Cross-Layer Architecture for H.264 Video Streaming in Heterogeneous DiffServ Networks

Gabriel Lazar, Virgil Dobrota, *Member, IEEE*,
Tudor Blaga, *Member, IEEE*

THE TECHNICAL UNIVERSITY
CLUJ-NAPOCA

COST 290

Agenda

I. Introduction
II. Reliable Multimedia Network
III. QoS-Enabled Network – DiffServ
IV. Service Differentiation over WLAN
V. Real-time Multimedia Streaming
VI. Cross-Layer Architecture
VII. A DiffServ PHB for Multimedia Traffic
VIII. Implementation and Preliminary Results
IX. Conclusion and Further Work

I. Introduction

- Proliferation of real-time multimedia traffic
- Heterogeneous Internet
- E.g. – Video streaming over hybrid, wireless-wired IP networks
- Different nature of real-time traffic - not handled well in *best-effort* networks
- Over-provisioning – prohibitive due to limited resources in wireless environments
- Users expect high service quality independent of underlying access technologies
- => Reliable, real-time multimedia streaming:
  - challenging task
  - requires cooperation of all involved "actors": *all* networks, nodes and layers must collaborate and optimize functionality to achieve this common goal

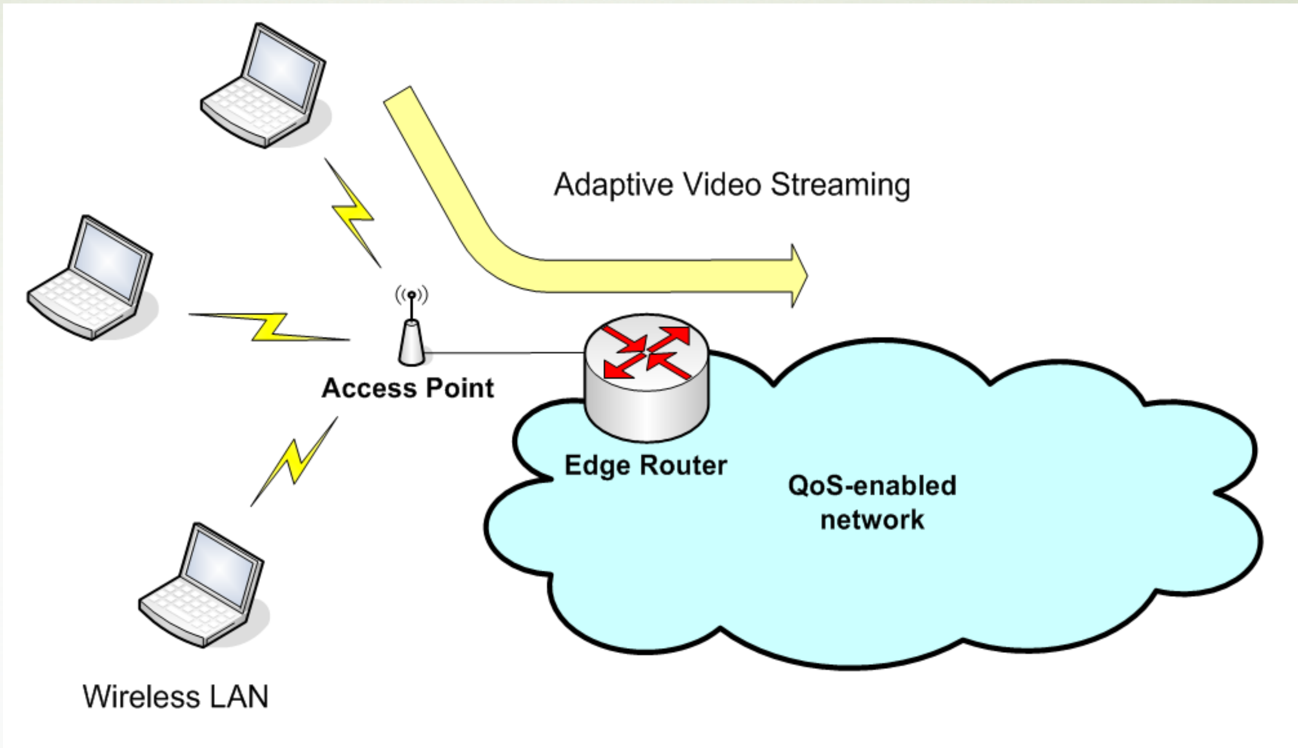
I. Introduction (cont.)

- Technologies designed to increase the quality of media streaming over the Internet:
  - Latest media technologies (improved compression efficiency and error robustness of audio/video data)
  - Scalable, packet-based, QoS frameworks – e.g. DiffServ
  - Traffic control blocks (resource reservation, resource allocation, shaping, admission control, routing, policing, classification and marking, queue management, scheduling)
  - High-speed wireless standards : IEEE 802.11g (54Mbps) and IEEE 802.11n (100Mbps), IEEE 802.11e (QoS-enhanced MAC layer)
- Strong demands imposed on video codecs and wireless links => new paradigm in network architecture design: the *cross-layer design* (CLD)
- Applying cross-layer optimization to multiple layers (application, network, data link) – optimal adaptation of the network
- *Best-effort* Internet should be replaced by QoS-enabled core networks, augmented where necessary with CL solutions

II. Reliable Multimedia Network

- High-quality multimedia service conditions:
  1. *The network must adapt to the traffic requirements of the applications if possible*
     - QoS-enabled network: intelligent nodes that differentiate between flows of different nature (elastic, multimedia), allocate resources and set required priority
  2. Only when first condition cannot be applied (i.e. in network segments with insufficient physical resources, or not QoS-enabled), *the application must adapt to the network*
     - The application must be able to adapt to changes in network characteristics, maintaining good perceptual user quality and graceful quality degradation in adverse conditions

II. Reliable Multimedia Network (cont.)



- Possible implementation of the reliable network concept:
  - start with existing technologies
  - employ modifications/additions relevant for multimedia streaming

III. QoS-Enabled Network – DiffServ

- DiffServ architecture – can provide class-based QoS guarantees in the core network:
  - complex decisions – made in the edge routers
  - edge-to-edge services – built from a set of PHBs in the core routers
  - flow aggregates - recognized by the DSCP of their packets, in each core router
  - PHB – node level treatment for packets of different QoS classes
    - EF PHB – low loss, low delay traffic, suitable for multimedia services; traffic from this class uses in each node a separate queue, has highest priority and fast service rate; EF traffic must be limited (policed) at the ingress node to avoid starvation of other flow aggregates
    - AF PHB Group – 4 AF classes of traffic and 3 drop precedence values; usual implementation:
      - each flow aggregate from an AF class is sent to a separate queue
      - packets from the same traffic class, having different drop precedence values, are discarded using a form of random early detection (RED)
  - A DSCP marking VoIP application, or an edge router performing a MF classification to recognize and mark a multimedia packet = basic form of CL optimization: information from an upper layer is used by the network layer for an appropriate QoS mapping

IV. Service Differentiation over WLAN

- High-speed multimedia communication over wireless links: IEEE 802.11g (54 Mbps) and 802.11n (100 Mbps)
- Data Link Layer QoS: IEEE 802.11e
- DCF (distributed coordination function)
  - most used channel access mechanism in 802.11 WLANs
  - all stations compete to channel access with the same priority
  - when medium is busy, transmission is deferred using a backoff timer, having a value which is a random number selected between 0 and the contention window (*CW*)
  - the backoff timer is decremented if the medium has been free for the duration of a DCF interframe spaces (*DIFS*)
  - if the timer expires and the channel is still idle, the station initiates the transmission
  - in case of collision, the size of CW is doubled until it reaches a maximum value *CW[max]*; if the transmission is successful, CW is reset at the minimum value *CW[min]*.

IV. Service Differentiation over WLAN (cont.)

- IEEE 802.11e - the enhanced DCF channel access (EDCA):
  - services differentiation using access categories (ACs)
  - traffic assigned to a category - sent to a separate transmission queue
  - each AC has different channel access parameters: *CW[min]*, *CW[max]*, arbitrary interframe space (*AIFS*) and transmission opportunity duration limit (*TXOP[lim]*)
  - traffic packets from a class with smaller *CW[min]*, *CW[max]* or *AIFS* will wait less, on average, before being sent than traffic from a category with bigger values
  - 4 ACs:
    - from AC0 (lowest priority) to AC3 (highest priority)
    - AC3 and AC2 - for multimedia transmission, AC1 and AC0 - *best effort* and background traffic

V. Real-time Multimedia Streaming

- Efficient, error resilient video compression – key factor to improve streaming over network segments with limited bandwidth resources
- H.264 – enhanced compression performance, provision for "network friendly" error resilience tools
  - video coding layer (VCL) – efficient representation of the video content
  - network abstraction layer (NAL) – encapsulation of video data into entities suitable for a variety of transport layers (or storage media)
  - NAL unit (NALU - 1-byte header followed by a bit string containing the picture partitions (macro blocks - MBs) or coding parameters
  - NAL_Ref_IDC (NRI) - NAL header field (2 bits) specifying the *priority* (importance of video information) of the payload: from 00 (lowest) to 11 (highest)

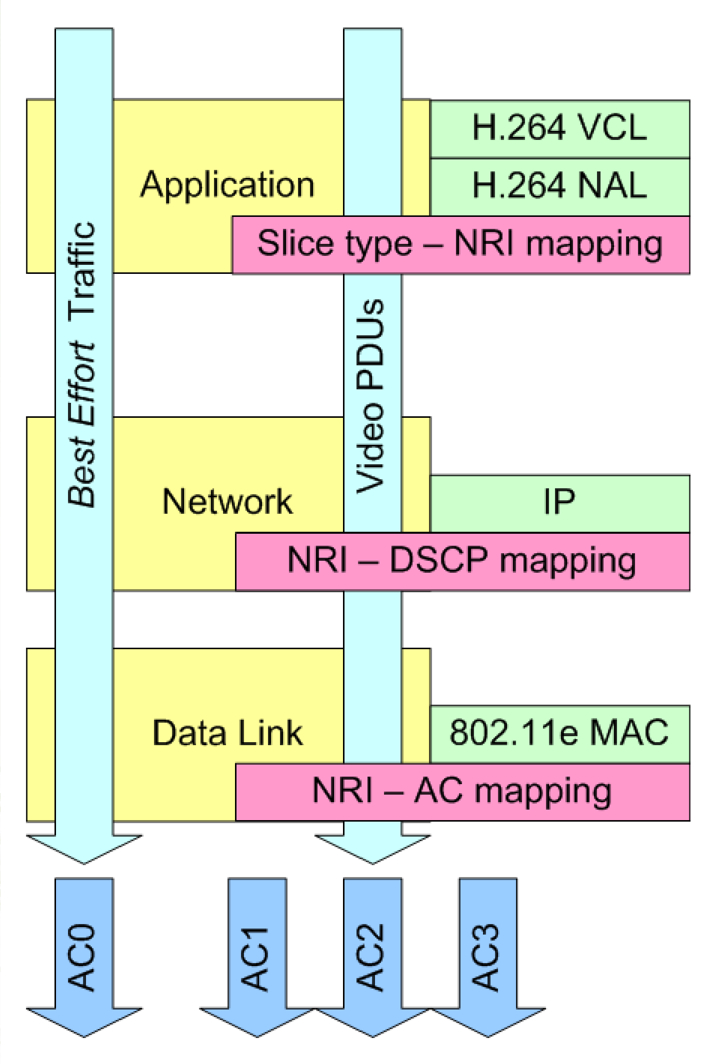
VI. Cross-Layer Architecture

- Traditional approaches in wireless multimedia transmission:
  - no interaction with lower layer transmission parameters or statistics
  - application-level (only) adaptation of generated traffic for reliable streaming
- Alternative: CLA for robust video transmission over 802.11e MAC layer using H.264:
  - MAC-centric CLA solution - application passes relevant information to the MAC layer, which decides how to prioritize resources for each packet based on its importance
  - The H.264 encoder sets the NRI field value of each NALU based on the importance of its contents
  - At the MAC layer, each data frame encapsulating the units is mapped into an access category in the range AC1-AC3 that reflects its importance. AC0 is reserved for *best-effort* traffic.

VI. Cross-Layer Architecture (cont.)

Proposed solution:

- extension of the above CLA that takes into consideration the IP layer – the video related QoS information is propagated to the other end of communication
- NRI information is mapped to DSCP field values at the IP layer and to the AC at the MAC layer
- Transmission based on MAC-only CLA has effect only at the source node – sufficient only inside a WLAN; priority information is lost after first node and all video traffic is treated as *best-effort*, or in the same manner.



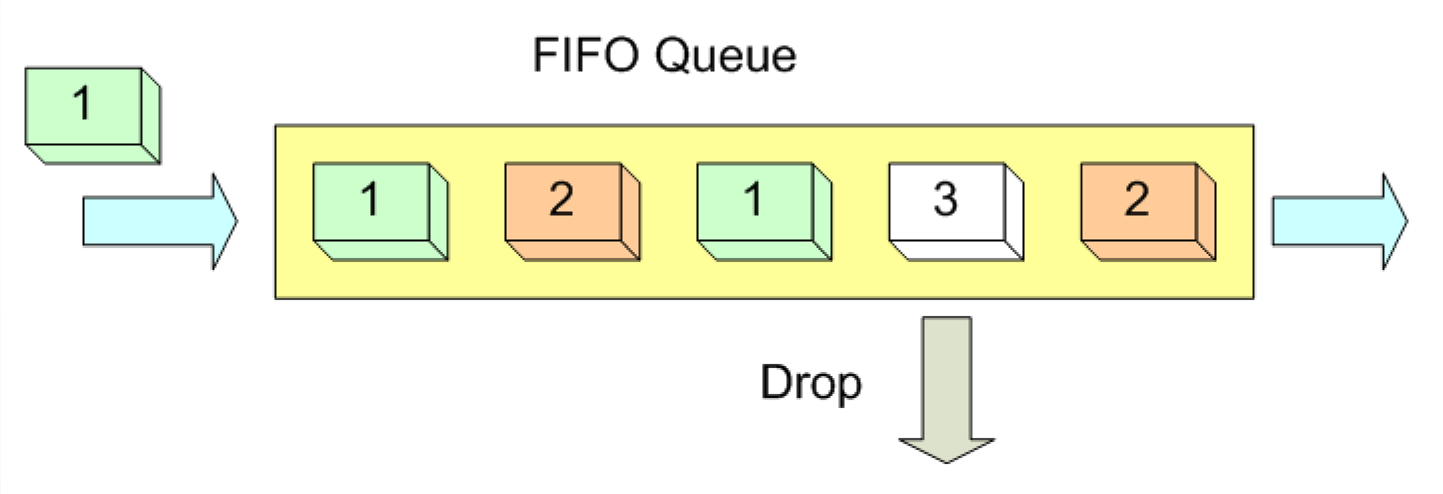
VII. A DiffServ PHB for Multimedia Traffic

- Shortcomings of current PHBs with respect to video traffic
  - policy design problem for EF assigned video streams
    - due to the variable rates of these flows (caused by the dynamic nature of the encoded scenes) and because multiple flows can be placed in the same FA – hard to design a maximum limit for traffic policing at the ingress router of a DiffServ domain
    - excessive EF traffic – starvation of other flow aggregates, large packet dropping (short queues)
    - no protection against elimination of important video packets, either at the ingress router (policing) or in the core network
  - video stream assigned to an AF class
    - drop priorities for AF PHBs – usually implemented with a form of RED. Due to the mechanism's statistical approach, important multimedia packets can be discarded (albeit with lower probability) instead of less important one. The priority dropping is not strict.
    - in addition, RED is designed for TCP (elastic) flows

VII. A DiffServ PHB for Multimedia Traffic (cont.)

Proposed solution: new Multimedia (MM) PHB

- 3 DS code points – for packets with different importance in the stream
- defined for high-priority, low loss, low latency traffic similar to EF, but with an added *strict drop precedence* scheme: at congestion, the core router will always drop a packet with highest drop precedence from its queue
- Implemented in a straightforward manner – FIFO queue with strict priority drop policy
- ingress policing for MM traffic can benefit of the 3 DSCP values to selectively drop less important packets first
- The DS code points can be used at the Data Link Layer of *any* node from the end-to-end path, to prioritize important traffic



VIII. Implementation and Preliminary Results

- Implementation of the CLA at the source node
  - Application Layer
    - modified Linux build of VideoLan Client (VLC) – H.264 enabled, sets the socket's SO_PRIORITY value for each packet based on the NRI field of each NALU analyzed
  - Network Layer
    - DSMARK queue discipline, part of the Linux Traffic Control mechanisms – sets DSCP values of IP datagrams by translating the SO_PRIORITY value to a DS code point. The NRI value is mapped to a DSCP through the SO_PRIORITY socket parameter sent between layers
  - Data Link Layer
    - The MadWifi WLAN Linux driver for Atheros chipset based wireless cards can use TOS or DSCP bits to select the required MAC access class

VIII. Implementation and Preliminary Results (cont.)

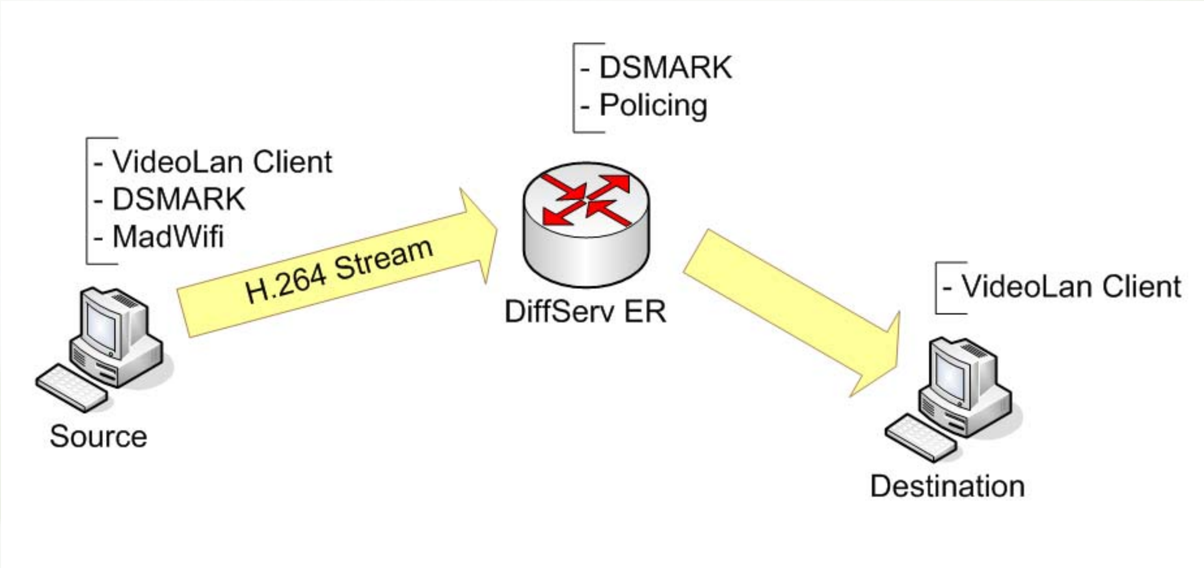
❑ Testbed

- Purpose - the importance of policing based on drop priorities
- DiffServ edge router - configured to police traffic according to the DSCP values of traffic packets
- traffic conditioning was implemented with 4 policy filters combined with a DSMARK queue discipline
- out-of-profile traffic from a class is re-marked and sent to a lower class
- the forth filter is associated with *best-effort* traffic, and *out-of-profile* packets are discarded

VIII. Implementation and Preliminary Results (cont.)

Preliminary tests

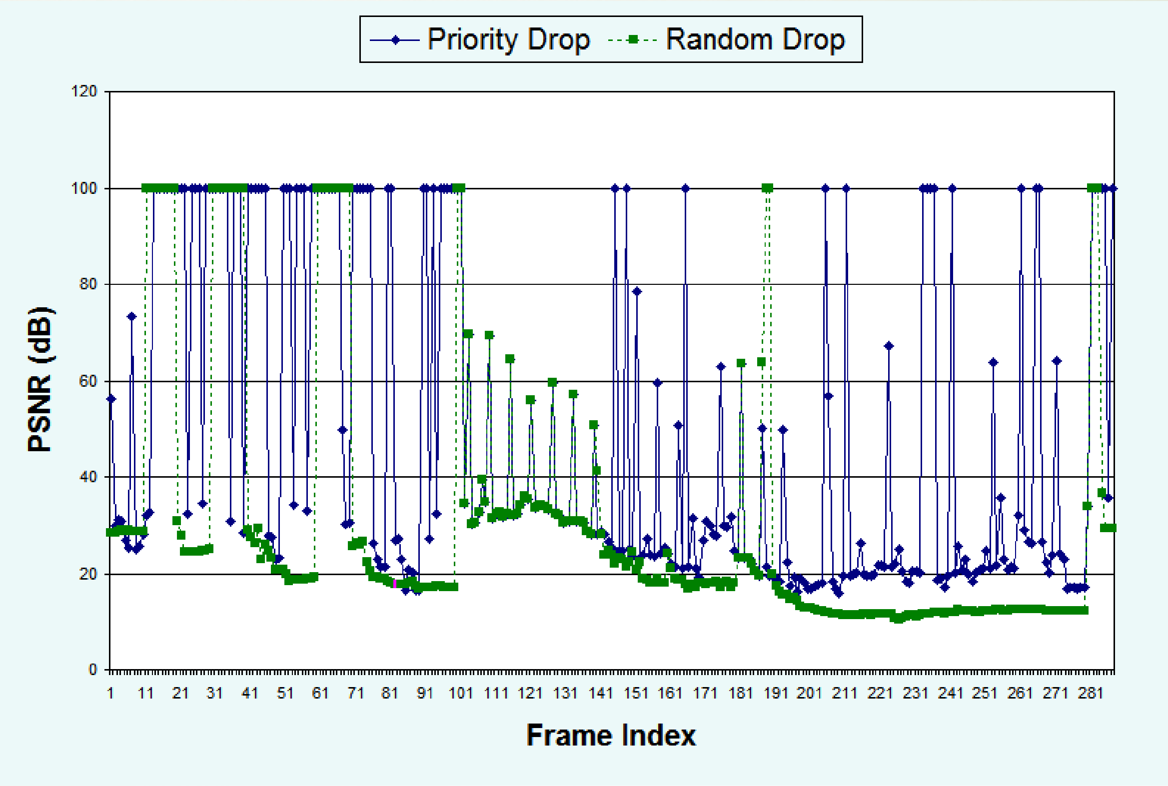
- CLA-enabled client as traffic source
- DiffServ edge router for traffic policing
- fast receiver (no congestion – no loss on second link)
- H.264 encoded Foreman sequence – sent to the destination through the ingress router
- total rate – limited to 1.1 Mbps to enforce re-marking and dropping
- router discarded excess packets according to their DSCP set by the video source
- second experiment – similar setup, but excess packets are discarded randomly



VIII. Implementation and Preliminary Results (cont.)

Results

- image quality was compared using peak SNR (PSNR) for each video frame, for both video sequences received at destination, relative to the source Foreman sequence
- the average PSNR (APSNR) values: 48.72 dB for experiment 1, 31.13 dB for experiment 2 (random drop)



IX. Conclusion and Further Work

Conclusion

- Reliable multimedia network concept
  - Established or emerging technologies – DiffServ, CL design
  - Robust communication for real-time video traffic over heterogeneous network segments
- CL-based solution at the source node
  - Takes advantage of the H.264 and IEEE 802.11e QoS mechanisms, allowing in addition the preservation of packet importance beyond the first node
- New MM PHB
  - Robust transmission – important packets are better protected against drops in the core network (strict drop priority scheme)
  - Simple proposed implementation

IX. Conclusion and Further Work (cont.)

Further work

- ❑ Linux implementation and testing of an MM PHB queuing discipline
- ❑ Quality measurements of end-to-end video streaming through CLA-enabled clients, wireless access links and DiffServ core network with MM PHBs