Architectures and Tools Enabling Seamless Mobility in Future Collaborative Networks*

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Abstract. This paper focuses on the concept of the seamless mobility (provided by vertical handover mechanisms) in heterogeneous Future Internet Networks in the context of the HURRICANE project. We discuss future open collaborative network architectures and propose a set of entities that ensure seamless mobility and service continuity, from infrastructural/operational and business standpoints: an 802.21-like implementation of vertical handover, supported by an innovative business modelling software package, which replaces the traditional operations support stack with a more dynamic, marketplace-oriented system. We also discuss, an approach to distributed, policy-based, vertical handover management and a model for such policies, based on the monitorization and analysis of Call Detail Records that reveals users' behavioural patterns and allows personalization.

Keywords: Vertical Handover, Seamless Mobility, Collaborative Networks.

1 Introduction

In the future, wireless networks will be composed of multiple interconnected Radio Access Networks (RANs) using different Radio Access Technologies (RATs). End-user terminals will be expected to support several RATs, while possessing cognitive radio capabilities allowing them to operate flexibly on different frequency bands. Consequently, modern terminals will often be able to connect, and/or perform vertical handover (VHO), to the best RAN, according to specific network-related or user-related criteria. HURRICANE [1] aims to specify, design, implement and test innovative vertical handover mechanisms to provide seamless inter-system mobility.

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There are two sides to HURRICANE.

- Firstly, it provides mobility management entities and mechanisms for performing seamless media independent handover in a composite wireless network, supporting current and emerging radio access technologies, such as: fixed and mobile WiMAX (IEEE 802.16x); UMTS-LTE; WiFi (IEEE 802.11x); and DVB (S/T/H). HURRICANE leverages the Media Independent Handover Function (MIHF) from IEEE 802.21 [2], which links the lower OSI layers (1 and 2) to the IP based mobility management protocols, both on the operator and user sides. HURRICANE will also build a Policy-based Management (PBM) framework based on the approach given in the IEEE P1900.4 standard [3], providing common means to improve the overall composite network capacity and service quality, through distributed optimization of resource usage with the support of context information. This information is to be exchanged between the composite wireless network and the terminals.
- Secondly, HURRICANE lies in the business model that supports the entirety of a composite wireless network's operation. Rather than relying on the traditional interconnection agreements between operators, we have realized that the dynamism inherent to a composite wireless network is an opportunity to explore new and innovative ways for operators to do business. Thus, we propose that a subscriber is seen as a permanent roamer, to which network services acquired in real-time on a public market place are resold/provided.

This document is organized in the following way: Section 2 discusses relevant future open collaborative networks architectures; Section 3 presents an approach for distributed vertical handover policy-based management; section 4 will discuss a suitable model for policy derivation based on Call Detail Records (CDRs) monitoring, along with some supporting results and section 5 will present the set of novel business tools that are being developed in order to fully exploit the economical benefits of the seamless vertical handover mechanisms.

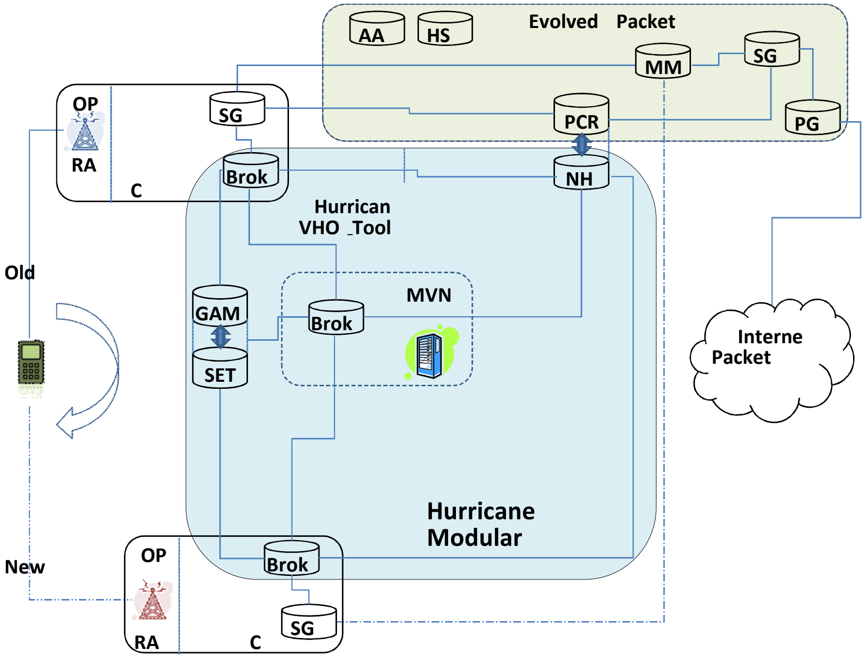

Fig. 1. Architecture of Collaborative Networks interconnection enabling vertical handovers

2 Future Collaborative Networks Architectures for Seamless Mobility

Figure 1 depicts the architectural elements of a roaming scenario, involving the concepts of the System Architecture Evolution (3GPP SAE).

This figure, beyond presenting the novel elements introduced by the HURRICANE tools, namely the Broker, Global Auction Market (GAME) and Settlement Exchanges (SeTX), depicts the scenario according to which a mobile node that is a subscriber of the Mobile Virtual Network Operator (MVNO) is currently physically connected to the mobile Operator OP1. During this connection, the user is within the coverage area of the RAN belonging to OP1 and the data traffic is forwarded by the Serving Gateway of OP1.

Each operator (either incumbent or virtual) is assumed to include a Broker entity, that is responsible for interfacing the operator with the other elements of the heterogeneous network, such as the other operators (and their respective brokers) for context information exchange, the Global Auction Market for purchasing resource credits and access business/institutional information the Settlement Exchanges for managing the logistics of the conducted calls and contracts management, and the Network Handover Manager for sending context information and receiving appropriate VHO policies.

The Broker has a critical impact on the envisaged HURRICANE architecture, given that it is the module that runs all the necessary functionalities to ensure the seamless provision of a service during a vertical handover. It should include a specific list of sub-blocks that will run the different tasks efficiently. Its architecture should also be generic in order to allow reuse by any operator (either Mobile Network Operator [MNO] or full/enhanced/basic MVNO).

Additionally, the architecture illustrated above allows for the abstraction of the architectural layer that is related to the HURRICANE VHO procedure. This layer is modular and can be in full synergy with the Evolved Packet Core (EPC) architecture of the 3GPP SAE.

It is of interest to determine the interactions between the entities of the HURRICANE VHO architecture (Figure 1) with the other external entities such as the Serving Gateway of each MNO (which is responsible for the signaling exchange between the user terminal and the Broker of the MNO during the VHO preparation and for the seamless data traffic re-direction during the VHO execution) and the Policy and Charging Rules Function (PCRF); the PCRF should have an interface with the Network Handover Manager (NHM), since it is the VHO policy derivation entity.

3 Vertical Handover Policy Based Management

Composite wireless networks require the use of efficient resource management schemes to regulate their usage and balance their loads. The most promising load balancing schemes are based on distributed radio resource usage optimization concepts that allow decentralized solutions with lower complexity and signalling load, compared to centralized solutions. To manage a distributed system, it is required to monitor the activity of its components and perform control actions to modify its behaviour. Policies are one aspect of information that can influence the behaviour of the system by permitting its objects to perform a specific set of actions, based on the observation of specific events and on the validity of pre-defined constraints. Therefore, Policy-Based Management is a management paradigm that separates the rules governing the behaviour of a system from its functionality. PBM can reduce maintenance costs of information and communication systems while improving flexibility and runtime adaptability.

In HURRICANE [1], the proposed PBM framework follows the same approach as the IEEE P1900.4 standard [3].The standard provides common means to improve the overall composite network capacity and service quality, through distributed optimization of resource usage with the support of context information that will be exchanged between the composite wireless network and the terminals.

Vertical handover policies originate from different levels of hierarchy within the network. For example, the NHM may formulate a VHO policy based on inputs from the PCRF module or another entity residing in the EPC (e.g. related to a global spectrum manager/regulator) that transcends over all MNOs and MVNOs that are connected to (and controlled by) the NHM. Thus, this sort of policy could have an extended scope, regulating the operation of multiple networks by setting specific constraints and rules for each. This global policy enables the centralized control of a heterogeneous network over long intervals, allowing static resource allocation, which may have the coherence time of traffic changes observed over large periods of time (e.g. months or days or even hours). For example, a regulator may impose a policy on each of the different operators' networks during peak hours of the day, so as to not exceed the available resource volume, ensuring a fair allocation among all operators and avoiding unbalanced network loads. To this effect the regulator use the available network measurements and other related context information.

Dually, a policy may have a local effect. It may be destined only to a specific user of a specific MNO or MVNO. For example, based on a user's CDRs, the Broker of an MVNO may determine the daily usage profile of the specific user. The Broker can thus identify specific periods of the day that the user initiates calls to specific numbers of different MNOs. Therefore, it may try to allocate the user to the most appropriate MNO for each time of the day, in order to reduce the signalling required for each call (by only limiting the required interactions within each MNO's network). The Broker may try to acquire the necessary network usage allowance through GAME and then, based also on the contracts it has with the involved MNOs, it will be able to issue a user-specific policy that will dictate the preferred networks to which the user should be connected on a timely basis. Again, this policy can be viewed as static, since it relates to the placement of a user in an MNO's RAN before even making a call and does not follow the temporal dynamics of an ongoing call, i.e. when a user is having a call the policy does not hand him/her over to another network due to the ongoing call characteristics.

4 Vertical Handover Policy Derivation Based on Users' Behavioural Patterns

This section describes the modules as well as the main functionalities employed during the data processing of the operators' Call Detail Record (CDR) files. Moreover, it includes a section that describes a typical CDR structure, as well as a proposed profiling module (a probabilistic neural network architecture) along with its initial assessment and evaluation.

4.1 CDR Structure

In telecommunication, a CDR is a record containing information about recent system usage, such as the identities of sources (points of origin), the identities of destinations (endpoints), the duration of each call, the amount billed for each call, the total usage time in the billing period, the total free time remaining in the billing period, and the running total charged during the billing period. Therefore, call detail records can be associated with the customer's calling behavior. This means that the choice of the variables/parameters described are critical in order to obtain a useful description of the customer. The format of the CDR varies among telecom providers and call-logging software.

Due to the fact that most of the times a considerable amount of CDRs is quite difficult to be collected for research purposes, we use CDRs along with a probabilistic neural network architecture, since this kind of networks present high generalization ability and do not require large amount of training data. Table 1, presents a set of CDR record fields used for the problem addressed in this paper. This set consists of 20 record fields.

Table 1. The record fields set used in our approach

Simulated CDR record fields			
GenSys	*Elapsed*	*DestTNA*	*Direction*
RecordingOffice	*TimeZone*	*DestPort*	*GPID*
ConnectDate	*ReleaseCause*	*ConnID*	*SvcLevel*
TimingInd	*SrcTNA*	*Encoding*	*Diversity*
ConnectTime	*SrcPort*	*Traffic*	*Contract ID*

4.2 Proposed Profiling Module Architecture

We personalize the process of provision through the analysis of CDRs. There are several techniques that enable us to do this, such as decision trees or (the many kinds of) neural networks. To choose the most adequate technique, we opted to analyse existing sets of CDRs. However, legal and privacy concerns dictate that network operators are limited in the amounts of call data that they can provide for research purposes; thus, we considered the application of algorithms and techniques capable of clustering and categorizing small, sparse sets of data. Probabilistic Neural Networks (PNNs) seem to provide an ideal compromise, as this kind of network presents high generalization ability and does not require large amounts of training data.

Probabilistic Neural Networks are a class of neural networks, which combine some of the best attributes of statistical pattern recognition and feed-forward neural networks. PNNs are the neural network implementation of kernel discriminate analysis and were introduced into the neural network literature by Donald Specht [5]. PNNs feature very fast training times and produce outputs with Bayes posterior probabilities. These useful features come with the drawbacks of larger memory requirements and slower execution speed for prediction of unknown patterns compared to conventional neural networks. Additionally, a probabilistic neural network uses a supervised training set to develop distribution functions within a pattern layer. These functions, in the recall mode, are used to estimate the likelihood of an input feature vector being part of a learned category, or class. The learned patterns can also be combined, or weighted, with the a priori probability, also called relative frequency, of each category to determine the most likely class for a given input vector. If the relative frequency of the categories is unknown, then all categories can be assumed to be equally possible and the determination of category is solely based on the closeness of the input feature vector to the distribution function of a class.

Probabilistic Neural Networks (PNNs) contain an input layer, with as many elements as there are separable parameters needed to describe the objects to be classified as well as a middle/pattern layer, which organises the training set so that an individual processing element represents each input vector. Finally, they have an output layer also called summation layer, which has as many processing elements as there are classes to be recognised. Each element in this layer is combined via processing elements within the pattern layer, which relate to the same class and prepares that category for output. However, in some cases a fourth layer is added to normalise the input vector, if the inputs are not already normalised before they enter the network. As with the counter-propagation network, the input vector must be normalised to provide proper object separation in the pattern layer. A Probabilistic Neural Network (PNN) is guaranteed to converge to a Bayesian classifier, provided that it is given enough training data.

4.3 Evaluation and Results Over Simulated CDRs

The topology of the proposed neural network that plays the role of the Profiling Module is 20-3000-2. The input layer consists of 20 nodes, which correspond to the number of the record fields set used in our approach (see Table 1). The second layer stands for the middle/pattern layer, which organises the training set in such a way, that an individual processing element represents each normalised input vector. This layer consists of 3000 nodes, which correspond to the total amount of the used CDRs. Finally, the network has an output layer of 2 nodes, representing two classes: The class that defines calling behaviour from landlines (L), and the class that defines calling behaviour from mobile communications (M).

Table 2 depicts the results of a first set instances tested over the proposed PNN architecture, which was firstly used in order to train the neural network classifier. The training set consisted of 194 instances. Among them 91 instances belonged to class L (landline calls) and 103 belonged to class M (mobile calls). The quality of prediction was examined using the jackknife test in which each instance was singled out in turn, as a test instance with the remaining instances used to train the PNN. The overall performance (OP) and the precision (P) regarding the training phase is depicted in Table 2.

Table 2. Evaluation Results (testing phase)

L: Landlines M:Mobiles		Predicted		
		L	M	Precision (%)
Actual	L	306	46	86,93
	M	46	376	89,09
Overall performance				88,11

The accuracy of prediction by jackknife tests for all instances is depicted in the confusion matrix of Table 2. The diagonal cells correspond to the correctly identified instances for classes L and M respectively, while the other cells present the misidentified instances. Every row expresses the ability of the system in terms of correct identification over a tested class. In other words, the system correctly identified 306 out of the 352 tested instances of class L and 376 out of the 422 tested instances if class M, meaning that the precision levels for these two classes reached 86,93% and 89,09%. The overall performance derived from the total amount of the correctly identified instances (diagonal cells) versus the total amount of instances used was measured above 88% (overall performance = 682/774 • 88.11%). These results were quite encouraging in respect to the aims of the HURRICANE project and towards CDR monitoring for revealing personalization and users' behavioral patterns.

5 HURRICANE Business Tools Supporting Seamless Mobility

HURRICANE shares a vision of convergence between networks and their related services. The basic premise is that customers should not be bound to a single operator, nor should operators be dependent on the providers of the physical infrastructure. Competition should be intense and more efficient, reducing prices on telecom services and increasing profitability to operators and service providers.

This vision will undoubtedly lead to the creation of Virtual Operators in the true sense of the word, that is, operators that can use the underlying infrastructure of physical operators, but are not tied to any such operator to provide services to their subscribers.

In our vision a Virtual Operator will select, in real-time, the best radio access technology available to the subscriber, based on his/her preferences, to initiate a call (or any other service); at the same time it will be able to negotiate, also in real-time, call agreements with any other physical operator (and even with other Virtual Operator) in order to constantly find the "best" value for the service provided (where "best" does not necessarily means lowest possible price).

Subscribers may then be "transferred" from one physical operators' network to another, seamlessly, via vertical handover. We see this as a natural extension to the horizontal handover mechanisms currently supported by all mobile operators (when a subscriber moves from one cell to another).

Subscribers can be seen as being "always" roaming. Their Virtual Operator being simply a broker to the services they require at any given time. It is up to the Virtual Operator to negotiate, in real-time, the best value for the services required by the subscriber.

In what follows we will briefly describe two of the novel business tools that we have been developing within the HURRICANE project. For a detailed description of these tools as well as the remaining tools please check the project's public website [1].

5.1 Global Auction MarkEts (GAME)

GAME is an implementation of an Electronic Communications Network (ECN). ECNs are electronic trading systems that automatically match, buy and sell orders at specified prices. The main purpose of GAME is to provide operators with sophisticated mechanisms to better manage the capacity of their networks and to correctly price their services.

Some potential benefits we expect from GAME are:

- By using the aggregate knowledge of all market participants, each individual operator will be able to better predict future trends.
- By creating a global market for their products (call duration, bandwidth, QoS, etc.) operators will be able to respond faster to changes in demand and supply.
- By providing real-time information regarding trading prices and volumes, operators will be able to better negotiate prices among themselves, and therefore reduce inefficiencies that exist when markets are not transparent.
- By providing a dynamic environment that facilitates the creation of new operators, more competition will ensue, leading to lower prices and better use of resources.

Before we can delve on architectural aspects of GAME, we must first analyze its core entities. With regards to the marketplace, our schema is similar to the one employed by the London Stock Exchange [11]. Participants place orders on tradable instruments, which are units representing a network service that was previously validated and known to be possible. Tradable instruments are contained within segments, which reflect eventual rules and restrictions to trading, such as available types of order, order size/price limits, etc. Segments on their turn are contained within markets, which also package similar trading rules.

On the participants' side, they can be divided into: Trader Groups, which in turn contain Traders; Participants that can assign distinct responsibilities and restrictions to each group and each trader; And orders, that can be placed on order books by traders or by participants, but never by groups.

In order to maximize the performance and through put of GAME, the system is comprised of four different applications with distinct goals.

The marketplace structure is contained within the *TradeSystem* application; it is here that all elements of the structure are defined and managed.

Participants interact with the system by means of the *MarketParticipant* application, which should reside in their intranets. This application obtains its marketplace data from the central TradeSystem application. It is available in two variants – Trader-Group and Participant. Trader-Group instances are satellites of Participant instance and obtain their data from that instance, much like Participant instances obtain the market data from TradeSystem.

Users place orders through *MarketParticipant*, which leverages the marketplace information obtained from TradeSystem in order to validate placed orders against the market rules, besides the restrictions inherent to their owntrader accounts'. Validated orders are sent to the Matching Node associated to the market; the *MatchingNode* application simply finds matches for placed orders and returns the result for maximum efficiency. When orders are matched, a trade is generated and sent by the Matching Node to the *DataFeedSystem*, which broadcasts the updates to all participants. Traders will see the update in real-time in their web browsers. The figure below presents the integration we have just discussed.

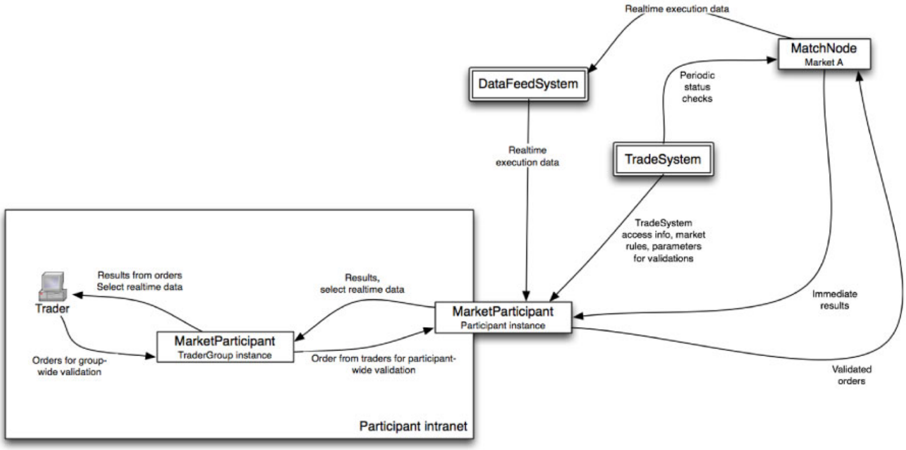

Fig. 2. Information flow between GAME applications

5.2 Settlement Exchanges (SeTX)

Settlement solutions provide tools to support several aspects of partner interconnection management such as accounts or contact information, or financial bookkeeping such as billing and invoicing or cash flows. The main priority of a settlement application is to apply the "settlement rate" which means the amount the originating carrier pays the foreign carrier to complete the call is typically half the accounting rate, Wallsten and Scott [10].

SeTX is responsible for all activities from the time a trade is made, until its usage is settled. It provides carrier's billing reports and data on the state GAME's volumes and monitoring tools of the contracts that were made.

SeTX is an application that is part of HURRICANE's Business Suite. This suite is composed by GAME, SeTX and some profiling tools including the Mobile Operator Billing Manager. The scope of the latter is to manage the active contracts that certain operator has made in GAME. MOBM stores all the information needed to calculate interconnection costs between Mobile Operators. The SetX application works as the "glue" between the other elements of the business suite. Therefore, it must interface with GAME, MOBM and the Broker (to collect usage data); to this effect, each module is implemented as a distinct component with distinct responsibilities. It can be separated in three distinctive interfaces where, each one of them will be responsible for trading useful data and notifications. The interface that connects to GAME will be responsible for exchanging all the relevant trade and institutional information between the applications while the Broker interface will collect usage data reports obtained from CDRs. Finally, the interface connecting MOBM will notify the latter about the state of contracts that were previously made in GAME.

Like other current exchanges, our Settlement Exchange supports commonly accepted functionalities, such as error management, the reconcilement of disputed CDRs (related to data supplied by operators), reporting, event rating and charging. Settlement mechanisms are fully configurable in time, units and length. Financial management functionalities are also provided.

However, HURRICANE's version of this fundamental tool will also provide a new set of features, which are required to support the new competitive eco-system we envision, like the support for multiple types of CDRs all belonging to same call (due the newly possibilities opened up by the handover mechanisms) as well as Fraud Detection and Prevention, by being able to cross check local patterns with global trends, where unusual rating of incoming or outgoing calls, high mobility and high usage patterns search are the top priorities regarding finding fraudulent usage as well as others fraud detection techniques like pre and post-call methods [6] and Churn Management, by detecting patterns leading to subscriber churn ahead of time and, therefore, allowing operators to apply tactics to prevent it, further study in [7], [8]. We also envision the possibility to develop Business Intelligence and Reporting tools, for instance by developing Cost Analysis real time reports which can be used by individual operators to optimize their orders in GAME and Customer Relationship Management which will help operators understand the real value of each subscriber [9]. Finally we also expected to provide Real Time Billing by using information received by GAME to calculate operator costs in real time.

5.3 Possible Usage Scenario

We now present a possible usage scenario for the HURRICANE framework, assuming that it was already in production phase.

Consider the 2010 World Cup in South Africa. This sporting event is expected to mobilize thousands of people around their respective teams. Realizing that a considerable number of subscribers may travel to South Africa for the duration of the championship, the management of HURRICANE MVNO, a Portuguese virtual operator, decides in a top-management meeting that will offer bargain prices for calls from/to South Africa to all its subscribers.

Consequently, the operator's marketing department representative is told to survey GAME for services that can be used to this effect. He logs into HURRICANE MVNO's *Market Participant* application, navigates to the market corresponding to their geographical region and then realizes that a new segment called "Services for 2010 World Cup" is available.

He checks which instruments are currently being traded in that segment and sees an instrument corresponding to a Call Transit service, routing calls from Portugal to all RANs in South Africa.

This service is provided by MNO_X, a Portuguese physical operator, and will be valid during the duration of the World Cup.

Realizing that that service will likely be useful for subscribers that will place calls to South Africa, he checks that instrument's order book for current quotes and finds that the cheapest sale price is around 50e/GB; he then places a bid for 10TB at that price and goes to lunch. Sometime later, he receives a message notifying him that the order had gone through, therefore resulting in a trade.

Market data, sales volume data and institutional data are sent to SETX, where HURRICANE_MVNO's operations department director decides how and when to activate the new acquired traffic volume. When the volume is activated a notification is sent to MOBM informing that a new volume is available. The volume will be spent according the subscriber's network usage, being always possible to halt its execution. The director will receive periodical Usage Reports informing him about the volume's status. It is now up to the HURRICANE MVNO to derive network usage policies, in order to optimize the usage of the existing resources; in this case subscribers with a large volume of calls terminating in South Africa will be allocated to MNO_X's RAN.

6 Conclusions

The HURRICANE project is, at its core, an exploration of new business models for mobile operators, with the ability to seamlessly perform vertical handover as a technological cornerstone. In this paper we presented concepts related to seamless mobility (provided by vertical handover mechanisms) in heterogeneous future networks, more specifically in the context of the HURRICANE project.

We discussed future open collaborative network architectures and, specifically, the entities that HURRICANE introduces to ensure seamless mobility and service continuity.

We also discussed an approach for distributed vertical handover policy based management for the optimization of the networks' resources' usage; policies can be used at several levels of detail, ranging from single subscribers to entire heterogeneous network. Policies can be derived using a tool that employs data mining techniques on bulk call data, extracting users' behavioural patterns and allowing the customization of the network usage.

We then gave a brief description of the business tool suite that will allow operators to fully exploit the business opportunities resulting from the widespread deployment of seamless handover. These tools eschew the traditional operational/business support systems associated to the telecom business; particularly, network services in HURRICANE are seen as tradable commodities that operators acquire and sell on a London Stock Exchange-like market, then manage independently with the other tools. We then provide a use case for those business tools, showing how they can make the process of providing a service to subscribers a quick and painless process. Note that we have left legal considerations regarding the implementation of HURRICANE to a later phase.

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References

[1] INFSO-ICT-216006 HURRICANE (Handovers for Ubiquitous and optimal bRoadband connectIvity among CooperAtive Networking Environments), `http://www.ict-hurricane.eu`

[2] IEEE P802.21, EEE Standard for Local and metropolitan area networks - Part 21: Media Independent Handover Services. IEEE Computer Society (January 21, 2009)

[3] IEEE P1900.4, IEEE Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks. IEEE Communications Society (February 27, 2009)

[4] Call Detail Records for UNI 1.0 Billing, version OIF-CDR-01.0, Optical Internetworking Forum (April 2, 2002)

[5] Specht, D.F.: Probabilistic Neural Networks. Neural Networks 3(1), 109–118 (1990)

[6] Fawcett, T., Provost, F.: Adaptive Fraud Detection. Data Mining and Knowledge Discovery 1, 291–316 (1997)

[7] Dasgupta, K., Singh, R., Viswanathan, B., Chakraborty, D., Mukherjea, S., Nanavati, A.: SocialTies and their Relevance to Churn in Mobile TelecomNetworks. University of Maryland, Baltimore County

[8] Chih-Ping, W., I-Tang, C.: Turning telecommunications call details to churn prediction: a datamining approach. Expert Systems with Applications 23, 103–112 (2002)

[9] Lee, J., Park, S.: Intelligent profitable customers segmentation system based on business intelligence tools. Expert Systems with Applications 29, 145–152 (2005)

[10] Wallsten, Scott, J.: Telecommunications investment and traffic in developing countries: The effects of international settlement rate reforms. Journal of Regulatory Economics 20(3), 307–323 (2001), `http://ideas.repec.org/a/kap/regeco/v20y2001i3p307-23.html`

[11] London Stock Exchange website, `http://www.londonstockexchange.com/`