A Probability based Vertical Handover Approach to Prevent Ping-Pong Effect

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Abstract—Vertical handover is a new trend for heterogeneous next generation networks, in order to assure ubiquitous and seamless connectivity to mobile users. This paper presents a novel vertical handover algorithm based on a probabilistic approach for decision strategy. The proposed technique deals with the assessment of a Wrong Decision Probability (WDP), which assures a trade-off between network performance maximization and mitigation of the ping-pong effect. The WDP is evaluated using network parameters, such as instantaneous estimated goodput. Analytical and simulation sections are presented in order to validate the VHO assessment. Basically, a simulated network scenario has been considered, where a mobile device moves at low speed. Specifically, simulated results have been evaluated for typical wireless access technologies (i.e. with small and medium transmission ranges). Results depict the effectiveness of the proposed vertical handover algorithm in terms of maximization of cumulative received bits, and minimization of unwanted and unnecessary vertical handovers.

I. INTRODUCTION

Next generation networks foresee the coexistence of many different wireless and mobile technologies, including 2.5G/3G cellular, satellite, WLAN, WiMAX and Bluetooth, where each network has peculiar features, such as bandwidth, security, coverage areas. When a Mobile Terminal (MT) moves inside of a heterogeneous environment, seamless connectivity between different networks and maximum bandwidth allocation are desirable feature to achieve. The choice and selection of the best available network, when to initiate a handover and how to achieve seamless connectivity between networks are currently main research topics.

Basically, a vertical handover (VHO) is defined by a connectivity switching from a serving network (SN) to a candidate network (CN) [1]. VHO decision can be based on several metrics, such as the traditional Received Signal Strength (RSS) [1], link-layer parameters (i.e. bandwidth, delay, signal-to-noise ratio, etc.) [2], as well as quality of service (QoS) metric [3]. An overview of main decision metrics is described in [4].

Moreover, limitation of the number of VHOs is another performance issue [5]. Namely, the so-called “ping pong effect”, for which an MT switches repeatedly between two access networks, can strongly affect MT’s battery life and the QoS level. Various techniques can be adopted to limit VHOs, and hence the ping-pong effect [6], [7].

VHO analytical methods based on a VHO Probability (VHP) are described in [8], and [9]. In [10] VHO decision criterion based on Wrong Decision Probability (WDP) is presented. Basically, the authors adopt the WDP as a VHO decision metric based on network parameters (i.e. available bandwidth). WDP is also assumed as a performance result for the proposed algorithm. The WDP is based on maximum capacity and available bandwidth from a CN. It is not considered how WDP probability affects MT’s performances in terms of QoS.

In this paper we present an analysis of WDP and VHP, based on the goodput performance parameter. The VHO decision is performed in order to limit unnecessary vertical handover occurrences affecting MT performances, (i.e. battery life) [6]. In our proposed WDP-based technique a VHO is initiated and controlled by the MT. It is defined as a Mobile Terminal-Controlled Handover scheme [11].

This work is structured as follows. Section II presents the details of the proposed WDP-based VHO approach is introduced. Section III shows simulation results, in terms of mitigation of VHOs and network performance.

II. WDP ASSESSMENT AND VHO ALGORITHM

Let us consider a dual-mode MT moving inside of an area with double radio technology coverage, i.e. offering network connectivity throughout either network $i$ or network $j$. A vertical handover scheme between network $i$ and network $j$ is adopted in order to assure seamless connectivity in the visited area and optimize network performance. This can be evaluated on the basis of several network parameters, such as transmission delay, error transmission probability, packet loss probability, throughput, and so on.

The MT goodput, i.e. the application level goodput, is considered as the performance metric to drive handover decisions. Namely, the purpose of the handover algorithm is
to select the network with the higher goodput level at any time. However, handover decisions are taken so as not to cause algorithmic instability and prevent the so called ping-pong effect.

It is assumed that the MT is able to assess the achievable goodput in both network $i$ and $j$, while attached to either network $i$ or $j$, e.g. by detecting the carrier-to-noise ratio, and knowing the network load in the current cells of network $i$ and $j$, respectively.

Let $\Delta t$ be a convenient interval of time for goodput estimation in network $i$ and network $j$, supposed equal for both networks. Let us consider the discrete time variable $k$, where consecutive instants $k$ and $k+1$ differs of exactly $\Delta t$ seconds. Consequently, every instant $k$ a new assessment of goodput for networks $i$ and $j$ is available.

A delta goodput stochastic process $\Delta GP[k]$ can be defined as a function of $k$:

$$\Delta GP[k] = GP_i[k] - GP_j[k],$$  \hspace{1cm} (1)

where $GP_i$ and $GP_j$ are goodput assessments for network $i$ and $j$, obtained for every time instant $k$, respectively.

Let us suppose that at time $k$, both $GP_i$ and $GP_j$ can assume a maximum value, specific for each radio technologies $i$ and $j$, (i.e. max $GP_i$ and max $GP_j$), and a minimum value equal to zero, (i.e. min $GP_i = 0$) being network capacity always non-negative and equal to 0 when no connection is available. Therefore, for the $\Delta GP[k]$ process the maximum and minimum value is calculated as follows:

$$\begin{align*}
\Delta GP_{\text{max}} &= \max GP_i, \\
\Delta GP_{\text{min}} &= -\max GP_j
\end{align*}$$  \hspace{1cm} (2)

When the $\Delta GP[k]$ variable is positive, network $i$ should be selected by the vertical handover algorithm, as it exhibits better goodput than network $j$. A trivial reactive vertical handover scheme could simply select the best network $i$ or $j$ at any instant $k$, and hence changes network every time the sequence $\Delta GP[k]$, $k=0,1,\ldots,\infty$, changes sign. However, this solution can be subject to instability (i.e. ping pong effect) on account of two possible causes:

1. fast changes of signs of the sequence $\Delta GP[k]$, when the MT roam in an area where $GP_i[k] \approx GP_j[k]$;
2. low accuracy in the assessment of $\Delta GP[k]$ samples (i.e. time instants $k$ sampled at high frequency values).

As a measure to prevent the first cause of instability, we are using the conditional probabilistic density function $\Delta GP[k+1]$ given $\Delta GP[k]$. We make the following assumptions to select a suitable conditional probabilistic density function with variables $\Delta GP[k]$ and $\Delta GP[k+1]$, when no specific knowledge of the probabilistic behaviour of $GP_i$ or $GP_j$ is known a priori.

Namely, the function,

- given $\Delta GP[k] = g^*$, has a maximum in $g^*$;
- it decreases with the distance from $g^*$;
- it is equal to zero out of the interval $[\Delta GP_{\text{min}}, \Delta GP_{\text{max}}]$.

According to previous function characteristics, a linear decrement can be considered as the conditional probability density function with variables $\Delta GP[k]$ and $\Delta GP[k+1]$. So, a triangular shape with maximum in $g^*$ will be obtained (Figure 1). Its analytical form is as follows:

$$p(\Delta GP[k+1] = g | \Delta GP[k] = g^*) =$$

$$= \begin{cases}
2(g - \Delta GP_{\text{min}}) & \text{if } \Delta GP_{\text{min}} < g < g^* \\
\frac{2(g - \Delta GP_{\text{max}})}{(\Delta GP_{\text{max}} - \Delta GP_{\text{min}})(g^* - \Delta GP_{\text{min}})} & \text{if } g^* < g < \Delta GP_{\text{max}}
\end{cases}$$  \hspace{1cm} (3)

The probability that $\Delta GP[k+1]$ is greater than zero, given $\Delta GP[k]=g^*$ and when $g^* \geq 0$, is obtained by integrating (3) in the range $0 \leq g \leq \Delta GP_{\text{max}}$:

$$p(\Delta GP[k+1] > 0 | \Delta GP[k] = g^*) =$$

$$= - \frac{\Delta GP_{\text{max}}^2}{(\Delta GP_{\text{max}} - \Delta GP_{\text{min}})(g^* - \Delta GP_{\text{max}})}.$$  \hspace{1cm} (4)

Similarly, the probability that $\Delta GP[k]$ is lower than zero, given $\Delta GP[k]=g^*$ and when $g^* \geq 0$, is:

$$p(\Delta GP[k+1] < 0 | \Delta GP[k] = g^*) =$$

$$= \frac{\Delta GP_{\text{min}}^2}{(\Delta GP_{\text{max}} - \Delta GP_{\text{min}})(g^* - \Delta GP_{\text{min}})}.$$  \hspace{1cm} (5)

By means of the conditional probabilities (4)-(5), it is possible to define the $WDP$ (Wrong Decision Probability).
Namely, whenever $\Delta GP$ function changes sign at the instant $k$, (i.e. $\Delta GP[k-1]-\Delta GP[k]<0$), the probability to change sign again at time $k+1$, (i.e. $\Delta GP[k]-\Delta GP[k+1]<0$) is:

$$\text{WDP} = \begin{cases} \frac{\Delta GP_{\max}^2}{(\Delta GP_{\max} - \Delta GP_{\min})(g^*-\Delta GP_{\max})} & g^* < 0, \\ \frac{\Delta GP_{\min}^2}{(\Delta GP_{\max} - \Delta GP_{\min})(g^*-\Delta GP_{\min})} & g^* > 0. \end{cases} \tag{6}$$

Then, to prevent low accuracy in the assessment of $\Delta GP[k]$ samples, an exponential smoothing of the first order is applied to the sequence $\Delta GP[k]$. The trend sequence $\{\Delta GP[k]\}$ is obtained as,

$$\{\Delta GP[k]\} = \alpha \cdot \Delta GP[k] + (1-\alpha) \cdot \{\Delta GP[k-1]\}, \tag{7}$$

where $\{\Delta GP[k]\}$ is used in equations (5)–(6) in the place of $\Delta GP[k]$ as a better assessment of the $\Delta GP$ dynamics to assess WDP. The parameter $\alpha$ is in the range $[0, 1]$.

On the basis of the WDP assessment, the proposed reactive VHO algorithm can be so built. Let us introduce the $\text{WDP}$ threshold (i.e. $P_{TH}$), defined as the value below which a vertical handover is executed, after a $\Delta GP$ sign transition. In other words, when the $\text{WDP}$ is estimated lower than a minimum $P_{TH}$ value, a sign transition in the sequence $\{\Delta GP[k]\}$, with $k = 0, 1, \ldots, \infty$, determines a vertical handover.

Namely, the algorithm proceeds as shown in Figure 2, by a finite state machine (FSM). The FSM is composed by two states, called as “Network $i$” and “VHO ($i, j$) attempt”, where the MT is connected to Network $i$. As the same time, if the MT is connected to Network $j$, it will be in states “Network $j$” or “VHO ($j, i$) attempt”.

Whenever a sign transition for sequence $\{\Delta GP[k]\}$ is detected at time $k$, a vertical handover procedure is attempted. The MT will move from “Network $i$” or “Network $j$” to “VHO ($i, j$) attempt” or “VHO ($j, i$) attempt”, respectively.

If the estimated $\text{WDP}$ is below the chosen threshold $P_{TH}$, the handover is accomplished. So, the MT will move to a stable state (i.e. “Network $i$” or “Network $j$”, if the VHO is from network $j$ to network $i$, or vice versa).

Otherwise, if $\text{WDP}$ is upper than the chosen threshold $P_{TH}$, it will be recomputed every $\Delta t$ seconds, till either a new change of sign in $\{\Delta GP[k]\}$ (vertical handover attempt aborted) or $\text{WDP}$ becomes lower than $P_{TH}$.

The computational complexity of the novel VHO algorithm is $O(1)$. Indeed, the core algorithm is implemented by (6). The values of $\Delta GP_{\max}$ and $\Delta GP_{\min}$ are required to be known a priori.

### III. Simulation Results

The algorithm presented in Section II is evaluated in a heterogeneous network environment consisting of two networks with different radio characteristics:

- **Network 1** is a network with a medium transmission range up to 600 m. Network coverage is provided by three access points (APs);
- **Network 2** is a network with a small transmission range up to 120 m. Ten APs are considered in the scenario.

The same capacity is assigned to the two networks in order to evaluate the handover algorithm without one network privileged over the other for its capacity.

The MT moves for 2500 steps at man walking velocity, (i.e. 0.5 m/s speed) [6] with a random mobility pattern. The main parameters of Network 1 and 2 are summarized in Table I.

The effectiveness of the proposed VHO algorithm is evaluated in terms of two parameters:

- the cumulative received bits (CRBs), defined as the total number of received bit from step 1 to step 2500 to be maximized;
- the number of vertical handover occurrences to be minimized.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Network 1</th>
<th>Network 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity [Bits/s]</td>
<td>$1\cdot10^6$</td>
<td>$1\cdot10^8$</td>
</tr>
<tr>
<td>Cell radius [m]</td>
<td>600</td>
<td>120</td>
</tr>
<tr>
<td>Sensibility [dB]</td>
<td>-100</td>
<td>-100</td>
</tr>
<tr>
<td>Maximum Tx Power [dBm]</td>
<td>43</td>
<td>20</td>
</tr>
<tr>
<td>Receiver gain [dB]</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transmission gain [dB]</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Carrier Frequency [Hz]</td>
<td>2400</td>
<td>2400</td>
</tr>
</tbody>
</table>
If the objective is to maximize the CRBs, the best choice is setting $P_{TH}$ near to 0.5, and $\alpha$ in the range [0.5, 0.9]. As an analogy, in such case the number of vertical handovers grows for high values of $P_{TH}$.

Finally, Figure 4 depicts the number of vertical handovers that an MT performs during its random walk (i.e. called as VHO frequency) vs. the $P_{TH}$ probability. Different values of $\alpha$ show that the lower the number of vertical handovers is required, the higher $\alpha$ is to be set.

IV. CONCLUSIONS

A novel VHO algorithm for an MT having two generic network interface cards has been presented. The proposed approach can be applied when no knowledge of the probabilistic behavior of the achievable goodput in the two networks is known a priori. The focus is both on maximization of goodput as well as on limitation of vertical handover frequency, which strongly affects mobile terminal performance, in terms of seamless connectivity and consumed energy during a vertical handover.

The function referred to as delta goodput stochastic process is modelled and used in the algorithm to reduce the vertical handover frequency and keep the received bits as high as possible. Through the monitoring of delta goodput stochastic process it is possible to estimate a WDP function and comparing it with a VHO probability threshold $P_{TH}$, in order to limit the vertical handover frequency. In the presented approach a first order exponential smoothing technique is used to assess the delta goodput stochastic process. Empirical results show how it is possible to choose a convenient value for $P_{TH}$ that depends on the smoothing factor $\alpha$, and gives the best trade-off between cumulative received bits and vertical handover frequency.

REFERENCES


