Cross-layer Architecture for Adaptive Real-time Multimedia in Heterogeneous Network Environment

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***Abstract*—Despite the interest, the utilization of today's networking environment including a variety of access technologies and various services and capabilities is still minimal. Multiaccess mobile devices already on the market provide a capability to hand over the heterogeneous networks but so far there has not been any commonly approved way to efficiently capitalize on this feature. Media Independent Handover Services standard specified by the IEEE 802.21 working group is expected to establish the basis for heterogeneous handovers. Although IEEE 802.21 has usage also beyond heterogeneous handovers, its capabilities do not fulfill all the requirements of adaptive multimedia transmission. For example, upper layer events and end-to-end traffic control communication are outside the scope of IEEE 802.21. In this study, we introduce an information service architecture for adaptive multimedia which enables to collect and disseminate events and information from the different layers of the protocol stack locally and also between network entities regardless of their location in the network. Our architecture presents a Triggering Engine on top of the IEEE 802.21 services in order to introduce upper layer events, flexibility to event distribution, and end-to-end event based signaling to adaptive multimedia transmission.**

I. Introduction

Today, mobile devices are equipped with multiaccess support enabling the use of multiple different access technologies, also in parallel. This together with the proliferation of overlapping networks based on different access technologies allow better mobility potentials for mobile nodes (MN). On the other hand, this increases the challenge of MN to assess the available networks and choose the best one for its needs. In order to take the full advantage of networks in range supporting different services and bandwidths, collaboration between the MN and network entities is required. For this, the IEEE 802.21 working group has specified an open standard called Media Independent Handover (MIH) Services [1].

The scope of IEEE 802.21 is restricted to only to facilitate heterogeneous handovers by providing a framework to obtain both dynamic and static information from networks in range, to monitor the conditions of current and available links, and to negotiate with handover targets. However, for example, with unreliable multimedia transmissions, the end-user perceived quality is affected by the end-to-end (e2e) performance. Providing e2e performance guarantees across multiple networks operated by different Internet Service Providers (ISPs) and enforcing different Quality of Service (QoS) classes can not be seen as a conceivable way. The popularity of the best effort scheme and the differing policies regarding, for example, traffic prioritization used among the ISPs take care of that. Thus, there are needs for a flexible technique that enables e2e performance signaling to maintain the quality of QoS sensitive traffic, for example, by means of a traffic adaptation.

Novel multimedia codecs (e.g. MPEG-4/H.264 SVC [2]) support conformity to changing network conditions through adaptivity features. In a heterogeneous network environment, the efficient exploitation of adaptivity necessitates information obtained from different layers of both local and remote network protocol stacks. In this paper, we present a cross-layer architecture which satisfies the requirements of intelligent mobility with the assistance of IEEE 802.21 and an efficient traffic adaptation achieved through the internal and e2e cross-layer signaling based on the triggering framework [3]. Both frameworks are already implemented and tested in practice. However, the frameworks include features which supplement each other's functions. Thus, we study how IEEE 802.21 and the triggering framework could be integrated in order to enable standardized mobility and full local and e2e cross-layer signaling. As well, since IEEE 802.21 deployment is yet to begin, the proposed architecture also introduces mechanisms how entities responsible for mobility are provided with the information needed in proactive mobility decision-making. Based on this information, handover policies and decision process methods like those presented, for example, in [4] aim at keeping the end-users always best-connected (ABC). Although the presented architecture is not traffic type dependent, we present it in the context of adaptive video.

In anticipation of next generation communication, studying of cross-layer architectures have been in the center of many projects during the last few years, for example, [5]–[9]. Network infrastructure and access selection architecture based on the triggering framework are presented in [6] and [7], respectively. These studies utilize only triggering framework, not any of the IEEE 802.21 services. [8] presents a framework for assuring e2e QoS in heterogeneous networks. The framework includes capabilities to utilize multiaccess properties through IEEE 802.21 and to provide e2e QoS, but do not provide e2e event reporting for traffic adaptation. In [9], TRG and IEEE 802.21 co-operation is initially mentioned, but not studied further. Real-time Transport Protocol (RTP) [10] and Session Initiation Protocol (SIP) [11] also provide e2e signaling but they are very much multimedia type dependent and can not handle well adaptation during handovers.

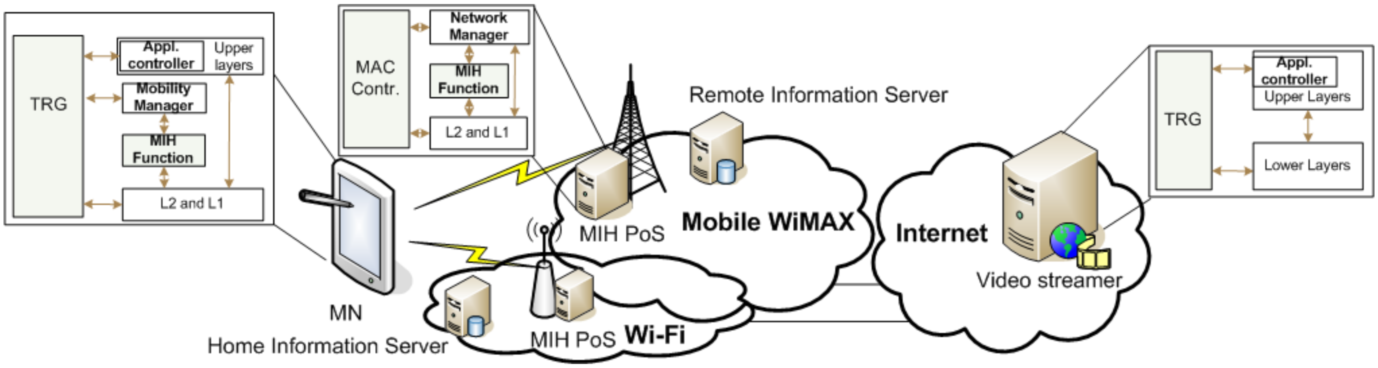

Fig. 1. The Architecture in a Typical Network Environment

The rest of this paper is organized as follows. Section II presents the architecture proposed for adaptive video streaming as well as provides an overview of the studied components. In Section III, the IEEE 802.21 and triggering framework integration is detailed. Finally, Section IV concludes this paper outlining future work items.

II. Information Service Architecture for Adaptive Multimedia

Fig. 1 illustrates a typical network topology we face today including heterogeneous overlapping networks and a multi-access featured MN. Despite the typicality, the exploitation of overlapping networks and their various services is still minimal. IEEE 802.21 is expected to change this by providing a standardized solution to facilitate the MN to intelligently handing over the access points of various networks. ABC is sustained through a constant monitoring of currently employed and available links and also traffic flows.

In order to overcome the inability of IEEE 802.21 to provide signaling service for traffic flow control between end-hosts and upper layer events, we introduce Triggering Engine (TRG) into the architecture to expand the cross-layer communication also to the e2e context. Especially, this is needed with real-time multimedia transmissions in order to adapt the media streams according to changing network conditions. A handover to another access point is not always the best solution to improve the stream quality. As well, the access link is not necessarily always the bottleneck in the path between a traffic source and sink. TRG is employed on the end-hosts and is purely based on event dissemination between different entities.

Dynamic information collected from each protocol layer enables various ways to timely and effectively adapt network traffic to varying link and network conditions. For example, RObust Header Compression (ROHC, IETF RFC 3095) can be used over a one-hop link to compress the network headers introduced by RTP/UDP/TCP/IP to few bytes only. Packet aggregation can be used to bundle multiple small packets into one packet, thus, reducing the amount of injected packets and packet header overhead. On the access point, MAC controller initiates the traffic efficiency methods based on the current link conditions and events revceived from the MN. Application Controllers on the end hosts are introduced as entitities adapting the video stream encoded using a scalable video codec. Application Controller on the video streamer uses the proposed e2e signaling architecture to receive events (e.g. frame error ratio) from the MN and scales the video accordingly.

A. Media Independent Handover Function

Fig. 2 illustrates the general reference model of IEEE 802.21. IEEE 802.21 specifies a new logical entity called MIH Function (MIHF) to the protocol stack. The role of MIHF is to assist in handovers and handover target decision-making by providing all necessary information to the network selector or mobility management entities, commonly referred to as MIH Users (MIHUs). In the presented architecture, Mobility Manager (MM) and Network Manager are designed to run MIHU responsibilities on the MN and the network-side IEEE 802.21 entities, respectively.

The MIH_SAP Service Access Point (SAP) lets MIHU to access three main MIHF services: 1) The Media Independent Event Service (MIES) provides event reporting regarding dynamic changes in link conditions that are, for example, new link-level connection and changes in link quality parameters. 2) The Media Independent Command Service (MICS) enables MIHU to control and manage parameters related to link behavior and handovers. 3) The Media Independent Information Service (MIIS) provides static information about the characteristics and services of the serving and candidate

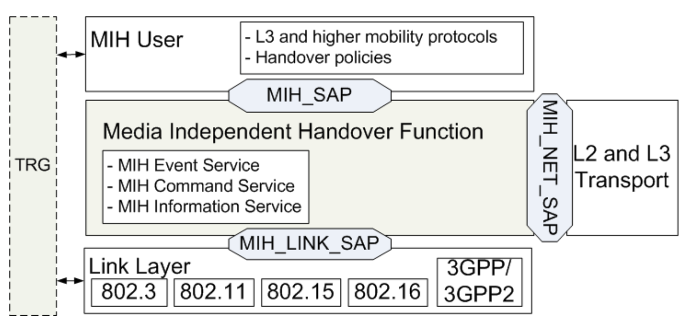

Fig. 2. The General Reference Architecture of IEEE 802.21 Embedded in the Presented Architecture

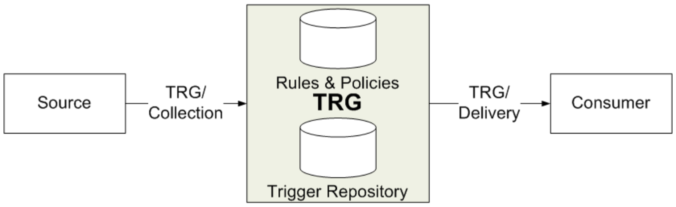

Fig. 3. Overview of the Triggering Architecture

networks in range. This information comprises, for example, QoS support, usage cost, and address and location information of Point-of-Attachments (PoAs). Information is queried from the Information Server in network which is, basically, an MIHF entity maintaining a database about different networks.

IEEE 802.21 provides a sufficient amount of physical layer (PHY) and link layer (L2) information to execute intelligent and proactive handovers. Link parameters available through MIES and MICS include link type specific and independent information and L2 QoS class parameter information. In the handover preparation phase, it is possible to obtain the assured QoS metrics for certain service classes in the network such as jitter and delay. However, these QoS levels can be guaranteed only inside the serving network. MIES and MICS are also allowed to be used remotely by registered peer-MIHFs over the network. For example, the MN can subscribe for a particular set of IEEE 802.21 events from an IEEE 802.21 enabled MIH Point-of-Service (PoS) in the network. As well, an MIH PoS can initiate an IEEE 802.21 assisted handover based on, for example, local congestion information.

In addition to MIH_SAP, the other two IEEE 802.21 SAPs caters MIHF access to the link layer (MIH_LINK_SAP) and L2 and Layer-3 (L3) transport services (MIH_NET_SAP). MIH_LINK_SAP is an access technology dependent interface and consequently a separate one is needed to each link type.

B. Triggering Engine

TRG provides a unified service for cross-layer information collection, temporary storage, and dissemination within the network protocol stack. TRG is the central component of the triggering architecture [3] and is depicted in Fig. 3. The role of TRG in the triggering architecture is to collect events from various event sources, to process the information carried in the events into triggers, and to deliver the triggers to their consumers according to specific rules and policies defined for the trigger delivery. In specific, TRG utilizes common interfaces for event collection and trigger delivery, and defines a common data format for the event information, referred to as *a trigger*. The triggering architecture also allows information transferring between separate network nodes through the use of cascaded TRGs [12].

TRG can be used for collecting information from various event sources, including for example a Wi-Fi NIC, a mobility management software, and an adaptive application. The event sources typically feed TRG with relatively fast changing information reflecting their status. A source must first register to TRG before it is able to send events to it. During the registration process, a source may specify policies to enforce access control for the event information it generates. The registration and event delivery is done through TRG's Collection Interface. After its reception, an event is translated into a trigger format by TRG and placed into the Trigger Repository, from which it is delivered to its consumers.

The trigger consumers subscribe to TRG through its Delivery Interface in order to receive triggers of their interest. A same entity may act as both an event source and a trigger consumer to a TRG, provided that it implements both TRG's interfaces. Trigger consumers specify the triggers they are interested in receiving from TRG by defining filtering rules during the subscription process. TRG controls trigger delivery based on these consumer-defined filtering rules as well as system specific policies stored in its Rules & Policies database. The consumers use the information carried in the triggers in their own decision-making (e.g. traffic adaptation decisions).

In the proposed information service architecture, the role of TRG is to facilitate information transfer between 1) MIHF and higher layer entities through interfacing with the Mobility Manager (MM) and 2) the nodes hosting the Application Controllers (i.e. the MN and the video streamer).

C. Application Controller

The purpose of the Application Controller is to adjust the properties of video (e.g. data rate and frame rate) in order to adapt the video transmission according to current characteristics of a transmission channel [13]. Moreover, the aim is to utilize the available transmission capacity as efficiently as possible, at the same time trying to maximize the viewing experience of the end-user. In the case of scalable video, the video adaptation can be easily done by extracting the desired bitstream with selected parameters from the original, non-scaled bitstream. Interested reader can refer to [14] for further details on the scalable video extension of H.264.

In order to take full advantage of the adaptive video stream, adjustments to the video stream are required. Preliminary adjustments to the resolution, frame rate and bit rate should be made during the negotiation phase (e.g. with SIP or Real Time Streaming Protocol (RTSP)) but in order to utilize changing transmission capacity more efficiently, for example, when a vertical handover occurs, adjustments are needed also during the transmission. At the application layer, adjustments to video should be made on regular time intervals (e.g. one second interval) but not too often in order to keep the system simple. Faster adaptation should be made at lower layers, for example, at the PHY by utilizing the information obtained from TRG.

We have based our controlling algorithm on the fuzzy logic which brings the needed adjustments to the requried target bit rate, while taking into account several input parameters from different system layers in the decision making. In the proposed controller, we are using packet loss ratio (PLR) and an estimate of received bit rate from application layer together with an estimate of channel capacity in the form of channel signal-to-noise ratio (SNR) offered by the PHY or link layer.

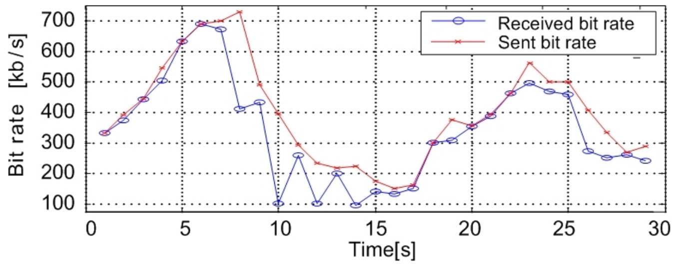

Fig. 4. Adapted bit rate of SVC video stream and an estimate of received bit rate

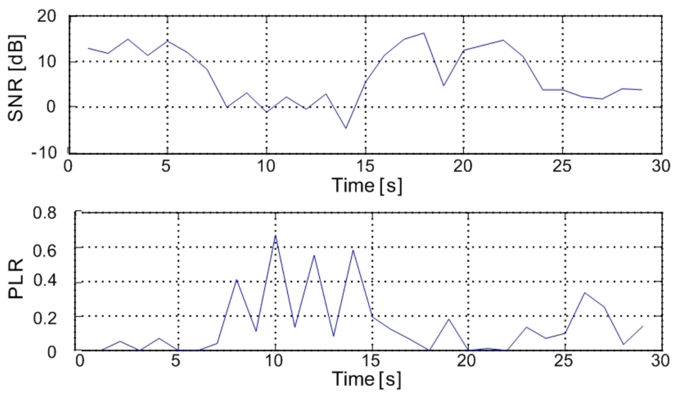

Fig. 5. Detected SNR and PLR of the non-selective block fading channel

Fig. 4 and Fig.5 illustrate the adaptation capability of the proposed controller. Foreman video sequence (CIF, 10 sec, 3 times) is transmitted through the wireless channel. As be seen from Fig. 4 and Fig.5, the controller adapts the transmission rate based on changing transmission conditions. When SNR of the wireless channel and PLR dramatically change, the fuzzy logic algorithm reacts on this by changing the rate of the sent video faster than in a situation where the channel state changes slowly. If the channel state is good and steady, the algorithm increases the bit rate moderately.

III. Integration of IEEE 802.21 and Triggering Engine

In the presented architecture, TRG adds features on top of IEEE 802.21 so that IEEE 802.21 facilitates assessment of networks in range and execution of intelligent handovers between them, and TRG enables event dissemination between local and remote networking modules despite their location.

Fig. 6 illustrates the internal architecture of MN. In the architecture, TRG provides a unified service for transferring information between entities located on the different layers of the local protocol stack. In specific, TRG is interfaced with MIHF through the MM, which is responsible for making mobility-related decisions on the MN. In order to facilitate MIES through TRG, the MM also translates the IEEE 802.21 events into TRG triggers. At the application layer, the Application Controller acts as both a trigger source and a consumer to the local TRG to be able to receive triggers carrying, for example, IEEE 802.21 event information and to provide the

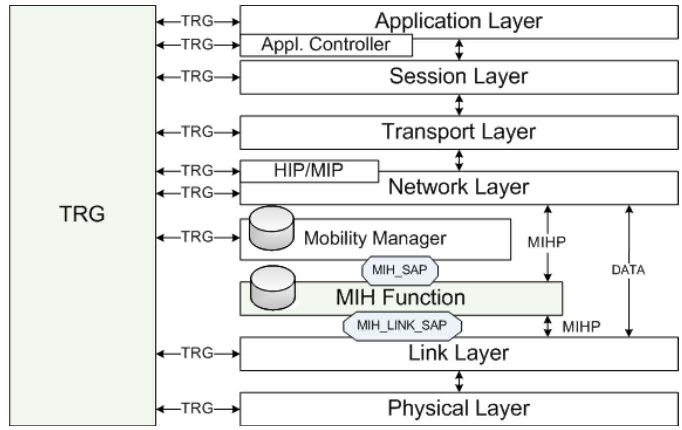

Fig. 6. Schematic of the Internal Architecture of MN

MM information about its QoS requirements and performance. The use of cascaded TRGs allows trigger delivery between the local Application Controller and the one running on the server to facilitate e2e adaptation.

The MM is responsible for initialization of handovers and decision making upon handover targets. This requires three main functions from the MM: I) The MM needs to collect information related to QoS requirements for candidate networks from different modules involved in the networking. For this, TRG brings a simple solution to obtain the necessary information to specify and maintain internal handover policies. II) The MM needs to have timely information about the traffic flows and link states of MN. This is achieved utilizing both IEEE 802.21 events (MIH_SAP) and TRG triggers produced by, for example, Application Controller. III) The MM needs to inform, for example, video streamer about the forthcoming handover so that it is able to react to handovers accordingly beforehand (e.g. reduce the video stream bitrate).

The database in MIHF is for storing the information from previous information queries (MIIS) and keeping track of the registered remote MIHFs including their address and state information. MIHF has interfaces for both the L2 and L3 MIH protocol message exchange.

A. Use Case for Scalable Video

Sequence diagram depicted in Fig. 7 goes through a simple use case of the communication between the architecture blocks in practice. The video streamer adjusts the quality of the streamed video according to the TRG triggers and the MN executes an IEEE 802.21 assisted handover. The MM, Application Controller, and TRG on the video streamer have subscribed for a particular set of triggers indicating timely information about the received video quality and other MN states that may affect the end-user experienced video quality. In the video streamer, Application Controller has subscribed for the same triggers from the local TRG.

The first trigger created by Application Controller indicates the current video frame loss which has exceeded the moderate level. Thus, video streamer adjusts the scalable video stream

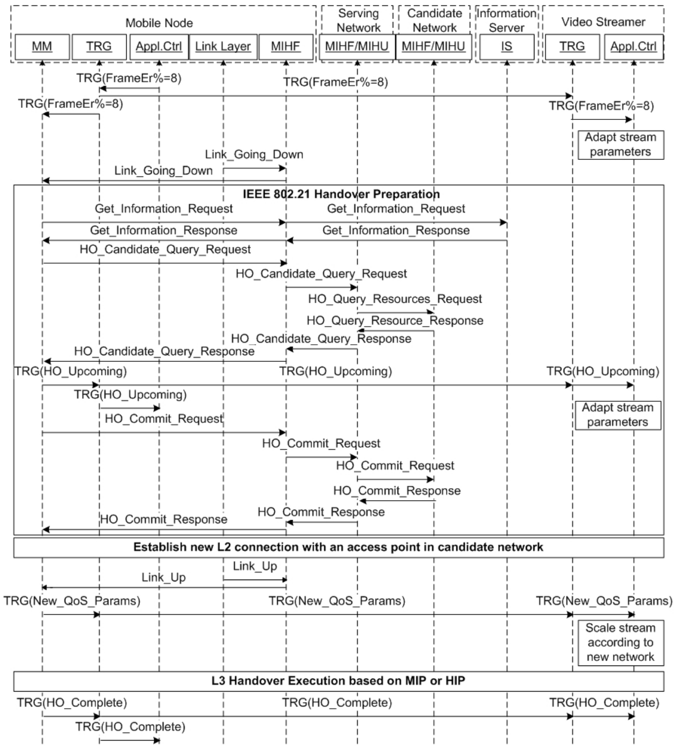

Fig. 7. Sequence Diagram for Simple Use Case Scenario

parameters in order to decrease the number of erroneously received frames. However, the frame errors seemed to be a corollary of the deteriorating link conditions since soon after the trigger the link layer sends an event indicating that the current link is going down. This initiates a mobile-initiated and IEEE 802.21 assisted handover procedure consisting of three phases. First, the MN queries for information related to candidate network capabilities from the IEEE 802.21 Information Server. Second, the MN prepares the handover by asking resources for the handover from the potential candidate networks. The actual resource inquiry is carried out by the serving network. Third, based on the resource information, the MN commits the handover to the most potential candidate network. In the network-initiated handover procedure, the serving network initiates all queries but the target decision is MN's anyway. The actual handover is executed using some higher layer mobility protocol, such as Mobile IP (MIP). After the handover completion, IEEE 802.21 allows of releasing the resources from the former network (not shown in Fig. 7).

TRG can be utilized during the handover execution to disseminate triggers concerning the handover procedure progress and to accommodate the received video stream to the new serving network and link capabilities before executing the L3 handover to it.

IV. Conclusion and Future Work

This paper presents an architecture for intelligent handovers and internal and e2e cross-layer signaling. IEEE 802.21 has already attracted a following among the major device and network vendors as an assisting standard for heterogeneous handovers. TRG brings a flexible way to establish an event based signaling between internal networking modules and end-hosts upon the IEEE 802.21 services. We showed how IEEE 802.21 and TRG can collaborate in order to improve the multimedia quality in varying network conditions.

First in the future work agenda is to measure and evaluate the architecture benefits for adaptive video in OMNeT++ simulation environment. After that, we plan to capitalize on our existing implementations of IEEE 802.21 and TRG and integrate them also in practice. With the real implementation, the architecture will be employed also with a traffic other than video.

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