QoS-aware, Adaptive Throughput-Enhancement for CSMA-based Mobile Ad Hoc Networks

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Overview

1. **Motivation for IP-capable Mobile Ad-Hoc Networks (MANETs)**
2. **Identification of problems affecting throughput**
   1. Multihopping
   2. MAC-efficiency
   3. Overhead
3. **QoS-aware schemes to mitigate MAC influences**
   1. Concatenation
   2. Piggybacking

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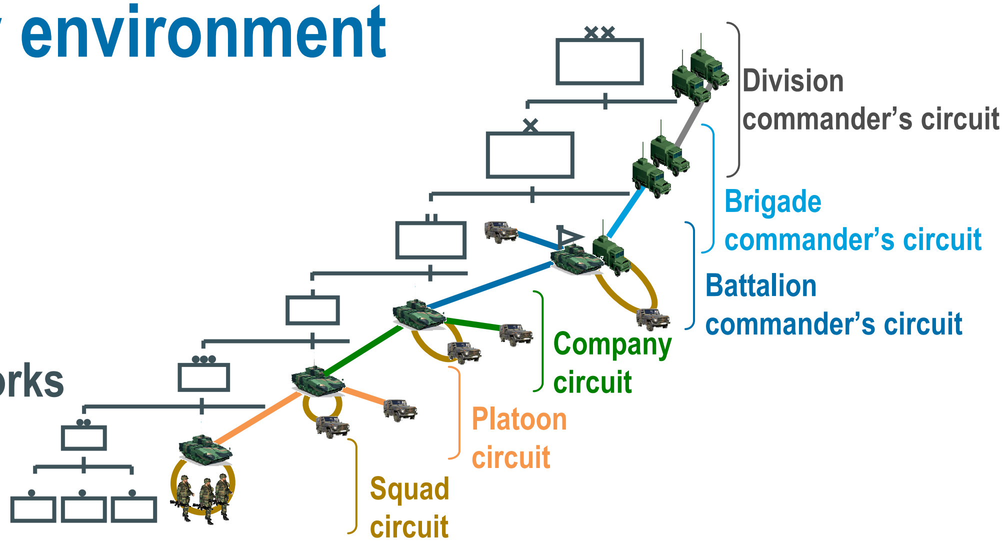
Networks in the military environment



Today's legacy networks:

- Organized in circuits
- Single-hop connections
- Voice and data in separate networks

Upcoming SDR-networks:

- Part of a larger heterogeneous network. Waveforms need to be optimized for the internet protocol (IP)
- Mobile Ad-Hoc Networking due to rapid deployability and absence of a single point of failure
- Range increase through multi-hop capability (IP)
- Need to handle different applications of differing importance (e.g. network control, voice, data) → QoS mechanisms needed
- For the case of heterogeneous traffic and varying load CSMA/CA MAC protocol is very popular (e.g. WiFi IEEE 802.11)

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Problems encountered with Multihopping, CSMA, and IP

a) **Multihopping reduces throughput R. With N nodes and ideal MAC-Layer we get [1]:**

$$\text{Throughput } R \sim \frac{1}{\sqrt{N \cdot \log(N)}}$$

b) **MAC-Layer has limited efficiency**

  a) CSMA → Collisions (TDMA → waste of bandwidth at low network utilization)

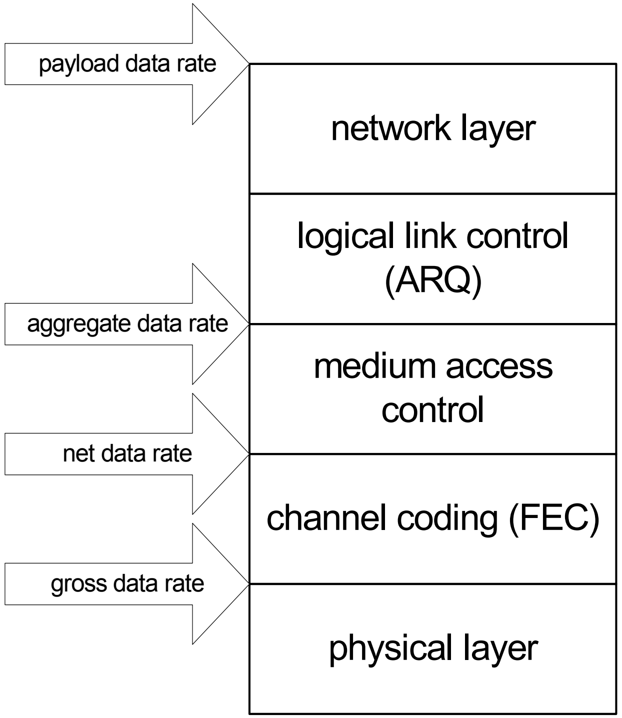
c) **Bandwidth is wasted due to overhead**

  a) UDP, TCP, IP … header

  b) MAC preamble and header

[1] P. Gupta, P. Kumar, "The Capacity of Wireless Networks," IEEE Transactions on Information Theory, March 2000.

Data Rate Definitions



Bytes: $M_{overhead}$, $M_{payload}$

Payload Rate R_p :

$$R_{p,\max} = R_{a,\max} \cdot \frac{M_{payload}}{M_{payload} + M_{overhead}}$$

Effiency K_{MAC}

Aggregate Rate R_a :

$$R_{a,\max} = R_{n,\max} \cdot K_{MAC}$$

Net Data Rate R_n :

$$R_{n,\max} = R_{b,\max} \cdot R_c = 72\frac{Mbit}{s} \cdot \frac{3}{4} = 54\frac{Mbit}{s}$$

Coderate R_c

Gross Data Rate R_b :

$$R_{b,\max} = \frac{N \cdot b_N}{T_S} = \frac{48 \cdot 6bit}{4\mu s} = 72\frac{Mbit}{s}$$

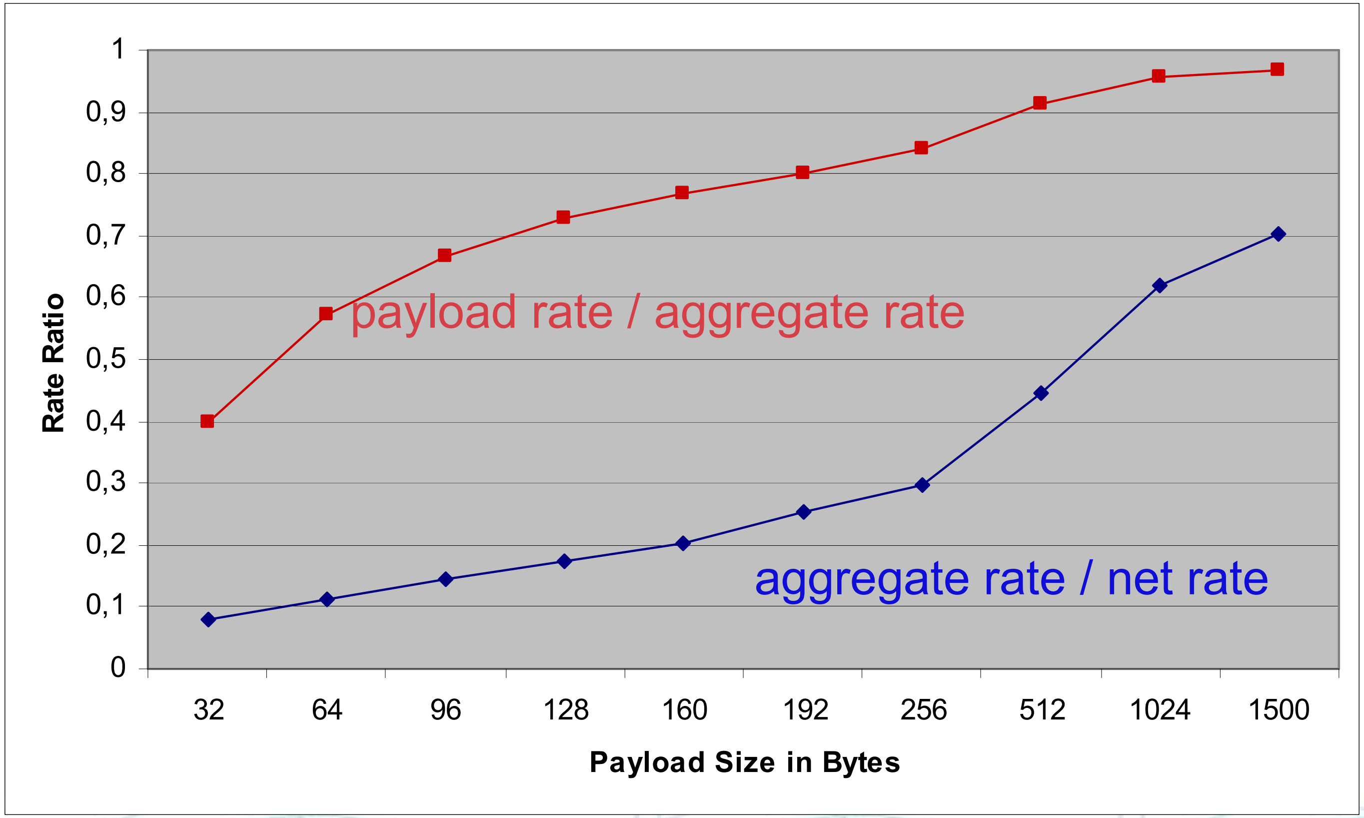
Example: IEEE 802.11a, 64-QAM modulation

Data Rate Loss over the OSI Layers (example IEEE 802.11a)

Net rate = 54Mb/s
$M_{overhead}$ = 48 Byte

1 Hop

a) Multihop



c) Overhead

b) MAC

Highest loss of data rate caused by MAC layer

Data Rate Loss over the OSI Layers (example IEEE 802.11a)

Net rate = 54Mb/s
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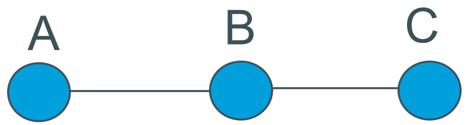
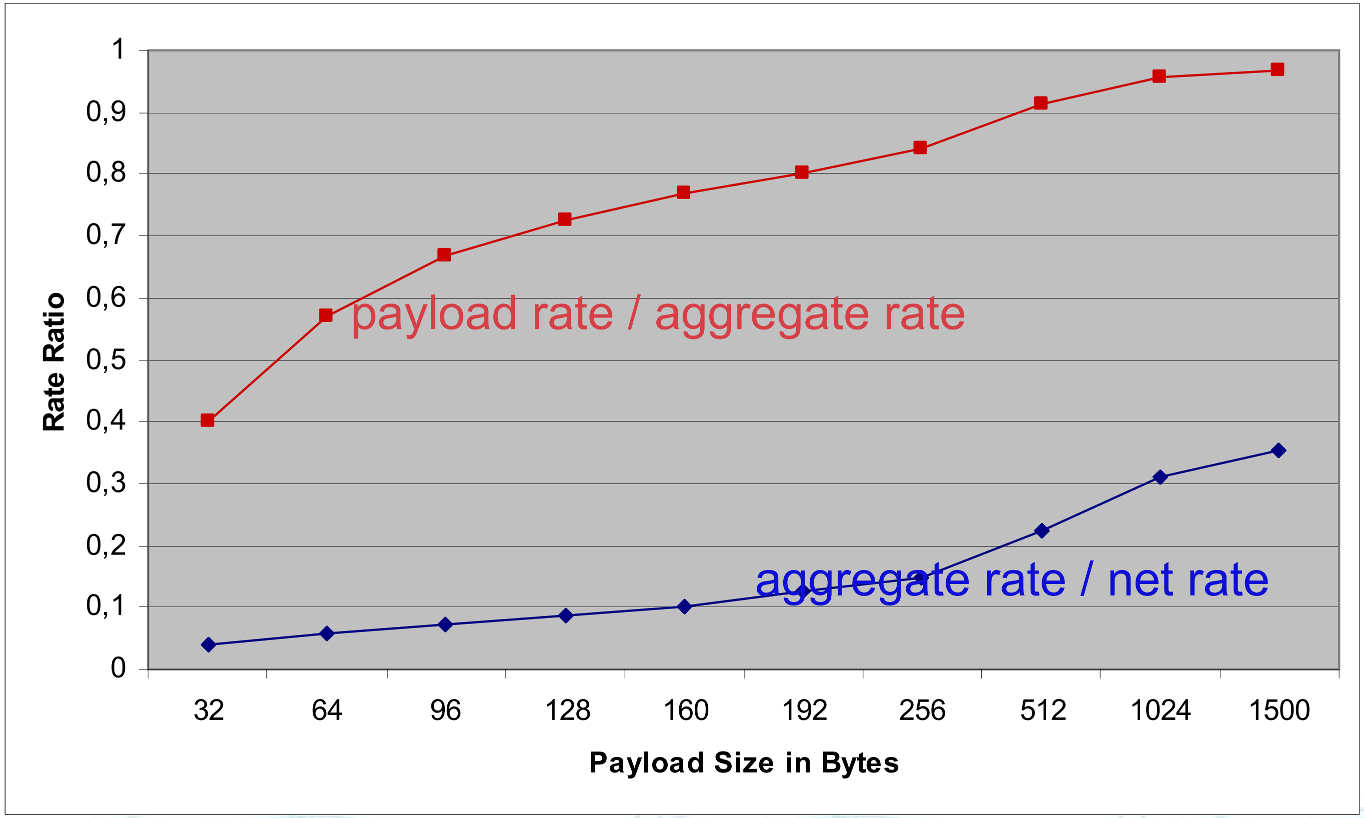
2 Hops



a) Multihop



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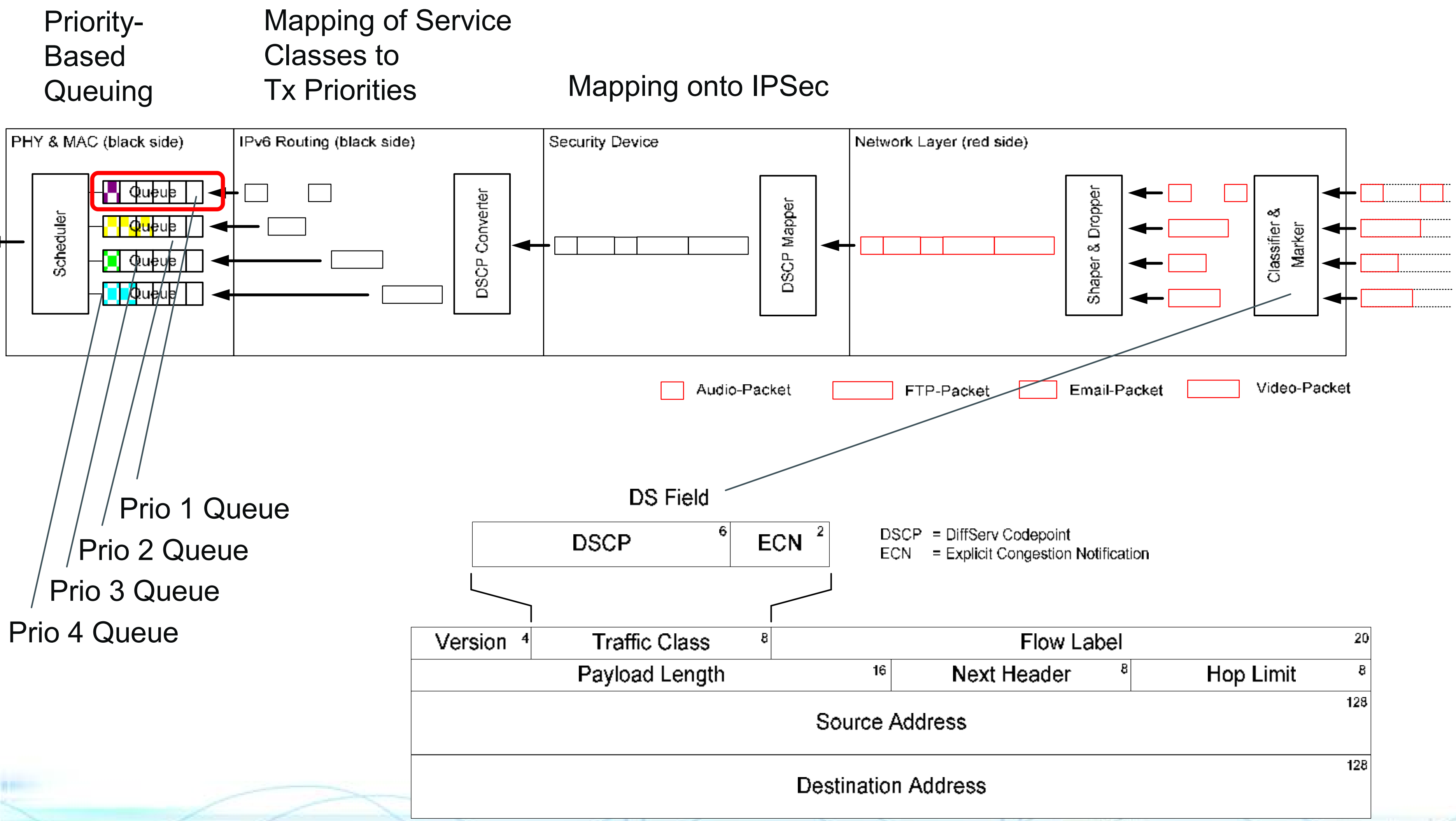
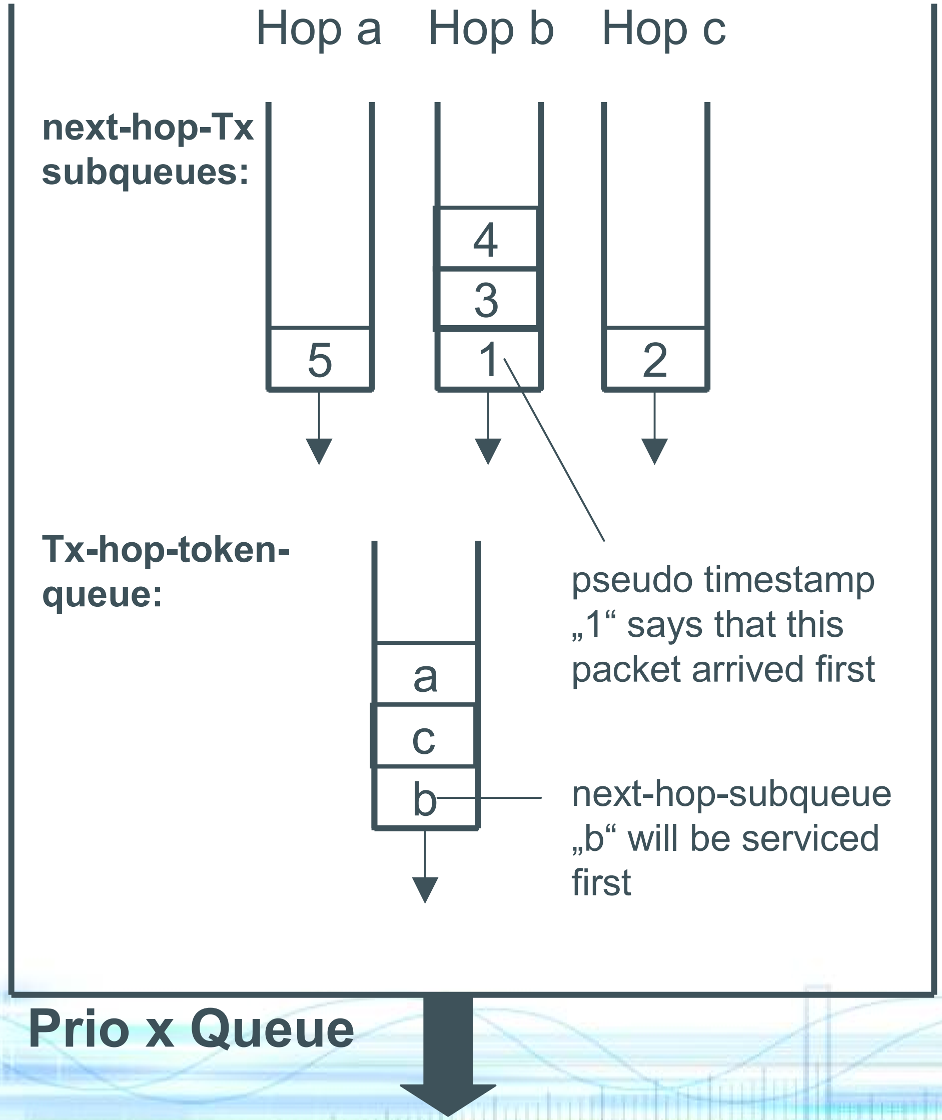
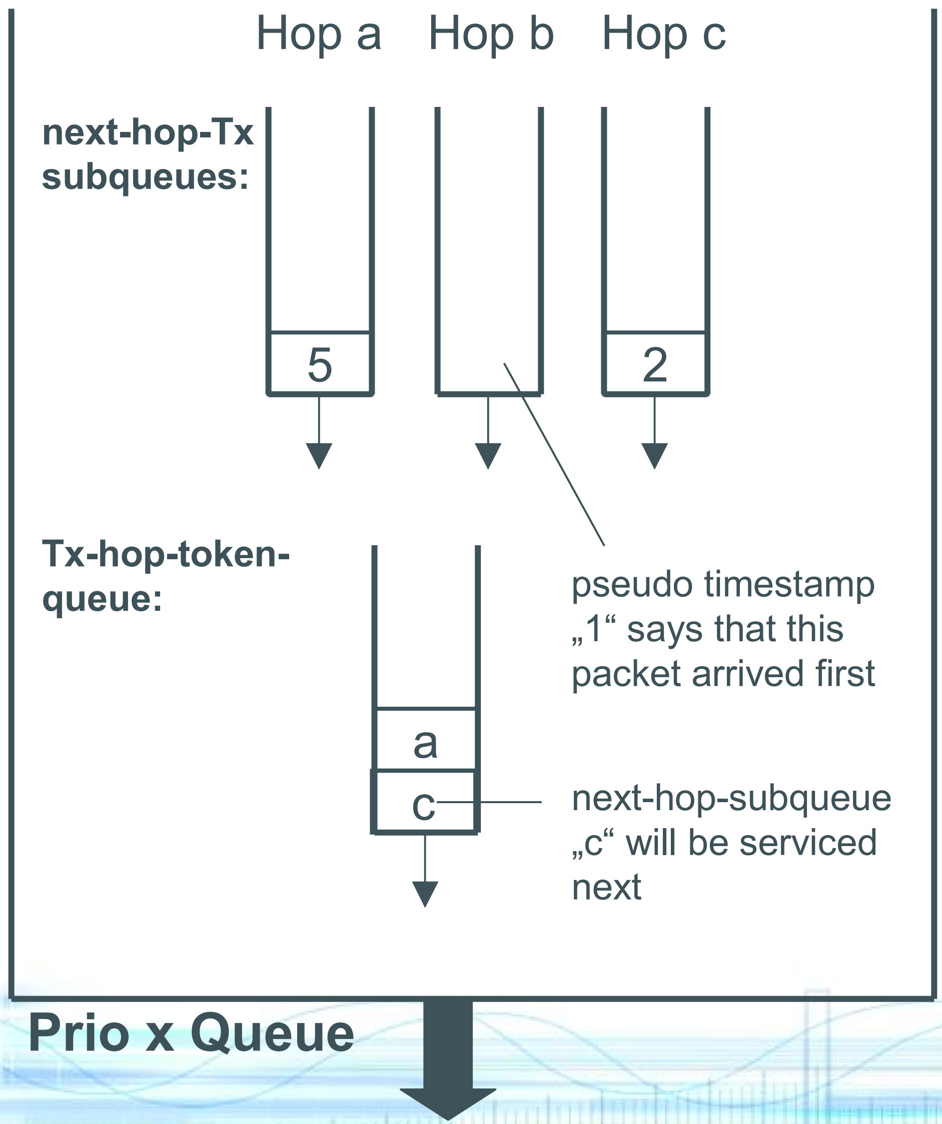
DiffServ: Mapping of Services to Tx Priorities (Example)



Adaptive Concatenation within Priority Queues

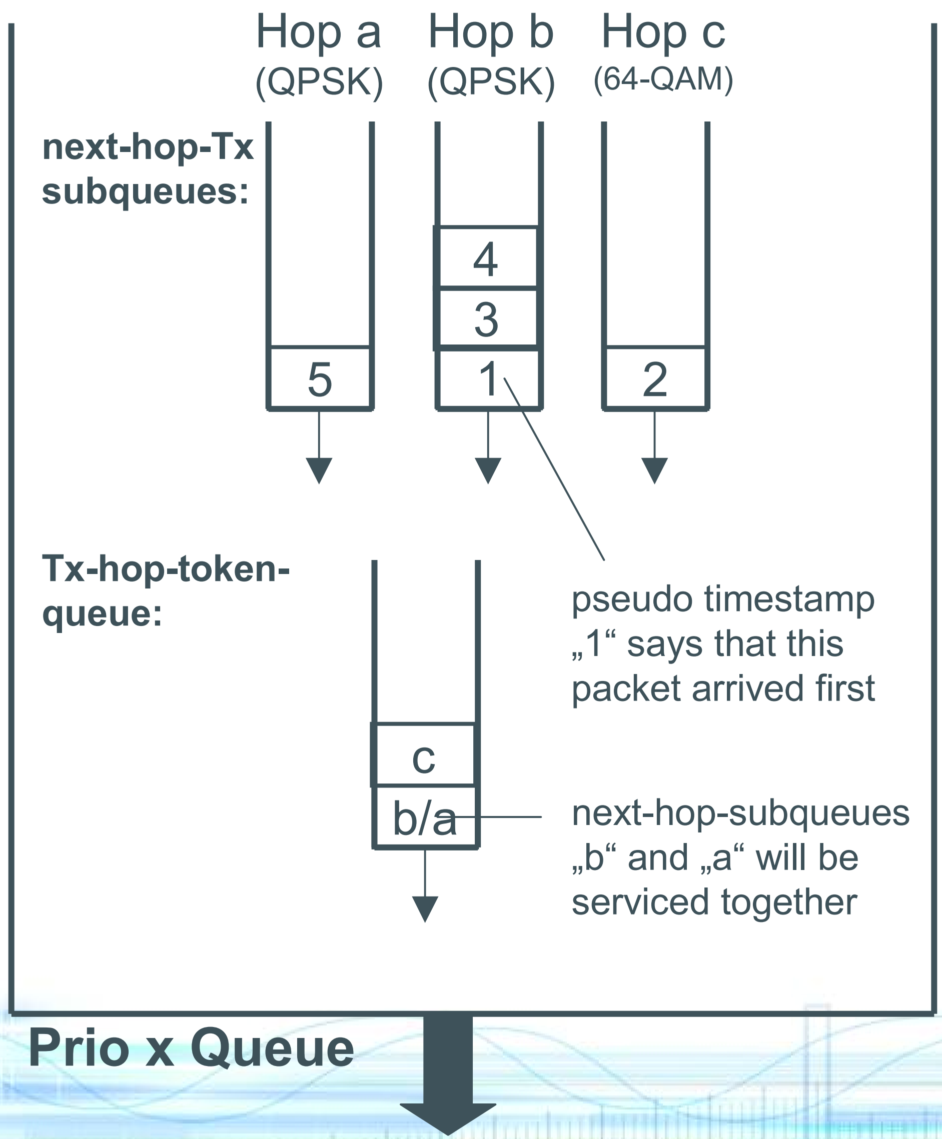


Adaptive Concatenation within Priority Queues

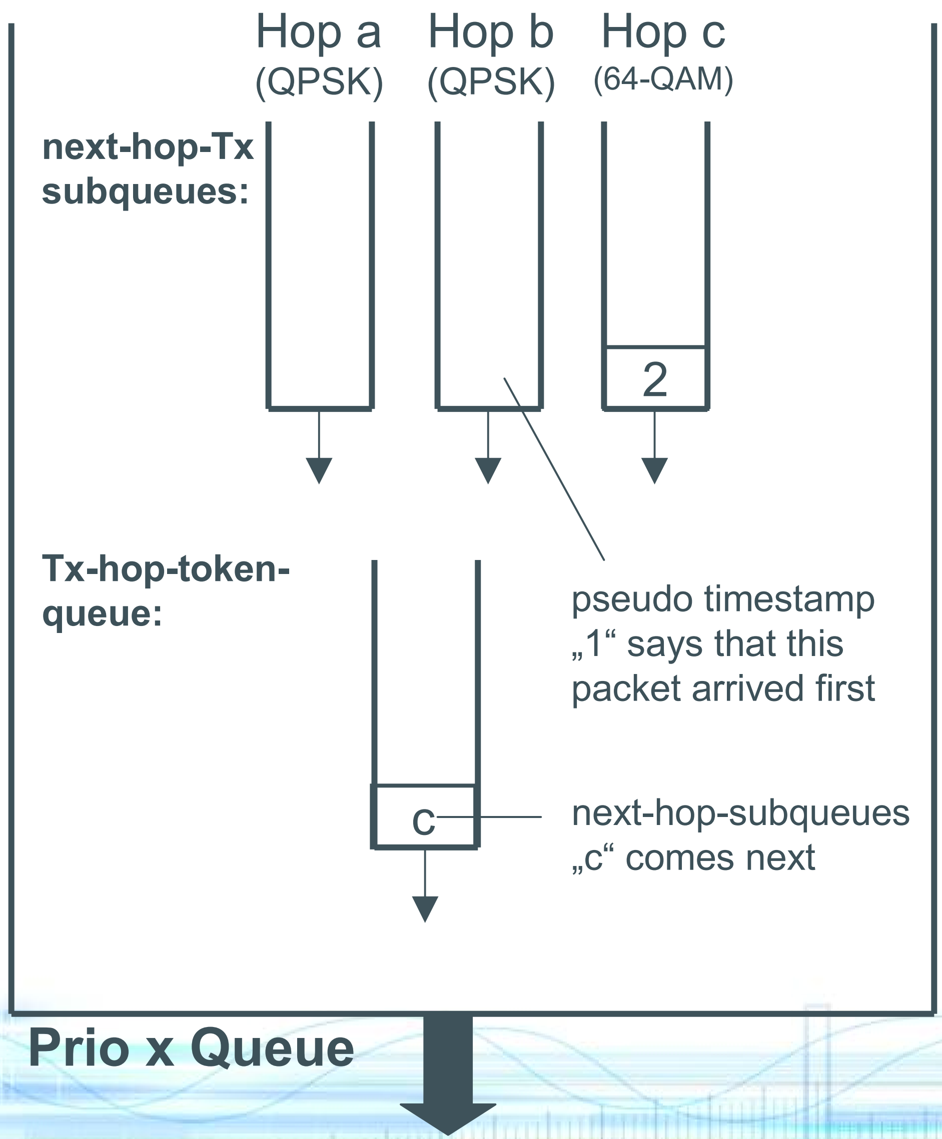


- + Tx-Queues will be emptied as far as possible
- + Concatenation increases payload and hence increases throughput
- + Latency increase is adaptive and stays as small as possible
- – Complex queue processing
- – Busy period is increased
- – Packet loss destroys more information

Modulation-aware Hop Token Queue



Modulation-aware Hop Token Queue



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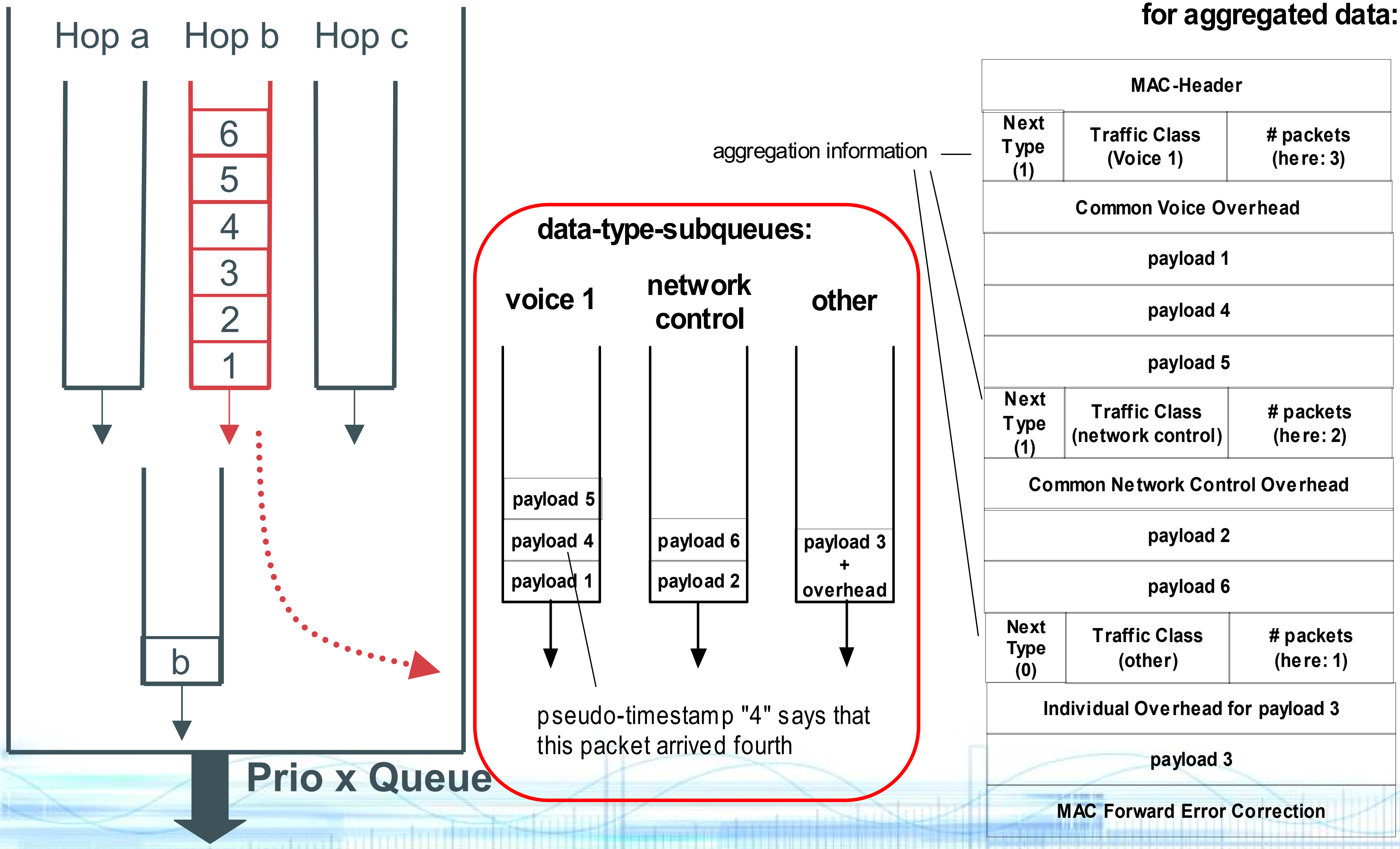
+ Concatenation increases payload and hence increases throughput
+ Latency increase is adaptive and stays as small as possible
– Complex queue processing
– Busy period is increased
– Packet loss destroys more information
– Modulation has to be monitored and hop-token-queue content updated continuously

Further structure of next-hop-Tx-Subqueue

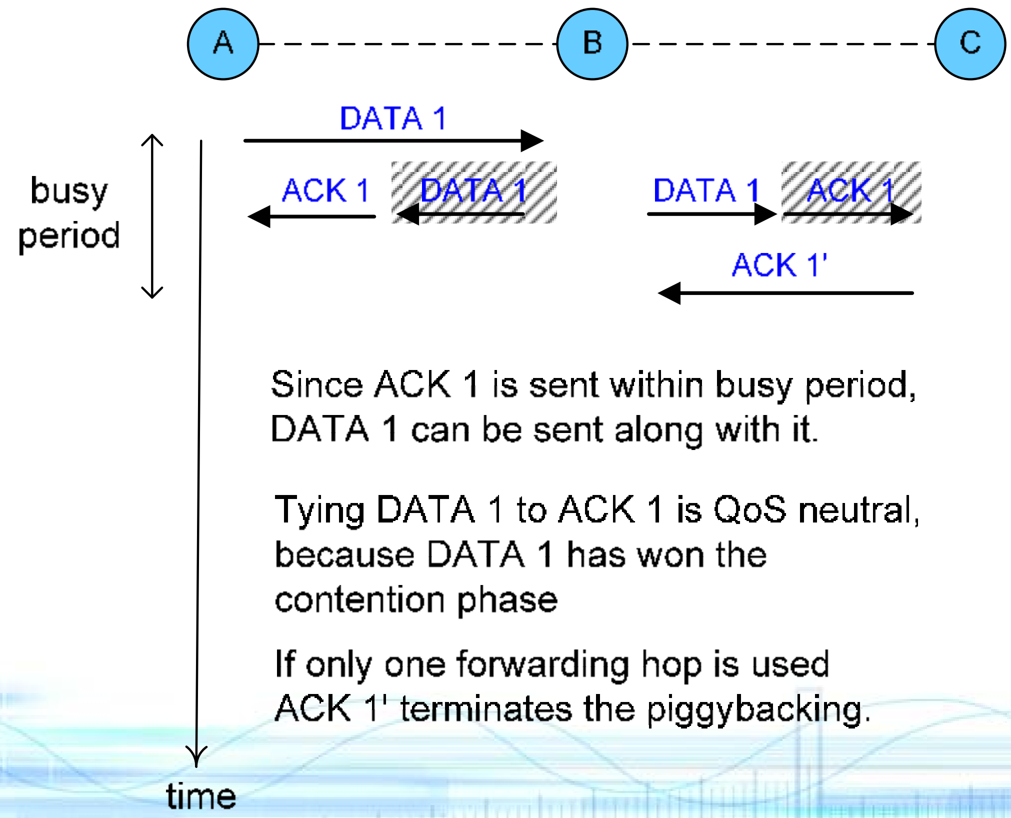
Modified MAC frame structure for aggregated data:



Piggybacking of DATA on MAC-layer

Prio X Queue of node B may be selected for transmission in two ways:

- By scheduler
- By incoming ACK



Since ACK 1 is sent within busy period, DATA 1 can be sent along with it.

Tying DATA 1 to ACK 1 is QoS neutral, because DATA 1 has won the contention phase

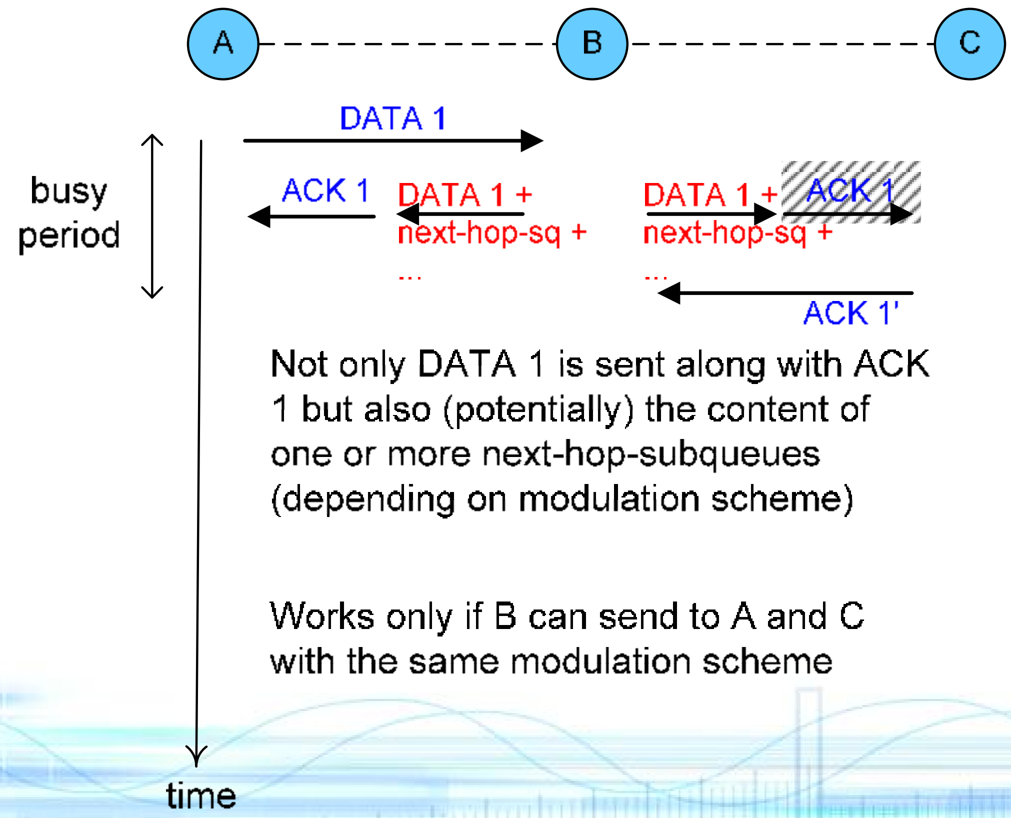
If only one forwarding hop is used ACK 1' terminates the piggybacking.

- \+ No address comparisons
- \+ ACK is sent immediately & independently of data destination address
- \+ ACKs are never sent without data at the forwarding node
- \+ QoS not violated
- − Busy period is increased
- − Modulation B→C and B→A has to be taken into account

Combination of Piggybacking and Concatenation

Prio X Queue of node B may be selected for transmission in two ways:

- By scheduler
- By incoming ACK



Not only DATA 1 is sent along with ACK 1 but also (potentially) the content of one or more next-hop-subqueues (depending on modulation scheme)

Works only if B can send to A and C with the same modulation scheme

- \+ No address comparisons
- \+ ACK is sent immediately & independently of data destination address
- \+ ACKs are never sent without data at the forwarding node
- \+ QoS not violated
- – Busy period is increased
- – Modulation B→A and B→C has to be taken into account

Benefits of concatenation and piggybacking

- **Due to adaptivity no concatenation and hence no increased latency for lightly loaded networks (important for realtime traffic like voice)**
- **High load → high probability of collisions → high probability of concatenation**
  - 2 packets concatenated → throughput increases 2 times
  - 4 packets concatenated → throughput increases 3 times
  - Piggybacking renders a further throughput increase of up to 50% [1)]
- **Schemes look promising, but realistic [2)] simulations needed that consider:**
  - Error correction scheme and packet loss due to collisions
  - Traffic mix, traffic load, packet arrival process
  - Network type, size and node movement
  - MANET protocol

Payload packet size	Payload rate (Mbps)
32	1.7
64	3.5
128	5.2
192	6.9
256	11.0
512	13.6
1024	22.1

Example: net rate 54 Mb/s, IEEE 802.11a, 64-QAM

1) Langguth, T., Bässler, A., Haas, E., Schober, H., Nicolay, T. and Storn, R., A Novel Approach for Data Piggybacking in Mobile Ad-Hoc Networks, SDR Technical Conference, Orlando 2006 .

2) S. Kurkowski, T. Camp, and M. Colagrosso, MANET Simulation Studies: The Current State and New Simulation Tools, Technical Report MCS-05-02, The Colorado School of Mines, February 2005.

Conclusion

- **The main throughput-reducing effects in IP-based MANETs have been summarized**
  - Multihopping
  - Low MAC-efficiency, especially for small packets (e.g. voice)
  - Protocol-Overhead, especially due to IP and potentially IPSec
- **Concentration on MAC for CSMA/CA since most of the incurred data rate loss happens in the MAC layer**
- **Several schemes to counteract data rate loss**
  - Adaptive concatenation (next hop aware, modulation aware, application aware)
  - Piggybacking
- **Schemes look promising, but realistic simulation needed to find out net benefit**

Thank Your For Your Attention

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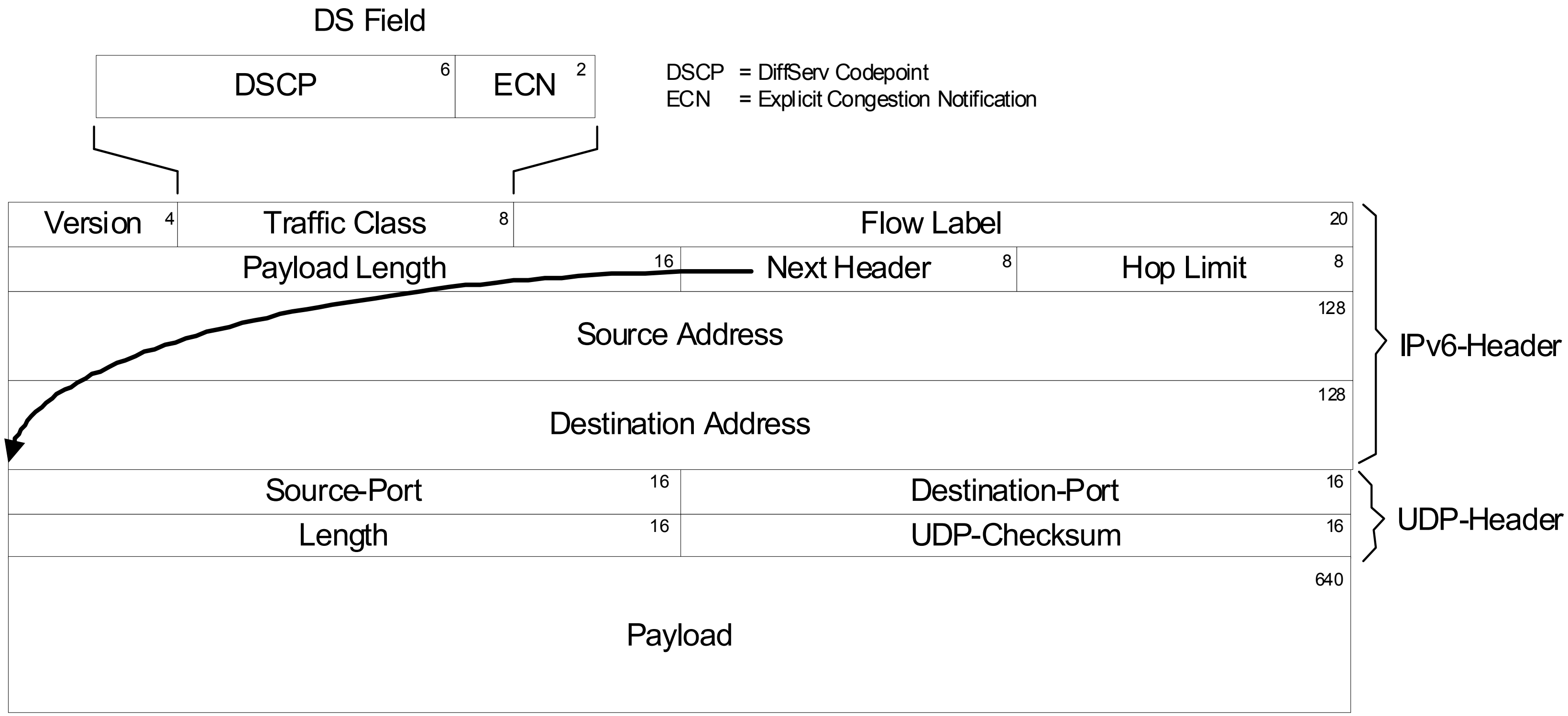
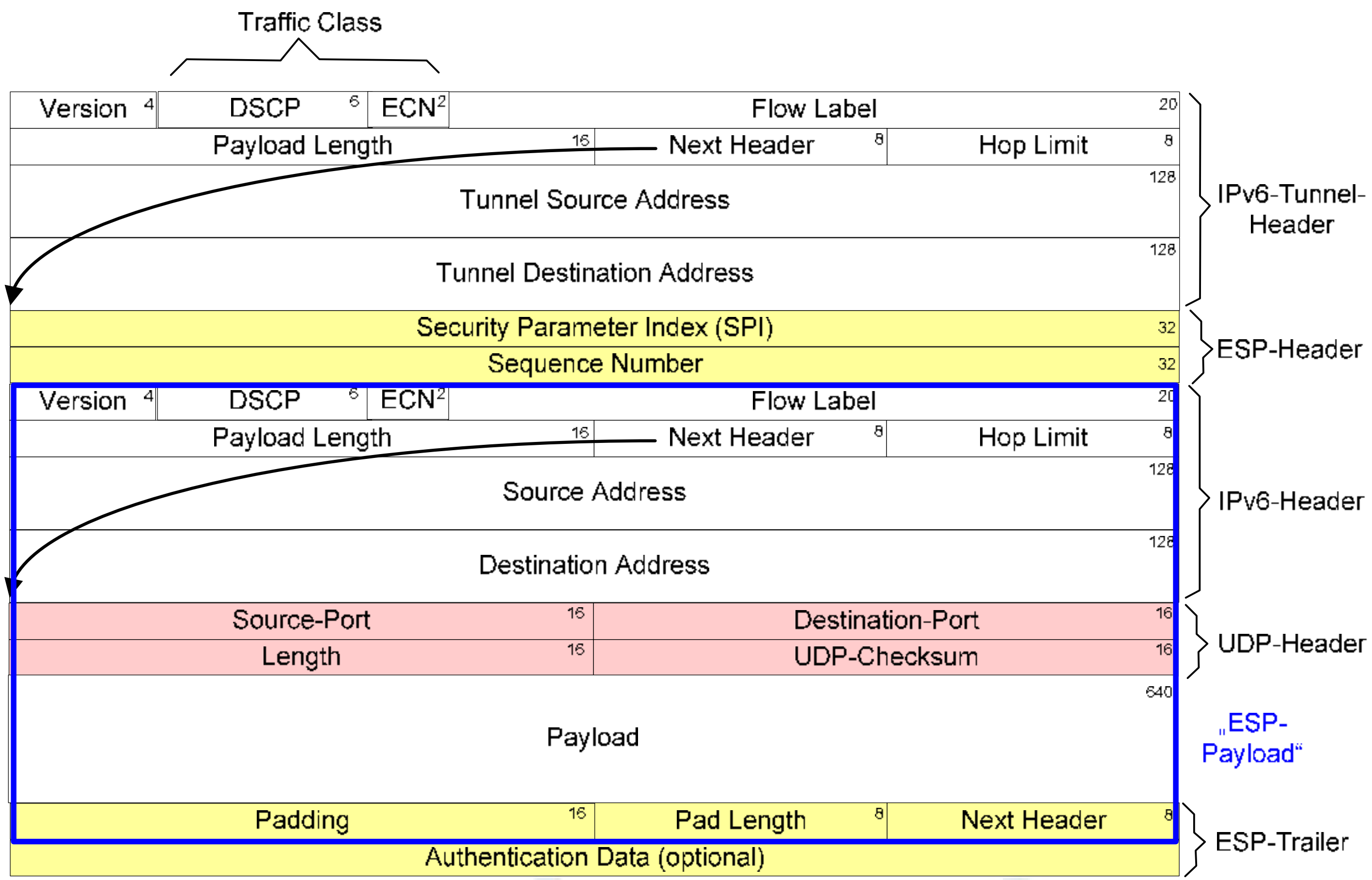
IPv6- and UDP-Overhead



Overhead: 48 Byte

IPv6- and UDP-Overhead if IPSec is used



Overhead: 100Byte