

# Connectivity Support in Heterogeneous Wireless Networks

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## 1. Introduction

Recent advances in wireless technology and decreasing costs of portable devices strongly contributed to increase the popularity of mobile communications.

Wireless communication and device integration have lead to the so-called *nomadic computing* (or *mobile computing*) where portable devices (such as laptop and handheld computers) allow users to access Internet and data on their home or work computers from anywhere in the world. Multimedia services requirements nowadays encompass not only large bandwidths, but also *on-the-move* facilities. Future 4th generation wireless communications systems will provide seamless mobility support to access heterogeneous wired and wireless networks (Makhecha & Wandra, 2009), (Lin *et al.*, 2010).

Emerging and pre-existing wireless technologies exhibit different characteristics, access technologies, available services and network performances. For example GSM, UMTS, WLAN and WiMAX have different bandwidth (70 Mbps for WiMAX and 9.6 kbps for GSM), cell diameter ( 50 km in LoS for WiMAX and 100 m for WLAN), or handover latency (3 s for WLAN and 50  $\mu$ s for WiMAX).

The increasing demand for services with high QoS requirements and novel mobility scenarios, like *on-the-move* business users, home and office networks, *on-the-move* entertainment, info-mobility etc., provide users to be connected to the Internet anytime and anywhere, as well as user services and connectivity be maintained, and kept alive. *Mobility management* in heterogeneous networks is the essential support for roaming nomadic devices switching from one access technology to another, at the same time maintaining seamless connectivity at high QoS services (*i.e.* video-streaming).

New emerging multimode mobile devices are equipped with multiple wireless network interface cards, providing *Vertical Handover* capability to autonomously select the best access network. The design of innovative handover mechanisms –sometimes called as *handoff*– between heterogeneous mobile devices (*e.g.* PDA, laptop, smart phones) and seamless integration of different integrated network (*e.g.* GSM, UMTS, HSDPA, GPS, WLAN, Bluetooth and so on) is an open research issue.

In this way, a mobile user can seamlessly switch between different networks, supporting the same services. This process must be performed to automatically adapt to change access networks and environments, without any user participation. In order to do this, cross layer design for multimedia communications is required. Mobile computing then becomes more feasible, *e.g.* a mobile user performing a videoconference using UMTS maintains this service even though the link breaks down, accessing into a WLAN network.

Vertical Handover (VHO) is a mechanism allowing heterogeneous connectivity by enabling switches from a serving network to a candidate network, whenever users or network requirements (*i.e.* power level, network congestions, or other QoS constraints) impose or suggest it. Notice that VHO allows switching from one access technology to another, thus offering additional functionalities with respect to classic horizontal handover where mobile nodes move from an access point to another without changing the serving access network (Balasubramaniam & Indulska, 2004), (McNair & Fang, 2004).

In this chapter we show how heterogeneous networks for next generation multimedia systems can cooperate in order to provide seamless mobility support to mobile users requiring high multimedia Quality-of-Service (QoS) constraints (Knightson *et al.*, 2005).

We describe the traditional techniques of Vertical Handover in heterogeneous wireless networks. Basically, in Section 2 we introduce the main characteristics of handover process and our effort is addressed on a first handover classification, which distinguishes between horizontal and vertical, hard and soft, upward and downward procedures, and more. Beyond several handover algorithms, in Subsection 2.1 we give an overview of current IEEE 802.21 standard for seamless connectivity in heterogeneous environments. In Section 3 we describe different decision metrics for handover mechanisms. Various metrics triggering handover decisions, including multi-parameters QoS, and mobile terminal location information, will be described in details in Subsection 3.1, and 3.2, respectively. Moreover, a hybrid approach which exploits both power measurements and location information will be presented in Subsection 3.3. Finally conclusions are drawn in Section 4.

## 2. Vertical handover procedures overview

New-generation wireless networks adopt a heterogeneous broadband technology model aiming to guarantee seamless connectivity to mobile users, anytime and anywhere. Different network characteristics are expected for different multimedia applications, each of them requiring a specific QoS level. Ubiquitous access through a single network technology could not always guarantee seamless connectivity, due to geographical coverage limitations, so that the cooperation of different access networks represents an important feature for heterogeneous environments.

A general definition of handover assumes it as the process by which a mobile terminal keeps its connection active when migrating from the coverage of one network Access Point (AP) to another. Basically, different types of handovers can occur in wireless overlay networks. Network switching can be performed not only to maintain user connectivity but also to keep high QoS. There are some decision handover parameters based on QoS, available resources, channel quality or preference consumer.

In GSM, handover decision is based on the perception of channel quality, reflected by the received signal strength and the availability of resources in neighbour cells. The Base Station (BS) usually measures the quality of the radio link channels used by Mobile Nodes (MNs) in its service area. Measures are periodically updated so that degradations in signal strength

going below a prescribed threshold can be detected and handover toward another radio channel or cell can be initiated.

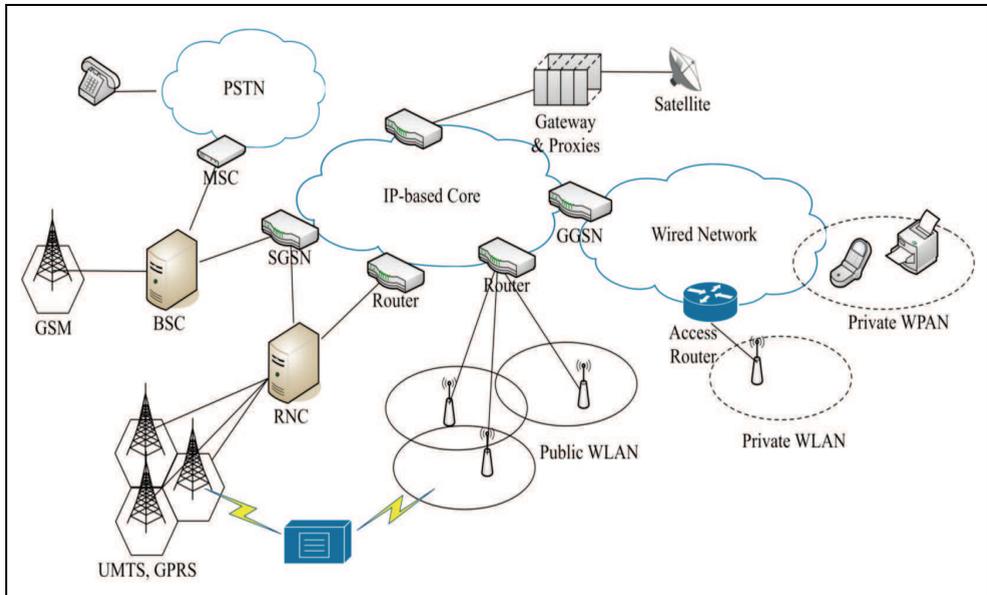


Fig. 1. Heterogeneous networks scenario

*Horizontal handover* (HHO) occurs between the APs of the same network technology, while *vertical handover* (VHO) occurs between APs belonging to different networks. Several kind of VHO can be envisaged, as described as follows. According to Figure 1, *upward* vertical handover is a handover to a wireless overlay with a larger cell size and generally lower bandwidth per unit area. It makes a mobile device disconnect from a network providing faster but smaller coverage (e.g. WLAN) to a new network providing slower but broader coverage.

Viceversa, a mobile device performing a *downward* VHO disconnects from a cell providing broader coverage to one providing limited coverage but higher access speed. In this case, a link layer trigger can inform the mobile device that it is now under the coverage of a new network (e.g. WLAN) and the mobile node may wish to execute the handover.

Downward VHOs may be *anticipated* or *unanticipated*, such that a mobile device may already be under the coverage of the new network but may prefer to postpone the handover based on requirements of the applications running on the mobile node. Handover is then performed later, being already aware of the coverage status of the new network.

A main issue is to decide if or when to start the handover, and who performs it. Handover policies are based on different metrics for handover decision. Traditional solutions simply consider RSSI (Received Signal Strength Indication) and channel availability. More sophisticated handover policies also consider: (i) Quality-of-Service, as different types of services require various combinations of reliability, latency, and data rate; (ii) costs, i.e. different networks may employ different billing strategies; (iii) network conditions like traffic, available bandwidth, network latency, and congestion; (iv) system performance,

such as channel propagation characteristics, path loss, inter-channel interference, Signal-to-Noise ratio and Bit Error Rate; (v) mobile terminal conditions like battery power and dynamic factors such as speed, moving pattern, moving histories, and location information. In the latter case, if the battery level of a MN is low, the handover commutes toward a network that guarantees lower power consumption. In the case when the user requires a guaranteed QoS level for her applications, handover switches to a network meeting such requirements.

A more detailed description of handover decision metrics will be given in Section 3.

### 2.1 IEEE 802.21 media-independent handover

The IEEE 802.21 group is developing standards to enable handover and interoperability between heterogeneous network types, including both 802 and non 802 networks.

The standard provides quick handovers of data sessions across heterogeneous networks with small switching delays and minimized latency. The handover in heterogeneous networks could become more flexible and appropriate with this standard, through the use of innovative IEEE 802.21 mobile devices. The standard considers both wired and wireless technologies such as 802.3, 802.11, 802.16, 3GPP2, and 3GPP.

The analysis of IEEE 802.21 standard aims to understand the scope of this protocol. Seamless handover of data sessions is the main target, based on Media Independent Handover (MIH) functional model. IEEE 802.21 specification classifies the function that enhances handovers across heterogeneous media. The MIH protocol entity is to every extent a new protocol layer located between the Network Layer (Layer 3) and the interface-specific lower layers (MAC and PHY in the case of IEEE interfaces, RRC and LAC in the case of 3GPP or 3GPP2 interfaces, respectively).

The main entities of IEEE 802.21 are (Gupta *et al.*, 2006):

1. The *Media Independent Information Service* (MIIS) that includes policies and directives from the Home Network (HN). The mobile terminal refers to the HN policies when performing handover decisions;
2. The *Service Access Points* (SAPs), exchanging service primitives between the MIH layer and its adjacent layers and functional planes;
3. A *Decision Engine* (DE) within the MIH instance, residing in the mobile terminal, which identifies the best available access technology to support the current connectivity. The DE is a state machine that selects a preferred link based on available interfaces, policies, QoS and security parameter mapping;
4. A *Transport Mechanism* to facilitate the communication between the mobile terminal MIH and the Information Service (IS) instance to access in the network.

The MIH function at the mobile terminal is continuously supplied with information regarding the network conditions, measured to perform the access into one available heterogeneous network. The MIH function receives the information through dedicated interfaces by exchanging messages with the IS entity positioned in the HN. Generally, the MIHF defines three main services to perform handovers between heterogeneous networks, such as (i) the *Media Independent Event Service* (MIES), (ii) the *Media Independent Command Service* (MICS), and (iii) the *Media Independent Information Service* (MIIS).

MIES provides event reporting, event filtering and event classification corresponding to dynamic changes in link characteristics, link quality and link status. It acts all the instances to make event detection and notify, still maintaining the actual link connection to the MN.

Some of these events employed are “Link Up”, “Link Down”, “Link Detect”, “Link Parameter Reports” and “Link Going Down”, (Gupta, *et al.* 2006).

MICS uses the MIHF primitives to send commands from higher layers to lower ones. It determines the status of the connected links, performing mobile and connectivity decisions of the higher layers to the lower ones. Then, MIIS is a mechanism to discover available neighboring network information in order to facilitate handover process. It assures a set of information entities, both static and dynamic. In the first case, there are the names and services providers of the MN's current network, while the dynamic information include link layer parameters such as channel information, MAC addresses, security information and other higher layer service information.

Three main handover schemes have been developed within IEEE 802.21 standardization process, defined as follows:

1. *Serving Network-Initiated and Candidate Network-Canceled Handover*: the Service Access Network (SAN) sends messages about information request to the IS in order to know if a handover mechanism can be initiated. The Candidate Network (CN) could not be an available resource, because of link quality level or network traffic status;
2. *Serving Network-Initiated and MN-Canceled Handover*: after sending information request messages to the IS, the MN could be not available to perform handover, because of MN movement or user intervention or low battery that let the MN renouncing handover mechanism. In this case, the handover could be canceled directly by interaction between SAN and CN;
3. *MN-Initiated and MN-Canceled Handover*: in this case, the MN communicates only with the SAN, which sends messages of Resources-Request to the CN. The MN could be no more available to perform handover, (*e.g.* movement or time out or user intervention). The MN sends HandoverCancel message to SAN which is asked to interrupt the handover mechanism. Figure 2 shows the flowchart of this approach.

### 3. Techniques for connectivity support in heterogeneous networks

Vertical Handover preserves user connectivity *on-the-move* (Pollini, 1996). It is applied when network switching is expected in order to (i) preserve host connectivity, (ii) optimize QoS as perceived by the end user, and (iii) limit the number of unnecessary vertical handover occurrences.

Different VHO schemes can be classified on the basis of the criteria and parameters adopted in the handover initialization phase. The following list collects the main metrics whose monitoring can drive handover decisions:

- *Received Signal Strength* (RSS)-based VHO algorithms are largely used in cellular networks (*i.e.* 2G and 3G networks). The handover process is initiated on the basis of a decreasing level of measured RSS (Ayyappan & Dananjayan, 2008); (Inzerilli & Vegni, 2008);
- *Signal-to-Noise and Interference ratio* (SINR)-based VHO algorithms are typically used in UMTS networks. SINR factor directly impacts achievable goodput in a wireless access network. The handover is driven by a reduction of measured SINR below a fixed threshold (Yang *et al.*, 2007); (Vegni *et al.*, 2009);
- *Multi-parameter QoS*-based VHO algorithms: this approach is based on the overall quality assessment for the available networks obtained balancing various parameters – subjective and objective quality metrics – (Vegni *et al.*, 2007);

- *Location-based VHO algorithms estimate network QoS levels on the basis of the MN's location relatively to the serving access point (Kibria et al., 2005); (Inzerilli et al., 2008); (Inzerilli et al., 2010).*

The above-mentioned VHO algorithms are analyzed here in the following.

The RSS-based VHO is the traditional technique for connectivity switching in heterogeneous networks. It is driven on power level measurements, such as when the measured RSS coming from the SN drops below a predefined threshold. The RSS of the monitored set of CNs is evaluated, and a vertical handover will be executed towards the best—most appropriate—candidate network. This approach represents the primitive and simplest handover mechanism, which however does not aim to optimize communication performance but only focuses on maintaining seamless connectivity (Ayyappan & Dananjayan, 2008). Moreover, since RSS value suffers from severe fluctuations due to the effects of shadowing and fading channels, filtering techniques (*e.g.* exponential smoothing average (Inzerilli & Vegni, 2008)) should be considered to estimate the trend of RSS signal.

On the other hand, the SINR-based approach compares received power with noise and interference levels in order to obtain a more accurate performance assessment. SINR factor represents a valid handover decision metric, as it directly affects the maximum data rate compatible with a given Bit Error Rate (BER). SINR-based VHO approach is more suitable to meet QoS requirements, since a reduction of SINR factor produces a reduction of data rate and QoS level (Yang et al., 2007). Both RSS and SINR-based schemes are reactive approaches, whose aim is to compensate for performance degradation.

The multi-parameter QoS-based VHO scheme in (Vegni et al., 2007) represents a proactive approach performing regular assessment of the QoS level offered by the current SN, as well as by other CNs. In general, a multi-parameter QoS-based VHO technique is well suited for multimedia applications like real-time video streaming.

In location-based VHO solutions, the knowledge of MN's location information is exploited to assess the quality of the bidirectional link between SN and MN (Inzerilli et al., 2008). Moreover, the estimation of MN's position can drive the initiation of a reactive handover mechanism. Information about MN's position can be determined in several ways (Kibria et al., 2005), including Time of Arrival, Direction of Arrival, RSS, as well as A-GPS (Assisted Global Positioning System) techniques.

Notice that in general each time a vertical handover is initiated the traffic overhead increases. The limitation of handover occurrences is an issue specially when unwanted and unnecessary vertical handovers are executed. This represents the case of a mobile node moving back and forth between the two neighbouring wireless networks—or in general around a corner that involves three or more wireless networks—. This aspect is known in literature as *ping-pong* effect (Kim et al., 2007).

Repeated vertical handover attempts lead to frequent location and registration updates (with network resource consumption), frequent connectivity interruptions, as well as serious affections to MN's QoS (*i.e.*, decreasing battery life). Frequent handovers lead the user to experience many unpleasant transients of service interruption.

Techniques to prevent unnecessary and unwanted handovers have been proposed (Kim et al., 2007); (Inzerilli & Vegni, 2008); (Inzerilli et al., 2008). A hysteresis cycle or a hard limitation in maximum handover frequency can mitigate this phenomenon.

The above descriptions have shown the main vertical handover approaches, which are based on single metrics (*i.e.*, RSS, SINR, QoS, and location). Still, many handover techniques are based on the combination of two or more metrics, which generate most effective VHO

decisions, and avoid unnecessary and unwanted vertical handover occurrences (Vegni *et al.*, 2009). These approaches are called as *hybrid* (or combined) vertical handovers. The following Subsection 3.1 and 3.2 offer a more detailed description of QoS- and location-based vertical handover algorithms, respectively.

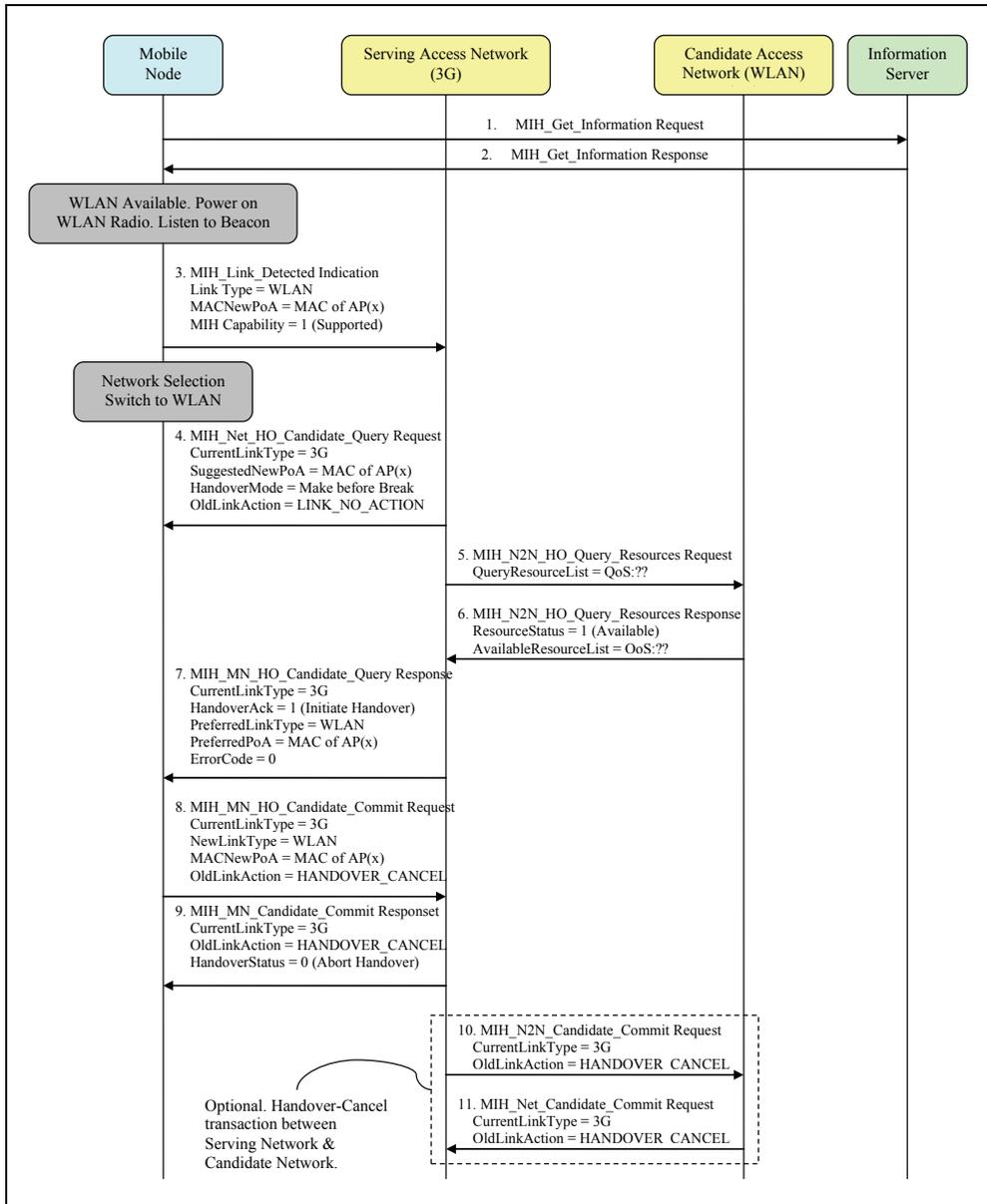


Fig. 2. MN-initiated and MN-cancelled handover

### 3.1 QoS-based vertical handover

As defined in IEEE 802.21 standard, QoS-based HO decision is based on current and expected network conditions, according to the application QoS requirements (Golmie *et al.*, 2006). Current network conditions are measured using network performance parameters from various layers, *e.g.* signal strength from layer 1, packet loss from layer 2, throughput and delay from layer 2+, etc.

According to the ITU-T Y.1540, the applications QoS requirements are defined by:

- Packet Transfer Delay (PTD), maximum end-to-end tolerated delay [s];
- Packet Delay Variation (PTV), *i.e.* jitter: maximum packet jitter [s];
- Packet Loss Ratio (PLR): maximum tolerated packet loss;
- Throughput: required data rate of successful packets [bit/s].

QoS-based Decision Engine (QDE) is a main network entity that implements a QoS-based handover for assigned application QoS requirements (Golmie *et al.*, 2006). QDE is a MIH user that considers application QoS requirements and network performance measurements provided by the MIH. The MIH function exchanges information between network entities and the QDE, including technology, protocol types and network measurements. Network performance conditions, such as instantaneous measurements for current conditions, are evaluated from past observations and previous connections, or as default estimates.

QDE entity is located as a remote entity, as part of the MN, or the AP/BS. For our scope, we consider it as a network entity, as illustrated in Figure 3. No limitation occurs if QDE function is distributed over remote entities of each network. In this way, the MN receives Video Quality Metrics VQMs from QDEs of neighbouring candidate networks.

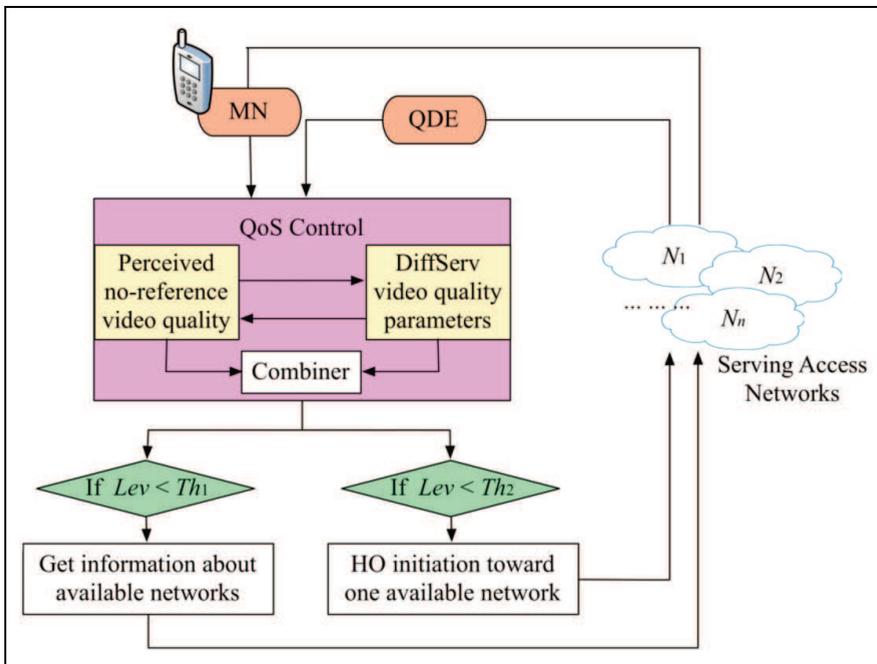


Fig. 3. Proposed network architecture for QoS-based handover

During the last decade several techniques to assess the quality of multimedia services without performing a subjective test have been investigated, leading to objective quality metrics that approximate the MOS (Mean Opinion Score). Such metrics are usually classified as *full-reference*, *reduced reference* and *no-reference* metrics. They differ in the degree of knowledge about the original multimedia flow used in the quality assessment. Full reference methods evaluate the difference between the original signal and the received one and are, thus, rarely employed in real time assessment of video quality. On the other hand, reduced reference metrics require a channel for sending side information concerning some characteristics of the original signal, while No-Reference (NR) metrics do not require any knowledge of the original. On the other hand, the perceived video quality highly depends on the end-user, according to her *a priori* knowledge of the topic, level of attention while looking at the video, and assigned task.

In general a QoS-based VHO technique focuses on the maximization/enhancement of QoS level experienced by the mobile user. The connectivity is switched from the serving network to a selected candidate network, which provides high QoS. In (Vegni *et al.*, 2007) an innovative NR-Video Quality Metric (NR-VQM) has been assumed. This metric incorporates both spatial and temporal resolution reduction, packet losses, latency, and delay jitter, as well as indicators for the evaluation of (i) blocking, blurring and ringing introduced by current video coders, and (ii) jerkiness and other effects produced by packet losses. Jerkiness is evaluated by a neural network feed with estimated dynamics of objects composing the scene, trained by means of subjective tests.

The impact of packet losses on perceived quality is based on the analysis of the inter-frame correlation measured at the receiver side. Presence of error concealment algorithms employed by the receiver is also taken into account. The packet losses degradation assessment presents best performances for long sequences with slow motion.

Since the NR algorithm directly processes the rendered video, no information about the kind of errors, delays and latencies affecting the links is required. In addition, the NR techniques easily account for continuous increase of computing power of both mobile and wired terminals, and allow a wide spread of error concealment techniques to increase the perceived quality.

Subjective test evinced good agreement between NR metric and MOS, regardless of intrinsic video characteristic and spatial-temporal resolution.

In the scheme presented in (Vegni *et al.*, 2007) the NR-QoS is combined with a packet classification originally designed for DiffServ (DS) protocol, allowing different QoS grades to be mapped into different classes of aggregated traffic flows, (Shin *et al.*, 2001). It is an adaptive packet forwarding mechanism for DS networks. It allows mapping mechanism of video packets onto different DS levels based on Relative Priority Index (RPI), that is the relative preference per each packet in terms of loss and delay. The packets are classified, conditioned, and remarked to certain network DS levels by considering the traffic profile based on the Service Level Agreement (SLA) and the current network status.

The proposed QoS-based handoff scheme in (Vegni *et al.*, 2007) is well suited for real-time applications in IEEE 802.21 scenarios. The overall vertical handover process is organized in five phases, such as (i) measurement phase, (ii) QoS prioritization, (iii) initialization, (iv) candidate networks scanning, and (v) VQM conversion. Figure 4 depicts the pseudo-code of the QoS-based vertical handover algorithm. Basically, the multi-parameter QoS-based handover algorithm considers three inputs, such as (i) the RSS samples, (ii) the mobile node distance and (iii) the current QoS level (*i.e. Lev*). As output it returns the number of vertical

handovers executed by the mobile node (*i.e.*  $n_{VHO}$ ). In the following we shall describe the overall mechanism in more details.

Given a video application, the QoS mapping process is accomplished by considering the relative prioritized packets to maximize end-to-end video quality. In the *measurement phase*, each  $T$  seconds, the MN gets samples of RSS and position, as well as monitors  $Lev$  parameter for the video stream received from the current serving network. QoS monitoring is performed on the basis of the NR metrics<sup>1</sup>. In our scope, NR technique addresses on audio and video flows evaluations to the receiver side, although it could be also tuned and optimized by means of a full-reference metric applied to some low rate probe signals.

In the *QoS prioritization phase*, the probability to perform a handover is evaluated (*i.e.*  $P_{VHO}$ ). By opportunistically weighting the QoS- $Lev$  parameter the handover probability will be mainly driven by QoS factors. The received video-streaming quality is monitored according to a subjective evaluation. On the basis of user preferences, two appropriate QoS thresholds are defined, called as  $Th_1$  and  $Th_2$ , with  $Th_1 > Th_2$ .

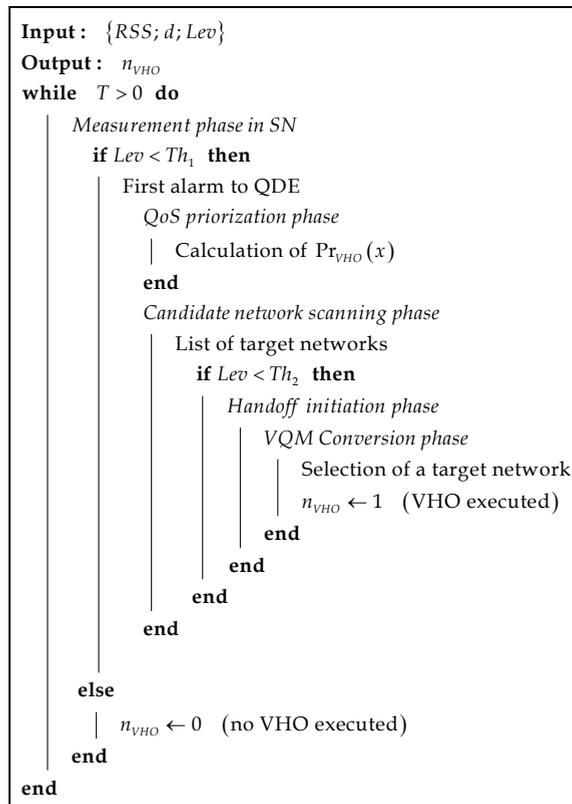


Fig. 4. Multi-parameter QoS-based vertical handover pseudo-code

<sup>1</sup> NR method presents some basic indicators for temporal and spatial analysis: block distortion is evaluated by applying first a coarse temporal analysis for each frame, to extract blocks potentially affected by artefacts produced by lost packets.

Traffic congestions, transmission errors, lost packets or delay can keep QoS level lower than a first threshold, *i.e.*  $Lev < Th_1$ . If  $Lev$  keeps on decreasing, the *handoff initiation* phase can be required by the MN whenever  $Lev < Th_2$ .

The MN alerts to change the serving network and sends this alarm message to a closer QDE. So, the *candidate networks scanning* phase occurs on the basis of VQM parameters, such as throughput, link packet error rate, Packet Loss Probability (PLP), supported number of Class of Service (CoS), etc. All these parameters are sent inside the information message "LINK QoS PARAMETER LIST".

Based on the statistics computed on previous NR-QoS reports produced by the served MNs, when the QDE communicates with a MN, it can operate a *conversion of VQM parameters* for each network in NR parameters. The MN evaluates which candidate network is appropriate for its video application. As an instance, let us suppose that a MN is in a WLAN area. When it realizes a QoS reduction, it sends a first alarm to the QDE, which will start a candidate network scanning process in order to select a target network providing a QoS enhancement to the MN (*i.e.*  $Lev_1 > Lev$ ). A set of target networks to hand over is selected, and the best network is chosen on the basis of MN preferences and handover policies. Finally, the handover is performed according to the IEEE 802.21 message exchange in the scheme of Figure 2.

Finally, in order to determine the probability to perform a vertical handover (*i.e.*  $Pr(VHO)$ ), we shall provide the following assumptions:

1. A mobile node is locating at position  $P = (x, y)$ , in the middle of two active networks (*i.e.*  $N_i, i = 1, 2$ );
2. The averaged received signal levels over  $N_1$  and  $N_2$  radio links are assumed as lognormal distributions, respectively  $\overline{r_{N_1}}(P)$  and  $\overline{r_{N_2}}(P)$ , with mean signal levels  $\mu_{N_1}$  and  $\mu_{N_2}$ , and the shadowing standard deviations  $\sigma_{N_1}^2$  and  $\sigma_{N_2}^2$ ;
3. The distance  $d_{N_i}$  from the MN's position to the reference BS of network  $N_i$  can be assumed as a stationary random process with mean value  $d$  and variance  $c^2\sigma_{t_{dn}}^2$ , where  $c$  the speed of light and  $\sigma_{t_{dn}}^2$  is the standard deviation of the signal delay measurement<sup>2</sup>;
4. On the basis of each single parameter (*i.e.* RSSI, distance, and QoS) different thresholds are assumed, called as  $R, D$  and  $Q$  for RSSI, distance and quality criterions, respectively. Each threshold is typical for a single access network (*i.e.*  $R_W$  and  $R_U$  are the RSS thresholds for WLAN and UMTS, respectively).

Let us suppose to perform a handover from UMTS to WLAN. The handover decision occurs when both (i) the RSS measurement on WLAN is higher than  $R_W$  (*i.e.*  $\overline{r_W}(P) \geq R_W$ ), (ii) the distance from MN to WLAN AP is lower than  $D_W$  (*i.e.*  $d_W \leq D_W$ ), and (iii) the QoS- $Lev$  in WLAN is upper than  $Q_W$  (*i.e.*  $q_W \geq Q_W$ )<sup>3</sup>. Thus, the probability to initiate the handover from UMTS to WLAN in the position  $P$ , is

$$Pr_{U \rightarrow W}(P) = P\left\{\left[\overline{r_W}(P) \geq R_W\right]\right\} \cdot P\left\{[d_W \leq D_W]\right\} \cdot P\left\{[q_W \geq Th_2]\right\}. \quad (1)$$

On the other hand, the handover decision from WLAN to UMTS is taken only when it is really necessary, such as when (i) the RSS measurement on WLAN is lower than  $R_W$  (*i.e.*

<sup>2</sup> Basically, the delay measurement of the signal between the MN and the BS is characterized by two terms, (i) the real delay and (ii) the measurement noise  $t_{dn}$ . It is assumed to be a stationary zero-mean random process with normal distribution.

<sup>3</sup> Notice that due to chip WLAN monetary cost the handover decision does not take account to the RSS, the distance and the QoS criteria on UMTS network.

$\overline{r_W(P)} \leq R_W$ ), (ii) the RSS measurement on UMTS is higher than  $R_U$  (i.e.  $\overline{r_U(P)} \geq R_U$ ), (iii) the distance from MN to UMTS BS is lower than  $D_U$  (i.e.  $d_U \leq D_U$ ), and (iv) the QoS-Lev in UMTS is upper than  $Q_U$  (i.e.  $q_U \geq Q_U$ ). Thus, the probability to initiate the handover from WLAN to UMTS in the position  $P$ , is

$$\Pr_{W \rightarrow U}(P) = P\left\{\left[\overline{r_W(P)} \leq R_W\right]\right\} \cdot P\left\{\left[\overline{r_U(P)} \geq R_U\right]\right\} \cdot P\left\{\left[d_U \leq D_U\right]\right\} \cdot P\left\{\left[q_U \geq Th_2\right]\right\}. \quad (2)$$

### 3.1.1 Analytical model

In this subsection we introduce the analytical model behind the QoS-based VHO technique described in (Vegni *et al.*, 2007). Particularly, we shall define two main network parameters for handover decision from a serving network to a candidate network, such as (i) the average time delay and (ii) the average packet rate. Based on these parameters, the handoff mechanism shall be performed only if it is necessary to maintain the connection on.

We recall the *average time delay* [s] for the  $k$ -th network from the Pollaczek-Kinchin formula, which considers the average time delay as the sum of average time delay for the service and waiting one, such as

$$\tau_k = \frac{1}{\mu_k} \cdot \left[ \frac{1 + \rho_k(1 + Cb^2)}{2(1 - \rho_k)} \right]. \quad (3)$$

From (3) we consider the average time delay for a single packet sent from a  $N_1$  to  $N_2$  (i.e.  $T_{N_1 \rightarrow N_2}$  [s]) such as

$$T_{N_1 \rightarrow N_2} = \sum_{k=1}^N \tau_k \gamma_{N_1 \rightarrow N_2}^{(k)}, \quad (4)$$

where  $\gamma_{N_1 \rightarrow N_2}^{(k)}$  is the probability that packets are sent from  $N_1$  to  $N_2$ , on the  $k$ -th link with capacity  $C_k$  [bit/s].

The *average packet rate* represents how many packets are sent from  $N_1$  to  $N_2$ , i.e.  $r_{N_1 \rightarrow N_2}$  [packets/s]. Considering all the available networks (i.e.  $N_1, N_2, \dots, N_n$ ), the total *average packet rate*  $\Lambda_{tot}$  [packets/s] is

$$\Lambda_{tot} = \sum_{i=1}^N \sum_{j=1}^N r_{N_i \rightarrow N_j}, \quad (5)$$

and the total mean time delay  $\Delta T_{Mean}$  [s] is

$$\Delta T_{Mean} = \frac{\sum_{i=1}^N \sum_{j=1}^N T_{N_i \rightarrow N_j} \cdot r_{N_i \rightarrow N_j}}{\sum_{i=1}^N \sum_{j=1}^N r_{N_i \rightarrow N_j}}. \quad (6)$$

In the case of handover occurrence from  $N_i$  to  $N_j$ , the mobile user moves from  $N_i$  to  $N_j$  with a probability  $\beta_{i \rightarrow j}$ . So, the probability  $\nu_j$  that an user moves from her own serving network is:

$$v_j = \sum_{i \neq j} \beta_{i \rightarrow j} = 1 - \beta_{i \rightarrow i}, \quad (7)$$

where  $\beta_{i \rightarrow i}$  represents the probability a user stays in her serving network. In this way, we can find the average packet rate from  $N_i$  to  $N_j$  during handover, as

$$r_{N_i \rightarrow N_j}^{(HO)} = \sum_m r_{N_j \rightarrow N_m}^{(HO)} \beta_{j \rightarrow m} + \beta_{i \rightarrow j} \sum_h r_{N_i \rightarrow N_h}^{(HO)}. \quad (8)$$

So, the total packet rate  $\Lambda_{tot}^{(HO)}$  [packets/s] will be:

$$\begin{aligned} \Lambda_{tot}^{(HO)} &= \sum_{i=1}^N \sum_{j=1}^N r_{N_i \rightarrow N_j}^{(HO)} = \sum_i \sum_j \sum_m r_{N_i \rightarrow N_m}^{(HO)} \beta_{i \rightarrow m} + \sum_i \sum_j \beta_{i \rightarrow j} \sum_h r_{N_i \rightarrow N_h}^{(HO)} = \\ &= \Lambda_{tot} + \sum_i \sum_j \beta_{i \rightarrow j} \sum_h r_{N_i \rightarrow N_h}^{(HO)}. \end{aligned} \quad (9)$$

Let us assume  $\rho_j$  [packets/s] as the average rate of packets sent to  $N_j$ . By replacing (7), the expression of  $\Lambda_{tot}^{(HO)}$  becomes

$$\Lambda_{tot}^{(HO)} = \Lambda_{tot} + \sum_j v_j \rho_j. \quad (10)$$

If we consider an uniform handover probability (*i.e.*  $v_j = \nu$ ) then  $\Lambda_{tot}^{(HO)}$  becomes

$$\Lambda_{tot}^{(HO)} = \Lambda_{tot} (1 + \nu). \quad (11)$$

Finally, let  $\chi$  be the ratio between the average time delay in case and in absence of handover,  $\tau^{(HO)}$  and  $\tau$  respectively

$$\begin{aligned} \chi &= \frac{\tau^{(HO)}}{\tau} = \frac{\frac{1}{\mu_k} \left[ \frac{1 + \theta^{(HO)} (1 + Cb^2)}{2(1 - \theta^{(HO)})} \right]}{\frac{1}{\mu_k} \left[ \frac{1 + \theta(1 + Cb^2)}{2(1 - \theta)} \right]} = \frac{1 + \theta^{(HO)} (1 + Cb^2)}{1 + \theta(1 + Cb^2)} \cdot \frac{(1 - \theta)}{(1 - \theta^{(HO)})} = \\ &= \frac{1 + \theta(1 + Cb^2)(1 + \nu)}{1 + \theta(1 + Cb^2)} \cdot \frac{(1 - \theta)}{1 - \theta(1 + \nu)}. \end{aligned} \quad (12)$$

where  $\theta^{(HO)}$  [Bit/s] is the throughput experienced by a mobile user during handover.

### 3.2 Location-based vertical handover

In this subsection we shall introduce a location-based vertical handover approach (Inzerilli *et al.*, 2008) which aims at the twofold goal of (i) maximizing the goodput and (ii) limiting the *ping-pong* effect. The potentialities of using location information for VHO decisions, especially in the initiation process is proven by experimental results obtained through computer simulation. Leveraging on such results, in this subsection we shall introduce only the handover initiation phase since it represents the core of our location-based VHO technique. A detailed description of the proposed algorithm is in (Inzerilli *et al.*, 2008).

The mobile node's location information is used to initiate handovers, that is, when the distance of the MN from the centre of the cell of the candidate network towards which a handover is attempted possesses an estimated goodput, *i.e.*  $GP_{CN}$ , significantly greater than the goodput of the current serving network, *i.e.*  $GP_{SN}$ . The *handover initiation* is then followed by a more accurate estimate (*handover assessment*) which actually enables or prevent handover execution (Inzerilli *et al.*, 2008).

In the *handover initiation* phase, the algorithm evaluates the goodput experienced by a MN in a wireless cell. The goodput depends on the bandwidth allocated to the mobile for the requested services and the channel quality. When un-elastic traffic is conveyed (*e.g.* real-time flows over UDP) the goodput is given by:

$$GP = BW \cdot (1 - P_{out}), \quad (13)$$

where  $BW$  [Bit/s] is the bandwidth allocated to the mobile node and  $P_{out}$  is the service outage probability. When elastic traffic is conveyed (typically when TCP is used), throughput tends to decrease with increasing values of  $P_{out}$ .  $BW$  is a function of the nominal capacity, of the MAC algorithm which is used in a specific technology and sometimes of the experienced  $P_{out}$ . We consider the maximum value of  $BW$ , *i.e.*  $BW_{max}$  which is obtained in the case of a single MN in the cell and with a null  $P_{out}$ <sup>4</sup>.

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

$$P_{out}^{UMTS} = \Pr \left\{ \frac{E_{b,Tx}^{UMTS}}{I_0 + (\gamma\sigma_N^2)_{UMTS}} \cdot A_d^{-1}(r^{UMTS}) \leq \mu^{UMTS} \right\}, \quad (14)$$

where  $E_{b,Tx}^{UMTS}$  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,  $A_d(r^{UMTS})$  is the signal attenuation factor dependent on the MN's distance  $r^{UMTS}$  from the centre of the cell, and  $I_0$  is the inter and intra-cell interference power. The service outage probability for a WLAN network  $P_{out}^{WLAN}$  can be calculated theoretically in a similar fashion using the following formula:

$$P_{out}^{WLAN} = \Pr \left\{ \frac{E_{b,Tx}^{WLAN}}{(\gamma\sigma_N^2)_{WLAN}} \cdot A_d^{-1}(r^{WLAN}) \leq \mu^{WLAN} \right\}. \quad (15)$$

We define as the radius of a wireless cell  $R_{cell}$  the distance from the cell centre beyond which the signal-to-noise ratio or the signal-to-interference ratio falls below the minimum acceptable value (*i.e.*  $\mu$ ).  $R_{cell}$  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.*  $R_{cell}^{WIFI} \approx 120$  m for IEEE 802.11a outdoor, and  $100 \text{ m} \leq R_{cell}^{UMTS} < 1$  km for a UMTS micro-cell.

<sup>4</sup> In an IEEE 802.11a link, the maximum theoretical  $BW_{WLAN}$  is equal to 23 Mbps (out of a nominal capacity of 54 Mbps), although it decreases rapidly with the number of users because of the contention-based MAC. In HSDPA network, the maximum  $BW_{UMTS}$  is equal to 14.4 Mbps, which decreases rapidly with  $P_{out}$ .

Since the path loss  $A_d(r)$  is approximately proportional to  $r^\gamma$ , the SNR( $r$ ) can be written as

$$\text{SNR}(r) = \mu \left[ \left( \frac{R_{\text{cell}}}{r} \right)^\gamma + \delta A_d \right]. \quad (16)$$

Maximum GP in a WLAN and UMTS cell can be calculated with the following approximated formulas, respectively

$$\begin{cases} GP_{\text{max}}^{\text{UMTS}} = BW_{\text{max}}^{\text{UMTS}} \cdot \Pr \left\{ \left( \frac{R_{\text{cell}}^{\text{UMTS}}}{r^{\text{UMTS}}} \right)^\gamma + \delta A_d < 1 \right\} \\ GP_{\text{max}}^{\text{WLAN}} = BW_{\text{max}}^{\text{WLAN}} \cdot \Pr \left\{ \left( \frac{R_{\text{cell}}^{\text{WLAN}}}{r^{\text{WLAN}}} \right)^\gamma + \delta A_d < 1 \right\} \end{cases} \quad (17)$$

which 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 WLAN to UMTS, the following equations applies:

$$GP_{\text{max}}^{\text{UMTS}} < GP_{\text{max}}^{\text{WLAN}}. \quad (18)$$

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.

### 3.2.1 Simulation results

In this section we report on network performance of the Location-based Vertical Handover algorithm (also called as LB-VHO). Particularly, we investigate the Cumulative Received Bits (CRB [Bits]), and the number of vertical handovers performed by the user moving in the grid, obtained using our event-driven simulator. Details of the simulator can be found in (Vegni, 2010).

We modelled movements of a MN over a grid of 400 x 400 square zones, each with an edge of 5 m, where 3 UMTS cells and 20 IEEE 802.11b cells are located. Typical data rate values have been considered for UMTS and WLAN. The location of each wireless cell has been generated uniformly at random, as well as the the MN's path.

Table 1, shows the statistics on the CRB collected for  $S = 20$  randomly generated scenarios, each of them differs from the other in terms of the UMTS/WLAN cell location and the path of the MN on the grid. Performance have been compared to a traditional Power-based Vertical Handover (PB-VHO), which uses power measurements in order to initiate VHOs instead of mobile location information (Inzerilli & Vegni 2008).

For each approach LB and PB three parameters are reported related to the CRB, *i.e.* the mean value, the standard deviation and the dispersion index, defined as the ratio of the standard deviation over the mean value. The three value for LB and PB are reported versus different values of the waiting time parameter  $T_{\text{wait}}^5$ .

<sup>5</sup> Notice that if the MN moves at 1 m/s, a 10 s waiting time results to 10 m walked.

The LB approach brings about a reduction of CRB between 6.5% for a null waiting time and 20% for waiting time equal to 60 s. It follows that the waiting time constraint is not suitable for LB approach in order to reduce the number of vertical handovers while keeping a limited reduction of CRB.

Table 2 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 handover 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 remarks that the PB approach requires a constraint on handover frequency limitations, while this approach is counterproductive with LB.

Waiting Time [s]	LB Mean [Gb]	LB Stand. Dev [Gb]	LB Disp. Index	PB Mean [Gb]	PB Stand. Dev. [Gb]	PB Disp. Index
0	5.82	2.38	40.91%	6.23	2.30	36.90 %
60	4.59	2.34	50.88%	5.76	2.14	37.13 %

Table 1. Statistics on the CRB for LB and PB approach

Waiting Time [s]	LB Mean [Gb]	LB Stand. Dev. [Gb]	LB Disp. Index	PB Mean [Gb]	PB Stand. Dev. [Gb]	PB Disp. Index
0	9.65	2.00	20.73	329.85	794.50	240.87
10	7.25	1.15	15.93	30.20	46.36	153.51
20	5.85	2.31	39.48	19.90	22.54	113.26
30	5.15	1.15	22.42	14.10	16.29	115.53
40	4.35	1.15	26.54	11.80	12.49	105.85
50	4.20	2.00	47.62	9.80	10.58	107.99
60	3.70	1.15	31.21	9.15	7.57	82.75

Table 2. Statistics on the Number of VHO for LB and PB approach

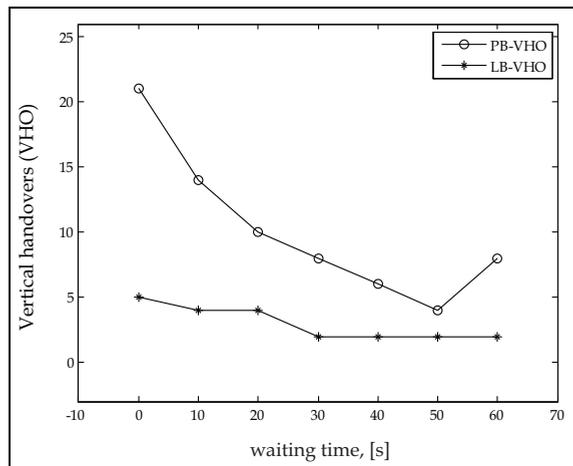


Fig. 5. Number of vertical handover occurrences for PB and LB VHO algorithm

In Figure 5, the mean values of vertical handovers for 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, limits handover initiations, resulting in about a little performance gain. In contrast, 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.

Finally, in Figure 6 (a) and (b) are reported the dynamics of the CRB over the mobile node steps during the simulation (a step is performed every 5 seconds) for a null waiting time and a waiting time of 60 s, respectively. The instability of PB approach when no waiting time constraint is applied is clearly shown in Figure 6 (a).

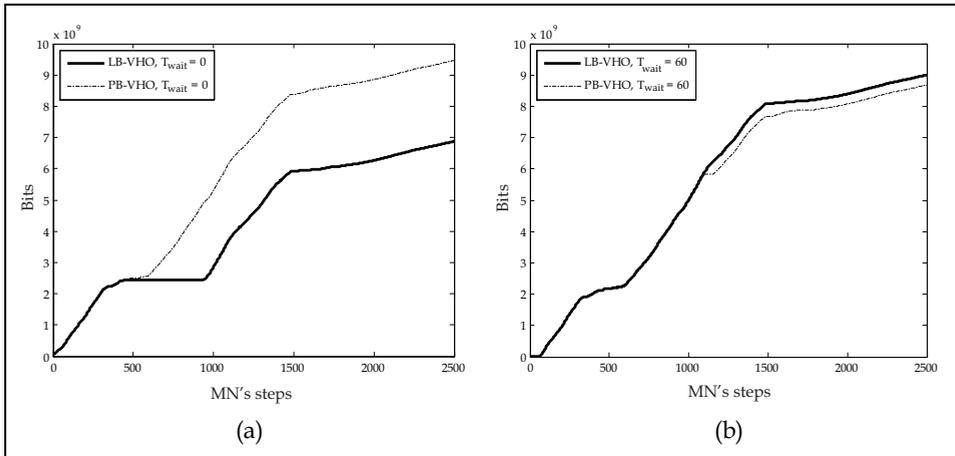


Fig. 6. CRB during a simulated scenario with PB and LB-VHO approaches, for (a)  $T_{wait} = 0$  s, (b)  $T_{wait} = 60$  s

### 3.3 Hybrid vertical handover technique

In this section we complete the overview of the main vertical handover techniques in heterogeneous wireless networks, by introducing a hybrid scheme for connectivity support<sup>6</sup>. Different wireless networks exhibit quite different data rate, data integrity, transmission range, and transport delay. As a consequence, direct comparison between different wireless links offering connectivity to a MN is not straightforward. In many cases VHO requires a preliminary definition of performance metrics for all the visited networks which allows to compare the Quality-of-Service offered by each of them and to decide for the best.

VHO decisions can rely on wireless channel state, network layer characteristics and application requirements. Various parameters can be taken into account, for example: type of the application (*e.g.* conversational, streaming, interactive, background), minimum bandwidth and maximum delay, bit error rate, transmitting power, current battery status of the MN, as well as user's preferences.

In this section we present a mobile-controlled reactive Hybrid VHO scheme—called as HVHO—where handover decisions are taken on the basis of an integrated approach using three components: (i) power map building, (ii) power-based (PB) VHO, and (iii) enhanced

<sup>6</sup> An extended version of this technique is described in (Inzerilli *et al.*, 2010).

location-based (ELB) VHO. The HVHO technique is suitable for dual-mode mobile terminals provided with UMTS and WLAN network interface cards, exploiting RSS measurements, MN's location information, and goodput estimation as discussed in Section 3. The overall procedure is mobile-driven, soft and includes measures to limit the *ping-pong* effect in handover decisions. The flowchart of HVHO is depicted in Figure 7.

Basically, the HVHO approach proceeds in two phases:

1. In the initial learning phase when the visited environment is unknown, the RSS based approach is used, *i.e.* hereafter referred to as Power-Based (PB) mode. In the meanwhile, the MN continuously monitors the strength of the signals received from the SN, as well as from the other candidate networks. By combining RSS samples with location data provided by the networks or some auxiliary navigation aids, like GPS, the MN builds a path losses map for each discovered network in the visited environment;
2. At the end of this phase the MN enters the ELB-VHO mode and it can exploit the path losses map to take handover decision using its current location.

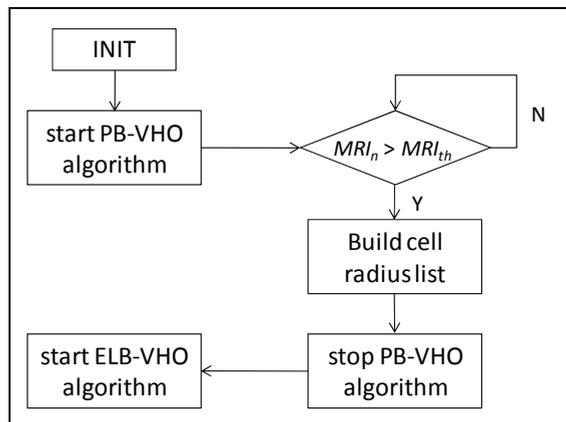


Fig. 7. Flowchart of hybrid vertical handover algorithm

In the initial learning phase, the new environment is scanned in order to detect the UMTS and WLAN access networks eventually present and, then to build a *path loss map* for each of them. The path losses associated to the UMTS base stations in the monitored set and to the access points of the WLAN network are estimated by taking the difference between the nominal transmitted power and the short term average of the received signal strength. Averaging is required in order to smooth fast fluctuations produced by multipaths, and can be performed by means of a mean filter applied to the RSS time series multiplied by a sliding temporal window (Inzerilli & Vegni, 2008).

Let  $n$  be the discrete time index and  $p_n$  be the power measure at time  $t_n$ . The moving average estimate  $P_N$  of the received power on a sliding window of length  $K$  is

$$P_N = \frac{1}{K} \sum_{i=N-K+1}^N p_i, \quad N \geq K. \quad (19)$$

Though averaging over the last  $K$  samples, it allows reducing the impact of instantaneous power fluctuations in power detection and reduce the power error estimation. On the other

hand, as the MN is assumed to be moving, the length of moving windows depends on the actual MN speed. However, moving average filters are prone to outliers. A more robust estimate can therefore be computed by replacing the linear mean filter with the (non-linear) median filter.

Let us suppose a mobile node is moving in an area approximated with a lattice of  $M \times M$  square zones, each with a width  $L_{\text{zone}}$  [m]. While moving on the lattice, the MN calculates the power received for each visited zone  $Z_j$ . Let  $P_n^{Z_j}$  denote the average of the power samples collected inside  $Z_j$  and associates it with the planar coordinates of the centre of the zone  $(x_j, y_j)$ . Namely, power level calculated at time  $n$  for the zone  $(x_j, y_j)$  is given by

$$P_n^{Z_j} = P_n(x_j, y_j) = \frac{1}{\|Z(j)\|} \sum_{i \in Z(j)} p_i, \quad (20)$$

where  $Z(j)$  is the set of the power samples  $p_i$  collected in the last visited zone  $j$  up to time  $n$ , and  $\|Z(j)\|$  is the cardinality of the set  $Z(j)$ .

Equation (20) provides a criterion to assess received power from both the UMTS and WLAN networks on which handover decisions of the PB approach are based. In addition, it allows assessing the power  $P(x_j, y_j)$  for each  $Z_j$  zone which can be stored in the terminal and populate a power map for the visited area. Once each zone of the lattice were visited at least once, the power map would be completed. However, it is possible that the complete visit of all the zones of the map can take long, and perhaps never occurs, especially if the number of zones  $M^2$  is big. As a consequence, in order to accelerate power map building we can use polynomial interpolation to assign a power value to zones which has not been visited yet.

Namely, let us assume that zone  $Z_j$  has not been assigned a power value yet. Moreover, let  $Z_{j_1}$  and  $Z_{j_2}$  be the nearest zones and aligned to  $Z_j$  (as depicted in the examples of Figure 8), with a power value assigned. We can use linear interpolation to assess the power value  $P(x_j, y_j)$  of  $Z_j$  as follows. When the zone  $j$ -th is between zone  $j_1$  and  $j_2$  (Figure 8(a) and (b)), assessed power value of  $P(x_j, y_j)$  of zone  $j$ -th is given by:

$$P(x_j, y_j) = \frac{D_j^{j_2}}{D_j^{j_1} + D_j^{j_2}} P(x_{j_1}, y_{j_1}) + \frac{D_j^{j_1}}{D_j^{j_1} + D_j^{j_2}} P(x_{j_2}, y_{j_2}), \quad \text{with } D_j^{j_1} < D_j^{j_2}, \quad (21)$$

where

$$D_j^{j_1} = \sqrt{(x_j - x_{j_1})^2 + (y_j - y_{j_1})^2}, \quad D_j^{j_2} = \sqrt{(x_j - x_{j_2})^2 + (y_j - y_{j_2})^2} \quad (22)$$

are the Euclidean distances between the centers of the zones  $Z_{j_1} = (x_{j_1}, y_{j_1})$  and  $Z_{j_2} = (x_{j_2}, y_{j_2})$  with  $Z_j = (x_j, y_j)$ , respectively. Conversely, when  $Z_j$  is not between  $Z_{j_1}$  and  $Z_{j_2}$ , as depicted in Figure 7 (c) and (d), the assessed power value  $P(x_j, y_j)$  of the zone  $j$ -th is given by:

$$P(x_j, y_j) = \left| \frac{D_j^{j_2}}{D_j^{j_2} - D_j^{j_1}} P(x_{j_1}, y_{j_1}) - \frac{D_j^{j_1}}{D_j^{j_2} - D_j^{j_1}} P(x_{j_2}, y_{j_2}) \right|. \quad (23)$$

It is worth highlighting that linear interpolation through (22) and (23) brings about errors in the power map. In addition, the exploitation of (22) and (23) starting from the power values of all visited zones does not guarantee completion of the power map. In general, a sufficient

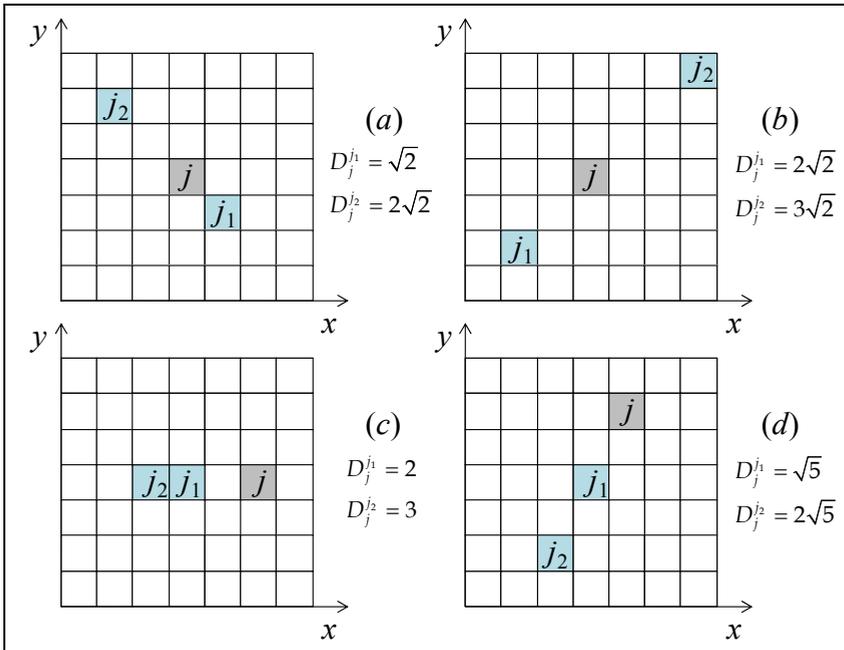


Fig. 8. Power Map built according to the displacement of zones

number of visited zones has to be achieved prior completion of the power map is possible. Such number is also dependent on the actual path of the MN in the lattice.

Let us introduce a coefficient to denote the degree of reliability of the power map at time  $n$ . Let  $VZ_n$  be the set of visited zones up to time  $n$ . We introduce the Map Reliability Index  $MRI_n$  at time  $n$  as follows:

$$MRI_n = \frac{\|VZ_n\|}{M^2}, \tag{24}$$

where  $M^2$  is the total number of zones in the square lattice. We fix empirically a threshold value  $MRI_{TH}$  for the index in (24) beyond which the knowledge of the visited environment is regarded acceptable. Only when this threshold value is reached  $MRI_{TH}$ , polynomial interpolation with (22) and (23) is started. As in (Wang *et al.*, 2001), a lookup table of power profiles in each visited area is stored in the MN's database.

Basically, each visited zone size depends on the rate of change of the received power signals. For example,  $L_{zone} = 50$  m is typical for a macro-cell with a slow average power variation, and  $L_{zone} = 10$  m for a microcell with a fast signal change. Then, each zone size has pre-measured signal means and standard deviations for the serving cell and the neighbouring cells.

Figure 9 shows how a visited zone is built. The MN is in position  $P_1 = (x_1, y_1)$ , while  $P_2 = (x_c, y_c)$  is the centre of a WLAN/UMTS cell. We can evaluate the angle  $\alpha$  between the line from  $P_1$  and  $P_2$  and the horizontal plane, as:

$$\alpha = \arcsin\left(\frac{y - y_c}{P_1 P_2}\right), \tag{25}$$

where  $\overline{P_1P_2}$  is the distance from  $P_1$  and  $P_2$  obtained according to the Euclidean formula. The angle  $\alpha$  is adopted to get the power attenuation, as we assume that the WLAN/UMTS cell radius  $r_{\text{WLAN/UMTS}}$  strictly depends on a factor  $\gamma(\alpha)$ , that modifies the cell radius value, as:

$$r_{\text{WLAN/UMTS}}(\alpha) = \gamma(\alpha) \cdot r_{\text{WLAN/UMTS}} \quad (26)$$

The factor  $\gamma(\alpha)$  is expressed as:

$$\gamma(\alpha) = 1 + 0.8 \cdot \sin\left(\frac{\alpha - \varphi_k^{\text{WLAN/UMTS}}}{2}\right), \quad (27)$$

where  $\varphi_k$  represents the  $k$ -th WLAN/UMTS cell down-tilt value, such as

$$\varphi_k^{\text{WLAN/UMTS}} = k \cdot \frac{360}{N_{\text{WLAN/UMTS}}}, \quad (28)$$

which depends on the number of WLAN/UMTS cells  $N_{\text{WLAN/UMTS}}$ , (*i.e.* 10 and 3 WLAN access points and UMTS base stations, respectively). So, the factor  $\gamma(\alpha)$  is in the range [0.2, 1.8], and  $r_{\text{WLAN/UMTS}}(\alpha)$  will be decreased or increased of 80% of  $r_{\text{WLAN/UMTS}}$ .

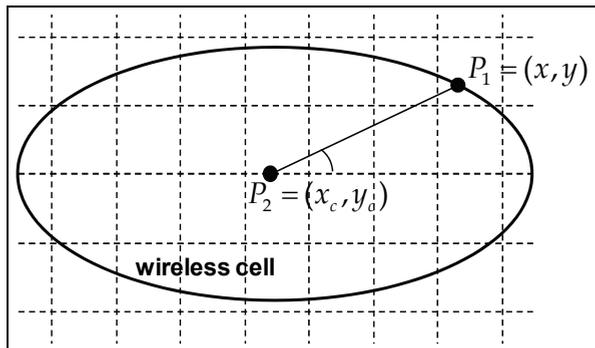


Fig. 9. Trigonometric approach for path loss map building in a (circular) wireless cell environment

### 3.3.1 Power-based approach for hybrid vertical handover

The Power-based VHO approach is exploited by the HVHO technique during the power maps building phase. Particularly, from mobile switch-off up to the completion of the power maps of both the UMTS and WLAN networks, the mobile node uses the PB-VHO approach to guarantee seamless connectivity (Inzerilli & Vegni, 2008). It performs handover using power measurements only, and does not take account of location information.

With the PB-VHO scheme the MN selects a network access, either UMTS or WLAN, and keeps it till the received power from the current network drops below the receiver sensitivity. Hence, the other network is scanned in order to verify if a handover to the other network can be done. Namely, if the power from the other network exceeds the receiver sensitivity, a handover to the new network is executed. In case power from both networks is below the minimum sensitivity, power scanning in both networks is continued repeatedly till one of the two networks exhibit a power value above its sensitivity threshold.

Power scanning frequency is limited in order to preserve battery charge as well as to prevent the ping-pong effect. When the mobile switches on it attempts selecting the WLAN network interface. Namely, if the measured power from the WLAN network interface card is above the value of MN WLAN receiver sensitivity, then the WLAN connectivity is available and the WLAN access is selected. Otherwise, if the measured power from the UMTS network interface card is above the value of MN UMTS receiver sensitivity, UMTS connectivity is available and the UMTS access is selected. When both checks fail, the mobile node waits a waiting time pause before re-trying the WLAN network scanning again.

### 3.3.2 Enhanced location-based approach for hybrid vertical handover

In the location-based approach presented in Subsection 3.2 we have assumed WLAN/UMTS circular cells. When the mobile terminal accesses a power map of the visited area representing the WLAN coverage area, as well as the UMTS coverage area, it is possible to derive a more accurate assessment of the *GP* in the UMTS and WLAN links, respectively. In this subsection we introduce a modified version of the location-based approach as described in Subsection 3.2, that is suitable for non-circular wireless cells. In particular, we consider a variable radius for each cell  $k$ -th, such as the cell radius becomes a function of the angle  $\alpha_k$  between the horizontal axis and the axis connecting the border of the cell with its centre. This approach is then called as Enhanced Location-based (ELB) VHO, for non-circular wireless cells. The ELB-VHO approach is exploited in order to obtain a characterization of the wireless cell geometry coming from the power map building phase, as depicted in Figure 10.

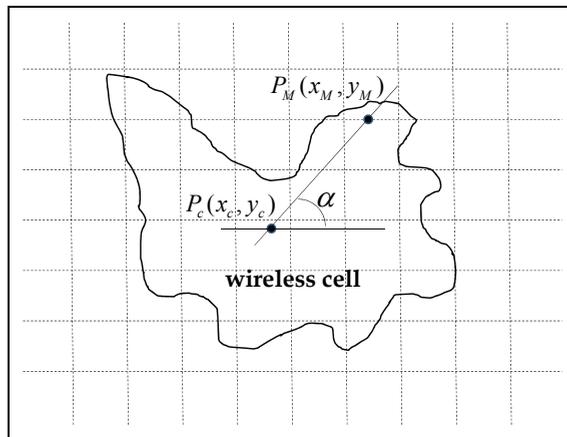


Fig. 10. Trigonometric approach for path loss map building in (anisotropic) wireless cell environment

The boundary of a cell in the power map is identified by a set of values of the power approaching the network sensitivity  $\mu$ . When such values are not available in the power map they can be obtained through polynomial interpolation. The centre of the cell is instead identified with the maximum power value.

Once the boundary and centre of each cell  $k$ -th in the power map has been identified as a set of points, it is possible to assign an angle  $\alpha_k$  to each point of the boundary with respect of the centre of the cell and its distance  $R_{cell}(\alpha_k)$ . The list of radius  $R_{cell}(\alpha_k)$  for each cell  $k$ -th is exploited by the ELB scheme.

It follows that the maximum  $GP$  in a WLAN and UMTS cell can be calculated with the following approximated formulas, which replace (17) as:

$$\begin{cases} GP_{\max}^{UMTS} = BW_{\max}^{UMTS} \cdot \Pr \left\{ \left( \frac{R_{cell}^{UMTS}(\alpha)}{r^{UMTS}} \right)^{\gamma} + \delta A_d < 1 \right\} \\ GP_{\max}^{WLAN} = BW_{\max}^{WLAN} \cdot \Pr \left\{ \left( \frac{R_{cell}^{WLAN}(\alpha)}{r^{WLAN}} \right)^{\gamma} + \delta A_d < 1 \right\} \end{cases} \quad (29)$$

However, the handover decisions are still taken on the basis of (19).

#### 4. Conclusions

In this chapter we described the main aspects of vertical handover procedure. This mechanism is oriented to ensure and maintain service continuity for mobile users in heterogeneous wireless network environments. Three different vertical handover strategies have been investigated, such as (i) the multi-parameter QoS-based approach, (ii) the location-based algorithm and (iii) the hybrid vertical handover technique.

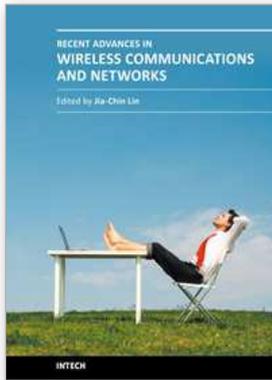
The multi-parameter QoS-based VHO assumes both subjective and objective video quality metrics as handover decision criterion, such as a vertical handover is initiated whenever the QoS level is decreasing under a fixed threshold. In the location-based VHO the mobile node position is exploited in order to estimate some network performance (*i.e.* goodput figure). A handover is then initiated whenever a selected candidate network guarantees higher performance than the serving network.

Finally, we illustrated the third vertical handover technique (*i.e.* HVHO), that is an hybrid approach based on both power measurements and location information. The HVHO develops an enhanced location-based approach to build and maintain path loss maps, which provides an updated description of the wireless cells in a visited environment. The use of combined location and power information to drive handover decisions brings about goodput enhancements, while assuring a limited VHO frequency with respect to simple single-parameter techniques.

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