Vertical handover criteria and algorithm in IEEE 802.11 and 802.16 hybrid networks

Z. Dai[a], R. Fracchia[a] (roberta.fracchia@motorola.com), J. Gosteau[b], P. Pellati[a], G. Vivier[a]
[a]Motorola Labs Paris, Parc les Algorithmes de Saint-Aubin, 91193 Gif-sur-Yvette, France
[b]Sequans Communications, 19 le Parvis de la Defense, 92073 Paris La Defense Cedex, France

***Abstract*— Next generation wireless communications will likely rely on integrated networks consisting of multiple wireless technologies. Hybrid networks based, for instance, on systems such as WiMAX and WiFi can combine their respective advantages on coverage and data rates, offering a high Quality of Service (QoS) to mobile users. In such environment, WiFi/WiMAX dual mode terminals should seamlessly switch from one network to another, in order to obtain improved performance or at least to maintain a continuous wireless connection. This paper proposes a new user centric algorithm for vertical handover, which combines a trigger to continuously maintain the connection and another one to maximize the user throughput (taking into account the link quality and the current cell load). Moreover, we detail the implementation of that algorithm in existing standard technologies like 802.11 and 802.16. We show that, compared to more classical handover approaches, our proposed algorithm raises the system capacity, thus increasing the gain that can be achieved with a WiMAX and WiFi heterogeneous deployment.**

I. Introduction

In a homogeneous cellular system, a handover occurs when the connection is transferred between two base stations using the same access technology: the signal strength is the common metric used to predict the connection loss and to find the best neighboring cell to associate to.

The notion of vertical handover was introduced with the development of different wireless technologies and the coexistence of their network deployment including GSM, GPRS, and UMTS as cellular networks and WiFi, WiMAX as broadband access networks. Thus, a mobile station able to operate on several technologies should roam freely from one interface to another, being able to maintain its network connection and the QoS required by higher layer applications.

The vertical handover is a very important capability in the future wireless communication era, where an integrated network grouping multiple technologies will try to offer a global broadband access to mobile users. However, compared to the horizontal handover, the signal strength metric is sometimes not suited and often not sufficient to appropriately trigger the vertical handover: as heterogeneous networks have different system characteristics, their performance cannot be simply compared using the signal strength of two cells.

This paper aims at defining an efficient user-driven vertical handover mechanism which does not require any change on network and protocol architecture, and that can furthermore be easily applied in current WiFi/WiMAX hybrid systems. To this purpose, we first introduce the estimation of two common network performance parameters, data rate and network load, based on a measurement of Signal to Interference-plus-Noise Ratio (SINR) level and channel occupancy respectively. We then propose a novel algorithm which embeds two independent triggers: the first one aims at maintaining the wireless connection, the second one at maximizing the network performance.

The paper is organized as follows: Section II presents the related work, Section III describes the considered WiFi/WiMAX hybrid system model. Section IV details the SINR and channel occupancy measurements for both networks, and the estimation of the data rate based on these measurements. In Section V we describe the proposed algorithm which is evaluated by means of simulations in Section VI. Finally we outline some conclusions and future work in Section VII.

II. Related Work

Research activities carried on in heterogeneous handover context suggest the need for some modifications in the underlying network architectures. The most recognized among them is certainly the Media Independent Handover (MIH) layer proposed by IEEE 802.21 working group [1]. Two standard drafts have been produced by the working group in 2005 and 2006, and many protocols and signaling have been proposed for the inter-network handover. However, their scope is limited to the initiation and the preparation phases of the handover, whereas the definition of trigger mechanism and the evaluation of their performance, which are precisely the object of this paper, are not addressed by the standard.

Other works, specifically related to the WiFi/WiMAX vertical handover can be found in the literature [2]-[6]. Authors of [2], [3] introduce the estimation of WLAN network conditions based on NAV occupancy, using a Fast Fourier Transform to detect the WLAN signal decay; however both works lack a method for estimating the WiMAX network conditions. Paper [4] presents a handover criterion that combines the GPS location and the IEEE 802.21 information elements. However only few mobile devices currently have GPS access, and the 802.21 architecture is not fully defined and really commercialized yet. Authors of [5] propose handover rules based on a theoretically computed throughput, but without presenting a method to collect this metric. Authors of [6] propose a generic handover criterion accounting for interesting, but very difficult to collect, parameters such as cost, security, power, QoS and velocity.

III. WiFi/WiMAX Hybrid System

In this paper we consider a hybrid deployment of 802.16 [7] and 802.11g [8] wireless networks in an urban environment. The 802.16 addresses Non-Line-Of-Sight (NLOS) operations and it has about 400 meters of radius when used at 3.5 GHz with a maximum 20 Mbps data rate when using a 7 MHz bandwidth. Whereas 802.11g, well developed and commercialized at this day, operates in the 2.4 GHz unlicensed band and offers coverage of about 70-80 meters with a maximum data rate of 54 Mbps. For convenient notation, in what follows we will use the term WiMAX to refer to the 802.16 based deployment and WiFi for the 802.11g based Basic Service Set (BSS).

The WiFi and WiMAX networks are deployed considering their complementarities in terms of data rate performance and coverage: we assume that the WiMAX network guarantees users mobility in a large area and is accessible everywhere, while the 802.11 APs are selectively deployed in locations with a concentration of mobile users and heavy network traffic (Hot Spot).

We introduce a dual stack Mobile Station (MS), i.e., a user equipment that embeds two MAC interfaces with different IP addresses assigned respectively by the AP and the 802.16 Base Station (BS). These two MAC interfaces work independently and periodically monitor several metrics as link quality, channel occupancy, error rate. This information is then forwarded to a "mobility management" process implemented at the top of the MAC layer: this entity controls continuously the behavior of each stack and triggers the vertical handover when required.

We recall that this paper focuses on the handover decision and its implementation in existing technologies, and does not handle either the associated handover procedure at IP layer, usually managed by Mobile IP, nor the architecture of the "mobility management" process.

IV. Performance Monitoring

On both air interfaces, link quality parameters are reported by the MAC layer to the mobility management process for analyzing connection performance and taking handover decisions. The measurement of these parameters is required to satisfy the following properties: i) it should be periodical, in order to continuously monitor the access network condition; ii) it can take place without sending and receiving any data traffic on a currently unused interface; iii) it does not need any special AP and BS cooperation; iv) measured parameters should lead to comparable indicators in terms of performance.

Considering these requirements and taking into account also properties and constraints of existing standard technologies, we propose to monitor two fundamental parameters: the downlink SINR and the channel occupancy percentage. We then infer the used data rate from the former.

A. Estimation of the channel occupancy percentage

The method to estimate the bandwidth occupancy is not the same in WiFi and in WiMAX since they rely on different medium access mechanisms.

TABLE I

SINR and Modulation

.11g	SINR (dB)	5.5	8.8	13.6	13.9	20.3	23.3	28.2
	Rate (Mbps)	6	12	18	24	36	48	54
.16	SINR (dB)	2	6.43	12.5	18.93	20	24.65	
	Rate (Mbps)	2.2	4.4	6.8	13.3	17.8	20	

A WiFi system uses a contention-based access mechanism (CSMA/CA) and all subscriber stations continuously listen to the channel before competing for the access. The usage of the channel bandwidth can be approximated as the ratio between the time in which the channel status is busy according to the NAV settings and the considered time interval. The MAC process records the channel busy time, then periodically calculates the channel occupancy percentage.

In the WiMAX system, access to the channel is synchronized and network resource usage is controlled by the BS. The resource allocation is specified in the UL/DL_MAP messages: these messages are broadcasted by the BS (sent every 5 ms) and occupy the first DL burst of each frame. The bandwidth usage can thus be derived by decoding the broadcasted UL/DL_MAP messages: indeed, the UL/DL_MAPs specify the number of symbols allocated to each user, in uplink and downlink respectively. By calculating the total number of allocated symbols and comparing it to the number of symbols per frame, the channel occupancy percentage can be estimated.

The channel occupancy is then handed from both MAC layers to the mobility management process, which obtains in this way a first common parameter to compare the performance of the two different technologies.

B. Measurement of downlink SINR

SINR is measured on Beacon messages for the WiFi interface (typically sent every 100 ms) and on preamble or specific broadcast DL zones for the WiMAX interface. However, since WiFi and WiMAX are based on different physical layers leading to different data rates for the same SINR, the SINR measured on both networks cannot be directly compared and a different common parameter should be identified.

C. Data rate and Packet Error Rate estimation

To obtain a second common parameter we transform the measured SINR of both networks into the used data rate value. This approach is well suited for current and future devices implementing a SINR Link Adaptation (LA) algorithm.

A LA mechanism [9] consists in the selection for each packet transmission of the Modulation and Coding Scheme (MCS) most adapted to the instantaneous wireless link quality, and lets to better exploit the channel performance compared to a fixed data rate. The required SINR per MCS is 5.5 dB for WiFi and 2 dB for WiMAX. Assuming that the best MCS is used for the current SINR, it is possible to know at all times the used data rate. Similarly, since the Packet Error Rate (PER) as a function of the SINR is well known for all the used MCS, the PER can be easily inferred from look up tables combining the SINR and the MCS.

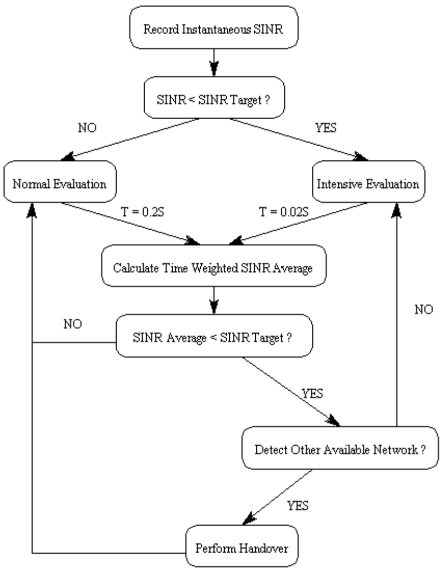

Fig. 1. Wireless Connectivity Trigger

V. Vertical Handover Algorithm

In the previous section we identified two major metrics that can be easily used to trigger an efficient vertical handover. We now propose two independent triggers: the wireless connectivity trigger, used to maintain the wireless connection, and the performance trigger. As a general comment we can say that the wireless connectivity triggers uses the SINR indication to determine whether a connection is going to be lost, and thus to activate the handover only as a "recovery" solution. The performance trigger instead uses the data rate and the load to derive an estimation of the throughput that could be achieved: in this case, the aim is to maximize the user performance.

A. Wireless connectivity trigger

This trigger is activated to guarantee an available wireless connection for the mobile station and only occurs when the current connection degrades and is likely to be lost. The algorithm is reported in Figure 1. A target SINR is defined, to obtain a PER $< 10\%$ with packets of 1500 bytes on a BPSK. Note that the 10% of the PER is the value normally used as a reference to define the minimum SINR value admitted in the cell coverage.

By default, the period of evaluation for the SINR is 0.2 s, but, when the SINR decreases under the target, it can be increased to 0.02 s for an intensive evaluation in order to anticipate a disconnection from the current BS or AP. Considering all the SINR values collected during the evaluation period, the average SINR is determined. If the average SINR is lower than the target, thus meaning that the quality of the communication has degraded, then the handover is triggered. Notice that it is likely that this trigger will be activated only when the lower MCS is not sufficient to guarantee a low PER.

B. Performance trigger

The performance trigger combines the data rate and the network load in order to maximize MAC layer performance. We combine these two parameters to obtain the estimated throughput, defined as: Data Rate · (1 - PER) · (1 - Channel Occupancy). By computing Data Rate·(1 - PER) we deduce the instantaneous PHY layer throughput that reflects the link quality. Instead, the Channel Occupancy indicates that part of the network resource is already occupied by other users: the handover decision is only based on the remaining bandwidth at the user disposal.

Note that, this estimation does not take into account the MAC layer overhead and the WiFi contention-based access. Nevertheless, this MAC overhead depends on many parameters, including the number of users, the MAC settings and the traffic characteristics of each user. The MAC overhead could thus be estimated but would introduce a bias in our index.

The handover trigger is based on a comparison between the estimation of the throughput on the current cell (namely, Current_throughput) with the one that could be achieved on the other cell (namely, Target_throughput). If the ratio between Target_throughput and Current_throughput is bigger than a threshold,

$$\frac{\text{Target\_throughput}}{\text{Current\_throughput}} > \text{throughput\_threshold} \qquad (1)$$

then the handover is triggered. We decided to set the throughput_threshold to 1.1, a value that avoids ping-pong effects and at the same time does not limit the gain that can be achieved with handovers. Moreover, a hysteresis time (i.e., a minimum time between two handovers) is set to 5 s.

Compared to the wireless connectivity trigger which periodically evaluates the link quality for maintaining the connection, evaluations of the performance trigger are less frequent. Indeed, a time average of more samples can better express the user performance in the long term: we considered time windows of 2 s.

VI. Simulation Results

Simulations are carried out on the OPNET 11.5 [10] platform, with the OPNET WiFi and WiMAX models. These models have been modified to implement the environment and parameters detailed in Section III, the SINR based LA mechanism as presented in Section IV-C and the MS embedding the mobility management process and enabling vertical handovers.

A. Handover validation scenario

We consider the scenario depicted in Figure 2 to describe the activation and the benefits of the two proposed triggers. At the beginning of the simulation, a mobile station is located at 40 m from AP1 and at 250 m from the WiMAX BS and it initially uses the WiFi technology. Then, at 50 s, it starts to move down through the WiMAX cell with a speed of 2 m/s crossing another WiFi cell.

Figure 3 depicts the throughput achieved by the mobile station when long-lived FTP applications generated at the

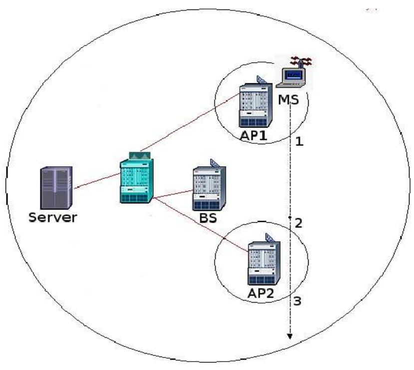

Fig. 2. Handover validation scenario

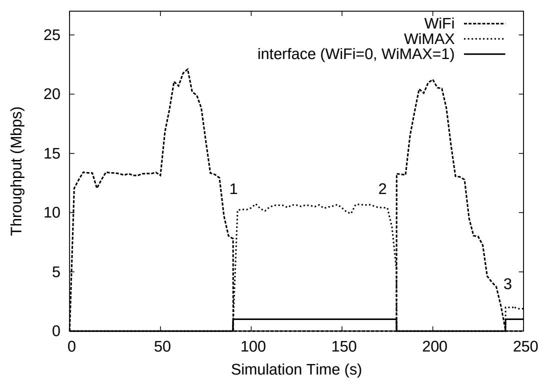

Fig. 3. Handover validation simulation results

server node are considered. As expected, and as Figure 3 illustrates, the mobile station uses consecutively the WiFi and WiMAX interfaces, with the following transitions (cf. numbering on Figure 2 and Figure 3):

1) The MS is initially in the AP1 coverage and the throughput it achieves depends on its distance from the AP. Then, when the throughput estimate in the WiMAX cell overcomes the one in the WiFi, the handover to the WiMAX BS is triggered.
2) Later on (i.e., at about 150 s), it enters the coverage of the AP2: when the WiFi throughput increases over the WiMAX one, the performance trigger originates the second handover, from WiMAX to WiFi.
3) Finally, the third handover from WiFi to WiMAX is triggered by the wireless connectivity criterion. Indeed, since the MS is fare away from the BS, the WiMAX throughput is lower than the WiFi throughput and the performance trigger is not activated. However, the wireless connectivity trigger correctly estimates that the MS is exiting the AP coverage and starts the handover to maintain the connection.

Now, after having demonstrated the correct and timely activation of the proposed triggers, we show the gain that can be achieved using the performance trigger. We consider a MS under the coverage of both a WiMAX BS and a WiFi AP, initially connected to the BS. We assume that, due to its placement, the SINR of the radio channel between the BS and

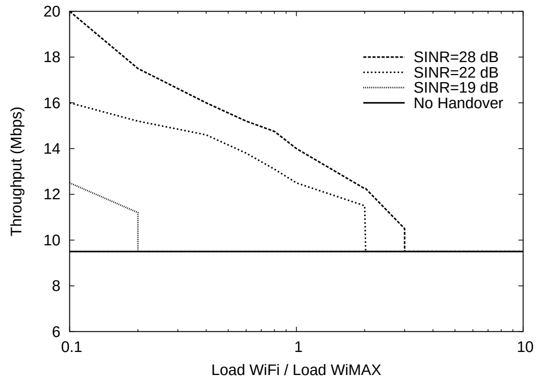

Fig. 4. Average throughput of the MS as a function of the ratio between WiFi and WiMAX load for different WiFi SINR

the MS is 22 dB. Then we vary the position of the AP to achieve a SINR on that link equal, lower and higher than that on the link to the BS. Moreover, we assume that other nodes connected to BS generate a load of 5 Mbps, while we vary the load of AP, generated by 802.11 users.

Figure 4 reports the layer 2 throughput achieved by the MS, as a function of the load ratio between WiFi and WiMAX, for different values of the SINR of the WiFi connection. This figure shows the throughput gain achieved with the handover (the throughput achieved transmitting towards the BS, that is if no handover is performed, is reported as a reference). First of all, note that all the handovers result in a throughput gain. The estimation of the throughput indeed lets the user correctly judge if advantages in performance can be achieved handing over. Moreover, we can gather that when the WiFi SINR is higher than the WiMAX one, the handover is performed until high values of the WiFi load, thus increasing the user throughput. For equal SINR, ther is an advantage in handover even when the WiFi is more loaded than the WiMAX since higher data rate can be used. Otherwise, if there is no gain in the signal strength and thus in the used data rate, the handover is performed only when the WiFi load is lower than the WiMAX one.

B. System capacity evaluation scenario

The goal of this scenario is to show the advantages of the performance trigger compared to more classical ones. This is done by analyzing the influence of the handover criterion used by a group of mobile stations on the total throughput of the hybrid system and on the per user throughput.

In the simulation set, users are uniformly distributed in the vicinity of an AP (i.e., between 0 and 80 m) where the access to a WiMAX network is also granted (the distance from the BS is on average 300 m, with an average data rate of 4.4 Mbps). We considered a video conferencing application transmitting 10 frames of 400 bytes per second both in uplink and downlink, resulting in a data rate of 640 kbps on each mobile. Every 10 s, a new mobile initiates its traffic, so that the traffic in the hybrid system gradually increases.

When the users arrive in the cell, they are primarily served by the AP; then, during the simulation, they are free to choose

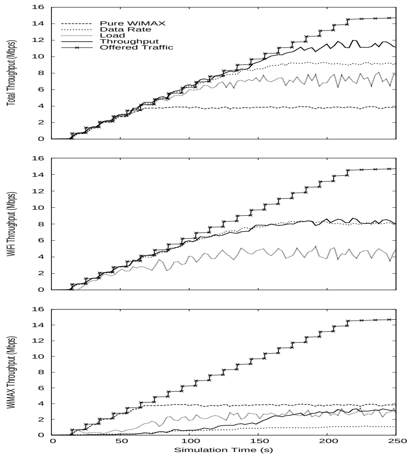

Fig. 5. Handover criterion influence on the achieved throughput

their favorite wireless interface using a specific handover criterion. Different criteria are considered:

- No handover - All mobiles use their WiMAX interface.
- Data rate - Mobiles choose the interface on which they estimate an higher data rate.
- Load - MSs choose the interface on which they observe a lower network load.
- Performance - MSs choose the interface providing the higher estimated throughput, combining load and data rate information.

In Figure 5 we report the total throughput of the heterogeneous system, together with the WiFi and WiMAX throughput for the different handover triggers. Moreover, we report in Table II the average throughput achieved by users selecting WiFi or WiMAX, when stationary load conditions are achieved (i.e. from 100 s in Figure 5).

Consider first the case of all users connected to WiMAX: the total system throughput corresponds to the WiMAX throughput (see dotted line on the bottom and top graphs in Figure 5). Note that the maximum WiMAX throughput is about 4 Mbps, meaning that we can serve up to 6 users at 640 kbps. Since this total bandwidth is shared among 20 users, the per user average throughput is 190 kb/s only. When the data rate criterion is used, the MSs close to the AP select the WiFi technology, since they can use higher data rates, even if the WiFi cell is already congested whereas the WiMAX cell has not been exploited enough. Thus, the 8 Mbps of maximum WiFi throughput (see dashed line on the middle graph in Figure 5) are shared among several users, resulting in a per-user throughput of 440 kbps. In case of load based criterion, users partition themself equally between WiMAX and WiFi until they estimate the WiFi not too loaded. After that, they remains connected to WiMAX, resulting in an unbalanced user distribution. The estimated throughput metric instead combines the load and the data rate metrics, which tends to balance fairly both systems when the WiFi becomes loaded; as a consequence the throughput metric results in a better use of the available spectrum, resulting in a higher system throughput. Obviously, also the per-user throughput and the fairness between WiMAX and WiFi users increase.

TABLE II

AVERAGE USER THROUGHPUT (KBPS)

	Pure WiMAX	Data Rate	Load	Throughput
WiFi	0	440	640	568
WiMAX	190	640	195	502

To conclude, the gain on the cell capacity (cumulative throughput at the maximum load of the AP and of the BS) when using the proposed metric in the choice of the best system is of:

- 280% w.r.t. to WiMAX only (from 4 to 11.5 Mbps)
- 64% w.r.t. to the bandwidth occupancy (from 7 to 11.5 Mbps)
- 27% w.r.t. to the data rate (from 9 to 11.5 Mbps).

VII. CONCLUSION

This paper proposed a new realistic approach for vertical handover between WiMAX and a WiFi networks. This algorithm, which combines data rate and channel occupancy in order to fairly balance users among the two networks, can be easily integrated in all 802.11 and 802.16 products. By testing this algorithm in a scenario simulating a urban environment, we showed that significant gain, compared to approaches involving the disjoint use of the load or the data rate as a trigger metric, can be achieved. Moreover, even if we focused on vertical handover only, the same methodology can be applied for horizontal handover. Some future work can be envisaged in order to improve the handover algorithm by taking into account the requirements in terms of Quality of Service of the application, or the the MAC layer overhead of the different access technologies.

ACKNOWLEDGEMENTS

This work was performed in the framework of the IST FIREWORKS project, which is funded by the European Commission.

REFERENCES

[1] V. Gupta et al., "IEEE P802.21 Tutorial," July 2006

[2] Q. Zhang et al., "Efficient Mobility Management for vertical handoff between WWAN and WLAN," IEEE Communications Magazine, Vol. 41 No. 11, Nov. 2003

[3] Q. Zhang et al., "A seamless and proactive end-to-end mobility solution for roaming across heterogeneous wireless networks," IEEE Journal on Selected Areas in Communications, June 2004

[4] A. Garg, K. C. Yow, "Determining the best network to handover among various IEEE 802.11 and IEEE 802.16 networks by a mobile device," 2nd Int. Conf. on Mobile Technology, Nov. 2005

[5] Y. Choi, S. Choi, "Criteria for vertical handoff between IEEE 802.16e and 802.11 systems," Joint Conference on Communications and Information, Apr. 2006

[6] A. Hassawa, N. Nasser, H. Hassanein, "Generic vertical handoff decision function for heterogeneous wireless networks," Mar. 2005

[7] IEEE Computer Society and the IEEE Microwave Theory and Techniques Society, IEEE 802.16 standard, Part 16: Air Interface for Fixed Broadband Wireless Access Systems, Oct. 2004

[8] IEEE Computer Society, IEEE 802.11 Standard, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Nov. 2001

[9] A. J. Goldsmith, S. G. Chua, "Adaptive coded modulation for fading channels," IEEE Trans. on Communications, Vol. 46, Is. 5, May 1998

[10] OPNET Technologies INC, hhttp://www.opnet.com