Broadcasting User Content over Novel Mobile Networks

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Abstract—In the "Youtube Era", mobile consumption of video, such as Video on Demand (VoD) and User Generated Content (UGC), has been steadily increasing. However, mobile networks are showing to be unprepared for such phenomenal traffic volume, whereas the devices' multiple interfaces are being exploited to address this problem. As such, the interest in offloading techniques has significantly increased, not only at access level, but also at IP layer – boosting solutions based on Distributed Mobility Management (DMM) technologies. Connectivity management taking into account different applications requirements and multiple interfaces calls for a cross-layer solution, where IEEE 802.21 Media Independent Handover (MIH) may take a crucial role. In this paper, we describe an architecture for the support of UGC over the upcoming mobile networks using DMM and IEEE 802.21 concepts. We develop two entities, the Connection Manager and Flow Manager, for managing the connections throughout all the mobility session for either video producers or consumers. We implemented a real testbed in which we collect throughput and packet loss statistics on usage scenarios. The provided results show how the Connection Manager can be used to automatically take advantage of multiple interfaces and how the Flow Manager can be used to trigger multicast context transfer, with added performance results.

Keywords — User Generated Content, Broadcasting, Multicast Context Transfer, Connection Manager, Flow Manager, IEEE 802.21

I. INTRODUCTION

The generation and consumption of User Generated Content (UGC) is an astonishing increasing trend, especially hard to handle in the form of mobile video. Mobile networks need to greatly evolve in order to be able to deliver the expected 1000-fold increase in mobile data traffic [1], with the number of devices expected to surpass the world's population [2]. Capacity-magnifiers at radio level include massive deployment of micro-to-femto cells or increases in available spectrum and its efficiency (e.g. Multiple Input Multiple Output - MIMO). At higher layers, offloading techniques are being proposed, not only at access level (e.g. Selected IP Traffic Offload - SIPTO), but also at IP layer, with a promising effort being the Distributed Mobility Management (DMM) concept. DMM is seen as a way to avoid problems identified in centralized mobility management solutions, in particular those related to efficiency, e.g. data and control plane centralization. Although, DMM represents a single step forward in the path to efficient mobile video support.

IP multicast couples native characteristics towards efficient multimedia support. The application of DMM features to IP multicast mobility, which generally leverages on the tunnel forwarding for all users, is worth research. Besides, in order to benefit from application-aware connectivity management, a cross-technology solution is required.

Within the EU-funded project MEDIEVAL [3], a cross-layer framework for multimedia distribution over mobile networks has been proposed, relying on IEEE 802.21 [4]. In this paper, we expand this basic architecture for supporting Personal Broadcasting Services (PBS), in particular for scenarios where the user is broadcasting a life event (e.g. a sports game or a concert being watched) to his/her friends. We envisage both producer and consumers mobility during the broadcasting. The referred architecture relies in two functional entities, the Connection Manager (CM) and Flow Manager (FM), for managing connections throughout the different lifecycle circumstances of a broadcast session, such as mobility or network congestion events. The two entities comprise a global view of client status and network conditions. As an example, the CM includes an API to allow video applications (PBS) to request the required resources (bandwidth).

We develop a testbed over the basic MEDIEVAL infrastructure, and use it as a specific realization to assess the performance of the introduced features. To this end, we aim to experimentally show how: i) CM can take advantage of the availability of multiple interfaces (namely 3G and LTE) and ii) FM can be used to trigger transfer of multicast sessions, avoiding the overhead from a tunnel-based solution. For demonstrating these features, we collect throughput, packet loss and handover (HO) delay statistics during the experiments. We verified that CM is able to take advantage of the multiple available interfaces and that multicast context transfer is a valid solution for multicast mobility in DMM scenarios.

The structure of the paper is as follows. Next section features related work: first on PBS, then on connectivity management, and finally on multicast mobility. In Section III, the proposed architecture is described, mainly in terms of its features and associated functional modules. Section IV presents

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evaluation details, including the testbed description, the analyzed usage scenarios and the collected results. We then discuss the obtained results in Section V, and conclude the paper in Section VI.

II. RELATED WORK

This section analyses related work on PBS, connectivity management and multicast mobility. We claim that an intelligent and API-rich CM is key for the sake of PBS robustness. Besides, we consider that a significant part of the PBS consumers will have a mobile profile, and we claim that IP multicast, as the de facto efficient distribution mechanism [5], may play a nuclear role for PBS and other real time video services.

A. Personal Broadcasting

A decade ago, most of the Internet contents provided to the users were generated mainly on centralized servers. Today, the business model from larger providers like Facebook, Flickr or YouTube depends of user generated contents, a reflex of the Web2.0 era, although these are distributed from a centralized infrastructure. Still a new frontier is coming where users not only generate and distribute their contents but they also do it live. Novel players, such as ustream [6] or livestream [7], provide thousands of simultaneously live videos streams, a proof of live video “hotness”. Standardization-wise, 3GPP is already considering how ordinary network users can generate and broadcast their contents over the network. 3GPP TR 22.947 [8] presents some envisaged use cases of personal broadcast services. Both professional and amateur users are coming together, sharing the same technology in video distribution. Professionals are trying to opt through cheaper and more accessible technology using the available mobile networks, while the amateurs aim at improving the quality and increase the reach of their tweet-like streams.

B. Connectivity Management

To simplify the management of the increasing number of interfaces available on mobile terminal and laptops, connectivity management applications are becoming more and more common. Typically they simplify the configuration and choice among the available interfaces, allowing users to focus on more demanding tasks. Still, these software components are also used to store user preferences, security profiles, and manage terminal HO. Moreover, newer and more complex scenarios arise extending these applications’ requirements to support features as multilink, smart interface balancing, per-application preferences, operator driven policies, monitoring-based selection, and even advanced mobility solutions. There are recent proposals, e.g. [9], that already offer solutions for WiFi authentication, mobility, offload management and simple traffic balancing mechanisms. Some already include a basic APIs to control some of those features. The Connectivity Manager presented in this paper allows Applications to take advantage of all the above mentioned extended requirements, by allowing them to request connectivity resources and configurations by using an integrated API for this purpose.

In particular, the management of multiple interfaces for being used simultaneously, i.e. multilink, is a very interesting feature. It allows users to efficiently “combine” multiple interfaces to increase the overall throughput, by delivering seamlessly the aggregate available bandwidth to the user. This is an excellent added value to mobile UGC, since the quality of their streams no longer gets restricted by the available network technology. Combining multiple mobile interfaces (even of different technologies) on the fly and according to the application bandwidth requirements, allows to greatly improve the overall users’ experience.

Multilink is addressed by multiple standardization bodies for under-L3 technologies, such as Multilink Point to Point Protocol (ML-PPP), Inverse Multiplexing over ATM (IMA) or Multilink Frame Relay (MFR). Many of those items are under study on the IETF, namely in [10] and [11]. 3GPP is also addressing multiple network interfaces, namely in [12]. The utilization of multilink for sending content is particularly important in PBS scenarios, where the quality of the uplink transmission affects all of the video subscribers.

C. Multicast support and distributed Mobility

A survey on existing mobility management solutions for future mobile networks is presented in [13]. It identifies several problems of centralized solutions as well as potential approaches for distributing mobility management functions. The general approach for DMM considers that each Mobility Access Router (MAR) has a different set of home network prefixes (HNP), which a Mobile Node (MN) uses to configure its IP address as layer 3 attachment. In case of mobility, the MN’s flows are anchored if necessary, in a HNP basis, so that new flows do not have to traverse a mobility tunnel.

Current standardization efforts within multicast mobility are centered in the IETF MULTIMOB [14] working group. So far, a base solution defines support for multicast under PMIPv6 scenarios [15]. Due to its limitations (e.g. tunnel convergence problem), alternatives are being developed, such as applications of fast HO or multicast context transfer, taking advantage of PMIPv6 entities. With DMM in its infancy, no detailed solutions have been yet proposed for supporting IP multicast mobility. In [16], the authors first discuss the utilization of multicast context transfer for supporting multicast listener mobility, while for mobile multicast sources a tunnel-based approach is referred. The analysis of different use cases for IP multicast support in DMM is done in [17], identifying several constrains resulting from the utilization of MLD Proxy for tunnel-based multicast forwarding. With the dynamic mobility management paradigm, where the presence of mobility tunnel is not mandatory, strategies for providing IP multicast mobility support must be redesigned.

III. ARCHITECTURE

In this section, we briefly present the modules and their basic operation within the proposed PBS architecture. The architecture relies on 802.21 signalling in a DMM environment (with MAR, Point of Attachment (PoA), etc) and multicast routing for transporting the PBS session. Besides, it incorporates 3GPP evolved Multimedia Broadcast Multicast

Service (eMBMS) functionality for IP multicast and extends it for IP multicast mobility support. The following new modules are introduced in this work: CM, FM, SM and MUME. We highlight CM and FM, which together comprise a global view of client status and network conditions.

As all PBS services, the architecture is comprised of a content provider and a content consumer. A downlink server is involved to adapt the stream and forward it to the MBMS-GW, which generates the multicast stream to be subscribed by the PBS consumers. The session is distributed over several cells within an operator domain.

We organized this section according to the two different processes undertaken on the PBS, i.e. generation and distribution of content produced by the user.

A. Content Generation at the mobile User Equipment

This section describes how proper connectivity management can enhance the content generation process in case of the availability of multiple interfaces. Within the proposed architecture, connectivity is managed by the Connection Manager (CM) functional unit, which is located on the user equipment. All the architectural modules located at the user equipment and their interactions are presented in Figure 1.

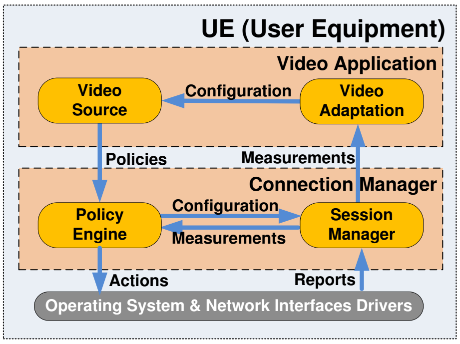

Figure 1. Architectural modules located in mobile devices

The CM implements access network policies which are stored in the Policy Engine. It selects the preferred access interface to use and/or splits the traffic among multiple available access networks. These policies can be provisioned directly by the user using GUIs or a 3rd party policy source, such as applications (APIs) or operators (e.g. 3GPP ANDSF or IEEE MIIS).

The CM can also take into account relevant monitoring data, in order to provide as much resources as possible, in the most efficient way. Examples of monitoring data are network interfaces parameters (e.g. status, signal strength, throughput), OS parameters (e.g. CPU, battery), end-to-end metrics (e.g. delay, loss, jitter), or quality of experience (QoE) (e.g. MOS), among others.

Multilink is a particular case of connectivity management, consisting of the utilization of multiple links (aggregation) for a single flow. Multilink can be used to bind traffic in the upstream, downstream or both. In the particular case of content generation and distribution, the interest is in the upstream case, in order to increase the uplink capacity and thus improve service reliability, which affects all receivers. This is particularly important since access technologies are designed to reserve smaller amount of bandwidth for the upstream than for the downstream.

The Session Manager (SM), part of the CM, is a key novel element for video services control described in [18]. It has direct responsibility in the perceived quality of experience of the video stream. SM's main role is to monitor the ongoing traffic of the application, in order to verify whether the application behaviour is desirable, and to estimate the network availability. It also interacts with the application to perform passive and active end-to-end measurements to estimate and analyze the video quality performance. The application performance and the estimated resources are fed back into the SM to enable further video control adaptation and/or to request additional resources. The SM is thus responsible for 2 main functions, Monitoring and Control: The Monitoring function comprises:

- The network availability inspection through active and passive end to end probing;
- The analysis of the application traffic along the transmission in order to estimate the average generated throughput and the application demands.

The Control Function operates based on the first function, and involves the following:

- The control of the video adaptation by assigning new bitrate targets for the content creation;
- The provision of measurements to the Policy Engine, which may allocate new resources to the application flow.

B. Content Distribution from the User Equipment

We consider two main features within the content distribution. The first comprises network-side IP multicast processing and generation (i.e. translation from unicast to multicast), provided by eMBMS. The second feature is IP multicast session continuity over DMM scenarios.

1) Network-side IP multicast transport

The eMBMS transport model is integrated in the proposed architecture, where the eNodeB is considered to be a LTE PoA and the WLAN AP a trusted non-3GPP access. The session start and resource setup procedures at eNodeB are executed when receiving requests from FM. FM resides in the MAR, and its main role is the management of data flows, thus being CM's counterpart in the network side for data flow management. It is responsible for detecting, deciding and enforcing mobility decisions, by communicating with the main network elements, from the core to the access subsystems. The modules situated at the MAR are depicted in Figure 2. Thus, the control plane function for the communication between the e-UTRAN and the MBMS-GW, collocated within the MME, is handled in the MAR.

2) IP multicast mobility in Distributed Mobility Management

To our knowledge, eMBMS does not yet consider seamless mobility, leaving enough space for solutions, and allowing the retrofitting of our concepts into the eMBMS standard. IP multicast mobility is operated the following way. If the core network is multicast enabled, the multicast mobility procedures (described below) are executed. The MBMS-GW operates as a multicast router and couples the FM with the proposed Multicast Mobility Engine (MUME) functions. If the network is not multicast enabled, the multicast tree starts at the MBMS-GW, allowing it to handle unicast traffic sent by users from such network sections. The BM-SC functions are located inside the Core Network. User service provisioning and announcement are handled by the network's Video Services Control block.

MUME is the module responsible for managing IP and session continuity support for the multicast flows. It comprises both tunnel-based and tunnel-free multicast mobility methods. The first method is activated on multicast source mobility, avoiding multicast tree reconstruction and service disruption, or in cases of listener mobility receiving time or loss-strict services (e.g. surveillance video), or where e.g. the operator wants to take advantage of the DMM mobility tunnels used for unicast traffic. For such cases, MUME allows the setup of the Multicast Routing Information Base (MRIB) entries based on the tunnel's endpoints addresses. The second method is used as a way to minimize the multicast packet loss during HO, namely using inter-MAR multicast context transfer. For such, MUME relies on a multicast explicit tracking function [19] in order to keep per-MN information regarding their multicast subscriptions.

Moreover, not only related to multicast mobility, the Media Independent Information Server is located at the network backend, and acts as the information repository that discovers and gets network information within a geographical area, enabling network selection and HO decisions. It has a global view of all the relevant heterogeneous networks around the MN, in order to facilitate seamless roaming across these networks. As such, it is crucial for all connectivity and mobility procedures.

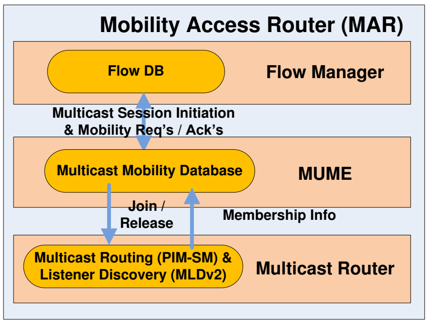

Figure 2. Architectural modules located in MARs

IV. EVALUATION

This section provides the testbed topology and operation, as well as the evaluation proceedings and collected results. Experimentally, we focus on multilink connectivity, from a content producer point of view, and on the multicast context transfer, from a content consumer point of view.

A. Testbed and Scenario Description

In this section we describe and evaluate the performance of the proposed architecture, by using a real but simplified testbed, represented in Figure 3. The testbed is composed by 3 MARs, each one serving different PoAs, and 2 MNs. The wireless access technologies supported by each MAR are as follows: MAR1 delivers 3G access, MAR2 has both LTE and WLAN PoA's, and MAR3 has a WLAN PoA. We used as LTE base station an Alcatel Lucent test station.

MAR2 and MAR3 have IP multicast routing capabilities, by using mrd6 [20] and deploy MUME functions. For such, mrd6 was modified in order to communicate with MUME. Because MAR1 doesn't have IP multicast support, the traffic is sent from MN0 using unicast.

The source of the video is physically distributed among 3 devices as follows: device Broadcast Unit, a commercial device LU-60, sends the stream towards a DSCP Marker machine, which is responsible for marking each packet with two alternate ToS values (0X02 or 0X3). Finally, MN0 acts as the initial endpoint of the video transmission. It receives the traffic from the DSCP Marker and broadcasts the video stream over two separated links (3G and LTE), which is then aggregated at the downstream server (LU-1000). The PBS capture scenery was a office chair, and the camera was mostly static, with most variations on capture properties being on the available light and background noise.

The traffic is then translated from IPv4 unicast to IPv6 multicast in a light version of MBMS-GW. MN0 is associated to MAR1 and MAR2 (i.e. 3G and LTE). MN1, acting as a multicast listener, is associated to MAR2 and subscribes the PBS session. MN1 has only WLAN interface, and doesn't have CM functionalities, i.e. is a regular IPv6 capable terminal.

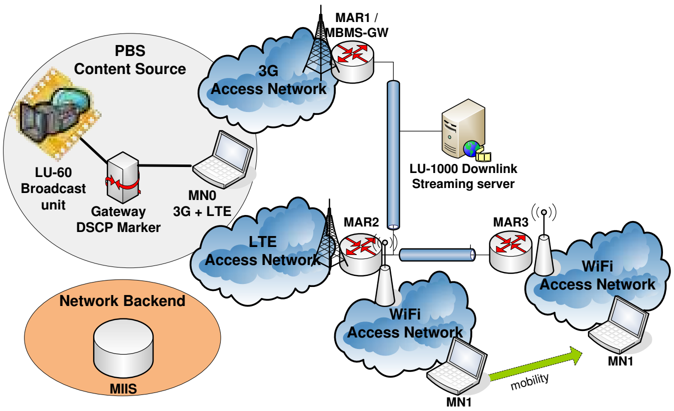

Figure 3. Evaluation testbed

Two wireless network accesses are used over the upstream of the broadcasting User Equipment / Content Producer: one 3G and one LTE, where upstream multilink policies are applied. We evaluated only a policy based on DSCP marking, where the video source application generates a single video stream, but using two different flows. One flow is marked with ToS=0x02 and the other with ToS=0x03. The video application has the capability to adjust the video quality (and bandwidth) to the conditions of each individual flow. The traffic marked with ToS =0x02 flows through the 3G interface, while the traffic marked with ToS=0x03 flows through the LTE interface. Note that the use of the DSCP field to differentiate flows was used on this testbed just for the sake of simplicity. In a real world, any other characteristic of the IP flow (IPs, TTL, port, protocols, etc.), could be used for this differentiation. Furthermore, other policies could also be considered, like differentiation based on Round Robin or similar mechanisms. In this case, the Application only selects the mechanisms to be used. It is the responsibility of the Connectivity Manager to smartly implement interface schedulers to manage efficiently the available resources.

B. Performance Analysis

Multilinked video streaming is potentially more relevant from the uplink perspective, especially considering mobile scenarios where reliability is constrained. In this section we evaluate relevant Quality of Service (QoS) parameters. First, we measure the throughput from the broadcaster; then, as the performance at the consumers is paramount to the PBS end-to-end chain, we evaluate several throughput and delay-related parameters over in order to assess the multicast context transfer mechanism.

1) Managing multiple links

Regarding the CM, only functionalities for basic 802.21 interactions with the OS and the FM/MIIS elements are used. Policies are provided using basic configurations and none of the provisioning methods are implemented yet (i.e. GUI, ANDSF, or APIs). The CM is configured for the particular case of upstream multilink (ToS-based or round-robin).

Initially, the MN was connected and streaming using 3G access interface only. After 10s, in order to explore the potential of the multilink, both 3G and LTE interface were used, enabling the CM to stream through both interfaces. The throughput values were measured at the MN0 during 20s over 10 runs, and the average value is represented in Figure 4. As expected, using both interfaces, the device is able to send the stream at significantly higher throughput, being the flow distributed across both interfaces. Also, although 3G provides a reduced bandwidth when compared with LTE, its value is considerably more stable.

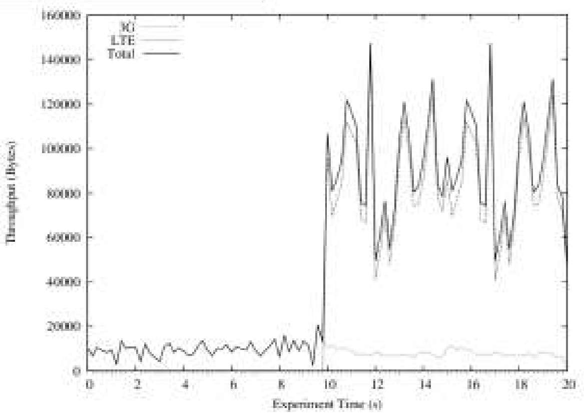

Figure 4. MN0 throughput using multilink in uplink (3G + LTE)

2) Pre-emptive Multicast Context Transfer

In this evaluation scenario, the content consumer (MN1) moved from MAR2 to MAR3. The duration of each run was 20s, with the HO being performed at t=10s. First, this was done using the legacy process, i.e. without any context transfer. We'll not focus in this case because of the high disruption resulting from the MLD timers [21].As the interruption is significant even configuring MLD timers with minimal values, , no results were collected. In the second case, the context transfer trigger was executed, but controlled manually before the user mobility. The goal in this stage was to observe the average bandwidth, and evaluate the packet loss - including the values during the HO. The experiments were repeated 10 times, and the results at the multicast content consumer (MN1) were collected. These results are shown in Table I.

TABLE 1 DOWNSTREAM STATISTICS (10 RUNS)

		Experiment									
		1	2	3	4	5	6	7	8	9	10
Packet loss (%)	Video	5,4	7	11,3	5,1	9	7,9	7,1	6,9	7,5	6,8
	Audio	5,8	3,6	4,7	4,4	3,6	5,8	7,6	7,6	7,4	6,2
Lost packets during the handover	Video	4	25	21	2	89	17	64	11	82	49
	Audio	0	4	2	2	4	2	6	2	3	3
Handover time (ms)		156.9	326.2	124.7	125.3	518.6	119.3	560.6	137.5	333.5	337.2
Bandwidth (Mbit/s)		1,272	1,502	1,213	0,577	1,219	1,539	0,986	1,557	1,619	1,832
Received Multicast Packets		6695	7861	6383	3611	6483	8103	5432	8218	8602	9657

V. ANALYSIS AND DISCUSSION

Our architecture deploys a PBS, supporting user generated broadcast traffic. The testbed is able to show how traffic flows are processed and distributed in our architecture. For the particular aspects of Multilink and Multicast HO, some more detailed discussion will be provided in the current section.

A. Multilink

It is clear from the results in Figure 4. that multilink allows users to bound upstream links, increasing significantly the available bandwidth and therefore the overall quality experienced by users. This work also shows that multilink policies, based on the ToS have clear inefficiencies. Namely, the source must be able to detect link status and adjust the traffic accordingly, which puts a significant burden on the application. A round robin policy for traffic balancing was also tested, but with no better results, since the available interfaces have quite different bandwidths, situation that contributes for the inefficiency of the model. The ideal situation occurs when bandwidths are similar.

Considering those results, the next step will be to increase the efficiency of this model by enriching the CM with the capability of monitoring the network access bandwidth and splitting the traffic accordingly, toward the more efficient use of the links, reducing the loss on low bandwidth interfaces and increasing the usage of high bandwidth interfaces. This will also simplify applications, relying on the CM quality assurance policies. The conclusion is that maximized upstream bandwidth can only be achieved with a smart CM mechanism, and should actually be a priority in PBS services in order to ensure service reliability to associated consumers. There are clear advantages on smartly balancing the traffic based on the multiple interfaces' monitoring data. This smart balancing is not implemented, but will be the next step on this implementation.

B. Multicast Context Transfer

Analysing the results from Table I, a large variation on the receiving streaming bandwidth between the 10 runs is noticeable (from 0.577 to 1.832 Mbps). The required bandwidth on a given time depends on the capture changes and movement. Also, the HO time is not always similar, since it depends on several factors like scanning, association and authentication. The packet loss during the HO may be affected by several factors. First, the testbed was located on a place where the presence of other WLAN networks might impact our results. Then, a fast HO at a moment with low video bandwidth requirement will mean a reduced amount of packet loss, as can be seen in the experiment 4. When the bandwidth is higher, which can be seen in experiments 5 and 9, the packet loss was greater. However, as the multicast stream was already being sent to the target destination of the MN1, a small amount of packet loss was observed; therefore, the session continuity of the video player was possible, with an almost imperceptible HO. As for the scenario without context transfer, the multicast stream took several seconds to be received on the MN1 after the HO as expected, leading the video to stop completely during that period. This is due to the need for waiting for the General Query plus the time before the MN sends a new MLD Report, showing its interest in the channel.

1) Alternative Multicast Mobility solutions

We now provide a short analysis on alternative solutions for IP multicast mobility. DMM is guided by the requirement for activating mobility for only those applications which require IP address continuity [22]. As such, there will no longer be fixed tunnels like those between Local Mobility Anchor (LMA) and Mobile Access Gateway (MAG), In DMM there is the added difficulty of deciding what traffic to anchor, and where to anchor it. The latter decision is particularly difficult for the case of IP multicast, where the tunnel utilization might lead into issues like the tunnel convergence problem. This problem has an even greater impact in DMM than in MIPv6 or PMIPv6, as the co-existence of a large number of MARs within a single domain is expected, where each pair of MARs can map into a tunnel. As such, careful tunnel activation must be decided; e.g. use remote subscription only if a multicast channel is not currently being received at the new MAR, in order to maintain the multicast routing efficiency. For these reasons, we consider IP multicast context transfer a valid and efficient solution for assuring multicast sessions continuity in future DMM environments.

VI. CONCLUSIONS

An architecture for user-generated broadcasting over future mobile networks was presented, supported on the DMM paradigm. We empirically verified the instantiation of intelligently devised CMs, along with video-aware policies are key for achieving maximum throughput in PBS stream generation. An initial implementation of the architecture was implemented, which allowed the evaluation of multi-linked CMs, as well as revisiting and extending the concept of multicast context transfer for PBS consumers over DMM environments. The next steps include smarter algorithms and fully automated switching and multicast mobility, with the integration of ODTONE [23]. Additionally, the user perception in terms of QoE will be evaluated.

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