WLAN-WiMAX Vertical Handover Hybrid Satisfaction Mechanism

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Abstract—Handover is the key enabling option to guarantee seamless mobility within any wireless communication system, where the inter-systems handover option has recently acquired large importance, both in the research and commercial fields. The motivation behind the vertical handover can be either based on the user demands to achieve larger data rates or lower service delays, but also it can be operator-based to balance the system load or to increase the system coverage. This paper presents a hybrid technique for vertical handover where both the operator satisfaction and the user satisfaction are concerned whenever a vertical handover is to be accomplished. Results are presented for the system behaviour with and without the proposed handover mechanism.

I. INTRODUCTION

The capability of switching between the different access technologies will provide a service added feature, as the user will select the most suitable technology in each location and for each application [1]. Such capability is widely known as the handover mechanism that has been a long time ago implemented in cellular systems, to allow the user to move over a large geographical area without any drop in the voice connection, and always within its network.

The heterogeneity of different wireless access systems has motivated the search for a modified version of the handover mechanism, where the user can handover to different networks based on the coverage, data rate, price per Megabyte, scheduling delay-jitter, etc. Such a kind of handover is named the Vertical Handover (VHO) approach [2] [3] that can be considered within the main wireless technologies as IEEE 802.11 WLAN, IEEE 802.16e WiMAX, 3G and 4G, among others.

The motivation behind any vertical handover technique must stand on the benefits from 2 main points of views: Customer interests and Operator interests. Several algorithms appear in literature to present the proposals to deal with either one of the two approaches, where the customer benefit-based techniques may collide with the operator benefit-based strategies, and vice versa. Therefore, for any handover proposal to succeed in realistic systems, a joint consideration of the interests of both parties should be tackled.

From the user part, the benefit from handover is presented in an improvement of the obtained Quality of Service (QoS) and data rate, and as long as the user is satisfied with its QoS, it is not interested in searching for another access technology through a handover mechanism, that can lead to a connection failure (remind that handover success probability is not 100%). The user satisfaction is shown to be based on thresholds [4] [5]. Regarding the minimum rate requirement per user, several studies have shown that the user satisfaction is insignificantly increased by a performance higher than its demands, while on the other hand, if the provided resources fail to guarantee its requirements, the satisfaction drastically decreases [6]. Therefore, the best scheduling approach is to deliver each user with its exact requirements, and do not allow for vertical handover unless its demands are not satisfied.

There are some predefined properties for each access technology and its usage/load. While WLAN is known to offer very large data rates, it lacks the control on the delay and its coverage is smaller than WiMAX. On the other hand, the latter shows wider coverage at lower data rate than WLAN, but a stricter control on the delay is accomplished [7]. As an example, if a user wants to run an online game, then the delay-jitter is its main requirement that motivates the user to move to WiMAX, while in the case of an FTP application, WLAN seems to be the most useful option.

Not only the user benefits from the VHO mechanism, but also the operator does. The benefits for the operator from the handover procedure can be presented in terms of a load balancing among the different cells and/or access technology, so that if some cell is saturated with users/rate, the system can redistribute some of the users to other access networks [8].

This paper tackles the two above benefits at the same time, and a joint metric is proposed to include both the user and operator satisfactions. Such a metric will indicate VHO mechanism to start or not, providing the system designer with the ability to offer both advantages at the same time, where the metric can be even modified to account for one single objective. The rest of the paper is organized as follows: while Section II presents the system model employed along the paper, Section III introduces the VHO proposed mechanism with the presentation of the joint metric. Section IV tackles the simulations to show the system performance with the proposed technique to end with the paper conclusions in section V.
Two access technologies are within the scenario, the IEEE 802.16e WiMAX and the IEEE 802.11n WLAN networks. We focus on the Downlink channel where \( N \) receivers, each one of them equipped with a single receiving antenna, are being served by a transmitter at the Base Station (BS) also provided with a single transmitting antenna. Even two access technologies are considered, but the connection BS-user is allowed though one single access technology on each time, where for each one of them, a channel \( h(t) \) is considered between each of the users and the BS with a quasi static block fading model being assumed, which keeps constant through the coherence time, and independently changes between consecutive time intervals with independent and identically distributed (i.i.d) complex Gaussian entries \( \sim CN(0, 1) \). Therefore each user is assumed to keep fixed during each fading block, and allowed to move from block to block, where the duration of each fading block is assumed to be 20msec to match with practical wireless broadband systems. Let \( s_i(t) \) denotes the uncorrelated data symbol to the \( i \)-th user with \( E[|s_i|^2] = 1 \), then the received signal \( y_i(t) \) is given by
\[
y_i(t) = h_i(t) s_i(t) + z_i(t)
\]
where \( z_i(t) \) is an additive i.i.d. complex noise component with zero mean and \( E[|z_i|^2] = \sigma^2 \). A total transmission power of \( P_t = 1 \) is considered, and for ease of notation, time index is dropped whenever possible.

### II. System Model

The advances in smart phones and portable equipment have driven the “always connected” requirement that customers demand the operators. Such demand is also linked to the increasing number of applications that the customers use to access through their mobile phones with an increasing pressure on the wireless link. Recent moves in the wireless arena have shown how several operators Worldwide (e.g., Vodafone, AT&T) moved the flat rate option to a restricted data download option for its customers, as the operator resources were not satisfying the huge demand on data rate over wireless links [3].

One of the possible approaches that the operators should have in order to decrease the load on their systems is by employing several wireless access technologies, so that users located at fixed locations (e.g., coffee shops, malls and even work), are pushed from the metropolitan or national network (i.e., cellular and/or WiMAX) towards hot spot networks (i.e., WLAN), to decongest the network.

Such a switch from network to network has to be smooth and without any disruption on the provided service. Therefore, a customer running any application does not have to stop the application when moving from an access network to the another; but it has to be seamless. Such motion is what is named as Vertical Handover (VHO) [3]. An important concept that enabled the seamless handover is the system being built on the Internet Protocol (IP) standard, where each user is assigned an IP address that is fixed whenever it moves within new broadband wireless technologies (e.g., WLAN, WiMAX and LTE). This paper focuses on the WLAN-WiMAX vertical handover option.

Several proposals in literature illustrate VHO based on the customer demands, so that to achieve larger data rate and lower delays for the user [2]. Other proposals study the operator demands and the load balancing on its network [4]. This paper presents a new VHO algorithm, where both targets must be achieved in order to obtain acceptable results for both the operator and its customers. Therefore, the VHO will be carried on basis of a hybrid satisfaction indicator given as
\[
Th = \alpha S_c + (1 - \alpha) S_{op}
\]
where \( S_c \) indicates the customer satisfaction indicator, while \( S_{op} \) refers to the operator satisfaction metric. An important role is played by the \( \alpha \) optimization parameter to identify the importance of \( S_c \) and \( S_{op} \). Notice that the proposed hybrid VHO algorithm can shrink back to achieve the satisfaction of a single entity, the operator or the customer, by changing the \( \alpha \) value, as \( \alpha \in (0, 1) \), where \( \alpha = 0 \) indicates a VHO algorithm dedicated to the operator satisfaction, while \( \alpha = 1 \) is devoted to the customer satisfaction. Practical values for \( \alpha \) are expected to be between the two extreme cases, as it provides the system engineer with a degree of freedom, to choose on the most suitable value on the basis of the scenario, the system load, and the running applications of the customers, among others.

### A. Satisfaction Indicators

The definition of the satisfaction indicators for both the user and the operator has to be based on thresholds, so that if the minimum requirement \( \gamma_{th} \) is satisfied, an increase in the performance over the requirement translates in a marginal satisfaction enhancement [4]. On the other hand, if the awarded performance \( \gamma_{ob} \) is slightly below the demands, it will make a severe decrease in the satisfaction indicator.

The satisfaction indicator for the customer \( S_c \) can be obtained as
\[
S_c = \begin{cases} 
  e^{0.01(\gamma_{ob} - \gamma_{th})} & \text{if } \gamma_{ob} \geq \gamma_{th} \\
  e^{(\gamma_{ob} - \gamma_{th})} & \text{if } \gamma_{ob} < \gamma_{th}
\end{cases}
\]
that presents values lower than 1 if the user is not satisfied, and larger than 1 if the user is fine with its obtained performance. The decay below 1 is exponential, while the increase above 1 is very small, to match with the customer satisfaction studies [4]. The performance can be presented through several metrics, and in this paper we select the Signal to Noise Ratio (SNR) as its metric, due to its link to both the data rate and the probability of error performance.

As for the operator satisfaction, it follows a different approach due to the economical objective behind the operator objectives. Therefore, the satisfaction does not follow an exponential decay. We can formulate a metric to account for
its obtained satisfaction $\beta_{th}$ and its comparison to the desired level $\beta_{th}$ as

$$S_{\text{op}} = \begin{cases} 1 + \frac{\beta_{th} - \beta_{th}}{\beta_{th} - \beta_{th}} & \text{if } \beta_{th} \geq \beta_{th} \\ \frac{\beta_{th}}{\beta_{th}} & \text{if } \beta_{th} < \beta_{th} \end{cases}$$

(4)

that shows a value below 1 if the operator is not satisfied (i.e., the load is larger than the threshold), and a value larger than 1 is the load is below the threshold load value. Along the paper, the operator satisfaction indicator is the system load, so that the objective of the operator is to make load balancing in its system.

IV. SIMULATIONS

In order to evaluate the proposed VHO algorithm, we developed computer simulations to test the algorithm efficiently, where we considered a wireless scenario covered by one WiMAX BS with coverage of 1 km diameter and multiple WLAN BSs with coverage of 30 m diameter each, scattered in a circular area of 1 km diameter. The added below table shows all the assumptions that have been used in the simulation.

<table>
<thead>
<tr>
<th>Area</th>
<th>circular 1 km diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiMAX Coordinates</td>
<td>x: 500, y: 500</td>
</tr>
<tr>
<td>WLAN Coordinates</td>
<td></td>
</tr>
<tr>
<td>WLAN1:</td>
<td>x: 940, y: 140</td>
</tr>
<tr>
<td>WLAN2:</td>
<td>x: 700, y: 860</td>
</tr>
<tr>
<td>WLAN3:</td>
<td>x: 460, y: 60</td>
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<tr>
<td>WLAN4:</td>
<td>x: 980, y: 700</td>
</tr>
<tr>
<td>WLAN5:</td>
<td>x: 620, y: 500</td>
</tr>
<tr>
<td>WiMAX Frequency</td>
<td>3.6 GHz</td>
</tr>
<tr>
<td>WLAN Frequency</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>WiMAX Bw</td>
<td>2 MHz</td>
</tr>
<tr>
<td>WLAN Bw</td>
<td>5 MHz</td>
</tr>
<tr>
<td>WiMAX Rx Sensitivity</td>
<td>3 dB</td>
</tr>
<tr>
<td>WLAN Rx Sensitivity</td>
<td>0.5 dB</td>
</tr>
<tr>
<td>WiMAX Coverage</td>
<td>1 km Diameter</td>
</tr>
<tr>
<td>WLAN Coverage</td>
<td>30 m Diameter</td>
</tr>
<tr>
<td>Modulation Scheme</td>
<td>64QAM, 16QAM and QPSK</td>
</tr>
<tr>
<td>Packet Size (w/t FEC)</td>
<td>216 Bits</td>
</tr>
<tr>
<td>CRC Size</td>
<td>16 Bits</td>
</tr>
<tr>
<td>FEC Size</td>
<td>50 Bits</td>
</tr>
<tr>
<td>Correctable Errors</td>
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<tr>
<td>WiMAX Tx AntGain</td>
<td>16 dBi</td>
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<tr>
<td>WiMAX Rx AntGain</td>
<td>2 dBi</td>
</tr>
<tr>
<td>WLAN Tx AntGain</td>
<td>5.5 dBi</td>
</tr>
<tr>
<td>WLAN Rx AntGain</td>
<td>0.5 dBi</td>
</tr>
<tr>
<td>WiMAX $\gamma_{th}$</td>
<td>$-54$ dB</td>
</tr>
<tr>
<td>WLAN $\gamma_{th}$</td>
<td>$-45$ dB</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.5</td>
</tr>
<tr>
<td>$\beta_{th}$</td>
<td>50% of Link Load</td>
</tr>
</tbody>
</table>

Table 1: Environment considered parameters

For a better presentation of the scenario, Fig.1 depicts the position of each WLAN BS and the only WiMAX BS in the system. The figure also shows the coverage strength, where as predicted, the nearby locations have better coverage than the farther locations. It also indicates the difference between the WiMAX and WLAN coverages, as already indicated in Table I previously presented.

The simulations examine the proposed algorithm in different scenarios by changing the WiMAX and WLAN cells load in each one. The user SNR value changes as the user moves through the considered area. We start by the equal load scenario where both WiMAX and WLAN show a 50% of their maximum allowed load, and we show the satisfaction indicator for both networks, to indicate when it would be better to switch to the other technology through the hybrid metric, that accounts for both network and user satisfaction. Fig.2 shows the satisfaction indicator where it can be seen that for the regions close to the WLAN BSs coordinates, the $Th$ value increases if connected to WLAN due to the large offered data rate by WLAN, while the operator load is the same over both access technologies.

Now we tackle the two extreme cases, where in the first one, the WiMAX system is not loaded, while the WLAN network is fully loaded. Fig.3 shows that the satisfaction indicator, that is controlled by the WiMAX system, leads the user to always desire to accomplish a handover to the WiMAX system. The satisfaction can be seen to remain high and stable as long as the received SNR by the user is higher than the set threshold, and dramatically decreases as the SNR drops below the threshold, which happens at the edge of the cell due to the path loss effect.
Fig. 3. Satisfaction indicator for a scenario with WiMAX-WLAN loads as 0%-100%. 3D view and Top view.

The other interesting scenario is the extreme case when the WiMAX system is fully loaded while the WLANs are not loaded. In that case, the operator desires to handover the customers to WLAN to decrease the WiMAX congestion, while the users also desire to go to WLAN to achieve larger data rate and service availability. Fig. 4 plots the satisfaction indicator, where it can be seen how the satisfaction greatly increases close to the location of the BSs while it is below 1 in all the other regions within the scenario. It means that the users within the WiMAX coverage alone are not satisfied while the users that get in the coverage region of any WLAN BS they immediately desire to handover to WLAN, so that their satisfaction increases.

Fig. 4. Satisfaction indicator for a scenario with WiMAX-WLAN loads as 100%-0%. 3D view and Top view.

In terms of the data rate received by each user, the number of the WLANs that are distributed within the WiMAX coverage impacts the resultant data rate, as it significantly increases the average data rate, specially if the WLANs are not highly loaded. In Fig. 5, it can be observed that with zero WLANs installed (i.e., the users are only serviced by the WiMAX system), each user receives the lowest average data rate in the figure. Installing more WLANs increases the possibility to handover to those networks when getting closer to them (i.e., when getting larger SNR) and consequently larger average data rates are obtained.

Indeed, a wise operator can optimize the network by installing more WLAN BSs as suitable (e.g., in indoor areas), to decongest its main network (WiMAX in this paper), and to provide more satisfaction to its customers. Current standardization bodies are working on this matter, keeping in mind that a large number of phones and smartphones are now equipped with several access technologies. For sure, it needs to carefully adjust the SNR thresholds for the user satisfaction as well as the load thresholds for the operator satisfaction.

The data rate performance of the system with and without the application of the proposed Vertical Handover mechanism is presented in Fig. 6, where the figure compares between the case of the users only serviced by WiMAX and the option that enables handover to WLAN BSs. The figure confirms the advantage of having WLAN cells in the scenario to increase the data rate as the users can handover to them.

V. CONCLUSIONS

The paper tackled with the vertical handover between WiMAX and WLAN systems, where the objective behind the handover process is to increase the satisfaction of the two entities in the communication process: the operator and the customers. A hybrid satisfaction indicator is presented to include the satisfaction of both entities, where the operator considers the handover as a mechanism to decongest its network so that to move them to another access technology that is less loaded than its current access technology. From the customer point of view, more satisfaction is obtained by

Fig. 5. The obtained Data Rate for an increasing number of WLAN BSs in the scenario under consideration. Case of WiMAX-WLAN loads as 50%-50%.

Fig. 6. Data Rate performance of the system with and without the consideration of the Vertical Handover approach. 3D view and Top view.
larger SNR values and consequently, more achieved data rate, lower error rate and more quality of service.

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REFERENCES