COmpAsS: A Context-Aware, User-Oriented Radio Access Technology Selection Mechanism in Heterogeneous Wireless Networks

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***Abstract*—5G networks will have to cope with an increase of data traffic, as well as a vast number of devices, which already transpires in the wireless/mobile communication environments. Several on-going efforts both from 3rd Generation Partnership Project (3GPP) and several proposals from the literature as well, attempt to overcome the existing barriers by enabling the use of Wi-Fis and femto-cells. The evolution of Access Network Discovery and Selection function (ANDSF) in Evolved Packet Core (EPC) networks, as well as the Hotspot 2.0 approach, can be used to facilitate a seamless integration of WiFis with the cellular networks. Although this integration clearly presents benefits, a handover mechanism that will capitalize on the new standards is still missing. This paper acts in a two-fold way. We design and evaluate a novel context aware selection mechanism that is using fuzzy logic to select the most appropriate Radio Access Technology (RAT). To this end, we propose network extensions that allow the ANDSF entity to be aware and provide up to date information to end devices about the network status. Extensive simulation results illustrate the advantages of our approach.**

Keywords-RAT selection;ANDSF;LTE;handover.

I. INTRODUCTION

Traffic analysis clearly indicates that 5G networks will have to cope with a huge increase of data traffic and the number of the end devices (e.g., smartphones, tablets, sensors etc). To address this issue the research community designs solutions to improve the spectral efficiency, to increase the network cell density and to exploit the underutilized radio spectrum resources [1]. Such approaches suggest the exploitation of the available femto-cells or Wi-Fi Access Points (APs) to reduce the network load of an operator in a particular area [2].

Integrating Wi-Fi access points with cellular networks has been a hot topic for over a decade. However, apart from limited deployment examples, this approach has not been widely adopted by the network operators. This is because of a number of reasons. Wi-Fi suffers from interference issues since it operates on the unlicensed spectrum. Typically, the installed access points in homes, offices, public spots do not belong to the cellular operator. Also, up to now, switching from a cellular network to a Wi-Fi access point was not a transparent process for the end users (e.g., authentication). Finally, there was not a clear business case for the operators on how to increase their revenues by supporting Wi-Fi access points.

Some new technological solutions may change the landscape. ANDSF and Hotspot 2.0 if combined together may prove the right solution for simplifying the access of end users among RATs. Also, roaming among cellular operators and wireless internet service providers may also be supported. The new business case for cellular operators would be the support of the same QoE for their services among different RATs that may even belong to another operator. Thus, the integration of cellular networks with Wi-Fi APs needs to be revised not only due to the new business cases that arise, but also because the new protocols can be exploited to design more efficient RAT selection mechanisms.

3GPP has already specified how Wi-Fi access points may be integrated with the Evolved Packet Core (EPC) architecture [3][4]. Also, a new network entity, which takes account of policy rules and security requirements was introduced, namely Access Network Discovery and Selection Function (ANDSF) [5]. Closely coupled with the Policy and Charging Rules Function (PCRF) [6], ANDSF implements dynamic data offload for the User Equipment (UE) in a structured method. The ANDSF is a cellular technology standard, which enables the operator to store its policies for discovery and selection of RATs on a server. The UEs are updated with these polices either via push (network-initiated information to the UE) or pull (UE-initiated request) methods by the server. The policies within ANDSF contain information on which of the available Wi-Fi hotspots are preferable during specific a specific time or day, and at a specific location as well, based on indications from past measurements.

The ANDSF information is represented by the ANDSF Management Object (MO) and may contain information with regard to the UE location, Inter-System Mobility Policies (ISMPs) and Inter-System Routing Policies (ISRPs) ([7]). The ISRPs are available for UEs, which support IP Flow Mobility (IFOM), multiple-access Packet Data Network (PDN) connectivity (MAPCON), or non-seamless offload [8] - [10]. MAPCON enabled UEs may establish different PDN connections through different RATs. IFOM enabled terminals may establish a single PDN connection via multiple access networks, for instance 3G/LTE and Wireless

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Local Area Network (WLAN). For such UEs, IFOM enables to move individual IP flows from one access network to another with session continuity. The ANDSF prioritized rules in the case of MAPCON apply per PDN connections, while in IFOM and non-seamless offload cases per flow. ANDSF communicates with the UE over the S14 reference point.

Hotspot 2.0 Wi-Fi technology standard from Wi-Fi Alliance acts in a complementary way to ANDSF as it improves the ability of WLAN devices to discover and connect in a secure way to public Wi-Fi APs. Hotspot 2.0 builds on 802.11u specifications that enable devices to discover information about the available roaming partners using query mechanisms. The query and response protocol, which supports Hotspot 2.0, is the Access Network Query Protocol (ANQP) [11]. ANQP is used to collect the following: the operator's domain name, the accessible roaming partners, the IP address type availability, the type of the access point (private, public free, public chargeable, etc.), and most significantly load information (i.e., total number of currently associated devices to the AP, channel utilization percentage and an estimate of the remaining available admission capacity).

The WLAN_NS working item of 3GPP ([12]) is working to Enhance 3GPP solutions for WLAN and access network selection based on Hotspot 2.0 and ensure that data, i.e., Management Objects (MO) and policies provided via HotSpot 2.0 and ANDSF are consistent. This alignment of ANDSF and HotSpot 2.0 provides an excellent basis for the complementarity of ANDSF and Hotspot 2.0, as well a number of multi-operator scenarios that can be supported. In [2], a rather exhaustive list of possible scenarios is presented.

From the above description it is clear that several efforts have already taken place to address the interworking between cellular networks and WiFi. In the new landscape it is imperative to design new mechanisms for the RAT selection for every terminal. The reason is that UEs will have to choose among typical macro-cells, femto-cells and APs. Due to the diverse set of parameters that have to be evaluated by a UE and the network we adopt the use of fuzzy logic [13] that can handle multi-criteria problems.

The rest of the paper is organized as follows. In Section II, we present related work from the literature, which attempts to deal with the aforementioned challenges. Section III is split into two main parts: the first presents a proposed extension of the ANDSF entity to collect information from HeNBs and APs to support the RAT selection process; the second part goes through a comprehensive description of our mechanism, which we call *COmpAsS*. In Section IV, simulation results based on a realistic business case are presented. In Section V, we describe the conclusions, which are derived from the overall work and we discuss our future steps.

II. RELATED WORK

There has been a lot of effort into further optimizing the standardized mechanisms, and plenty of proposals and algorithmic solutions to improve the handover procedure.

The survey in [12] provides an overview of the main handover (HO) decision criteria in the current literature and presents a classification of existing HO decision algorithms for femto-cells. According to this, some researchers focus on evaluating the Reference Signal Received Power (RSRP), the user location or speed, the mobility patterns, the battery level, the mean UE transmit power and the UE power consumption, the load of the cell and the service type. Apart from the case of RSRP, typically researchers are using multiple criteria (e.g., battery lifetime, traffic type, cell load, speed) and are using different tools (e.g., cost based functions, fuzzy logic, etc.) to reach a decision.

Xenakis et al. [14] present an overview of the vertical handover (VHO). Initially, a categorization of the information parameters of the VHO processes into layers is made: application (e.g., user preferences), transport (e.g., network load), network (e.g., network configuration, topology), data-link (e.g., link status) and physical (i.e., available access media). From the network perspective the ones highlighted are: latency, coverage, RSS, RTT, number of retransmissions, BER, SINR, packet loss, throughput, bandwidth, network jitter and the number of connected users. From the UE perspective, the parameters that are presented are user monetary budget, preferred network (user choice), location, movement (change of direction), velocity, technologies available in the device, as well as battery consumption. Many of the proposed mechanisms that this survey presents attempt to create an overall context-aware mechanism, by combining several of the aforementioned parameters for the VHO decision outcome.

Several other existing surveys attempt to present a unifying perspective with regard to HO mechanisms. Rao et al. [15] deal with the network selection concept as a perspective approach to the always best connected and served paradigm in heterogeneous wireless environment. From the origin point of view, they classify them in four categories: network-related criteria, terminal-related, service-related and finally, user-related. In addition, in [16]-[18], several efforts are described, which aim to improve the selection mechanisms, which support heterogeneous RATs. In principle, all mechanisms combine parameters like RSS, bandwidth, mobility, power consumption of the UE, security, monetary cost and user preferences.

In all the above a cases, the researchers are using for the most advanced schemes a number of parameters. However, very rarely they clearly state how this information is collected and from which network entities. Such information is necessary because the hypothesis that a value (e.g., the location of terminal) can be collected may require extensive signaling exchange among the network components. Also, in most cases solutions target either handovers for macro-femto cells or vertical handovers among different RATs. In this paper, we attempt to clearly indicate how the information required for our solution is collected and from which network entities. We also examine the possibility of UE to handover among macro-femto and Wi-Fi APs.

When dealing with diverse parameters in order to reach a decision, in the literature many authors have proposed Fuzzy Logic (FL) Inference Systems. Indicatively, Xia et al. [19]

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propose a scheme taking into consideration the actual RSS, as well a predicted RSS, and they combine it with the speed of the UE in order to determine if a handover should be made or not. Moreover, they estimate the suitability of a RAT for handover, taking as input the current RSS, the estimated RSS, as well as the available bandwidth. In [20], FL is also used for estimating the output suitability of a network based on the inputs of the environment (bandwidth, delay, charging, power consumption). In addition, Ma and Liao use GPS, in order to adapt the monitoring rate of the afore-mentioned values. For our solution we have also chosen to use a FL scheme to support the decision making process.

III. THE PROPOSED SOLUTION

A. *COmpAsS mechanism*

The aim of the COmpAsS is to enable a UE at selecting in an intelligent way the most suitable RAT to perform a per-flow handover. COmpAsS is a user-oriented, context-aware scheme, which takes into account the mobility of the UE, the Received Signal Strength (e.g., RSRQ for 3GPP access networks), the load of the (Home) eNodeBs ((H)eNBs) and WLAN APs, the backhaul load of the network, as well the sensitivity to latency for each of the candidate flows for handover (Fig. 1). Based on FL, the five inputs are assessed using a Fuzzy Inference process, which resides in the UE and calculates the suitability of the available RATs for each one of the flows of the UE. The calculation inside the FL Inference Engine is based on pre-defined rules regarding all the possible combinations of the different inputs. According to the rules, in principle, it is assumed that a RAT is more attractive to the UE when it is characterized by low (backhaul) load and high RSS. In addition, the higher the sensitivity to latencies, the more important is the mobility of the UE; high mobile UEs prefer larger cells to avoid unnecessary handovers. In the proposed scheme, the information is obtained from an extended ANDSF network entity, which is described in detail in the following section.

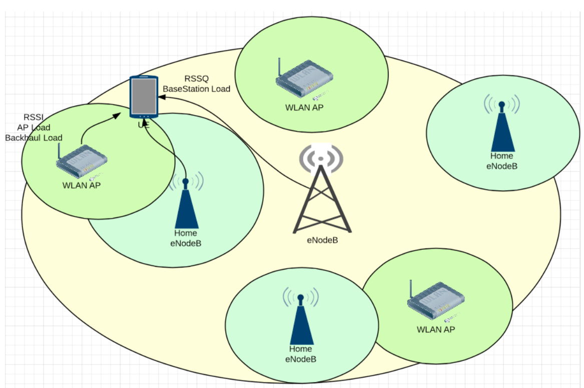

Figure 1. Context-aware RAT selection by COmpAsS

Although the FL computational requirements are minimum, in order to further optimize the energy consumption of COmpAsS inside the UE, as well as to minimize the unnecessary handovers, additional mechanisms are used (Fig. 2), i.e., a) a suitability threshold: no FL computation is performed if the current RAT's suitability is higher than 90%, b) a suitability hysteresis value, i.e.: neighbor RAT's suitability must be at least 10% higher than the current RAT's (if a neighbor RAT is a macro cell) or at least 1% higher than the current RAT (if neighbor RAT is a femto-cell) in order to trigger a handover. The higher hysteresis in the case of macro neighbor RAT is chosen aiming to impel the handover to smaller RATs for offloading reasons.

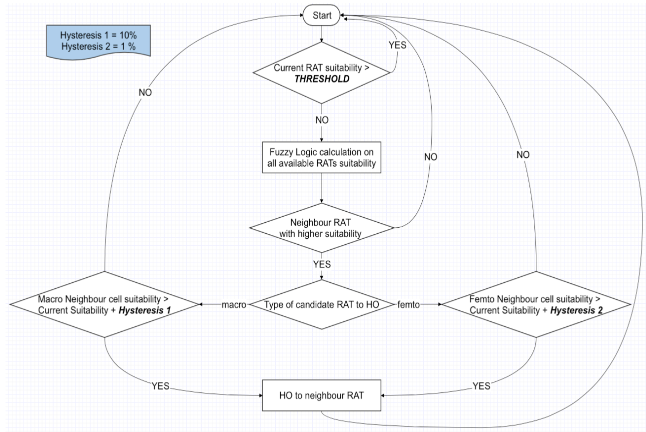

Figure 2. RAT suitability Hysteresis and Margin for minimizing unnecessary handovers

B. *Extension of Access Network Discovery and Selection Function (ANDSF) functionality*

As described earlier in this paper, ANDSF is a cellular technology standard, which implements dynamic data offloading for the UEs in a structured way. However, the purpose of ANDSF is currently limited to provide the UE with policies with regard to access networks. Moreover, one of the most crucial aspects in relation to offloading and handover mechanisms, that the ANDSF MO is missing, is real-time network conditions, such as the load of a Base Station. This type of information, as well as additional features, which are not provided by the ANDSF, may be provided by the Hotspot 2.0 standard described earlier, supported by the ANQP protocol.

On the contrary, ANDSF provides WLAN AP location information, supports UE location reporting, as well as may provide a list of preferred or restricted access networks, -features, which are not provided by Hotspot 2.0 -.

It becomes clear that ANDSF and Hotspot 2.0 could act in a supplementary way to maximize the available information to the UE, resulting in more efficient offloading mechanisms. In this paper, we propose an enhanced version of the ANDSF server capable of:

a) collecting real-time load information regarding the available 3GPP access networks, based on a new logical interface (e.g., between the (H)eNB and the ANDSF entity). This information is evaluated in a coarse manner (i.e., low, medium, high).

b) supporting queries to Hotspot 2.0 enabled WLAN APs using the ANQP protocol

c) gathering information from the UE measurements regarding RSRQ measurements

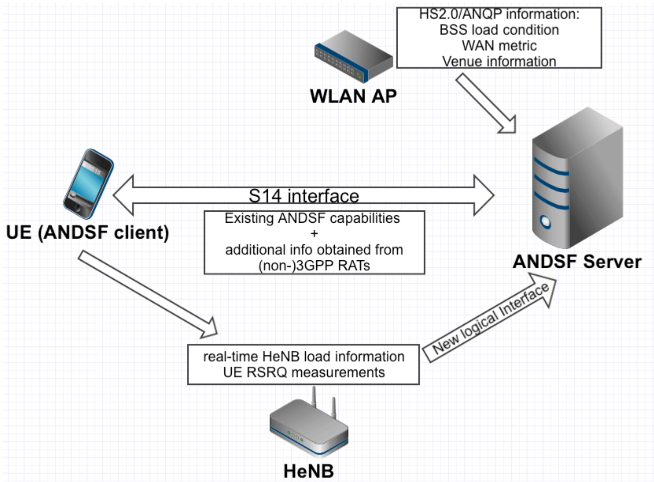

Figure 3. Extended ANDSF architecture

As a result, the UE will be capable of assessing both 3GPP and non-3GPP available RATs using the same input parameters and ultimately take the optimal decision for handover. S14 existing interface between the UE and the ANDSF component will provide to the UE already-supported information, as well as the additional information obtained from the available (non-) 3GPP RATs. A high-level description of the above architecture is demonstrated in Fig.3.

IV. SIMULATION RESULTS

In order to evaluate the performance of COmpAsS mechanism advanced topology simulations were carried out using the *ns-3* simulator [21]. The *fuzzylite* C++ Fuzzy Logic library is also integrated inside the custom *NS-3.19* build. The figure, which follows, presents a realistic business case scenario of a shopping mall comprising 3 floors (ground floor, 1st and 2nd floor), and 20 shops per floor (Fig. 4). The UEs are either static or moving, and are roaming around the shopping mall rooms (shops, cafes, etc.). Several HeNBs are deployed in the three floors. In addition, two macro cells (eNBs) exist outside the mall area in a distance of 200m to different directions. Due to the fact that COmpAsS handles Wi-Fi APs and HeNBs in a similar way, with regard to the pre-defined rules of the Fuzzy Inference Engine, for the sake of simplicity, in the simulations only macro and femto-cells are deployed.

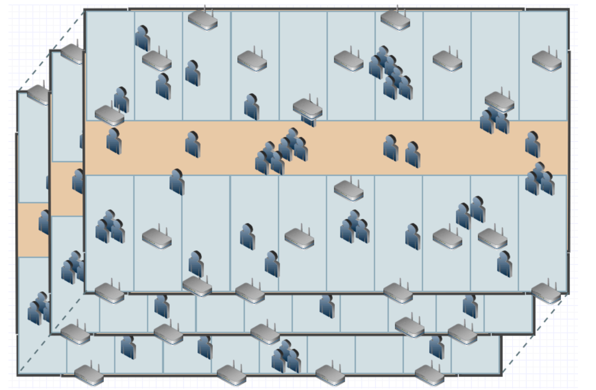
Figure 4. Shopping Mall with 3 floors and 20 shops per floor (simulation environment)

Besides the several UEs, which are roaming inside the mall area and creating respective traffic to the HeNBs, we use one "test UE", in which COmpAsS is deployed. Different simulations were carried out to test the UE at different velocities (low, medium, high), in each one of the scenarios in order to evaluate the proposed scheme for varying UE mobility, as mobility is one of the inputs, which are taken into consideration for the decision. The test UE is moving with linear velocity between the rows of the shops, on the 1st floor. An overview of the simulation details is presented in the following table:

Table 1 SIMULATION DETAILS.

Environment	Shopping mall: 3 floors, 100 x 200 meters per floor, 20 rooms per floor (2 rows of 10 equal rooms)
Number of UEs	Variable (UEs connecting/disconnecting)
Number of (H)eNBs	2 eNBs, 9 HeNBs
Carrier frequency (MHz)	Downlink: 2120.0, Uplink: 1930
Channel bandwidth	50 RBs for eNBs, 15 RBs for HeNBs
Transmit power	35.0 dBm (eNBs) , 23.0 dBm (HeNBs)
Simulation time	100 s
Time unit	0.1 s
UE mobility	0.4 m/s, 0.8 ms, 1.4 m/s (linear constant velocity)
HeNB load	Varying depending on the number of associated UEs (very low, low, medium, high, very high)
Traffic sensitivity to latency	High (0.7/1.0)

The proposed scheme is evaluated against A2A4 RSRQ mechanism –a well-established handover algorithm found often in the literature-. A2-A4-RSRQ may be triggered by the two events; Event A2 is defined as the situation during the serving cell's RSRQ becomes worse than a *threshold*. A4 event describes the situation when a neighbor cell's RSRQ becomes better than a *threshold*.

The following figures illustrate the measured Key Performance Indicators (KPIs), which resulted from the two mechanisms with regard to the number of overall handovers which took place during the simulation, the throughput of the test UE, the experienced delays, as well as the packet loss during the measurements.

Variable load of the femto-cells of the shopping mall was tested, calculated in relation to the overall associated users per base station and traffic that is generated. In particular, the load of the base stations varies from 10% up to 90% of their available resources (horizontal axis in Fig. 5-11).

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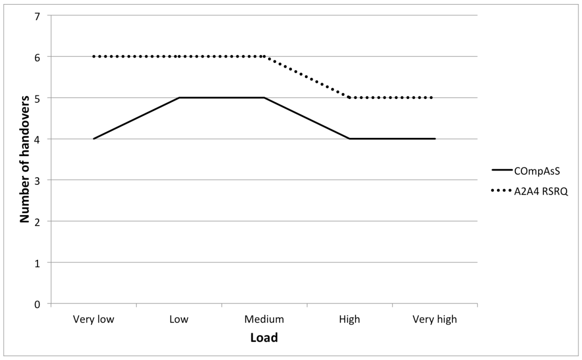

Figure 5. Number of handovers

In Fig. 5, the overall number of handovers is shown. According to the graph, the proposed mechanism tends to minimize the number of handovers as it realizes less handovers than A2A4 RSRQ in all load situations.

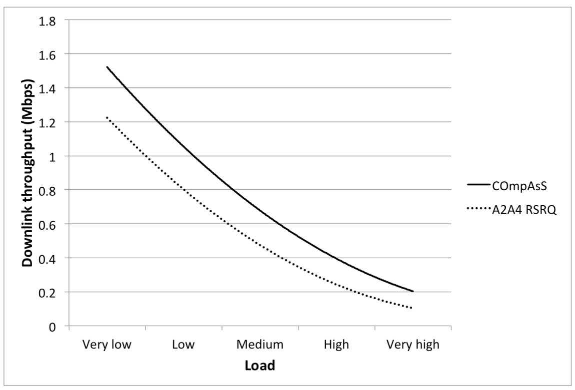

Figure 6. Downlink throughput

In Figs. 6-8, the results of the downlink are illustrated: throughput, delay and packet loss. With regard to the throughput (Fig. 6), COmpAsS outperforms the A2A4 RSRQ algorithm in all load scenarios by 10-20 %. In the case of the proposed scheme, the high interference, which results from the tested environment retains the UE from handing over to the femto-cells, which suffer more; instead, the UE tends to stay more time attached to the eNBs, achieving finally a higher throughput. Moreover, the UE mobility is taken into consideration from COmpAsS, in contrast to A2A4 RSRQ; for high mobile users femto-cells are less attractive, particularly if the load of them increases as well, which makes them even more unattractive. In the case of the delay (Fig. 7), a significant difference between the two mechanisms is observed throughout the measurements. Similarly, the packet loss (Fig. 8) that experiences the UE, which uses the COmpAsS mechanism, is by 20% lower than the other scheme, no matter how high the load of the network –and as a result the experienced interference as well- is.

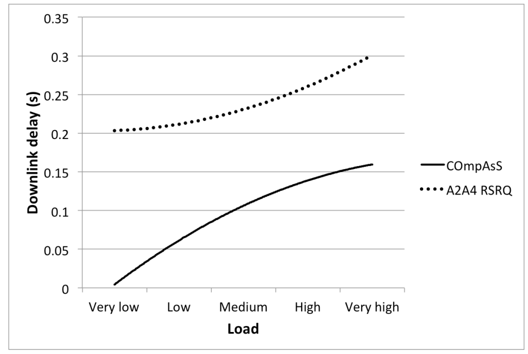

Figure 7. Downlink delay

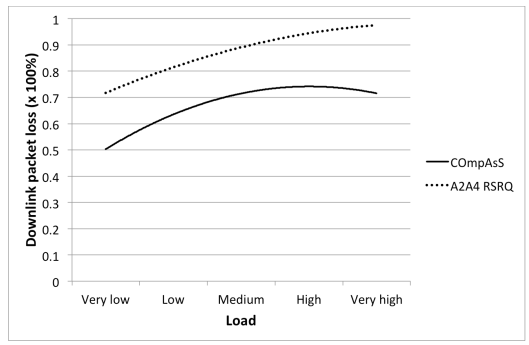

Figure 8. Downlink packet-loss

Figs. 9-11 illustrate the measured KPIs of the uplink. Noticeably, the difference of the throughputs of the two schemes is even higher than in the case of the downlink, i.e., 200 – 400 Kbps (Fig. 9).

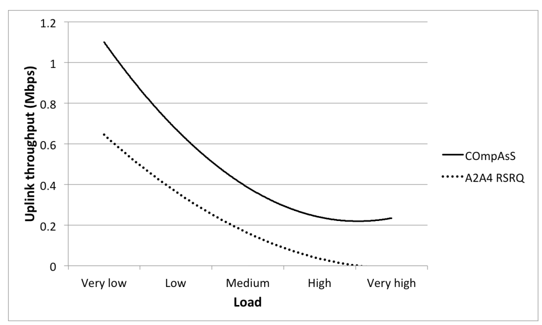

Figure 9. Uplink throughput

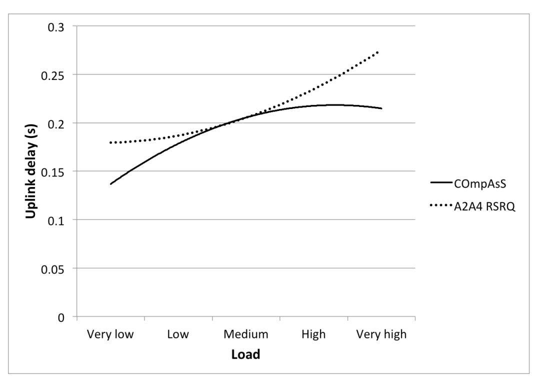

Figure 10. Uplink delay

With regard to the uplink delay (Fig. 10), it is shown that, although at medium load the two algorithms have almost identical results, as the load increases further, COmpAsS's performance is significantly better –roughly 50ms-, maintaining constant delay. In contrast, A2A4 RSRQ's delay is increasing further. This is explained by the fact that, the suitability by COmpAsS during the load increase of the femto RATs, reduces radically, particularly for faster users.

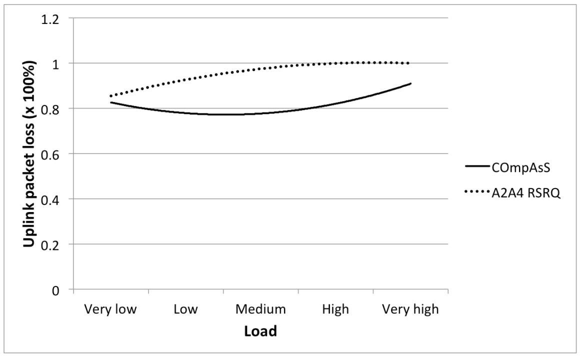

Figure 11. Uplink packet-loss

The packet-loss in the uplink case (Fig.11), similarly with the previous figures confirms the superior performance of the proposed mechanism.

V. Conclusion and Future Steps

This paper proposed COmpAsS, a context-aware RAT selection mechanism, based on Fuzzy-Logic. The proposed solution emphasizes on the actual way of obtaining the different types of information, which ultimately lead to the handover decision, via an extension of the current solutions such as ANDSF and Hotspot 2.0. The realistic business case scenario, which was simulated, and the extensive results confirm the high performance of COmpAsS in challenging environments of several mobile users and different co-existing RATs, while at the same prove that it can be broadly applicable, in simpler, less demanding use cases as well.

The proposed mechanism, on the one hand avoids the unnecessary handovers minimizing the redundant signaling overhead; on the other hand, the context awareness of the UE remarkably improves the handover decisions resulting at the end in higher service quality and -eventually- higher quality of experience for the end-user.

Future steps will be: (a) define an adaptive sampling rate of the mechanism, in order to further optimize the battery consumption of the UE and minimize the unnecessary signaling, and (b) carry out more simulation scenarios with more users and diverse service types.

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