NIESIM: A Simulation-based Application for Estimating the Value of Information in Mobile Network Management

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Abstract

In this paper we introduce NIESIM (Network Information Economics SIMulation), a software for simulating a mobile communications scenario and studying the value of information in the context of mobile network management.

The modelling principles and the simulation strategy used to design and develop NIESIM software are introduced, along with simulation results. We consider an application of NIESIM to support the definition of the grade of service in a network that is exposed to failures. An exploratory discussion of the findings and their implications to future work is also presented.

Keywords: Telecommunications, Mobile Networks Management, Value of Information, Simulation

JEL Classification: C63, D81, L96

1. Introduction

In a period in which market players make huge competitive efforts, operators need to achieve excellence and optimise customer experience, in order to retain the existing customer base and maximise its value.

The relationship and interdependencies between service quality, perceived value and customer satisfaction in the context of telecommunication services are well documented in the academic and technical literature. Those dimensions are frequently used in models seeking to understand customer behaviour, which is a critical issue in highly competitive telecommunications contexts. This topic might be presented as post-purchase intention of customers (Kuo, Wu, & Deng, 2009), post-purchase behaviour of customers (Tam, 2004), behavioural intentions of the customer (Wang, Lo, & Yang, 2004) or customer loyalty (Edward, George, & Sarkar, 2010), but the underlying relations between Quality of Service (QoS) and perceived value or customer satisfaction are always in the same direction: QoS is reported as influencing positively the perceived value, thus the enhancement of service quality should be part of any strategy aiming to influence customer behaviour. This implicitly means the reinforcement of business relations and an increase in value capture (from the provider's perspective).

Network management activities are the instruments that telecommunications providers possess in order to ensure service availability and to manage QoS and the related, user centric, concept of Quality of Experience (QoE), at an operational level. In the end, the network management challenge is to ensure an efficient use of network resources (current and future) while maintaining a satisfied customer base. Recent research in the area of QoE has demonstrated that QoS mechanisms may need to be complemented with more user-centric approaches in order to truly meet end-user requirements and expectations (Baraković & Skorin-Kapov, 2013). Regardless of the methods and models used (Baraković and Skorin-Kapov report that no universal objective quality assessment approach exists), activities such as QoS and QoE measuring, monitoring, control and optimization are information intensive activities and their main challenges can be summarized in questions such as: what to collect?, and where, when, and how to collect data? These questions shall be complemented with optimization-oriented ones: what to improve?, and where, when and how to improve QoE? Altogether, those questions impose tremendous challenges on network management functions.

Recent trends in the industry may suggest that infrastructure-related activities are getting behind in the rush for value capture, in comparison with value-added services provided by companies that do not own nor operate network infrastructures (Herrera-González, 2014). Since networks are not dispensable elements in these business models, one should expect higher pressures on network management functions in order to deliver complete, coherent, and vertical service offerings under integrated technical and economic optimal conditions, as anticipated by Pras et al. (2007) and confirmed by subsequent industry reports (Alcatel-Lucent, 2009) and academic research (Shayani, Mas Machuca, & Jager, 2010).

Information management and decision support systems evolved towards the production of data with an unprecedented scale, velocity and diversity (Big Data is the buzzword these days), creating new challenges concerning the best ways to use collected data in a profitable way. This is particularly the case in the mobile telecommunications industry, where increasingly complex systems generate a continuously growing number of state and performance signals that network managers struggle to collect and interpret in order to achieve optimal performance of the network infrastructure.

Modelling the costs of network management mechanisms is part of the research trends identified by Pras et al. (2007) and information management activities are certainly an important part of those costs. Practitioners face a tough scenario on a daily basis: how do you manage increasingly complex infrastructures, providing a higher QoS along with flat (if not diminishing) resources? Actually, the network management team struggles to demonstrate the return on investment on new initiatives related to information management (perhaps even to demonstrate their own contribution to the company value). The key element is to demonstrate the value of information, and thus the goal of this research project is to develop tools and methodologies that allow companies in the telecommunications industry to adopt information value as a driver to decision making in the context of massive data generation, such as the case of mobile telecommunications network management activities.

We notice that massive quantities of events occur in telecommunications networks, which means that hundreds of different performance indicators and metrics must be analysed in order to ensure a high QoS, and even more if the goal is to manage QoE, since the latter demands user-centric metrics (detailed by each individual user). Those pieces of information are costly to gather, manage and transform into actionable insights (either from a technological or from a human point of view). However, the real problem is that it is not feasible to cover all the available information in this effort because of the limited resources (economic, technical and human); it would also be highly inefficient to do so, since not every piece of information is economically worthy of such endeavour.

Thus, network management faces the need to prioritize and filter information to cope with those challenges. Value of information offers an elegant and promising path to economic optimization of those activities related to QoS and QoE. This paradigm is being successfully used, not only in the analytics field, as a way to choose the best performing models (Provost & Fawcett, 2013), but also in telecommunications engineering, where value-of-information-based approaches are being incorporated in order to prioritize and filter information, thus improving communication systems' performance (Suri et al., 2015).

Concluding, to attain an integrated technical and economic optimization of the network management activities, new paradigms are needed, such as the information value as a driver to decision making for the network monitoring activities. In more general terms, we believe information economics theories and tools, namely the information value paradigm as a guide to action, might significantly help the economic optimization expected from management network functions in the present industry landscape, and we expect to present contributions towards these ends with this research.

In this paper we put forward a simplified mobile telecommunications scenario presenting the main features of the world to be captured by our models. Our goal is to evaluate how valuable is the information used to manage the network infrastructure and how different sources and types of information might impact the value of information, from a management perspective. We believe that the information value paradigm as a guide to action might significantly help the economic optimization expected from network management functions in the present industry landscape and, with this research, we expect to present contributions towards those ends.

The remainder of the working paper proceeds as follows: Section 2 presents the mobile voice communications and the value of the information used to manage the service and Section 3 introduces the NIESIM software and the modelling principles and simulation strategy followed in the implementation of the software; Section 4 presents the results obtained using NIESIM to support decisions concerning the grade of service, including scenario description and outcomes from the simulation process such as the network performance observed and the financial performance; Section 5 concludes the paper presenting the main conclusions and future directions of the research.

2. The mobile voice communications and the value of the information used to manage the service

The goal of this section is to provide technical background for our modelling efforts in the telecommunications domain but also in the strategy to estimate the value of information used to manage that type of systems.

In the first subsection, we provide a technological background of the mobile voice communications service since this service is our reference towards the estimation of information value in the context of mobile network management. This technical briefing will be kept as simple as possible and will cover the essential elements that we consider key aspects in our subsequent effort to simulate one population using the mobile voice service.

In subsequent subsections we introduce the strategy to estimate the value of the information used to manage the telecommunications service and the performance indicators commonly used in the industry that we adopt in this research.

2.1 Mobile telecommunications – introduction to technological aspects

Advanced telecommunications services increased enormously over the last years and Long-Term Evolution (LTE)[1] is one of the recent steps in the evolution of mobile cellular systems. Previous technology specifications were designed mainly with voice services in mind, but LTE was designed primarily for high-speed data services such as multimedia upload and exchange services such as file sharing, mobile blogging, social networking, video on demand, music on demand, etc. Nevertheless, only the key elements participating in the mobile voice communications service will be addressed here.

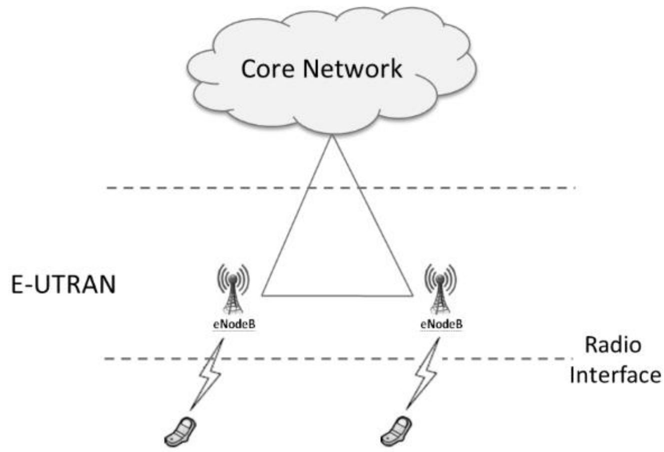

Figure 1 - Radio interface architectures of E-UTRAN in LTE (adapted from Ghosh et al., 2011)

Figure 1 presents a simplified architecture of a modern mobile telecommunications infrastructure within the LTE paradigm. The radio interface of a wireless network is the interface between the mobile terminal (user equipment) and the base station, named "eNode-B" within LTE architecture. The base station basic function is to provide radio transmitter/receiver capabilities by which the mobile terminals are connected to the core telecommunications network. Along technological changes new features and functions have been attached to these structures (base station), thus new labels have been introduced. The eNode-B, compared to previous technological paradigms, supports additional features such as radio resource control, admission control, and mobility management, which were contained in the radio network controller (RNC) in previous technological standards. This simpler structure simplifies the network

[1] LTE standard is part of the 3rd Generation Partnership Project (3GPP) Release 8 specifications. 3GPP unites [seven] telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC) and provides their members with a stable environment to produce the reports and specifications that define 3GPP technologies, covering mainly cellular telecommunications network technologies (http://www.3gpp.org/about-3gpp/about-3gpp).

operation and allows for higher throughput and lower latency over the radio interface (Ghosh et al., 2011).

Radio or mobile networks are more generally known as cellular networks when the cellular concept is used in the radio network infrastructure. In the cellular concept, a base station is transmitting and receiving a radio signal and providing service for a particular coverage area called a cell[2]. Several cells are needed to cover a wide geographical area because transmit power is typically limited due to technical challenges (Lempiäinen, 2003). One base station may be designed and equipped to cover adjacent areas, which could lead to a 360^{o} coverage using three complementary radio cells (A, B and C) as depicted in Figure 2, where we also observe the common way this paradigm is represented within planning or management activities, using hexagon shapes.

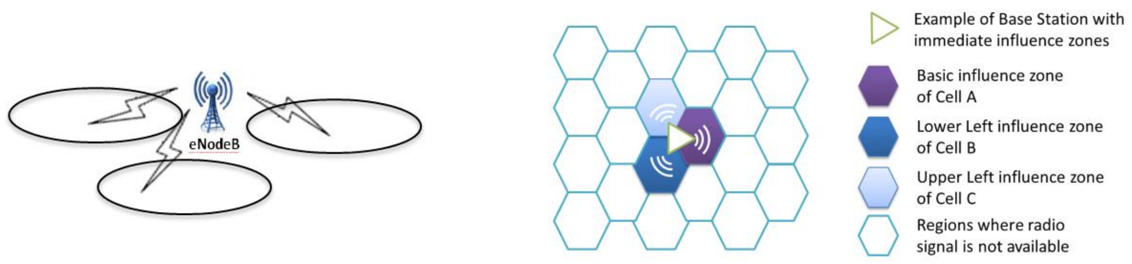

Figure 2 - Cellular concept used within mobile telecommunications industry.

The telecommunications industry witnessed a changeover from being interconnection driven to being service driven and a new discipline called telecommunications services engineering emerged along with new management paradigms. A major trend in the area of service provision has been toward dissociating service control from the underlying network equipment (Hubaux & Znaty, 2000). This technological trend is also valid from a customer perspective, since a typical user cares about the successful service being provided but he/she does not necessarily care about the technical hurdles that made the service possible. Thus, a simplified vision of the service, focused on the major steps that are necessary to a successful delivery of that service in a user's perspective, is enough for our goal of estimating information value (a management quest rather than an engineering one).

2.2 The value of the information used to manage the telecommunication's service

Following a service perspective, a typical mobile call between two users will require both users to be connected to a service provider; both users being available and willing to

[2] In United States a cell is called a sector.

establish the call; and that there are available resources to establish a communication channel between those users, ensuring proper routing of the messages they will interchange, as depicted in Figure 3. In other words, from a service perspective, the complex technological orchestration necessary to physically establish the call is reduced to a simple sequence of steps resulting in a successful service delivery.

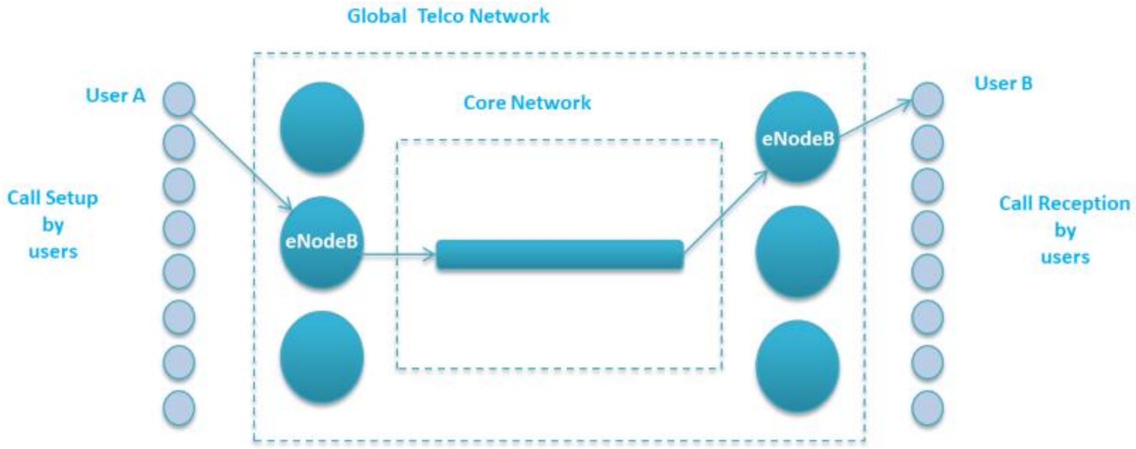

Figure 3 - Mobile call routing through the simplified mobile network architecture

We are able to estimate the value of this system (regardless of our simplified description) just by measuring the ability to successfully deliver the service, assuming that each successfully established call grants a monetary compensation for the service delivery, charged to the user initiating the call, according to certain billing rules. The value of the network is thus related to the ability to provide the service under certain quality requirements and the value of information used in the management activities can be estimated by comparing the financial performance of the system under distinct scenarios of information availability and information usage.

Under “regular” market conditions and assuming that a flat rate will be charged for the service, the value captured by the telecommunications operator, through this mobile network system, is related to the number and duration of successfully established calls by users within a certain time frame (which could also be expressed as the traffic processed by the system within that time frame).

If the system is unable to establish a certain call (service denial), the operator loses the opportunity to charge that service and thus the captured value is reduced. This direct financial impact will depend heavily on the extent and severity of “active failures” on the network, and also on the time that the network is working under those fault conditions.

The value of the network is directly related to the ability of the network to provide the service under certain quality requirements. Quality of Service (QoS) is a complex but fundamental concept to understand how users behave and is highly correlated to the price the user is willing to pay for the communications service (Oodan, Ward, & Mullee, 1997). We assume a rational behaviour by the users, which means that they only use the service if the QoS is perceived to be worth the cost of the service, otherwise they will leave the operator.

The value of information within the mobile telecommunications service is also directly related to the improvement in effectiveness and efficiency of the global system, as a result of those management activities associated with the process of network monitoring, failure detection, problem diagnosis and subsequent resolution, when based on that information.

So, in simple words, if the service provider aims to maximize profit, the network management team must achieve a certain level of QoS (enough to retain users), at the minimum cost. Since network monitoring and supervision activities are information intensive, an information value driver to decision making is the natural path towards applying management criteria on information selection, gathering and processing in order to achieve those optimization goals (along with other efforts to minimize costs and ensure QoS).

2.3 Measuring the performance of the telecommunications service provider

The financial performance of the system is measured in terms of value captured by the service provider, which corresponds to the total amount that is due by users resulting from charging the communications that each user has been able to setup. The cost for the user of each of those communications depends on the billing plan that has been agreed between the user and the service provider. Defining *n* to be the number of users, and *k*(*i*) the number of calls established by user *i*, we can write:

$$\textbf{Value Captured} = \sum_{i}^{n} \sum_{j}^{k(i)} CD_{ij} . T_{ij}$$

CD_{ij}: Call Duration of call *j* from user *i*

T_{ij}: cost per time unit of the call *j* made by user *i*, according to the applicable service rate

To compute the value captured we have to consider:

- User initiating the successful call
- Initial moment of a successful call (which is key to identify the service rate applicable to each call)

- Call duration (in seconds)
- The service rate (per second) applicable to the specific call by that user (each user have a billing plan assigned)

The technical performance of the system it is not so simple to define and calculate as the financial one. We wish to keep our analysis as simple as possible although aligned with telecommunications engineering best practices, so we have chosen the key metrics from a service perspective (Call Setup Success Rate (CSSR), Call Drop Rate (CDR), Service Availability (SA)) along with the essential metrics of any telecommunications system, i.e. traffic metrics, such as carried traffic (Ec), offered traffic (Eo), blocked traffic (Eb) and probability of blocked traffic (Pb) which are explained in subsequent paragraphs.

The Call Setup Success Rate (CSSR) metric is computed as the ratio between successful call attempts and total call attempts, within a certain time period from t_0 to t_1:

$$CSSR = \frac{\sum_{t0}^{t1} SCA_t}{\sum_{t0}^{t1} CA_t}$$

SCA_t: successful call attempts at instant *t*;

CA_t: total call attempts at instant *t*.

The Call Drop Rate (CDR) metric is defined as the ratio between the number of interrupted calls and the number of successful calls, within a certain time period from t_0 to t_1:

$$CDR = \frac{\sum_{t0}^{t1} CD_t}{\sum_{t0}^{t1} SCA_t}$$

SCA_t: successful call attempts at instant *t*;

CD_t: unexpected interrupted calls at instant *t*.

Service Availability (SA), from a system perspective, is usually computed at Cell level and is given by

$$SA = \frac{\sum_{t0}^{t1} AvCell_t}{\sum_{t0}^{t1} TCell_t}$$

$AvCell_t$: number of available cells to provide service at instant;

$TCell_t$: total number of cells (installed capacity) at instant *t*.

Now let us cover the traffic metrics, starting by introducing the Erlang which is a unit of traffic intensity: one Erlang represents one hour of line (circuit) occupancy. From a telecommunications engineering perspective the traffic that is instantaneously processed by a system or network (carried traffic – Ec) is as important as the traffic that does not get processed (blocked traffic). Blocked traffic is a denial of service which should be very unlikely to happen if one claims high QoS (and that is why we use this indicator (Pb) as the decision criteria by management team, as detailed in subsection 3.3). Actually, in the telecommunications industry, the blocking probability (Pb) is a key input for network design and planning (note that Pb is synonymous of Grade of Service – GoS – which should not be confused with QoS). Blocking probability goals, at the planning stage, are usually stated as Pb = 1% which means that during the busy hour (uninterrupted period of 60 minutes during the day when the traffic offered is maximum), 1 in 100 calls can be expected to meet blockage (Freeman, 2005).

In order to measure traffic flowing in a certain network (expressed as a certain number of Erlangs), we have to count the exact number of calls taking place at a point in time. If we take measures at each second, then the traffic in one hour between t_0 and t_1 (assuming t_1-t_0=3600 seconds) is given by:

$$One\ hour\ traffic = \frac{\sum_{t0}^{t1} AC_t}{3600}$$

AC_t: Active Call at instant t.

Thus to compute the traffic flowing in a certain network we have to gather the active calls per each of the instants of the time period aggregated at the desired granularity of the network (e.g.: core network, base station, cell).

The offered traffic (Eo) is the incoming traffic, thus it is the sum of Instantaneous traffic with Blocked traffic (Eo=Ec+Eb), whereas Blocked traffic (Eb) is the incoming traffic that could not get processed by the system (Eb=Eo-Ec). The probability of blocked traffic (Pb) can be computed using the following expression:

$$Pb = 1 - \frac{Ec}{Eo}$$

To compute the Pb at "base station" level we need to consider:

- Carried traffic (Ec) at the base station
- Blocked traffic (Eb) at the base station or the ideal alternative of directly observing the Offered traffic (Eo)

We are able to compute Ec easily, from successful calls that are registered by the system, but to compute Eo may not be so straightforward because a service provider does not necessarily get to know all the call attempts by users. Nevertheless, within NIESIM context, we compute Eo by considering that unsuccessful calls are observable.

The mobile telecommunications context is heavily contingent on the time dimension (service demand is highly correlated with human activity along the day), so performance indicators will vary accordingly along the day. The worst case situation is when the system experiences service peaks and thus the "busy hour" concept was adopted by the telco industry and is used when we wish to measure the performance of the system in generic terms. Considering the ITS[3] definition, the busy hour, in a communications system, is the sliding 60-minute period with the maximum total traffic load in a given 24-hour period[4]. Table 1 describe examples of common usage metrics that can be computed considering the busy hour period in order to characterize the system.

Concept	Description
Busy hour	One hour period of the day when processed traffic is the highest observed within that day
Busy hour traffic	Busy hour traffic (in Erlangs) is the traffic "handled" within the busy hour period which could be the blocked traffic (Eb), the carried traffic (Ec) or the offered traffic (Eo).
Busy hour Pb	Busy hour probability of blocked traffic (Pb) computed considering busy hour offered traffic and busy hour carried traffic.
Busy hour CSSR (Call Setup Success Rate)	Busy hour Call Setup Success Rate is the rate of calls that users have been able to setup successfully during the busy hour period.
Busy hour CDR (Call Drop Rate)	Busy hour Call Drop Rate is the rate of calls that users did not complete explicitly (service unexpectedly interrupted) during the busy hour period.
Busy hour Service Availability	Busy hour Service Availability is the percentage of available infrastructure (compared to installed infrastructure) during the busy hour period.

Table 1 – Examples of relevant concepts and performance indicators used by the Telecommunications Industry.

The Telecommunications industry adopts the busy hour paradigm to produce general performance metrics, thus obtaining insights on how the system performs in a highly demanding context where the risk of poor performance is higher. Nevertheless, in some situations we may wish to evaluate and analyse performance over a certain period of time, either to obtain cumulative values or to obtain periodic values, thus gaining insights on the dynamics of performance over time. In our research, all those options are used in order to maintain as much alignment to industry practices as possible.

[3] ITS - Institute for Telecommunication Sciences (https://www.its.bldrdoc.gov)

[4] https://www.its.bldrdoc.gov/fs-1037/dir-006/_0757.htm

3. Modelling the mobile voice communication context using NIESIM – high level architecture and features

In this section we introduce NIESIM (**N**etwork **I**nformation **E**conomics **SIM**ulation), a software for simulating a mobile communications scenario with the goal of studying the value of information in the context of mobile network management.

The modelling principles and the simulation strategy used to design and develop NIESIM software are briefly introduced along high level architecture. In subsequent subsections, simulation results will be presented along with the discussion of the findings for one use case. NIESIM was implemented using R[5] version 3.4.4.

3.1 Model's general assumptions

Modelling is all about capturing the core elements that define a system (regardless of its nature) and thus simplification is both a matter of necessity (to reduce complexity and be able to solve the problem) and convenience (focus on the topics that really matter). In our case, in order to grasp the value of the information used within the monitoring and operation of a mobile network system (our ultimate goal) we have to establish a common ground for modelling the service and the contexts where information can contribute to improve the service, which in our case means improving the management ability to operate the system in the most favourable conditions, and thereby improving the system's value.

At a macro level we could describe the mobile communications situation as one dynamic interaction between the service provider and a population of users, as depicted in Figure 4. The customer acquisition process is out of our scope, thus we will skip that process and consider the following reference context: customers trying to use the mobile communications service (requesting or accepting service from the network) and getting the corresponding bill charging for the services. On the provider's side, the network management team receives information on the status and performance of the network (including service failures) through network monitoring systems and might change network configurations and settings or decide to take field actions in order to correct faults or improve performance. Note that Operations Support Systems (OSS) are computer systems used by telecommunications service providers to manage their networks, whereas Business Support Systems (BSS) are the components used to manage processes aimed to run the business and the interactions with customers, for example dealing with product management, order management, revenue management and customer management. In Figure 4 we present a simplified mobile communications context that includes activities supported by OSS type of systems (network monitoring) but also by BSS type of systems (billing, customer service).

[5] https://www.r-project.org/

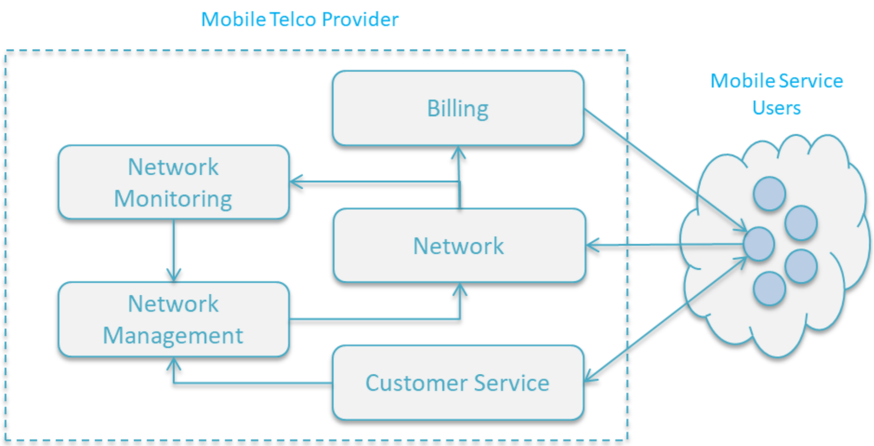

Figure 4 – Simplified mobile communication's context

In the event of service failure, customers might decide to contact the customer service, complaining about these failures. The customer service should then decide whether the issue reported by the customer was meaningful from a technical point of view and, if so, report those inputs to the network management team, thus helping detect and correct network issues.

In order to model improvements in network management resulting from information availability and information usage we have to understand why the service might fail, since some prerequisites are not under the control of the service provider and do not depend on information availability and information usage. A series of conditions have to come together in order to successfully establish the service including:

a) Agent availability
b) Service availability
c) Network resources availability

Agent availability refers to the users involved since a user A could be unable to establish a call with user B because the latter is already in a call with other user C or because the battery of the phone is exhausted, for example. Service availability is related to geographical coverage that a service provider is able achieve - even if user A takes the initiative to set up a call with user B, he could find himself unable to even initiate the process if his geographic region is out of reach from the radio coverage of the mobile network infrastructure of the service provider (of course the same applies to user B). Although service availability is the basic prerequisite to initiate the process, other factors related to the physical and technical requirements to deliver the service might block the processing of a certain call, resulting from "active failures" on the network. We use the term network resources availability as an umbrella to refer to these factors.

Even if the agents (users A and B) are able to establish the call, this might not be enough to communicate since mobile communication uses complex signal transformations that could be affected by technical problems resulting in poor quality communication channels and thus unfeasible communication between humans. Nevertheless, our effort to model the mobile communication service will not include quality problems of the communication channel itself (we assume that if a call is successfully initiated then users are able to communicate without problems). This simplification conveys significant limitations in the ability to measure QoS related parameters within our model, thus only key aspects of network performance that contribute towards QoS will be considered, such as: service availability, ability to establish the service and complete the delivery flawlessly. QoS in telecommunications is very contingent on user perceptions and expectations, thus we will also use probability of blocking traffic in our analysis since it is the closest we can get to a user perspective metric within our model.

We also assume some simplifications on the way failures take place and impact performance, and on the process of correcting failures. Failures are modelled as events that happen at a certain daily rate (the rate is calculated over the complete resources of the communication channels within the system) and at random timing. Performance indicators are computed at base station level and decisions are evaluated also at base station level. Thus, when it comes to fault correction actions, we assume that (i) any action will take place at base station level and that (ii) all active failures in a given base station will be corrected by one field action. Other aspects that are modelled in a simplified way are the decision moment, the instant when action in field takes place and the elapsed time period until resources are back in action. On the "decision moment" we assume this is taking place on an hourly basis, along with management KPI's computation. The scheduling of the field action is assumed to take place a certain fixed period after the decision if field teams are available (otherwise a rescheduling is activated). Finally, we assume that a team field will always correct the failure within a certain fixed time period.

In conclusion, at a macro level the model implemented in NIESIM is a mobile communications situation described as one dynamic interaction between the service provider and a population of users, as depicted in Figure 4. Users use the mobile communications service (requesting or accepting service from the network) and get the corresponding bill charging for the services. On the provider's side, the network management team receives information on the status and performance of the network either from user's feedback or through network monitoring systems. The management team performs periodic reviews of performance metrics and applies decision rules that might translate into actions on the network, including changes in network's characteristics and actions towards fault correction, thus improving the performance of the system The billing step, although important for financial performance metrics, does not play any role in the dynamics of the simulation. Therefore, it is handled as a post processing analysis.

For modelling purposes, a set of assumptions has been considered. Some of them were already mentioned, but we repeat them here in order to present a complete list of such assumptions:

a) The minimum period of time modelled by the system will be 1 second.
b) The duration of each call is defined by a Poisson distribution (the average is a simulation parameter, common to all groups of users and all time periods).
c) We assume that each day of the week is split into distinct periods (the default is one hour), with specific patterns of usage frequency and activity of the users.
d) In order to assign the geographical position of a user at each period of the day, we assume that people will mostly be at their work area in day periods from 8 a.m. until 6 p.m. and will mostly be at a residential area in the remaining periods of the day.
e) A global service usage pattern is defined for the global population, although this pattern is not imposed to individual users.
f) The budget of the user will be ignored (for now, it will not constitute a constraint).
g) Network infrastructure will be modelled considering that any base station is composed by three cells, each one assembled with several radio units with a certain number of communication channels (seven in our current implementation of NIESIM). Thus each base station will have a limited capacity (i.e. communication channels) of inbound and outbound requests for service.
h) The time line is segmented in hourly periods and, at each period, each user is assumed to stay within the same area. In practical terms this means the BTS serving the user is the same in each of those time periods.
i) Location changes are expected, taking into account the existence of two periods with different characteristics: a resting period and a working period. The working period goes from 8 a.m. to 6 p.m. and the resting period takes place before 8 a.m. and after 6 p.m. (these are input parameters).
j) The population scenario is built assuming N groups of people and each group has a certain probability to be in a preferential location during the working period and at another preferential location during the resting period. If a person is not in that preferential location, the model assumes he/she will be at an adjoining region, with an identical probability of being in each neighbouring region.
k) Failure events are modelled as following a predefined daily rate (this percentage refers to the total number of network channels). The time instant when those events take place is established within each day using a random variable.
l) A failure will impact one individual radio element only (which means all channels within this radio element are affected).

m) Performance indicators such as CSSR and Pb are computed at base station level and decision by management is based on that information.
n) The material impact of the decisions is to act on the system at base station level, correcting all the active faults at that base station and leading to an increase on the available communication channels. These actions are executed by teams dedicated to maintenance on site (at a specific and well-known base station).
o) A team field will always correct the failure within a certain fixed time period.

3.2 Formal description of the model of user behaviour

Here we will establish the formal grounds for the approach to model the mobile network management context, which have been translated into a computational implementation. The design principles of the approach are the following:

i. Mobile communication service's usage is modelled at individual level, meaning that users have individual and independent characteristics and behaviours (although they collectively represent a population, whose the behaviour is also modelled).
ii. Mobile communication service failures are modelled at an infrastructure level, based on the representation of each relevant component.
iii. Information flows are modelled in order to reproduce organizational and technical contexts along with constraints and business rules.
iv. The goal is to model the service usage and the role of information flows that significantly influence service usage. Thus, technical complexities of the telecommunications systems are parsimoniously modelled and only to the extent that such modelling improves the understanding of service usage (and service failure) and information flows.

3.2.1 Mobility and geographical behaviour of users

From a formal standpoint, the population of users is formed by groups of users with common characteristics which might be interpreted as distinct segments of that global population.

$\varphi = 1, 2, 3, \ldots, G$: distinct groups forming the global population;

Customer segmentation is a major concern within telecommunications industry, thus many characteristics might be considered in any population model. However, in order to keep focus and simplicity, we will incorporate only a few dimensions of user profile and characterisation:

- Mobility and geographical behaviour;
- Consumer behaviour regarding mobile communications service.

Either of the previous dimensions are highly time dependent since people usually have routines and regular habits such as going to work, having some free time, going home and staying with family or friends, and so on, which leads us to define relevant time periods when characteristics of the behaviour might be assumed stable.

$\tau = 1, 2, 3, \ldots, T$: relevant time periods for modelling purposes.

We assume that people mobility is restricted to a certain region. For modelling purposes, this region is mapped as a matrix of regular areas (a hexagon shape is assumed) with a total of L distinct locations.

$\lambda = 1, 2, 3, \ldots, L$: distinct locations that form the region where users move.

Users belonging to the same group are assumed to share characteristics and, in our case, we assume they share mobility patterns. This means that, for all the users of the same group, the probability of being in a given area λ at period τ is the same.

$$\begin{cases} \beta_{\varphi\,\tau\,\lambda} \in [0,1]\text{: Probability of a user from group } \varphi\text{, being located in area } \lambda \text{ at time period } \tau\text{, with:} \\ \forall\, \varphi, \tau :\ \sum_{\lambda} \beta_{\varphi\,\tau\,\lambda} = 1 \end{cases}$$

From a mobile telecommunications service perspective, mobility and geographical behaviour of the users is a fundamental input for any modelling effort and we have just introduced the elements needed to establish the location of any user at any instant of time: user location at instant t (which belongs to a certain time period τ) is stochastic, with a probability distribution determined by the time period and by the group the user belongs to (these probability distributions are inputs to the modelling process).

Thus, as an input to the simulation process, we must provide a population description in terms of groups and the corresponding properties, such as $\beta_{\varphi\,\tau\,\lambda}$, which will ultimately determine the location of users over time.

3.2.2 Consumer behaviour and expected usage of the telecommunications service

Beside the location of the users, the other key aspect of any mobile telecommunications service operation is the expected usage of the service, which is a matter of consumer behaviour. We recognize that individual behaviour might translate into significant variability of service usage among users, thus additional group characterization is needed to segment population according to usage patterns. The very straightforward metric we use to capture this is the number of calls that a regular user from group φ is expected to set up in the period of one day or, in more general and formal terms, the corresponding average value per each group of users.

Regardless of individual behaviour and of how that behaviour is translated into different group characterizations, there are collective patterns of service usage observed in real life that must be considered for a good modelling of a telecommunications context. These patterns were obtained from a real life service provider and used as inputs, and they consist of the number of calls per period τ that are expected from the global population of users we are modelling. Such patterns are particularly relevant for network planning and operation, since peaks of service usage may compromise user experience if the network is not properly designed to process all offered traffic.

Thus, at each instant t, a user from group φ either starts a call (1) or does not start a call (0) and, at an aggregated level, we know the average number of calls per day of a generic user from group φ as well as the total number of expected calls of the global population in the period τ. Thus, we assign calls to users using a stochastic procedure, considering some constraints. Letting *i* represent a user and *t* a time moment:

$$\begin{cases} UserCallSetup_{i}(t) \in \{0,1\}; \\ \sum_{t\in\tau,i} UserCallSetup_i(t) = \alpha_\tau, \\ \frac{\sum_{i\in\varphi} UserCallSetup_{i}(t)}{N_\varphi} = \mu_\varphi \end{cases}$$

with:

μ_φ: the average number of calls per day from a generic user from group φ;

N_φ : number of users in group φ;

α_τ: the average number of calls from all the population of users in period τ.

Combining both inputs related to consumer behaviour with respect to telecommunications service usage (population level and group level), we are able to assign each user a specific behaviour that respects the global population as a whole along with the group specific behaviour, thus attaining the goal of modelling the population of mobile telecommunications users at individual level.

3.3 Considerations on information flow modelling

As we have stated before, as far as this work is concerned, the source of value is a possible action an agent might undertake and we follow the valuation principle suggested by Birchler & Butler (2007:32), applicable to the context of information as a guide to action: “value of Information is the increase in utility an individual expects from receiving the information and from optimally reacting to it”. In the case of this work, we consider financial value instead of utility. The pay-offs from alternative courses of action, measured by the financial value, are the underlying criteria for establishing the value of information (computed comparing the system’s performance with and without a certain piece of information).

The simplified mobile communication’s context (see Figure 4) might be interpreted as a control situation in which the system under control is the network infrastructure, the controller is the network management team and the system output is the communications service (Figure 5). The management team’s goal is to operate the network assuring a certain grade of service is provided, which demands constant information gathering (internal “sensors” and feedbacks from customers) and information processing (computation of performance indicators) in order to evaluate performance and decide if actions to “adjust” the system (correct active failures at the network) are needed. The effectiveness of those actions relies on qualified information that ultimately will guide field teams on where (specific hardware location) and what should be done.

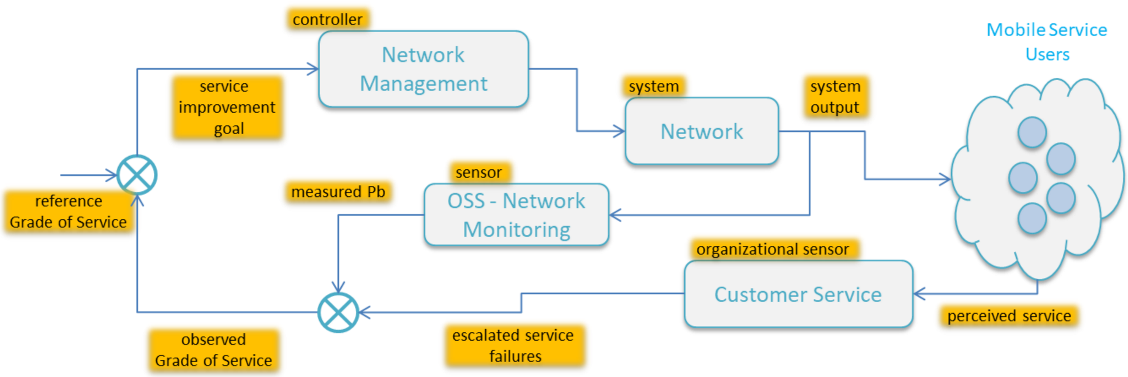

Figure 5 - The mobile communications service depicted in a control perspective.

It is important to note that there are two fundamentally distinct sources of information that are used by management teams:

(i) internal information gathered mainly by OSS type of information system and
(ii) feedback from users that inform their service provider about their experiences when using the telecommunications service, especially when they face difficulties or experience quality problems.

We could just consider the internal type of feedbacks (OSS systems), but the human type feedbacks are a fundamental element in this process since the perception of QoS by the end users is highly relevant and will influence their decision to use the service (ultimately the profitability of the service provider operation depends on the customer decision). Therefore, NIESIM was designed to cope with both information flows, although in the example presented in this working paper only the internal information scenario will be considered.

3.4 NIESIM modelling goals and the simulation strategy

From a simulation perspective, we will have entities that interact during the process of a mobile communications service in a certain time period. Individual users (from multiple locations) establish interactions with the network through call setup initiatives and the network responds (under certain conditions, which depend on network resources available at each time for each location) by establishing the call. Information comes to play when network failures produce service denial (along with revenue loss) and subsequently either by internal sources or from customer's feedback, management can decide to take action in order to assure that the grade of service is compliant with the business goals (in telecommunication's industry these goals may be attached to regulatory requirements).

In order to evaluate which simulation strategy is the most suited to our context, we shall characterize our system with respect to time and state behaviour. As far as our goals are concerned, we just need to know if a certain person, at a given moment, was able to establish a call. Thus, the state of the service (in a sense, the main variable of the global system) may only assume on/off values at the user level, and we can reduce and simplify other aspects of the model following the same paradigm (for example, network usage and availability). This means that we can use a discrete-state model. From a time perspective, although people live in a continuous time mode, our simulation will still be close to the reality if we consider that calls only happen in discrete moments (we will consider the second as the minimum time interval), since even the billing of the service considers discrete moments. Therefore, our model shall be a discrete-state and discrete-time model.

On the other hand, we wish to simulate the population that uses the service at user granularity, meaning that each user shall be treated as an independent and unique agent (not as a density or concentration). This means that an agent-based simulation (a special type of discrete simulation, which could also be labelled as discrete-time event-driven simulation) is the suitable simulation strategy since, in our model, the individual entities (users, network, etc.) are represented directly and possess an internal state, and their evolution along the simulation period (the state of each entity is updated from one time step to the next) is governed by their own properties and characteristics (Guizani et al., 2010: 5).

3.5 NIESIM Architecture – Entities and Events

The entities that we need to consider in the simulation model are:

a) Users (representing a population)
b) Telecommunications Network (detailed at the level of the communications channel)
c) Management (responsible for deciding and taking action towards the telecommunications network)

The status of these entities evolves over time, through interactions with each other, by means of events such as call setup, network registration, feedback messages and fault correction, to name a few. These interactions are represented in Figure 6. Some entities are influenced by external events that may be part of a scenario definition, like random call attempts by users, random network failures that happen by chance (in Figure 6 attributed to "Nature") or the business rules that govern management activity (periodicity of the business review and decision making).

The complete list of events that represent explicit agent interactions during the simulation period is represented in Figure 7. Some of those events generate changes in both entities' statuses, but others only change the status of one of the agents.

NIESIM is a tool to execute experiments, thus the running of a simulation should be one step within a carefully designed experiment comprising a general and stable context along with specific elements that will change in each step of the experiment. After comparing the outcomes of each simulation, one should be able to determine and study how the changing elements influence the performance and eventually obtain valid conclusions. So, one should start by designing the experiment and thus establishing a reference context (repeatedly used in each simulation execution) along with the strategy to introduce variable elements at each step in a controlled and perfectly known way.

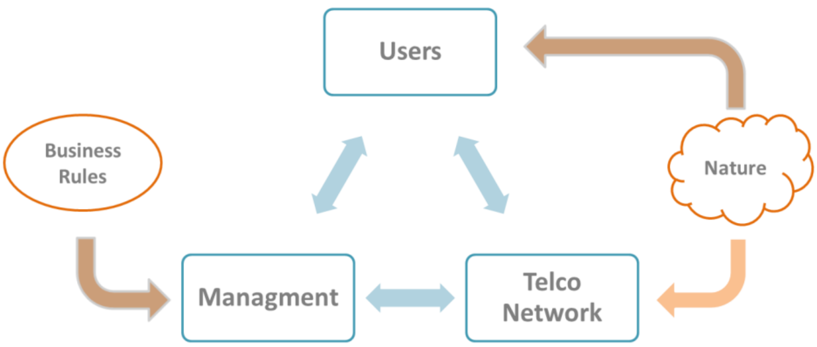

Figure 6 – Entities modelled by NIESIM and their macro interactions

To set up a simulation context, we have to define some general characteristics (for example number of users; geographic area) along with some business rules (for example when management reviews should happen; decision criteria such as a goal for the grade of service) and then a setup process takes place which produces the complete set of events (Figure 8). These events are randomly generated at the beginning of the experiment (setup process) so, when the actual simulation begins, they are already defined and, therefore, they may be seen as "pre-determined" at this stage. These events actually define our reference scenario, which we term the baseline scenario, since they attach each agent their specific behaviour during the simulation process (call attempts, geographical position of the users; management reviews in case of management team and fault injection events that will change network availability).

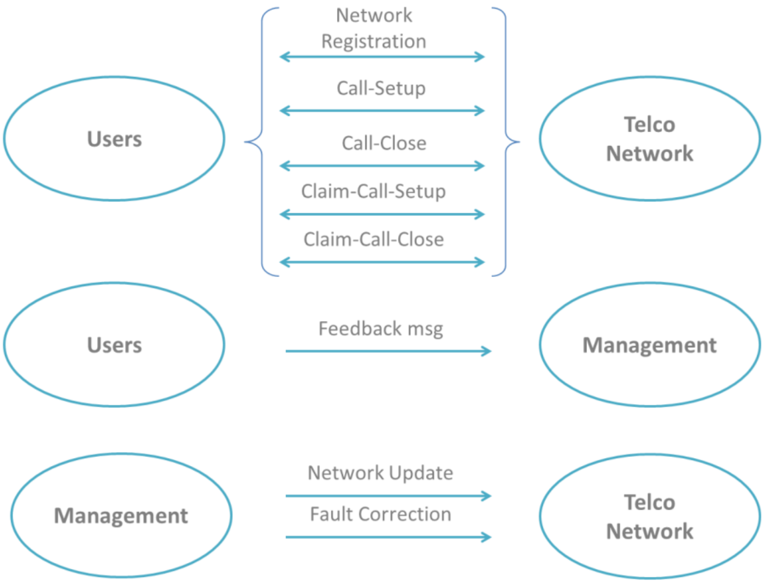

Figure 7 – List of events used to model explicit agent interaction during the simulation period in NIESIM

By changing specific conditions (for example, information flow and decision making rules) and keeping exactly the same set of "pre-determined" events (and the same general context), we are able to simulate the influence and impact of our control variables over the baseline scenario.

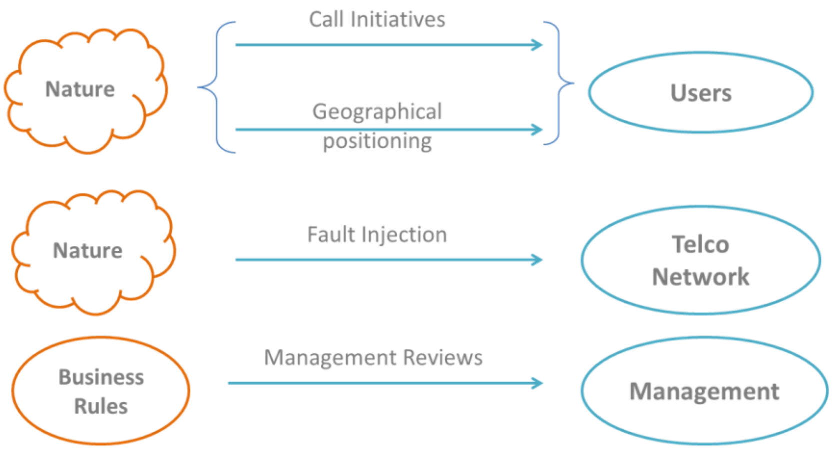

Figure 8 – List of predetermined events that influence agent's behaviour during simulation period.

Thus, an experiment developed using NIESIM should follow a process with three independent steps:

- Setup – context, in the form of a set of parameters, is provided for scenario initialization and the complete set of random events that defines a baseline scenario (Figure 9) are created and saved for iterative processing in subsequent steps of the experiment;
- Processing – at each step, the baseline scenario (with the corresponding set of events) is combined with certain values assigned to control variables (aligned with the experiment plan) in order to constitute the scenario of that step. This scenario is then submitted to the actual simulation processing, thus producing specific raw results;
- Analysis – The performance indicators are extracted from the raw data gathered in the processing phase, computations and aggregations are produced and translated into graphical plots.

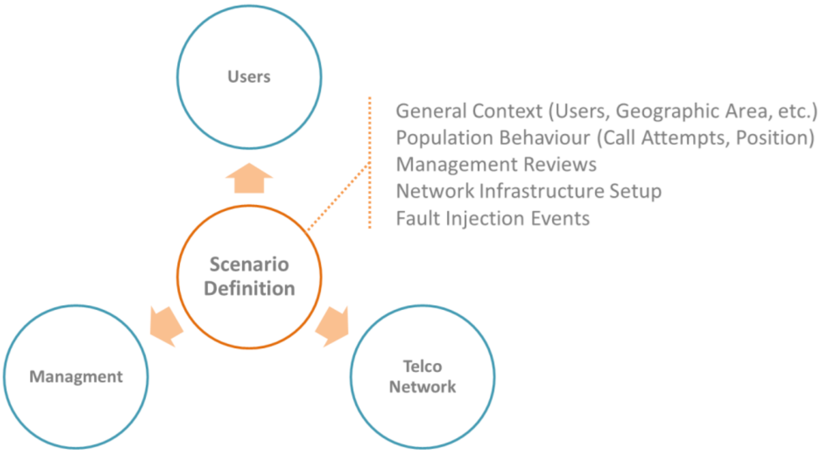

Figure 9 – The main elements that contribute to a scenario definition during setup phase of NIESIM.

4. NIESIM applied to the definition of the grade of service

We will now discuss how NIESIM can be used to support decisions related to the definition of a grade of service, by comparing simulation results for distinct scenarios (regarding information availability and usage). We introduce the business context we used as input to the experiment design and subsequently to the simulation process and we discuss the results both in terms of technical performance and financial performance. In the following pages we will use the expression “scenario” when referring to any autonomous instantiation (with particular parameters) of the business context that we intend to model using NIESIM. Any experience designed and executed using NIESIM is built on the premise that each scenario generates observations which express the impact of certain elements on the business context modelled. Thus, comparing those observations we expect to draw conclusions about the impact on business performance (usually in financial terms) of a certain business variable (for example: grade of service value used as decision criteria).

4.1 Description of the business context

Let us consider one "ideal world" were mobile communications are supported by a certain network infrastructure which is exposed to a certain type of failure at a certain rate over time. Then, let us assume also that the net effect of this type of failure is to interrupt the availability of communication channels (and ongoing calls supported by those channels) within the geographic area (cell) served by this hardware. After a failure event, we observe a diminishing QoS provided by the system (consequence of higher probability of blocking traffic - Pb) and, since the failures are occurring at a certain pace, the QoS will degrade until this information is available to management and a decision is made to subject the faulty hardware to a field action. This action results in the correction of the failure, thus re-establishing full communication capacity of that specific hardware. Note that the action is not automatic, but it is the outcome of a decision process, which in our case is assumed to be associated to a reference value of the grade of service (Pb) that management uses as a decision-making criterion.

We will compare the performance of the system under different circumstances of information availability and different information usage by the management team. We will consider three distinct scenarios:

a) Baseline context – the system is simulated assuming that no failure event interferes with its performance;
b) "No Information" context – the system is simulated assuming that it is subject to failures but it has no ability to detect and correct those failures (no information)
c) "Information Available" context – the system is simulated assuming that it is subject to failures, but with ability to detect and correct those failures (information available)

The idea is to perform a sequence of simulations, starting with the situation where the system runs without failures affecting its activity (baseline), then proceeding towards a new scenario where the same basic context is processed under failure stress (which resembles real world infrastructure that is error prone), considering two opposite situations in terms of information usage: (i) information is not available thus management is not able to take action and correct failures (resulting in continuous decay of QoS, in our case observable in indicators like CSSR and Pb of the network); (ii) information is available and management is able to make decisions and take action accordingly thus correcting the failures (resulting in QoS recovery).

The simulation context details (call attempts by users; geographic location of the users at each call attempt; network infrastructure; etc.) are kept equal in each of these scenarios. We will combine the outcomes of these simulations to understand the differences between those scenarios both in terms of service performance and financial performance.

Before proceeding we have to clarify another aspect: the source of information. In a real scenario there are two fundamentally distinct sources of information that are used by management teams: (i) internal information gathered mainly by OOS type of information system and (ii) feedback from users that inform their service provider about their experiences when using the telecommunications service, especially when they face difficulties or experience quality problems. In this example we only consider the first situation, thus feedback from users is not considered, only internal information is assumed to be available.

In the experiment example presented in following pages, a business context is introduced and used to simulate the behaviour under multiple scenarios, such as considering multiple decision thresholds in terms of service grades (Pb equal to 4%, 6% and 8% tagged AFACINTPB4, AFACINTPB6 and AFACINTPB8[6]), which are "Information Available" type of scenarios, complementing the baseline (tagged REF) and "No information" (tagged AFNCINT[7]) scenarios. This experiment strategy will deliver a preliminary view of the relation between the grade of service[8] used as a business goal (thus the decision criteria to take action) and the financial performance that results from those options.

Now let us present the business context itself. We chose a simplified context in which the population (service users) is uniformly distributed across a certain region served with a radio telecommunications infrastructure. We considered a population of 7000 users distributed evenly along all the operating region with smooth variations in terms of population location between adjacent areas (implemented using the concept of "mobility rate" in this case with assigned value of 5%). This leads to a high number of user at the centre of the region, as shown in Figure 10 and Figure 11. The service usage profile by the population is variable along the day and we used a profile from a real situation as input for the simulation process, thus making sure that the appropriate volume of calls were generated at each time period (on an hourly basis) by this population. In Figure 12 we compare the input profile of a real telecommunications provider with the usage profile that resulted from the baseline scenario.

The population and the region where that population evolves along time is very important for planning the infrastructure topology that a service provider has to deploy in order to assure a certain grade of service. However, it is not our intention to discuss geographical optimization of the infrastructure and other complex technical details related to the radio telecommunications engineering perspective. Thus, we chose to follow a general standard in the industry for expected grade of service (1%) and combine that with the simplest topology possible: we assume that each cell is served by one base

[6] Acronym for "Active Failure, Active Control using INTernal information with Pb of 8% as decision threshold" scenario.
[7] Acronym for "Active Failure, No Control using INTernal information" scenario.
[8] In telco industry "grade of service" is synonym of probability of blocked traffic (Pb)

station with only one operative cell, thus no redundancy (in terms of radio coverage of each geographical area) is considered for this basic business context. As we applied this simplified topology model into practice, we considered the operative region itself to be evenly segmented in cells in such a way that a matrix with five lines and five columns of cells is used to assign radio network infrastructure able to assure mobile communication coverage for the whole operative region. Finally we assigned 4 radio units (thus 28 communication channels) to each cell (and consequently for each base station in this particular case). We have verified through simulation results that this infrastructure is adequate to assure that grade of service is not perfect (thus we did not reach an over-dimensioned infrastructure) yet always within the industry limit (Pb<=1%). Finally, we assigned 6% daily rate for steady inflow of faults, thus completing the business scenario definition as summarized in Table 2. Both figures ("communication channels by base station" and "daily rate for steady inflow of faults") ware chosen after a trial and error process given practitioners recommendations (regarding the network planning part) and the convenience of fast impact on the performance (failure rate). The "failure rate" is obviously a pure hypothetical and convenient value, otherwise we would have to produce simulations for long periods (many weeks or months), thus it would be impractical.

Concept	Value Assigned
Total geographical zones	25
Longitudinal range	5
Latitudinal range	5
Total users	7000
Average user per zone	280
Mobility rate during "leisure period"	5%
Mobility rate during "working period"	5%
Total base stations	25
Average communication channels by base station	28
Total communication channels	700
Daily rate for steady inflow of faults	6%
Average call duration	120s

Table 2 - Technical summary of our simulation context

As said before, users do not stand still in a certain location but they are expected to move within the geographic area in which the simulation evolves. In Table 3 we present a summary of the values of the simulation parameters related to the process of decision making and subsequent actions (those parameters only apply to "Information Available" scenarios). The simulation parameters have been chosen considering an idealized scenario with no limitations on the teams available for field actions (unlimited number of teams, hypothetically working at any moment in a day), a smooth decision-to-action procedure is in place (small delay between decision and execution) and that a team field will always correct the failure within a certain fixed time period.

Concept	Value Assigned
Decision to field action delay	1h
Elapsed time for a field action team solve a problem	1h
Number of field action teams	Unlimited
Limitation on field teams work periods	NO
Time granularity of computation of performance indicators	1h
Management evaluation of KPIs and decision making period	1h

Table 3 - Simulation parameters related to the process of decision making and subsequent actions

The decision criterion (Pb) is not included in table 3 because we repeated the simulation considering several Pb goals to get some insight on the impact of this business restriction on the performance of the system. We are aware that those options are fairly optimistic and we expect to explore how those options might impact the economic performance in subsequent studies.

4.2 Business scenario validation though basic outcomes from the simulation process

Before we go deep into simulation results we wish to provide some generic information on how the business context inputs presented in the last subsection actually translate into the baseline scenario.

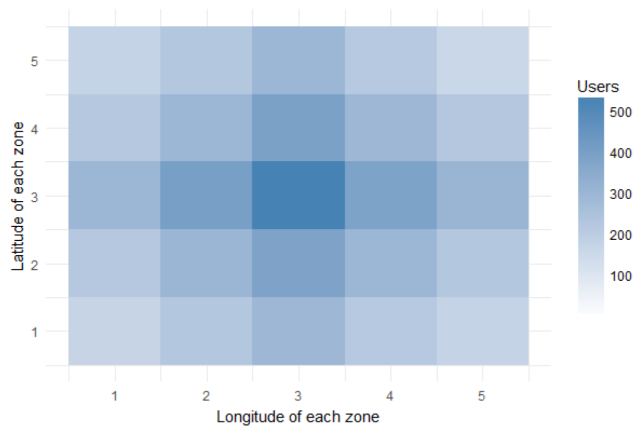

Figure 10 - Average number of users in each region, during the working period.

Beginning with the population of users, Figure 10 presents the user distribution per zones during the working period (considering the average number of users in each area) and Figure 11 represents the user distribution per zones during the resting period. These figures illustrate the geographic distribution trends of this scenario.

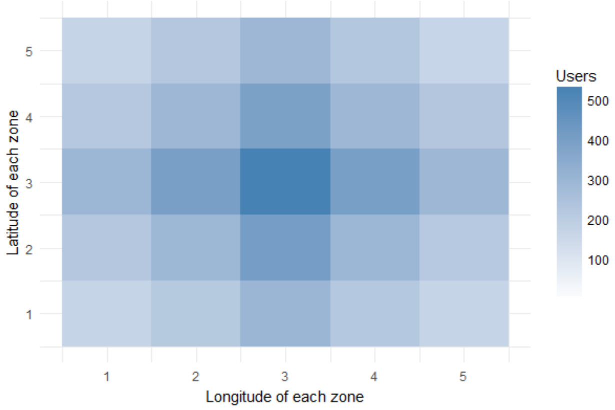

Figure 11 - Average number of users in each region, during the resting period.

Next we review the behaviour of users in terms of service usage along time. In real life, the mobile telecommunications service demand is time dependent, with periods of the day with high demand and other periods with low demand, as shown by field data obtained from a Portuguese service provider. In Figure 12 we compare the input profile of the real telecommunications provider with the usage profile that resulted from the NIESIM's setup phase that generated the baseline scenario.

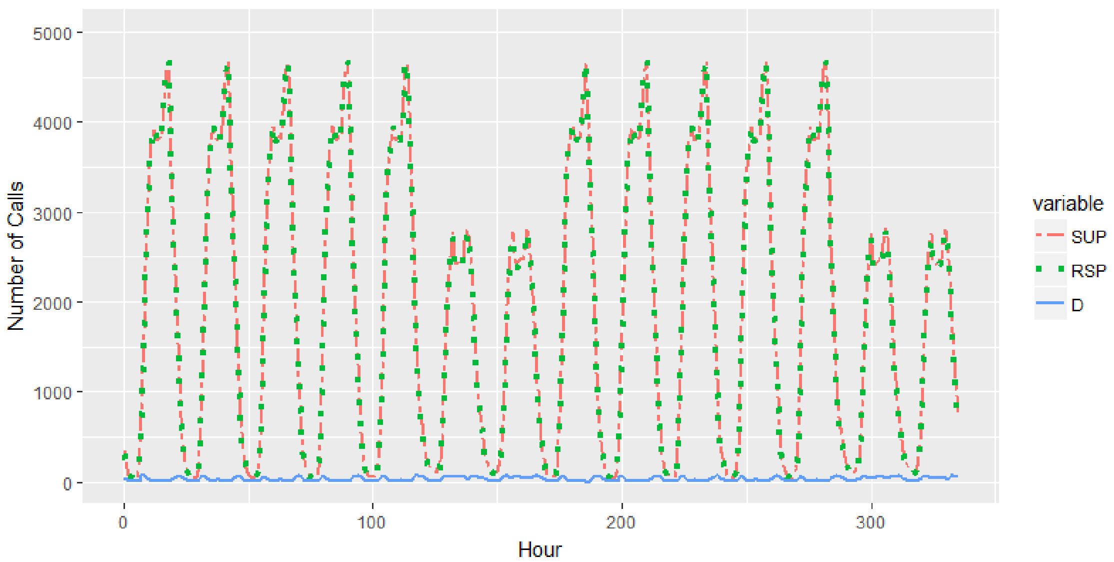

Figure 12 – Comparison of service usage pattern from a "real" service provider (RSP), which is one input to the setup process, and the service usage pattern (SUP) of the population created for the baseline scenario. The difference (D) between those curves is also plotted.

Finally, let us review the network infrastructure, particularly the ability to process traffic resulting from the simulation context just described. We considered that the traffic capacity of the infrastructure should be dimensioned at a minimum configuration assuring that, in the absence of faults (REF curve in Figure 13 corresponding to baseline scenario), the grade of service would be aligned with industry reference recommendations (Pb<=1%) as suggested by Freeman (2005), which means a *quasi-*

perfect service level is provided to users but avoiding over-provisioning of resources (thus a limited traffic blocking is observable).

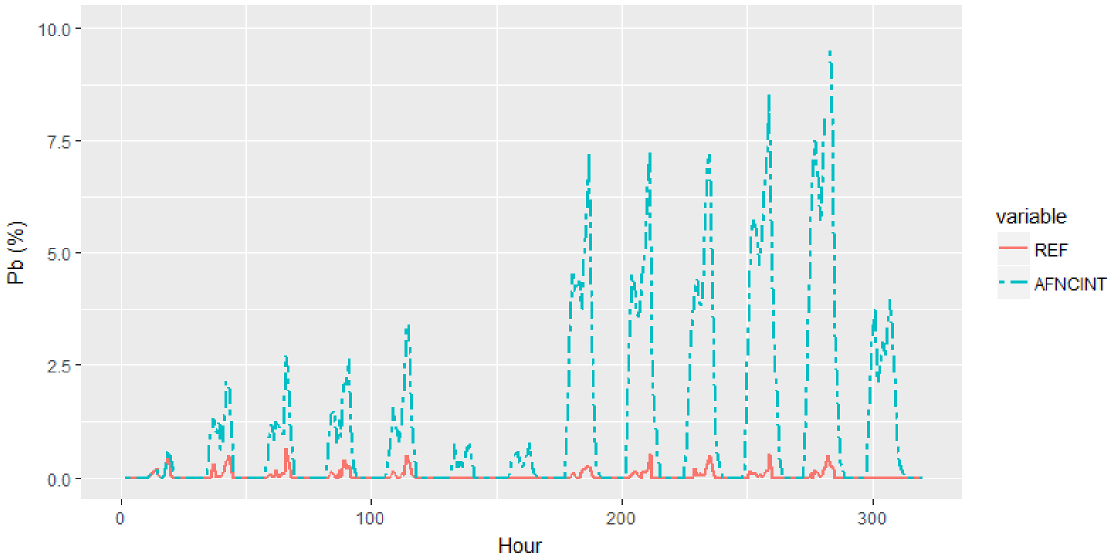

Figure 13 – Impact on the performance of the system of a steady inflow of faults (rate 6% of installed capacity) measured in terms of Pb. REF is the baseline scenario without faults and AFNCINT is the "No information" scenario with active faults.

In Figure 13 (curve AFCNINT corresponding to "No information" scenario with active faults) we also plot the performance in terms of Pb when a steady inflow of faults (rate 6% of installed capacity) is injected into the system (with no information available, thus no ability to correct faults). This plot shows that the infrastructure is fitted to our goal (in the baseline scenario, in which the system is under no stress by failure events, we observe small perturbations in the service, thus we are sure to avoid over-provisioning) and also gives some insight on the impact of faults over time if no action is taken to correct those faults.

4.3 Simulation results for the "Baseline", the "No Information" and the "Information Available" scenarios

We chose to present results from the simulation process combining the baseline, the "No Information" and the "Information Available" scenarios, showing the main differences between them as we present and explain the performance of the system considering several analytical perspectives. Recall that the "Baseline" scenario (tagged REF) is the one assuming no failure event interferes with the systems performance, whereas the "No Information" scenario (tagged AFNCINT[9]) assumes the system is under failure pressure but not able to detect and correct failures (no information).

Finally we also introduce one example of an "Information Available" scenario, which assumes that information is available for the management team to take action, thus

[9] Acronym for "Active Failure, No Control using INTernal information" scenario.

allowing the detection and correction of those failures. In this example we chose a threshold of 6% of probability of call failure (Pb) as the trigger to act upon correcting faults. The "Information Available" scenario (tagged AFACINTPB6[10]) assumes the system is under failure pressure but now with ability to detect and correct those failures (information available)

The simulation went throughout two weeks and the pattern of attempts to use the service is presented in Figure 14. Along with the attempts to use the service, we also show the attempts that were successful and the attempts that could not be completed successfully regardless of the reason.

As discussed before, there are three major causes for the failure of a call attempt: the receiving user is already in a call, thus unavailable (A); unreachable users that are not registered in network (either for service availability limitations or for user option to be disconnected, for example) (B) and finally call attempts that fail because of network resources limitations (C). Our focus shall be the call attempts that fail due to technical problems, which correspond to the latter ones.

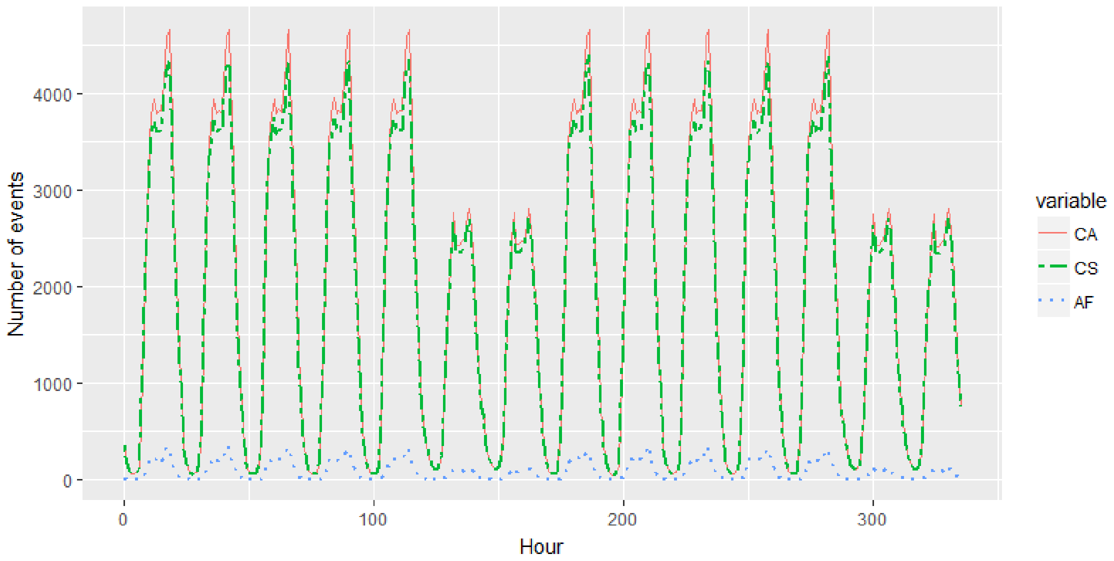

Figure 14 - Pattern of attempts to use the service (CA - call attempts) along with successful (CS) and unsuccessful (AF) counterparts ("Baseline" scenario).

A significant number of call attempts do fail due to simple fact that those were unviable (example: the destination user is already in a call). The unviable calls are identified as A in Figure 15 while unsuccessful calls due to resource limitations are identified as C. Also, in Figure 15 we observe that only a small portion of those failures result from network

[10] Acronym for "Active Failure, Active Control using INTernal information with Pb of 6% as decision threshold" scenario.

limitations, actually capacity limits, since in the "Baseline" scenario we assume no faults are active in the system.

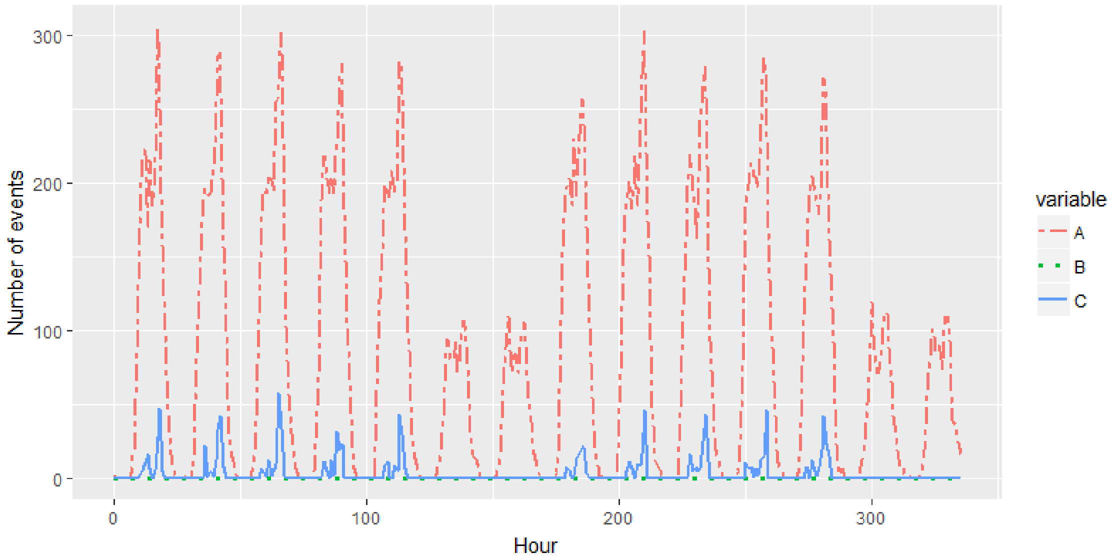

Figure 15 – Patterns of distinct reasons for call failure obtained for the "Baseline" scenario namely unavailable user (A), unreachable user's (B), network's resources limitations (C).

Since the ability to provide the service is contingent to availability of resources of the telecommunications infrastructure, the full understanding of service usage must consider not only the number of attempts to use the service (successful and not successful) but also the duration of the service (duration of calls), since the service could be denied because of unavailability of resources (either because they are in use in that moment or because they are under a failure status, thus not available). Using traffic theory to describe the service usage gives us a complementary perspective on performance. Hereby we recall the concepts that are relevant for us:

- Offered traffic (Eo): incoming traffic, the sum of carried traffic and blocked traffic;
- Carried traffic (Ec): instantaneous traffic, expressed as a certain number of Erlangs;
- Blocked traffic: traffic that the system has been unable to process (thus lost traffic).;
- Probability of blocked traffic (Pb): the probability of blocked traffic is probably the best proxy for the Quality of Service (QoS) provided by the system to the end user in the context of NIESIM.

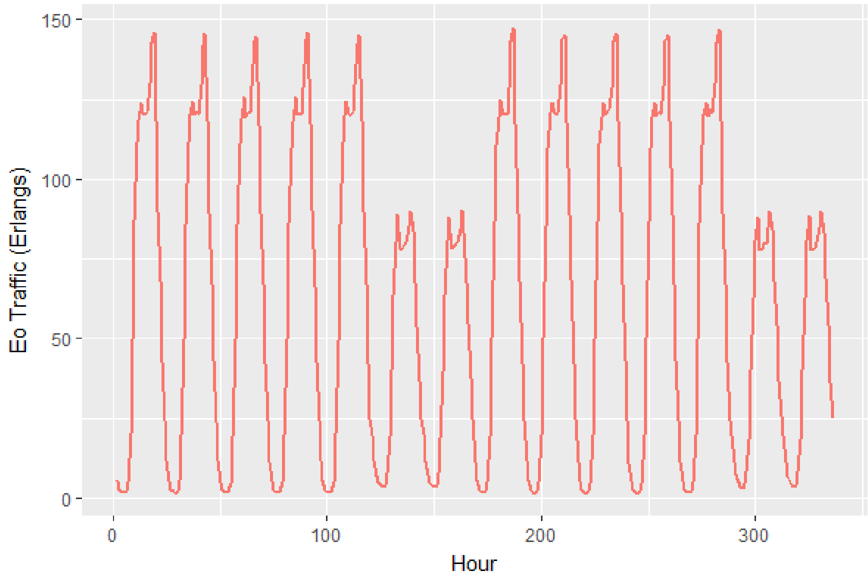

Figure 16 - Pattern of Offered traffic (Eo) obtained for the baseline scenario

Those concepts are internally computed and used by the simulation process. They are assumed to provide decision information to the "management team" (to decide when to take action and correct network failures) in the "Information Available" type of scenarios. Figure 16 presents the offered traffic (Eo), Figure 17 shows the carried traffic (Ec), and Figure 18 depicts the probability of blocked traffic (Pb).

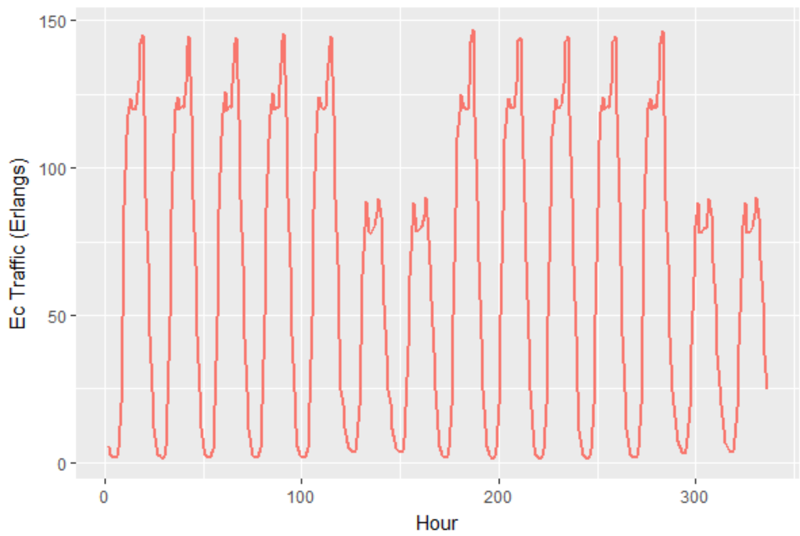

Figure 17 - Pattern of Carried traffic (Ec) obtained for the baseline scenario.

As expected, the value of Pb in the baseline scenario is always low (assuring a high service is provided to the users), but it is not zero, thus taking into account the requirement of avoiding over-provisioning of resources since that circumstance would jeopardize our efforts to evaluate the importance of information towards an optimal financial performance.

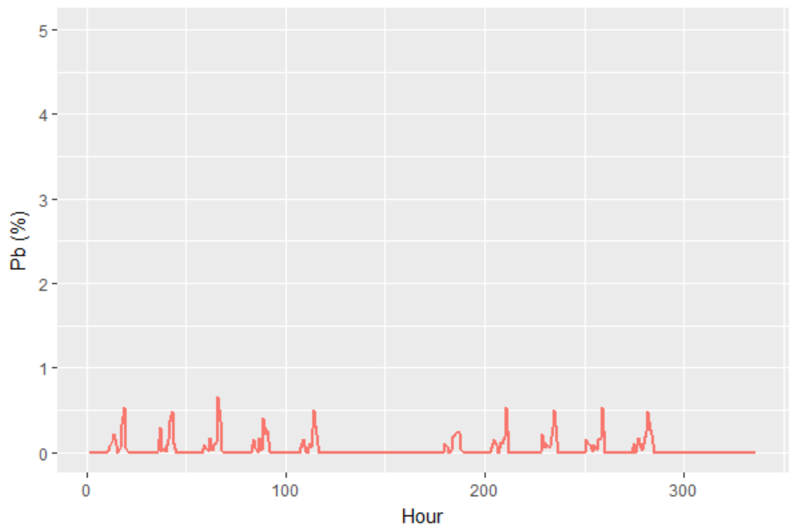

Figure 18 - Pattern of Probability of blocked traffic (Pb) obtained for the baseline scenario.

Now let us introduce the nuances from failures and actions to correct those failures in terms of call failures originated by network's resources limitations. Note that, to assure comparable results, the "No Information" and the "Information Available" scenarios assume the system is under failure pressure (in this case we considered a 6% rate of equipment failures on a daily basis) and that the exact same failure events take place in both simulations. The 6% rate is higher than observed in real systems but it is instrumental for the purpose of getting a visible impact on performance in a small period of time (we chose to only consider two weeks as simulation period).

Since the failure events are the trigger element for the differences between the baseline scenario and the other ones, we start by observing the failure events (Figure 19) and the correspondent impact on the infrastructure in terms of available channels to provide the service.

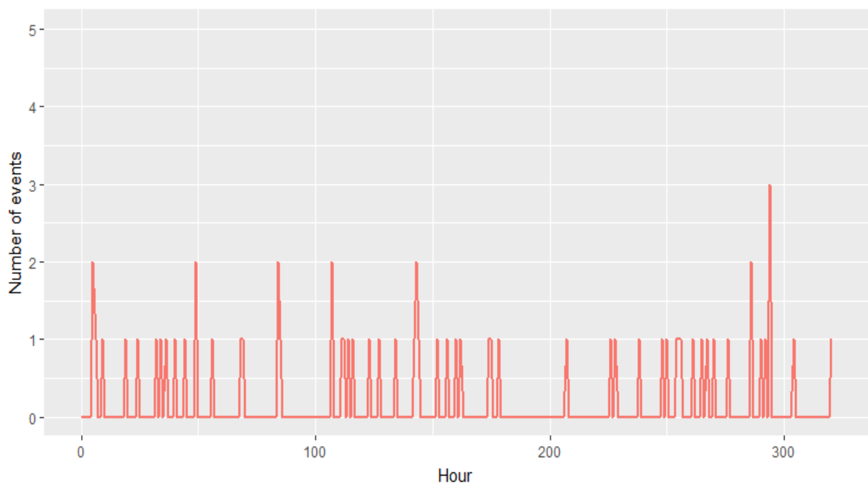

Figure 19 - Number of failure events by hour, cumulative number of events along time (hourly) common to the "No Information" and the "Information Available" scenarios.

Figure 20 presents the contrast of those three complementary scenarios in terms of channels availability: “Baseline” (subsequently referenced using REF in the plots); “No Information” (subsequently referenced using AFNCINT in the plots) and the “Information Available” (subsequently referenced using AFACINTPB6 in the plots) following the decision threshold of 6% of probability of call failure (Pb). It is clear that information availability and the actions based on that information result in a responsive system regarding failures and a completely different performance in the long term.

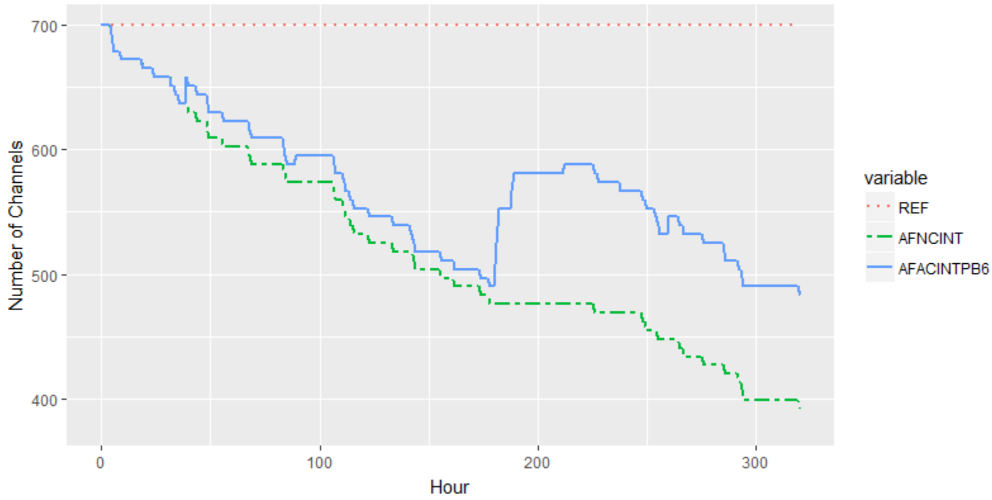

Figure 20 –Comparison of different scenarios regarding communication’s channels availability (minimum within each hour period). REF: baseline scenario (without faults); AFNCINT: “No information” scenario with active faults; AFACINTPB6: “Information available” scenario with a grade of service of 6% at the base station level.

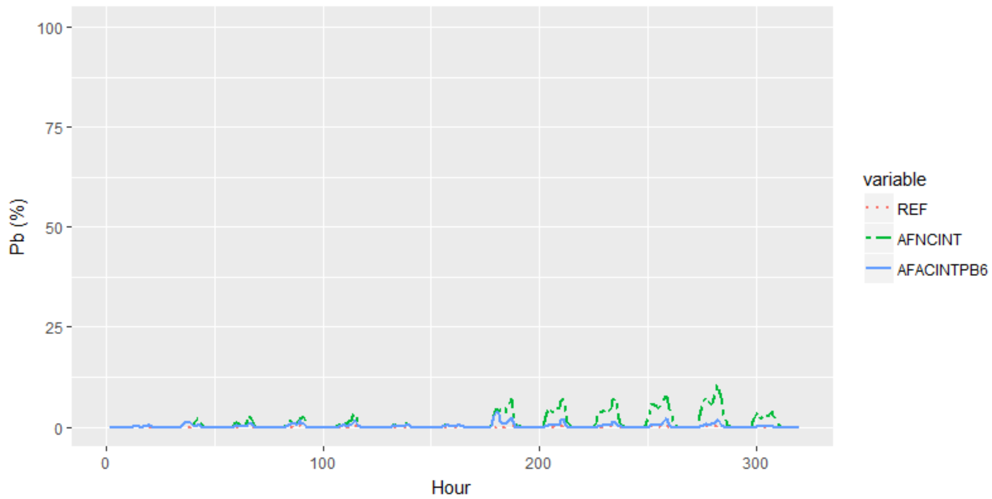

Figure 21 –Comparison of the different scenarios regarding the probability of blocked traffic (Pb). REF: baseline scenario (without faults); AFNCINT: “No information” scenario with active faults; AFACINTPB6: “Information available” scenario with a grade of service of 6% at the base station level.

If we compare the Pb performance indicator across these scenarios (Figure 21), the obvious conclusion is that the “Information Available” scenario does assure that the service level is kept under control while in the “No Information” scenario, the service level is in continuous decay. Such decay is also observable when we consider other performance indicators, such as CSSR (Figure 22).

The Call Setup Success Rate (CSSR) relates successful attempts to call attempts and it measures the ability of the provider to setup a call attempt by the user. The performance we got in our simulation for the three scenarios is presented in the Figure 22, showing that the system under the "Information Available" scenario is able provide a much better service level to users when compared to the "No Information" scenario.

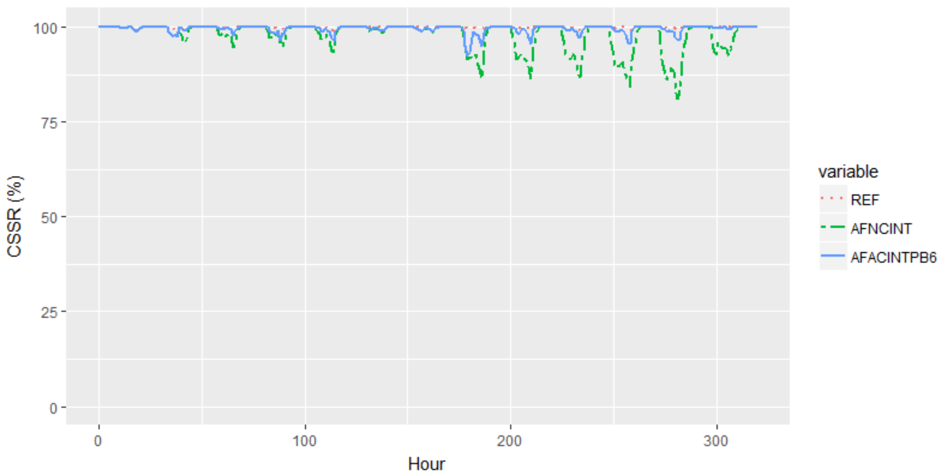

Figure 22 –Comparison of the different scenarios regarding Call Setup Success Rate (CSSR). REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB6: "Information available" scenario with a grade of service of 6% at the base station level.

A macro analysis of the main performance indicators, considering busy hour observations for the entire network (or system), is commonly adopted by the Telecommunications Industry. Comparing the three scenarios using busy hour performance indicators gives a clear picture of the performance trends of each one and thus a simpler way to reach insights.

In terms of processed traffic (Figure 23), it is clear that, in absence of information (and control), there is a continuous decline in traffic (weekend days should be ignored within this exercise since the expected traffic is far below that of a regular working day). However, when information is available (and action taken based on that information), the traffic loss is stanched and an equilibrium is achieved (in this business context, after the first week), and traffic shape is aligned with the baseline scenario, confirming that the system is performing under a stable condition although at a lower level of service.

If we compare those scenarios considering Pb performance indicator (Figure 24), which is a proxy for QoS provided to users within this experimental context, the description would be similar: when information is available, the service level is kept stable (after an stabilization period - in this scenario, after the first week) although at low performance when compared to the baseline scenario.

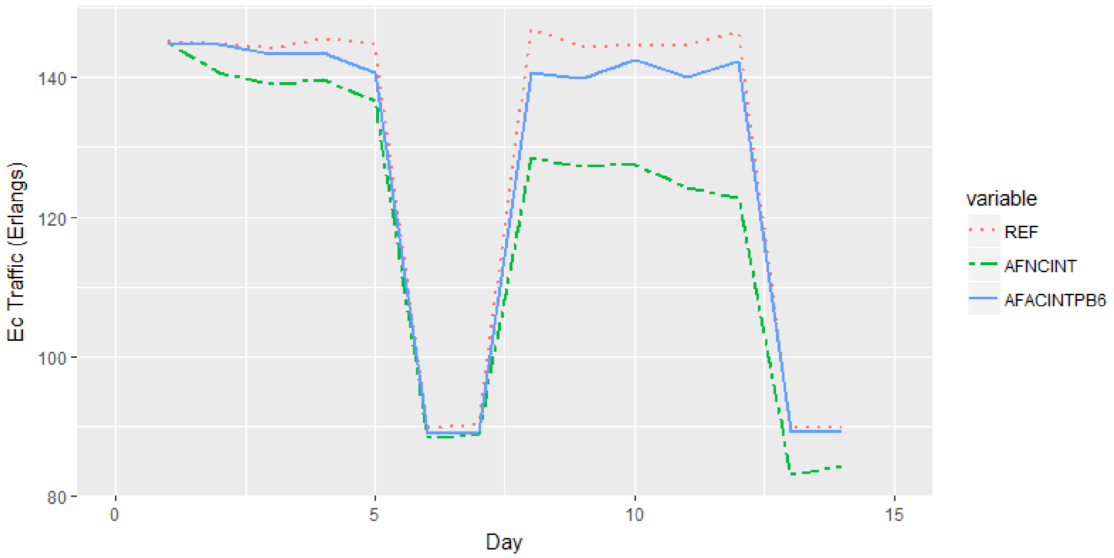

Figure 23 –Comparison of the different scenarios regarding the observations for Carried Traffic (Ec) in the busy hour. REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB6: "Information available" scenario with a grade of service of 6% at the base station level.

Reviewing those plots is very insightful in terms of sensing the difference that one should expect in terms of performance of a telecommunications network if information on system faults is available and action based on that information can be taken.

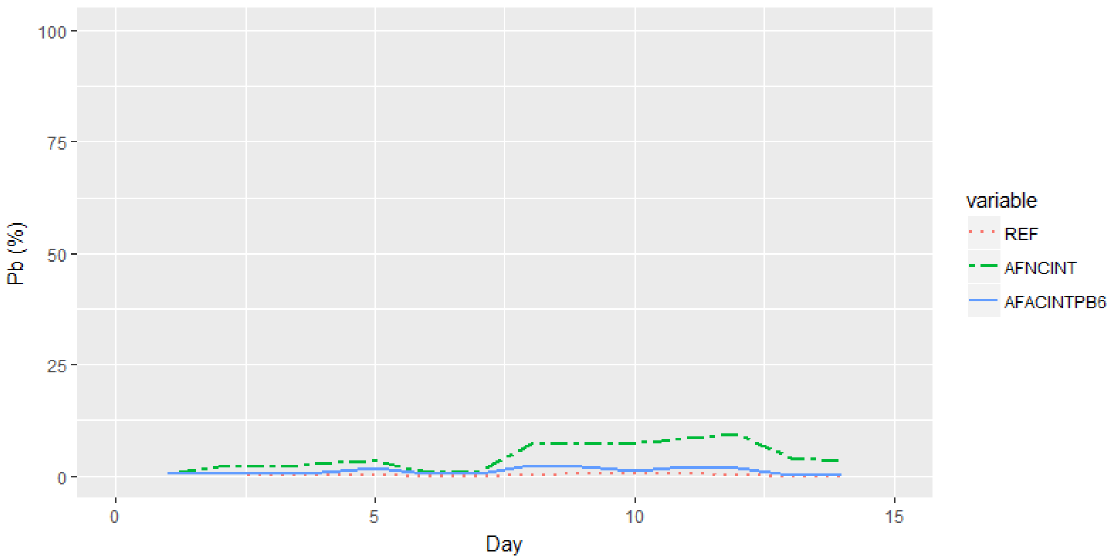

Figure 24 –Comparison of the different scenarios regarding the observations for Carried Traffic (Ec) in the busy hour. REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB6: "Information available" scenario with a grade of service of 6% at the base station level.

4.4 Financial performance

We will now set the grounds for computing the financial performance of the mobile telecommunications provider that we modelled. The financial performance is obviously related to the way service plans are charged to customers. Yet, in this particular simulation we did not distinguish groups of users with respect to service plans, neither did we consider different expectations that those groups might have, for example with respect to quality of service. Thus, we assume that a single and generic flat rate service plan applies to all users, defined under the guidelines presented in Table 4.

Features of the service plan	Value or Option Assigned
Calls are limited to the same service provider	Yes
Other services then calls (SMS, Internet) available	No
Service is charged on a “per second” basis	Yes
All users use the same service plan	Yes
Service is charged to the user initiating the call	Yes
Price of one minute of communications	0,01 m.u.
Price applies for any call at any instant of the day	Yes

Table 4 - Generic flat rate service plan applied in our simulation.

If we wish to produce a strict analysis of the simulation context we have been presenting in this document, after applying the charge plan, the aggregated data of the financial performance of the system (per each day) leads to the Figure 25.

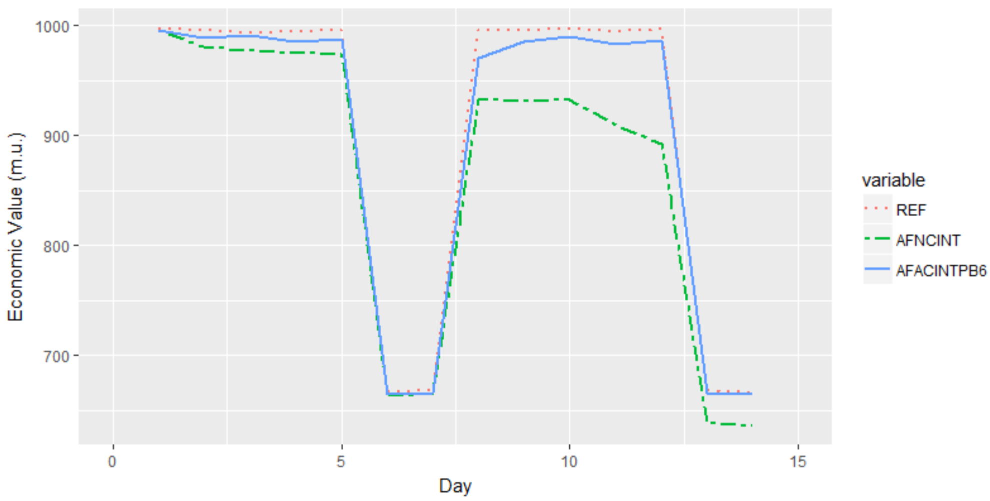

Figure 25 – Daily financial performance of the system based on billed services to users (values for each day) expressed in monetary units (m.u.). REF: baseline scenario (without faults); AFNCINT: “No information” scenario with active faults; AFACINTPB6: “Information available” scenario with a grade of service of 6% at the base station level.

The financial value is a mirror of the traffic processed (Ec) as one might expect from this flat rate plan applied to every user (see Figure 23). However, our goal is to draw conclusions beyond the specific simulation context just presented. Thus, to estimate the value of information we evaluate the financial performance of the system for each of the scenarios imposing certain restrictions that allow us to set the path for more general conclusions. We hope these conclusions may be applicable to practitioner’s contexts and not only to this particular experiment.

At this point, the main restrictions we consider are:

a) To exclude weekends from this initial analysis, since traffic is substantially lower when compared to business days;
b) To focus on a period that is expected to be similar to a continuous operation of the telecommunications service.

This last restriction applied to our simulation scenario means that the initial period of one week will not be included since the system is adapting and reacting to the initial perturbation: random faults are injected in the system at regular pace and the information flow and decision procedures eventually lead the system to a stable operation that is our proxy to a continuous operation of the telecommunications service.

Combining both restrictions, our eligible period for collecting financial performance data of the system starts at the 8th simulation day and goes until the 12th day. In Table 5 we gather the relevant data and compute the average value capture by the system at each scenario and in Figure 26 we plot those values for visual comparison.

	Scenario		
Day	REF	AFNCINT	AFACINTPB6
8	996,41	932,86	970,34
9	995,69	931,79	985,33
10	996,89	932,07	990,02
11	994,64	909,91	982,91
12	997,31	892,07	987,05
Average	996,19	919,74	983,13

Table 5 – Daily financial value captured (billed) by the service provider from their users (expressed in m. u.). REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB6: "Information available" scenario with a grade of service of 6% at the base station level.

The significant insight at this point is that operation in a "No Information" situation might lead to significant losses, surpassing 7,7% of expected value captured by the system operation under perfect conditions (the baseline scenario, tagged as "REF") on a daily basis. Since there is no fault correction, the performance would degrade even more if subsequent weeks were considered. On the other hand, if the system is operating under those same stressful conditions (6% of fault rate on a daily basis) but with available information and ability to take action (in this case considering target Pb of 6%), the losses fall to 1,3% of the baseline scenario.

These financial improvements resulting from information usage and taking action to correct faults will become more evident if we extrapolate this simulation context to a more common sense situation (one million active customers) and a real charging plan for the mobile service (9,9 cents of an euro, considering UZO[11] charging plan for prepaid mobile service, a Portuguese service provider).

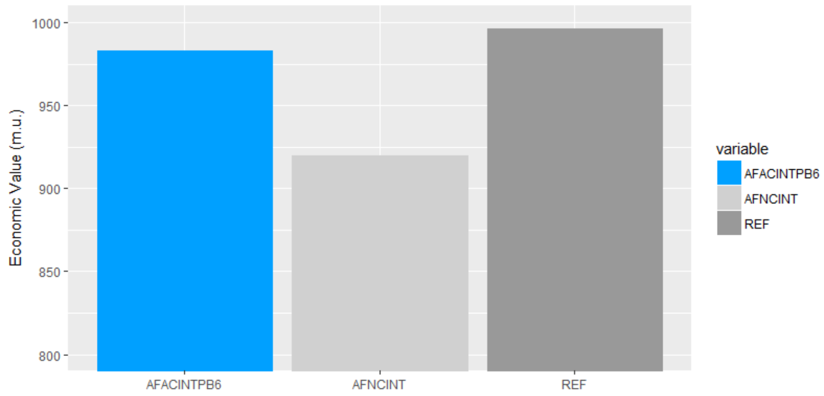

Figure 26 – Comparison of scenarios regarding the average value captured per day (expressed in m. u.). REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB6: "Information available" scenario with a grade of service of 6% at the base station level.

Table 6 summarizes this extrapolation exercise considering only working days (250 per fiscal year). This should be considered a conservative estimate, although very insightful, about the huge financial savings that one should expect from information usage.

	Scenario		
Description	REF	AFNCINT	AFACINTPB6
Value captured on a daily basis considering 1 million users	1 408 892 €	1 300 776 €	1 390 426 €
Value captured in 250 working days considering 1 million users	352 223 108 €	325 193 915 €	347 606 561 €

Table 6 – Extrapolation of financial value captured (billed) by a service provider with 1 million active customers adopting a flat rate of 9,9 cents of Euro charging plan. REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB6: "Information available" scenario with a grade of service of 6% at the base station level.

The extrapolation to one million users challenges us to acknowledge that the magnitude of savings resulting from information usage and action taken to correct faulty infrastructure within the telecommunications context could easily reach millions of Euros per year. Based on the previous example, the loss under a "No Information" situation could reach 27 M€ whereas the uplift in value resulting from information availability and action taken by the management team would be 22 M€ (improvement from the "No Information" to the "Information Available" scenario). The "Information Available" scenario, although leading to a huge improvement compared to "No Information" scenario, still represents a loss of 4,6 M€ when compared to the baseline scenario in which there are no faults. Since the management team is reacting to faulty conditions considering a certain grade of service as a goal (in this example Pb of 6% was

[11] https://www.uzo.pt/pt/tarifario/pagina.uzo, accessed in 3th of January 2019.

the "take action" threshold), we should investigate how this target is related to the financial performance, which is the topic of the next subsection.

4.5 The impact on financial performance from adjustments in the grade of service (Pb) used as decision criteria

There are multiple factors that might influence the dynamics and outcome of the system modelled. We chose to explore the impact on financial performance from adjustments in the grade of service (Pb) used as a decision criterion. We considered three alternative values for Pb, beginning with a more restrictive option (4%), the reference value (6%) used in the previous exercise and a more relaxed option (8%), thus obtaining a preliminary view of the relation between the grade of service and the financial performance that results from those options.

The material impact of the decisions is to act on the system, correcting the faults, translates into available communication channels. Figure 27 presents the multiple scenarios considered and clearly shows the differences in the way the system adapts to the incoming faults.

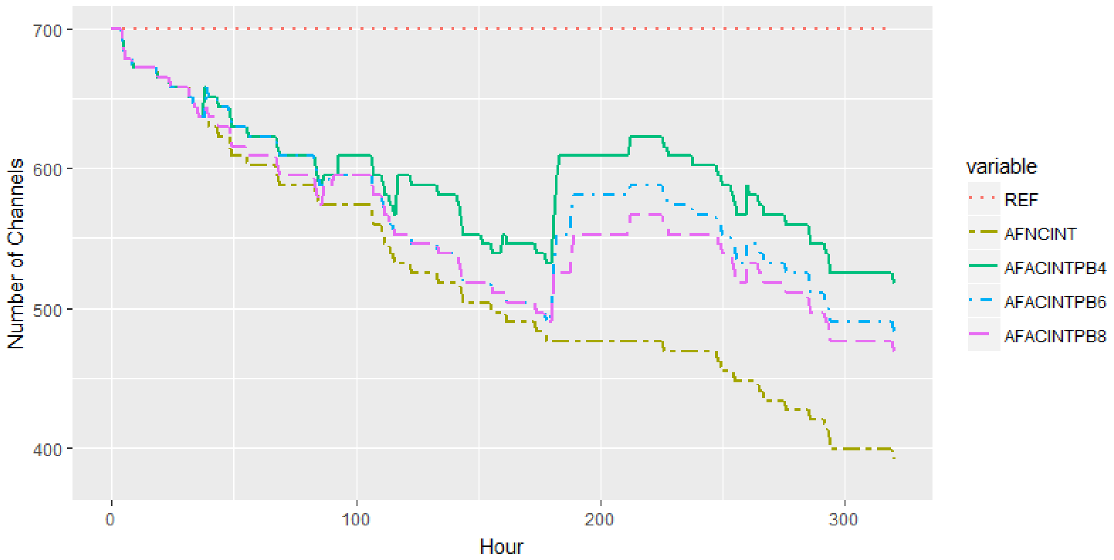

Figure 27 - Comparison of the different scenarios regarding communications channels availability. REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

Now we focus our attention on the service level, which is the relevant outcome of those decisions from a user perspective. Thus we present the evolution of Pb confronting the same scenarios and using the busy hour values of Pb for each day. The differences in performance are clear, as expected, and the best performance is associated with Pb value of 4%, as expected (Figure 28).

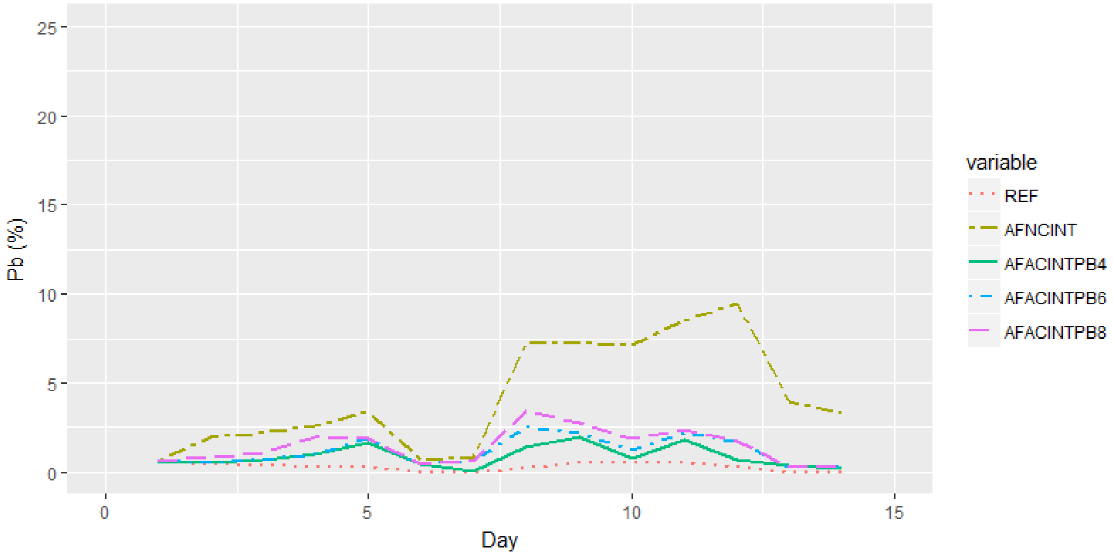

Figure 28 - Busy hour Pb. REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

The financial value captured by the system in each scenario is presented in Figure 29, and again the differences between scenarios are clear.

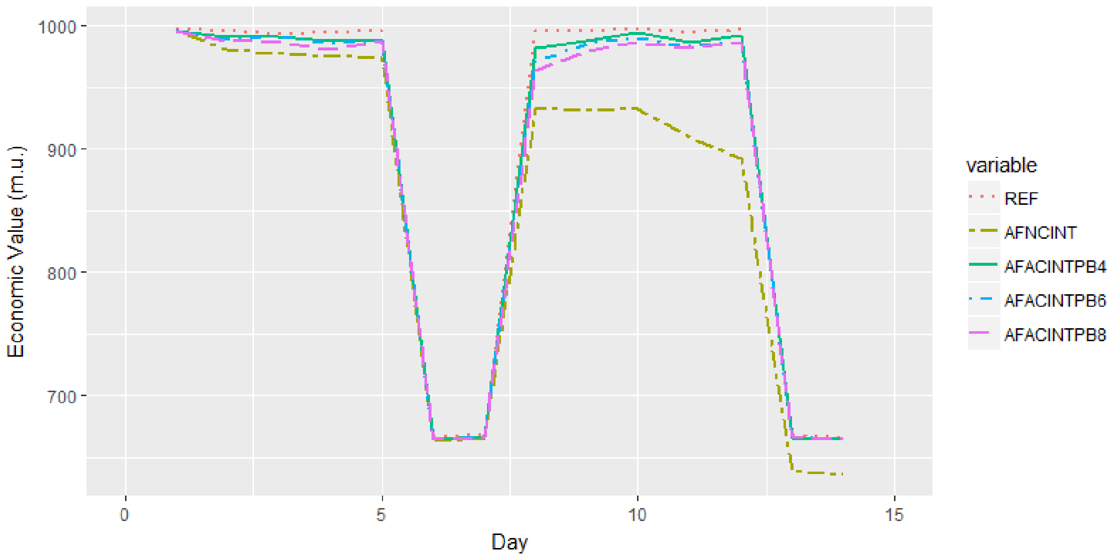

Figure 29 - Financial performance of the system based on billed services to users (the aggregated data per each day) expressed in m.u. REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

As before, considering that the eligible period for collecting financial performance data starts at the 8th simulation day and goes until the 12th day, we obtain the results presented in Table 7 and plotted in Figure 30. Considering the interval from 4% to 8% Pb, the data suggest an average negative impact of 0,23% on financial performance per each 1% of service level downgrade (measured in terms of Pb) which is portrayed in Figure 31.

	Scenario				
Day	REF	AFNCINT	AFACINTPB4	AFACINTPB6	AFACINTPB8
8	996,41	932,86	982,29	970,34	963,99
9	995,69	931,79	988,15	985,33	979,37
10	996,89	932,07	994,84	990,02	987,08
11	994,64	909,91	986,55	982,91	981,70
12	997,31	892,07	992,72	987,05	986,31
Average	**996,19**	**919,74**	**988,91**	**983,13**	**979,69**

Table 7 – Daily financial value captured (billed) by the service provider from their users (expressed in m.u.). REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

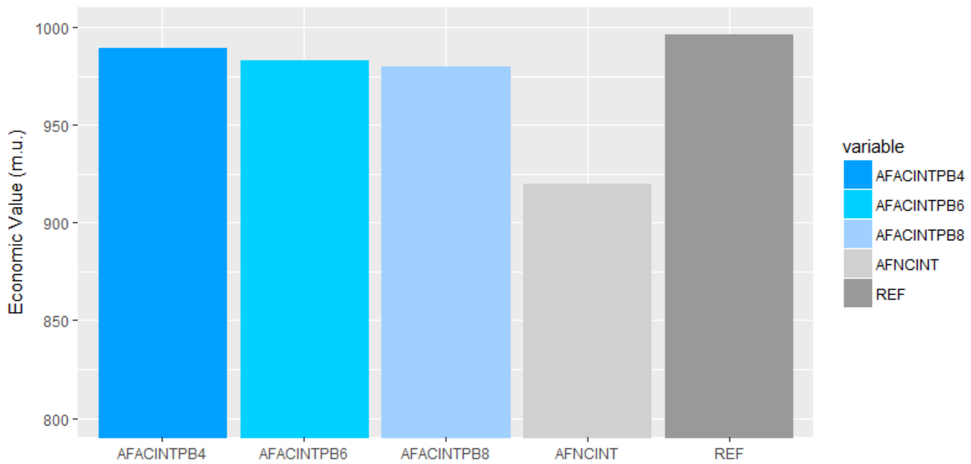

Figure 30 – Average value captured per day. REF: baseline scenario (without faults); AFNCINT: "No information" scenario with active faults; AFACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

Note that if we accept the terms of the previous extrapolation exercise towards a service provider with one million active users, and assuming the same charging plan of 9,9 cents of Euro, this impact of 0,23% on financial performance per each 1% on service level downgrade (measured in terms of Pb) represents a loss of 810.113€ over one year (recall that our reference for value captured in 250 working days considering one million users, under perfect operation conditions, was 352.223.107 €).

Finally, in Figure 31 we also observe a different pace in financial loss between the interval 4%-6% Pb when compared to the interval 6%-8% Pb (higher pace in the first interval), which could lead us to conclude that there is not a perfect linear relationship between the chosen Pb and the associated financial loss. The difference is small (and our data is very limited), so we shall consider this as one hypothesis requiring further investigation.

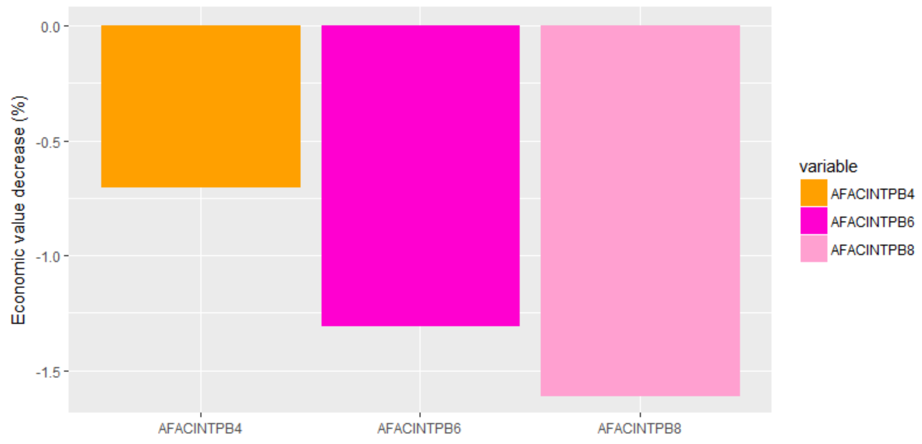

Figure 31 – Financial loss (%) for different values of Pb. AFACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

To further investigate the differences in financial performance of each scenario, we have to consider the side effect on operating costs associated with the required actions to correct faults. One expects that higher service level (low Pb) would require more actions to repair faults and the results presented in Table 8 are compatible with this expectation.

Scenario	Total Number of Actions
AFACINTPB4	15
AFACINTPB6	11
AFACINTPB8	11

Table 8 - Accumulated number of fault correction actions considering the whole simulation period. FACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

In Figure 32 we plot aggregated daily actions taking place for each scenario. The 4% Pb option (higher service level) is clearly more demanding from the maintenance perspective, requiring field actions almost every working day, whereas the other options have more days with no actions at all. It is also clear that Pb 6% and Pb 8% options have very similar profiles in terms of field actions to correct faults.

We expect that a longer simulation period would have shown more differences between the Pb 6% and the Pb 8% options. Inspired by this similitude between the Pb 6% and Pb 8% options in terms of field actions to correct faults, we went through a deeper performance analysis at base station level. One example of different performance between options Pb 6% and Pb 8% happens at base station 23. Figure 33 presents the timeline of events taking place (two failure events followed by a correction action and finally another failure event) and how those events impact communication channels availability (and subsequently the overall performance) for the Pb 8% option.

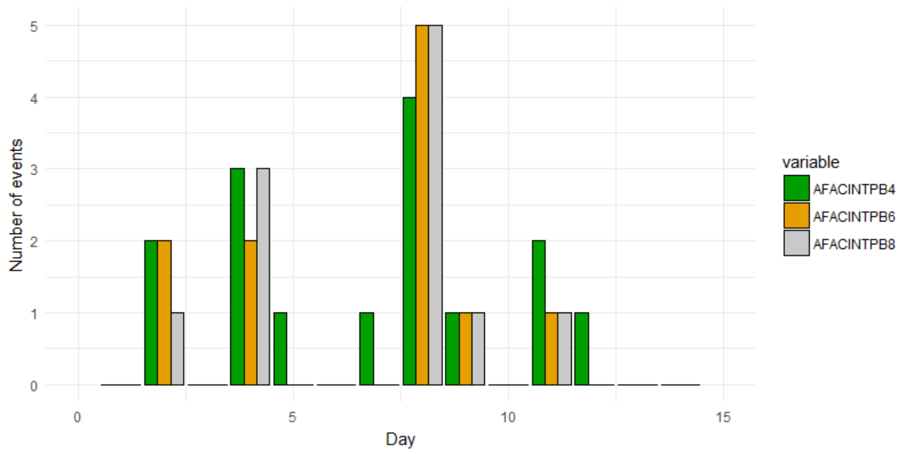

Figure 32 – Number of actions towards failure corrections (aggregated on a daily basis). AFACINTPB4, AFACINTPB6 and AFACINTPB8: "Information available" scenario with a grade of service of 4%, 6% and 8%, respectively, at the base station level.

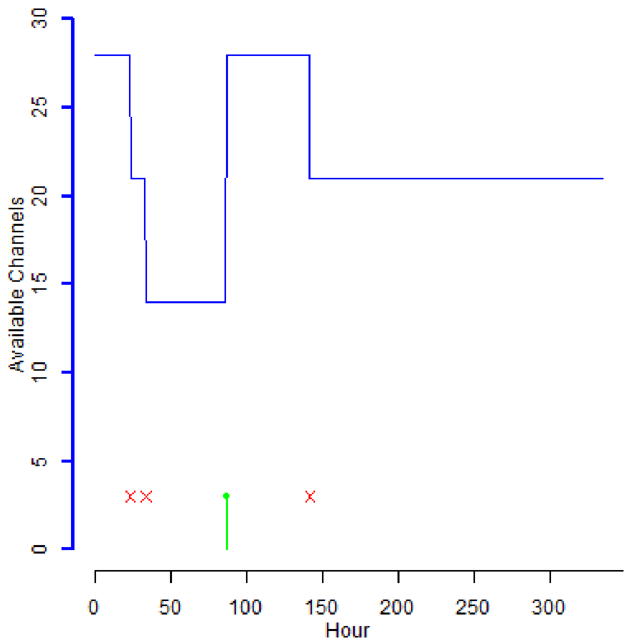

Figure 33 – Failure events and actions towards failure corrections at base station 23 along with the communications channel's availability for the Pb 8% option. The X symbol signals the fault events in the timeline whereas the | (vertical line) symbol signals the field action that corrected the active failures at this base station.

In Figure 34 we present the Pb timeline showing a growing trend of Pb until the threshold is reached (the 8% Pb is surpassed in the 90th simulation hour), thus triggering the corrective action.

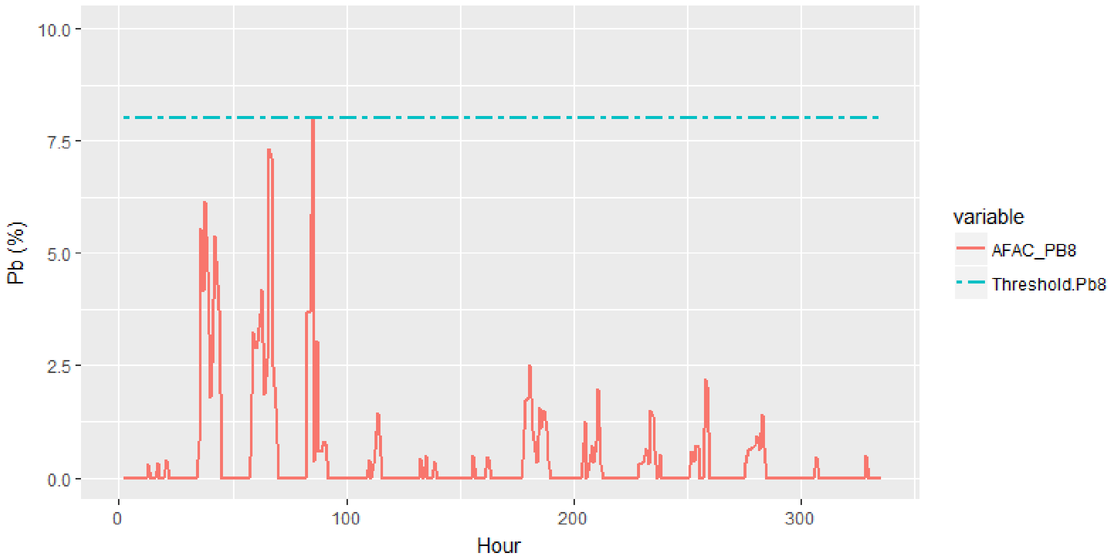

Figure 34 – Probability of blocked traffic (Pb) obtained for base station 23 when the Pb 8% option is used.

Now, if we compare the previous performance of Pb with the one obtained using Pb 6% as decision criteria, the moment the action takes place is anticipated, since immediately at the 38th simulation hour, the 6% value of Pb is surpassed, as shown in Figure 35. This value of Pb triggers the corrective action several hours before, if compared to the previous option (Pb 8%). Note that Figure 34 and Figure 35 are very similar except for the period between 38th hour and the 90th hour of simulation.

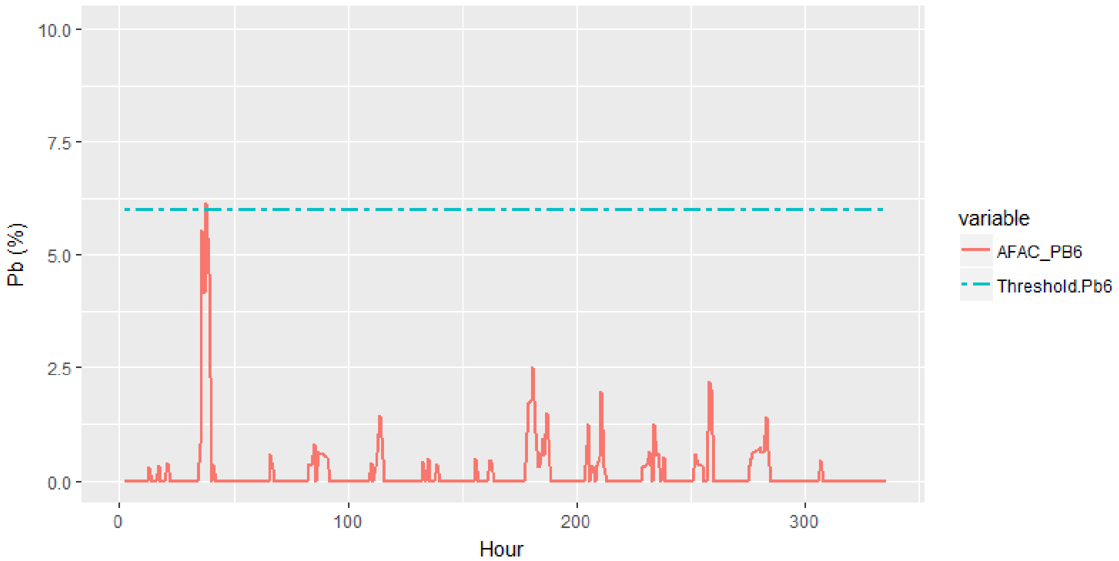

Figure 35 – Probability of blocked traffic (Pb) obtained for base station 23 when the Pb 6% option is used.

The timeline of events taking place for the Pb 6% option is presented in Figure 36. The type of events and their sequence is very similar (two failure events followed by a correction action and finally another failure event), but the corrective action takes place almost immediately after the second failure event and consequently there are more communication channels available for the Pb 6% scenario (compared to the Pb 8% scenario) between the 38th hour and the 90th hour of the simulation.

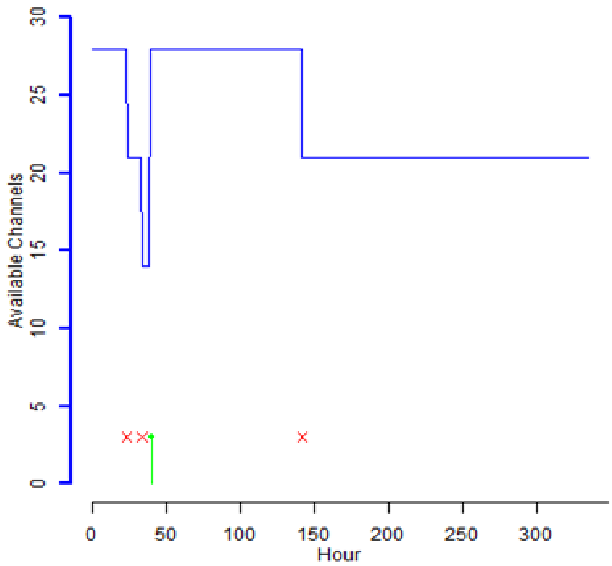

Figure 36 – Failure events and actions towards failure corrections at base station 23 along with the communications channel's availability for Pb 6% decision option. The X symbol signals the fault events in the timeline whereas the | (vertical line) symbol signals the field action that corrected the active failures at this base station.

The net effect of this difference in channel's availability is a superior amount of traffic processed in the period from 38th hour and the 90th hour when the decision option is Pb 6%, as presented in Figure 37.

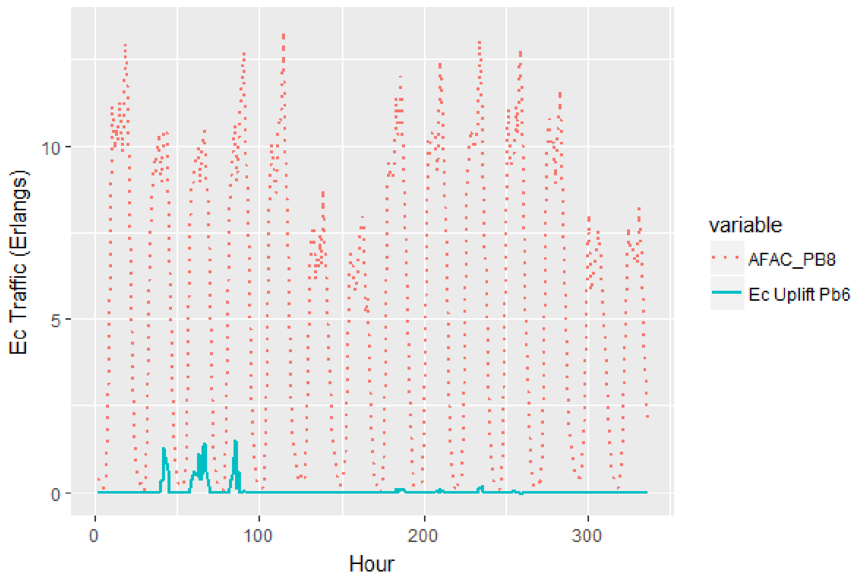

Figure 37 – Net difference, in terms of carried traffic, between Pb 6% and Pb 8% decision option at base station 23. AFAC_PB8: Traffic processed in the Pb 8% scenario; Ec Uplift Pb6: additional traffic processed in the Pb 6% scenario (as compared to the Pb 8% scenario).

The amount of additional traffic is 16 Erlangs, which could represent an extra income of 92 Euros (assuming the same charging plan of 9,9 cents of Euros discussed previously). Notice that we are able to estimate financial value from correcting faults at base station granularity, which might be useful in subsequent studies since the cost of a field action could differ for different base station and certainly the traffic carried out by each base station is also different, thus opening many opportunities for optimization research regarding the field actions of the telecommunications service providers.

5. Conclusions

This paper introduces NIESIM (Network Information Economics SIMulation), a software aimed at simulating a mobile communications scenario. A preliminary analysis resorting to this software provided some insights on the magnitude of financial value that is at stake when it comes to use information to detect and correct failures affecting a mobile communications service.

In order to estimate the value of the information required to act on correcting a specific telecommunications network event, we put forward a business context and simulated the behaviour of that context under multiple scenarios:

a) Perfect conditions of operation (no failures);
b) Operation under stress (incoming random failures) and no ability to monitor and correct any faulty condition (no information scenario);
c) Operation under stress (incoming random failures), with the ability to monitor and correct the faulty conditions detected (information scenario) considering multiple decision thresholds in terms of grade of service (Pb of 4%, 6% and 8%).

The experiment that was made does not distinguish between the value of information and the value of the complete process towards sustainable network operation, which comprises gathering information, computing performance indicators, making decisions and taking action to correct active failures in the network. Nevertheless, our extrapolation to one million users (with a realistic charging plan) does provide the order of magnitude for financial loss associated with service level decay (caused by problems on the network): 1% downgrade on service level (expressed in terms of Pb) could be worth as much as of 810.113€ over one year. Since decisions to correct failures are based in computed metrics (such as Pb) these findings should alert practitioners that it is extremely important to use accurate data within the decision process (and take action based on accurate information), since a small deviation (in this case of 1% in Pb) might have significant financial impacts.

Another important perspective is that when we chose different business targets for grade of service, we get significantly different financial performance (value captured is higher for higher level of service (lower Pb). Back to our one million users extrapolation, a fairly good level of service (Pb of 6%) still represents a loss of 4,6 M€ when compared to the baseline scenario with no faults, which is far from negligible. Adopting a Pb of 4%

as decision criteria for corrective actions is expected to improve financial performance up to 2 M€ per year (compared to the Pb 6% option).

The following steps in this research include the improvement of the model in order to distinguish the value of information from the value of the complete process towards sustainable network operation; the evaluation of the sensitivity of the business scenario regarding delays in the field actions, limitation in the periods in which the field teams are available and the time it takes for a field team to correct a fault; and considering user feedback as a source of information within the management process.

List of Acronyms

OSS	Operational Support Systems
BSS	Business Support Systems
QoS	Quality of Service
QoE	Quality of Experience
GoS	Grade of Service

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