Make-Without-Break Horizontal IP Handovers for Distributed Mobility Management Schemes

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Abstract—**There is a new trend to consider Distributed Mobility Management (DMM) for flat network architectures to cope with the increased distributed nature of the mobile networks. DMM improves the routing optimization and reduces the scalability issues when compared with the centralized mobility management, through the traffic anchoring distribution at the Access Routers (ARs). However, the handover optimization, which also demands for fast and soft handovers to reduce/eliminate the handover latency and the respective packet loss, is not properly addressed in the DMM.**

Although current seamless handover approaches, already integrated in centralized mobility schemes, could also be adapted to the DMM schemes, they introduce new entities/functionalities, messages and buffering/bicasting mechanisms to reduce the handover latency or the packet loss.

In this paper, the seamless IP handover is addressed from a novel make-without-break perspective, which is able to maintain two logical connections in the same physical interface with two Access Points (APs) from distinct IP networks. The outcome of the evaluation shows that make-without-break with a DMM scheme is able to reduce or even eliminate the handover latency and the packet loss from link disconnection, providing seamless IP session continuity in mobile environments.

I. Introduction

As the number of mobile users increases and the mobile data traffic explodes [1], with users being both generators and consumers of data, centralized architectures for mobility management may undergo scalability and performance issues (e.g. network bottlenecks, single point of failures and attacks, centralized and non-optimal routing).

Hence, there is a paradigm shift in the network architectures with the introduction of flat models to deal with the evolution of users' traffic behavior. Moreover, mobility management architectures and protocols need to be adapted for such evolution. Several efforts from both industry and academia are being performed on specifying DMM approaches [2] [3]. The main focus of these DMM approaches is to optimize the routing and improve scalability, leaving the seamless handover subject out of the scope of these schemes. The DMM approaches already enforce the maintenance of the IPv6 addresses to ensure session continuity, but they suffer from temporarily link disruptions when the user roams among IP networks.

The seamless handover remains a relevant requirement, specially with the increase of mobile scenarios with demanding multimedia content. In these scenarios, a user might cross several IP networks in a short time, while it desires to maintain a high quality of experience in the multimedia content. There are proposals for seamless handovers [4] [5]; however, they introduce high complexity with: new entities/functionalities, messages to anticipate/prepare the handover, and buffering/bicasting mechanisms to reduce the packet loss. Despite the efforts, handover latency and packet loss remain with values that negatively affect the user's quality of experience.

We propose to address the seamless handovers from a distinct perspective, in order to reduce or even eliminate the handover latency, without new entities, signaling messages or even packets buffering/bicasting. We propose a make-without-break handover approach, which exploits the overlapping regions of APs through two logical connections from the Mobile Node (MN) during the handover. In several scenarios, the MN may be able to execute the handover to a new IP network, without breaking the previous connection, reducing or eliminating the packet loss. Thus, the ongoing traffic sessions might be maintained through a previous Access Point (AP), while the signaling for the MN configuration in the new network is performed through the new AP.

The paper is organized as follows. The seamless handover solutions are presented in Section II. Section III gives an overview of the distributed mobility management. Section IV presents the make-without-break solution, and Section V depicts its evaluation. Finally, Section VI concludes the article.

II. Seamless Handover

The current trend in the seamless handover solutions for mobile IP networks is related to [4], [5], [6]. In fact, the possibility to continuously access the Internet anytime/anywhere has brought on a cumulative complexity to the handover management. Most of current solutions use techniques based on make-before-break, to overcome the limitation of the standard break-before-make approaches and provide seamless handovers. In standard break-before-make solutions as in [7], the MN does not prepare the configurations in the new network in the overlapping region of the two APs.

In make-before-break solutions, such as the case of Fast Handover for Mobile IPv6 [5] or Fast Handover for Proxy Mobile IPv6 [4], the MN needs to be able to estimate/predict whether to perform the handover, which brings extra complexity to calculate the optimal times. Additionally, in the make-before-break handover, the advantages of buffering utilization strictly depend on the applications; in break-before-make, the buffer might not be sufficient for real-time applications, causing more packet loss when compared with make-before-break. There is an approach performing bicasting [6] by sending packets to the MN via two alternative routes, which receives copies of packets until establishing a new connection in the new AP. However, it causes a large data overhead provided by the packets duplication, as well as issues related with the packets reordering. Moreover, there is an extra signaling required by the make-before-break solutions to prepare the configurations in the new network for the MN, before it really executes the handover, which increases the overhead and introduces new entities to exchange these messages.

With respect to these approaches, the make-without-break with DMM schemes has the following requirements to achieve: no additional signaling or data cost to operator and mobile user; no new network entities involved; no prediction; no packet duplication and no buffering/bicasting or reordering; and low or null packet loss during the handover execution. The main goal is to provide seamless IP session continuity, just introducing some functionalities in the MN to provides a double logical connection in the same physical interface during the handover.

III. Distributed IP Mobility Management

Distributed Mobility Management aims at adapting existing IP mobility protocols, such as Mobile IPv6 [8] and Proxy Mobile IPv6 [9], to the emerging flatten mobile network architectures, considering the increasing of communications in the same geographical region due to the migration of content servers closer to the user. The increasing research on the distributed and dynamic mobility management led to the creation of the IETF DMM workgroup, which has been working on the identification of the problem statement and the specification of DMM schemes [10].

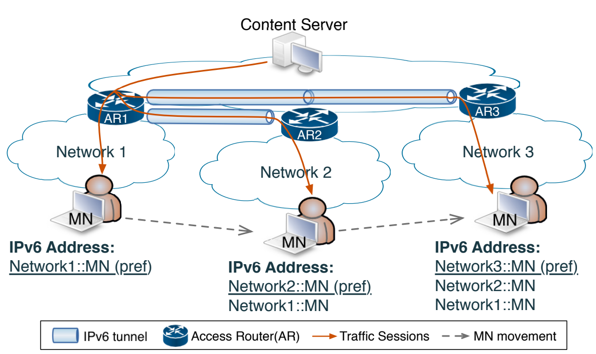

Figure 1. Distributed Mobility Scheme Overview

A common feature between the proposed schemes [2] [3] is the distribution of the anchoring at the AR level, such as AR1, AR2 and AR3 from Figure 1. The MN establishes new sessions through the current AR, which are maintained for the whole session duration, even if the MN moves among ARs, as presented in Figure 1. The connected AR establishes a tunnel with the previous ones to forward the traffic sessions between the IPv6 address from the previous AR, and the IPv6 address obtained from the connected AR. In Figure 1, the traffic session remains anchored to AR1 through the IPv6 address Network1::MN, which is maintained in the wireless interface to ensure IP session continuity, while the MN roams to Network 2 and 3. When all sessions anchored at a given AR are terminated, the MN deregisters from that AR. From Figure 1, when MN is attached to AR3 and terminates traffic session (anchored to AR1), the AR1 does not need to be maintained as a MN mobility anchor, neither the IPv6 address received there (Network1::MN). This concept, called dynamic anchoring, aims at optimizing the routing path assuming that most of the sessions are short enough, such that a session is terminated before experiencing several IP handovers. Under this assumption, most of the sessions do not require to keep their initial AR for a long time, and hence, a MN has mostly one or two ARs active at a time.

DMM approaches exploit the IPv6 features to improve the mobility management performance regarding the routing optimization. IPv6 stack allows to have multiple IPv6 addresses configured in the same interface at the same time, with different preferences or status. In DMM schemes, the IPv6 obtained from the connected AR is the preferred (pref) one for the establishment of new sessions, while the previous IPv6 addresses are maintained just to ensure continuity of the ongoing sessions.

IV. Make-without-break with a DMM Scheme

The make-without-break handover is defined as the ability of a MN to perform a seamless handover to a new network while maintaining two logical/virtual connections in the same physical interface, during the handover. The make-without-break handover can be provided without introducing complexity in the network, just introducing functionalities in the user's mobile device. It might also ensures continuous communications in both directions, while the user roams across different IP networks with the same wireless technology, performing horizontal handovers.

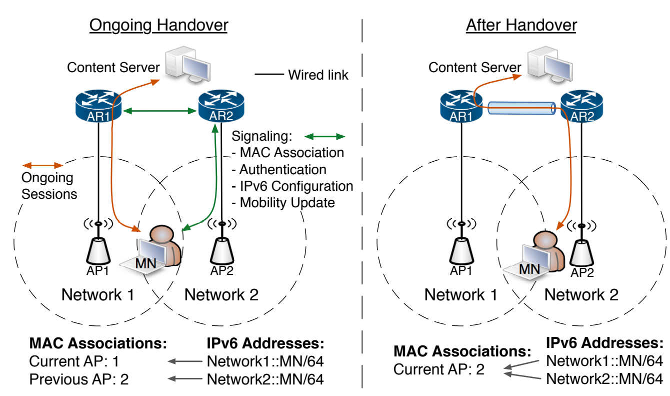

Figure 2. Make-Without-Break Overview

The achievement of a make-without-break handover requires the maintenance of two logical connections with two different APs, which involves physical, MAC and IP layers.

As illustrated in Figure 2, while the ongoing traffic sessions are maintained through the previous AP, the signaling involved in the configuration for the new network is performed through the new AP. The notion of AP is adopted in a broader scope in this article, since it can be a Base Station (BS). When the MN is in the overlapping region of AP1 and AP2, it is decided that MN should perform an handover from AP1 to AP2. Then, the MN initiates the configurations in the AP2 from Network2 (e.g. MAC association, authentication, IPv6 configuration and Binding Update), maintaining the ongoing traffic sessions through the AP1 from Network1. When the handover is concluded, the MN receives the ongoing traffic sessions through the wireless interface connected to AP2, and the logical association with AP1 could be removed.

A. Concept Application

The proposed concept assumes, from the physical layer, that the handover is performed between two APs in the same channel, or that a MN physical layer is capable to provide a fast channel switching [11], or assumes the virtualization of the MN physical interface during the handover [12]. The work in [11] shows how virtual interfaces can multiplex a single interface across more than one communication end-point. It describes a link-layer implementation of a virtual 802.11 networking layer, called Juggler, that achieves switching times of approximately 3 ms between different channels, and less than 400 μs for switching between the same channel. However, this work does not provide IP session continuity, which is the main goal of the proposed approach.

The possibility to maintain the previous IPv6 addresses in the DMM approaches already ensures the continuity of the ongoing sessions at IP layer. In the DMM host-based approach [3], the MN is able to maintain the previous IPv6 address in the preferred status, as well as the respective route, while the new one is being configured, ensuring IPv6 connectivity during the handover execution. However, it is not performed any route/association at the MAC layer during the handover execution, since a new MAC association is usually performed assuming a disassociation from the previous AP. Make-without-break for DMM should be able to maintain two MAC associations or/and a simple selection for which packets should use which AP.

In order to send packets from the MN to other devices (uplink) during the handover execution, it is maintained a default route to the previous AP through the link-local IPv6 address of the AP, as well as the respective entry in the neighbor discovery cache. It is also needed a decision function at the MAC layer to enforce the AP (e.g. destination and BSSID MAC addresses in 802.11b/g) according to the IPv6 source address of the packet. From the time the mobility anchor (e.g. AR) is updated, the MN transparently removes the logical connection with the previous AP.

The AP selection could be based on the Received signaling strength indication (RSSI) metric, received in the beacons from the APs in the range of the MN, or on any other selection mechanism, if it ensures an overlapping region during the handover. When a new AP is selected, the MN performs a new MAC association with this AP, without disassociating from the previous one.

B. Comparing Approaches

The different handover techniques provide different values for handover latency and packet loss, since they adopt different strategies for the handover. We analyze and compare the different handover strategies: break-before-make, make-before-break and make-without-break in order to understand their impact on handover latency and packet loss due to link disconnection. The handover execution time is always considered from the MN perspective, which might not have the same value as the handover latency, since the handover execution could be performed maintaining the reachability of the MN. The handover latency, in the scope of this paper, is the time that a MN remains unreachable for the ongoing/new sessions, while roaming between APs. A null handover latency represents a MN always reachable and always receiving the required contents, even when executing the handover. The packet loss, in the scope of this paper, is related with the packets lost due to the link disconnection, thus it is strictly associated with the handover latency, since no buffering mechanisms are used.

The handover consists in the sequence of several steps: i) MAC association, ii) authentication, iii) IP configuration, iv) binding update. A seamless handover technique should be able to reduce or even eliminate the required time for all the several handover steps, prepare steps before the execution, or even try to perform steps in parallel. Some techniques are able to divide the handover in two distinct phases, in order to reduce the handover latency. The first phase, called handover preparation, is performed while the MN is still connected to the previous AP, in order to pre-configure as much as possible the future MN configurations. The second phase, called handover execution, corresponds to the phase where the MN really performs the link disconnection and the connection to the new AP.

The standard break-before-make (BBM) handover does not distinguish the two phases, not providing any handover preparation while the MN is ready to roam. Thus, all the configurations are performed during the handover execution phase, increasing the handover latency and the packet loss. This technique provides high handover latency values, which are not acceptable for real-time applications nor even for highly mobile scenarios, where several handovers might be performed in a short time period. Some BBM solutions provide buffering mechanisms to reduce the packet loss during the handover, but this might not be helpful for demanding real-time content, which requires continuous packet reception.

The handover latency of a make-before-break (MBB) handover is usually reduced when compared with a break-before-make, since part of the handover required tasks are performed in the preparation phase, and not in the execution phase. The preparation of the handover starts when a new AP with a better quality (e.g. RSSI) is selected. Thus, the conclusion of the handover preparation phase might be performed while the MN is in the range of both APs. The handover latency of a MBB handover is usually the same as the handover execution time. However, for highly mobile scenarios, the preparation phase could not finish before the attachment of the MN to the new AP.

Using the same AP selection or prediction mechanism, the make-before-break (MBB) and make-without-break (MWB) should initiate the handover at the same time. However, while the MBB initiates the handover through the preparation phase, the MWB goes directly to the execution phase, but maintaining the logical/virtual connection with the previous AP.

The configurations involved in the preparation phase of a MBB are performed through the current AP, which is an intermediary node in the entire process, as well as the new AP. The MBB imposes an architecture or framework in the network side, since the configurations of the MN in the new network should be requested by the network entities that represents the MN, as well as buffering/bicasting techniques in the mobility anchor(s). In MBB handovers, at least the channel switching and the MAC association have to be done after the disassociation from the previous AP, being impossible to achieve a nearly null handover latency.

The handover latency of a MWB might be reduced or even eliminated, when compared with the other handover approaches. The handover latency of a MWB is related with the MN's trajectory time (related with MN velocity), the overlapping time (related with overlapping region), and the channel switching. If the MN is able to perform periodically and quickly channel switching, there is not a really a considerable handover latency, just small periods of time (e.g. 100 ms), where the MN is switching between the two APs, being always reachable.

In MWB, the handover latency is considered nearly null if the MN is able to execute the handover during the double logical connection period, which means that it is able to configure the interface for the new network while receiving ongoing sessions from previous AP. For low MN's trajectory times and/or low overlapping time, the handover latency is equal to the remaining time to finish the handover execution after MN gets out of previous AP range. The packet loss due to the link disconnection depends on the handover latency, the number of handovers performed, the data rate and the data packets size.

V. Evaluation

In the evaluation with ns-3 simulation environment [13], we define a scenario (Figure 3) with a MN traveling just in one dimension, with a constant speed s between IP Networks 1 and 6. It crosses a set of 6 APs closer to them, which are connected to different ARs. Each MN starts a stream session with a constant bit rate r at the first AP (AP1), and keeps it active until the last one (AP6); thus, a session suffers 5 IP handovers during the MN movement. The APs are configured with the Friis propagation model with a wireless range wr of 120 meters, and they are placed in order to exist an overlapping region of o between each two, where the handover execution

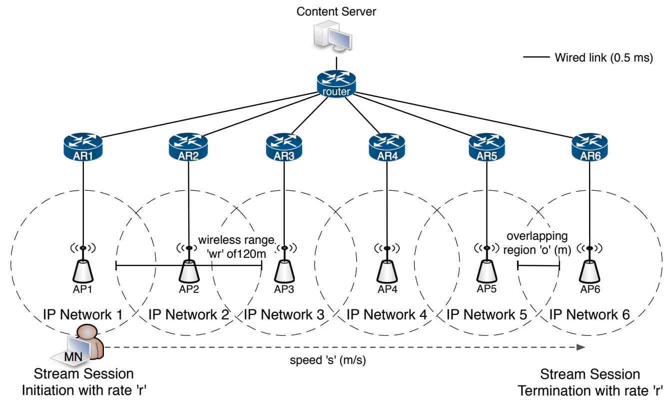

Figure 3. Simulated Scenario

could be performed. The APs are placed in a line, where the y position is the same for all APs and the x position is calculated from the following equation (1), in order to ensure an overlapping region o for the APs, with a fixed wireless range of wr:

$$x_i = x_{i-1} + 2 \times wr - o \quad (1)$$

To allow a double MAC association in ns-3, the STA class from the regular MAC was changed. Moreover, all APs were configured in the same Wi-Fi channel, which allows the STA to receive beacons from different BSSID/SSID and select the one with the best RSSI to perform an handover. It was added a selection function in the STA class to enforce the destination MAC and BSSID, according to the source IP address of the packets. The handover approaches for MAC layer are integrated with a DMM solution, called Dynamic Mobile IP Anchoring [3], configured with all ARs providing mobility support. The technology standard for the wireless APs is the IEEE 802.11g, and three different handover approaches were evaluated under the ns-3 simulation environment [13]:

- **Beacon Missed**, in which the MN only changes the MAC association to a new AP after missing a predefined number of Beacons (configured with 5 missed beacons). After the missed beacons, the MN sends a Probe Request message to obtain the APs available in the area, and it associates with the one that first replies. The MN performs authentication and exchange Neighbor Discovery Messages to obtain the new IPv6 address from the new network. After the configuration of the new IPv6 address, the previous ARs with anchored sessions are updated with new IPv6 address of the MN, and MN continues to receive packets from ongoing sessions.
- **Break-Before-Make**, in which the MN breaks the current MAC association and performs a new one, when a Beacon is received from another AP with a higher RSSI. The MN is constantly evaluating the APs available in the area through the beacons sent by the APs. When an AP with a higher RSSI is detected, the MN sends an Association Request message to it in order change the MAC association. The remains configuration after the

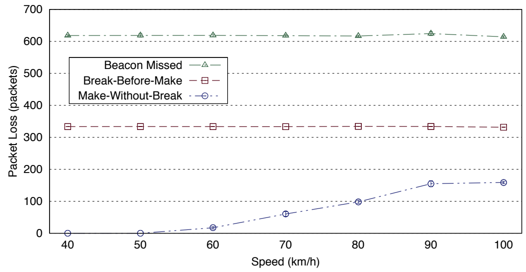

Figure 4. Evaluation of packet loss for different speeds

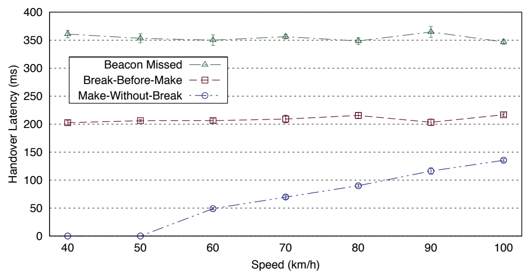

Figure 5. Evaluation of handover latency for different MN speeds

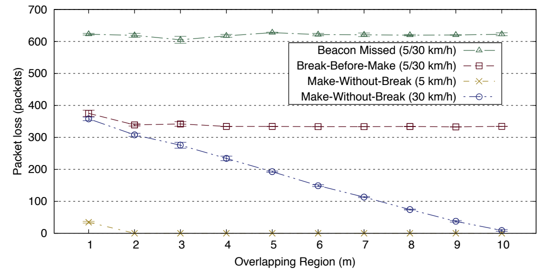

Figure 6. Evaluation of the overlapping region impact on packet loss

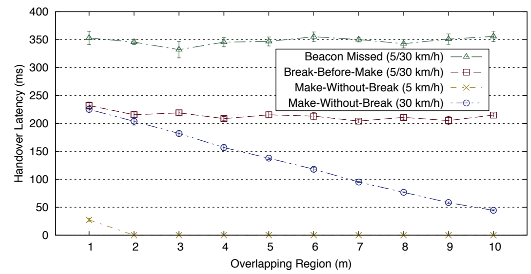

Figure 7. Evaluation of the overlapping region impact on handover latency

MAC association are the same as in beacon missed.

- **Make-Without-Break**, in which the MN performs a new MAC association when a Beacon with higher RSSI is received, without disassociating from the previous AP, as long as it remains in the coverage area. The handover sequence used is the same as break-before-make, but the MAC layer was modified to allow to be associated with two APs during the handover, as well as receive packets from them. It was also added a selection function in the MAC layer that looks at the source IP address of the sent packets, enforcing the destination and BSSID fields of the MAC header with the respective AP MAC address.

The metrics evaluated are the packet loss from the link disconnection, and the handover latency, which were previously defined. The packet loss and handover latency results are mean values from 10 independent simulations with a confidence interval of 95%.

A. MN Speed

In order to evaluate the impact of the MN speed s in the handover latency and packet loss, it is defined an overlapping region of 20 meters (distance of 220m between the APs for a wireless range of 120m), a traffic rate of 1Mbps and a packet size of 1KB. The MN speed does not influence the handover latency nor the packet loss of beacon missed and break-before-make strategies (Figure 4). The handover execution time of both approaches just depends on the time involved in the exchange of messages to configure the MN to the new network. Oppositely, the increase of MN speed, increase both the packet loss and handover latency of make-without-break, since the time of the MN in the overlapping region is reduced. However, even with a MN speed of 100 Km/h, the handover latency and packet loss of the make-without-break are lower than the ones of other approaches, with a maximum handover latency around 150 ms and a maximum packet loss around 150 packets. The make-before-break decreases the packet loss (Figure 4) and handover latency (Figure 5) for a large set of vehicular speeds when compared with other approaches, if an overlapping region of 20 meters exist. The make-without-break is able to take advantage of the overlapping region to execute the handover, eliminating the handover latency and packet loss for pedestrian speeds, and reducing the handover latency and packet loss for vehicular speeds.

B. Overlapping Region

The evaluation of the overlapping region is performed, defining constant MN speeds of 5 and 30 km/h, and a traffic rate of 1Mbps for a packet size of 1KB. The different overlapping regions are achieved through the placement of the APs, according to the equation (1). The make-without-break decreases the packet loss (Figure 6) and the handover latency (Figure 7), even for small overlapping regions. While higher overlapping regions reduce the packet loss of make-without-break for higher speeds, it does not influence the other two approaches. The make-without-break exploits the overlapping regions through the double logical connection, presenting a null packet loss with an overlapping region of: 2 meters for pedestrian speed (5 km/h), and 11 meters for low vehicular speed (30 km/h).

C. Traffic Rate

The impact of traffic rate on packet loss and handover latency is evaluated for a constant speed of 30 km/h, an overlapping region of 20 meters (distance of 220m between the APs for a wireless range of 120m), and a packet size of

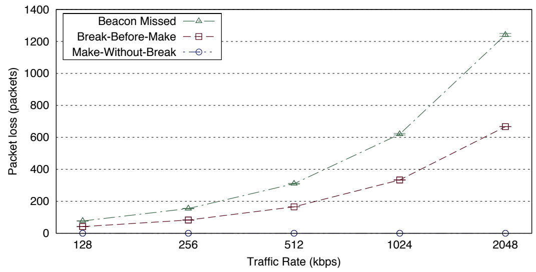

Figure 8. Evaluation of the traffic rate impact on packet loss

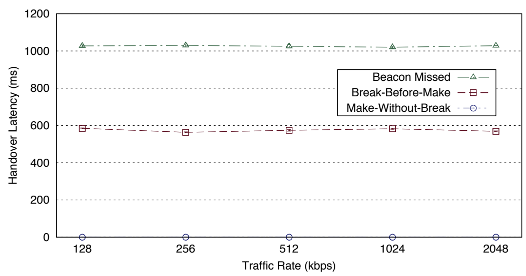

Figure 9. Evaluation of the traffic rate impact on handover latency

1KB. It is observed a null packet loss for the make-without-break approach (Figure 8), independently of the traffic rate for the defined overlapping region and MN speed. The handover latency is nearly null, Figure 9, since the overlapping region is enough to perform the handover. While beacon missed and break-before-make approaches are significantly influenced by the traffic rate, that does not happen in the make-without-break approach, when the overlapping region is enough to execute the handover. The handover latency does not depend on the traffic rate (Figure 9), since it is related with the MN speed and the overlapping region. However, a higher traffic rate for the same positive handover latency increases the packet loss, since more packets are sent for the same handover latency.

VI. Acknowledgments

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VII. Conclusion

This paper proposed a novel make-without-break approach for seamless IP horizontal handover, which is based on the idea of maintaining two logical/virtual connections on the same interface while a user's device is executing the handover. The make-without-break is achieved through the maintenance of a double logical connection at physical, MAC and IP layer, during the handover. It might be achieved through the integration of an IPv6 Distributed Mobility Management solution, a double MAC association and a virtualization of the physical interface. The make-without-break is implemented through modifications in the mobile device, eliminating the complexity of current make-before-break approaches.

The evaluation of the make-without-break approach shows that it is able to reduce or even eliminate the handover latency and the packet loss during handover. The values obtained for make-without-break are enough to provide seamless session continuity for a large set of applications, including real-time applications, such as Voice over IP or Video on Demand.

As future work, we would like to implement the make-without-break approach in a real testbed scenario.

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