Location-Based Vertical Handovers for Heterogeneous Wireless Systems

Valdemar Monteiro and Jonathan Rodriguez

Instituto de Telecomunicações, University of Aveiro,
Campus de Santiago, 3810-094 Aveiro, Portugal
`{vmonteiro,jonathan}@av.it.pt`

Abstract. Efficient radio resource management in wireless networks is increasingly becoming a necessity as current trends drive towards increased number of users and bandwidth hungry applications and services. In this paper, two concepts for targeting this capacity challenge are addressed: cooperative and localization based radio resource management. In cooperation we refer to the concept of a sole entity responsible for managing radio resources for heterogeneous networking environments, and herein we explore an IEEE 802.11e overlay for WiMAX. If a multimode terminal supports several radio access technologies the question arises, which one should be used for a particular communication? To answer this question, one first needs to investigate which systems are available, and what is the required criteria to select the most suitable network based on service, capacity and current load. This paper includes the notion of positioning information and SINR database to propose a vertical handover between the most recent versions of the standards of WiMAX and Wi-Fi. The results showed that there is a QoS gain of the proposed algorithm, over the traditional power-based handover, translated in the reduction of the number of handovers. The results show as well that there is a trade-off of overall system throughput decrease when using the proposed positioning-based algorithm.

Keywords: Vertical Handovers, Positioning, Suitability RAT selection, WiMAX, IEEE 802.11e.

1 Introduction

In an era where spectral resources are at a premium, it is essential for mobile operators to explore new technologies that can maximize the spectral efficiency of the system in order to deliver these services at a low cost. One technology trend is to exploit the notion of cooperation to allow heterogeneous wireless systems to exchange system information for enhancing protocol performance. So called "cooperative architectures" already exist between (Wireless Fidelity) Wi-Fi and Universal Mobile Telecommunication Systems/High Speed Downlink Packet Access (UMTS/WiMAX) like the loose and tight coupling approaches proposed by European Telecommunications Standards Institute/Broadband Radio Access Networks (ETSI/BRAN) [1] and 3rd Generation Partnership Project (3GPP) [2]. Furthermore,

J. Rodriguez, R. Tafazolli, C. Verikoukis (Eds.): MOBIMEDIA 2010, LNICST 77, pp. 255–265, 2012.

MIND [3], CAUTION [4], EVEREST [5], AROMA [6] have investigated architectures and platforms for cooperation schemes between heterogeneous Radio Access Networks, mainly between UMTS/HSDPA and Wi-Fi. In [7] the requirements and algorithms for cooperation of several radio access networks are presented. Cooperation between networks based on the load suitability for delay constrained services was investigated in [8]. The notion of suitability is based on the most preferred access system to accommodate the service, but this concept, suitability, can change as load increases in order to maintain the quality of service across the networks. So the goal should be to optimize the load in each RAT without loss of quality of service (QoS) guarantee. However, these works have not considered the effects of positioning information on network cooperation performance which can have a positive impact on protocol performance.

Research on the area of localization, wireless or cellular geo-location or positioning has been conducted since the late sixties. Localization has attracted much more interest after the U.S. Federal Communications Commission (FCC) announced that it is mandatory for all wireless service providers to be able to provide location information to public safety services in case of an emergency [9], [10]. Nevertheless, that was just the initial motivation, since researchers soon envisioned new commercial services that could become feasible if the exact location of the mobile user is known to the provider. Inspired by the difficulty of the localization problem and motivated by the aforementioned new commercial services, research exploited the nature of the wireless channel in an attempt to estimate meaningful parameters that could in turn be used for geo-location. Amongst the numerous techniques that were developed, the most commonly used and accepted are the geometrical ones and especially those based on the estimation of the Angle of Arrival (AoA), the Time of Arrival (ToA), the time difference of Arrival (TDoA), or a combination of two or maybe three of the above, or even the estimation of the received signal strength (RSS) [11], [12].

This paper includes the notion of positioning information and fingerprint database to assist with vertical handovers for the most recent versions of WiMAX and Wi-Fi.

This paper is organized as follows: section 2 presents the addressed Interworking scenario; section 3 presents the Inter-system handover Sojourn-time based algorithm; the numerical results accounting for localization in RAT selection are given in Section 4; and finally the conclusion is presented in Section 5.

2 Interworking Scenario

An algorithm for RAT selection is proposed for handover decision between WiMAX (802.16e) and Wi-Fi (IEEE 802.11e). The addressed scenario is depicted in Figure 1. An IP-based core network is assumed to act as the bridge between Wi-Fi, and WiMAX. The depicted scenario is aligned with future wireless trends that envisage a B3G network, a network of wireless networks that allow the users to attain the same service through, as covered by the 802.21 standard, whose details are neglected in this work. Within this IP cloud, we envisage a cooperative networking entity that logically communicates with WiMAX, and Wi-Fi to provide this networking bridge, more specifically referred to as the Reconfiguration Module entity, which is responsible for: i) gathering system and user specific information; ii) processing this information according to operator specific criteria; and iii) triggering a new handover event minimizing the so called Ping-pong effect, while maximizing the overall system performance. Moreover, it is assumed that a common operator deploys either systems, or that those systems from different operators share a service level agreement to cut-out any constraint related to heterogeneous systems management.

This scenario addresses the delivery of near-real-time video (NRTV) services that can be streamed either over WiMAX or Wi-Fi systems. The end user is currently subscribing to an IPTV service, which is currently also being delivered over the Wi-Fi hotspot. The default selection of the Wi-Fi network was chosen since it was deemed to be the most "fitting" network for the requested service. An example is the following. The operator, which is monitoring both networking entities, observes a sudden surge in Wi-Fi subscribers overloading the Wi-Fi network, or leak of coverage, whilst WiMAX is either under-loaded or in coverage area of the subscriber, and handling the usual internet services. The Radio Reconfiguration entity suddenly decides that it would be more efficient to shift one or some of the Wi-Fi users to the WiMAX network, since this leads to better QoS provisioning, and exploits the existing network capacity in a more efficient way. When a user is triggered for handover, the multi-mode terminal will initiate a new connection with WiMAX, whilst gracefully terminating the existing connection with Wi-Fi.

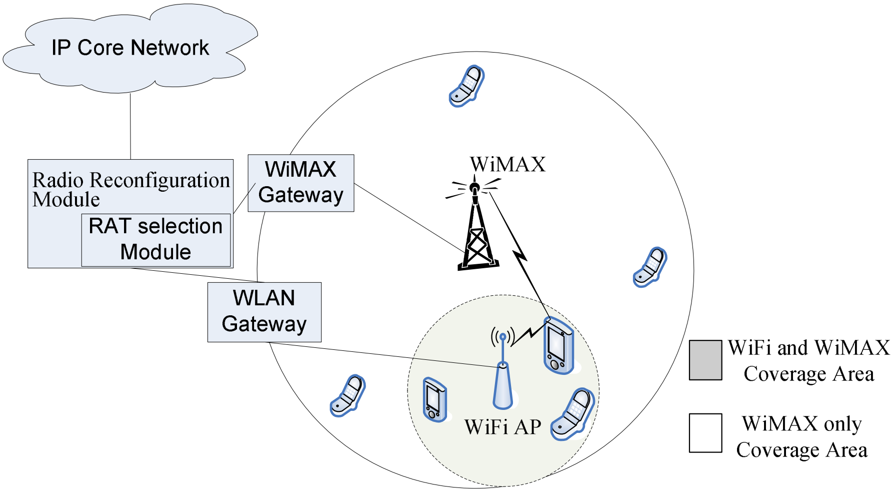

Fig. 1. Coverage area for Wi-Fi, WiMAX and for both systems

The study will mainly be focused on the criteria for handling a handover event, whilst neglecting architectural aspects of the intersystem handover, (tight/loose coupling, centralized or decentralized), including signaling aspects. It is assumed that the values for the metrics are available and can be obtained with no errors. By using signal strength, positioning information and predicting a mobility pattern not neglecting the load measurement for both systems, based on the Sojourn value, the algorithm selects the RAT which the user should be attached to. The details and decision criteria are the scope of the work presented in this section and are detailed in the next section.

3 Inter-system Handover – Sojourn-Time Based Algorithm System

3.1 Models and Parameters Used in Hard-Handover

Since the appearance of the WCDMA (UMTS), Soft-Handover has been introduced in order to extend and improve the capacity and coverage. WCDMA uses the fact that cells coverage is separated by spreading codes to increase the notion of coverage, as opposed to GSM, which would require hardware costs, since the cells are separated or distinguished by frequency bands. Apart from being a more power consuming solution, HSDPA, which uses fast scheduling and fast cell selection, is shown to be more efficient in packet based applications. [13] has indicated that hard handover is recommended, instead of soft-handover, for the packet based HSDPA. We will use the same approach for vertical handover, where while assuming multi-mode terminals, hard-handover case will be used.

Ping-Pong Effect, Average Window and Hysteresis

Typical radio propagation environment is characterized by fluctuations in the received signal power due to slow fading caused by buildings and obstructions as well as fast fading resulting from multiple propagation paths that the receivers are exposed to. Handover theoretically deals with these variations in the cells boundary where there is a signal decrease from one cell and increase on the other cell. As a results of the user mobility in the cell boundary, these fluctuations are fast and occur in frequent increase and decrease of signal strength. These signal fluctuations will lead to many handovers if a user is going to simply handover to a cell which provides a better quality of signal, when the user is moving from one cell to another. This impact, very significant around the cell boundary, forces the user to handover back and forth between two cells. This is normally referred to as the Ping-Pong effect.

To effectively reduce this Ping-Pong effect two mechanisms are normally adopted in hard handover algorithms: the Averaging Window and the Hysteresis value, which are explained below.

The averaging window is basically a filter that is applied in the received signal in order to average it during a certain period. The averaging window is applied so that N instantaneous measured received energy over interference plus noise (*Ec/Io*) samples of the pilot (or preamble) to be averaged with the same weight. The N is indicated as the averaging window size. For instance, the i_{th} averaged *Ec/Io* from pilot channel from cell j can be presented as,

$$Avrg(Ec/Io)_{i,j} = \frac{1}{N}\sum_{k=1}^{N}(Ec/Io)_{j,i-k} \tag{1}$$

The hysteresis value, *Hyst*, is used to prevent immature handovers. When the pilot of the best candidate cell is better than the current serving cell by *Hyst*, the handover will be performed. By doing this, the handover algorithm now can be explained as,

$$Avrg\,(Ec\,/\,Io)_{\max} - Avrg\,(Ec\,/\,Io)_{serving} > Hyst \tag{2}$$

where (Ec/Io)max indicates the best CPICH among candidate cells and (Ec/Io)serving corresponds to the CPICH of current serving cell.

While the averaging window *N* and the hysteresis *Hyst* prevent successive handovers avoiding the Ping-Pong effect, sometimes these will lead to late handover in some cases provoking firm degradation of communication quality. For this purpose the selection of the averaging window and the hysteresis are crucial for the network performance and communication continuity.

Optimization point and instant on handover decision will depend essentially on the system dynamics tracking and measurements prediction. In other words, if we can track the dynamics of the system by the meaning of the channel variation, optimized point for the handover decision can be reached. This is one of the most important challenges on the study of handover algorithms, and has been based on channel parameters characteristics evaluation [14] [15].

3.2 Sojourn-Time Based Handovers

We propose a vertical HO algorithm based on the Sojourn time of a mobile user within each RAT during a given period. The sojourn time theory is based on the Little theory, and Sojourn time corresponds to the amount of time that an entity remains in Steady-State within system S. The Little theorem referenced is a straight model to relate the concept of the Sojourn-time model in systems with wireless mobile networks. Figure 2 shows an entity moving in the system S1 and across S2.

Fig. 2. Motion of an entity in systems S1 and S2

The proposed algorithm is based on two principles which are, (1) the average measured SINR in the local vicinity and (2) the positioning information of the mobile station (MS). The proposed algorithm is based on the fact that if the motion of a MS can be tracked and predicted, then together with the average propagation conditions, unnecessary handovers can be avoided by estimating the best point in time for a handover decision.

In the case of wireless systems, we will assume that the Steady State time is the time that the received signal SIRi,j of MS i and RAT j is above a threshold Thj. The flow of entities can be attached to the call arrival rate, and the transit duration as the call duration. If a successive handover from one RAT to the other should not be made after a period of T, due to the Quality of Service degradation related to the handover, a Sojourn time Si,j based on estimated conditions of each mobile i in relation to the RAT j can be calculated. The selection of the suitable RAT can only be performed if it is assured that the Sojourn time is equal to T.

We have proposed a function that identifies the Sojourn time during a period T for each RATj, and the best RATj for attachment is given by:

$$BestRAT_j = \arg \underset{j}{Max}(S_{i,j}^{t0->t0+T}(t)) \tag{3}$$

Being

$$S_{i,j}^{t0->t0+T}(t) = \int_{t_0}^{t_0+T} f_{i,j}(t)dt \tag{4}$$

Where,

$$f_{i,j}(t) = \begin{cases} 1 \text{ if } \mathrm{SINR}_{\mathrm{i,j}}(\mathrm{t}) \geq Service\_\mathrm{threshold}_{\mathrm{j}} \\ 0 \text{ if } \mathrm{SINR}_{\mathrm{i,j}}(\mathrm{t}) < Service\_\mathrm{threshold}_{\mathrm{j}} \end{cases} \tag{5}$$

The success of the proposed algorithm is directly attached to the precision of the positioning information available, and the accuracy of the prediction algorithm for future positions.

3.3 Mobility Prediction

A) Mobility Model

The mobility model is based on 3GPP model [16]. The model is a pseudo random mobility model with semi-directed trajectories. Mobiles' positions are updated according to the decorrelation length [16], and direction can be changed at each position update according to a given probability. Direction can be changed within a given sector to simulate semi-directed trajectory.

Mobiles' speed is constant and the mobility model is defined by the following parameters:

- Speed value : 3 km/h
- Probability to change direction at position update : 0.2
- Maximal angle for direction update : 45°
- Mobiles are uniformly distributed on the map and their direction is randomly chosen at initialization.

B) Mobility Prediction

Among many methods proposed for the mobility and positioning tracking e.g. using Markov, White Noise [17], we adopt the Least Mean Square Error method fitted to linear function, assuming availability of present and past positions. The future positions are estimated using the previous 50 positions samples, obtained during each measurement period, which is 0.4 s.

4 Numerical Results

4.1 Simulation Scenario and Models

The scenario is based on a WiMAX area with an overlay of Wi-Fi Hotspot. The WiMAX is a cellular system with 3 tiers in a hexagonal layout consisting of 19 cells. To minimize the simulation duration due to complexity, we consider for transmission purposes only the central cell, acting all the others as interfering cells. 35 users are uniformly distributed in the central cell, moving at the speed of 3 km/h and experiencing high-priority NRTV video traffic at 64 kbps characterized by the 3GPP model [18]. To confine the movement of the mobiles on the central WiMAX cell, a wrap-around technique is applied. One Wi-Fi hot-spot is inside of the central cell for demonstrating the sojourn-time based handover concept. The simulation sample duration is 6 min real-time, and results were collected for 20 simulation samples. The mobility model is based on the 3GPP model for outdoor urban presented in [16]. For more details about the simulations platform used in this work please refer to [19] for the WiMAX platform and [20] for the Wi-Fi part. The key simulation parameters are presented in the Table 1.

Table 1. Main WiMAX and Wi-Fi simulation parameters

Parameter	WiMAX (802.16e)	Wi-Fi (802.11)
Tx Mode	-	EDCA (MAC Tx mode)
CRRM HO measurement period	0.4 s	0.4 s
CRRM HO decision period	10 s, 20 s	10 s, 20 s
Scheduler	MaxCI	Round-Robin
Link Adaptation	BLER 10%	-
Radio propagation model [16]	3GPP Urban + Fast Fading	ITU 2GHz propagation (Path Loss)
Cell type	Omni	Omni
Bandwidth	-	Variable with the user SNR
Environment	Urban Micro Cell	Outdoor Hotspot
Cell Radius	175 m	100 m

In the simulations we don’t use a fingerprint database itself. The notion of fingerprint database is used in the sense that with the available channel models, one can calculate the average channel composed by path loss and shadowing loss, for each position, given the position coordinates. The multiple cell scenario is created in the beginning of the simulation, and based on this the average SINR can be calculated for any position in the environment.

4.2 Simulation Results

The performance of the handover (HO) algorithms is measured in terms of the Number of handovers occurred during the simulation period, and Overall System Throughput. There are some additional parameters that should be introduced which are: the measurement period, which is the period during which the signal strength is measured; and handover decision period, used in the positioning-based HO proposed algorithm. The measurement period used in our simulations is 0.4 s which is approximately the measurement period utilized in cellular GSM network. The handover decision period should be related to the Quality of Service degradation during a handover. If we assume a handover delay around 2-3 seconds, and a QoS target of 90%, two values for the location based handovers can be proposed of 10 s and 20 s. These parameters are summarized in the Table 2.

Table 2. Handover parameters

Parameter	Positioning Based HO	Power Based HO
HO measurement period	0.4s	
HO decision period	10 s, 20 s	-
Number of Windows	-	10
Signal Hysteresis	-	3 dB

Figure 3 compares the CDF of the number of handovers for both the positioning based HO and the power based one. One can notice that there were significantly less handovers when the handover algorithm uses positioning information.

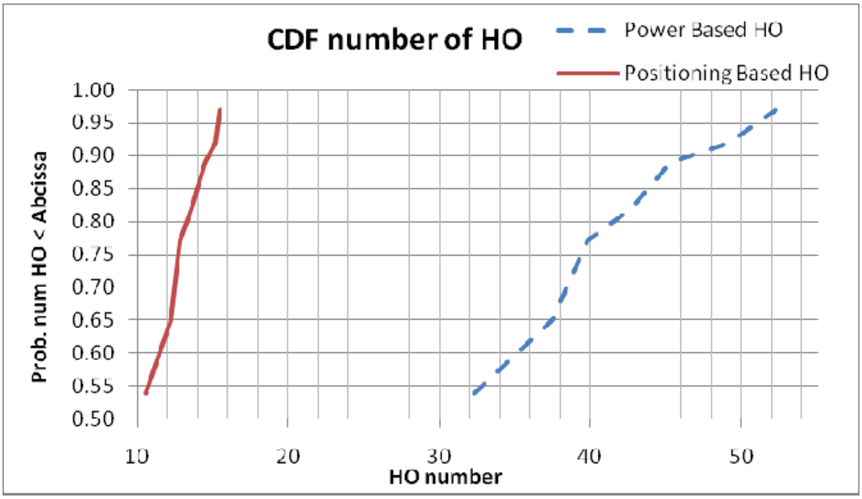

Fig. 3. CDF of number of Handovers with Positioning-based HO and Power-based HO

Figure 4 presents the system throughput. One can notice a reduction in the handover throughput when using the Positioning-based HO. This can be explained by the fact that the positioning algorithm fails to track the mobility due to the re-evaluation period. Increasing the evaluation period will result in more precise handover decisions, but can sometimes lead to a late handover decision, which can result in some degradation throughput.

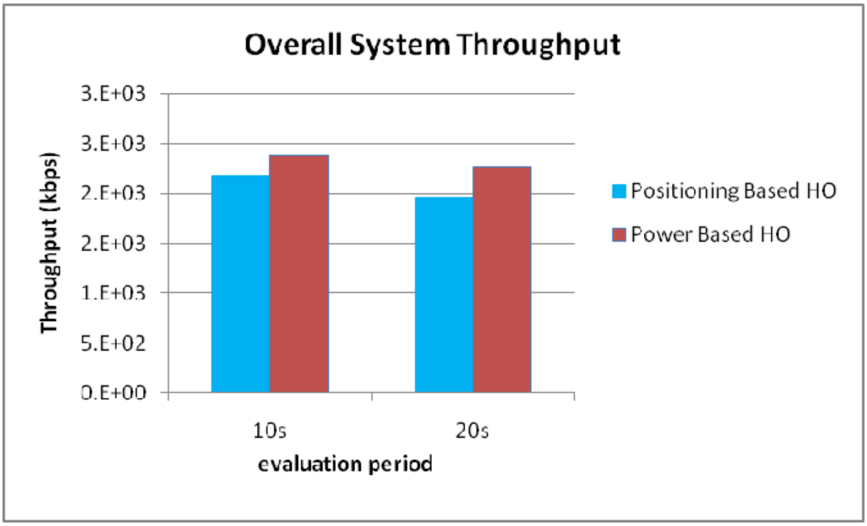

Fig. 4. Overall system throughput with Positioning-based HO and Power-based HO

5 Conclusions

In this work a positioning-based vertical handover algorithm was proposed using the mobile WiMAX (802.16e) with a mobile Wi-Fi (802.11) overlay. The algorithm assumes the existence of a fingerprint database that stores average channel measurements for a given area and availability of positioning information of each mobile. The proposed algorithm is based on the short-term mobility prediction for assisting with handover decision. The results showed that there is a QoS gain by using positioning information in contrast to traditional power-based handover, however this was at the expense of some loss in global throughput, translated in the reduction of the number of handovers.

Acknowledgements. This work has been performed in the framework of the MOBILIA project (CP5-016) under the Eureka Celtic Framework, as well as the ICT projects ICT-217033 WHERE and ICT-248894 WHERE2, which are partly funded by the European Union. We also would like to thank the Portuguese government for the funding of the MOBILIA project, through the QREN Framework – PO Centro (project n. 5555). The authors acknowledge and thank IT-Covilhã for the use of their Wi-Fi simulator.

References

1. ETSI TR 101 957: Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Requirements and Architectures for Interworking between HIPERLAN/2 and 3rd Generation Cellular Systems, V1.1.1 (August 2001)
2. 3GPP Third Generation Partnership Project, 3GPP, `http://www.3gpp.org`
3. MIND Evolving systems beyond 3G, IST-2000-28584 MIND, `http://www.ist-mind.org`
4. CAUTION IST project CAUTION, Capacity Utilizations in Cellular networks of present and Future Generation, `http://www.telecon.ece.ntua.gr/cautionplus`
5. EVEREST Evolutionary strategies for RRM, IST project EVEREST, `http://www.everest-ist.upc.es`
6. AROMA Advanced Resource Management Solutions for Future All IP Heterogeneous Mobile Radio Environments, IST Project AROMA, `http://www.aroma-ist.upc.edu`
7. Vegni, A.M., Carli, M., Neri, A., Ragosa, G.: QoS-based Vertical Handover in heterogeneous networks. In: Proc. on Wireless Personal Multimedia, Communication, WPMC 2007, Jaipur India, December 4-6 (2007)
8. Rappaport, T.S., Reed, J.H., Woerner, B.D.: Position location using wireless communications on highways of the future. IEEE Communications Magazine 34 (1996)
9. Mihovska, A., Tragos, E., Mino, E., Luo, J., Mensing, C., Fracchia, R., Horrich, S., Hui, L., Klockar, A., Kyriazakos, S.: Requirements and Algorithms for Cooperation of Heterogeneous Radio Access Networks. Wireless Personal Communications (published online, October 2008)
10. Figel, W.G., Shepherd, N.H., Trammel, W.F.: Vehicle location by a signal attenuation method. IEEE Transactions on AES 18(3), 245–251 (1969)
11. FCC, Revision of the Commission's Rules To Ensure Compatibility with Enhanced 911 Emergency Calling Systems, CC Docket, No 94-102
12. Reed, J.H., Krizman, K.J., Woerner, B.D., Rappaport, T.S.: An overview of the challenges and progress in meeting the E-911 requirement for location service. IEEE Communications Mag. 36(4), 30–37 (1998)
13. Pedersen, K.I., Toskala, A., Mogensen, P.E.: Mobility Management and Capacity Analysis for High Speed Downlink Packet Access in WCDMA. In: IEEE Proc. VTC-2004-Fall (September 2004)
14. Yap, J.H., Yang, X., Tafazolli, R.: Position assisted relaying and handover in hybrid ad hoc WCDMA cellular system. In: Proceedings of IEEE PIMRC 2002, pp. 2194–2198 (2002)
15. Jetzek, U.: Methods and System for Dynamic Threshold Adjustment for Handoffs in Radio Communication Systems. International patent, no.WO 00/38456 (June 29, 2000)
16. ETSI-UMTS, Selection procedures for the choice of radio transmission technologies of the UMTS, Universal Mobile Telecommunication System (UMTS), TR 101 112 v3.2.0 (April 1998)
17. Park, M.-H., Hong, J.-H., Cho, S.-B.: Two-Stage User Mobility Modeling for Intention Prediction for Location-Based Services. In: Corchado, E., Yin, H., Botti, V., Fyfe, C. (eds.) IDEAL 2006. LNCS, vol. 4224, pp. 538–545. Springer, Heidelberg (2006)

18. 3GPP TR 25.892 v6.0.0, Feasibility Study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancement, 3rd Generation Partnership Project, Technical Specification Group Radio Access Network (June 2004)
19. Nascimento, A., Rodriguez, J., Gameiro, A.: Dynamic Resource Allocation Architecture for IEEE802.16e: Design and Performance Analysis. Journal on Mobile Networks and Applications 13(3-4), 385–397 (2008)
20. Monteiro, V., Rodriguez, J., Gameiro, A., Cabral, O., Velez, F.: RAT and Cell Selection Based on Load Suitability. In: IEEE Proc. VTC 2008 Fall (September 2008)