A study of multimedia application performance over Multiple Care-of Addresses in Mobile IPv6

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***Abstract*—Mobile and multi-access devices have become commonplace today. In this context, nodes have multiple interfaces that can form the foundation for the always best connected paradigm. Mobile IPv6, the staple mobility management technology for the Internet, enables nodes to roam between different networks while minimising session disruption due to handovers. However, in standard MIPv6, a mobile node can register only a single IP address as its Care-of-Address (CoA), therefore the multiplicity of network interfaces may be managed suboptimally while simultaneous multi-access is not possible. Recently, MIPv6 has been extended with a much-anticipated feature, namely Multiple Care-of Address (MCoA) registration. MCoA allows a MIPv6 node to register all active addresses configured on the respective interfaces and then use them at will, possibly in an alternating fashion as well as simultaneously. MCoA is anticipated to improve the performance of multimedia applications, yet this is still to be quantified. This paper provides a first answer to this question. In particular, we employ simulation to evaluate the benefits for multimedia applications, such as VoIP and video, from the use of MCoA. We compare the MCoA results with those obtained when MIPv6 with single address registration is used based on objective multimedia evaluation metrics, such as PESQ. In addition we examine the tradeoffs between application benefits and signaling costs for the network.**

Keywords – Multimedia, MIPv6, Multiple CoA, Resilience, mobility modelling, and performance

I. INTRODUCTION

Nodes are multi-access capable due to the heterogeneous technologies that are currently available. In this context, the performance of multimedia applications can be improved through the use of the diverse interfaces, allowing the anywhere and anytime connection paradigms to the Internet.

Mobility management protocols, specially, Mobile IPv6 (MIPv6) [1], are able to provide uninterrupted access on handover events, within certain quality levels. Nevertheless, these protocols have limitations concerning the support of multiple interfaces/prefixes, as a single Home Address (HoA) and Care-of-Address (CoA) binding pair is assumed. In view of this, a MIPv6-aware node cannot register multiple bindings corresponding to the several prefixes that can be configured. The Multiple Care-of Address Registration (MCoA) protocol [2] overcomes this limitation by endorsing the support of the registration of multiple addresses. With such registration, nodes are able to improve their multihoming support by increasing their resilience to failures [3], [4], with this approach, if the path associated with a prefix fails another can be used seamlessly, since all the available prefixes have been registered.

The use of MIPv6 empowered by MCoA is not devoid of drawbacks. In particular, MCoA does not specify any mechanism to use the several CoAs that are registered. For instance, data applications may be interested in paths with higher throughput capacities [5], while VoIP and video applications benefit if using paths with the lowest possible delay. In addition, cross-layer mechanisms like IEEE 802.21 [6] are required to allow information sharing between network protocols (e.g., MCoA) and applications. With such kind of mechanisms applications can be informed when new addresses are available, and which one fulfils the applications requirements (e.g., offering the lowest delay).

In this paper we investigate on how multimedia applications performance can be improved with multiple care-of-addresses. For such, we rely on our MCoA implementation [7] for OMNet++, available from *http://mcoa.dei.uc.pt/*, which implements the most recent version of the MCoA protocol and includes cross-layer notifications to allow VoIP and video applications to be informed about binded addresses. As the address usage is not specified in the MCoA protocol, in this paper we consider two diverging types of use: *SIM* that uses all the available addresses simultaneously, and *ONE* that use alternatively one address, behaving as standard MIPv6. Moreover, the extended multihoming support of multimedia applications is assessed by application performance metrics such as ITU Perceptual Evaluation of Speech Quality (PESQ) [8] and traditional network performance metrics like packet loss. We have used real audio files, instead of synthetic traffic patterns. We have linked VoIPTool [9], enabling the creation of VoIP packets with audio data, with our MCoA implementation to determine PESQ relying on the ITU PESQ tool [10]. Within such study, this paper is the first, to the best of our knowledge, to provide an answer on how the performance of multimedia applications is improved with MCoA protocol.

The remainder of this paper is organised as follows: Section II overviews related work and introduces Multiple Care-of Address functionalities. Section III details the methodology to assess multimedia application performance. Section IV discusses the results and Section V concludes the paper.

II. Related Work

This section overviews related work on the evaluation of multimedia applications within mobility contexts and Multiple Care-of Address protocol performance assessment.

A. Multimedia Applications

Muslim et al. [11] propose a hybrid Session Initiation Protocol (SIP)-MIP approach to improve the performance of VoIP applications in terms of jitter reduction. MIP mechanisms are employed to hold the handovers, e.g. roam between Access Points (APs), while SIP is used to allow the session management. Interestingly, the work defends the use of different paths to improve the session management, but no evaluation is performed.

The multimedia mobility manager architecture is proposed in [12] to enable seamless mobility management for multimedia applications. The architecture includes a network selection algorithm to allow the choice of a network, enabling the "Always Best Connected" paradigm. Such algorithm is based on the Relative Network Load (RNL) metric, which is determined for each access network based on the Round Trip Time (RTT) and jitter. The policy function, where the RNL metric is employed, considers the monetary cost, power consumption and network load. In addition, all the policy functions (decision, enforcement) are located in the Mobile Node (MN). However this architecture only targets IPv4 networks, what restricts an efficient mobility support.

The architecture for adaptive multimedia streaming in mobile nodes (ADIMUS) [13] and multimedia transport for mobile video applications (MEDIEVAL) [14] architectures include overlay networks configurations to support video applications. In ADIMUS, proxy nodes are employed in the overlay networks to allow the adaptation of multimedia flows routing in the network. Nevertheless, the Mobile Node (MN) does not include mechanisms to choose different paths, or even to use them simultaneously. MEDIEVAL is in a early phase, with no available results, despite proposing optimisation mechanisms for video delivery, through Quality of Experience.

An architecture compliant with IP Multimedia System (IMS) is proposed in [15] to allow vertical handoffs for mobile nodes. The proposed architecture supports nodes with multiple addresses, nevertheless all the mobility management occurs at the application level by employing SIP signalling, as in [16]. This kind of solution has scalability issues, since each application must incorporate SIP support, as opposed to solutions based on MIP protocol, that may not require changes to applications.

B. Multiple Care-of Addresses

The Multiple Care-of Address Registration protocol [2] extends Mobile IPv6 to support the registration of multiple CoAs. MCoA introduces a new element, the Binding Identifier (BID) number that is used to identify the bindings, which are distinguished by the Care of Address in the MIPv6 protocol. The BID extension introduces modifications in the data structures such as the binding update list and the binding cache, as well as amendments in the MIPv6 core signalling messages, such as Binding Update (BU) and Binding Acknowledgment (BA). The message modification is needed to convey the information regarding the multiple care-of-addresses and the respective registration status.

MCoA introduces two possible modes of registration. First, bulk registration that allows multiple addresses to be registered within a single BU message. This way, the BU message is extended to include several BID mobility options that specify the addresses to register. The second registration mode employs a BU message per each address to register. This last mode is the only one that is supported by the correspondent nodes, to avoid the complexity of the return routability procedure on a set of addresses. Despite the performance gain with the bulk registration mode, nodes participating in the binding, namely the Home Agent and the Mobile Node, must support this mode. If no such support is offered by the Home Agent, the Mobile Node must be informed in the BA message.

MCoA is compatible with MIPv6. For instance, if a Home Agent does not support the BID mobility option, the mobile node is informed and on further registrations it rollbacks to the standard procedures of MIPv6.

The added multihoming support of MIPv6, empowered by MCoA registration, lacks the specification on how the multiple registered addresses can be used. For instance, if the addresses can be used simultaneously or if an address is chosen based on the link characteristics. Some may argue that this open specification can be tailored to the specific application requirements. For instance, real-time applications are interested in a link/CoA with smaller end-to-end delay, while data applications in a link/CoA with higher (nominal) throughput. Nevertheless, a non-standard mechanism may lead to a situation where different MCoA implementations become non interoperable.

Tran and Tem [17] developed an extension of Multiple Care-of Address registration [2] to enable the simultaneous use of interfaces when the MN is connected to the home and to the foreign networks. The extension relies on the modification of router solicitation and router advertisement messages to include the *M* flag, which dictates the behaviour of the home agent and correspondent nodes. Nevertheless, the proposal is neither implemented and tested nor evaluated analytically.

The Capacity-aware preferred Multiple Care-of Address (CAPMCoA) [5] allows a MN to choose a CoA from the several addresses. The selection relies on the determination of the best throughput of a specific link-address pair, without relying on link layer information. Nevertheless, the choice of CoA based solely on the throughput of a link does not meet the requirements of today's applications. In addition, the implementation refers to an old version of the Multiple CoA specification [18]. As the throughput acts as a decision key in the CoA selection, applications with bandwidth requirements are targeted in the evaluation, namely FTP applications.

The widely integrated distributed environment (WIDE) project [4], [19] adds Multiple Care-of Address support to Network mobility (NEMO) to achieve load balancing and fault

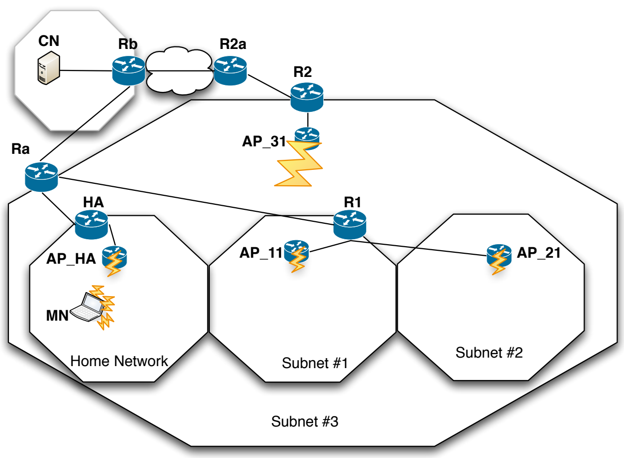

Fig. 1: Simulation Scenario

tolerance. The reported evaluation is based on a MCoA implementation from a first version of the specification performed in a testbed. The applications assessed include only TCP-based applications and Internet Control Message Protocol (ICMP).

Several studies [20], [21] point out on the direction of using multiple addresses to improve applications performance. Nevertheless, while the fist only considers ICMP traffic on mobile routers, the second considers VoIP [21] but without the simultaneous use of addresses.

To the best of our knowledge, this paper is the first to provide an objective evaluation on the multimedia application performance with MCoA within simultaneous and single address usage.

III. Evaluation Methodology

This section details the methodology followed in the evaluation to determine the performance of VoIP and video applications.

A. Scenario

VoIP and video streaming traffic is used in the simulation scenario, depicted in Fig. 1, to assess the impact of multiple care-of addresses in the performance of multimedia applications. Video streaming traffic is generated through the transmission of packets with 500B and interarrival rate of $50ms$ according to [22]. VoIP applications are configured with packet interarrival rate of 20ms, within a compressed bit rate of 128kbps, a sampling rate or 8kHz and 16 bits per sample, which correspond to speech characteristics [23]. Both application sessions are configured with a duration of 200s.

The VoIPTool [9] is employed to generate VoIP packet streams, because it allows the use of real audio data, in such a way that a recorded phone-conversation is used as the input audio. Moreover, we employ the ITU Perceptual Evaluation of Speech Quality (PESQ) tool [10] to assess the Mean Opinion Score (MOS). ITU PESQ [8], [24] is a standard that establishes a quality score, by comparing the original signal with the degraded version. PESQ allows listening quality objective measurements, which in part justifies its wide-use for VoIP quality assessments. Values of PESQ rely in the $[-0.5, 4.5]$ range and are mapped in the MOS scale (see Table I) according to the mapping function depicted in Eq. 1, which is specified in ITU P.862.2 recommendation [25].

TABLE I: Mean Opinion Score

MOS	Impairment/Description
5	Imperceptible / Excellent
4	Perceptible but not annoying / Good
3	Perceptible and slightly annoying / Fair
2	Annoying but not objectionable / Poor
1	Very annoying and objectionable / Bad

$$y = 0.999 + \frac{4.999 - 0.999}{1 + e^{-1.3699 \cdot x + 3.8224}} \quad (1)$$
$$where\ x\ is\ the\ PESQ\ value$$

The simulation scenario also includes wireless LAN subnets (*Subnet #1*, *#2* and Home network) and a wireless network with high transmission power (*Subnet #3* - to model a 3G network, in terms of coverage). Routers *Ra* and *R2a* connect to *Rb* that manages the correspondent node network.

The Wi-Fi technology (IEEE 802.11b) is employed due to its popularity and support in the OMNeT++ simulator. The Ethernet connections are configured with a transmission delay of *10ms*, while the links simulating an Internet connection (links *Ra-Rb* and *R2a-Rb*) have a propagation delay of *30ms* and *100ms*. Router *R2*, managing *Subnet #3*, is connected to a wireless point configured with high transmission power (100mW), in comparison to the remaining wireless access points (2mW), in order to provide a wide wireless coverage.

The handovers are triggered by the availability of new addresses and by the unreachability of neighbours, as in standard MIPv6. For instance, when roaming from the home network, to *subnet #1*, the Home Agent is no longer reachable (according to Neighbour Unreachability Detection - NUD protocol) and a new prefix is available. After the connection to a new access point, mobile node receives prefixes, from which Care-of-Addresses are formed. Moreover, procedures like Duplicate Address Detection (DAD) are executed to assure that the CoA is a unique address. Thus, handover execution time, besides including the association at the link layer also includes time to execute procedures at the IP layer, lying in values around 1s [26].

The simulation scenario was configured in OMNeT++ using our MCoA++ simulation model [7], which extends MIPv6 to support the registration of multiple addresses.

B. Methodology

The analysis considers two failure cases: The first one corresponds to failures due to handovers-*HO*, which are caused by the movement of the MN when roaming between networks. The second corresponds to failures on the elements of the networks-*Net* (e.g., routers). *HO* cases correspond to failures that are normal due to mobility of nodes. Despite that the same recovery procedures are used in both failure situations the consequences are different. On the first case, the mobile node switches to a new network, while on the second case,

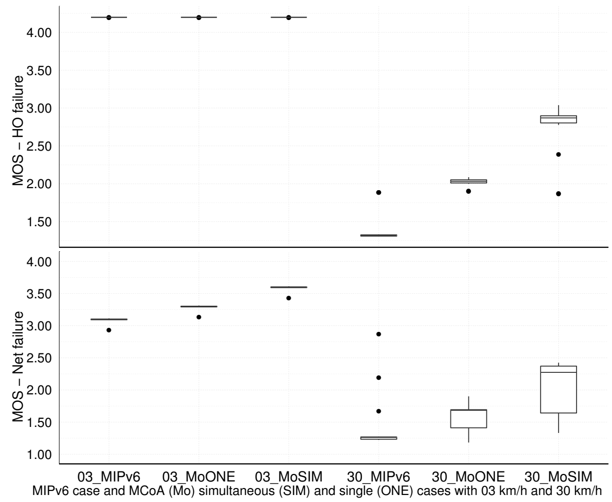

Fig. 2: VoIP MOS

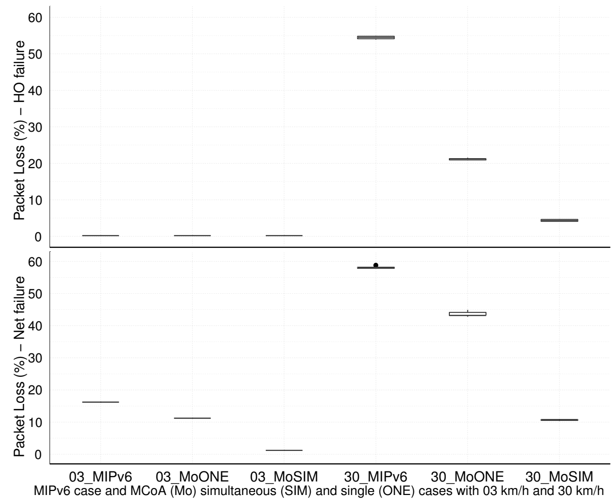

Fig. 3: VoIP Packet Loss

the MN stays on the current network, but needs to determine a new default router. The network failures include non working periods of $5s$. Such long periods are considered to allow the expiration of bindings. These failures are generated systematically each $20s$, alternately between *HA*, *R1* and *R2* routers. The network failures consist on dropping all packets in the Ethernet interfaces of routers. The handover failures are caused by the different speeds of the MN, namely 3km/h and 30km/h, configured to simulate pedestrian and vehicular speeds, according to [27]. When correspondent nodes support Mobile IPv6 procedures, routing optimisation mechanisms can be used. Thus, failures in the Home Agent should not impact Mobile Nodes when at foreign networks. Traditional evaluations [12], [15] only consider the failures due to mobility, *HO* cases, this paper also includes failures in the network, in order to assess the resilience gain of multimedia applications empowered by MCoA.

Different ways of using the multiple addresses available were considered. *SIM* uses all the addresses simultaneously, falling into the *1+1* protection model, where both can be used concurrently. *ONE* chooses randomly a CoA from the several that are available, while *MIPv6* corresponds to the standard Mobile IPv6. Both *ONE* and *MIPv6* sets correspond to the *1:1* protection model, commonly known as primary-backup model (see [28]). The difference between *ONE* and *MIPv6* relies on the fact that in the first case, all the care-of-addresses are registered, while in MIPv6 only one address is registered, regardless the set of different IPv6 addresses. In the *SIM* test case packets are replicated for all the established tunnels.

IV. Results

This section presents the results achieved with the different tests. All the reported results have a confidence interval of 95% and are based on 50 runs.

A. VoIP Applications

Quality of VoIP applications, illustrated in Fig. 2, varies with the different scenarios, handover and network failures, as well as with the diverse MIPv6 and MCoA test cases. In fact, simultaneous use of addresses provides perceptible quality, even with higher speeds (e.g., 30km/h), while the remaining cases present a poor or bad quality. With *SIM*, the probability of an application being affected by failures (network or handover) is reduced, as packets are replicated on all the established tunnels at the same time. Not only the fact of using all the addresses simultaneously, but also the fact of registering the available addresses can enhance VoIP quality. By using MCoA, even with only one address, if there is a failure in one address another can be employed, as opposed to MIPv6, where if failure occurs with a care-of-address, no recovery is possible due to its single-bind nature.

When failures are constrained to handovers, the objective quality of VoIP (MOS) is higher. For instance, a good quality is achieved with 3km/h speeds. Notwithstanding, in more realistic scenarios, including failures at network elements (e.g., routers), the quality of VoIP is degraded, but good quality is still achieved when all the addresses are used simultaneously.

Fig. 3 shows that the packet loss rate of VoIP applications is high for speeds of 30km/h, as naturally expected. For instance, $\sim 40\%$ of packet loss is reached when using MCoA with one address under network failures. Inline, with objective VoIP quality, packet loss is higher with network failures and higher velocity. In all configurations (e.g., speed, failure type) the simultaneous use of addresses introduces the lowest packet loss ratio, as the probability of loosing VoIP streams is reduced. On a best-effort basis, packets will arrive to the destination on a working path (in this context a tunnel between mobile node and correspondent node), even if paths associated with other registered addresses experiment failures.

B. Video Applications

Video applications, despite the different characteristics from VoIP applications (e.g., packet size, sample frequency), have a performance similar to VoIP, as illustrated in Fig.4. For instance, taking into consideration the simultaneous use of addresses, packet loss ratio of video applications are equal

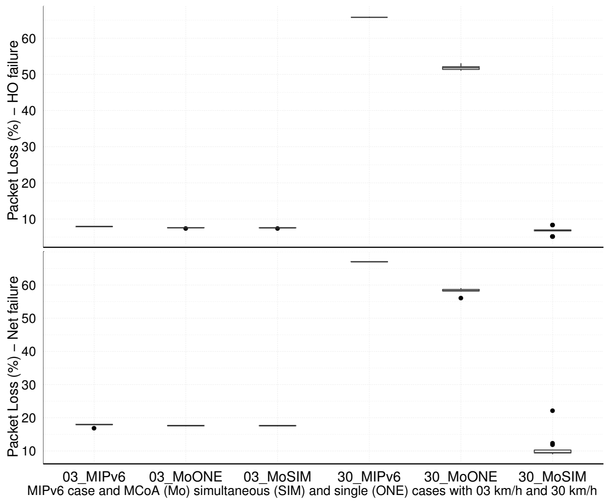

Fig. 4: Video Packet Loss

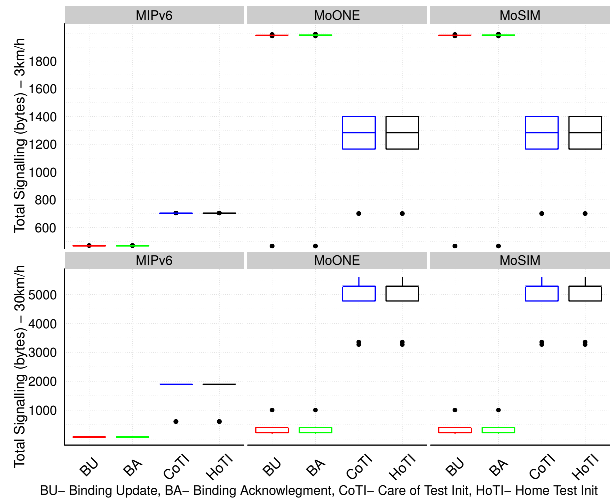

Fig. 5: VoIP and video Signalling Cost

to the loss ratio of VoIP applications at 30km/h, with values around $\sim 10\%$ and bellow 10%, for network and handover failures, respectively. Such results highlight the advantage of employing all the addresses simultaneously, no matter the characteristics of applications.

As with VoIP, video applications also benefit with the registration of multiple addresses, and thus MCoA with one address usage results in low packet loss ratios in comparison to MIPv6. With MIPv6, the addresses advertised by router *R2* might not be registered, despite the extended wireless coverage associated with the access point in this network.

Video applications experiment higher packet loss ratios under network failures, in contrast to handover failures, where packet loss ratio is bellow 10% for reduced velocity. Non-working periods are higher under network failures 5s, causing a high number of packets to be lost, in comparison to handovers that are completed in less time, having failures of around $\sim 1s$.

C. Signalling Cost

The quality improvement obtained with the use of multiple care-of-addresses by VoIP and video applications is achieved with a certain cost. We assess the cost in terms of the size of messages created on the signalling procedures of MIPv6 and MCoA protocols throughout the applications sessions (configured with a length of 200s). In particular, Binding Update (BU), Binding Acknowledgment (BA), Care of Test Init (CoTI) and HoTI (HoTI) messages are considered. Results are based on the bulk registration mode, where a single binding message (BU, BA) conveys information about several addresses. Another possibility, not illustrated, is to proceed as standard MIPv6, where a binding update message only conveys a single address. Nevertheless, this last option incurs in increased overhead, as more signalling messages would be created and transmitted.

Fig. 5 illustrates signalling cost for VoIP and video applications. MCoA configurations introduce more overhead, due to the multiple addresses that are conveyed in the signalling messages, in comparison to MIPv6. That is, the signalling procedures in the simultaneous and single address do not differ (recall that the distinction relies on the address usage).

Standard MIPv6 has lower overhead due to its single-bind nature, as only one address is registered, therefore signalling only includes information for the address being registered.

With a high number of handovers, considering the 30km/h cases, the cost is higher. As mobile nodes roam more frequently between networks, more registrations are required, leading consequently to more overhead in terms of signalling cost, as for instance 2000 bytes for CoTI messages. The main difference between the cost of return routability messages (CoTI, HoTI) and binding messages (BU, BA) relies on the fact that CoTI and HoTI are exchanged more often since they convey only one address. In other words, the bulk registration mode is not supported when performing return routability in MCoA for security reasons [2].

V. Discussion and Conclusion

Multiple access networks enable the configuration of multiple addresses. Nonetheless, an efficient multihoming support cannot simply rely on the plurality of technologies/interfaces. Instead, all layers must accommodate mechanisms to support multihoming and act synchronised when aware of multihoming context (e.g., multiple addresses available) [29].

The results in this paper put in evidence that the use of multiple addresses brings benefits that impact directly applications performance assessed by loss rate metrics and MOS. Even the sharing of capabilities, when the mobile node informs the correspondent node that it can be reached on different addresses, represents a gain in terms of resilience support. Thus, in a multihoming context, multimedia applications, such as VoIP and video herein assessed, that use multiple addresses become more fault-tolerant, as failures in the core network, network cases, or due to mobile events, handover cases, introduce less impact.

The enhanced multihoming support has a price in terms of requirements and cost. Cross-layer mechanisms are needed to exchange the information related with the multihoming context. For instance, multimedia applications need to subscribe to events related with the availability of new addresses at the network layer. In addition, other information associated with addresses and respective paths is relevant to applications, such as delay and throughput, The cost, as demonstrated here, increases in terms of signalling, as core mobility management procedures of MCoA need to convey more information or are triggered more often. In addition, other costs may be determinant in the way that multiple addresses can be used, with a monetary concern, some interfaces can only be used if strictly necessary (e.g., no other alternative is suitable) or with energy saving restrictions [30].

The results obtained with this study provide a practical demonstration of the principle that multiple care-of addresses enhance the performance of multimedia applications. So far, this principle has only been demonstrated at a theoretical level [21]. Moreover, the achieved results, and given the always increasing capabilities of end-user devices, pave the way to an easily achievable and successful trade-off between improved performance of multimedia applications and associated cost

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