Abstract — In this paper a location-based algorithm is proposed for managing soft mobile-controlled vertical handover between wireless systems. The case of a dual-mode terminal equipped with UMTS and IEEE 802.11 network interface cards is analyzed in detail, and an novel approach for optimizing goodput and limit the so-called ping-pong effect is defined. The novel algorithm is based on a preliminary handover initiation phase triggered on the basis of mobile node location. Handover is then carried out by following a goodput estimation phase allowed by a transient of by casting during soft handovers. Experimental results provide an assessment on the use of location information to drive handover decisions.

Index Terms— Vertical handover, ping-pong effect, goodput, localization information.

I. INTRODUCTION

Current research efforts in the networking area strongly address the proliferation and coexistence of multiple wireless technologies like IEEE 802.11, UMTS, and WiMAX, especially in the urban environment. Next-generation mobile devices will be equipped with multiple network interfaces, e.g., they will be multi-mode terminals. When simultaneous coverage from multiple interface is assured to a roaming mobile terminal, intelligent mechanisms could allow it to select the network providing the best QoS over time, and then move from a network to the other thus implementing the so-called Vertical Hand-Over (VHO). Location information can be suitably exploited for this purpose.

The classic way to initiate an handover procedure is to detect significant changes of the RSSI (Received Signal Strength Indication) level, though other approaches can be used. In [1] a Quality-of-Service (QoS) based VHO makes handover decision by quality, either subjective and objective. In addition, handover decisions can be taken when the observed quality metrics reach a critical value (reactive approach). Location information can drive handover initiation allowing a mobile node to select the network which currently assures the best performance on the basis of its proximity to the nearest wireless cell.

VHO classical approaches include two main classes, i.e. the Mobile Terminal-Controlled Handover (MCHO) and the Network-Controlled Handover (NCHO), where the HO procedure is initiated and controlled by the Mobile or by the Network, respectively [2]. MCHO is in fact the most common case, and is employed, for example, in IEEE 802.11. On the other side, NCHO constitutes the typical operator approach for resource optimization and load management to preserve the best possible QoS level. More recent technologies developed frameworks supporting both approaches: for example, WiMax Forum considers an architecture that integrates both NCHO and MCHO, [3].

Variants to the classical MCHO and NCHO encompass a negotiation between the serving network (SN) and the mobile terminal (MT) in order to decide the VHO [4]. In [5] a new VHO for next-generation heterogeneous networks considers a neighbor node (NN) to decide the initiation of VHO. Namely, the NN takes over the VHO procedures from the MT and carries out handover procedures requiring large latency such as registration and authentication before handover initiation. Then, in [1] the VHO from UMTS to WLAN is driven by a functional entity, called QoS-based Decision Engine (QDE), that communicates with the MT during VHO procedure.

Many handover algorithms incorporate a hysteresis cycle within handover decisions so as to prevent a mobile node moving along the boundary of a wireless cell to trigger handover attempts continuously. This phenomenon is well known in the literature under the name of ping-pong effect and hysteresis is largely adopted in practical implementations.

In this paper we propose a location-based vertical handover approach which aims at the twofold goal of maximizing the goodput and limiting the ping-pong effect. Results obtained by Matlab simulations provide an assessment of the potentialities of using location information for VHO decisions, especially in the initiation process.

The paper is structured as follows. In Section II the proposed vertical handover approach is described. In Section III simulation results are discussed to evaluate the performances of the proposed algorithm. Finally, some conclusions are drawn in Section IV.

II. HANDOVER APPROACH

We are proposing a vertical handover algorithm for dual-mode mobile terminals provided with a UMTS and a WIFI network interfaces. Our vertical handover approach is mobile-driven, soft, based on mobile location information and measured goodput which is performed during handover attempts. In order to limit the so called ping-pong effect a hysteresis cycle is introduced in handover decisions.
Namely, we use mobile terminal’s location information to initiate handovers, that is, when the distance of the MT from the centre of the cell of the new network towards which a handover is attempted (hereafter referred to as new network) possesses an estimated goodput, i.e. $GP_{\text{WIFI}}^{\text{NEW}}$, significantly greater than the goodput of the current network, i.e. $GP_{\text{WIFI}}^{\text{CURR}}$. Following a handover initiation a channel goodput estimation procedure is performed for both the current network, which terminates with an effective handover execution if the goodput of the new network is effectively greater than the goodput of the current network.

In our handover approach we are interested in defining a simple mechanism (handover initiation) to initiate handovers to estimate GP, followed by a more accurate estimate (handover assessment) which actually enables or prevent handover execution.

\[ GP = BW \cdot (1 - P_{\text{out}}), \]

where $BW$ is the bandwidth allocated to the mobile and $P_{\text{out}}$ is the service outage probability. When elastic traffic is conveyed (typically when TCP is used), throughput tends to decrease with increasing values of $P_{\text{out}}$.

$BW$ is a function of the nominal capacity, of the MAC algorithm which is used in a specific technology and sometimes of the experienced $P_{\text{out}}$. The maximum theoretical $BW_{\text{WIFI}}$ is equal to 23Mbps (out of a nominal capacity of 54Mbs) in a IEEE 802.11a link [6], though it tends to decrease rapidly with the number of users because of the contention-based MAC. The maximum $BW_{\text{UMTS}}$ is equal to 14.4Mbps for a HSDPA network, which however, decreases rapidly with $P_{\text{out}}$. In handover initiation we are considering the maximum value of BW, i.e. $BW_{\text{max}}$ which is obtained in the case of a single MT in the cell and with a null $P_{\text{out}}$, as the actual goodput will be measured directly in the handover assessment phase.

$P_{\text{out}}$ is a function of various parameters. In the UMTS network it can be calculated theoretically [7], using the following formula:

\[ P_{\text{out}}^{\text{UMTS}} = \Pr \left( \frac{E_{\text{b}}^{\text{UMTS}}}{I_0 + \left( \frac{P_{\text{out}}^{\text{UMTS}}}{\sigma_N^2} \right)^2} \cdot A_d^{\text{UMTS}} \leq \mu^{\text{UMTS}} \right), \]

where $E_{\text{b}}^{\text{UMTS}}$ is the bit energy in the received signal, $\mu$ and $\gamma$ are parameters dependent on the signal and interference statistics, $\sigma_N^2$ is the receiver noise power, $A_d^{\text{UMTS}}$ is the signal attenuation factor dependent on the MT’s distance $r^{\text{UMTS}}$ from the centre of the cell, and $I_0$ is the inter and intracell interference power. $I_0$ can be rewritten in terms of the number $N_{\text{inj}}$ of effective interfering users as follows:

\[ I_0 = \frac{N_{\text{inj}}}{G_{\text{spread}}} E_s, \]

where $G_{\text{spread}}$ is the WCDMA spreading factor.

The service outage probability for a WiFi network $P_{\text{out}}^{\text{WIFI}}$ can be calculated theoretically in a similar fashion using the following formula:

\[ P_{\text{out}}^{\text{WIFI}} = \Pr \left( \frac{E_{\text{b}}^{\text{WIFI}}}{\left( \frac{P_{\text{out}}^{\text{WIFI}}}{\gamma \sigma_N^2} \right)^2} \cdot A_d^{\text{WIFI}} \leq \mu^{\text{WIFI}} \right), \]

We define as the radius of a wireless cell $R_{\text{cell}}$ the distance from the cell center beyond which the signal to noise ratio or the signal to interference ratio falls below the minimum acceptable value $\mu$. $R_{\text{cell}}$ can be obtained resolving the above equations or empirically, through measurement on the network. As an alternative, typical value for well-known technologies can be used, e.g. $R_{\text{cell}}^{\text{WIFI}} = 120m$ for IEEE 802.11 a outdoor [8], and $100m \leq R_{\text{cell}}^{\text{UMTS}} < 1km$ for a UMTS micro-cell [9].

The path loss $A_d(r)$ is approximately proportional to $r^\gamma$, and the received power $SNR(r)$ can be written as, [10]:

\[ SNR(r) = \mu \left( \frac{R_{\text{cell}}}{r} \right)^\gamma + \delta A_d. \]

Maximum $GP$ in a WIFI and UMTS cell can be calculated with the following approximated formulas:

\[ GP^{\text{WIFI}}_{\text{max}} = BW_{\text{max}}^{\text{WIFI}} \cdot \Pr \left( \frac{E_{\text{b}}^{\text{WIFI}}}{\left( \frac{P_{\text{out}}^{\text{WIFI}}}{\gamma \sigma_N^2} \right)^2} \cdot A_d^{\text{WIFI}} \leq \mu^{\text{WIFI}} \right). \]

\[ GP^{\text{UMTS}}_{\text{max}} = BW_{\text{max}}^{\text{UMTS}} \cdot \Pr \left( \frac{E_{\text{b}}^{\text{UMTS}}}{I_0 + \left( \frac{P_{\text{out}}^{\text{UMTS}}}{\sigma_N^2} \right)^2} \cdot A_d^{\text{UMTS}} \leq \mu^{\text{UMTS}} \right). \]

they will be regarded as zero out of cells.

Handover initiation will be performed when the estimated goodput of the new network is greater than the current one. Namely, in the case of vertical handover from WIFI to UMTS, the following equations apply respectively:

\[ GP^{\text{UMTS}}_{\text{max}} < GP^{\text{WIFI}}_{\text{max}} \]

It is worth noticing that when handover executions are taken too frequently, the quality as perceived by the end user can degrade significantly in addition to wasting battery charge. This phenomenon is well-known and called in the literature ping-pong effect. It can be useful to limit handover frequency by imposing a minimum interval of time between two consecutive handovers, which can be set different when connected to WIFI or UMTS. We refer hereafter to the
minimum interval between consecutive handovers with the parameter $T_{\text{wait, UMTS/WIFI}}$

B. Handover assessment

When a handover procedure is initiated a soft transition from the current network to the new network is attempted. In this phase channel goodput through the two networks is estimated for a short transient of time during which the sessions currently received are bycasted to both the current and new network interface. During the transient, the goodput experienced from the two interfaces is measured. The assessment of the goodput experienced through two interfaces can be done with various channel estimation methods, e.g. using the Weighted Moving Average, which is defined as follows.

Let us consider a convenient interval of time, divided into $K$ subintervals of duration $\Delta t$, during which the UMTS and WiFi channels are estimated. Let $i$ be the discrete time variable.

If channel estimation begins at time $N$, $i$ will then range in $[N, N+K]$. Let $g_i$ be the received amount of data in the $i$-th subinterval over $\Delta t$, the WMA-based goodput estimation at time $N$ is given by:

$$ GP_N = \sum_{i=1}^{N} a_i \cdot g_i, \quad N \geq K. $$

Following the handover assessment, the goodput measured for UMTS and WIFI are compared and if an improvement of the goodput is expected in case of change of network the handover is executed, that is, if $GP_N^{\text{NEW}}$ is greater than $GP_N^{\text{CURR}}$ is performed.

C. Handover algorithm flowchart

The steps of the proposed LB-VHO algorithm is depicted in Fig. 1. It starts selecting by default the WIFI network if the measured power from the WIFI NIC, i.e. $P_{\text{WIFI}}$, is bigger than the MT’s WIFI receiver sensitivity, i.e. $P_{\text{min, WIFI}}$, generally set to $-100\text{dBm}$. Otherwise, the MT detects UMTS network availability.

If either WIFI or UMTS connectivity is not available, the algorithm performs attempts to select a network at regular interval of times till a network is available and is selected.

Different $T_{\text{wait, UMTS/WIFI}}$ values were chosen in the simulation setup, as this parameter affects the algorithm’s performances, in terms of ping-pong effect limitation. In our simulations, we considered the following $T_{\text{wait, UMTS/WIFI}}$ values:

$$ T_{\text{wait, UMTS/WIFI}} = i \cdot 10, \quad i = 0, 1, 2, ..., 6, $$

respectively, corresponding to no wait, 10s, 20s, and so on until 60s. So, if the MT moves at 0.5m/s, a 10s waiting time results to 10m walked.

Movement from one network to another is performed, as detailed in Section II, and limited with the $T_{\text{wait, UMTS/WIFI}}$ parameter discussed in Section II A.

III. SIMULATION RESULTS

Some simulation results are now presented to assess performance of the Location-based Vertical Handover (LB-VHO) algorithm. We have compared performance of the LB-VHO described in Section II with a corresponding handover with a traditional Power-based vertical handover, (PB-VHO), [11] i.e. using power measurements in order to initiate VHOs instead of mobile location information.

We modeled movements of a MT by Matlab environment, over a grid of 400x400 square zones, each with an edge of 5m. Three UMTS cells and 20 IEEE 802.11b WIFI cells are located. The MT moves with a low speed (i.e. 0.5m/s), corresponding to a man walking speed, inside an heterogeneous map with UMTS and WIFI coverage for 12500 seconds. The MT’s path is generated randomly.

In the simulations, we set the following parameters:

- the transmitted power in the middle of UMTS and WIFI cells are about 43 and 30dBm, according to UMTS and WIFI cell requirements, respectively;
- the UMTS/WIFI receiver sensitivities are set at $-100\text{dBm}$, according to UMTS/WIFI cell requirements, respectively;
- UMTS and WIFI cell radius are set to 600 and 120m, respectively. For the channel model, we considered a typical AWG (Additive White Gaussian) one, and we referred to the Okomura-Hata model for the signal power attenuation [12].

As PB approach is based on power threshold [ISCE], we considered the $P_{\text{UMTS-TH}}$ and $P_{\text{WIFI-TH}}$ parameters, both set at $-100\text{dBm}$. This value is equal to the UMTS/WIFI sensitivity, $P_{\text{UMTS/WIFI-min}}$, respectively. Power threshold represents one parameter for vertical handover initiation, in PB approach. As explained in [11], when the measured power on the new interface is greater than a power threshold, old connection is moved from the current interface to the new one.
On the other side, LB approach is based on localization information, evaluated at the beginning of the algorithm, just after a waiting time period.

We have collected statistics on the total amount of bits received by the MT, for 4 cases, i.e. a dual-mode WIFI/UMTS terminal using LB-VHO algorithm, a dual-mode WIFI/UMTS terminal using PB-VHO algorithm, a WIFI single-mode terminal, and a UMTS single-mode terminal used. Each scenario differs from the other in terms of the UMTS/WIFI cell location and the path of the MT on the grid.

Table I, shows the statistics collected for $S=20$ randomly generated scenarios. Performance are assessed against:
1. the cumulative received bits (CRB) from the beginning to the end of the simulations with the LB and PB strategies;
2. the number of vertical handovers performed by the user moving in the grid.

Table I shows statistics on the CRB collected in the simulations. For each approach LB and PB and waiting time 3 parameters are reported related to the CRB, i.e. the mean value (in Gigabit), the standard deviation (in Gigabit) and the dispersion index, defined as the ratio of the standard deviation over the mean value. The three values for LB and PB are reported for a waiting time $T_{\text{wait}}$ of 0s and 60s, respectively.

Table II shows results of the number of VHO experienced with the LB and PB approach, still in terms of the mean value, standard deviation and dispersion index for various waiting time values. It can be noticed that the number of vertical handovers with LB is on average significantly smaller, (i.e. ranging in [9.65, 3.70] than that experienced with PB approach, i.e. ranging in [9.15, 329.85]). This demonstrates that the PB approach really requires a constraint on handover frequency limitations, while we have already shown that this measure is counterproductive with LB.

In Fig. 2, the mean values of vertical handovers with LB and PB vs. the waiting time constraint are depicted. This shows even more clearly how the LB approach, providing a more accurate assessment for handover initiation, is able selfcontrol handover initiations and prevents handover execution which can bring about little performance gain. PB approach is unstable even for high values of waiting time, as it can be noticed from the fact that the PB curve is not monotone. On the other side, LB approach is stable to limit vertical handover frequency. Difference between the number of vertical handovers for 0s and 60s is 3. This represents the stabilization of ping-pong effect, independent by waiting time parameters.

In Fig. 3 (a) and 3 (b) are reported the dynamics of the CRB over the mobile terminal steps during the simulation (i.e. a step is performed every 5 seconds) for a null waiting time and a waiting time of 60s. Curves in Fig. 3 (a) do not follow the same profile, unlike in Fig. 3 (b). This shows the reduction of CRB for LB approach when no waiting time constraint is applied. On the other side, the PB approach follows almost the same curve for CRB, either for 0s and 60s waiting time.

In Fig. 3 (a), up to 500 steps, CRB for LB approach does not follow the PB performance, and at the end of the simulation, the gap between two curves is very strong. Instead, in Fig. 3 (b), LB and PB performances are the same until up to 1000 steps, and the gap at the end of the simulation is very small. This represents a tradeoff between high CRB values and limitation of vertical handoff frequency. So, LB can represent a good compromise.
IV. CONCLUSION

In this work we have presented a location-based vertical handover approach for dual-mode terminals with WIFI and UMTS interfaces, which is able to control the ping-pong effect without specific constraint on minimum interval of time between consecutive handovers, while keeping performance high.

We have evaluated performance of the location-based approached with a corresponding approach which is power based, [11]. We have used the goodput as overall performance metrics for the two handovers and we have monitored the number of vertical handovers executed by the two algorithms over 20 simulation scenarios. Statistics collected with the two approaches have shown that the LB is more stable than the PB one. Specific limitation on minimum interval of time between consecutive handovers turns out to be counterproductive.

REFERENCES