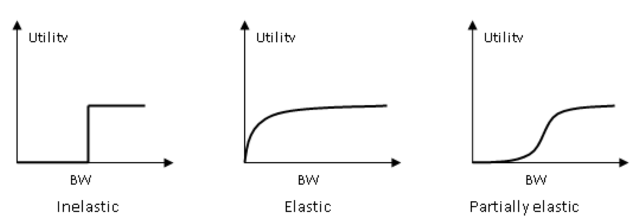

Fig. 8. Pricing model

Many authors have studied the usefulness and thus, over time, different models have been proposed, such as the aforementioned model by Steigliz [4]. However, these models are basic in its basic form, very similar, so many contributions have been extended models useful. We have already commented on that one introduces the concepts of demand and extended service replacement. Other utility models are extended, for example, Stidham proposed in [9], where the authors discuss about an utility function that depends on the delay. The expression of the utility function is as follows:

$$U_r(x_r) = h_r x_r \sum_{j \in r} D_j(y_j) \tag{2}$$

- $r \in R$: Users
- $j \in J$: Resources (equivalent to the slots in GSM)
- $D_j(y_j)$: Average delay that a packet experiences at resource j
- $y_j = \sum_{j \in R} x_j$: Total throughput
- $h_r d$: Delay cost per bps
- d: average delay experience by the user

The proposed model is a generic model for Stidham to any network with heterogeneous users with different utilities each, so that each individual user reacts differently to others in the QoS offered by the network. Thus, in these last model expands the possibility that each user has an independent behavior different from the price.

Finally, another expanded model, that differs from the previous ones is proposed by Saraydar et al. in [10], shown in Figure 9. The study is focused on wireless networks based on CDMA, so chosen as QoS parameter to define the CIR utility or, in the case set the CIR, the transmitted power. CIR is considered as the signal to noise and interfering signal or simply to interfere, since the study is to access networks based on CDMA:

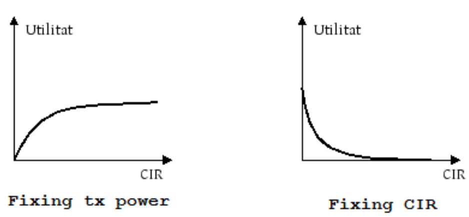

Fig. 9. Pricing model

Thus, this new model proposes a utility function that is based on the transmitted power, as well as the BLER, which is closely related to the CIR.The utility function proposed by the authors is of the form:

$$u = \frac{L \cdot r \cdot f(p_e)}{M \cdot P} \tag{3}$$

- $f(p_e) = (1 - 2 \cdot p_e)^M$: Efficiency function
- p_e: BER
- L: Transmitted bits per frame (data+header)
- M: Data bits per frame
- R: bit rate
- P: transmitted power

This model is in contrast to the above the fact that resource allocation has to do with the behavior of users seeking to maximize their individual utility. Thus the model analyzes a setting with n access CDMA users maximize their utility by analyzing it as a non-cooperative game of power control through models of Nash equilibrium.

We have already discussed and justified the important relationship between CRRM policies and pricing. Thus, when designing a network for a particular scenario should take into consideration this new parameter CRRM. It will be important to take into account the behavior of user on the price, and to mold the behavior of the most fitting possible scenario is considered. Thus, the utility function model that comes closest to the actual behavior that will be the starting point when designing the optimum charging system for this network.

3.3 Charging a network based on the utility model: Pricing

Although a network operator is always facing the problem of pricing services offered through this. The design of this pricing based on a model of user behavior on the price, such as a utility model, called pricing.

Because, in the end, the pricing is the income derived from the operator, the main aspect to be taken into account when designing the pricing is appropriate revenue. Even in those situations where the pricing strategy has a specific purpose, such as the strategy proposed in [11] to perform admission control function, the main criterion will still always incomes operator as discussed below. Thus, within the framework of network QoS, the objective of a pricing strategy to maximize income while maintaining a minimum QoS at all times.

As previously mentioned, the pricing tries to adjust to a model of user behavior in order to achieve their goals. In this model, which is based on pricing derived from the two possible types of pricing. The first is the static pricing, which is basically to have a fixed price for each service, although, as we will see in the next section, may vary in some specific moments. An example of this type of pricing would be pricing according to time of day, with a different price in the morning, night, weekends, etc., or in some cases depending on the type of user. These static pricing models are defined in the following section.

On the other hand we have dynamic pricing, also known as usage-based pricing.In this case the price fluctuates according to some parameter of the network, such as the level of congestion.

In the study of these pricing strategies for both approaches assume that the network operator has the ability to fix the price and vary it at any time.

3.3.1 Static pricing

Static pricing policies are generally the most simple and easy to study. Based on a variation of price is not based on any parameters of the network. That is, the price change has nothing to do with the network and is marked independently. Thus, this definition of static pricing is broad enough to encompass both common charging systems such as time-of-day pricing to be defined below.

The nature of these strategies are of implementation means that, in general, relatively simple. Generally offer very good results, as discussed below, have been demonstrated to be optimal or approached very carefully the behavior of dynamic pricing strategies. But they have some drawbacks. So, are not suitable for low volume users, do not allow any way to recover the costs of congestion and, in some cases, are not suitable for services with very different QoS.

The main distinctive feature of these policies is that, besides being a variation of the independent state of the network, the price changes rarely. This gives very little price change little if the design of practical applications of RRM, unlike strategies of dynamic pricing. With the constant price variation in these other strategies can achieve a very direct influence on the behavior of the user, thus, for example, solve congestion problems on the network. This type of application resource management are not possible with static pricing strategies, so your goal is basically limited to maximize profits while maintaining the minimum required QoS.

Within the field of static pricing are different systems or capabilities. Some early models were proposed by Cocchi et al. [12] The most ill Senz is flat or flat rate pricing, which simply defines a tariff in Euros / area that is kept constant. Actually the first basic model shows no pricing strategy, but simply sets a price consistent with the rmeti eg maximize profits by balancing the traffic that each user will set the price.

From this basic model first derive the true static pricing strategies. These models are based on different variables such as priority, time, etc.. The same authors also propose a model of pricing priority. This scheme applies a bit higher price than those with a higher priority, they also experience a higher QoS as it passes through the network.

More complex models are also static pricing proposed by Parris et al [13] who speak a pricing model that, in addition to shape priorities assumes that each user determines the type of service you want and the length of transmission, thus making a reservation of resources. Call this reservation-based pricing strategy. This pricing policy of the function that the network is based on a simple acceptance or rejection of incoming call from a very simple way. The network accepts the call if there is sufficient network resources to guarantee ”reserve” which prompts the user and on the other hand, if the price you have the call is less than or equal to the maximum price you are willing to pay the user according to the QoS.Once you have established the connection can also be paid a fee for this, appearing in the literature and the classical establishment cost per call.

The same authors also speak of the time of day pricing, introduced at the beginning of this section and static pricing model is known and applied. This model is usually the basis of pricing for mobile networks. This strategy tries to exploit the maximum and minimum utilization of the network, similar concepts in the busy hour telephone networks. Thus, users have to pay more if they want to convey during the peak network utilization. Moreover, during periods of minimum use, which tend to be very early in the morning or late in the evening, users have to pay much less. For more realistic user behavior under this strategy, he added the concept of elasticity of demand by users, thus marking a change in the amount transmitted to each user with respect to a change in the price, usually differently depending on the type of service. Thus it is modeled, naturally, users may seek to convey the maximum at times cheaper, or whatever it is, must be used only when the busy hour. In this situation always looks a tendency to balance the offered traffic at all times, seeking a balance between the variation of the traffic offered and the price change.

All these strategies and others that have appeared in the literature were analyzed and aggregated Breker in [14] in order to compare them with different dynamic pricing policies that further comment.

Apart from the different strategies and focusing on results, it is important to mention that, although the design does not allow static pricing MRR practical applications such as dynamic pricing models, which is not very useful in small towns of users have shown that the static pricing model is optimal from the point of view of revenue for the operator and utilization of network resources. Ioannis Ch. Paschadilis recently did numerous studies on pricing models, in most cases without focusing on specific applications, but making extensions to existing utility models and studying the suitability or otherwise of different policies, so comparing the two types of pricing. A very important conclusion of [7] is the asymptotic optimality of static pricing, so that as you increase the number of users tends to asymptotically optimal results as could be achieved with a dynamic pricing strategy. We show that in a system of many users relatively small, static pricing policies are optimal asymptotically provided in case you do not want to carry out some specific practical application of RRM, which would require a dynamic pricing policy.Thus, for example, but not actually an application of congestion control, the blocking probability in the network tends to 0 very quickly with the use of a static pricing policy accordingly.

Another interesting result of the same study shows how optimal dynamic pricing policy can be a very close approximation to a static pricing policy chosen correctly, if in case the latter policy is class-dependent, ie, assign a different price for different services, and what you want to achieve is to maximize profits and maintain a minimum QoS. Clearly applications, such as congestion control or access, may not be carried out with a static pricing policy.

The conclusion made by these studies Paschalidis is as follows. Applying a dynamic pricing strategy, which adjusts the price instantly snapshot and continuous use of the network achieved the best results ever. On the other hand, you might think initially that a static pricing strategy, which adjusts the price of each discrete period of some time and, therefore, does not fit optimally use the network, it will reach best possible results. However, a properly designed pricing strategy provides static optimal results in terms of performance and resources of total revenue for the operator, without the complexity of a dynamic strategy.

These results were studied and analyzed by Keon and Anandalingam in [15] confirm that policy is optimal static pricing strategy with pricing based congestion control for multiservice networks with guaranteed QoS. That is, all q eu applying dynamic strategy for optimal results are achieved revenues of the operator and the network congestion, with a static pricing strategy is properly designed have benefits over maintaining the network are free congestion, although the strategy is not static captions a direct function congestion control.

These same authors also propose an algorithm, based on these results, provides optimal solutions through static pricing strategies. Specifically apply this algorithm to analyze a policy against a flat rate pricing multi.

We commented earlier that Paschalidis proposed a new model extended utility, which spoke of expanded demand. Thus, when a user is willing to pay a price for a service that is below current price, you can use another service to replace flawed. For example, in current cellular network in the event that the price of the call set was very high, a user may choose not to call or send a text message instead. Thus, in this model, the utility of each user depends on the current price and the price of all other services potentially substitutes. The author analyzes this expanded model proposed and reaches the same result as mentioned above. With this new model are also valid demand extended the previous findings of optimality of a static pricing policy accordingly.

According Paschalidis, these results are based on a network model with many small users. This refers to the author that the results will be suitable for a very large network model, where an individual session occupies a small part of the total capacity of the network. These results and conclusions are applicable to networks that are studied in the current project, both the GSM and the UMTS.

As a final comment of this author, who has made many contributions in the field of the study of pricing strategies and is quoted by most authors, said the study is important with respect to [8] on several dynamic pricing policies with a view to implementing congestion control. In the next section we discuss the results of dynamic pricing strategies designed to control congestion. What interests us now is that through this study proved how an optimal solution to this goal is through a static pricing strategy chosen correctly, reaching strategy classical time-of-day pricing. Thus, we see how a policy of time-of-day pricing, used in all public mobile communication networks, optimal results are obtained and also achieved a practical application that normally only be imaginable through a strategy of dynamic pricing, the congestion control.

This is achieved in a very simple way. By combining time-of-day pricing and demand elasticity achieve that, tarify a high price during the peak utilization and a very low price when the network is less congested, reduce congestion and busy hour traffic is distributed better throughout the day.

Looking at these results we can imagine that such strategies would be the most suitable in principle for networks that are studied in the current project. Basically because the tarification these networks already operating under a strategy of time-of-day and always look for the user convenience. Not a very positive value of a network that is constantly changing and the price has to be consulted before deciding whether to use a server transmitted or not. Instead, we prefer a network is known a priori current price depending on the time of day, and that prices vary rarely during the day.

However, as it became heterogeneous networks consisting of two rats (GERAN and UTRAN), it will have two independent price variations for each network. If combined properly these fluctuations in the price and selection of RAT can achieve a dynamic pricing strategy that is transparent to the user. Thus, although prices vary dynamically, the price paid by the user constant.

3.3.2 Dynamic pricing

Dynamic pricing strategies are those in which the price varies according to some network parameter, being a model and the price varies continuously. These strategies are more complex and generally require more complex processing and computing, so they tend to be much more expensive to implement. Its main strength is the flexibility offered to react to changes in the offered traffic, being able to set the optimal price that maximizes profits at all times.

Although, as explained below, allow useful practical applications, elaborate, have some negative points that can be impractical. As mentioned above, require a level of complexity, but the main problem is the user's reaction to these policies. You can find these strategies very complicated and inappropriate when budgeting their transmissions because you can not predict in any way the behavior of the price as they pass the time. Also negative and uncomfortable for the user having to consult the current price on the net every time he wants to make a transmission to act according to their utility function. However, we emphasize that heterogeneous in a network environment, this problem could be solved by making the strategy of pricing transparent to the user. In fact, this is what has made the study of Chapter 6.

The main feature of dynamic pricing strategies is operating under a model very similar to the market. The main objective is to maintain the network at optimal benefits, a balance between user demand, which in our case is the utility and the discount carrier's network resources. And the price is achieved through maintaining this optimal point.

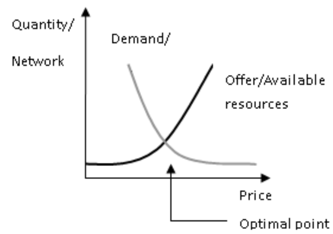

Fig. 10. Pricing model

Thus, these strategies attempt to manipulate user demand through price in order to maximize profits and efficiency of the network. This allows developing a variety of practical applications.

From this point, due to the effect of pricing on network management, the study of networks has evolved tarification the framework of communications away from the initial study based solely on economic terms. Thus speaks DaSilva [8] some major aspects of network engineering can be met from a perspective of dynamic pricing.

The author discusses several sources who have conducted studies on issues such as congestion control, admission control, resource management, etc.. There have been many studies that from the behavior of the user demand with respect to price, seeking different methods to solve congestion problems on the network. Thereafter develop other approaches, based on the same principles, discourage the user to pass through price, carrying out a similar function in access control. All these applications and others more complex and elaborate, are always based on the behavior of user with respect to changes in price, that is, the basic concept we have discussed previously useful.

It is interesting to note some aspects of dynamic pricing strategies before moving on to analyze more complex applications. Jon M. Peha done in [6] study a dynamic pricing strategy for congestion control, but during its study comes to some interesting conclusions. In its initial analysis of such pricing policies concludes that are suitable for voice traffic, while the current project is to design pricing strategies applied to voice traffic. By working with heterogeneous networks to facilitate this type of application. Meanwhile, on the fact that it is comfortable for the user that the service charge varies dynamically, Peha suggests some strategies for these pricing policies are more comfortable for the user to other types of traffic without having to be what the user see the current price at all times. So talking to configure the browser traffic loads www because no audio, video or images when the price is high, or in the case of videoconferencing, to vary the price according to the quality and can pass a videoconference B / W if price increases very much.

Many models have been proposed to date and dynamic pricing strategies which, in their majority, have led to some practical applications such as those we discuss below. However, there are very few models discussed in the literature that have no specific purpose, and are general models that can be relied on others. One of the most studied is the smart market model proposed by Mackie-Mason and Varian [16]. The model is based on an interaction through price between the user and the network. The user specifies a value for each packet to transmit, in a manner similar to a model with priorities. For its part, the network sets a price for each link so that the total capacity of the link is enough for packages priced above this.

3.4 Practical applications of dynamic pricing model

In this section we briefly discuss some very specific and practical applications of network engineering recently developed. With this brief selection is intended to show a general idea of the endless possibilities offered by dynamic pricing strategies. In all these applications exploits the flexibility of the user behavior on the price, shaped by the utility. Initially all the applications were based on a profit maximization network operator maintaining a minimum QoS, but as mentioned, these applications have recently been moving away from the economic and tended to the framework of network engineering.

3.4.1 Admission control

DaSilva said as in [8], there have been many studies about the decision to integrate the network admits a new connection entering the elasticity of demand for bandwidth, influencing some connections because of services not are real time is postponed to when the network is not too congested.

In wireless networks, especially cellular networks, access control clearly has two distinct stages. In this type of network is talk of two blocking probabilities, distinguishing between new well connections and connections in the process of handover. One drawback is that decreases the QoS drops calls or droppings, which occur especially during a handover process that fails. Facing the user and the QoS perceived, the droppings are more annoying than the initial blockage, so I usually give a certain priority to the process of handover calls. This priority is managed through different strategies. For example, channel reservation schemes, some of the available channels are reserved exclusively for handover calls in phase, while the rest are shared by these calls and new calls.

An interesting study on the subject and related pricing strategies is performing Hou, Yang and Papavassiliou at [11]. The authors propose the integration of access control with a dynamic congestion pricing that encourages users to use wireless resources efficiently. This scheme implements an implicit prioritization of traffic based on distributed users. The model used for the analysis is based on a utility function, while the QoS they believe is a weighted sum of the probability of blocking new calls and handover calls on stage. This study analyzes pricing as a source of revenue for the operator and are looking to maximize them, but focuses on the function of Call Admission Control (CAC), admission control.

This prioritization is based on distributed traffic, through price incentives as negative charge state of the network, thereby somehow mold the traffic entering the network. From simulations resulting in confirmation that, through pricing, achieved a significant improvement in the QoS, thus reducing significantly the probability of blocking new calls and confirming the suitability of a strategy dynamic pricing to perform a function of access control.

Moreover, a very important aspect of the study of these authors is the pricing model proposed by integrating the access control system. The pricing applies only to new incoming calls, because the traffic from the handover is always desirable to be always accepted. To reduce the probability of blocking for λ_{HO} apply other techniques such as the already mentioned booking channels exclusively for handover traffic coming from. Thus, in this proposed scheme, the pricing model is represented as shown in Figure 11 (taken from [11]), as a system $H(t)$ that filters incoming traffic generating traffic not accepted that, after passing a retarder which simulates the average time it will take for a real user to retry the call, joins the new calls traffic entering the system as $H(t)$.

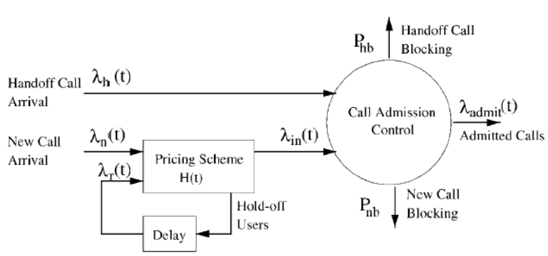

Fig. 11. Schematic of a Call Admission Control model based on a dynamic pricing strategy

Later, the authors extend this model. Purified pricing system considered in the case of incoming calls rejected (New Call Blocking) will again be new calls after a certain delay, when the user retry the call, or leave a small percentage of the system so that the user gets tired after a certain number of retries. This modification is shown in Figure 12.

3.4.2 Power control

The concept of power control is very important in cellular wireless networks, especially in working with access CDMA networks, such as some of the analyzed in the current project. It is in this context where there is a more specific application of the economic concept far have been studied in relation to pricing. Saraydar, Mandayam

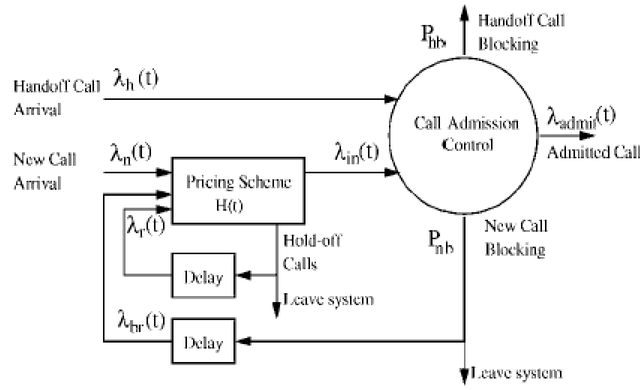

Fig. 12. Diagram of an enlarged Call Admission Control model based on a dynamic pricing strategy

and Goodman studied in [10] a new system of power control for wireless networks.

The motivation of the study is that because there have been numerous studies on power control, basically motivated by the importance of systems that perform this function in modern wireless networks based on CDMA networks as new Mobile working on UTRAN. However, despite these numerous studies, this issue has been exhaustively analyzed by voice traffic, so your study is focused on other services in that it has worked.

To perform the study are based on a utility model which we have already mentioned in section 3.2 of this study. In this model the QoS parameter chosen as the relationship between received power and interfering signal (CIR), and the utility is a linear FUCI power transmitted.

To carry out the control of power users looking to maximize their utility in a non-cooperative game with pricing power control (NPGP). We propose a complex model is analyzed in its breakeven point to find the right job. In this model individually anyone looking to maximize their utility. As mentioned, the price is a linear function of the transmitted power (P-T Price = k) k be a variable called pricing factor.So basic pricing model allows easy implementation of this system.

The power control is done from the base station to users announcing the value of k. The response of each user is adjusting its transmitted power to maximize its utility in the net. It is considered a link in an uplink CDMA system with a single cell.

With the analysis of the model are more of a break, but show that the operating point that maximizes the utility of the network where a Nash equilibrium. Moreover, at this point of equilibrium where utility is maximized, minimizing the transmitted power of all users, resulting in a decrease in CIR, which is always different for everyone.

The same authors had previously conducted a study [17] which initiated the analysis of the possibilities for the application of power control via pricing. This first implementation was based also on each user maximize their utility, measured in bit / Joule, through adjusting its transmitted power. The first study, in the same way that the first thing mentioned, also based on the study of application services data traffic field in far fewer studies that had been made with respect to voice traffic .

An important aspect of this first study is also analyzing base station allocation algorithm that also maximizes the utility of each user.

Should be considered, although it is an interesting application of a dynamic pricing model for CDMA networks, a model would not be applicable to UTRAN, the network can not be performed on power control. That would be a CDMA model applies only to generic.

3.4.3 Congestion control

DaSilva also discussed in [8] and there have been many authors who have studied the problem of congestion in the network through an analysis of pricing. Thus, several studies have suggested that an appropriate pricing strategy can help avoid situations of overuse of the network. One way to perform this function congestion control is dynamically set prices in a way that reflects the current state of the network, raising prices when the network is saturated and thus discourages users to make calls.

An interesting study on this application is Jon M. Peha [6]. Initially, the author focuses on analyzing and commenting pricing strategies based on the use of the network, where the price depends on how users use the network, such as how many packets are sent and when. This type of dynamic pricing can influence and change parameters for each user, such as the transmission speed.

It is important to mention that the model studied by the author is that of a network without QoS guarantee a minimum. It is a best effort network flow oriented model with pricing based on use. Thus, the process of arrival of the flow of information from the network user is declared before the transmission begins, and the network transmits those flows higher value than the current price. Certain mechanisms responsible pricing policy of penalizing users check if the process is specified with the transmission does not fit too far then the user.

In the proposed model all best-effort flows transmit at full speed, but when there are too many active link is congested and the throughput is not optimal. Variant prices are dynamically force that flows through all the current price exceeds the value of the transmitted information, stop transmitting, and the rest are still transmitting at maximum speed. The maximum speed at which they can transmit the source is determined by the congestion control mechanisms.

Based on this model, the author proposes three models of congestion control, NC (no congestion control), SC (Slow-reacting congestion control) and FC (Fast-reacting congestion control). The first is equivalent to not actually implement any congestion control, while the other two slow-reacting fast-reacting congestion control and congestion control, based on the Rb MAX range that can be transmitted to the sources of value than money today.The maximum baud rate varies each time it starts or ends a trick seconds in the case of SC, or whenever ? varies in the case of FC.

3.4.4 Scheduling

Dynamic pricing policies influence the behavior of the user and the volume of traffic this will generate. This ability to modulate the load expected through the price can be useful for network operators to measure and to manage network resources.

Jyrki Joutensalo made in [18] study the possibilities of managing network resources through pricing and propose a scheduling scheme that guarantees a minimum QoS, considering the bandwidth and QoS parameter. It is a model with priorities (with different classes of user), because it ensures more bandwidth for users who pay a higher price for the connection.

Basically the objectives of the proposed model are sharing the bandwidth among different classes of service while maintaining a certain level of QoS and on the other hand, managing the available bandwidth in a controlled manner that can be easily predicted. These objectives are achieved by analyzing the problem in a way that seeks to maximize the benefits of the network by optimizing an objective function of profit.

In the proposed scheduling scheme using a polynomial function of the form pricing $P_i(B_i) = r_i B_i^p$ with $p > 0$. This feature results in benefits which is a transmission class and a bandwidth B_i. The factor $r_i > 0$ is a parameter that depends on money paid for the class and priority of the user, which in turn depends on the bandwidth of the connection of this person. That is, referring to the priorities already mentioned before, if a user will pay more money in a higher priority class and, therefore, the value of r_i and will be larger.

In the study get a simple model that works and can be easily implemented on a single proposed algorithm is optimal. Finally some conclusions that extract to add to your model an access control system also based pricing. The authors verified how the proposed model always guarantees a minimum QoS in the form of bandwidth and it works properly on TCP and UDP traffic.

The authors have continued to work on the same model [19]. The study is based on a maximization of profit operator that guarantees a minimum QoS in the form of bandwidth. In this second study analyzes further incorporating an access control mechanism based on pricing that works well in conjunction with the scheduling model already discussed, and the aforementioned classes of services depending on the price paid. So talk clients gold class customers and bronze class, repeating the fact to make more bandwidth to those users who pay a higher price.

4 POLICY-BASED INITIAL RAT SELECTION

In a heterogeneous network, as they are studied in this project are applicable CRRM strategies. The fact of being a heterogeneous network makes use of a new network functionality that manages and controls provide the resources available to each radio access network (RAN), allowing better management of these resources belong to different access technologies (RAT).

The functional models proposed in the Third Generation Partnership Project (3GPP), as mentioned in the first chapters of the project, gather all the resources available to a radio operator in pools [1]. All available resources are managed by two types of entities, entities in charge of each access network RRM and CRRM single entity in charge of all the networks together. Thus, each RRM entity manages radio resources of such a resource pools individually, while, on the other hand, the CRRM entity performs control and coordinated set of all resources, even if they belong to different pools .

This model can not work through an implementation independent institutions of RRM and CRRM. The organization that oversees the management of all of the resources must maintain a constant interaction with the elements responsible for RRM functions. This interaction requires a constant exchange of information and action network among entities. Depending on the distribution of tasks between the elements of RRM and central body we have different levels of centralized network management.

Thus, as defined in [2], network management can be very centralized, delegating most of RRM functions in the central entity, speaking thus set access control, congestion control set and so on. This centralization can offer many advantages with regard to network performance, but otherwise require excessive signaling, which in turn may adversely affect the performance. Moreover, the network can be managed in a very decentralized, leaving the central bank merely intercom function between the elements of RRM.

In general, repeating once again that was introduced in the second chapter, may tend to apply an intermediate centralization, avoiding excessive signaling, but at the same time taking advantage of the advantages that offers CRRM. In this model the intermediate network element responsible for the CRRM performs several functions, some of which are always present, such as vertical handover and the Initial RAT Selection.As introduced above, this chapter, and the project in general, focus on the role of CRRM.

The role of initial RAT selection can be performed using different algorithms, focusing on the project in algorithms based on policies, and speaking of Policy-Based Initial RAT Selection.In this model, algorithms selection of RAT based on functions or policies to establish access network chosen depending on the system parameters, measurements, type of user, type of service, etc..

This function is basically when a user is about to launch a new connection, which decided by the different access networks in the network heterogeneous global convey. This decision is based on policies already mentioned, always with the aim of optimum allocation in the face of overall performance on the network in terms of the quality of the transmission to be received by the user, ie, the QoS introduced in the second chapter.

4.1 Initial RAT selection policies

The algorithm Policy-Based Initial RAT Selection is based on the different policies used. Each policy is a simple function that, using different input parameters of each RAN, resulting in a RAT appropriate to make the connection.

In [1] the politics of selection of RAT are defined mathematically as follows. Assuming a scenario with heterogeneous network with a set of different access networks available, R is defined as the domain of the corresponding RATs. Thus, in the case of this project, R = UTRAN, GERAN. A basic function of RAT selection can be defined as a function f that, given a set of input parameters $\xi_1, \xi_2 ... \xi_m$ resulting in an appropriate RAT to connect to .These input parameters can be as diverse as the load on each RAN, the type of service connection, the propagation loss of the user, etc. Thus, a basic function of RAT selection of p, is expressed as:

$$p = f(\xi_1, \xi_2 ... \xi_m) \in \mathbb{R} \tag{4}$$

It discusses basic policy of selection of RAT to distinguish between these early policies and other policies that are derived from complex materials. Therefore, one can also use complex policies (Complex Policies) which are usually a combination of two basic policies (Basic Policies).

4.1.1 Basic policies

As defined, the basic policies are functions that result in an appropriate RAT to connect it using different parameters. When applied in a scenario like that are considered in this project, which consists of heterogeneous network UTRAN and GERAN, with multi-user and interactive voice and data traffic (www), which in turn can be indoor, basic policies used are the keys defined in [1]:

VG (Voice GERAN)

This policy has a single input, type of service, diverted users to GERAN voice traffic and other types of service to UTRAN. This is due to several reasons. As an example, the chart below shows the results of average delay for each site during a session of interactive traffic. We consider a scenario with the radius of the cells of 500 meters and a number of users of www traffic that varies between 200 and 1500.

It is easy to see how the average delay greatly increases the traffic to GERAN interactive completed with just a small increase of users, while UTRAN is much more resistant to increases in users and remains almost the same QoS to a greater number of users. This result can give a small idea of what the most suitable divert traffic UTRAN and interactive, so voice traffic for

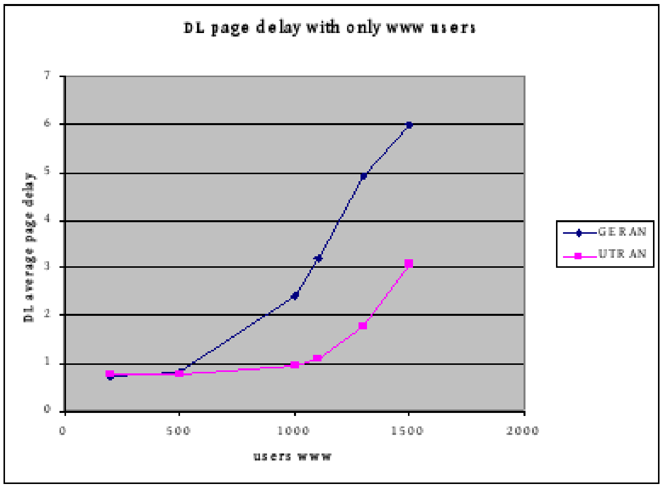

Fig. 13. Comparison of average delay on DL for www traffic between GERAN and UTRAN

GERAN, which gives meaning to the first basic policy. In [20] presented a similar result.

The outline of the operation of this policy is as follows:

$$P_{VG} = f(\text{service}) = \begin{cases} \text{GERAN, if service = voice} \\ \text{UTRAN, if service = www} \end{cases}$$

Fig. 14. Voice GERAN

VU (Voice UTRAN)

The second policy is the opposite of politics VG, so that its operation is basically select UTRAN connection when it comes to voice traffic, and moreover select GERAN in the case of a transmission of interactive traffic.

Thus, the operation of this policy can be defined as follows:

$$P_{VU} = f(\text{service}) = \begin{cases} \text{GERAN, if service = www} \\ \text{UTRAN, if service = voice} \end{cases}$$

Fig. 15. Voice UTRAN

IND (Indoor)

In this case, the selection of RAT is considering whether the user is indoor or outdoor, based on the fact that users of indoor traffic causing a serious decline in the capacity of WCDMA as scores at [21].

Thus, to try to keep the QoS in heterogeneous network globally, it will be interesting to try all traffic away from indoor UTRAN.Thus, this type of traffic will be diverted to the alternative RAT, GERAN, so how this policy is simply select GERAN for all indoor connection from a user.Although, apparently, is a very simple operation, as discussed below, the application of this policy in a real network would be complex because you can not tell whether it is indoor or outdoor user so simple.

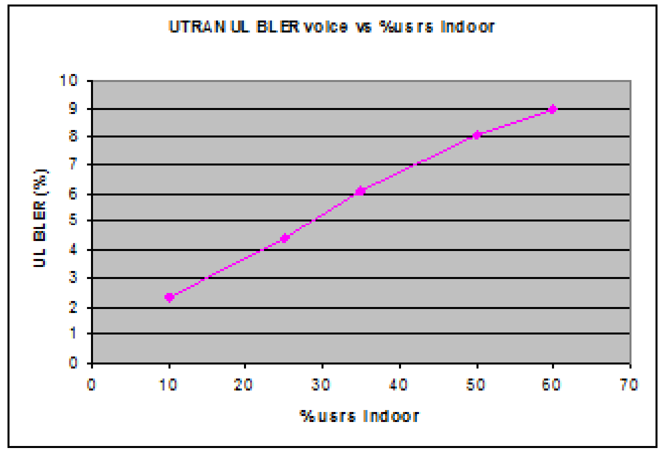

Fig. 16. QoS degradation as a function of the percentage of indoor users

The following graph shows the significant deterioration of quality UTRAN as it increases the percentage of people in indoor setting.In this case is simulating a multi-stage voice with 700 users and 700 users www. In addition to the significant deterioration of QoS for voice traffic as it increases the percentage of indoor users is also interesting to look at as high a stage with a load like this, just a small percentage of users because it indoors the BLER is higher than desired.In this case the BLER target for voice traffic is 1%, and a small percentage of people indoors, 10%, is already causing the resulting BLER is twice the one fixed objective.

Similar results have for interactive traffic, which also observed a strong disminuaci of QoS as it increases the percentage of people indoors.Also repeated the fact that a mere 10% of indoor users, the BLER for the interactive traffic is twice the value that establishes the goal of 10%.

In a schematic way, the operation of this policy is as follows:

$$P_{IND} = f(\text{indoor}) = \begin{cases} \text{GERAN, if indoor = true} \\ \text{UTRAN, if indoor = false} \end{cases}$$

Fig. 17. Indoor

4.1.2 Complex policies

It is important to consider that the use of the above basic policies would, in case there was not enough capacity in the selected RAT selected, there is a locking connection.Therefore, these policies could lead to blocking situations if there is sufficient capacity in the selected RAT selected, without ever having tried before connecting block through the RAT alternative.It is this problem which may arise from the complex political.

The policies are also complex functions with one or more input parameters, but in this case the result is a prioritized list of unemployed, which must try to connect in the same order in which they are listed. So if it is a list of two RATs, ie, following the mathematical definition proposed at the beginning, an element of the set R 2 is selected the lectionary RAT appears in first position in the list.If you do not have sufficient capacity, try connecting to the second RAT from the list. It is the case that none of the RATs in the list have enough capacity when there is blockage in the connection request.

Mathematically, and also following the model proposed above, we can define an n-complex policy as follows:

$$p = f(\xi_1, \xi_2 ... \xi_m) \in \mathbb{R}^n \tag{5}$$

Complex policies are formed from the combination of two or more basic policies. This combination is symbolized by the symbol *, and applied to the basic policies presented above allows us to obtain the following complex political, also defined in [1]:

VG_IND=VG*IND=f(servei, indoor)

IND_VG=IND*VG=f(servei, indoor)

VG_VU=VG*VU=f(servei)

Fig. 18. Complex policies as a combination of basic policies

VG_IND

This policy is the first complex formed from the combination of policies and VG IND.Aims to combine the advantages of both policies because of diverted traffic to www UTRAN and GERAN to indoor traffic, and it does give priority to political VG.

The policy underlying the selection of RAT initially on the type of service the transmission, interactive diverting traffic from UTRAN and GERAN voice. In the event that the selected RAT leccionada not have sufficient capacity becomes to the selection of RAT, this time based on whether or not the user is indoor.The following table shows schematically the operation of the policy.

It is interesting to look at how, in some situations, the policy may lead to try to connect to the same RAT two consecutive times. In fact, in these situations, if the first attempt to connect the RAT does not have the capacity, the call falls without making a second attempt.

Service	Indoor	$VG * IND \in \mathbb{R}^2$
voice	true	{GERAN,GERAN}
voice	false	{GERAN,UTRAN}
www	true	{UTRAN,GERAN}
www	false	{UTRAN,UTRAN}

TABLE 1
Diagram of VG_IND

IND_VG

In this case we have to reverse the previous policy, which is based on giving priority to the selection of RAT whether the user is indoor or outdoor, in case you have blocked the first attempt connection is the second attempt by type of service.

The following table shows schematically the operation of this policy.

Service	Indoor	$IND * VG \in \mathbb{R}^2$
voice	true	{GERAN,GERAN}
voice	false	{GERAN,UTRAN}
www	true	{UTRAN,GERAN}
www	false	{UTRAN,UTRAN}

TABLE 2
Diagram of IND_VG

VG_VU

The latter complex policy is easier than before. The selection of RAT is based solely on the type of service required for transmission. It is basically an extension of politics VG with a second attempt to RAT alternative.

So, first of interactive traffic is diverted towards UTRAN, where they generally run with higher quality, and voice traffic for GERAN. In the case of blocking attempts to connect to the RAT alternative.This behavior is described schematically in the following table.

Service	$VG * VU \in \mathbb{R}^2$
voice	{GERAN,UTRAN}
www	{UTRAN,GERAN}

TABLE 3
Diagram of VG_VU

4.2 Study and analysis of initial RAT selection policies

After explaining the function of CRRM selection of RAT based policies and described the various existing policies, there is an analysis of how these policies. CRRM as a function of the application of the Initial RAT Selection based policies intended to achieve an improvement in terms of QoS across the network on whether this feature is not enforced.

Being a heterogeneous network is required depending on selection of RAT to initiate a connection, so it is not possible to model a case where there is no such function. However, the aim is to achieve an improved quality of service and network performance if not done with respect to the selection of RAT through policies.

So, we decided to use as a reference the QoS obtained by making the selection of RAT without judgment, simply as equiprobable. For this we designed a new basic policy simply performs this function. We Choose the UTRAN or GERAN form equiprobable, thus being defined politics Random (RND).

This section seeks to maximize the benefits offered from the global study of the role of initial selection of RAT. The aim is to define the optimal in terms of QoS policies for each type of scenario with many different variations of parameters. Through simulations of the behavior of the network to work with every policy removes the results of service quality. It usually works with multi-stage, with different proportions of voice users compared to www. We are also working with different values of the radius of the cells and the percentage of people indoors. So we want to analyze the optimal policy for each combination of these three parameters: the number of users of each service, the size of the cells and percentage of people indoors.

This analysis is done, as mentioned above, studying the results of network performance in terms of QoS, but added two parameters in order to make this more realistic analysis.

4.2.1 New variables for analysis

In the current study the behavior and policies of optimality selection of RAT added two extra parameters, the total income generated by the network operator and the percentage of users onlyGERAN.

The network performance in the face of the operator in the form of total revenues, are shown separately as income for voice traffic or revenue www is very important and should be a basic parameter to consider. It is very important to evaluate the quality of service offered by the network to the user according to the policy used, but to determine the optimal policy for a certain scenario should also assess the benefit that removes the network operator that will never be willing to offer a QoS at the cost of much of their income.

Moreover, as already noted in the chapter on pricing CRRM in the current draft charging network and the applications that are extracted are an important issue. Therefore the whole system is modeled pricing service on the network in the face of possible network functions based pricing, as discussed later in the chapter selection of RAT based pricing, and especially also with regard to evaluate the performance which extracts the network operator, provided in the form of income.

Finally, we also evaluated the possibility that some users have a GSM mobile terminal, which can connect via UTRAN. This results in more realistic simulations, modeling the behavior of mobile terminals, like most of those in operation today, can not connect through the two RATs. Other users then have multi-mode terminals that can connect to both GERAN and UTRAN.

Total profits

As already mentioned, as introduced in Chapter Pricing on CRRM in the current project pricing heterogeneous networks is a very important issue. Later models proposed new pricing very specific purposes, but also is important in assessing the behavior of political Initial RAT Selection, taking into account the income of the operator.

Thus, as the performance of the network to the user is that the perceived QoS, you should also consider the performance of the network with regard to the operator, provided in the form of total revenue .These two bands total revenue sold. On one hand you have the traditional pricing of mobile networks, in a certain price that is charged per minute for phone calls, on the other hand is tarify data transmission at a price per Mb of information transmitted or received.

Facing the simulation of the behavior of different policies with the sole objective of assessing their suitability for different types of scenery, not yet molded into complex pricing strategy. Simply sought to draw a more revenues indicating that removes the network operator working with that policy. So working with a static pricing model which sets a constant price for the entire simulation.

Revenues for interactive traffic are calculated from the traffic of each user, using a constant price of 2 Euros / Mb, which is a common setting in tarification of this type of service in mobile networks.So just take into consideration the traffic transmitted, regardless of the number of sessions of traffic www.

Moreover, compared to voice traffic, the cost of each call is calculated by multiplying the bsicame nt call duration for a fixed cost of 5 Euros per minute / minute for both UTRAN and GERAN, which is also a typical value of calls in this type of network. You can apply a different cost transmitted calls for GERAN and UTRAN for that.

onlyGERAN users

In the future we will have reached the point where UMTS network completely deployed and we are faced with a heterogeneous network UTRAN & GERAN. Will this network to apply different CRRM strategies being developed and studied.

In the case of the selection of RAT so far is based on a theoretical basis on which any user can select either of the two possible RATs. This will be possible with the new multi-mode mobile terminals that allow you to connect via GERAN and UTRAN. However, in the medium term, when the UTRAN network is fully deployed, there will still be a large percentage of the population with a GSM terminal, able to connect only to GERAN.

This is modeled by adding a new variable to consider with regard to the results. Defined percentage of users with a mobile terminal can only work in GERAN. These users are defined as users onlyGERAN, and so we talk about the percentage of people onlyGERAN.

In order to obtain results as well as the total income of the operator will be a key factor in the analysis of different policies, the percentage of users onlyGERAN used only to analyze a simple variation in the overall performance of the policies in the presence of different percentages of users of this type.

4.2.2 Simulation conditions

In order to analyze the behavior of political RAT RAT selection of results extracted from simulations. The siulacions are always in a scene that consists of 7 cells omnidirectional both GERAN and UTRAN for, and in case of GERAN are a whole cluster, so that each cell works with different frequencies.

The aim of the simulations and the results of their study is to determine the policies that provide better results, both in terms of total revenue and QoS based on different parameters. These parameters are taken into consideration are the number of users, the percentage of users and the size of indoor cells.

Regarding the number of users working with multistage presence with users of interactive voice traffic and traffic www. The parameters for users to generate traffic are constant and are as follows (mean values):

- Voice traffic
  - 10 calls per hour.
  - $T_m = 180 seconds$
- www traffic
  - 24 www sessions per hour.
  - 5 web pages per session.
  - 25 packets/page.
  - $L_{packet} = 366$ bytes
  - Arrival time in between packets exponentially distributed with average 0.125 seconds (UPLINK) and 0.0228 seconds (DOWNLINK)

As mentioned above, in order to obtain results varying the number of users of each service, and varies the percentage of users who are indoors. It simulates the behavior and policies in environments with a low percentage of indoor users (10%) and a high percentage of these users (50%). It also simulates the behavior in environments with radii larger cells, and compared the results between environments with cell radii of 500 meters and environments with higher cells, radius 1000 meters.

4.2.3 Analysis of results

Basically all the simulations and the results are extracted focus on analyzing two specific case studies:

- Basic policies (Indoor - voice GERAN - voice UTRAN)
- Complex policies (IND_VG - VG_IND - VG_VU)

The analyzed results are always the QoS for users and the total revenue obtained operator. Regarding the QoS and other parameters of network performance, we study the quality of the voice traffic from the average BLER, while the interactive traffic is also considered the average BLER but especially the delay of a half page. Also consider the total throughput achieved as a result of analysis.

Basic policies (IND VG VU)

Initially we analyze the results of the policies in multiservice scenarios that have the common feature that the radius of the cell is 500 meters.

First we consider a scenario with 30% of indoor users, and each user sees. Comparing the results of the policy indoor (IND) (which diverts users to GERAN indoor) a policy random (RND), which we use as a policy reference in terms of BLER in the uplink direction. RND policy simply assigns each user GERAN or UTRAN so equiprobable.

Intuitively, given the negative effects of indoor users have regarding the QoS in W-CDMA networks, as discussed in [21], one can imagine that all users take for indoor GERAN, UTRAN delivered to the Indoor traffic load, will be a clear improvement in BLER for UTRAN.

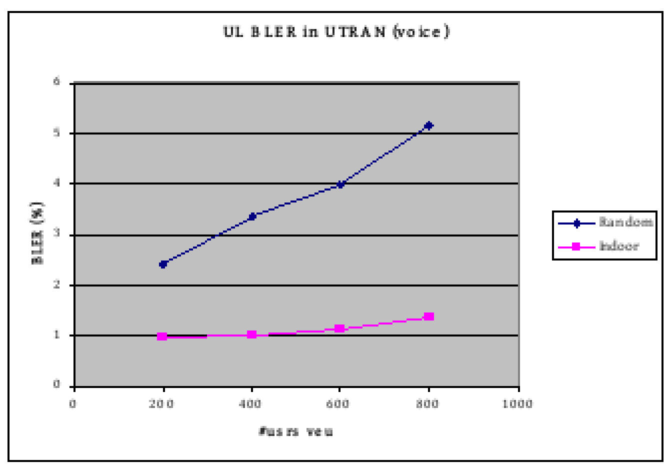

Fig. 19. UL BLER in UTRAN (voice)

Figure 19 and Figure 20 shows how the policy IND BLER is reduced by the UTRAN, GERAN while increases.This is because we are sending to all users GERAN indoor stage (30% usrs. Indoor). But you can see

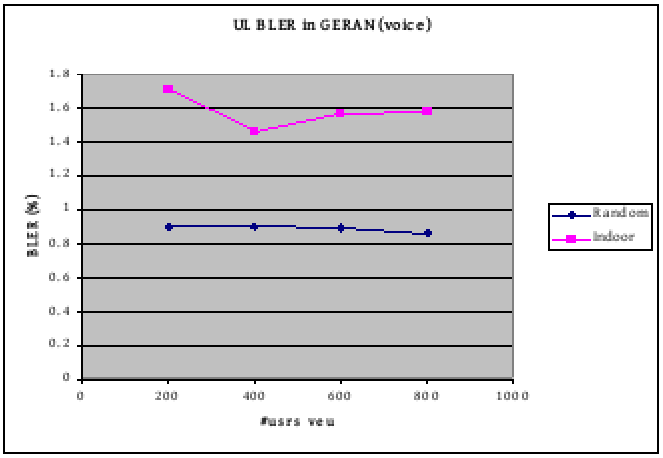

Fig. 20. UL BLER in GERAN (voice)

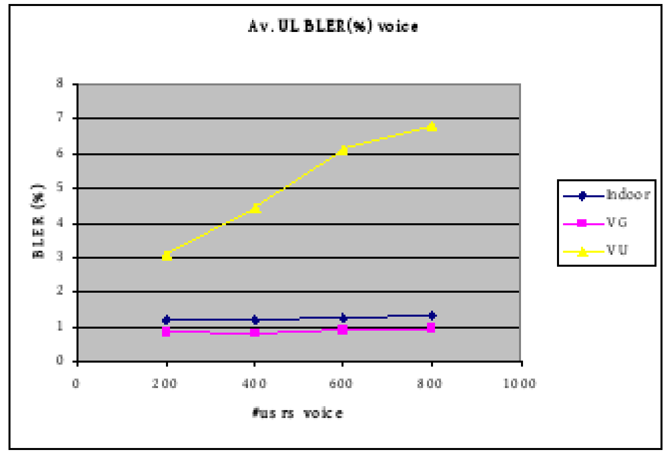

Fig. 21. Average UL BLER (voice)

how the decrease in UTRAN is much more important than the increase in GERAN, and even increase, the BLER is kept close to the target value of 1

These results indicate that it is useful to turn users into GERAN indoor scenarios where the percentage of users is significant.As you can see, this strategy represents a very significant improvement of the QoS for voice traffic in UTRAN and GERAN small deterioration.However, as mentioned above, the application of this strategy is about levels of QoS desired by both RATs. The usefulness of this policy will be strongly correlated to the percentage of users present in the indoor stage. Thus, this policy will produce an important BLER disminuaci both in indoor scenarios with few users, or simply do not fully apply to outdoor scenarios.Furthermore, it would not be useful to divert users through GERAN indoor basically indoor scenarios.

Regarding the other two basic policies, VG and VU, being algorithms whose input parameter type of service, it makes sense to analyze the results in the same scenario populated only by users of voice traffic.

The scenario for comparing the results of policy IND with the policies and VU VG is different.In this case it is a multi-stage, where we have 400 users still www. In addition to these users, we also have between 200 and 800 users voice. Of these users, 30% are indoor.

If we look at Figure 21 we can see the improvement in the quality of service in terms of BLER.With the poetic VG achieve a significant improvement in voice traffic, which in this case is sent to GERAN.Achieved an average BLER for voice traffic below the desired value, reaching approximately around 0.9%. This improvement is due to the interactive race UTRAN traffic, network offered much better performance in this kind of service. Thus, the interactive traffic also race with superior quality.

The results obtained with VU policy, which diverts the ususaris voice to UTRAN are much worse.The users of BLER for voice grows with the number of these users, reaching very high values with which it is impossible to have a good quality.This is because we are sending many indoor ususaris (30%) in UTRAN, making the network quality deteriorates much.

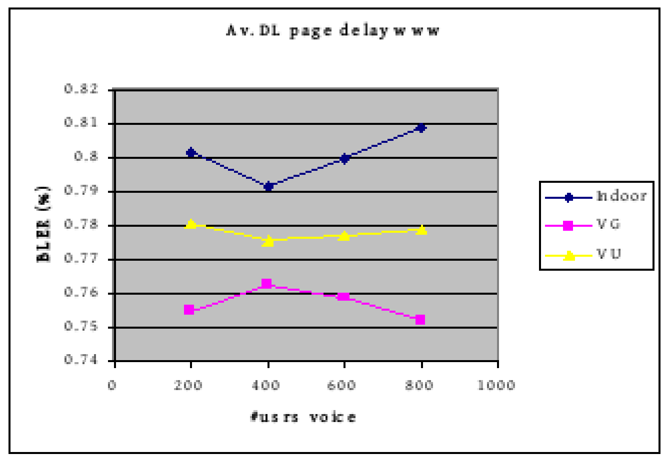

Fig. 22. Average delay (www)

Moreover, the strategy taken by UTRAN traffic www working with policy VG also provides good results for this type of traffic.Figure 22 shows the results obtained by means of traffic delays www. Seen as the strategy reduces the value of VG delay values obtained by improving policies and VU IND.In the case of IND obtained worse results than the other two policies due to the worsening delays in GERAN. Besides not provide good performance for such traffic, loading the RAT with 30% of users that transmit data traffic indoor www. This causes some users do not receive the minimum power required to work with an appropriate QoS GERAN.

Regarding the throughput, Table 4.4 shows the results for the three policies in this last scenario. It is calculated by adding the throughput of the UTRAN and the GERAN and considering together the two types of service.

The throughput is higher with the policy when VG is not too high load of users.As the load grows, GERAN

30% indoor		IND		VG		VU	
www users	voice users	UL	DL	UL	DL	UL	DL
400	200	0.99	1.06	1.07	1.12	1.00	1.07
	400	1.65	1.72	1.65	1.72	1.57	1.66
	600	2.32	2.39	2.12	2.20	1.96	2.07
	800	3.53	3.63	2.24	2.31	2.13	2.22

TABLE 4
Total throughput (Mbps) for the 3 basic policies

was saturating all users to receive voice traffic. Likewise, the performance decreases www traffic through UTRAN, which is forced to take a large number of indoor transmissions. It is from here when it is useful to divert traffic indoor GERAN, which, although the performance of interactive traffic is lower than GERAN UTRAN, provides better results in half the total throughput.

Therefore it can be concluded that for low loads, it is useful to divert voice traffic GERAN and UTRAN interactive traffic, and thus achieve a good quality in addition to throughput than other basic policies. When the load is high is very useful for diverting traffic indoor GERAN.

The fact that good results with two policies (IND and VG) leads us to think that could optimize results using new policies that combine these two strategies. These policies, called complex political, are analyzed in the following case study.

Complex policies (IND_VG, VG_IND, VG_VU)

To study these policies using two different scenarios. The first is a scene that has three variants with a fixed number of voice users (200, 400 and 600), and a number of users of www varies between 200 and 1000. The other scenario, however, have a fixed number of users www (600) and a number of voice users between 200 and 800. In both scenarios we obtain results in two cases of indoor percentage of users (10% and 50%) for the behavior of policies vary regarding the number of users present in the indoor stage.

Www scenario with variable load and load fixed voice

Figure 23 shows the results in terms of the average BLER in both networks for voice traffic when 400 users have seen and fixed between 200 and 1000 users www, being 50% of these users turf. The BLER is calculated by weighting the average BLER we have for each RAT with the percentage of total traffic that each race.

An important factor to consider is that, depending on the policy used, traffic is distributed very differently. Do not get any results for voice traffic loads taken by UTRAN low when policy VG_IND used is because in this case all traffic for GERAN voice. This is because the voice is transmitted in the first instance to GERAN, and in no case enter the first attempt to retry, also deviates toward GERAN if a user is indoors, in this case

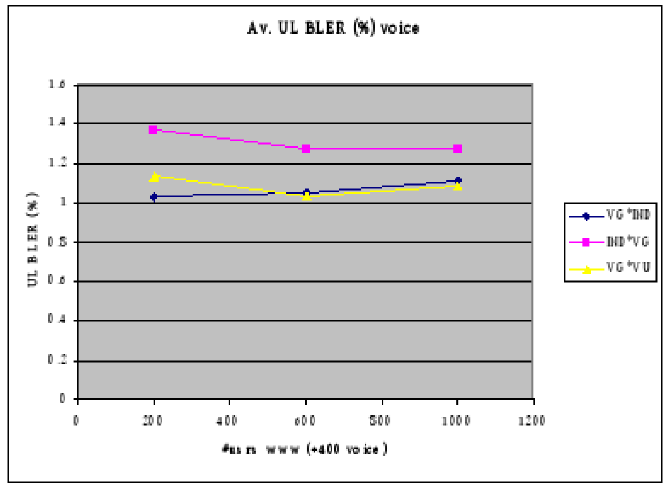

Fig. 23. Average UL BLER (voice) (50% indoor)

representing 50% of total users. Thus, in a situation of low load, no voice user than the first attempt to indoor selection of RAT GERAN not enter into.

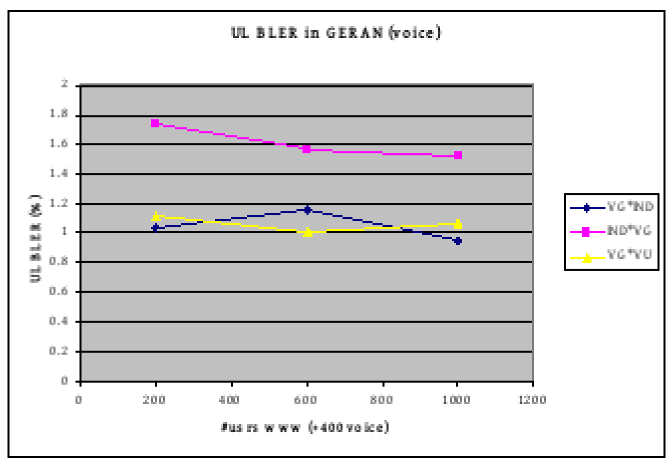

Fig. 24. UL BLER (voice) (50% indoor)

VG_IND and VG_VU are two policies that offer better QoS, while IND_VG has a higher BLER, although close to the desired value.This is due to the same effect that occurred with IND, a deterioration in the BLER for voice traffic through GERAN.Still a drop below the UTRAN improvement, but the other two do not have this complex political and drop in half, provide better QoS. This effect can be see in Figure 24.

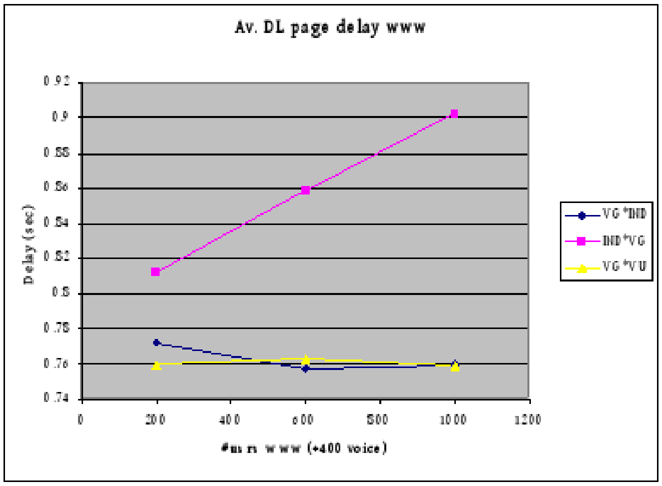

Fig. 25. Average delay (www) (50% indoor)

Regarding the interactive traffic, you can see the results of a half delay in the following figure (Figure 25). This delay would also weighted average value of each delay by the percentage of total traffic that each RAT race.

Again, the results are similar VG_IND and VG_VU and kept in appropriate values to the QoS required by IND_VG while the results are not as good, but keep in tolerable levels.This deterioration is due to UTRAN is taking 50% of indoor users, which greatly reduces throughput by interactive traffic, causing delays in this RAT grow.

These same results hold if the total load of voice traffic is 200 or 600 users. The only differences are that with a low voice traffic load, the average delay for interactive traffic IND_VG is at the same level as the other two policies, with a high load of 600 users of BLER sees this type VG_VU traffic also increases, providing the best results VG_IND.However, it is important to note that a very high load of voice traffic (600 total users in this case) VG_VU policy is forced to divert 5% of voice traffic to UTRAN, where they race with a BLER very high value close to 6%, a value not acceptable for a network that guarantees QoS.

Next, Table 5 shows the results of total throughput for each of the 3 complex political burden for all 3 cases of simulated voice traffic. Color indicates the maximum value.

Seen, for small loads (200 voice users), the results are very similar except IND_VG offering underperformed.This is due to low loads of voice, other policies studied all this traffic for GERAN and UTRAN all traffic to www, while IND_VG transmits approximately 50% of traffic to www GERAN, network throughput can not provide for this type of traffic as high as it offers UTRAN.These results are lower IND_VG to note that the size www traffic load increases, because it will also increase the number of users of this service transmitting to GERAN with a throughput less than they would have in UTRAN.

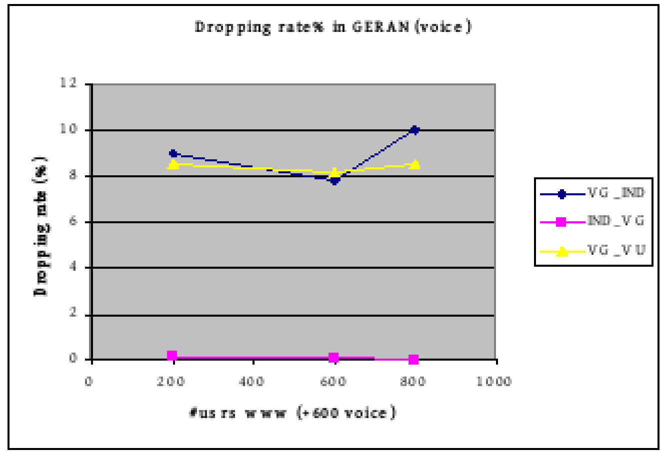

Fig. 26. Voice call drop rate (50% indoor)

However, when the load is increased, the policy offers superior performance IND_VG other.This is especially difernncia with few users www throughput due to the already mentioned reduction caused when users are served through GERAN www. In addition, this policy is more distributed load, taking in this case, approximately 50% of total traffic for each network, while for example VG_IND served approximately 99% of voice traffic for GERAN.The use of both high rise droppings in GERAN calls, as shown in Figure 26.

Table 6 shows the same results for total throughput in the case of a low percentage of people in indoor setting (10%).

Comparing this table with Table 5 we can see the results are very similar, so we think that the environment in which we and the current parameters of the system, the percentage of users in a very not affect indoor significant results in terms of throughput. However observed some differences.

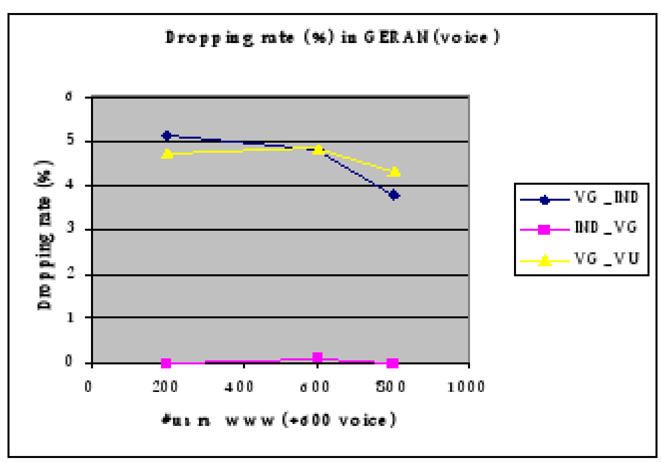

Fig. 27. Voice call drop rate (10% indoor)

For a low voice traffic load, all policies offer simi-

50% indoor		VG*IND		IND*VG		VG*VU	
voice users	www users	UL	DL	UL	DL	UL	DL
200	200	0.85	0.88	0.84	0.87	0.83	0.87
	600	1.24	1.33	1.14	1.23	1.19	1.29
	1000	1.58	1.73	1.51	1.66	1.61	1.75
400	200	1.50	1.55	1.48	1.52	1.48	1,52
	600	1.87	1.97	1.81	1.91	1.87	1.97
	1000	2.24	2.40	2.17	2.32	2.24	2.41
600	200	1.92	1.96	2.12	2.17	1.96	2.02
	600	2.30	2.39	2.50	2.61	2.35	2.46
	1000	2.49	2.61	2.63	2.75	2.51	2.66

TABLE 5
Total Throughput (Mbps) with different loads of voice traffic and www (50% indoor)

10% indoor		VG*IND		IND*VG		VG*VU	
voice users	www users	UL	DL	UL	DL	UL	DL
200	200	0.86	0.90	0.84	0.87	0.84	0.87
	600	1.25	1.33	1.23	1.31	1.24	1.34
	1000	1.61	1.74	1.60	1.72	1.61	1.76
400	200	1.53	1.56	1.47	1.50	1.52	1,56
	600	1.88	1.98	1.85	1.93	1.85	1.94
	1000	2.25	2.40	2.24	2.37	2.26	2.41
600	200	1.95	2.00	2.15	2.17	1.96	2.00
	600	2.32	2.42	2.46	2.63	2.34	2.44
	1000	2.52	2.64	2.65	2.73	2.56	2.68

TABLE 6
Total Throughput (Mbps) with different loads of voice traffic and www (10% indoor)

lar results, getting better throughput with policies and VG_IND VG_VU But unlike when we had 50% of indoor users, without the improvement on either IND_VG too remarkable.This is because in this situation, to implement the strategy IND_VG is only 10% of the traffic is www GERAN race track with a lower throughput.On the other hand, if the load is increased a lot, up to 600 users, we have better results with policy IND_VG, like when we had a 50% indoor users.The difference is still very large and small loads of traffic www IND_VG droppings still presenting a rate close to 0 while other policies have many drops calls because all cargo diverted to voice GERAN.This effect is shown in Figure 27.

Figure 28 shows the results for the same scenario with 10% of users indoors when the number of users of fixed voice is 400 and the number of users varies between 200 and 1000 www.

It repeats the same situation before. VG_IND VG_VU offer strategies and results over IND_VG, staying below the desired values.In the case of IND_VG once again to deflect the fact all users to GERAN indoor triggers the BLER is located slightly above the expected value.Moreover, in this case the BLER for UTRAN also is above the expected value because almost all users are taking the stage for the RAT.

Thus, in this case the load is distributed to all policy

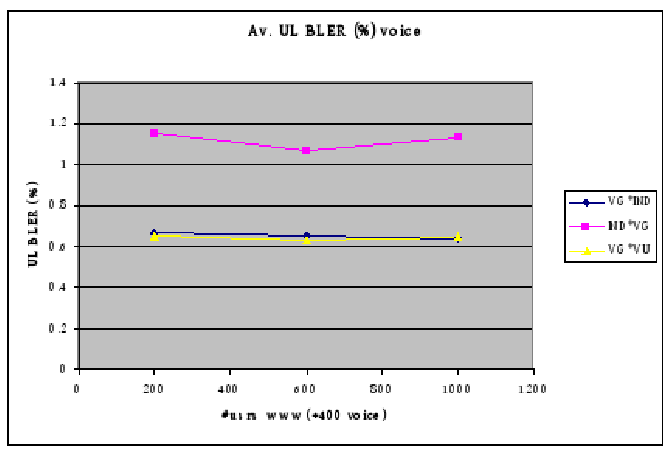

Fig. 28. Average UL BLER (voice) (10% indoor)

shortly. By having a low percentage of indoor users, the policy does not offer IND_VG results we would expect, and instead diverts much voice traffic to UTRAN (which is indoor), yet also a lot of traffic to www UTRAN.This causes UTRAN cheesy, in this case, 90% of the voice traffic and 92% interactive. This leads to two problems. The first and most obvious is that you are wasting a lot GERAN network, and the second is that, although the outdoor users being UTRAN supports the charge that these transfers represent, we run the risk of saturating with UTRAN Load factor too high, offering very poor quality and finish to many users.

Regarding traffic www, Figure 29 shows the results for the delay medium. Observed as in this case, a small number of users have indoor, interactive traffic race with about the same quality for all policies. Basically because the three strategies for almost all of this type of traffic is taken by UTRAN offering a lower delays if transmitted by GERAN.

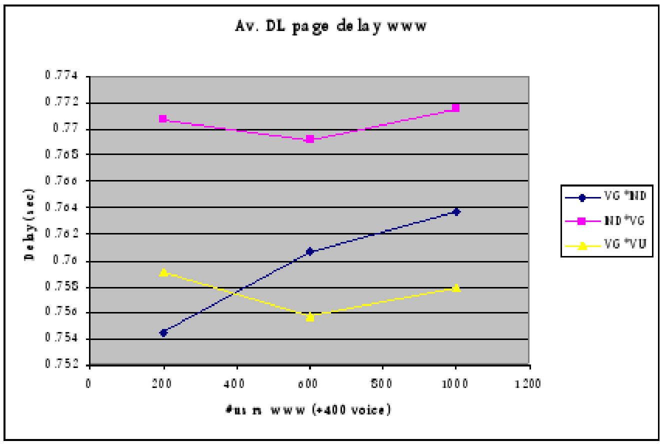

Fig. 29. Average delay (www) (10% indoor)

The results for different loads of voice traffic, from 200 to 800 users, are very similar to those already shown.In all cases VG_IND VG_VU and offer very good quality for voice traffic, reaching a level even lower than desired.Moreover, the strategy presents a IND_VG BLER than but close to the desired value. Regarding the interactive traffic reaches a similar quality for all strategies.

Entering the economic term, Table 7 present the total income of the operator depending on the type of service. We remind that these revenues have been calculated by applying a static pricing strategy with voice traffic charging 0.05 Euros per minute and 2 Euros per MB charging by traffic www. Coloration also the largest value.

The first thing you can see is how to obtain the maximum revenue always the policy that offers more benefits to traffic www. Because these benefits are directly proportional to the traffic throughput, before analyzing the results in detail since it can be assumed, and in fact can be seen in the table noted that the policy IND_VG will probably give you less profit. Thus, as demonstrated by the results, policies that provide greater benefits are those that divert traffic preferably interactive UTRAN. The policy conveys IND_VG part of this traffic to GERAN, specifically a percentage equal to the percentage of indoor users.As mentioned above, the traffic transmitted by www GERAN presents delays and higher throughput is achieved with less than UTRAN, and this causes the decrease in revenue.

The decline in profit is increasing in size with increasing number of users of voice traffic. If you have many users of this type of traffic, the current strategy preferentially diverted toward GERAN, where he held a number of slots. This will result in greatly reduced the number of slots available for data www, causing an even greater reduction of throughput.

The other two strategies, and VG_IND VG_VU show very similar results, although they are slightly higher than VG_IND. Table 8 presents the same results when we have 50% of indoor users. In principle, the behavior should vary little, while reducing benefits IND_VG should be more pronounced in this case because approximately 50% of the traffic will go to www GERAN.

In this case the results are very similar, but the negative effects to GERAN face because of all the traffic study indoor become more apparent as this is an environment with 50% of users like this.So revenues are slightly lower than VG_IND had a low percentage of indoor users, and this means that in some cases achieve higher profits with VG_VU.

Moreover, as mentioned by the study results throughput when the load grows much voice-based policies that divert traffic to GERAN droppings have a high rate, which leads to lower throughput and a decrease benefits.

Www scenario with variable voice load and fixed www load

Following analysis environments with a low percentage of indoor users (10%) now see the results of the simulated scenario with 600 users and a number of fixed www users voice that varies between 200 and 800.

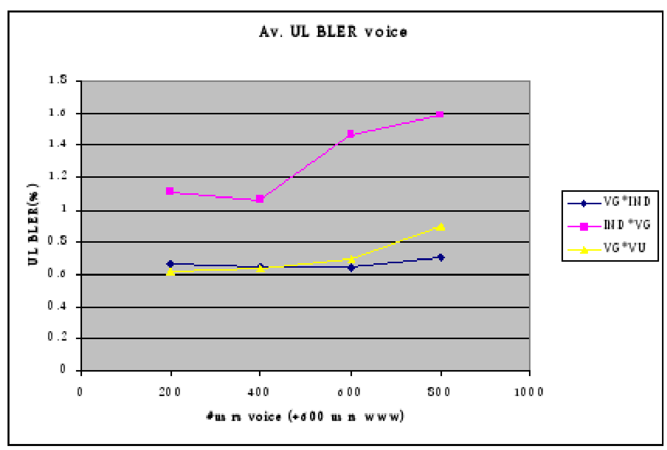

Fig. 30. UL BLER half (voice) (10% indoor)

Figure 30 shows the quality offered by each strategy for voice traffic in this scenario. Is repeated once more inferior quality policy IND_VG that, although present results very close to the desired value, works with a BLER than the other two strategies. Moreover, it seems that, as the load increases, the policy is that VG_IND presents better results. Regarding the traffic once more interactive, with most outdoor users, the delay means

Euros/min		IND*VG			VG*IND			VG*VU		
Voice	www	Voice	www	Total	Voice	www	Total	Voice	www	Total
	200	2.77	49.49	52.26	2.31	47.29	49.60	2.67	48.86	51.54
200	600	2.80	147.26	150.05	2.38	143.12	145.50	2.76	147.99	150.75
	1000	2.71	243.83	2.46.54	2.32	239.33	241.65	2.73	245.75	248.48
	200	5.51	49.23	54.74	5.33	48.13	53.46	5.49	48.87	54.36
400	600	5.40	148.25	153.65	5.34	143.77	149.10	5.32	147.76	153.07
	1000	5.27	248.21	253.48	5.38	241.32	246.71	5.45	247.16	252.61
	200	7.28	49.53	56.80	6.95	46.95	53.91	6.66	48.36	55.02
600	600	7.22	147.04	154.26	7.06	139.61	146.67	6.81	146.45	153.25
	1000	7.19	198.82	206.01	7.10	183.85	190.95	6.71	197.72	204.43

TABLE 7
Total Revenues (/ min) for different loads of voice traffic and www (10% indoor)

Euros/min		IND*VG			VG*IND			VG*VU		
Voice	www	Voice	www	Total	Voice	www	Total	Voice	www	Total
	200	2.39	49.01	51.40	2.31	44.16	46.47	2.31	49.04	51.36
200	600	2.43	144.23	146.66	2.32	130.41	132.73	2.36	146.42	148.77
	1000	2.34	245.84	248.17	2.32	218.59	220.91	2.30	243.45	245.76
	200	4.76	48.95	53.71	4.70	44.69	49.39	4.72	48.76	53.48
400	600	4.70	145.03	149.73	4.69	131.24	135.94	4.72	145.73	150.45
	1000	4.62	244.41	249.03	4.65	217.50	222.15	4.68	244.08	248.76
	200	6.71	49.15	55.86	7.04	43.50	50.54	6.73	48.68	55.41
600	600	6.67	146.30	152.96	7.15	130.76	137.91	6.75	144.31	151.06
	1000	6.53	194.10	200.62	6.99	173.94	180.93	6.93	195.67	202.61

TABLE 8
Total Revenues (/ min) for different loads of voice traffic and www (50% indoor)

for all policies is very similar and appropriate value, although IND_VG is slightly higher ent. This effect can be seen in Figure 31.

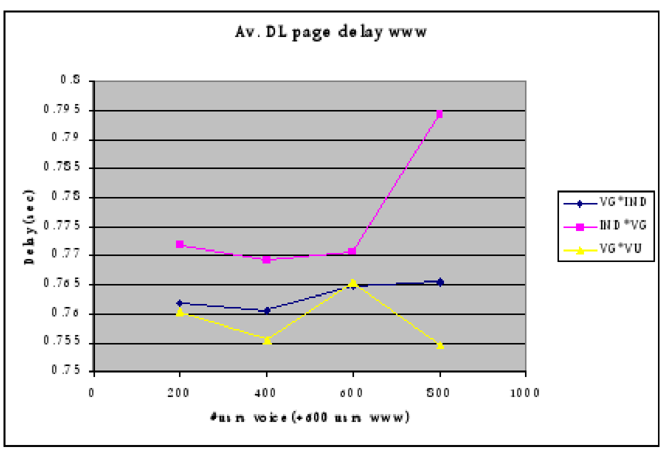

Fig. 31. Average delay (www) (10% indoor)

It is important to mention that in this scenario, to apply the policy VG_VU with a high load of users of voice traffic (800 users) get to take 12% of the traffic for UTRAN, which equates to about 100 traffic users of BLER with more than twice the desired value. So, working with this strategy, many users are transmitting a lot less than the desired QoS.

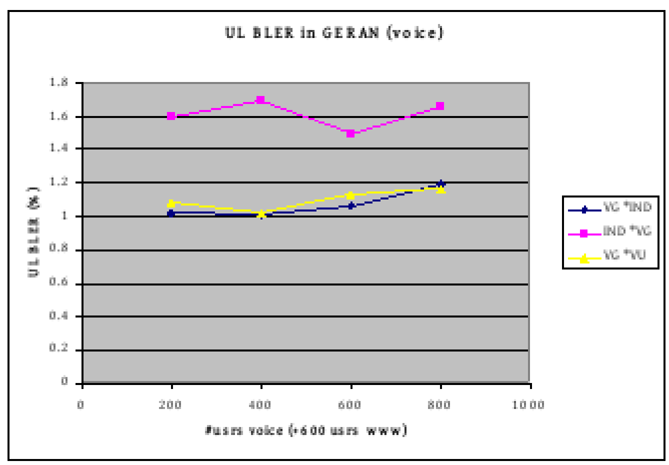

Fig. 32. UL BLER in GERAN (voice) (50% indoor)

Increasing the percentage of people indoors to a value of 50%, the results are quite similar, but generally worse. The policy IND_VG continued transmitting voice traffic with a BLER slightly above the desired value by the deteriorating we always divert all traffic to indoor GERAN. Furthermore, as shown in Figure 32, in such an environment with many users turf, the other two policies also have a BLER for voice traffic through GERAN slightly higher than desired. Users often have indoor losses very high, resulting in some cases in GERAN received power is not enough to guarantee a proper BLER. This force, on average, the BLER for voice traffic over the network worse. This effect is especially noticeable always turn all the indoor users to GERAN.

The voice traffic is transmitted through UTRAN with better quality. The policy has a BLER IND_VG tight around 1%, while the other two strategies do not transmit voice traffic in UTRAN to very high loads.VG_IND run approximately 2% of the total traffic of voice tight with a BLER desired value, while, once again, the voice traffic transmitted through UTRAN (up to 9% of the total) has a very BLER discharge of up to 6%, not acceptable for a network.

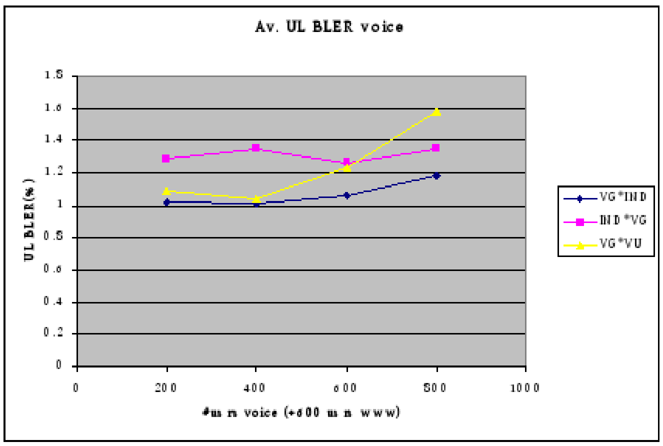

Fig. 33. Average UL BLER (voice) (50% indoor)

Thus, the average BLER for voice traffic is as shown in Figure 33.The trend of IND_VG transmit a BLER slightly higher than desired, but in this case the other two policies also have undesirable results above, an increase of BLER as they load up.In the case of VG_VU quality diminishes rapidly with high loads due to 9% of total traffic with QoS unacceptable completed.

Regarding the interactive traffic, the results show that the delay means and strategies VG_IND VG_VU still showing good results, whereas in this case the delay for interactive traffic IND_VG policy is greater when working with only 10% of indoor users.This is logical because it repeats the same thing happened before. In the case of this policy, a percentage of traffic is diverted towards GERAN interactive equivalent to the percentage of indoor users. Thus, half the traffic is www race to GERAN with lower throughput and higher delay. The results for average delay is presented in Figure 34.

Table 9 shows the results for the total throughput in this scenario. You can see how we repeat the same pattern as the results of the previous scenario, in which the number of users of voice was fixed. Thus, the policy has a throughput IND_VG lower low voice traffic loads, while for loads of this traffic presents results far superior

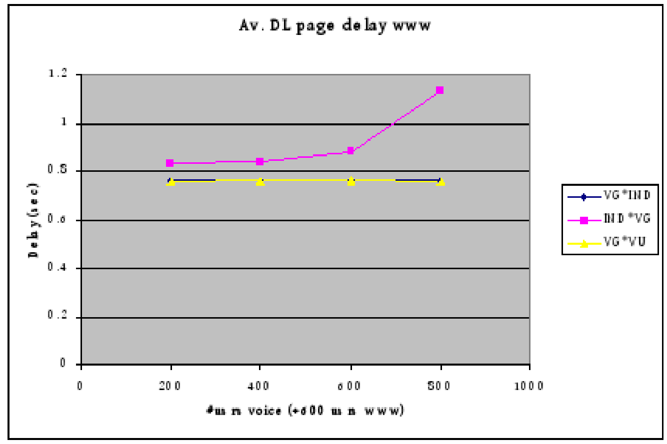

Fig. 34. Average delay (www) (50% indoor)

to other strategies.

With few users voice traffic policy IND_VG is transmitting part interactive traffic through GERAN. Specifically GERAN is transmitting to anyone www traffic coming from indoor users. As mentioned above this type of traffic transmitted by GERAN has a higher delay and lower throughput. Thus, the difference between IND_VG and the other two strategies is particularly high percentages of indoor traffic, because it means a greater amount of transmissions for GERAN www.

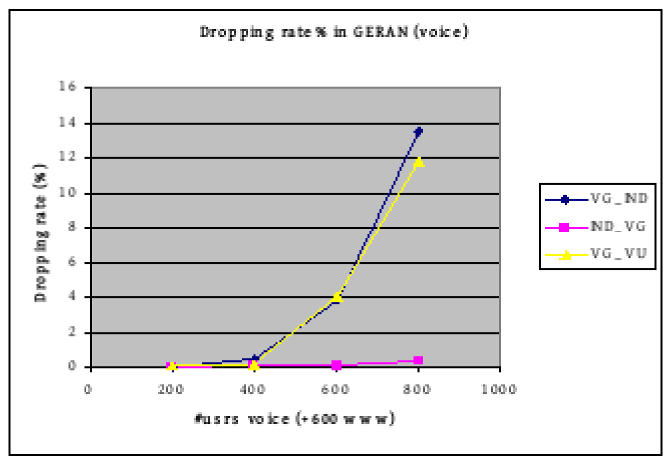

Fig. 35. Percentage of dropped calls in GERAN (50% indoor)

On the other hand, when the load of voice traffic grows much are the other two policies that have problems.IND_VG still taking part in GERAN www traffic resulting in a lower throughput, but VG_IND VG_VU and present a throughput much lower than the first.These two strategies almost all calls diverted to GERAN. This represents an excessive load on the network which again caused a large number of droppings. In Figure 35 shows the evolution of the rate of droppings in the three strategies.

Let us now analyze the re sults of total profit of the

600 users www		*IND*VG		VG*IND		VG*VU	
.% indoor	Voice users	UL	DL	UL	DL	UL	DL
10	200	1.25	1.33	1.23	1.31	1.24	1.34
	400	1.88	1.98	1.85	1.93	1.85	1.94
	600	2.31	2.42	2.46	2.53	2.34	2.44
	800	2.63	2.73	3.01	3.01	2.71	2.81
50	200	1.14	1.24	1.06	1.15	1.14	1.22
	400	1.69	1.80	1.63	1.73	1.69	1.80
	600	2.17	2.28	2.22	2.33	2.19	2.29
	800	2.41	2.53	2.76	2.87	2.54	2.65

TABLE 9
Throughput for different percentages of total indoor users

operator for this scenario. The trend seen in the previous scenario indicates that the benefits will be greater with some of the strategies that deflect calls for mostly GERAN.

Table 10 shows the results for the total profits of the operator e.We will see how this trend repeats have higher incomes policies in interactive traffic transmitted UTRAN. In this case, working with 50% of users turf, which will be completed by IND_VG GERAN, the throughput decreases in traffic www much and this causes the decrease of total revenues great.

Checking a similar trend in the evolution of the income percentage values for both indoor users.To see loads of high IND _VG generates revenues well above the other two policies, which in these conditions show a very high rate of droppings, which, as seen in Table 4.9, the throughput decreases for such traffic.However, charges for voice low to obtain the maximum revenue VG_IND.

Regarding the interactive traffic in general IND_VG is presented worse results, because much of the traffic transmitted by GERAN, through which it does so with a lower throughput. When the load is increased, GERAN is saturated and very few slots available to transmit data www, which makes dismiuci income for this type of traffic is very clear to over 400 users voice.

Finally, comment out the two common scenarios analyzed, it should be noted that even offer the best results in terms of BLER and income in all cases, strategies and VG_IND VG_VU have a major weakness.To forward all calls to GERAN, considering the capacity of the network in number of slots for GERAN is what gives the scene with 7 cells and 3 carriers in each cell reach the limit this capacity. So when charging about voice traffic is over 400 users, GERAN is saturated and has a very high rate of droppings and unacceptable network QoS. An example of this is shown in Figure 36. This problem, however, be solved by applying the vertical handover function.

The capacity limit for GERAN can be approximated based on the number of cells, number of carriers and the rate and duration of calls. It's a simple approach based on the assumption that all users can connect to any database from any stage. Thus, omnidirectional 7 cells with 3 carrier capacity is:

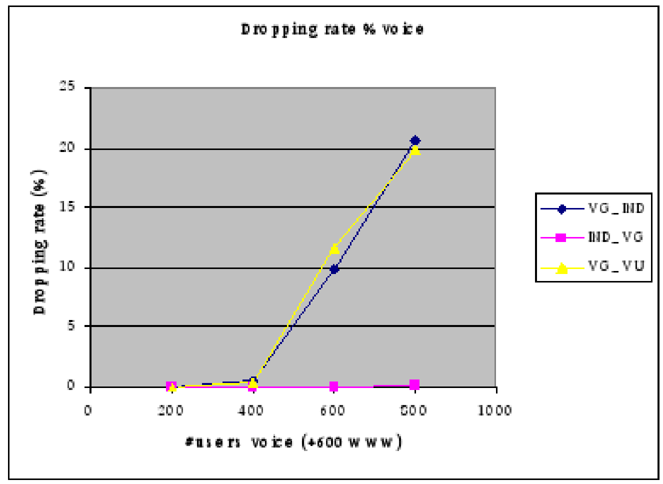

Fig. 36. Percentage of dropped calls in GERAN (10% indoor)

$$((3carriers/1cell)\cdot(8slots/1carrier)-1)\cdot 7cells = 161 \quad (6)$$

Because we have 10 calls per hour, equivalent to a call every 6 minutes, and the average duration of calls is 3 minutes, the activity factor is 0.5. So we have two users.

$$161\cdot\frac{10calls}{1h}\cdot\frac{3min}{1call} = 322users \quad (7)$$

4.2.4 Analysis of results for larger cells

We pass now to analyze the behavior and the results you have with different strategies Initial RAT Selection in environments with the size of the larger cells, in particular with a radius of 1km.

Analyze the results in some of the scenarios that have been covered by the case of cells within 500 meters.In this new study places us in environments with large propagation losses, which negatively affect both RATs. In GERAN cause some users do not receive the minimum power required to guarantee a certain BLER value, which will cause deterioration in quality.This effect will increase especially if users turn indoors, usually those

Euros/min	(600 downloads www)	IND*VG			VG*IND			VG*VU		
% indoor	Voice users	Voice	www	Total	Voice	www	Total	Voice	www	Total
10	200	2.80	147.26	150.05	2.75	145.81	148.56	2.76	147.99	150.75
	400	5.40	148.25	153.65	5.34	143.77	149.10	5.32	144.91	150.23
	600	7.22	147.04	154.26	8.12	132.21	140.33	7.34	146.31	153.65
	800	8.48	149.14	157.62	10.71	115.00	125.71	8.85	146.91	155.77
50	200	2.43	144.23	146.66	2.69	129.06	131.75	2.36	146.42	148.77
	400	4.70	145.03	149.73	5.40	132.41	137.81	4.67	147.31	151.97
	600	6.67	146.30	152.96	8.31	130.65	138.96	6.75	144.31	151.06
	800	7.66	146.61	154.27	10.84	127.90	138.74	8.22	145.28	153.50

TABLE 10
Total Revenues (Euros / min) for 600 users www different loads and voice traffic

with larger losses, to GERAN. With an increase in the percentage of indoor users, followed by GERAN will increase the likelihood of users who receive less than the minimum power to guarantee the desired BLER.On the other hand, UTRAN, the losses so high, users will be forced to pass a very high power. This will increase the interferents present in the network and the quality diminishes greatly.

This section seeks to analyze what order the reduction of both QoS RATs, in which the two most noticeable effects of these environments and high losses if a policy is more resistant to this trend of decline quality.

Although equivalent scenarios analyzed, the number of users approximately scaled by the same factor that has increased the radius of the cells. These scenarios set in motion reached up to 1400 users across multiple services at once. The results obtained with many users it could draw any conclusions regarding the behavior of different policies, but the result is very poor QoS.Thus, to achieve a minimally acceptable quality that will provide correct results and conclusions as to simulate maximum is 700/800 concurrent users.

Because the results for all policies are generally deficient environments such as large losses, some results are displayed as a general overview.

Basic policies (IND VG VU)

First consider the scenario with 30% of indoor users, and each user sees. Comparing the results of the policy with a policy RND IND in terms of BLER in the uplink direction.

Figure 37 and Figure 38 show how the same effect continues IND reduction policy by users of BLER for UTRAN who, being a very large reduction (from 8% to 15% approximately) RND towards politics.It also continues a worsening of the quality traffic that GERAN race, but in this case the drop is very large and is more important than the improvement that traffic to UTRAN.

It is verified and is not useful to work with this strategy in an environment of heavy losses. It is evident that users draw from GERAN indoor interference present in very low network, but users who are far removed from the base are forced to pass on a great power, which

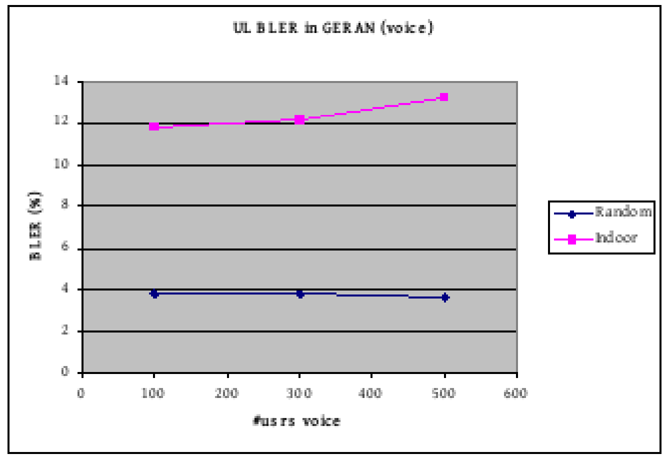

Fig. 37. UL BLER in UTRAN (voice)

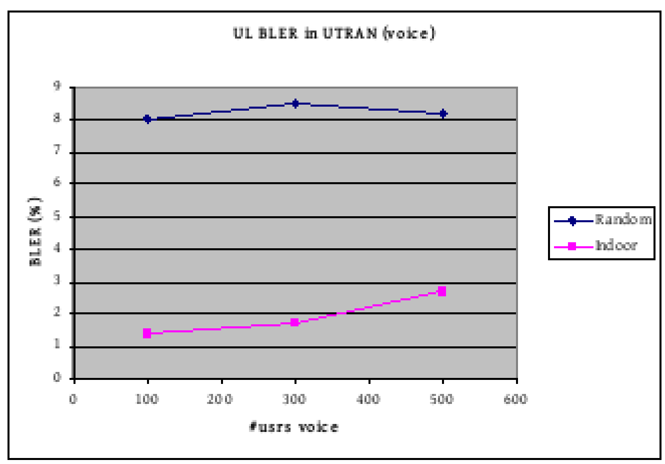

Fig. 38. UL BLER in GERAN (voice)

causes the resulting BLER get even to triple the desired value.On the other hand, GERAN, during all other users will be more indoor far away from the bases, there are many users who do not receive the minimum power to ensure the desired BLER, which means the quality is very poor .

The scenario for comparing the results of policy IND with the policies and VU VG is different.In this case it is a multi-stage, in which we have 200 users still www. In addition to these users, we also have between 100 and 500 users voice. Of these users, 10% are indoor.

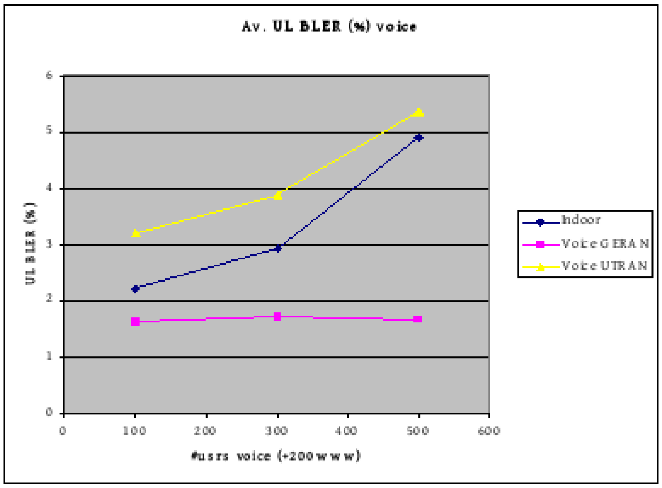

Fig. 39. Average UL BLER (voice) (10% indoor)

In Figure 39 shows the results for the average BLER, in the case of VG corresponds to the actual BLER for GERAN and in the case of VU corresponds to the UTRAN.The strategy of diverting users to GERAN voice traffic shows that better results are still very close to the desired value, while working in a large loss. Moreover, with respect to interactive traffic, delays are small circles obtained, having the best quality policy also VG.

Complex policies

To analyze the results of simulating complex political behavior in a scenario with 300 users www and a variable number of users of voice traffic.

For a percentage of users or large indoor half results are very poor, with unacceptable BLERS more than 5%. Thus, the only acceptable results in a network QoS are those obtained when there is a low percentage, but remain above the desired values. Figure 40 shows the average BLER in UPLINK traffic generated by the users voice.Seen how, as occurs when the radius is 500 meters, will have the best quality with the policy VG_IND, although BLER remains above the desired value.The other two strategies give a poor quality.

In all results for environments such as large losses, is a constant IND_VG provide very poor results. The strategy of diverting users to GERAN indoor loses its usefulness. The problem is that there are a large number of users with very large losses, and many of them are indoors more, and this causes many users to transmit GERAN not receive enough power to guarantee a BLER adequate. In addition, users transmitting through UTRAN also have large losses and are forced to transmit more power, generating more interferon, which reduces the QoS in the network.

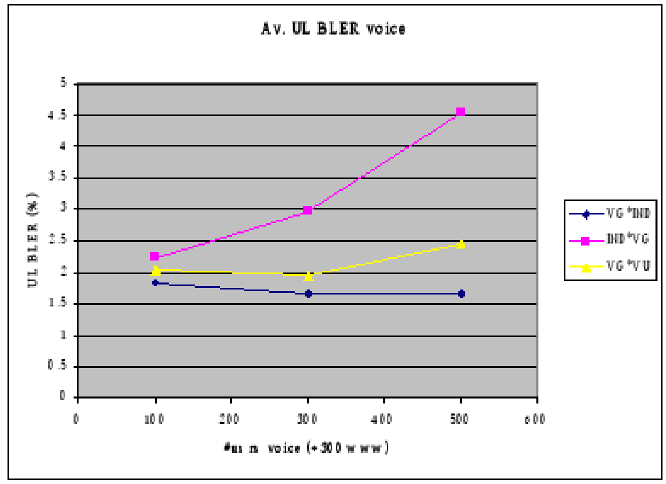

Fig. 40. Average UL BLER (voice) (10% indoor)

Thus, it is advisable to work in environments like this. But in the case that the operator sees forced to work with cells of 1 km radius should be in sparsely populated and with few indoor users.Regarding the selection of RAT, there should be a policy to divert traffic preferably interactive users to UTRAN, ie VG or VG_IND.

4.2.5 Analysis of results with users onlyGERAN

Since this parameter is intended to give more realistic results by simulating an initial application environment of heterogeneous networks in which there are still a large number of mobile terminals unable to make a connection through the UTRAN and that Therefore, there is no point function Initial RAT Selection. We perform simulations in environments with cell radius of 500 meters.

If you look such a high percentage of users, 50% in this case, a large number of transmissions should be made mandatory for GERAN. In scenarios with low percentages of users will not notice much effect turf by having users onlyGERAN basically because the situation is equivalent to approximately 50% of indoor users always apply in the case of policy-based strategies IND.

An example of this is shown in Figure 41. Presents the results for earnings policy VG_IND on stage and already tested with 400 users and fixed voice traffic between 200 and 1000 users traffic www. Specifically presents the difference between the income obtained without users onlyGERAN and we get with 50% of these users for both indoor curl percentage of users.Clearly shows the difference between having and not having onlyGERAN users is much higher when we're in a scene with a large percentage of indoor users.

This worsening in the case of being in an environment with a high percentage of indoor users is also observed in Figure 42. The decrease in revenue is due to a decrease in throughput for interactive traffic, which in turn is due to a growth delay for this type of traffic. Having a high percentage of indoor users and a high percentage of users onlyGERAN many users www indoor traffic

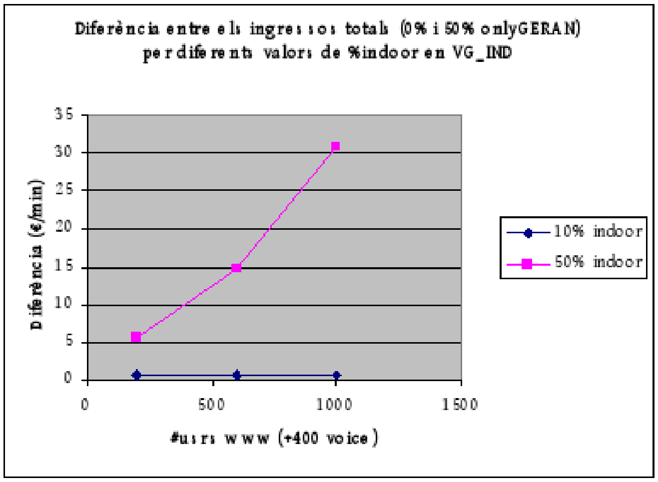

Fig. 41. Euros/min (0% onlyGERAN) - Euros/min (50% onlyGERAN) for two values of % indoor (VG_IND)

transmitted over GERAN and they grow much in half the delay.

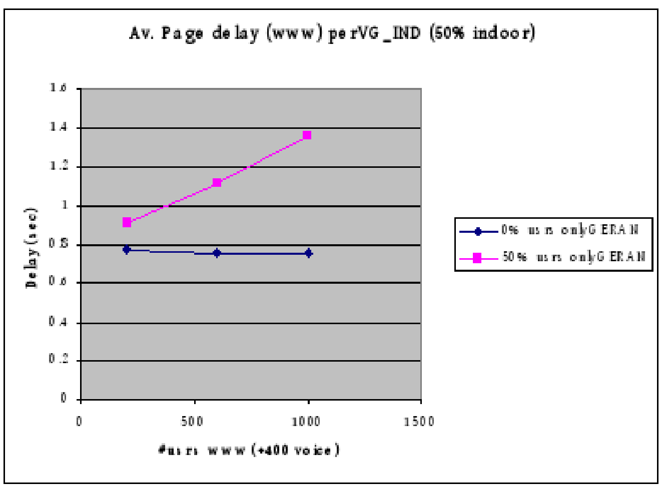

Fig. 42. Deterioration of the average delay with 50% of onlyGERAN users (VG_IND)

Clearly this is worse when a large number of users with a mobile unable to connect through UTRAN. However, aquestsa decrease in QoS is not too big in either case, and presents results that are not acceptable in a network QoS.

Thus, analyzing the political presence of users with VG_IND onlyGERAN, reducing income and quality come mainly for two reasons.Www mainly because many users are taken to be optimal when GERAN to UTRAN divert them, and also in the case of indoor high percentages of users, many of them are like this. Moreover, for high loads GERAN must take onlyGERAN all users and all users who are not but are of voice traffic. This will grow much load on the network, thus increasing the average delay for interactive traffic.

4.2.6 Conclusions

In this chapter we have defined the different possible strategies to perform the function of Initial RAT Selection in heterogeneous networks consisting GERAN and UMTS. Once defined behavior have been analyzed under different perspectives, especially the quality of service offered and the income you get the operator, as mentioned above, was sold at the equivalent point of QoS view of the operator.

Through simulations have attempted to study the performance and results of the different strategies in different environments by analyzing the results based on the number of users, the percentage of which are indoor, the size of the cells, etc. The aim is to define policies and strategies best suited for each type of environment.

In defining the different policies has distinguished between basic and complex political policies. Analysis of the results shows that it is more useful to work with complex political, mainly because it combines the virtues of the basic policies and because it allows a second attempt to connect to the RAT alternative in some cases.

It has been demonstrated both indoor divert users to GERAN and UTRAN interactive broadcast traffic offer very good results.

In [21] studied the degradation in the ability of W-CDMA network traffic caused by indoor. It is this fact which motivates the strategy of diverting this traffic rather than for GERAN UTRAN. In all cases, this technique provides a very significant improvement in QoS UTRAN, which presents values of the desired BLER tight.Furthermore, although the indoor divert traffic towards GERAN causes a slight increase in the average BLER of the RAT, this increase is less than the improvement in UTRAN and BLER is kept at levels adjusted target value (1%).

The characteristics of the network itself, GERAN capability is limited and inadequate for interactive traffic. In the case of UTRAN obtains a higher throughput through the use of DCH channels, while traffic to www completed GERAN is subject to the scheduling algorithm. This motivates an effective interactive traffic transmitted UTRAN. And that is precisely what the policy VG presents results slightly above strategy to divert traffic to indoor GERAN.However, when the voice load increases much higher throughput is achieved with IND, because from about 400 users GERAN voice traffic is saturated and has a high rate of droppings.

These results suggest that it will be useful to use a policy that combines both strategies. Thus, we may assume that IND_VG VG_IND or give the best results when reviewing the results for complex policies.And indeed it is, VG_IND always offers superior results to other strategies too high loads of voice traffic.

All three complexes provide good QoS policies for voice traffic. IND_VG always works with an average BLER for both RATs slightly higher than desired, but a value very close.On the other hand, not too high values of the load of voice traffic, and VG_IND VG_VU always offer a quality adjusted to the desired value, showing VG_IND slightly better in terms of QoS. Regarding the throughput is also VG_IND strategy that usually results presented above, also charges low / medium voice traffic.

If the scenario presents a large number of users of voice traffic, the burden of this type of traffic grows greatly and policies based on GERAN to divert this traffic presents some shortcomings. So, from approximately 400 users (in the case of scenario analysis and simulation of the current settings) access network GERAN does not have enough capacity to transmit all active calls and the rate of growth droppings to values above 10%. In this situation IND_VG achieves a higher total throughput.

The quality for interactive traffic is generally very similar for the three strategies to medium loads and low percentages of users indoors. However, the policy generates a delay of more than IND_VG, which becomes more evident as we increase the percentage of people indoors, a situation that increases the number of people passing through GERAN www.As mentioned above, the interactive traffic that is transmitted through GERAN do with a lower throughput and delays greater.

The behavior of the total throughput is equivalent to the QoS commented so far.Thus, policies that divert traffic in the first instance by www UTRAN results presented above, showing slightly better VG_IND policy.However, when the load grows very voice becomes IND_VG what works best.

In the case of analyzing environments of large losses, with the radius of 1 km cells, the results are usually very poor in terms of QoS. The results indicate that, in the event that the operator works with both large cells, should be in areas with low density of users and very few indoor users. In this case, the desired results are obtained with tighter policies that divert traffic interactive UTRAN, no longer useful in this context the fact that large losses indoor divert users to GERAN.

We have analyzed the functioning of the political side benefit of the operator, studying the behavior of total revenues in the network. For this study we applied a strategy to nzilla of static pricing with a fixed price of 0.05 for calls minute and a fixed price of 2 Euros per Mb for traffic www.The results are equivalent to the throughput.

The policy generated higher incomes is always more that enters dine rs for interactive traffic. Thus, the throughput decreases the effects of this traffic will affect much in total revenue. Thus, strategies to divert part of the traffic to www GERAN, which offers a throughput lower than UTRAN, generate lower profits.

For voice traffic loads low maximum benefits are achieved with VG_IND or VG_VU but to raise much cargo maximum benefits are clearly VG_IND.However, high traffic loads both voice and VG_IND VG_VU have a very high rate of droppings IND_VG generates much higher profits for the calls.

Thus, it is clear that the policy best suited for all situations is VG_IND offering better QoS, throughput and better benefits.However, if the load voice grows much above about 300/400 users in total, you will need to opt for politics IND_VG.This will, giving the maximum benefits and working with traffic www BLER slightly above the desired voice traffic, avoid dropping calls rates exceeding 10% in some cases go up to 20%. The delay for interactive traffic will increase slightly, but a network that guarantees QoS can not afford to work with rates as high as dropping pieces and VG_IND VG_VU under these conditions.

Finally, as a last comment, the analysis of the results obtained in the presence of a high percentage of users onlyGERAN shows a slight deterioration in QoS, especially noticeable when working in an environment with many indoor transmissions, at no time values are presented on a network QoS.

5 Initial RAT selection policies based on path loss

5.1 Motivation

So far it has been studying the role of Initial RAT Selection policy-based and once analyzed these policies has come to some conclusions as to the suitability divert traffic UTRAN interactive indoor or divert users to GERAN low loads. The analysis sought to find policies which are most appropriate and offer a superior QoS on different types of scenario. Thus, through multiple simulations have been studying different scenarios. One of the most representative of each stage is the size of the cells, inidcat via radio. And observing the behavior of different policies regarding the value of the radius where it has taken the following conclusion.

When analyzing the results of scenarios with a radius of 500 meters was verified the usefulness of diverting traffic preferably indoors to GERAN.Well preserved in UTRAN take the traffic generated by users of this type, which usually have large propagation losses, and therefore, need to transmit much power. This would cause an undesirable increase in the load factor and a decrease in UTRAN QoS in the network.However, the results were not always optimal. On the other hand, in environments with a cell size of very large losses for all users were very elevated and achieved good results by any policy, including those based on IND.In the above case GERAN could bear the burden of indoor users, but in this case the propagation losses in a scenario of cells within 1000 meters are great.Thus, users have indoor large losses, to which must be added the additional losses due to being indoor users. These losses penetration in the case of the simulations performed to date have $k_{indoor} = 20dB$. This causes the received power in GERAN is not enough to guarantee a minimum QoS.

To conclude the study and analysis of existing policies noted the possibility of ”smoothing” policy or modify indoor. That is, to divert traffic indoor GERAN but only up to a point, to avoid a worsening of the GERAN QoS because all connections to take indoor many users do not get the minimum power to guarantee a minimum BLER.On the other hand consider a very important fact. The indoor part of a political base that is easily implemented in a real application of a mobile communication system. In the simulation you can have all the settings for each user, even if it is an indoor or outdoor connection. In a real application would be difficult to know the nature of any user indoor and should be done through assessments or other methods such as the use of maps, GPS and so on. However, in a mobile communication system is periodically different measures of power, for example through the network UTRAN CPICH (Common Pilot Channel). This way we know the propagation losses have each user at all times.

From these bases we thought of designing new policies Initial RAT Selection, on the one hand ease the operation of policy IND and moreover exploit the fact of having information propagation losses of each user.

Initially, the motivation of these new policies only as part of the policy improvement IND to make it usable in a real system, where we do not have information on the indoor nature of each user.However, these policies are also intended to try to improve the results of existing policy.

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Work in progress. The rest of this section and the following sections still have to be formatted.

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5.2 Policies based on the path loss

5.3 Analysis of the policies based on the path loss

5.4 Conclusions

Having studied and analyzed the results of new policies based on propagation losses can be assessed it fulfills the objectives proposed. As mentioned initially, these new policies are developed primarily for a purpose, an application equivalent to IND policy more easily implementable in a real network.Thus, new policies should offer similar performance are based on the nature of indoor users, but on the other hand there is also the aim of, from politics smooth turf, to improve the results .

From simulations in different scenarios are the results in terms of QoS for new policies. Observing these results can be seen as, in general, algorithms based on the path loss results provide similar or even better based on the nature of indoor users. So, without thoroughly analyzing simulation results can be considered as these policies are appropriate and fulfilling their role implementable planning application in a real network. Thus, the complex political and policy LP_THR derived, and LP_THR_VG VG_LP_THR can be considered versions implementable in a real network policies IND.This may not make sense from now or continue making simulations student policies based on the nature of indoor users, while still applying toalment valid and useful principle, indoor divert users to GERAN UTRAN to preserve high levels of interference ..

In addition, it was found also in all cases based policies provide the path loss results slightly higher than those based on the nature of indoor users. So, especially voice traffic, achieved BLER lower levels when working under any of the algorithms based on propagation losses. In general, the improvement is very small, but in the case of working with cells within 1000 meters where, propagation losses were very large, and the effects more noticeable results divert users with a path loss superior to GERAN.However, as was the policy IND, applying policy LP_THR a scenario of loss so great, despite the improvement in BLER over IND, the QoS with which you work is not acceptable.

When set the threshold path loss, we opted for a strategy to distribute the total traffic between the two possible equivalent forms RATs, ie, both GERAN and UTRAN attend approximately 50% of total traffic, regardless of the type of service. This strategy has some drawbacks in practice, not much impact on the results but should be noted. To taking 50% of the traffic to www GERAN causes the delay means for this kind of traffic increase slightly. Thus, the results in half the delay interactive traffic are slightly higher with the complex political and policy LP_THR based on it, unless we have a high percentage of people indoors too.However, the value of the delay is kept in a very correct, always very similar to the results offered by other policies.

This suggests that it might be useful to set two thresholds for path loss, thus differentiating the two types of service. This will set the threshold for voice traffic tends to divert more traffic to GERAN and the threshold for www traffic tends to divert more traffic to UTRAN, but overall divert 50% of the load to each RAT. However, this possibility is not taken into account because they modify the algorithm so simply give priority to voice traffic for GERAN and UTRAN interactive traffic, which is precisely what makes it political VG and this application would tend much to the results we have with politics VG_LP_THR.

The results of analyzing complex policies based on the path loss compared to the existing results are similar to those already mentioned. It is interesting to note that the policy VG_LP_THR offers almost identical performance VG_IND policy, especially in the case of the environments within cells 1000 meters.With regard to other policies in general LP_THR_VG improves the results of its equivalent IND_VG, although as mentioned, with respect to interactive traffic has slightly inferior results, although incorrect.

In terms of throughput and revenue should also note a slight superiority of policies based on path loss, although, again, the fact that 50% of the traffic diverted to GERAN interactive causes in some cases a slight decline in total throughput this traffic and, therefore, a decrease in total revenue.

In summary, we can say that the new policies designed to meet targets for implemented. In particular, new algorithms offer the same performance as the existing based on the nature of indoor users, but offer the possibility to be implemented in a real network, it would be difficult to implement in a system that would determine whether a user is indoors or outdoor. On the other hand, the new policies provide results superior to existing policies.

6 INITIAL RAT SELECTION BASED ON PRICING

6.1 Motivation

Within the present project to study the CRRM, and more specifically the role of Initial RAT Selection, the analysis focused on the Policy-Based Initial RAT Selection, Selection policy-based Initial RAT . Thus, we have studied several existing policies and their performance in different scenarios and with respect to various parameters. At the same time new policies are designed based on the path loss as they get submitted an application feasible and implementable in a real network, replacing existing policies so far are based on the nature of indoor users.

The assessment of the performance and the results of these policies have been through different QoS parameters, such as may be the BLER for voice traffic.Meanwhile, following the idea and started the chapter on pricing in QoS networks, has added a new variable to analyze and evaluate the behavior of different policies, total revenues for the operator. Basically, a technique has been applied static pricing with a fixed price both for voice traffic as interactive, while not set any utility function by users that transmit traffic that have to be predefined whatever the price.

Thus, a possible next step in these studies would be both uni studies so far, and noted any chance of selection of RAT based pricing. And this is precisely the study in this section.

A theoretical study on the pricing, there are two possible applications of pricing, static pricing and dynamic pricing.Although it has been shown that they can achieve the same results with an application of optimal static pricing, if you want to perform specific applications need to follow a strategy of dynamic pricing.Thus, in this case the price we had earlier defined to calculate the total income of the operator will not be fixed. We define a time interval that mark the moments when the price vary both GERAN and UTRAN and all types of traffic. This interval is called CRRM_int. Although further analyzed, because we can imagine that this interval can not be too large because the network can react quickly to load changes, but it may be too small to allow changes that might result in the changes in the price behavior of users is effective until the next time instant in the net prices vary. When applying for initial RAT selection prices vary with a period similar to the duration of the call, so the effect of the price goes into effect the next call.

Regarding the users defined on the price behavior that marks its utility function. In this case, were working on a heterogeneous network consisting of UTRAN and GERAN, it is very useful and almost essential to apply ideas pointing Paschalidis replacement service in [7], although in this case we speak of a ”network Substitute ”. In this case, it is clear that somehow or another that modeling is an access network, UTRAN for example, may substitute for the other, GERAN, in the case of the latter has a price than the first. That is, if a user wants to make a phone call and would in principle through GERAN, if the tariff per minute of this network is very high and UTRAN is cheaper, or even just If that pricing is cheaper to UTRAN probably choose to transmit through UTRAN.

As a first simple application of RAT selection based pricing model the utility of a simple user as described in section 6.3. Thus the user behavior on the price is always so easy to convey what they want to RAT through tariffs with a lower price at the time of initiating the transmission.This pricing, as mentioned above, will vary each certain time and it will load as averaged for each RAT, the burden always keep looking around a threshold set initially. Thus, if the load is too high a RAT will increase the price of transmitting the network, prompting users to initiate connections to the other RAT.

In future studies could model a more complex user utility based RAT also choose cheaper, but also modifying their pattern of traffic generation depending on the price.This could vary the duration of such calls, the rate of generation of connections and the average number of pages viewed during a session based on the current price www to the network, thus shaping a utility function very more complex.

It then goes on to describe the pricing strategy adopted, the utility model by users and finally describes and discusses the first simple algorithm Initial RAT Selection based pricing.

It is important to mention that this study should not be regarded neither as current prices are transmitted to the network users. It is assumed that any individual user knows the price for both GERAN and UTRAN at all times. In addition it is assumed also that the price variations do not affect calls in progress. Thus when a call that is tarifica entirely with the price that was in effect at the time of startup.

6.2 Pricing strategy

6.3 Utility model

6.4 BASIC_PRICING policy

6.5 Simulation parameters

6.6 Analysis of results

6.7 New model combining a pricing strategy and LP_THR

6.8 Conclusions

This chapter has tried to finish from both sides to share theoretical analyzed so far. On the one hand there has been a theoretical and analytical functions CRRM in heterogeneous networks, focusing specifically on the role of initial RAT selection, analyzing the strategies and policies defined for this function and develop new. In addition, we investigated the applications and theoretical analysis CRRM strategies based on current pricing and charging networks.

Thus, in this final chapter we have tried to merge the two concepts and a model has been designed for easy implementation of pricing depending on the initial RAT selection.

Basically, we designed a simple pricing strategy that considers the aim of realizing a function of load balancing the two networks are heterogeneous networks study. Set a price for each separate service RAT, along with maximum and minimum for this price, we define a time interval (CRRM_int) that marks the moment when the updated price. Being intervals of the order of the length of calls, ie minutes, we have a mixed pricing strategy, which while not completely static pricing can not be considered fully dynamic pricing.

Later on improving the initial model for better results achieved pricing model which, being totally transparent for the user to work with values lower than CRRM_int achieve better results and higher revenues.

During these time intervals is performed by averaging the load in each RAT. Once that is done by adjusting the prices of two possible patterns, depending on whether you use pricing strategy A or B. The price is updated, which set a threshold load for each RAT, RAT that increases the price at which the load exceeds the threshold, while the price is reduced if the load is below the threshold .

Furthermore, we define a new policy of selection of RAT based on this simple charging network, named BASIC_PRICING.It works by simply choosing the RAT price is lower.In case the price is the same for both access networks, the selection is done in a equiprobable, as regards the policy RND.This ensures that the user always pay the lowest price possible.

The strategy of pricing policy and new selection of RAT applied jointly obtain a useful model. The network tends to divert users to the cheapest network, which in general will always have a lower load and can accept new connections. Moreover, when a RAT supports a load increase its price too high, so that users tend to leave the RAT alternative, avoiding the saturation of the first and guaranteeing balance the load and good QoS.

So far the operation has been detailed theoretical strategy. Once verified to work through simulations shows that the pricing strategy B gets a good load balancing in stationary regime. At this point, prices stabilized around that we had to apply the static pricing strategy, finding ourselves in half on the price, with a behavior very close to when prices unchanged.This helps the user to easily accept this new way of tarify service as fluctuations in the price will always be minimal and, moreover, will always pay the lowest price.

In terms of QoS, the new strategy offers a good BLER for voice traffic, comparable to LP_THR policy.However, the fact divert all users to a single RAT at certain time intervals leads to a drastic reduction in total throughput across both networks. Two RATs are saturated for any value of CRRM_int and attend traffic far below that race with LP_THR.This causes saturation often can not accept calls and work with a very high rate of droppings.

Moreover, the total revenue is highly dependent on the operator's throughput, ie the calls taken. A high rate of droppings which reduces significantly the total throughput causes a decrease obviously compared to other revenue strategies. Moreover, some results may not be considered income for very high loads because it has very high values unreal. This is because, as already mentioned, that the model is unstable, the price goes nonstop, and there has been little throughput, revenue rise much. These findings are significant because of price instability combined with simple utility model leads to a situation where users do the same number of calls although the price is high.

Thus, as can be seen how the new pricing strategy applied to the selection of RAT was working as designed, but it still shows the desired results in terms of QoS and income.

To improve the negative results that have been designing a new model based on the previously analyzed. On one hand it creates a new pricing model that we call C. Pricing In this case we set two thresholds that define the loading areas too high or too low. It is in these areas where they will act like they did with strategy B. Pricing For intermediate values of load price is set to the value used in the static pricing strategy of the previous sections.

The selection of RAT can also be done very easily. For intermediate values used to load LP_THR policy, but in any situation where at least one of the two RATs are in a situation of unwanted burden, the selection is done as it was done with politics BASIC_PRICING.Forwarding the call to the network that offers a lower price. This will create a new policy called LP_THR_PRICING.

The operation of this new model is also characterized by keeping the load stable and controlled, avoiding situations of saturation or misuse of networks. It also checks the model is completely transparent to the user. Thus, although the price varies from different RATs to control the load, the price paid by the user remains almost constant, as if working with a classical static pricing strategy.

If we analyze the results obtained by simulating this new model we find many improvements. On one hand, the BLER for voice traffic is still good, comparable to LP_THR, and even improves the values that we had with the pricing strategy B.On the other hand achieve throughput values much higher than we had with other pricing strategies. The total throughput is larger as it decreases the value of CRRM_int. It also substantially reduces the rate of droppings, which reaches down to 6% compared to that had worked with B. Pricing Although the rate is still higher than the droppings of LP_THR, values are low.

Finally, the new model achieved revenues that were clearly superior to the other models. These revenues, in the same way that the throughput, as you grow CRRM_int value decreases, reaching values comparable to LP_THR.

It was found that decreasing the value of CRRM_int significantly, the results follow the trend of improving the policy itself LP_THR, although the rate is still higher loads droppings very high and reaching revenues of approximately equivalent to this policy.However it is shown that the value of CRRM_int is a key parameter for the operation of this model, because it diminished very greatly improve the results, but the model operation is still completely transparent to the user.

7 Summary and conclusions

This project has conducted a study on two related fields CRRM strategies. Mainly focused on the study and analysis of multiple concepts and strategies related to one of the main functions of CRRM in heterogeneous networks, the initial RAT selection.

However, the project is also a theoretical approach to the study of new waves most recent and interesting at the same time on radio resource management, heterogeneous networks but not just any network, pricing. In this theoretical study of new strategies aimed at charging for network management and network resource allocation, it also presents the state of the art in such applications today.

Afterwards an analytical study of the function of the Initial RAT Selection for CRRM in heterogeneous networks. Through simulation, results are obtained for the behavior of different strategies Initial RAT Selection presented in [1] for different types of scenario. The analyzed results are basically the QoS in terms of BLER for voice traffic and delay by a half page www traffic, the total revenue and total througput.Through the study of the behavior of these policies depending on the size of the cells, the percentage of indoor users, the number of users of each service and other parameters is to determine which strategies are most appropriate for each type of scenario.

For this study we draw the following conclusions:

- The network works on a GERAN QoS which decreases rapidly with the number of users running interactive traffic, primarily due to the high number of appeals in this case slots, this type of traffic.Moreover, the UTRAN network presents very good results with this kind of traffic. So much better results if you tend to divert traffic towards UTRAN and interactive, so voice traffic to GERAN.
- Indoor users that transmit power than ever, produce a strong degradation in QoS for UTRAN, as studied in [21].Thus, it is useful mainly to divert traffic to indoor GERAN, achieving and major improvements in QoS. However, in environments with large propagation loss is still useful to divert all traffic to indoor GERAN.
- Regarding the complex political, formed from combining different basic policy, strategy VG_IND always offers superior results in both throughput and QoS as total revenue.
- However, when the number of users of voice traffic is large, longer useful transmit all traffic such as this for GERAN access network is saturated and provides results far below the QoS and a very high rate of droppings.That's why, with voice traffic loads, it is useful to apply the strategy to maintain QoS IND_VG correct, but wish to give a slightly higher throughput and revenue.
- Any strategy in a given situation divert a significant amount of traffic to GERAN interactive suffered an important reduction of total throughput and revenue.

Once the study has been designed new strategies Initial RAT Selection based propagation losses. The main motivation of these new policies is an alternative easy implementation strategies based on the basic policy IND.It also aims to soften from the selection of RAT whether or not the user is indoor, improve the results in all aspects of existing policies.

A study equivalent to the above with these new policies are to determine appropriate strategies for each environment, but this time also to compare them with the existing ones. The results are as follows:

- The policy has LP_THR proper operation deviating GERAN connections to users who have large propagation losses, usually corresponding to users off the bases, and studying for UTRAN transmissions of users with little loss.Also correctly handles situations very close to indoor user base, therefore, have a loss too great and can be transmitted by UTRAN.
- The strategy presents LP_THR results superior to IND in QoS, total throughput and revenue.
- The policies derived from complex LP_THR (LP_THR_VG and VG_LP_THR) present results superior to equivalent policies based on QoS for both IND throughput and as the total revenues.
- The best results were obtained VG_IND

VG_LP_THR and with the same limitations as VG_IND have been analyzed in the previous study.

Furthermore, this study and to extend the Initial RAT Selection and make other contributions, this project is designed in a simple theoretical model of pricing designed to perform this function CRRM.This new model is applied in practical heterogeneous network through simulations and its performance is studied and the results obtained. In this case the aim is to achieve a model that balances the load between the two rats through an initial RAT selection based pricing. It also aims to achieve results suitable for QoS and maximize revenue.

First design a simple model that achieves the expected results, as the model is redesigned to achieve improve performance. Thus, the final design is based on the following parameters:

- The pricing strategy used in the final model, Pricing C, is launching prices independently each RAT as follows.In case the load exceeds a threshold maximum load, the price increases, while if the load falls below a threshold minimum load, the price decreases. Always keep the load between these two thresholds the price is fixed at an average value which is in a static pricing strategy.The price change takes place each time interval called CRRM_int.
- The selection of RAT is done as follows.If the price is the same for both rats Selection LP_THR policy is applied, while if there are different prices is transmitted through the network with a lower price. This enables divert new connections in the network is saturated or send new connections to the network is transmitting very little load.

In this strategy and to analyze the results through simulations gotten the following results:

- The performance of the model is expected to serve as a load balancer avoiding situations of saturation.
- The pricing strategy is transparent to the user, although prices vary independently in each RAT is always paying the same price you would pay, for example, a model with time-of-day pricing.
- Results are achieved by enhancing the correct QoS policy LP_THR.
- The results for throughput and total revenues are lower than with LP_THR but increased significantly as they CRRM_int decreases, reaching values comparable to LP_THR when this interval decreases to 20 seconds.
- The results improve very CRRM_int size decreases, but at the same time that the interval size is small, the model remains completely transparent to the user.This indicates that this will be a key parameter to tune the model.

So, combining the two branches analyzed theoretical project is designed to model initial RAT selection based pricing which presents good results, but should be explored further as to adjust them to achieve a better level higher income. The critical parameter is the value of the model CRRM_int, which depend on income and inversely proportional model transparency to the user.

Regarding the study of political Initial RAT Selection, this study is still incomplete and could be extended by applying the vertical handover functionality not present in the simulator used here.

It's about this proposed future research.

7.1 Future lines of work

As discussed in section 6.8, the pricing model applied to the selection of initial RAT initially designed for heterogeneous networks is simple. However, all targets have been met in terms of performance and behavior strategy. Applying policy PATH_LOSS_PRICING combining first policy designed, BASIC_PRICING with LP_THR strategy, load balance is achieved between GERAN and UTRAN from C pricing strategy, which forces users to initiate calls through network that supports a lower load in the case of load situations very high or very low.

The behavior of the system in steady state is desired, adjusting in half a static pricing model and appearing completely transparent to the user. This allows the user to accept a model as unusual to him as this in which the price of a call is always changing.

However, how the system can be adjusted or defined. There exists a clear improvement in results as it decreases the value of CRRM_int. However, if this parameter was reduced, the price variations occur before we can have a clear effect on users because the price varies several times before that there is a new connection. This destabilizes the system and its operation causes longer completely transparent to the user. Thus, using this parameter can further refine the behavior of the strategy and the results.

Moreover, the results obtained with the new model designed in a scenario without users mono-service indoor traffic. However, the system is designed to work well for users with presence of interactive traffic, the same strategy is applied independently to the price of this traffic www. Thus, it would be interesting to conduct a study equivalent of Chapter 4 to define the behavior of the strategy Initial RAT Selection based pricing based on different parameters and different types of scenarios.

It would also be interesting to extend the utility model of users. To work with more realistic simulations would be to apply some basic utility model proposed by authors or any new design, from which user behavior vary by price, so that, for example, high prices the user does not directly convey information or chooses not to transmit. This should be seen as influences on operator revenues, because in a real application and user behavior would be.

Finally, focusing on CRRM functions, the study of the selection of initial RAT should be extended.Analysis of this function might be different if done in conjunction with Vertical IT function. In the simulations performed in this project, Vertical IT function has not been implemented, so you should see the behavior of different policies working together with this second function of CRRM.

You can develop new strategies that attempt to minimize the number of handovers between rats during the call, although it will be important to first analyze how they react and existing policies proposed in this project with the ability to perform this function during the call.

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