Location Aware Mobility Assisted Services for Heterogeneous Wireless Technologies

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Abstract—Mobile user tracking and seamless service continuity in heterogeneous network environments represent an issue, especially when users move from outdoor to indoor environments, and vice versa. Mobile terminals with these properties allow providers to enable new services. In this paper, a location aware mobility-assisted technique for both indoor and outdoor environments is presented. The technique provides local positioning service and non-homogeneous connectivity management for UMTS, IEEE 802.11, and GPS networks.

Index Terms—Local positioning, vertical handover, mobility, heterogeneous wireless networks.

I. INTRODUCTION

Next generation networks are characterized by multiple overlapping wireless radio technologies, such as IEEE 802.11, UMTS and GPS, coexisting in the same environment [1]. In such scenarios, mobility management becomes an issue due to users switching from one access technology to another, and requiring both seamless connectivity and high quality services (i.e. video-streaming). Vertical Handover (VHO) mechanisms allow such heterogeneous connectivity by enabling switches from a serving network (SN) to a candidate network (CN), whenever users or network requirements (i.e. power level, network congestions, or other Quality-of-Service (QoS) constraints) impose it or suggest it [2]. In those heterogeneous environments, location-aware services attracted the research community’s attention since they were proven to be useful and effective [3]. However, while Global Positioning Service (GPS) technologies guarantee stable user-tracking services in outdoor environments, sufficient strength of satellite signals cannot be assumed in indoor scenarios. Literature shows that independently by the adopted technology and from the scenario (indoor or outdoor), local positioning services should be provided [4]. We propose a location aware mobility-assisted technique, which aims at the twofold goal of tracking mobile users and providing seamless service continuity in heterogeneous environment.

Our contributions are as follows:
1) We propose a design of a Mobile Terminal (MT) prototype, currently under implementation, that shall be able to provide location aware mobility assisted services.
2) We describe the two algorithms that characterize the proposed technique, and whose cooperation guarantees both indoor-outdoor local position and mobility management services in heterogeneous UMTS, WLAN and GPS networks. Handover decisions are based on locality information of the mobile terminal, as opposed to traditional techniques based on received signal strength indication [2]. Such approach has been in fact proven to perform poorly in terms of battery consumption (energy), and traffic load (throughput), due to more frequent and unnecessary vertical handovers [5].
3) We support our study by presenting simulation results; in particular, we analyze both goodput performance and handover frequency, demonstrating the efficiency of our technique.

The rest of the paper is organized as follows: Section II illustrates the proposed technique, together with the most crucial building blocks of the mobile terminal architecture; in particular, the Local Positioning Service is illustrated in Subsection II-A, for both indoor and outdoor cases, while in Subsection II-B we present the Location-Based Vertical Handover (LB-VHO) algorithm. In Section III, we report simulation results while some relevant work is discussed in Section IV. Finally Section V concludes our work.

II. LOCATION AWARE MOBILITY-ASSISTED PROTOTYPE

In this Section we describe the main architecture components of a Mobile Terminal equipped with our Location aware Mobility Assisted technique, as well as the algorithms devised to support it.

Figure 1 shows the Mobile Terminal system decomposition. For the sake of clarity, only the blocks of our interest are represented, namely, the Network Interface Cards (NICs) needed to enable the proposed service. The mobile terminal opportunistically activates the available technologies to: (i) ubiquitously guarantee (indoor and outdoor) location mobility support and, (ii) to limit battery consumption avoiding unnecessary vertical handovers.
Let us describe the functionalities of each NIC: in an indoor scenario, when the satellite signal is too weak, the GPS NIC enters in energy-saving mode leaving only the IEEE 802.11 and UMTS interfaces active. The mobile terminal is then localized and tracked by means of our local positioning service technique [3]. A mobility support service is also provided by means of the IEEE 802.11 and UMTS NICs, throughout the location-based vertical handover algorithm described later in this Section.

When the GPS service is available, the OUTDOOR Local Positioning firmware of the GPS NIC is called, and the INDOOR Local Positioning module of the IEEE 802.11 NIC is deactivated.

The middleware that enables inter-process communication amongst NICs and amongst applications and NICs is not shown in Figure 1.

A. Local Positioning Service algorithm

In this Subsection we describe in detail the local positioning service that shall be used by our prototype. We will focus only on the indoor scenario since tracking is not an issue when we can reasonably assume reliability of the GPS signal.

In indoor scenarios, multipath phenomena and synchronization problems may strongly limit accuracy when tracking mobile terminals. Our local positioning technique provides tracking of the MT’s position by means of Time-Of-Arrival (TOA) measurements. A Location Packet (LP) is broadcasted to all the neighboring nodes. In particular, we consider a grid of cooperating Location Service Support nodes and a Location Service Server (LSS). The fundamental tasks of the LSS, are: (i) registration of incoming MTs, (ii) distribution of synchronization signals, (iii) coordination of TOA measurement, (iv) TOA measures collection, (v) location estimate, and (vi) location notification (detailed in [4]).

Each Location Supporting Node (LSN) –a static access point– estimates the TOA of the LP sent by the prototype, thus receiving its position. This information is then used for the mobility service.

When a new MT enters in a LSS coverage area, it sends a Localization Services Registration Request, specifying its mobility class (i.e. classes may define speed of the user and may be useful to define tracking parameter, such as frequency of TOA measurements), and an update interval.

B. Location-based VHO

In this Subsection the location based vertical handover algorithm is presented.

Independently from the nature of the environment (indoor or outdoor), the information arriving from the Local Positioning Service is a crucial input for our algorithm to make handoff decisions. The location-based vertical handover algorithm, after receiving the distance from the nearest UMTS and WiFi base stations, initiates a goodput assessment, and when necessary, it proceeds with a vertical handover.

The goodput experienced is a function both of the bandwidth allocated to the MT for the requested services, and of
the channel quality.

Formally we can model the goodput ($GP$) as:

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

where $BW$ is the bandwidth allocated to the MT, and $P_{out}$ is the service outage probability. Notice that $GP$ is an estimated value since $P_{out}$ is a stochastic variable.

When the distance of the MT from the centre of the cell of the current network (CN) has an estimated goodput, (denoted as $GP_{CN}$), greater than the measured goodput in the selected network (SN), denoted as $GP_{SN}$, the prototype switches from WiFi to UMTS or vice versa.

The outage probability $P_{out}$ is a function of various parameters [6]; in an UMTS network it can be computed as:

$$ P_{out}^{\text{UMTS}} = \Pr \left( \frac{E_{b,Tx}^{\text{UMTS}}}{I_0 + (\gamma \sigma_N^2)} \cdot A_d^{-1} (r_{\text{UMTS}}) \leq \mu_{\text{UMTS}} \right) $$

where $E_{b,Tx}^{\text{UMTS}}$ is the bit energy in the received signal, $\mu$ and $\gamma$ are parameters depending on the signal and interference statistics respectively, $\sigma_N^2$ is the noise power at the receiver, $A_d^{-1}$ 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 intra cell interference power. Similarly, for an IEEE 802.11a network, the service outage probability $P_{out}^{\text{WLAN}}$ is defined as:

$$ P_{out}^{\text{WLAN}} = \Pr \left( \frac{E_{b,Tx}^{\text{WLAN}}}{(\gamma \sigma_N^2)} \cdot A_d^{-1} (r_{\text{WLAN}}) \leq \mu_{\text{WLAN}} \right) $$

To proceed further with the analysis of our handover algorithm, we need the following:

**Definition:** we define radius of a wireless cell, and we denoted as $R_{cell}$, the distance from the cell center beyond which the signal-to-noise and interference ratio falls below the minimum acceptable value $\mu$.

Since the path loss $A_d^{-1}$ is proportional to $r^\gamma$, and the received power $SNR(r)$ is proportional to $R_{cell}$ [7], then the maximum goodput $GP$ in WLAN and UMTS cells is computed as:

$$ \begin{align*}
GP_{\text{max}}^{\text{UMTS}} &= BW^{\text{UMTS}} \cdot \Pr \left( \frac{E_{b,Tx}^{\text{UMTS}}}{I_0 + (\gamma \sigma_N^2)} \cdot A_d^{-1} (r_{\text{UMTS}}) \leq \mu_{\text{UMTS}} \right) \\
GP_{\text{max}}^{\text{WLAN}} &= BW^{\text{WLAN}} \cdot \Pr \left( \frac{E_{b,Tx}^{\text{WLAN}}}{(\gamma \sigma_N^2)} \cdot A_d^{-1} (r_{\text{WLAN}}) \leq \mu_{\text{WLAN}} \right)
\end{align*} $$

The handover initiation will be performed by our prototype when the estimated goodput of the current network CN is greater than that one in the selected network SN e.g. when UMTS is the SN and WLAN the CN, the handover is executed if $GP_{\text{max}}^{\text{UMTS}} < GP_{\text{max}}^{\text{WLAN}}$.

### III. Simulation Results

In this Section, we shall present simulation results to assess performance of our proposed technique.

**Simulation scenario:** We have generated an indoor-outdoor scenario placing at random, on a two square kilometers area, three UMTS base stations and twenty IEEE 802.11a access points. These numbers are reasonable for urban environments [6]. In this simulation scenario, a user with our prototype travels at walking speed, following a random walk. We set up the transmitted power at the center of the UMTS and WLAN cells to be 43 and 30 dBm respectively, the UMTS/WLAN receiver sensitivities at $-100$ dBm, and the wireless cell radius to 600 and 120 meters respectively, all typical values for such networks [6]. Moreover, a waiting time parameter $T_{\text{wait}}$ [8] has been imposed as a minimum interval of time between two consecutive handovers.

**Results:** All the results we present are obtained averaging one hundred different scenarios. We assumed a continuous data upload from a server to the prototype during its walk.

In Figure 3(a) we plot the average goodput, comparing our proposed LB-VHO algorithm with an ideal case that we called *Theoretical Vertical Handover* (T-VHO). In the T-VHO the mobile terminal downloads always from the connection whose signal strength is greater with null handover latency. As we can see, although our event driven simulator captures the latency of the handovers, on average the performance of our algorithm closely match the theoretical case. The waiting time $T_{\text{wait}}$ was set to zero for this experiment to assess performance when the terminal is free to do as many handovers as it needs.

In Figure 3(b) we show what happens to the goodput when the handoff waiting time increases. As we can see also from the T-VHO curve, the theoretical approach obviously does not suffer performance degradation since there is neither restriction on the number of network changes nor handover latencies. For our LB-VHO instead, performance slightly decrease as expected. For example, when the waiting time is brought to 30 seconds, the average goodput goes down from $12.3 \times 10^4$ MB for null waiting time, to $11.2 \times 10^4$ MB (i.e. degradation of 9.1%).

Depending on the application that the prototype will run, a 9% of goodput degradation may be acceptable, but clearly there is a tradeoff between the frequency of handovers allowed (and so the battery consumption) and the goodput at the receiver terminal. Usually, it seems more reasonable to guarantee higher data rate than longer battery.

To better understand this tradeoff we have reported, in Figure 3(c), the number of handovers occurred during the same experiment set up. As expected, handovers decreases with the waiting time. It is interesting to notice also that for the goodput degradation of 9.1% ($T_{\text{wait}}$ set to 30 seconds), the average number of handovers is on average halved. From these results, it seems convenient to set $T_{\text{wait}}$ even to higher values, but that is a misleading result since the performance of the algorithm depends on the speed of the user.

We are currently working on a control theoretical approach, which adaptively modifies the waiting time $T_{\text{wait}}$ according to the current battery level and to the mobile terminal speed, keeping in mind QoS constraints of the application.
Random walks: We end this Section justifying our choice of using random walks in our simulations. Clearly no human (and so no mobile terminal) follows a random walk. Adopting this model though, we stressed the handover algorithm even more significantly. More handovers on average are likely to occur when a user follows a random walk. The intuition behind this fact is that, if a mobile terminal has a higher probability of taking a different direction from the one just taken, then every time a handover occurs, it is on average more likely that the mobile terminal will again cross the threshold triggering another handover. This effect diminishes when $T_{\text{wait}}$ increases, since intuitively the mobile terminal has more steps to move away from such threshold.

IV. RELATED WORK

A. Local positioning

The problem of local positioning has been extensively exploited in the literature, and typically good results are obtained in indoor, but not in outdoor scenarios. One example is shown in [4], where the authors deploy a grid of reference nodes that communicate with mobile terminals, and then triangulate to determine their locations. Our technique provides such service even in outdoor scenarios. Other methods have been considered adopting IEEE 802.11 and Bluetooth networks, relying on the estimate of the user distance [3]. In this work though, the technique is based on the amplitude of the signals received by each node while we only look at Euclidean distances. Moreover, these techniques perform rather poorly compared to our distance based approach, since in complex indoor environments the received signal is prone to fading induced by multipath [4].

B. Vertical Handover

Typical vertical handover algorithms are based on physical parameters (i.e. Signal-to-Noise and Interference Ratio, bandwidth, data rate) [9], or user requirements (i.e. monetary cost, QoS) [10]. We instead use location information as handover metric allowing selection of the network on the basis of its proximity to the nearest wireless cell.

V. CONCLUSION

In this paper we have presented a location aware mobility-assisted technique that achieves two goals: mobile user tracking for indoor and outdoor scenarios, and seamless service continuity in heterogeneous environments. Moreover, we have introduced the design of a mobile terminal prototype that uses this technique by GPS, UMTS and IEEE 802.11 network interface cards.

Finally, a simulation study has showed that the location information employed to assist the user mobility performs very well in terms of goodput and limitation of vertical handover occurrences.

REFERENCES