Enabling Frame-Based Adaptive Video Transmission in a Multilink Environment

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***Abstract*—In order to increase the user Quality of Experience (QoE), transport functions could exploit the presence of multiple communication channels. Combining multilink architecture developed by the CELTIC MARCH project and adaptive video transmission can be an effective solution for transmitting video streams. Our multilink gateway method aims to increase the quality of the video transmission by splitting and merging the video stream in accord with the importance of the different parts of the video stream into multiple access networks ranked adaptively to the network performance. Our method guarantees the transmission of the highest priority MPEG-2 frames trough the best network available instantaneously.**

***Index Terms*—Adaptive control, Quality of service, Radio access network, Radio link, Video coding.**

I. Introduction

In a multilink environment the terminals dynamically operate over several access networks and simultaneously transmit multi-play services. Aiming to offer good user QoE and adequate Quality of Services (QoS) support in the network [1], [2], video transmission had attracted an important research effort nowadays [3]–[5] in order to offer best quality connections and optimal resource management. There are several benefits of sharing resources among multiple access technologies: increased network capacity, by splitting and merging traffic flows; increased network utilization, by balancing the traffic load and increased service reliability, by protecting the user against lost of connectivity even if one of the other access network is lost.

The scope of this paper is to highlight the performances of a proposed frame-based adaptive video transmission technique operating in a multilink access environment. As in multilink systems a user terminal communicates through different access links simultaneously [6], the interoperability between existing networks is exploited. In our study, by monitoring the traffic parameters on each access link, a network ranking in terms of packet error rate is performed. For the existing network ranking, the proposed transmission technique adaptively splits the video stream into separate sequences considering the priority of each frame.

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The originality of this work consists in evaluating the proposed frame-based transmission technique in a multilink network environment integrating different wireless access technologies. In our testing environment a centralized logic (multilink gateway, MLG) is present, which logic knows the instantaneous network load and is responsible for the network ranking. At the destination side multilink capable user equipments (MLUEs) were considered, that have connections towards each type of access network [7]. As all the network components model a comprehensive network behavior, the traffic conditions replicates a realistic variable context for the video sequences.

We assumed the case when the background traffic is monitored by the MLG and investigated how this information can be used for making the connection more reliable. For the sake of simplicity we restricted ourselves to the so-named frame-based adaptivity demonstrated on MPEG-2 video frame transmission; however, the proposed concept of adaptive video transmission applies to the case of other video coding methods as well.

The remainder of this paper is organized as follows. Section II points out the particularities of the multilink transmission technique and indicates the differences between this proposal and other state of the art techniques. In Section III the evaluation scenario is described. As the variable traffic conditions influences the quality of the video transmission, a network ranking is performed. In Section IV the adaptive frame-based assignment method is presented, which employs the result of the network ranking. Simulation results and the performance of the proposed transmission method are shown in Section V. Finally, Section VI concludes the paper.

II. Related Work

Combining several access network links for enhancing performance is well known. Different approaches require different changes to servers, clients, proxies, or a combination of these [7]. The common element for all these approaches is a method to schedule data over different links and a method to later combine the diverted bytes again [8]. In the literature, there has been extensive work to categorize the published multilink transfer options. In [8] the possible methods are differentiated according to the layer in which the network protocol stack solution is positioned, therefore application-layer striping, transport-layer striping, network-layer striping and link-layer striping are mentioned.

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Network-layer striping is mainly based on round-trip times [8], [9]. In [10] the available methods are categorized by the basis of the scheduling. Here packet-based scheduling, flow-level splitting and sub-flow level scheduling are mentioned. Our proposed method can be considered as a special case of "application-layer striping" and flow-level splitting. However, flow-level splitting implies that flows differ widely in terms of their sizes and rates, and once assigned, a flow persists on the path throughout its lifetime. It is not the case for this work: one flow (i.e. frames) is not allocated to one path definitively. In [8] application-layer striping is criticized due to all application-layer approaches imply software modifications at both endpoints. In our case, for MPEG-2 transmission, this limitation is not so significant since the available parts of the video stream (i.e. frames) are applied.

In the mean time, there are several interesting approaches presented in the literature. In [11], a multi-path and QoS routing in wired and wireless local area networks (WLANs) was simulated. The transport-layer striping and packet-based splitting was investigated. In [12] a cross layer system which resides between the data link layer and network layer was proposed. It encapsulates the existing multiple physical interfaces. A network-layer packet striping in High-Speed Downlink Packet Access (HSDPA) and wireless LAN (WLAN) was performed. In [13], a live news broadcasting (LNB) video service was measured over Worldwide Interoperability for Microwave Access (WiMAX), 3.5G and WLAN links. Here transport-layer striping was applied with multi-link SCTP. The transmission of a video flow over a multi-homed network was simulated in [10]. Here the multilink capability was enabled by transport-layer striping using concurrent multipath transfer (CMT) [14]. In [15] the transmission of H.264 advanced video coding (AVC) video stream over a heterogeneous wireless network applying transport-layer striping was investigated. In this case, the bursty video traffic (i.e. in [16]) was statistically modeled and a probabilistic flow splitting scheme was studied.

As it can be observed, different approaches were investigated in the literature. However, the originality of this work lies on the simultaneously investigated application-layer splitting, the properly simulated variant access networks, the applied different networks states in which the network ranking was based on and the frame-based adaptive video transmission.

According to the MPEG-2 standard raw frames are compressed into three types of frames: intra-coded frames (I frames), predictive-coded frames (P frames), and bidirectionally-predictive-coded frames (B frames) [17], [18]. These frames are coupled into Group of Pictures (GOPs).

As the importance and the size of the different frames are different, it is advantageous to transmit the most important parts of the GOPs (i.e. I frames) through the network that has the best quality and reliability, and less important parts (B frames) through the network with low quality.

Therefore applying adaptive video streaming according to the network conditions is a possible method of improving the reliability of the video transmission. The proposed method is highlighted in Fig. 1.

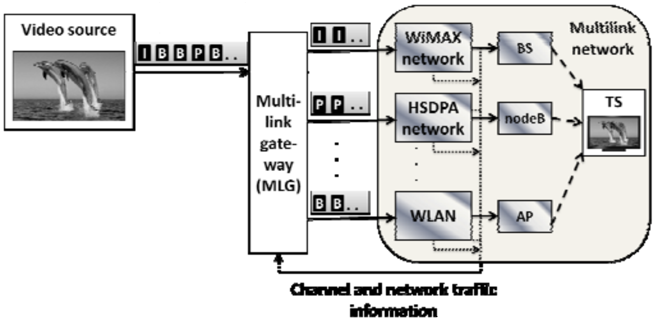

Figure 1. The concept of frame-based adaptive video transmission in the case of the investigated multilink environment

Due to the applied background traffic model (presented in Section III), the packet error rate on the investigated networks varies in time. We proposed an adaptive video transmission method which mitigates this degradation for the most important part of the video stream and improves the quality of service for the video stream by redirecting some parts of the data flow (typically I or P frames in the case of MPEG-2 video transmission) to another network that actually has better performance

III. MULTILINK TRANSMISSION ENVIRONMENT

A. *Description of the transmission environment*

Using the multilink techniques, a user terminal could handle multiple data flows across multiple radio access technologies. In our work, the multilink access environment is implemented in the QualNet Developer 5.1 [19]. QualNet is a comprehensive network simulator designed for creating wired and wireless network environments under user-specified conditions and analyzing their performance. It includes a highly detailed standards-based implementation for the wireless environment that enables a very accurate modeling of real-world networks. Setting up the network environment characteristics, form the physical to the application layer, QualNet predicts the behavior and evaluates the performance of networks in order to improve their protocol and standard design.

The evaluation scenario consists of three radio access networks: a WLAN implementing IEEE 802.11g Std. [20], a WiMAX implementing IEEE 802.16 Std. [21], and a 3.5G network with HSDPA support [22]. The multilink access environment models the characteristics of an outdoor cell. The base station (BS/WiMAX), the NodeB (HSDPA) and the access point (AP/WLAN) are located in the center of the cell. The proposed concept of frame-based adaptive video transmission was implemented for the multilink scenario presented in Fig. 2.

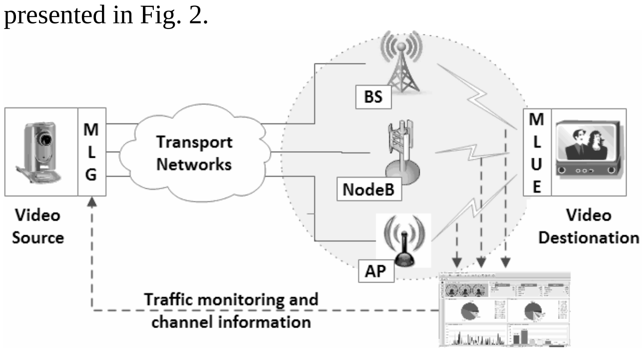

Figure 2. Multilink transmission environment implemented in QualNet

A multilink capable user equipment (MLUE) has connection towards each type of access network, therefore it contains a subscriber station (SSs/WiMAX), a station (STAs/WLAN) and a user equipment (UEs/HSDPA) as well. The MLUEs are distributed around the central transmitting stations.

The global parameters of the simulation environment, including the simulation time, propagation model, cell radius, number of clients and the source application parameters in the RANs are presented in Table I.

TABLE I. PARAMETERS OF THE SIMULATION ENVIRONMENT: PHYSICAL (PHY) AND APPLICATION (APP) LAYER PARAMETERS

QualNet Parameters		WiMAX	WLAN	HSDPA
PHY network layer parameters				
QualNet Parameters		Values		
		WiMAX	WLAN	HSDPA
Channel frequency [GHz]		2.5	2.4	UL: 1.95
				DL: 2.15
Transmission power [dBm]		40	40	40
Receiver sensitivity [dBm]		-120	- 96	-150
Antenna gain [dBi]	Transmitter	35	15	25
	Receiver	2	1	3
Transmitter antenna height [m]		20	5	20
Receiver antenna height [m]		1.5	1.5	1.5
Antenna mismatch loss [dB]		0.3	0.3	0.3
Antenna connection loss [dB]		0.2	0.2	0.2
Simulation time [sec]		3600		
Cell radio range [m]		800		
Pathloss model		Free Space		
Number of MLUEs in the RANs		10 stations per access network		
Mobility		None		
APP layer parameters				
Total number of packets sent		10^8		
Interdeparture time between the application layer items [sec]		0.0035		
Size of each application layer item [bytes]		188		

The medium access control (MAC) technique used in case of the WiMAX network is Time Division Multiplexing (TDD), with MAC frame duration of 20 milliseconds. The HSDPA QualNet model implementation is based on the FDD MAC with the downlink channel operates at 2.15GHz, and the uplink at 1.95 GHz. The WLAN implementation uses on the MAC layer the CSMA/CA technique with a beaconing interval of 200 microseconds.

The video stream to be split and merged at the source and destination nodes is generated by a constant bit rate (CBR) traffic generator using MPEG-2 standard specifications. The item size, the interval between transmitted packets and the number of packets sent by the CBR source model were chosen in order to obtain MPEG-2 throughput of 0.4 Mbps on the application (APP) layer. The MPEG-2 system layer specifies the structure of the transport stream, therefore according to the standard frame structure the size of a transmitted package was set to 188 bytes [17]. In order to statistically estimate the radio channel properties, for a packet loss of 10^{-6} to 10^{-3}, we need at least a minimum of 10^8 triggered events to be generated. The interval between transmitted packets was set to 3.5 milliseconds

B. Markov modeling of the transition of the scenarios

In our paper we considered three different states of the multilink network environment constituted by three different access networks. The network load is variable in time by setting up a number of applications that overflow the multilink environment during the investigated MPEG-2 video stream.

The transition of the scenarios was modeled with a three-state discrete time and state, homogenous Markov chain, where a state represents one of the three scenarios. The three-state Markov chain used to model the transition of the network scenarios is presented in Fig. 3.

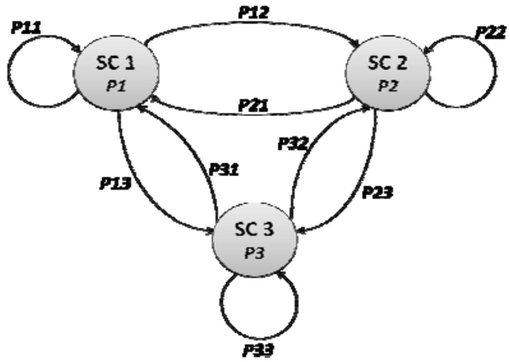

Figure 3. Markov chain to model the transition of the network states

The transition of the scenarios was modeled with a three-state discrete time and state, homogenous Markov chain, where a state represents one of the three scenarios. The three-state Markov chain used to model the transition of the network scenarios is presented in Fig. 3. For the sake of simplicity we set the state probabilities to p_i=1/3 for 1<=i<=3 and the transition probabilities to p_{ij}=1/3 (1<=i<=3, 1<=j<=3), subsequently. In the simulations, the interval between two transitions was set to 2.88 seconds (6 GOPs).

C. Description of the traffic load and the network ranking

A background network traffic is generated by running a set of CBR, FTP and HTTP traffic generators attached to the stations on each access network. All these applications determine different traffic conditions for the investigated MPEG-2 video transmission. The packet size, the number of transmitted packets, the interval between packets and the transmission time per traffic source is changing in time. In this way, a variable network context is provided.

According to the instantaneous constituting network context and traffic conditions, a network ranking was performed based on packet error rate at the MPEG-2 video receiver side. Considering the application configurations and the network context, the simulation results at the MLUE indicate the parametric results presented in Table II.

TABLE II. SIMULATION RESULTS: NETWORK RANKING BASED ON PACKET ERROR RATE AT THE MPEG-2 RECEIVER

Evaluation parameters	WiMAX	HSDPA	WLAN
First Scenario/First Network State			
Packet error rate	3.13×10^{-4}	2×10^{-6}	2.1×10^{-5}
Network rank	#3	#1	#2
Second Scenario/Second Network State			
Packet error rate	8×10^{-6}	2.3×10^{-5}	2.18×10^{-4}
Network rank	#1	#2	#3
Third Scenario/Third Network State			
Packet error rate	7.8×10^{-5}	5.15×10^{-4}	6×10^{-6}
Network rank	#2	#3	#1

IV. ADAPTIVE LINK ASSIGNMENT BASED ON MULTI-ACCESS ENVIRONMENT RANKING

In case of a multi-linked environment it is advantageous to split the video stream into separate sequences with different priority regarding the overall QoS of the video stream. Our aim was to provide reliable connection for the most important frames of the video sequences (e.g., I frames), therefore the different parts of the stream were routed according to the channel conditions and the importance of the actually transmitted stream. Our results proof, that the quality of the transmitted video stream can be enhanced with the proposed method highlighted in Fig. 1.

Since the intra-coded frames are used as reference frames for the other frames in the MPEG-2 standard, I frames have to be transmitted at the highest priority. On one hand, decoding of predictive-coded frames depends on the I frames and on the other hand, P frames are reference frames for the B frames. Therefore P frames should be handled as the second important frames and have to be directed to the best of the remaining possible networks, while B frames can be transmitted over the lowest trustable links. The receiver at the MLUE reschedules the frame structure and restores the video stream as it can be observed in Fig. 1.

A multilink gateway (MLG) has to be present in the multilink network in order to apply these multilink techniques, so the instantaneous channel conditions, packet error rate, delays or throughputs would be known at the server side. The MLG that is responsible for splitting/merging a service data flow was elaborated by the MARCH project [7]. Moreover, with the MLG adaptive radio resource management can be established in LTE networks [23] as it was shown in [24].

We compared a non-adaptive multilink and our proposed adaptive multilink transmission method introduced in [25] for the case of the above time varying multilink environment. In both methods we exploit the bandwidth aggregation capability of the multilink system and assume that the data rate is the same on each link.

We considered the GOP structure of I, B and P frames as presented in Fig. 4.

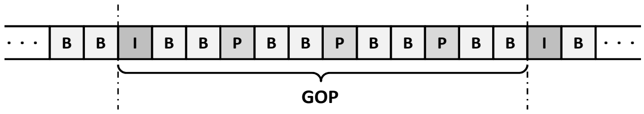

Figure 4. The considered frame series in a GOP of MPEG-2 video

By the scheduling of the frames the differences in size among the three types of frames was considered. P frames are predicted from I frames, therefore they require less data, which is assumed 50% of the size of the I frames. B frames are bidirectional predicted, therefore they need even less data than P frames, that is assumed 25% of the size of the I frames [18]. Since GOPs are transmitted through different networks, they are split into three slices. As it was introduced in [25], a so-called segment in a split GOP is as long as a B frame, therefore the transmission of a P frame lasts for two segments while the I frame lasts for four segments. Therefore the split sequences do not contain the same number of frames assuming the same bit rate on the different links. For the current case the split GOPs consist of 6 segments, since the whole GOP contains 18 segments as depicted in Fig. 5.

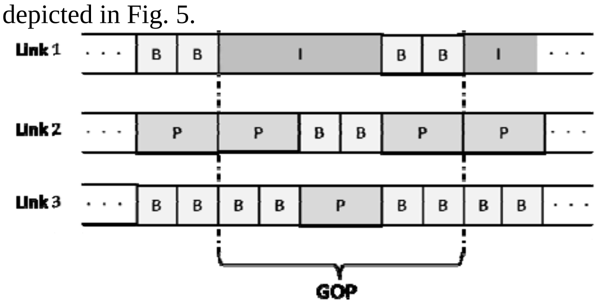

Figure 5. The schedule of segments in split GOPs assuming non-adaptive transmission and constant bit rate

In case of non-adaptive video transmission 6 segments are transmitted simultaneously through each network while the schedule of segments in split GOPs is constant and is based on the frame structure in the GOP as can be observed in Fig. 5. Assuming the link quality in decreasing order, if the first network/link has high quality, the receiver can restore the whole GOP because of the correctly decoded I frame, however, if the order of the links changed, i.e. the first link becomes the lowest quality, without applying our adaptation method, the I frame will be corrupted and therefore the whole GOP transmission will be unreliable.

In the second case the frame-based adaptive video transmission is investigated. The schedule of segments in a split GOP can be seen in Fig. 6 for the case when the first network/link has the best quality.

Therefore the I frame and the first P frames of the GOP are transmitted here. If the second network/link has the second best quality, segments of the rest of the P frames are transmitted here. In that case the third link has the lowest quality, it serves the less important B frames. Since the transmission is adaptive, it can be guaranteed that the important frames are transmitted through the highest quality networks.

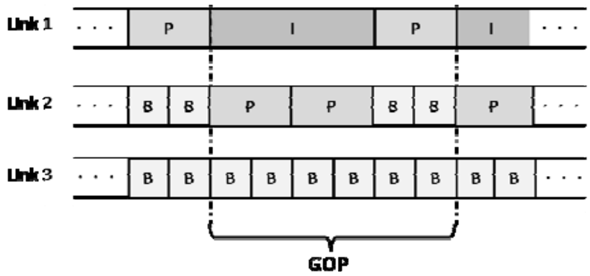

Figure 6. The schedule of segments in split GOPs assuming adaptive transmission and constant bit rate

V. Performance Evaluation of the Video Streaming Transmission

A. Simulation Assumptions

A frame was considered successfully transmitted if all of its segments are transmitted without any packet loss. For the sake of simplicity we assumed a worst case scenario, when no Forward Error Correction (FEC) is applied and one packet loss causes the loss of the entire segment. Moreover, to highlight the capability of the proposed method further assumptions are also made: i) if one segment is lost, the entire frame that contains the lost segment is lost as well; ii) therefore only one packet loss can cause a frame loss. With these assumptions the advantages of the adaptive versus non-adaptive transmission can be easily demonstrated.

When the channel conditions are poor or the high background traffic causes high packet error rate at the backhaul, the proposed technique still can mitigate the degradation. As mentioned in Section II, we assume constant data speed of the overall MPEG-2 video stream of 1.2 Mbps (0.4 Mbps per networks), the frame rate was set to 25 frame per seconds.

Therefore, when the GOP structure shown in Fig. 4 is applied, a segment consists of 8 packets. The interval between two transitions of the Markov-chain that models the variation of the application scenarios was set to six GOPs time, 2.88 seconds. For each simulation run we considered the same randomly generated packet loss series and multilink network scenario change series given by the Markov model, therefore the results and the achieved gains are comparable.

B. Non-Adaptive Transmission

In case of non-adaptive network allocation, split GOPs containing the segments of the I frames are forwarded always to the same network (referred as Link1 in Fig. 5) from the three available networks. Split GOPs containing the segments of the two P frames are transmitted through another network (referred as Link2), while the third type of split GOPs are transmitted through the remaining network (referred as Link3). Since in this case the information on the transmission conditions are not exploited, this network allocation can happen only blindfolded; the packet loss on each of the available links can be high with nearly equal probability because of the time varying multilink environment.

Therefore applying the segment order presented in Fig. 6 is unnecessary in non-adaptive case; no gain can be expected by this frame scheduling. Hence the schedule of frames in split GOPs presented in Fig. 5 was applied for the case of non-adaptive transmission.

In Table III the number of the different type of frames that cannot be decoded versus the number of the different type of lost segments are given separated by slash for all the six network allocation possibilities. The number of the frames that cannot be decoded for non-adaptive transmission is high, independently from the network allocation. The number of segment losses presented in Table III only comes from the packet losses during the transmission. For instance, the segments of the P frames that cannot be decoded because one of the segments of the I frame in the given GOP was lost, are not counted here.

TABLE III. NUMBER OF THE FRAMES THAT CANNOT BE DECODED AND NUMBER OF THE LOST SEGMENTS FOR DIFFERENT LINK ALLOCATION IN THE CASE OF NON-ADAPTIVE AND ADAPTIVE TRANSMISSION

	Non-adaptive Transmission						**Adaptive Transmission**
Link1 - First type of split GOP	WiMAX		HSDPA		WLAN		Adaptive
Link2 - Second type of split GOP	HSDPA	WLAN	WiMAX	WLAN	HSDPA	WiMAX	Adaptive
Link3 - Third type of split GOP	WLAN	HSDPA	WLAN	WIMAX	WiMAX	HSDPA	Adaptive
Number of I frames cannot be decoded / Number of lost I segments	11 / 11	11 / 11	15 / 15	15 / 15	8 / 9	8 / 9	1 / 1
Number of P frames cannot be decoded / Number of lost P segments	69 / 30	56 / 17	78 / 14	80 / 16	61 / 33	46 / 18	6 / 3
Number of B frames cannot be decoded / Number of lost B segments	287 / 23	231 / 36	316 / 35	321 / 33	265 / 22	204 / 37	81 / 60
Total number of frames cannot be decoded	367	298	409	416	334	258	88
Percentage of frames cannot be decoded	0.9787 %	0.7947 %	1.0907 %	1.1093 %	0.8907 %	0.6880 %	0.2347 %

For the case when Link1 corresponds to WiMAX, Link2 to HSDPA and Link3 to WLAN (see first column in Table III), the number of the successfully decoded frames can be seen in Fig. 7 for the first 1000 GOPs.

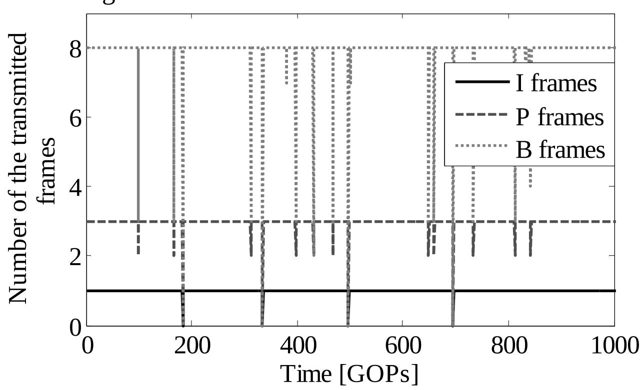

Figure 7. The number of the different types of properly transmitted frames in the case of non-adaptive transmission; WiMAX/HSDPA/WLAN link allocation

It can be observed, that the number of the frame losses is very high, therefore the quality of the MPEG-2 video transmission is very low in this case.

C. Adaptive Transmission

According to Fig. 6, split GOPs containing the segments of the I frames are forwarded to the best quality network (according to the network ranking based on the actual scenario, see Table III), the second type of split GOPs (containing two P and two B frames) are forwarded to the second best network and the third remaining network serves the split GOPs containing the B frames.

Therefore, by our adaptive method, the networks and links that are used to transmit the three types of split GOPs vary according to the network qualities. The number of segment losses that only comes from the packet losses for the case of adaptive transmission is given in the right column of Table III, after the slash.

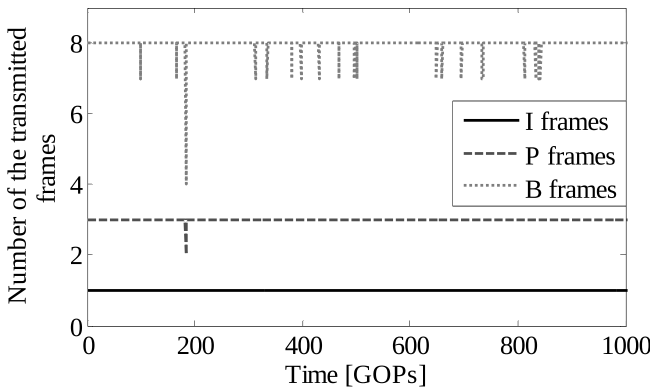

Figure 8. The number of the different types of properly transmitted frames in the case of adaptive transmission and adaptive network ranking

It can be observed that the probability of the packet losses for the important I and P frames was decreased compared to the non-adaptive case and the number of the frame losses is also significantly reduced.

The number of the successfully transmitted frames can be seen in Fig. 8 for the first 1000 GOPs. Comparing with the results illustrated in Fig. 7 it can be stated, that adaptive transmission and scheduling enhances considerably the video transmission quality.

VI. Conclusions and Future Work

Compared to single link radio access technologies, the multilink network techniques can be used to improve the utilization of the existing radio access infrastructure, to protect the user against lost of connectivity even if one the other radio access network is lost and to increase the user quality of experience by adapting user requested for quality of services to the varying network context.

In the present paper a frame-based adaptive MPEG-2 video transmission in a multilink environment composed by WiMAX, HSDPA and WLAN networks was investigated. A detailed description of the multilink access network ranking based on the application characteristics is offered.

The method proposed in this paper aims to increase the quality of the video transmission by splitting the video frames with different importance into multiple access networks ranked adaptively according to the constituting network performance by the multilink gateway.

The proposed method can be adopted for spatial scalability and layered video streams as well. Moreover, the authors aim to implement the proposed methods on a laboratory test-bed. Thus, a video traffic generator capable to split the frames over a multiple access environment is under construction. The physical test-bed will include an emulation server running the multilink scenario and two operational hosts corresponding to the video source and to the video destination. The emulation will create one-to-one mapping between the operational hosts and their own virtual representations. In this way, we will be able to evaluate the performances of the proposed frame-based transmission technique whereas running a real-time video stream.

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