Improved Inter-Network Handover for Highly Mobile Users and Vehicular Networks

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***Abstract*—Mobility management is a critical issue in vehicular networks. In this paper, we consider the case of highly mobile users in heterogeneous wireless environments. We propose a mobility management, based on a recently proposed mobile IP-based mobility management architecture, optimizing the calculation of its dynamic registration message frequency. The new calculation takes into account both the size of the radio access networks and the velocity of the mobile users. Simulation results show that this approach yields an effective control of the policy function and alleviates the high signaling cost introduced by high registration message frequencies. The derived mobility management thus allows an efficient control of the use of registration messages at congested access networks and guarantees appropriate handoff decisions.**

I. Introduction

Recent developments in wireless and mobile networks have facilitated the cohabitation of different radio access technologies and the creation of heterogeneous environments. Therefore, mobile users can connect to a variety of wireless access points, thus enabling continuous Internet connectivity. This *always best connected* vision formulated in [1] might be possible only by the mean of efficient mobility management schemes.

Mobility management has been studied intensively for cellular networks and Mobile IP networks. A large variety of mobility management schemes and protocols have been proposed over the past years. In the literature, we can find comprehensive surveys of mobility management in cellular networks and mobile IP networks in [2] and [3], respectively. Mobile IP (MIP) is commonly accepted by the research community as a solution for mobility management. It has been designed to support mobile users in the Internet. Defined both for IPv4 [4] and IPv6 [5], MIP makes use of a mobility agent located in the home network, a home agent (HA). In case of IPv4, there exists a mobility agent in the visited network, called foreign agent (FA), which participates in the communication. The principle of this protocol is as follows: the HA forwards packets to the mobile node who is assigned a home address (HoA) in the same subnet as the HA. The FA is responsible for assigning a care-of-address (CoA) for the mobile node. Packets are transported from the originating host, the correspondent node (CN), to the HA and then IP tunnelled to the mobile node. The mobile node continually sends binding update (BU) messages to the HA indicating its CoA. The binding cache is therefore updated accordingly and the HA returns binding acknowledgment (BA) messages to the mobile node. The packets, the mobile node sends to the CN can be sent directly. A possible direct communication between the CN and the mobile node exists in mobile IPv6 (MIPv6), when considering route optimization techniques.

In [6], the authors propose decomposing the Internet mobility management protocol into three components; namely the registration protocol, which specifies the registration procedures between the mobile node and the domain it is attached to, the micro mobility protocol, which manages local mobility and may differ from one domain to another, and the macro mobility protocol, which manages mobility across domains.

Another approach that enables mobile nodes to use more than one access point simultaneously is multihoming. Despite its advantages in terms of load balancing and the support of smooth vertical handoffs, multihomed MIP has not been yet standardized. However, some proposals can be found in the literature [7], [8].

Although MIP has some drawbacks with handover latencies, introduction of tunnelling overhead, and dependency on mobility agents, it is a well-known and well-investigated mobility management scheme. The work in [9] presents a mobility management architecture based on MIP and focusing on efficient network selection and timely handling of vertical and horizontal handovers. The solution proposed in [9] allows taking handoff decisions upon calculations of a metric combining delay and delay jitter. The dynamic frequency of BU facilitates a timely discovery of congested access points and cell edges, allowing smooth handoffs with minimized packet drops and handoffs delays. However, the dependency of this solution on only mobile node speed renders this approach ineffective in certain scenarios. Additionally, its signaling cost may become high as the speed of mobile users increases.

In this paper, based on the straightforward observation that the higher the speed of a mobile node and the smaller the size of a cell, the more frequent the registration messages should be sent, we improve the work presented in [9]. We accordingly propose a new approach for calculating the registration message frequency. Indeed, in addition to the velocity of mobile nodes, the approach presented in this work takes also the size of the radio access networks into account. This increases the degrees of freedom, facilitates an effective control of the policy function, and eventually alleviates the high signaling cost incurred due to unnecessarily high registration message frequencies.

The remainder of this paper is structured in the following fashion. In Section II, we provide an overview on the mobility management scheme proposed for highly mobile users and vehicular networks in [9]. Based on that, Section III describes the proposed enhancements to the scheme. The framework adopted for the evaluation of the proposed scheme is described in Section IV. Furthermore, Section IV discusses the obtained results and highlights the advantages of the proposed scheme in comparison to the original one proposed in [9]. Finally, we conclude in Section V.

II. Review of the mobility management for highly mobile users and vehicular networks

In this section, we present an overview of the mobility management presented in [9].

The design of a mobility management scheme for highly mobile users and vehicular networks requires two important decisions.

The first decision relates to the point of handover enforcement/control. As an extension of the work in [9], our proposed scheme is based on an end-to-end concept where the user is connected to an arbitrarily number of access networks at each time. We consider in this work a *user-centric approach* where the end-user's terminal undertakes decisions on handover timing and network selection.

The second decision relates to the placement in the layered networking stack. Indeed, when handling mobility management at the network layer there is no need to change the ongoing applications. Whereas, handling mobility management at the transport layer requires changes to existing applications. Thus, as in [9], we consider the network layer approach which requires the use of MIP, a widely used solution for network layer mobility management.

It has been shown in [10], that the usage of BU and BA messages to measure delay and interarrival jitter is beneficial as it allows performing continuous comparisons between access networks. In highly mobile users and vehicular networks, sending BU/BA messages at high frequencies could be advantageous, although they incur some overhead and may result in an increased consumption of the network resources.

The vertical handoff decision model presented in [9] is a policy-based decision model. It makes use of the cost function of the network defined in [11] with available bandwidth in the network, cost of different services in the network and power consumption of using the network as network parameters. More specifically, the policy function proposed focus on the available bandwidth or capacity of the network with respect to the user velocity. The user estimates the capacity of the network by computing the relative network load (RNL) [12] for all the available access networks. The RLN metric indicates how much congested the network is; it provides information about the bandwidth usage in the network. As expressed in (1) [13], its computation, for Message n, depends on both the round trip time (RTT) contribution, denoted by $\bar{z}_n$, and the RTT jitter contribution, denoted by J_n.

$$RLN_n = \bar{z}_n + cJ_n \tag{1}$$

where c represents a weight of the RTT in comparison to the value of the RTT jitter, and

$$\begin{aligned} \bar{z}_n - \frac{h-1}{h}\bar{z}_{n-1} &= \frac{1}{h}RTT_n \\ J_n - \frac{h-1}{h}J_{n-1} &= \frac{1}{h}|RTT_n - RTT_{n-1}| \\ \text{and} \quad RTT_n &= R_n - S_n. \end{aligned}$$

The initial variables are such that $\bar{z}_0 = RTT_0$, $D_0 = 0$, $J_0 = D_1$ with $D_n = RTT_n - RTT_{n-1}$. The variables S_n and R_n denote respectively the time of sending the BA message n and the time of arrival of the BU message n and the variable h is a history window for the weighted average calculations.

In order to adjust the frequency of sending BU messages according to the speed of the user, the authors propose in [9] a frequency f of the BU/BA messages given by

$$f = \begin{cases} f_{\text{min}} & \text{for} \quad v \leq v_{\text{low}}; \\ kv & \text{for} \quad v_{\text{low}} \leq v \leq v_{\text{high}}; \\ f_{\text{max}} & \text{for} \quad v \geq v_{\text{high}}. \end{cases} \tag{3}$$

where, k is a constant and v denotes the speed of the user. The lower speed, v_{low} (resp.the higher speed v_{high}), of the user is related to the minimum (resp. maximum) frequency of BU/BA messages, f_{min} (resp. f_{max}) as follows:

$$f_{\text{min}} = kv_{\text{low}} \quad (\text{resp.} \quad f_{\text{max}} = kv_{\text{high}}).$$

III. Improved Inter-Network Vertical Handover

In this section, we present a new approach for calculating the registration message frequency which leads to improved performance of the mobility management.

As one may observe on the flow chart of the classification of vertical handoff decisions (Fig. 4 in [14]), the mobile user conditions such as its geographical information and its velocity should be taken into account in the vertical handoff decision process. Therefore, the policy function proposed in this work completes and improves the one proposed in [9] in the sense that it also takes into consideration the geographical information, namely the size of the cell, in which the mobile user is currently active.

Admittedly, an accurate real-time estimation of the cell size of time-varying environments such as vehicular networks remains an open problem. Indeed, the cell radius strongly depends on the terrain categories under consideration [15]. For instance, in urban areas, cell size estimation based on the signal strength of the different paths may be impacted by buildings. Moreover, the heterogeneity of the wireless network environments may imply the coexistence of several cells of different size, rendering unefficient the solutions based only on the *a priori* knowledge of the cell size provided by the mobile network operator.

Nevertheless, it is worth mentioning that considerable works in estimating the size of the cells in realtime are in progress and promising results can be already found in the literature. In [16] for instance, the author proposes a method for detecting and estimating the size of a cell at the base station. The method proposed makes use of the statistics of the active users information such as their estimated distance to the base station, the path loss between them and the base station and their transmit power level, sent to the base station. In the sequel, the base station compares the estimated cell sizes with the thresholds provided by the network operators. In addition, the IEEE 802.21 standards [17] for handover handling and interoperability between heterogeneous networks will provide an information service which may be useful for mobile users in acquiring geographical information. Therefore, in this work, we assume that the terminals are able to roughly estimate the cell size or it is broadcast to them upon their attachment to the cell.

In the other hand, the approach in this work is based on the observation that the higher the speed of a user and the smaller the size of a cell, the more frequent the registration message should be sent; that is, the new frequency f_{new} of sending BU/BA messages should depend on both the speed of the mobile user and the size of the source cell in which the mobile node is performing the handoff decision. In the original design of the envisioned mobility management [9], the frequency f depends only on the speed of the mobile node as depicted in Fig. 1.

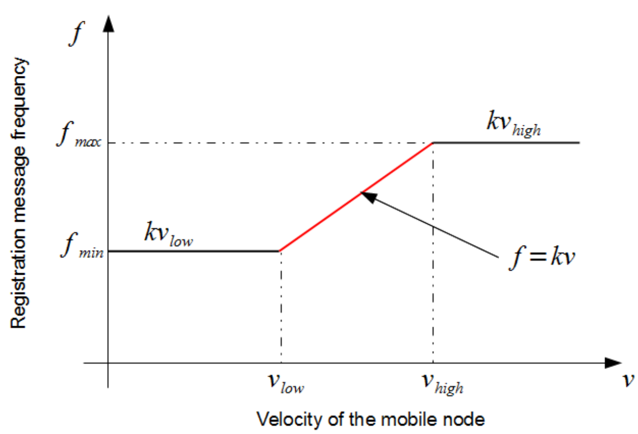

Fig. 1. Registration message frequency variation with respect to the velocity of the mobile node.

In this work, we propose that for cells of larger size, the number of BU/BA messages per second should be reduced to the frequency ($f_{\text{new}} = kv_{\text{low}}$ BU/BA messages per second), and for cells of smaller size, the registration message frequency does not depend on the size of the cell, but only on the speed of the mobile node ($f_{\text{new}} = f = kv$ BU/BA messages per second). Empirically, the registration message frequency f_{new} can be summarized as follows:

$$f_{\text{new}} = \begin{cases} kv_{\text{low}} = f_{\text{min}}, & \text{for} \quad R \geq R_{\text{max}}; \\ g(v, R), & \text{for} \quad R_{\text{min}} \leq R \leq R_{\text{max}}; \\ kv = f, & \text{for} \quad R \leq R_{\text{min}}. \end{cases} \tag{4}$$

where R is the cell radius, v is the speed of the mobile node, k and v_{low} are given in (3). $g(v, R)$ is a function which takes both v and R as inputs, such that for a given velocity v, the frequency f_{new} may increase as the radius of the cell decreases to a given value R_{min}, or, inversely, may decrease as the radius of the cell increases to a predetermined value R_{max} as it is illustrated in Fig. 2.

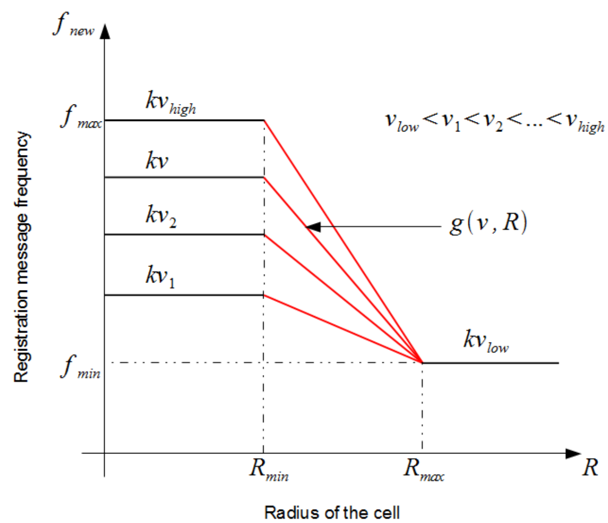

Fig. 2. Proposed registration message frequency variation with respect to both the cell radius and the velocity of the mobile node.

The slope of the straight line $g(v, R)$ depends on the speed of the mobile node v and the parameters R_{min} and R_{max}. For $R_{\text{min}} \leq R \leq R_{\text{max}}$, the registration message frequency $f_{\text{new}} = g(v, R)$ is given by

$$g(v, R) = k \frac{v - v_{\text{low}}}{R_{\text{min}} - R_{\text{max}}} \left(R - R_{\text{max}}\right) + kv_{\text{low}} \tag{5a}$$

$$f_{\text{new}} = \frac{f - f_{\text{min}}}{R_{\text{min}} - R_{\text{max}}} \left(R - R_{\text{max}}\right) + f_{\text{min}} \tag{5b}$$

Such a duality dependency does not exist in [9], as depicted in Fig. 1 which summarizes the variation of the registration message frequency with respect to the velocity of the mobile node.

IV. Performance Evaluation

This section is dedicated to the evaluation of the proposed mobility management scheme. In our scenario illustrated in Fig. 3, we consider a constant bit rate (CBR) application of 64 kbps, emulating a voice over IP (VoIP) application. The CBR runs from a server (i.e., a wired node) to a mobile node (i.e., a vehicle in Fig. 3).

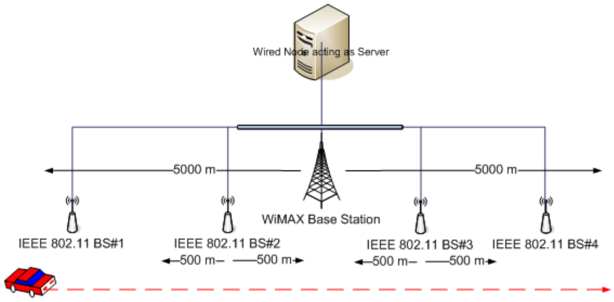

Fig. 3. Envisioned network scenario.

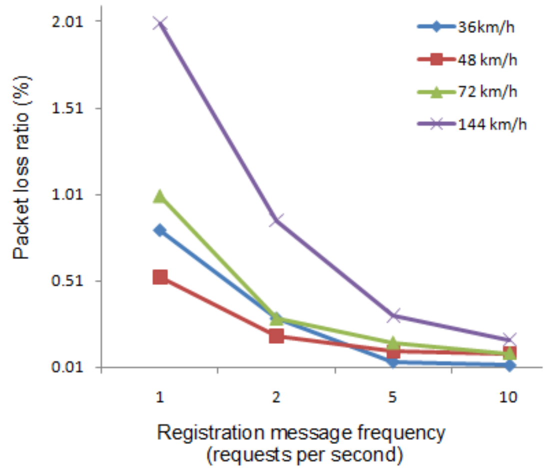

Fig. 4. Packet loss ratio with respect to the registration message frequency.

In the conducted simulations, the mobile node sends Internet control message protocol (ICMP) requests to the server. These messages are monitored using the optimized network engineering tools (OPNET) simulator [18]. The number of ICMP replies received at the mobile node are used to estimate the packet loss ratio (PLR). For the evaluation purpose, we do not allow two consecutive ICMP messages to be lost; otherwise, a vertical handoff is immediately applied. When the RNL metric can be computed, the decision of performing a handoff or not is based on the evaluation of the policy function. For the sake of performance evaluation of the proposed policy function, we do not include the impact of both the power consumption and the cost of the network services in the handover decision performance. This is done by setting to zero both the monetary cost weight [11] and the power consumption weight [11]. The value of the history window h is set to $h = 5$ and the speed of the mobile user is set to $v = 36$km/h, $v = 48$km/h, $v = 72$km/h or $v = 144$km/h.

The communication range of the WiMAX base station (BS) has a radius $R_{\text{WiMAX}} = 5000$m while that of each individual IEEE 802.11 BS has a radius $R_{\text{IEEE}} = 500$m. We assume that the IEEE 802.11 BSs do not overlap with each other so that there is no horizontal handover and also that the IEEE 802.11 and WiMAX BSs are all connected through an Ethernet wired connection to the server. We also assume that $R_{\text{WiMAX}} \geq R_{\max}$ and $R_{\text{IEEE}} \leq R_{\min}$ so that the frequencies at which the ICMP requests are sent, when the mobile node is communicating through the IEEE 802.11 BSs, are 1, 2, 5 or 10 per second. Furthermore, when the mobile node is communicating through the WiMAX BS, the frequency at which the ICMP requests are sent will always be maintained at 1 request per second, which corresponds to $f_{\min}$.

In the remainder of this paper, we present, on the one hand, the results illustrating the performance evaluation of our mobility management technique. This is achieved, quantitatively, through the study of the packet loss ratio (PLR). On the other hand, we compare our mobility management scheme against that presented in [9] with regard to the signaling cost.

The results of the PLR for different speeds of the mobile node are plotted in Fig. 4. From the figure, it can be seen that for a given velocity of the mobile node, the PLR decreases as the number of ICMP requests sent per second increases. This performance is contrary to the results in [9] whereby the velocity of the mobile node does not impact the PLR. As we can observe from Fig. 4, considering for instance the cases of velocities $v = 36$km/h and $v = 48$km/h, this performance results from the fact that the mobile node has handed off during its displacement. Indeed, in the proposed mobile management scheme, when the mobile node moves to a cell of different size, it automatically adjusts its registration message frequency to the size of the cell in addition to the velocity adjustment. The advantage of such a policy is its flexibility with regard to the applications as the number of degrees of freedom is increased.

In addition, it is obvious that the proposed mobility management scheme provides a good tradeoff of signaling cost with regard to the speed of the mobile node and the size of the cell. In fact, as shown in [9], the bandwidth used for signaling increases as the speed of the mobile node increases. For instance, when considering a cell of large size, and assuming a high speed mobility of the mobile node, the signaling cost becomes high since the MIPv4 standard recommends that BU messages should be handled by the HA at least once every second. Whereas, with our proposed improved management scheme, such a trade off can be alleviated by adjusting the registration message frequency (bandwidth) with regard to the size of the cell.

V. Conclusion

In this paper, we have presented a new approach for calculating the registration message frequency. The dual dependency to the velocity of the mobile node and the size of the radio access network yields more flexibilility and makes efficient usage of the resources of heterogeneous environments. From the simulation results, the proposed scheme proved to be useful for highly mobile users and vehicular networks in heterogeneous environments.

Finally, it should be admitted that the performance of the proposed scheme may be impacted by errors in the cell size estimation. The interaction of the proposed scheme with such errors and solutions to cope with such limitation defines the future research directions of authors in this particular area of research.

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