A Policy for Group Vertical Handover Attempts

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***Abstract*—The rising of heterogeneous networks brings vertical handover as an important topic in research. Current challenges include proposing efficient handover schemes or adapting classic existing schemes. In this paper, we propose a policy for Group Vertical Handover (GVHO) attempts. We evaluate our solution by modifying an existing GVHO scheme. Such scheme handles vertical group handovers based on a threshold that limits handover blocking probability. Although our study was made based on a specific scheme, the proposed solution is generic enough to be applied in other GVHO schemes. Results show that our solution reduces the handover latency in comparison to the original GVHO scheme studied while maintaining the handover blocking probability under a pre-defined threshold. In particular, we could reduce latency from 20% to 40% in the scenarios studied.**

Keywords-GVHO; handover; attempt; latency.

I. Introduction

Recently, the concept of handover (or handoff) has evolved to take into account the continuity of communication sessions even among different Radio Access Technologies (RATs) [1]. This replaces the classic concept of transferring an ongoing call or data session from one channel to another over networks using the same technology. The new definition is motivated by the recent popularity of devices such as tablets and smartphones, which are capable of supporting multiple link-layer technologies and handling different kinds of traffic. Inter-RATs handover is the main concern in Vertical Handover (VHO) studies [1]–[9] and issues such as the continuity of telephone calls and streaming sessions may also define requirements for handover decisions. Use cases in trains and on buses introduce new challenges. This leads us to look into the Group Handover (GHO) problem [10]. GHO takes place when two or more Mobile Nodes (MNs) intend to request handover at the same time to the same base station. During GHO, MNs are not necessarily aware of the presence of each other. Thus, GHO procedures must carry out load balancing. To achieve this, criteria such as energy saving, available bandwidth, and type of service may be considered [11]. Research related to Group Vertical Handover (GVHO) covers simultaneously issues from GHO and VHO [12]. GVHO brings the complexity of associating load balancing needs with the implications of choosing one technology instead of another. It must also handle legacy systems and individual handovers.

Among the handover phases of discovery, decision, and execution [9], the decision phase interests us the most. The decision process in GVHO is still an open issue and it may impact the GVHO overall performance, not only the decision algorithm itself, but the policy for GVHO attempts. GVHO research seeks to provide efficient decision techniques. Some of them are based on centralized entities [13], distributed algorithms [14], random delays [12], reinforcement learning [13], game theory [12], and optimization problems [11]. We give special attention to Lee *et al.* [11], since it addresses the latency reduction while considering load balancing, support to legacy networks, and handover blocking probability. Those issues are fundamental for advances in GVHO. The objective of Lee *et al.* [11] is to model GVHO decision as an optimization problem. Latency is minimized given the condition of maintaining the handover blocking probability under a pre-defined threshold. Although Lee *et al.* [11] present encouraging results, the scheme does not scale well. As the number of MNs grows, we have noticed a pronounced increase of latency.

We believe that if the handover scheme could control efficiently handover attempts, performance might be enhanced and the latency increase might be controlled as the number of MNs grows. In this paper, we propose a policy for handover attempts that is based on exponential backoff and uses information from the GVHO scheme itself. The proposed solution reduces average latency and eases the slope of the latency curve in comparison to results found in [11]. The main objective of this paper is to show the importance of choosing a proper policy for GVHO attempts. This paper is organized as follows: we present GVHO concepts in Section II. We present related work in Section III. We detail the scheme proposed in [11] in Section IV. We present the proposed policy for GVHO attempts in Section V. We present a comparative performance evaluation between the scheme with and without the proposed solution in Section VI. Finally, we highlight our conclusions in Section VII.

II. Group Vertical Handover - GVHO

Recently, technological evolution has allowed the rising of cheaper gadgets supplied with multiple network interfaces. This fact has encouraged new research in mobility management considering brand-new use-cases. A remarkable challenge is to manage different connections taking place at the same time in public spaces with a diverse number of available technologies. The problem of a high number of users connecting simultaneously to the same base station supporting a different technology from their previous base station is studied in the Group Vertical Handover (GVHO) area of interest [1]. A GVHO scenario is illustrated in Figure 1. Suppose an open event, like a music festival where users desire to communicate with friends, transmit multimedia data, and are constantly changing their location. There may be several available RATs and dozens of devices in communication sessions simultaneously.

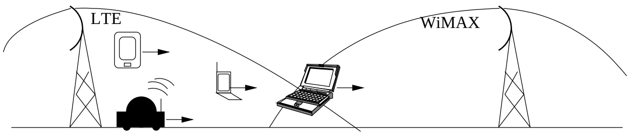

Figure 1. A GVHO scenario.

The proposal of efficient and effective handover procedures for mobility management including handover decisions and optimal resource allocation is a critical need for GVHO [1]. Proposals may involve the three handover phases [9]:

- *Discovery* - Service discovery and network information gathering. A specific criterion is adopted to determine if handover is necessary. It may be signal-to-noise ratio, transmission rate, Point of Attachment (PoA) load, battery consumption, etc.
- *Decision* - One network in a list of candidates is chosen, taking into consideration data collected in the earlier phase. This phase is the focus in this paper because the decision technique and the policy for handover attempts strongly impact the overall handover performance. Depending on the network technology, handover may be MN-initiated or network-initiated.
- *Execution* - Networks and MNs exchange control messages to make channel switching. This phase should minimize service interruption in order to appear imperceptible to the user. This phase is strongly media-dependent.

IEEE 802.21 standard [5] describes the Media Independent Handover Function (MIHF). MIHF intends to be a common mean over the link layer in order to allow different RATs to communicate with each other during handover. Each RAT must provide its own implementation of MIHF and map the MIHF messages to its media-dependent primitives. Thus, MIHF may offer information that can be used as discovery or decision parameters [11] [15]–[17].

There may be many different decision criteria for GVHO such as available bandwidth, expected QoS, or battery consumption. The type of service (voice or data) is a determinant factor for choosing the most suitable criterion for GVHO decision. Decisions made without network analysis and without considering the MNs in the neighborhood may bring disastrous performance results. Wrong handover decisions may cause MNs to choose the same PoA, overloading it, or to choose an inadequate network for the application in use. The main handover decision approaches found in GVHO research include:

- *Centralized entities* [13] - A relay station handles GVHO management, removing complexity from MNs. This approach also reduces the uncertainty level and ensures better performance than decentralized approaches. The main drawback is the lower fault tolerance.
- *Distributed algorithms* [14] - The decision algorithm makes use of well-known parallelism and synchronization techniques. Distributed algorithms are usually simple to understand. However, they are not built to adapt themselves to new scenarios.
- *Random delays* [12] - MNs attempt to handover after a random delay. This procedure minimizes simultaneous handover attempts and is considered a subtype of the distributed algorithm approach.
- *Reinforcement learning* [13] - It employs Artificial Intelligence (AI) techniques to make MNs learn about their surrounding environment as they make handover attempts. This approach does not require message exchange among users. However, learning algorithms can cause performance issues.
- *Game theory* [12] [13] - This approach maps handover scenarios in cooperative or non-cooperative games in which MNs are players interested in getting the best payoff as possible. The payoff may be a larger bandwidth, energy saving, or better security. Nash equilibrium is the desired stable state in which all MNs do not have anymore strategies to obtain better payoffs. The main advantage of this approach is the almost perfect match between a GVHO scenario and the Game Theory competitive models. On the other hand, it is not always possible to model additional parameters.
- *Mathematical optimization problems* [11] - Mathematical equations are used to describe the handover decision under predetermined conditions. Then, the problem is solved by finding the ideal value for the equation variables. This approach requires a more complex modelling and is more flexible than Game Theory-based models.

For any GVHO approach, the MN or the serving PoA may determine if it is possible to request handover in a certain time, or if it is preferable to postpone it, given the network conditions. Policies for handover attempts can influence handover performance, for better or for worse, depending upon the adopted solution.

III. Related Work

In [18], a relay station is used as a centralized entity to coordinate GVHO. The scenario studied is the movement of users in a train. Handover blocking and interruption probabilities are evaluated with the increase of the calls-per-minute ratio. The evaluation compares schemes with and without the relay station. The authors conclude that the proposed scheme reduces handover blocking and interruption probabilities. In this case, the relay station is responsible for executing the policy for handover attempts. The solution has limitations if co-existence with legacy systems is needed. This is due to the need of introducing a new infrastructure with special requirements.

Cai *et al.* propose three decentralized algorithms for GVHO in [12]. The first is a Nash equilibrium-based algorithm where the policy for handover attempts is based on the game strategy of each player. The second algorithm adopts random delays, thus using a simpler policy for handover attempts. The third algorithm is a more refined version of the previous one. It considers latency as a basis for delay calculations. Performance evaluations show that latency values under the three algorithms are similar. Handover blocking probability is not considered. Handover blocking probability is the probability of the MN having its handover request denied by the target network.

Niyato *et al.* propose a model for network selection that is based on evolutionary games [13]. The model consider two approaches: a central entity-based approach and a decentralized-based approach that uses a reinforcement learning model. In the first approach, the central entity controls handover attempts. In the second approach, MNs are allowed to infer the best period of time to request a handover. The fraction of MNs choosing the same PoA is the load-balancing metric adopted. They conclude that each approach has its advantages in accordance with the scenario. One drawback is not evaluating the impact of the approaches on latency.

Lei *et al.* [14] present three GVHO schemes. The first scheme schedules simultaneous attempts to random time periods. In the second scheme, MNs select PoAs using a predefined probability as a base. In this case, the policy of handover attempts consists in an immediate attempt. The last scheme requires the network to be responsible for the handover decision. Results show that the last approach is more efficient. However, it may be difficult to adapt it to legacy systems.

Lee *et al.* [11] propose a GVHO scheme, which is based on the solution of an optimization problem. The main objective is to minimize latency while limiting the handover blocking probability. Some factors make the scheme in [11] more promising than the other researches:

- it does not require the presence of a relay station.
- it may work together with legacy systems.
- it considers two of the main GVHO metrics: load balancing and latency.

Despite of presenting a promising GVHO scheme, the work in [11] lacks a good policy for handover attempts. It is based on a constant delay, which causes a negative impact on the overall GVHO performance as the number of MNs increases. We detail such scheme in Section IV.

IV. REFERENCE GVHO SCHEME

Lee *et al.* [11] propose an optimization for the total handover latency L, considering the handover blocking probability as follows:

Minimize L
Subject to $P_{HoBlock}(t) \leq P_{HoBlockThreshold}$,

where $P_{HoBlock}(t)$ is the handover blocking probability in a time t and $P_{HoBlockThreshold}$ is the maximum acceptable value for the handover blocking probability. Latency is calculated as follows:

$$L = N_{HO}.\Delta t, \tag{1}$$

where N_{HO} is the total number of attempts until the MN requests the handover; Δt is the period of time between consecutive attempts. If the MN decides to request in the first attempt, total latency would be Δt. This is because in [11], execution time is also equal to Δt.

Equation (2) presents the calculation of $P_{HoBlock}(t)$. The value of $P_{HoBlock}(t)$ is dependent on the number of candidate networks, their available bandwidth, and the number of participating MNs in GVHO. In [11], it is considered that these values can be obtained by using IEEE 802.21 MIH (*Media Independent Handover*) queries and *ad hoc* communication.

$$P_{HoBlock}(t) = \sum_{k=1}^{K} \sum_{i=C_k(t)}^{M-1} \frac{(i+1-C_k(t)).(M-1)!}{(i+1)!.(M-1-i)!} \times ((P_{sel}^k)^{i+1}.(1-P_{sel}^k)^{M-1-i}), \tag{2}$$

where:

- M represents the number of participating MNs.
- K represents the number of candidate networks with overlapping areas.
- $C_k(t)$ is the available bandwidth in a time *t* for a network$_k$. The model considers that the available bandwidth is represented by an integer value. Each MN takes one unity for handover;
- P_{sel}^k : The probability of selecting network$_k$.

The Karush-Kuhn-Tucker (KKT) condition is used in optimization problems and it can be applied to (2) to determine the P_{sel}^k value. However, P_{sel}^k can be obtained by using (3), which is simpler than using KKT and induces minor changes in results.

$$P_{sel}^k(t) = C_k(t) / \sum_{k=1}^{K} C_k(t). \tag{3}$$

Now, we can find the $M_{optimal}(t)$ value that ensures the optimization problem condition. This value can be found by setting it initially to one, then increasing it by one unit while the $P_{HoBlock}(t)$ value is still less than or equal to $P_{HoBlockThreshold}$. The probability $P_{HO}(t)$ with which a MN can request handover is given by:

$$P_{HO}(t) = M_{optimal}(t)/M. \tag{4}$$

If the MN decides not to request the handover immediately, a new attempt will be made after a constant time interval. The MN requires the number of attempts necessary to have a well-succeeded handover with blocking probability less than or equal to $P_{HoBlockThreshold}$. Algorithm (1) summarizes this process and can also be found in [11]:

where:

- `Mtotal` is the total number of MNs in GVHO.
- `Mremaining` is a counter that checks for the algorithm end.
- `decision()` is a function that returns `true` with probability $P_{HO}(t)$.
- `LHOexec` is the handover execution time. It is equal to Δt.

Algorithm 1: Reference GVHO scheme

```
L = 0;
c_atts = 1;
Mtotal = number of GVHO participants;
Mremaining = Mtotal;
while Mremaining ≤ 0 do
    find Moptimal in function of (2);
    calculate PHO;
    if decision(PHO) then
        choose networkk depending on P^k_sel;
        NHO = c_atts;
        break ;
    else
        L += t_atts(c_atts);
        c_atts++;
    end
    Mremaining = Mremaining - Moptimal
end
L += LHOexec;
```

- `t_atts()` is a function to calculate the period of time between consecutive attempts. In [11], the return value of this function is always Δt.
- `c_atts` counts the number of attempts. When `decision()` is `true` in the first attempt, the total execution latency is L_{HOexec}.

Function `t_atts()` characterizes the policy for handover attempts. In [11], the return value of this function is constant and equals to the execution latency L_{HOexec}. We observe that the increase of latency is directly related with the number of attempts. Latency always grows by a constant factor because of `t_atts()`. We conclude that this policy of handover attempts does not take advantage of information provided by the scheme itself. Additionally, it causes a negative effect in the overall handover performance as the number of MN grows, as shown in [11].

V. The Proposed Policy for GVHO Attempts

In this section, we present a policy for GVHO attempts that aims at providing reduced handover latency for GVHO schemes like the one proposed in [11]. At the same time, we intend to reduce the slope of the latency curve as the number of MNs grows.

In order to enhance performance results, we propose to modify the `t_atts()` function in Algorithm (1). Our proposed solution is exponential backoff-based. It depends upon the `c_atts` counter and the duration of a reference slot time. It is a particular case of random delay. Exponential backoff algorithms have the particularity of keeping the probability of collision and the probability of transmission stable as the number of nodes which are sharing a medium grows [19]. Although our solution is motivated by the performance issues in [11], it is generic enough to be applied in other schemes. Equation (5) shows our modified version of `t_atts()`:

$$t\_atts(c\_atts) = \begin{cases} random[0..2^{c\_atts} - 1] \ . \ timeSlot \ , \\ \quad if \ c\_atts \leq LimBackFactor \\ random[0..2^{LimBackFactor} - 1] \ . \ timeSlot \ , \\ \quad otherwise \end{cases} \tag{5}$$

where $random$ picks a uniformily distributed number over the given interval; $LimBackFactor$ is the number of attempts that limits the range of values for $random$; and $timeSlot$ is the duration of a reference time slot, which depends on the target network. This information is obtained via MIH.

Total latency depends directly on the number of attempts, which varies with the return of `decision()`. The exponential backoff approach in `t_atts()` give to the MN an opportunity for a new handover attempt after a time interval shorter than Δt, or even immediately. When the MN chooses not to request handover, other MNs may request it, reducing concurrency during the next attempts. Thus, the total number of attempts reduces, decreasing total latency and easing the slope of the latency curve as the number of MNs grows.

VI. Performance Evaluation and Comparison

The metrics evaluated are the same as in [11]: latency and handover blocking probability, both *versus* the number of MNs. The majority of the parameters also follows the work in [11]. The value of Δt is set to *0.1s*. We study scenarios with different values for $P_{HoBlockThreshold}$: *0.02* and *0.05*. Telecordia (formerly Bellcore) [20] recommends a value of *0.01* as a QoS objective. However, typical values range around *0.02* [21] [22]. We consider the value of *0.05* for $P_{HoBlockThreshold}$ in order to observe the effects of choosing a less conservative probability. The number of MNs varies from 20 to 100. It differs from Lee *et al.* [11], where this number varies from 20 to 65. The characterization of heterogeneity in simulations presented by Lee *et al.* [11] is made through the use of different available bandwidths. The number of available PoAs is 3, considering the following scenarios:

Scenario 1 - All PoAs have 18 bandwidth units.

Scenario 2 - PoAs have 5, 13, and 18 bandwidth units, respectively.

Scenario 2 is only used in [11] for validating their simulator and in a situation of co-existing individual handover, which is out of the scope of this paper. Nevertheless, we include Scenario 2 in our evaluations. The $FatorLimBack$ parameter is set to *10*. This value is based on preliminary experiments. We consider that MNs are switching from an arbitrary network to an IEEE 802.11 area. The parameter $timeSlot$ is set to $9.10^{-6}s$, which is equivalent to the SIFS time slot in IEEE 802.11 standard. We have implemented the reference scheme and our solution in a discrete-event simulator, which was written in C++. The implementation of the reference scheme in our simulator was validated by the authors of [11]. We consider a group of MNs simultaneously entering a new coverage area and starting handover procedures defined by the GVHO scheme studied. We represent confidence intervals with 99% of confidence level. Confidence intervals appear imperceptible in Figures 2-5. It is important to point out that we are not interested in evaluating the decision algorithm itself, but the impact of our policy for GVHO attempts on performance.

Figure 2 shows results for handover blocking probability under Scenario 1. The probability increases as the number of MNs grows to 45 for threshold *0.02* and to 50 MNs for threshold *0.05*. Thereafter, the curves are stable. This happens because blocking probability is getting closer to the threshold defined in the optimization problem. Since blocking probability is directly related to the cell utilization [23], it is necessary to limit the number of MNs entering a new cell at the same time in order to maintain the blocking probability under the threshold. When the blocking probability reaches the threshold, the value of $M_{optimal}(t)$ that is calculated in function of (2) can not increase anymore. This leads the remaining MNs to wait for another handover attempt. Thus, the stabilization of the blocking probability curve as the number of MN grows always implies the increase of the average latency. It is important to notice that the curves with and without our solution are similar because the optimization problem conditions are still the same. It means that the application of the proposed solution does not cause damages to the handover blocking probability, despite of the shorter time between attempts.

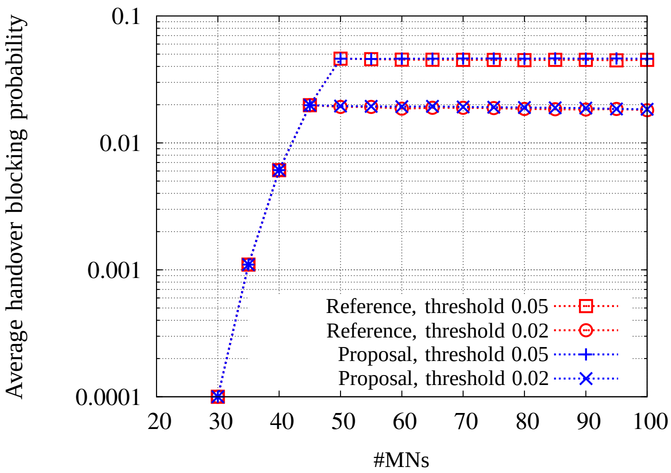

Figure 2. Handover blocking probability *versus* the number of MNs in Scenario 1.

Figure 3 presents results for the Scenario 2. It present similarities with Figure 2 but the curves gets stable sooner: from 30 MNs for the threshold *0.02* and from 35 MSs for the threshold *0.05*. This anticipation is due to the shorter total available bandwidth in the scenario studied. Thus, handover blocking probability increases faster, but it also gets stable in accordance with the established threshold.

Figure 4 shows results for latency in Scenario 1. With respect to the scheme in [11], we can observe that latency starts growing from 45 MNs for threshold *0.02*. Values in that curve are greater than those for threshold *0.05*, which starts growing from 50 MNs. As we have stated before, the stabilization of the blocking probability curve observed in Figure 2 implies the increase of the average latency. Also, there is a greater number of handover attempts when we use a lower threshold. Thus, the threshold *0.02* is more conservative and tends to make MNs wait for more time than those using threshold *0.05*. The lower the threshold is, the greater is the average latency. We can also observe in Figure 4 the impact of the proposed

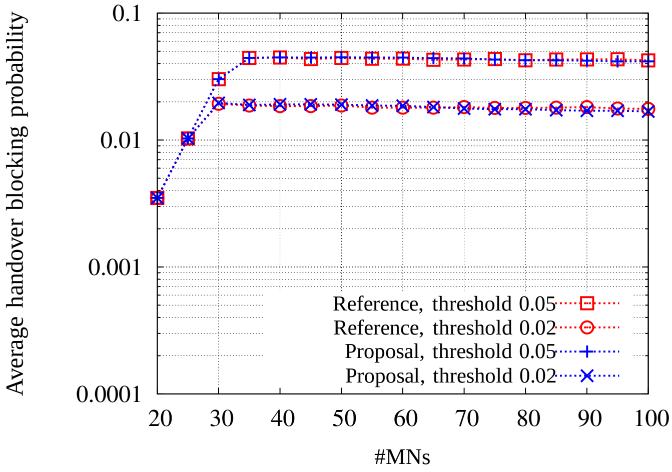

Figure 3. Handover blocking probability *versus* the number of MNs in Scenario 2.

solution on the latency curve. The curve becomes smoother than the curve that does not adopt the solution. For threshold *0.05*, the latency is 20% smaller in the case of 65 MNs and 28% smaller for 100 MNs. For threshold *0.02*, latency is 24% smaller for 65 MNs and 33% smaller for 100 MNs. The latency reduction is due to the proposed solution, which makes the delay between attempts more flexible. The exponential backoff also brought randomization to the scheme allowing MNs to try handover again sooner and in different periods of time, eventually reducing the total number of attempts.

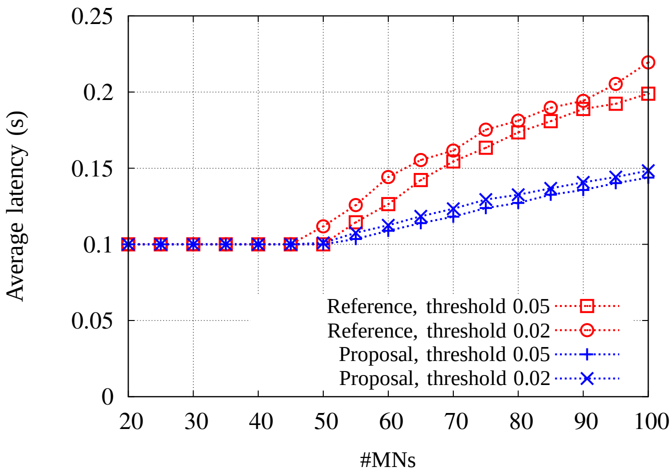

Figure 4. Latency *versus* the number of MNs in Scenario 1.

Figure 5 shows results for latency in Scenario 2. As in Scenario 1, the curve for threshold *0.02* has greater latency values than the one with threshold *0.05*. In [11], latency starts growing from 25 MNs for threshold *0.02* and from 30 MNs for threshold *0.05*. In Scenario 2, we also notice that there is a greater slope in latency as the number of MNs increases as shown in [11]. Greater latency values are expected because the total available bandwidth is shorter than in Scenario 1. However, the latency value is two times greater when the

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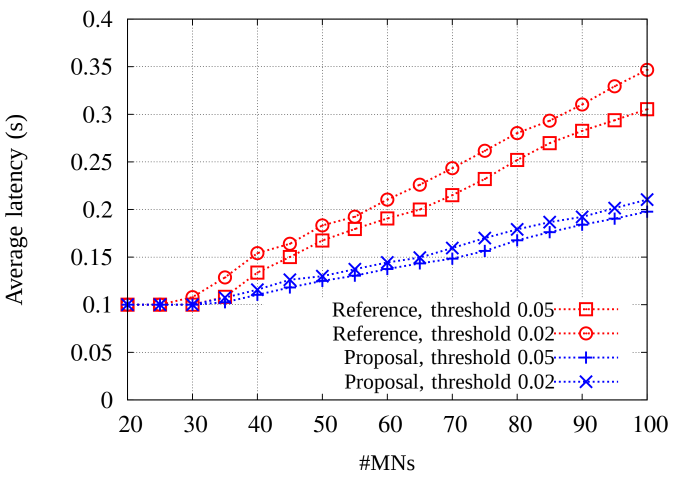

Figure 5. Latency *versus* the number of MNs in Scenario 2.

number of MNs reaches 60 for the threshold *0.02*. Regarding the same curve, we have 350 ms for 100 MNs. It is important to notice that more than two-thirds of this time is spent only in the handover decision in [11]. Figure 5 also shows that once again the proposed solution had the effect of reducing latency and easing the slope of the latency curve. For the threshold *0.05*, latency has a reduction of 29% for 65 MNs and 36% for 100 MNs. For the threshold *0.02*, we observe a reduction of 24% for 65 MNs and 40% for 100 MSs.

VII. Conclusion and Future Work

In this paper, we have proposed a policy for GVHO attempts. Our solution uses exponential backoff in order to allow a better distribution of handover attempts over time. Performance evaluations have shown that our proposal makes it possible to reduce handover latency and ease the slope of the latency curve as the number of MNs grows. In particular, results have shown that latency was reduced up to 40% in accordance with the scenarios evaluated. In future work, we will evaluate our proposal in other scenarios. We will take into account a varying number of PoAs, traffic data, different parameter values, and additional evaluation metrics. Also, we intend to include MIH queries in the solution design and to include the information gathering phase in performance evaluation. We are also planning to study the impact of our solution on other GVHO schemes.

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