Performance evaluation of a multicast-based solution for wireless resources discovery

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***Abstract* – An improved IP network service (e.g., for real time services) is expected in the near future in both wired and wireless environment. In this regard, the handover capabilities are extremely important and challenging, in particular if their use in operation must be seamless. One of the main steps to achieve seamless handover is the quick discovery of IP addresses and service capabilities of candidate access routers to hand over to. In this paper, we present a push-mode-multicast based solution to discover and timely update information about wireless resources. We evaluate the effectiveness of the proposed approach in terms of signaling burden and discovery time with respect to solutions already presented in literature.**

Keywords* – *IP mobility, access discovery, performance analysis

I. INTRODUCTION

In order to provide nomadic users with QoS-enabled services, advanced mobility management will prove to be of fundamental importance in the future Internet. It has been widely recognized that the basic Mobile IPv4/v6 protocols could perform poorly, especially with QoS-demanding applications. As highlighted by the IETF SEAMOBY Working Group (WG) [1], one of the main steps to achieve seamless handover is the quick discovery of IP addresses and service capabilities of candidate access routers (CARs) to hand over to. The quick achievement of IP addresses allows mobile nodes (MNs) to speed up the handover process, and some information about service capabilities are important to select the most appropriate wireless access (Target Access Router, TAR) among the set of CARs, according to a given metric (e.g., for load balancing purposes).

In this paper, we first describe the candidate access router discovery (CARD) solutions proposed by the IETF SEAMOBY WG. Then, we describe the distributed Push-Mode-Multicast based CARD (PMM CARD) approach and compare it with the IETF proposals. The novelty of our solution is the use of push-mode multicast transmissions, which allows both distributing CARD information within the network efficiently and highly reducing the latency due to explicit queries to a remote entity. Our approach presents the typical advantages of a distributed solution, while exhibiting high responsiveness to variations of the access network state. In addition, we have developed a theoretical model of the signaling burden associated with the different CARD solutions. Our analysis shows that, even if the amount of signaling necessary to implement all CARD approaches is in general low, our approach outperforms the IETF proposals in terms of average signaling load. This result was expected due to the efficiency of multicast transmissions in distributing information. In addition, we performed a simulation campaign to compare the discovery time of the various CARD schemes.

The paper is organized as follows. The next section summarizes the state of the art about CARD. In section III, our PMM CARD procedure is described. In section IV, we analyze the performance of the CARD solutions in terms of signaling burden. Section V reports numerical results. The peculiarities of the different CARD approaches are summarized in Section VI. Section VII reports our concluding remarks.

II. RELATED WORK

A CARD solution must cover two different aspects: (i) reverse address translation from L2 IDs; (ii) discovery and update of service capabilities (SCs).

An initial and straightforward solution is to embed the IP address, IP prefix, and SCs in L2 beacons, as suggested in [3]. This procedure has two main drawbacks. The former is strictly theoretical: encapsulating layer 3 data within layer 2 control frames violates the protocol layer architecture; the latter is that this approach would require modifications to the standard of existing technologies.

Thus, it is necessary to define a network-assisted CARD process. Each AR has to be able to obtain information about the state of neighboring pairs AR-AP and keep it in a local cache. Since the configuration of a wireless access network may be dynamic, the operations described request a continuous, dynamic signaling exchange among the network entities involved in the CARD process.

Generally speaking, each AR is connected with a number of APs; consequently, the coverage area of an AR is the union of the coverage areas of the relevant APs. Two ARs are neighbors if their wireless coverage areas are overlapping. The state stored by the AR should contain the IP address of the neighboring ARs, the L2 IDs of the relevant APs, and the SCs associated with the pairs (AR, AP). To reduce the complexity of the information management, it is organized in a table whose entries are soft states and, unless refreshed within a given amount of time, they are deleted. Therefore, when an MN, staying under coverage of an AR (current AR), obtains L2 IDs from the beacons of the some other APs, it passes them to its current AR. The current AR is in charge of providing the MN with either the IP addresses of CARs and the relevant SCs (if the TAR algorithm is run in the MN), or the TAR IP address (if the selection algorithm is carried out at the current AR). This means that, apart from the signaling exchange to resolve L2 addresses between an MN and its current AR, a SC exchange also has to be performed. The exchange between the current AR and CARs may be performed either upon an MN request or when the SC lifetime expires. CARD ([1]) and dyCARD solutions ([3]) assume that MNs are in charge of triggering/performing the TAR selection.

A very challenging issue of any CARD approach is the discovery of the IP addresses of the neighboring ARs (discovery phase), and the determination of the (L2 ID)→(IP address) mapping to be stored in the local cache. Specifically, the discovery phase consists of discovering the neighboring ARs/APs for each AR to build a coverage map of the surrounding area at both layer 2 and layer 3.

A manual AR configuration would not be a good solution since it is not feasible in large wireless networks, would not permit the adaptation to variable-topology wireless access networks; then, the coverage area of an AR could not be easily and exactly determined.

After the completion of the coverage map in each AR, the task of the CARD process is only to refresh SCs among neighbors (steady phase).

In the following, we illustrate the automatic solutions proposed in literature, which can be classified in two schemes: (1) handover-based solutions and (2) L2 beacon-based solutions.

A. Handover-based CARD approach

The basic idea of a handover-based solution [1][3] is that two ARs discover to be neighboring after a plain MIP handover between them. In more details, an AP connected with another AR is discovered after that a plain MIP handover is accomplished, which implies a layer 2 handover towards itself. After the handover, the MN has to send to the new current AR another signaling message (router identity message) containing the IP address of the old AR and the L2 address of the old AP. Thus, if the association (L2 ID)→(IP address) was unknown, the current AR can create a new entry in its cache. Moreover, a specific message exchange between the new current AR and the old one could also make the old AR aware that the current AR is a neighbor. Thus, the old AR can update its own coverage map as well. In order to complete the discovery phase between two ARs, the procedure described above must be repeated at least a number of times equal to the maximum number of overlapping APs per AR.

Note that the first handover towards an AR involving an AP of its not yet discovered (bootstrap handover) cannot be driven. This is a weakness for delay-sensitive applications and in a dynamic access network topology. In addition, the time needed to complete the discovery phase could increase in case of a dense wireless coverage. In fact, in this case, handovers are driven by the TAR towards those APs already discovered, so that a non-driven handover (discovery event, i.e., a plain MIP handover) is done only when there is no alternative.

B. Centralized L2 beacon-based approach

This solution has been illustrated in [1] and [2]. The basic idea is that each ARs must register with a centralized server, by indicating its own IP address and the L2 IDs of the APs associated with it. This server is a database that is dynamically updated by ARs. Its task is to process queries from ARs to resolve L2 IDs and, therefore, to contribute to the building of the wireless coverage map in ARs. L2 IDs are communicated by the MNs to the current AR.

The server-based solution proposed by the Seamoby WG extends the CARD protocol to support an AR-server message exchange, whereas in [2] the Authors make use of the SLP (Service Location Protocol) architecture with a centralized Directory Agent (DA). ARs act as SLP User Agents, that is they send service requests to DA. This centralized discovery clearly introduces additional signaling message exchange between ARs and the server to resolve layer 2 addresses.

C. Distributed L2 beacon-based approach

Without using any centralized server, each AR has to process queries to resolve L2 addresses. In [2], the Authors make use of the SLP distributed architecture, where each AR acts as both SLP Service Agent and SLP User Agent.

III. THE PMM CARD

In this section, we present a proposal for performing the CARD procedure within an administrative domain. The proposed PMM CARD procedure is network-assisted, distributed and based on push-mode multicast transmission. A first version of the procedure was presented in [7].

As regards the discovery phase, we follow a distributed L2 beacon-based approach. It allows us: (i) to avoid the drawbacks of a centralized solution; (ii) to avoid the bootstrap handover; (iii) to speed up the discovery phase with respect to the handover-based approach, due to the higher number of events (L2 beacons listening) that trigger the discovery of new wireless resources.

The network operator establishes a multicast group (MG_{OP}), including all the ARs that provide wireless connectivity. In other words, the ARs are the network entities that exchange signaling messages about address mapping (IP address-L2 ID) through MG_{OP}. With respect to [7], we change our approach from using multicast queries to push mode information transmissions.

In order to reduce the time needed to accomplish the selection process, the procedure provides for push-mode updates of SCs ([7]), as an alternative to update them upon requests. For this purpose, multicast transmission is used again. Each AR builds up a multicast group. Specifically, the *i*-th access router, AR_i, builds up the multicast group MG_i, which includes all its neighboring ARs, i.e., those with a coverage area overlapping with the coverage area of AR_i). We remind that the coverage area of each AR is the union of the coverage areas of all APs connected to it. This MG_i is used by the AR_i to efficiently distribute information about the SCs of its APs to the neighboring ARs.

A. The discovery phase

We present a procedure able to self-construct the geographical coverage mapping at each AR.

The network operator defines a multicast group (MG_{OP}), including all the ARs that provide wireless connectivity and act as multicast hosts. MG_{OP} is used to resolve the IP address of the AR from the L2 ID of any of its APs. For this purpose, when an AR starts offering wireless connectivity through some APs, it has to join MG_{OP} and to multicast to all other participant ARs its IP address and the L2 IDs of the active APs under its IP scope. In turn, one of the participants (e.g., the latest AR that has joined the MG_{OP}) sends a unicast reply with the address mapping of all participant ARs. Below, this preliminary phase will be referred to as initialization phase. Since the coverage area of the new AR does not typically overlap with coverage of all ARs, only a subset of this information will be used to build the CARD table. Nevertheless, we note that the data amount to be exchanged in the network and to be managed within ARs is very limited and simple.

Active ARs are in charge to promptly notify to MG_{OP} all variations in their radio coverage (e.g., (de)activation of APs), so that the interested ARs can quickly and suitably update their CARD table. This mechanism allows speeding up the address resolution phase, avoiding the latency to consult a remote entity. In this sense, the mechanism is proactive and gives a clear advantage over the IETF solutions.

Once each active AR has the complete address mapping in memory (address list), the discovery phase may take place. Please note that the address list is not the CARD table, which is more complex and structured. Assume that an MN, located under coverage of the *s*-th AP connected to AR_h ($AP_{h,s}$), enters the coverage area of another AP (say, $AP_{z,k}$) connected to AR_z,. The steps of the discovery phase are:

1. the MN listens to the beacons of the new AP;
2. the MN notifies its current AR (AR_h) of the L2 ID of the new AP, through the current AP ($AP_{h,s}$);
3. if the detected AP does not appear in the table, AR_h gets the IP address directly from the address list and asks AR_z for the SC relevant to $AP_{z,k}$. Then, it invites AR_z to join its own local multicast group and sends the SC associated with $AP_{h,s}$;
4. AR_z sends a unicast reply, containing the SC associated with the AR_z-$AP_{z,k}$ pair and the invitation to AR_h to join MG_z;
5. the process ends when AR_z and AR_h join the multicast groups MG_h and MG_z, respectively.

Clearly, the reciprocal invitations to join the local multicast groups are sent only when two ARs are discovered to be neighboring. As regards second step of the discovery phase, a question arises: when does the MN send the list of L2 IDs to the current AR? This event certainly occurs at the time of a TAR event. If TAR is performed at the current AR, the MN communicates the list of the L2 IDs received very recently, since they are candidate wireless access for a possible handover, and must be considered for the TAR selection. On the other hand, if TAR is performed at the MN, it has to obtain from the current AR all information about CARs. As regards step No. 3, if the L2 ID is not found in the address list, the procedure, for some unexpected reasons, has failed. Then, AR_h is allowed to issue a multicast request to MG_{OP} with the L2 ID of this AP, and waits for an answer from the (unknown) AR which manages it, which must send the unknown mapping [7]. The step No. 4 produces the update of the CARD table maintained in AR_h.

Optionally, the MN could also maintain a list of all L2 IDs received whilst being managed by the current AR. This additional list may be useful only for building the wireless coverage map and not for TAR selection, and has to be deleted after layer 3 handover. The MN is in charge of sending the list of the L2 IDs not yet previously communicated. This may occur either (i) at a TAR event or (ii) periodically, only if new L2 IDs have been received. The latter option would result in a larger use of signaling and would be particularly useful to better follow wireless network changes.

Finally, since initialization and discovery messages are quite critical for the correct execution of the procedure, we could envision application layer acknowledgements to overcome possible packet losses.

B. *The steady phase*

Each AR stores the information (address mapping and SCs) about the wireless coverage of the neighboring ARs in a local cache (namely CARD table). We use the following notation: $AP_{i,j}$ denotes the *j*-th AP connected to the *i*-th AR (AR_i). To reduce the complexity of the table management, the entries of the CARD table are soft states, which are deleted if they are not refreshed within a given time interval. This is particularly helpful in the case of a dynamic network access topology.

As regards the SC update, the use of local multicast groups aims to manage the geographical proximity of ARs. The generic AR_h, managing the multicast group MG_h, multicasts update messages of the SCs associated with its APs. This operation may take place either periodically or upon significant variations of the SCs. These updates arrive at all the ARs included in MG_h, which are neighbors of AR_h. This process enables ARs to continually update the service capabilities of their neighbors in their CARD table. It is important to remark that updates relevant to a given AR are sent in a push-mode. In other words, they are controlled by the sending AR, which decides when it is necessary to send additional information through its local multicast group. The SCs update process runs in background and is based on the local exchange of multicast messages. Such a message exchange is reduced in a network scenario that is not highly dynamic. The update process can be considered proactive, in the sense that any AR has always all information updated without issuing explicit query, as in the IETF procedures.

IV. SIGNALING LOAD EVALUATION

In this section, we evaluate the signaling burden of CARD operations for both PMM and IETF solutions.

To this end, we analyze the discovery and the steady phase separately. The motivation of this approach is that the discovery phase is typically executed once, thus its impact on the overall signaling on operational networks is really negligible on the long term. Differently, the steady signaling is the only one that can significantly impact on network performance. For this reason and for space limitations, in this paper we show the signaling burden evaluation of the steady phase in the next sub-sections. In the analysis we do not take into account the amount of signaling exchanged on the radio interface. The rationale of this choice is that the CARD signaling load is generally more significant in the core network, since in the wireless access part of the network it is nearly the same for each solution, and thus it does not contributes to the comparison significantly. In fact, CARD messages on the radio channel are mainly relevant to the communication from the MNs to the current AR of newly listened beacons, which is common to each scheme.

For what concerns the signaling load evaluation on the wired part of the network, we proceed by evaluating the number of signaling packets generated and multiply them by their size and by the number of crossed links. The result represents a measure of the network resource consumption (expressed in terms of bytes transmitted). We consider the packet size at layer 3, without taking into account eventual security headers and protocol control information introduced by lower protocol layers. This means that we take into account: (i) at the application layer the CARD protocol data unit, which includes both a header and CARD data; (ii) at the transport layer the header of the UDP protocol; (iii) at layer 3 the IP header.

We consider the general network topology depicted in Fig. 1. It can represent both the network of a regional provider serving a limited area (the core router CR_M acts a gateway towards the Internet) and a portion of a nationwide network composed of some sub-networks connected through an IP backbone. Then, it is necessary to define a number of parameters useful to formalize the problem (see Table 1).

While the discovery phase is executed once, during the steady phase the SCs update is repeated many times. In the IETF proposal [1], there are two options: (i) SCs are requested to the remote AR upon MN inquiries, and (ii) SCs are soft states, thus they must be requested and updated by an AR upon timeout expiry. We prefer the second option, since, as stated in [1], "An AR SHOULD preferentially utilize its CAR table to fulfill requests rather than signaling the CAR directly, and it SHOULD keep the CAR table up to date for this purpose, in order to avoid injecting unnecessary delays into the MN response".

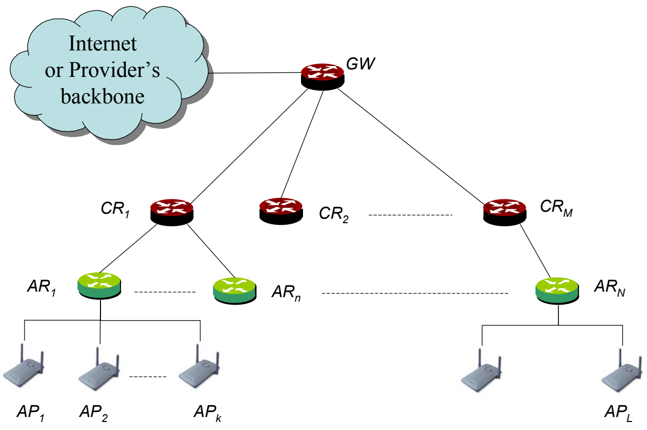

Fig. 1: Network topology.

Parameter	Description
M	Number of core routers (CRs)
N	Number of access routers (ARs)
L	Number of access points (APs)
n	The average number of ARs connected with the same CR (n=N/M)
k	The average number of APs connected with the same AR (L/N)
G	The average number of ARs having overlapping coverage with another AR
g_{ij}	The number of APs of AR_i overlapping with the coverage of AR_j
g	The average number of APs of an AR overlapping with the coverage of a neighbor AR
Q_1	The average number of ARs overlapping to a given AR connected to the same CR of that AR
Q_2	The average number of ARs overlapping to a given AR connected to a common CR
L_{L2}	Size of the layer 2 address
L_{IP}	Size of the IP address
L_{SC}	Number of bytes used to codify SC for each couple <AR,AP>
T_{SC}	Lifetime of SCs in ARs
H	Size of the overall packet header (layers 3, 4, and 5) for a generic inter-AR signaling packet

Table 1: Parameters of the network scenario.

We recall that an important advantage of our scheme is that the information repository itself is in charge of deciding when it is necessary to update the information by its neighboring ARs. Thus, the AR may decide to increase the value of T_{SC} also by an order of magnitude, so as to further lower the PMM signaling burden. This does not affect the effectiveness of the update process, since, upon significant variation of the SCs, the AR itself is allowed to timely send an update without waiting the timeout. If the status of the access network is strongly dynamic, SCs have to be updated more frequently, and policies merely based on time-out could lead towards a wrong TAR choice. On the other hand, IETF solutions should try to adapt the T_{SC} value to network conditions to maintain their tables always updated, as suggested in [1].

For what concerns the signaling evaluation of the PMM solution, we consider that ARs multicast SCs updates periodically, and we neglect transmissions due to significant variations of SCs. This implies that the signaling overhead in the steady phase is given by the amount of bytes transmitted in each period T_{SC}, constant for all schemes. In fact, if the network status is highly dynamic, both the schemes increase the signaling rate. The IETF one increases the signaling rate by decreasing the period T_{SC}, whereas the PMM one by sending updates when it detects significant changes in the proper SCs. Thus, also in this case, the resulting T_{SC} should be nearly the same and the analysis is valid as well.

A. *IETF solutions*

Each time the SCs timer associated with a generic <AR_x,$AP_{x,j}$> pair expires at a given AR, it requests the update of the SCs relevant to all the overlapping APs (in average g) which are connected to AR_x. The size of the request packet is equal to $H+gL_{L2}$, whereas the size of the reply packet is equal to $H+g(L_{L2}+L_{SC})$. This implies that the signaling amount in the time interval T_{SC} is equal to (see also (1) and (3))

$$\begin{aligned} O_{SC-IETF} &= NG\overline{D}\left(H+gL_{L2}+H+g(L_{L2}+L_{SC})\right)= ,\\ &= N(4G-2Q_1)(2H+2gL_{L2}+gL_{SC}) \end{aligned} \tag{1}$$

where $\overline{D}=(2Q_1/G+4(G-Q_1)/G)$ is the average IP hops between two overlapping ARs, N is the number of ARs, G is the average number of neighbors, i.e., the number of ARs to which an AR requests SCs updates, and Q_1 is the number of neighbors connected to the same CR of requesting AR, and thus with a distance of 2 IP hops.

B. *PMM solution*

Each time the timer associated with its own SCs expires, each AR sends over its local multicast group (including in average G participants) their updates. The size of this packet is equal to $H+k(L_{L2}+L_{SC})$. Thus, once defined p as $p=(G-Q_1)/Q_2$, the signaling amount in the time interval T_{SC} can be easily shown to be equal to

$$O_{SC-PMM} = N\cdot(2+p+G)\cdot\left(H+k(L_{L2}+L_{SC})\right). \tag{2}$$

V. NUMERICAL RESULTS

In this section, we show the numerical results of the PMM and the IETF solutions in terms of signaling burden and discovery time.

A. *Signalling overhead*

As regards the signaling burden evaluation, we consider a network topology characterized by the following parameters: L=150, M=5, N=25, Q_1=1.5, Q_2=2, T_{SC}=1 minute, L_{IP}=16 bytes (IPv6 address length), L_{L2}=6 bytes (compliant with the IEEE 802.11 MAC address), L_{SC}=8 bytes, H=56 bytes (IPv6 header=40 bytes, transport and CARD protocol headers=16 bytes).

Even if in this paper we do not present results for the signaling overhead associated with the discovery phase due to space limitations, our analysis asserts that it is very low (definitively no more than 1 Mbyte over a network of 31 routers) for all CARD schemes. This means that its impact on network performance is really negligible.

Fig. 2 shows the signaling rate (Kbit/s) required by both IETF solutions and the proposed PMM in the steady state. The figure presents this quantity as a function of G ranging from 2 to 8, and with g as parameter with values 3 and 4. We recall that g is the average number of APs (connected to the same AR) which overlap with the coverage area of a neighboring AR, whereas G is the average number of ARs neighboring to a given AR.

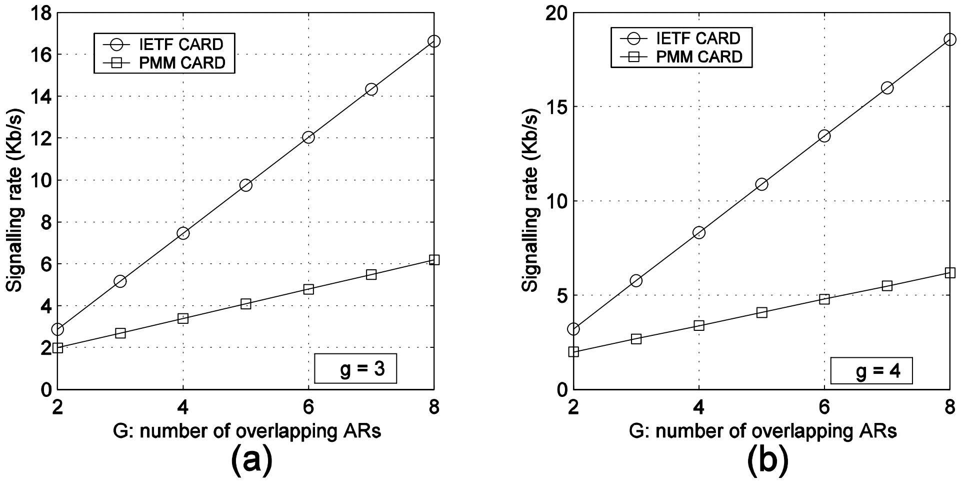

Fig. 2: Signaling load for the SC update phase vs. the average number of overlapping ARs.

It is worth to note that the values of the signaling rates increase when T_{SC} decreases. The advantage of the PMM scheme is really significant and highly increasing with both *G* and *g*. This is due to our design philosophy, which is based on the multicast approach. This result was expected, since it is the known advantage of multicast transmissions over repeated unicast transmissions, i.e., bandwidth saving.

B. Discovery time

Beyond the theoretical analysis of the signaling burden, we have also made a large number of simulations by NS-2 [5] to evaluate the discovery time of the CARD solutions. The discovery time is the time needed to complete all CARD tables, i.e., the time needed for all ARs to discover all their neighbors.

We have used the same configuration as in the theoretical evaluation of the steady state signaling load, with the exception of $L=N=25$. This is due to the intrinsic limitations of NS-2, which forces only an AP for each AR (thus in the following, we will use the term AR and AP indifferently, since they are co-located). This implies that the value of *g* is equal to 1.

We have distributed the ARs with a hexagonal cellular pattern over a square area with side equal to 100 m. This implies that the ARs in the center of the simulated area have always six neighbors. However, since border ARs have necessarily less neighbors, the value of *G* is 4.48.

The selected layer 2 technology is the IEEE 802.11b. In order to simulate a real setting, we adopted a frequency reuse strategy based on a triangular structure, and selected the channels number 1, 6, and 11. This implies that in our simulator in any point of the simulation area, there is only one AP active for a given frequency channel.

In order to test the peculiarities of the considered CARD schemes, we adopted a common TAR criterion. In more details, the chosen metric takes into account two factors: the amount of available bandwidth, and the power level. The score associated with each CAR AR_z by the current AR (AR_h) is $M_{TAR}(AR_h,AR_z)$, which is equal to

$$M_{TAR}\left(AR_h,AR_z\right)=f_1\left(SC_z\right)\cdot f_2\left(PW_z\right). \tag{3}$$

$f_1(SC_z)$ represents the contribution related the amount of available bandwidth on AR_z, which is equal to

$$f_1\left(SC_z\right)=\begin{cases}\min\left\{1, e^{\beta\left(\frac{SC_z+(-1)^j B}{C}\right)}-1\right\} & \textit{if}\ SC_z \geq jB\\ 0 & \textit{otherwise}\end{cases}. \tag{4}$$

With reference to (4), *B* represents the MN bandwidth demand, SC_z is the current service capability of AR_z, *C* is the net wireless capacity of AR_z, and β is a design parameter. In order to avoid ping-pong effects the value of *j* is set to 1 for all the candidates but the current one, for which $j=0$. The higher the value of β, the higher the score associated with the bandwidth $(SC+(-1)^j B)$ available after the hypothetical execution of the handover, normalized to the capacity of the AP taken into account. In addition, if the new network access (i.e., the new AR/AP) cannot accommodate such a traffic flow with the necessary bandwidth, *B*, its score is zero. The value of β is such that when $(SC+(-1)^j B)$ is higher than or equal to $0.8\cdot C$, then the weight associated with the service capability is equal to 1. This implies that the value of β is equal to $\beta=0.866$. For values of the service capability lower than $0.8\cdot C$, such a weight rapidly decreases, and consequently the importance of the load balancing criterion increases. In the simulator, $C=5$ Mbit/s and $B=64$ Kbit/s. Call arrivals are modeled as a Poisson point process with average frequency equal to 0.1 s^{-1}, while their duration is exponentially distributed with average length of 4 minutes.

$f_2(PW_z)$ is the factor related to the power level of AP_z, equal to

$$f_2\left(PW_z\right)=\begin{cases}1-e^{-\gamma\left(\frac{PW_z-PW_{\min}}{P_T-PW_z}\right)} & \textit{if}\ PW_z > PW_{\min}\\ 0 & \textit{otherwise}\end{cases}. \tag{5}$$

We define PW_{opt}, so that $f_2(PW_{opt})=0.95$; in other words, when the power level is equal to the value of PW_{opt}, we set the weight associated with the received power level equal to 0.95. For values of received power lower than $PW_{opt,i}$, this weight rapidly decreases. Consequently, the power-based criterion is important when the received power level from an AP is lower than PW_{opt}. The coverage radius is equal to 22.4 m, the overlapping between two adjacent APs is equal to 16 m (PW_{min} equal to 6.677 nW), and the overlapping between their "optimal" zone is equal to 8 m (PW_{opt} equal to 9.889 nW). P_T is equal to 33.962527 mW and γ is set equal to $33.2*10^6$.

The MIP advertisements are sent one each second, while the L2 beacons are sent each 100 ms. Since the used 802.11b channels are three, the duration of the beacon listening phase is bounded by 200 ms; this is the time needed to scan the two channels different from the current one. This operation is repeated either periodically (one time each minute) or upon a TAR event due to a power level lower than PW_{opt}.

In our simulator, we implemented the TAR on the current AR; however, this is not mandatory, and the TAR process might also run on the MN.

We evaluated the discovery time of both L2 beacon-based solutions (PMM and Server based) and handover-based solution. We considered a default scenario with 50 MNs moving according to a Gauss-Markov mobility model [6], with directional parameter $\alpha = 0.5$, average speed equal to 1.5 m/s, and step fixed to 1 s (i.e., the MN position is updated every one and a half meters on average). We adopt this model since it avoids sharp direction changes, by allowing previous speed and direction to influence future mobility.

Fig. 3 shows the discovery time as a function of the MN average speed, ranging from 0.5 to 2.5 m/s, with 50 MNs, with the relevant 95% confidence intervals. As expected, a higher number of MNs triggers a higher number of discovery events, and thus the discovery time decreases with the number of MNs. As the reader can note from the figure, in order to appreciate the behavior of L2 beacon-based solutions (PMM and server-based) and of the handover-based one, we divide the overall plot in two subplots, since the time scales of the two schemes are quite different. In more details, the time required by the handover-based scheme to complete the CARD tables of all the ARs (discovery time) is about 14 times larger at 0.5 m/s than the discovery time of the L2 beacon-based approaches, to decrease to about 6.3 times at 2.5 m/s.

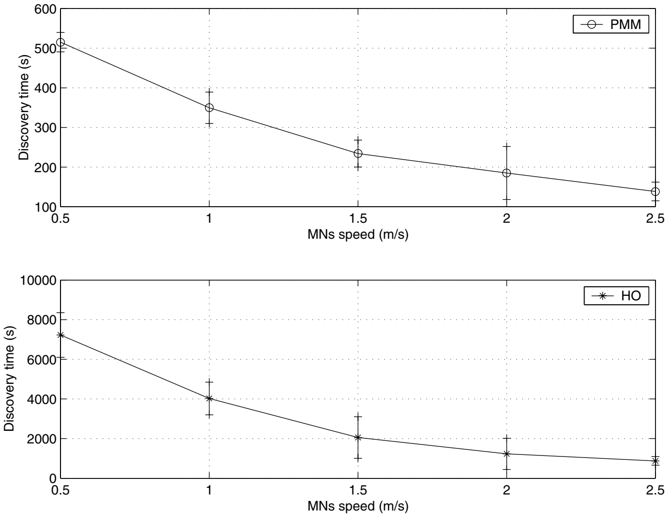

Fig. 3: Discovery time as a function of the MNs speed.

We stress that this large difference is due to the fact that in the L2 beacon-based schemes the discovery events are triggered by beacons listening process, which is periodic. Instead, the discovery of a new neighbor in the handover-based scheme is triggered by a plain MIP handover by a MN. This phenomenon is more frequent in the very initial transient, when the CARD tables of all the ARs are empty, and thus only plain MIP handovers can happen. When the filling of the CARD tables starts, due to the quite high value of G, the TAR process can run. In many cases, it is able to provide a choice and thus to drive the handover even with partial information on the surrounding wireless coverage. Thus, only when a MN enters the internal area of a "new" AP, it loses the wireless connectivity and requires a MIP handover.

This behavior can be appreciated by analyzing Fig. 4, in which the discovery percentage (number of couples of neighboring ARs discovered over the total number) is plotted versus the simulations time (in a log scale). The number of MNs is 50 and the average speed is 1.5 m/s. This figure shows the results of three different runs for the handover-based scheme (solid line) and for the L2 beacon-based schemes (dotted line). In order to cover the interval between 90% and 100%, both the two schemes require a quite long time with respect to the one needed to reach the 90%. This phenomenon is due to the mobility model, which tries to maintain MNs far from the edges of the simulated area. The consequence is that the border ARs take a time quite long to discover their neighbors in comparison with the other ARs. This is mainly evident in the handover-based simulations, in which, for different movement patterns (associated to different simulation runs), the time required to fill up all the CARD tables is highly variable. However, an important information retrievable by this figure is the slope of the discovery percentage for the two categories of CARD scheme. In fact, in the first part of the curves (below the value of 90%), the lines are nearly overlapped, independently of the simulation run (and thus on the specific MNs trajectories), and the slope of the L2 beacon-based scheme is strongly higher than the one of the handover-based scheme. The time required by the former scheme to reach the 90% of the discovery percentage is few tens of seconds, whereas the one of the latter scheme is about some hundreds of seconds. This implies that, independently of border effects due to the particular mobility model adopted in the simulations, the discovery time of the handover-based strategy is higher than the discovery time of L2 beacon-based schemes by about one order of magnitude.

Finally, Fig. 5 shows the discovery time for both schemes (L2 beacon-based and handover-based) versus the number of MNs, with an average speed of 1.5 m/s. It is clear that the higher the number of MNs, the lower the discovery time for both the schemes. This is due to the fact that a larger number of MNs is able to trigger a larger number of discovery events (both handovers and L2 beacon listening). However, as in previous cases (see Fig. 3 and Fig. 4), the difference remains always noticeable.

VI. CARD SOLUTIONS COMPARISON

In conclusion, Table 2 reports a comparison of the main peculiarities of the different CARD approaches. The proposed PMM CARD shows better performance from the user viewpoint (proactive, no bootstrap handover, and lower discovery time). For the operator side, the PMM CARD is distributed, produces a lower amount of signaling in the steady phase and shows high responsiveness to network topology changes, while maintaining the signaling burden in the discovery phase low.

The main drawback of our proposal is the need of multicast support. In fact, even if nowadays it may be easily supported within IP domains, it is implemented more likely in backbones than in access networks. It is also worth to note that L2 beacon-based solutions require MNs authentication to trust their coverage information. Finally, inter-domain deployment implies further complexity for L2 beacon-based solutions (a possible solution could use a gateway in charge of managing inter-domain signaling). In any case, plain deployment of inter-domain procedures is generally critical, since it requires both technical and business agreements among involved parties, sufficient to convince them to exchange some confidential information such as the ongoing network status.

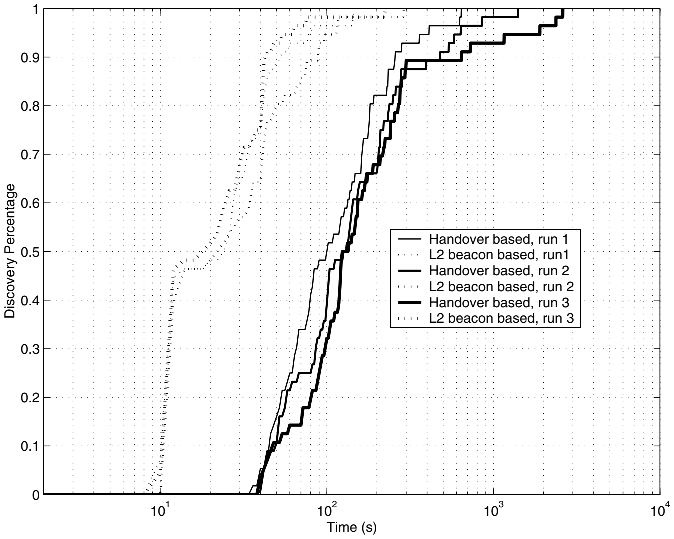

Fig. 4: Discovery percentage as a function of the time in the default scenario.

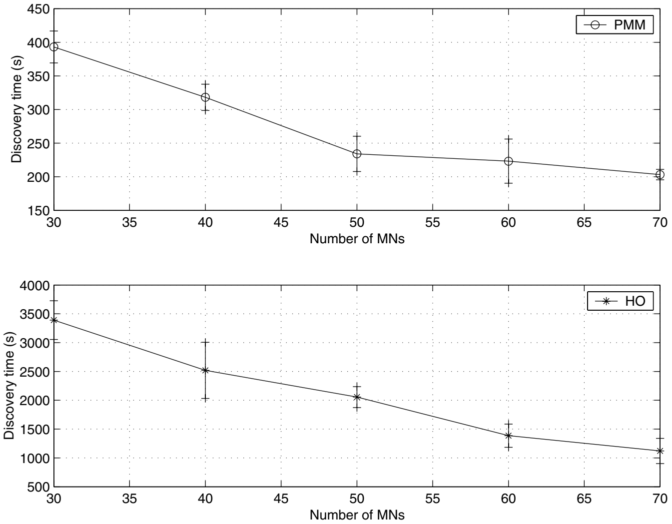

Fig. 5: Discovery time as a function of the number of MNs.

VII. CONCLUSION

We have described an intra-domain, distributed CARD procedure, called PMM CARD. The essential novelty of our approach is the use of push-mode multicast transmissions, whereas IETF solutions use the pull-mode unicast transmissions.

Through a theoretical analysis, we have shown that in the steady phase the signaling burden associated with the PMM CARD is reduced in comparison with the corresponding IETF solutions. However, it is worth noting that the overall signaling amount associated with all CARD solutions is always very low. Thus, the benefits that can be obtained by implementing a CARD mechanism (improved MIP performance, load balancing) justifies the relevant cost in terms of network resource consumption and implementation complexity, which is low.

As regards the discovery phase, our simulation analysis shows that the time required by our PMM scheme to complete the surrounding wireless coverage map at each AR is very low (some tens of seconds to fill up the 90% of the tables in a topology with 25 ARs and 5 CRs), and outperforms the handover-based solution. The reason is that the frequency of discovery events is higher than in the handover-based solution.

We also stress that, beyond the advantages in terms of performance described above, another peculiarity of our PMM scheme is its distributed and proactive nature, which avoids single points of failure and guarantees timely actions to follow variations of the coverage status.

CARD approaches		**Handover based**	**Server based**	**PMM**
Signaling burden	Discovery	Very low	Low	Low
	Steady	Low	Low	Very low
Distributed		Yes	No	Yes
Bootstrap handover		Yes	No	No
Proactive		No	No	Yes
Inter-domain extension		Straightforward	Gateway required	Gateway required
MN authentication		Optional	Required	Required
Discovery time		↑ (handover based)	↓(L2 beacons based)	↓ (L2 beacons based)
Multicast support		No	No	Required

Table 2: Comparison among CARD approaches.

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