A Framework for Qualitative Communications Using Big Packet Protocol

2nd Workshop on Networking for Emerging Applications and Technologies (NEAT 2019)

19th August 2019

Richard Li[1], Kiran Makhijani[1], Hamed Yousefi[1],
Cedric Westphal[1,2], **Lijun Dong[1],** Tim Wauters[3], Filip De Turck[3]
Futurewei Technologies[1], University of California, Santa Cruz[2]
IDLab, Ghent University ś imec[3]

Agenda

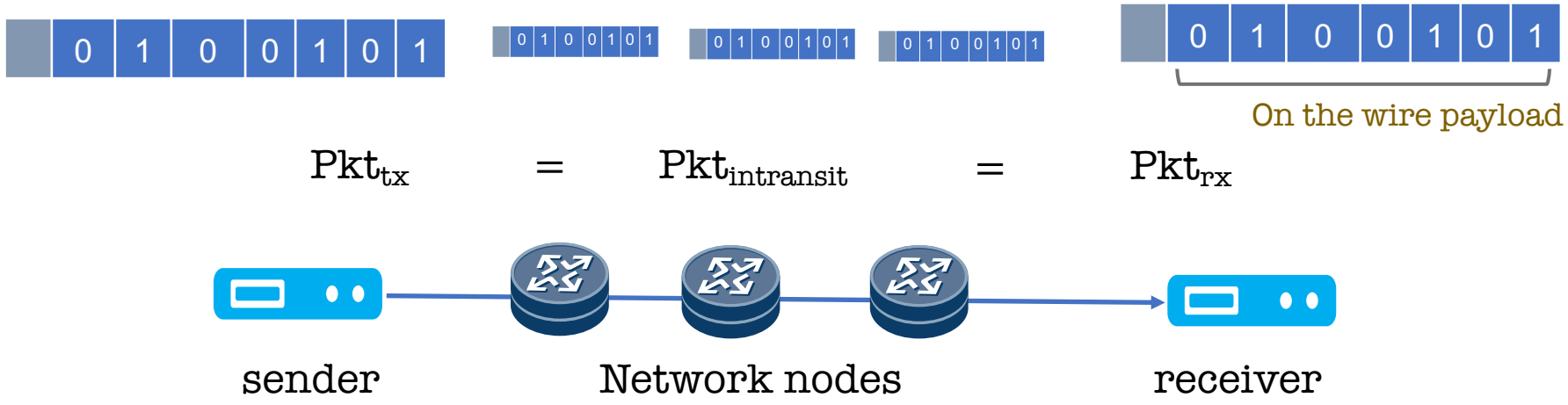
- Motivation & Concept
  - Traditional means of dealing with retransmission.
  - Qualitative Service
  - New Packetization
- Qualitative Service Techniques
  - Qualitative Service Framework
  - Generic Packet Wash Operation
  - Adaptive Rate Control
  - In-Packet Network Coding
- In-Network Qualitative Packet Processing
  - BPP Based Implementation Strategy

Agenda

- **Motivation & Concept**
  - Traditional means of dealing with retransmission.
  - Qualitative Service
  - New Packetization
- Qualitative Service Techniques
  - Qualitative Service Framework
  - Generic PacketWash Operation
  - Adaptive Rate Control
  - In-Packet Network Coding
- In-Network Qualitative Packet Processing
  - BPP Based Implementation Strategy

Packet as Fundamental Unit

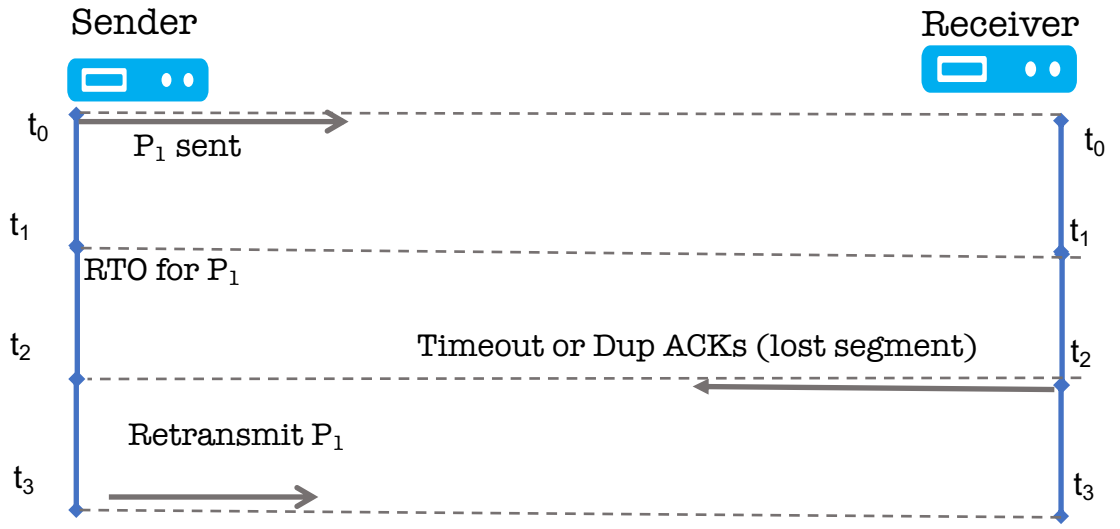
- Information Integrity is verified at packet level
  - Traversed:- complete forwarding information (addressing)
  - Treated:- Forwarded as an atomic entity (*fragmentation: leads to new pkt*).
  - Verified:- Checksum computation over entire packet
- Consequences
  - Dropped:- In entirety by network elements



Cost of Retransmissions Due to Packet Dropping

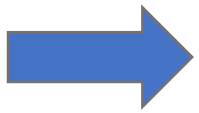
- When reliable transport layer protocol is used, packet drops result in the retransmission of the packet.

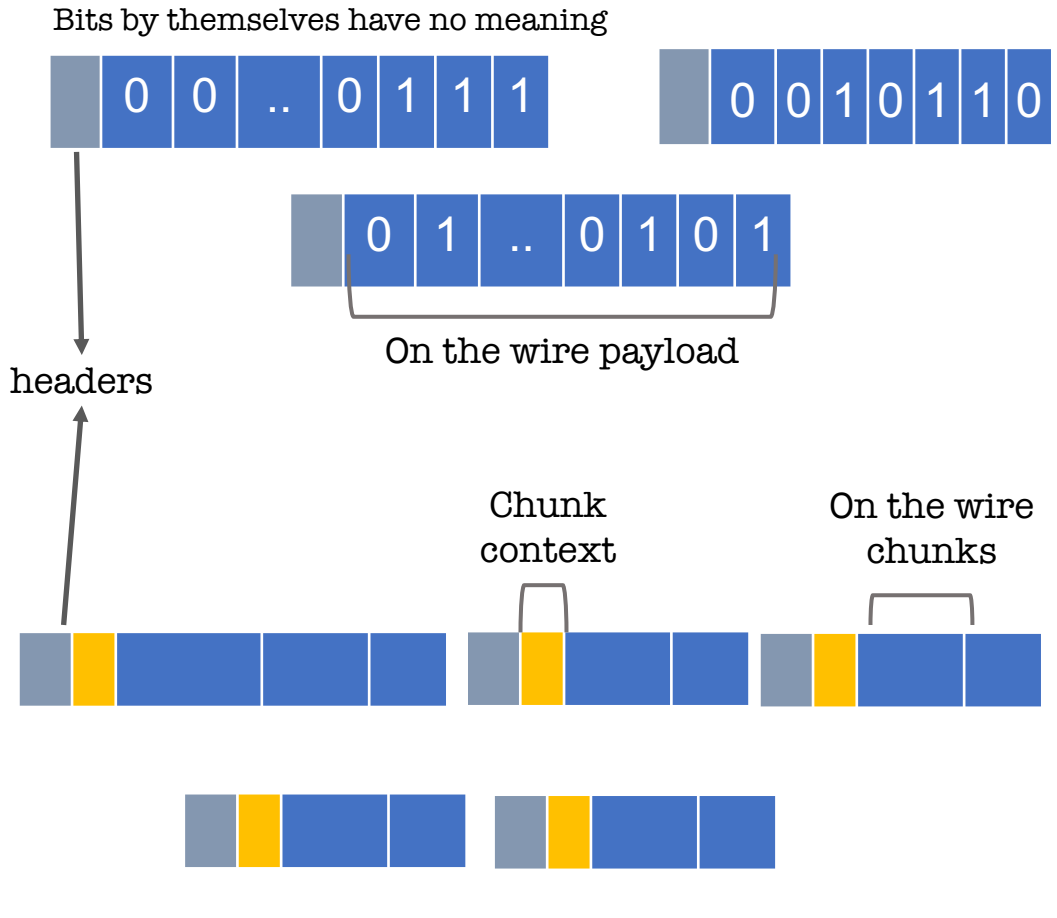
- Cost of re-transmissions
  - Wastes network resources
  - Reduces the overall throughput,
  - Unpredictable longer delays.



Basic Idea – Packet as Logical Unit

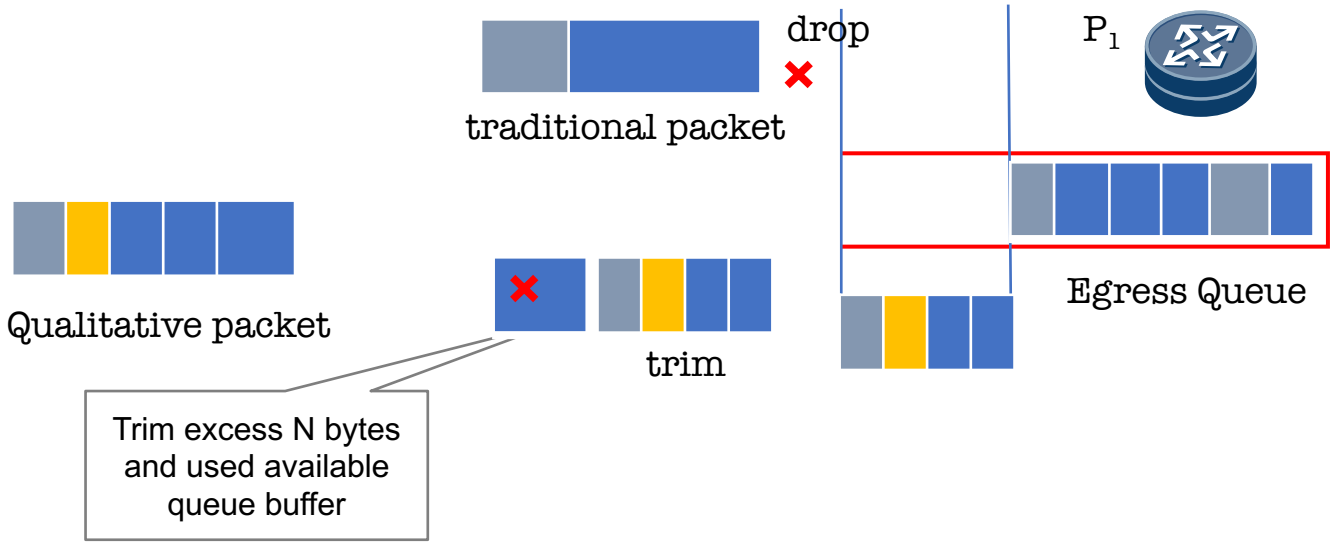
Application Semantics
(what information, how to use it)





- Organize packets according to semantics.
  - Utilize application data semantics for a more predictable delivery of data even in adverse network conditions.
- Each local unit (called chunk) is self-describing
  - Its significance in the context of information carried in the payload.
  - Operate on chunks not no the bit-stream.
- Purpose:
  - Ability to perform finer granularity of Operations on Packets

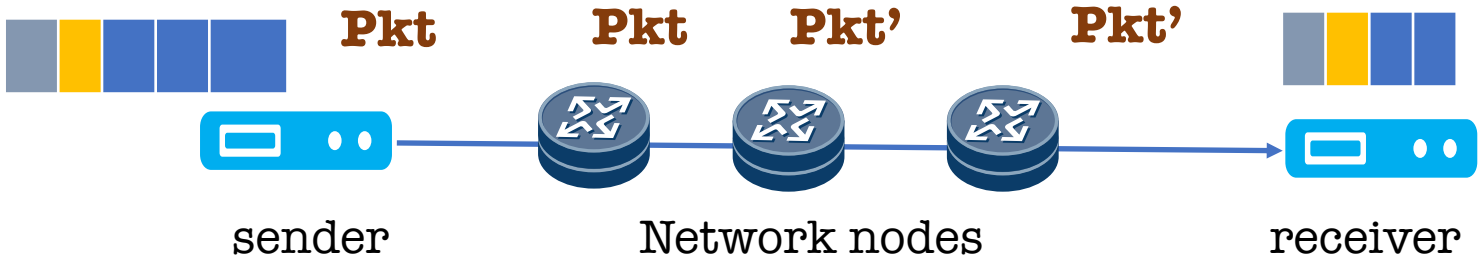
Why Logical Units?



Logical units within packets enable selective drops as against full packet drop

Qualitative Communication Service

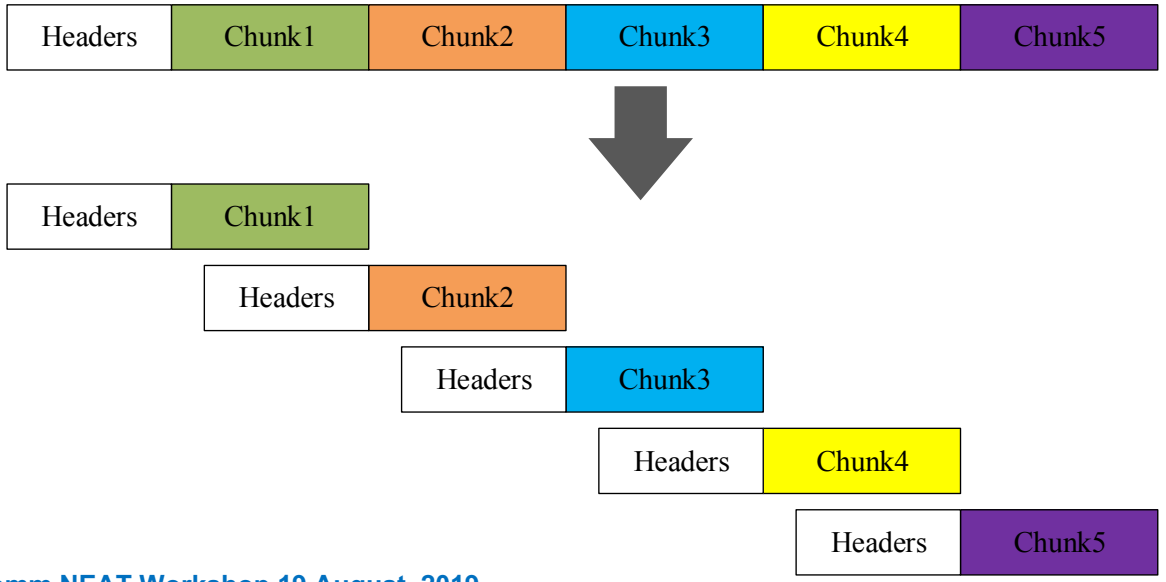
A **packetization scheme** that breaks down the payload into multiple chunks, each with a certain semantics or significance. The network nodes make decisions* to process chunks based on the current situation and the significance carried in the packet.



Note*: Network does not understand semantics, only operate on the meta data, without any knowledge of information carried in chunks.

Question May be Raised

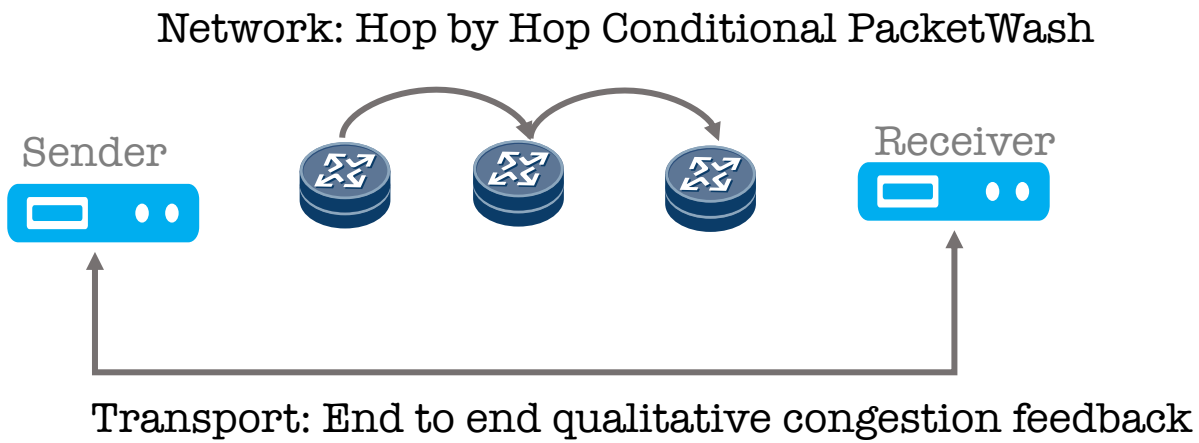
- Can we simply reduce the packet size to the chunk size, and transmit each chunk as an independent packet?
  - Increased overhead of the protocol headers and underlying packet latency for the same amount user data.
  - Reduced bulk protocol throughput, and a greater number of packets to be processed by the network.



Agenda

- Motivation & Concept
  - Traditional means of dealing with retransmission.
  - Qualitative Service
  - New Packetization
- **Qualitative Service Techniques**
  - Qualitative Service Framework
  - Generic Packet Wash Operation
  - Adaptive Rate Control
  - In-Packet Network Coding
- In-Network Qualitative Packet Processing
  - BPP Based Implementation Strategy

Qualitative Service Framework



Application Qualitative Payload (chunks, priorities)
Transport Layer (congestion notification protocols)
(Qualitative Context and Action) Network Layer

Application Level Support:

- Only an application can tell what can be treated qualitatively and how to treat it.
- Application feeds meta-data to network layer.

Transport Level Support:

- Sender should be informed of Qualitative operations.
- The partial dropping of a packet should be understood by sender as a warning that some level of congestion is occurring.

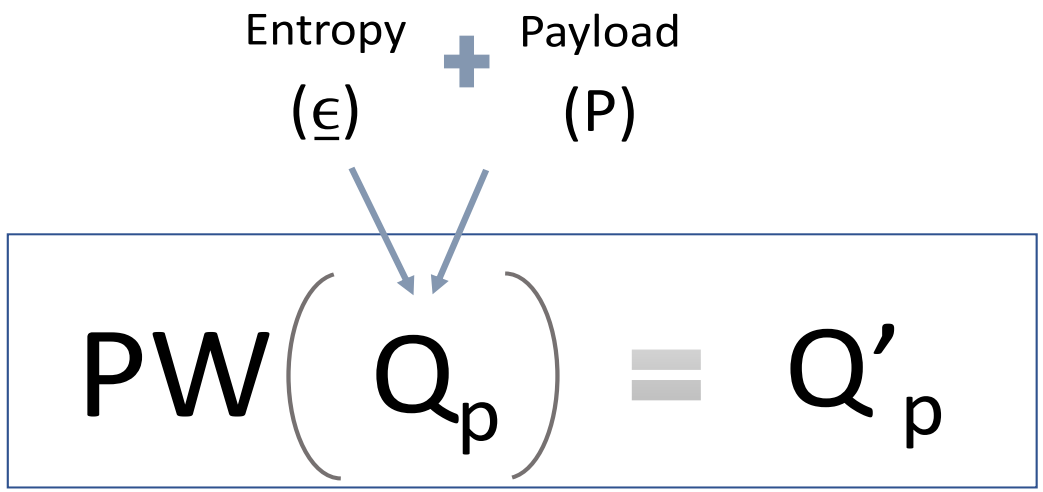
Network Level Support:

- Network layer needs a well-formed meta-data to conditionally do operations
- In-network Processing

Generalized Packet Wash Operation

Q-Entropy: describes the rule to alter the payload.

- A chunk-dependent significance parameter understood by this function;



PacketWash: Action that changes the payload.

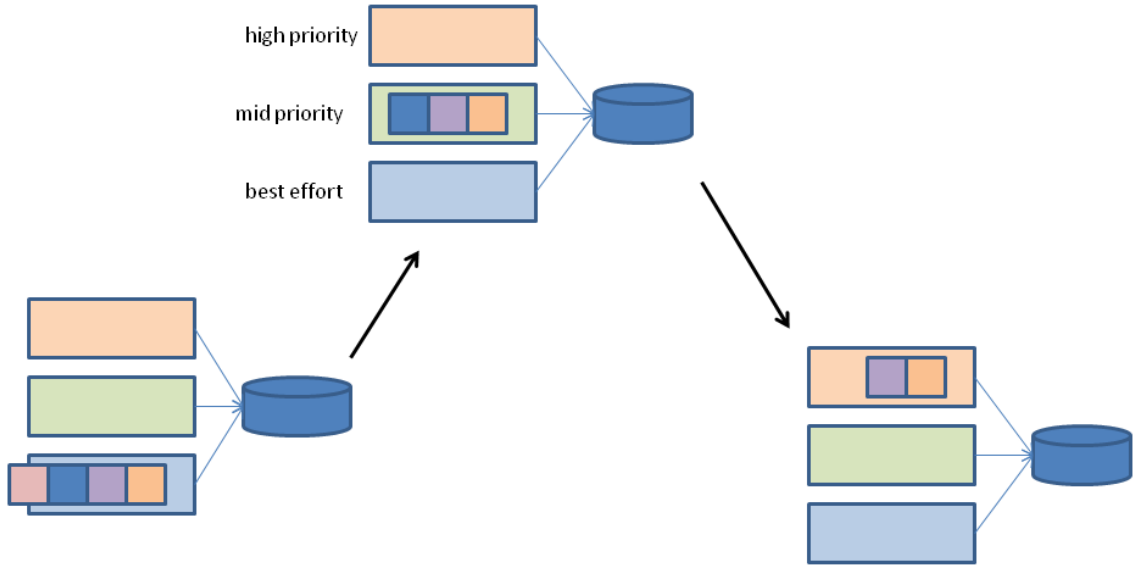
- Is a function through which network nodes treat a qualitative packet;
- Has thresholds beyond which a packet cannot be further degraded (as it would become useless);
- Triggered on Network conditions or congestion.

Adaptive Rate Control

- Packet Wash performs selective trimming of a payload from less to higher significant chunks.
- Trimming of packets is a signal of congestion
- This can be viewed as a form of Early Congestion Notification (ECN) coupled with an immediate reaction
  - The receiver selectively acknowledges the received chunks, and not the packets
  - The sender can take action to reduce the sending rate to match the observed throughput, so as to avoid further chunk drops
  - Optimal control loop is for further study

Transport Layer for Qualitative Services

- After a trimming operation, the network may increase the priority/TOS of the packet
  - Occurs from the lowest priority first

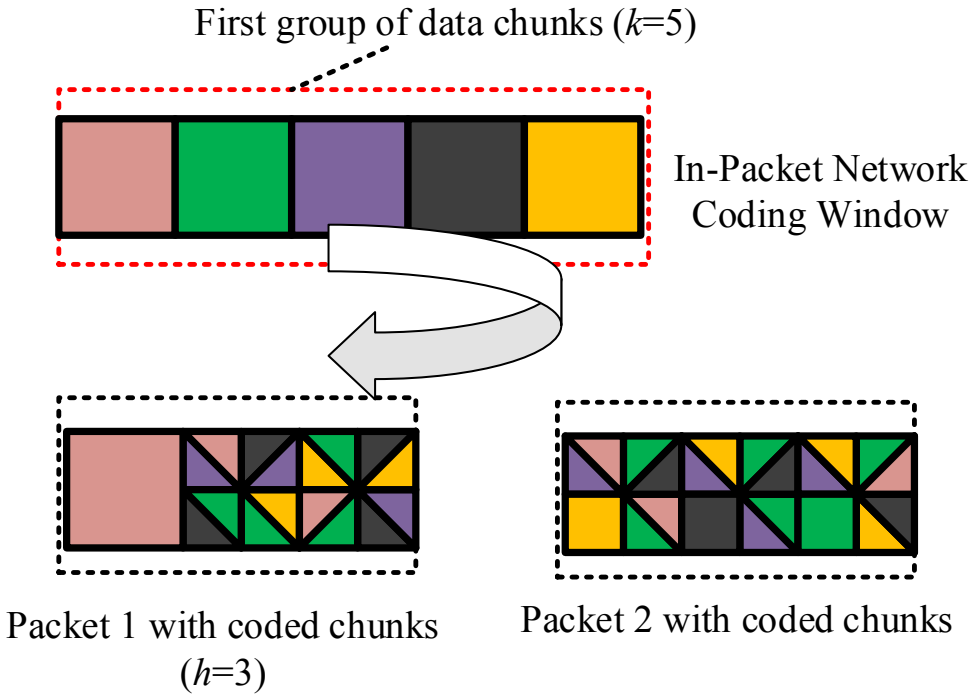


- For fairness:
  - To ensure the same flow is not trimmed twice before another flow is trimmed once

- For performance:
  - To speed up the delivery of a packet that has already encountered congestion

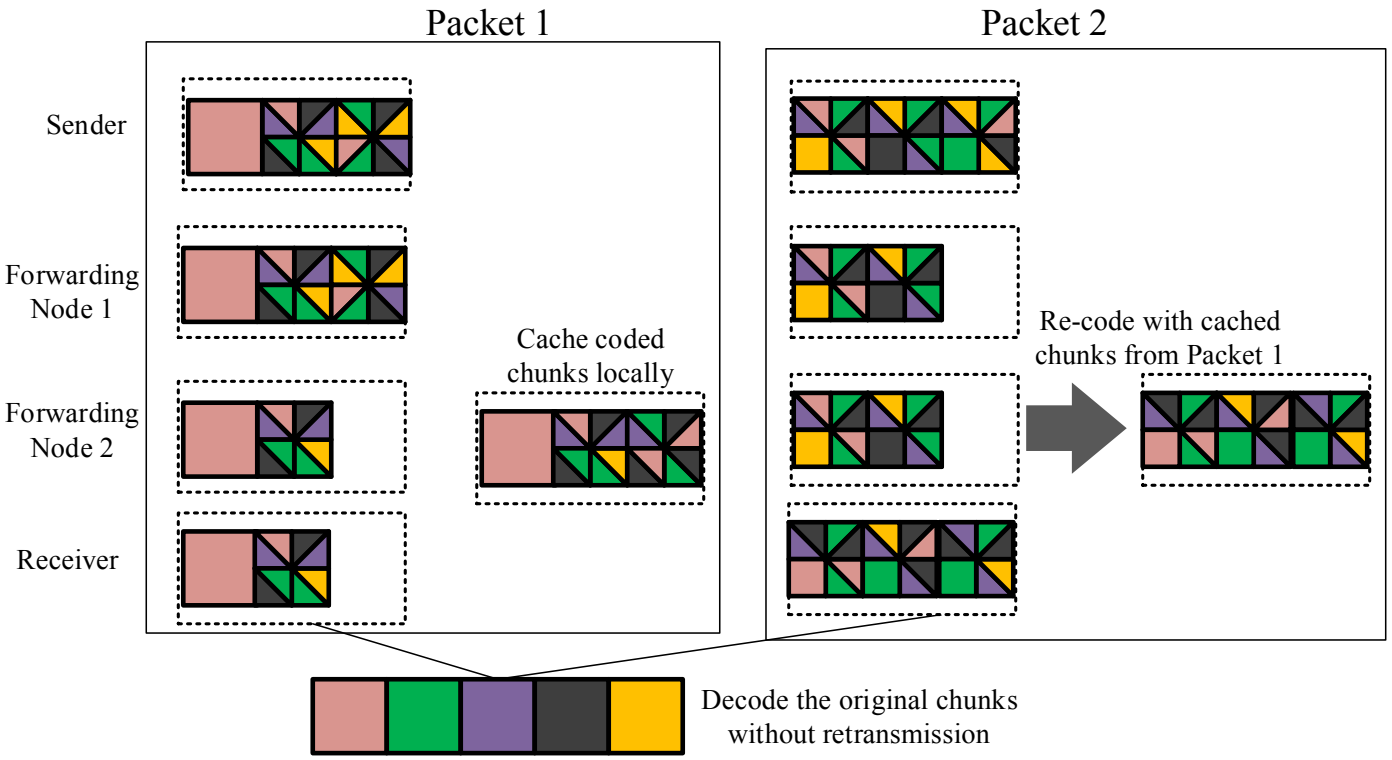
In-Packet Network Coding

- Network-coding granularity is reduced from packets to chunks.
- The data to be transmitted is segmented into groups of *k* chunks.
- Create payloads by inserting network coded chunks.
- The receiver needs *k* chunks (or degrees of freedom) to decode the chunks.
- Qualitative communication services can be facilitated by utilizing the in-network packet wash on coded packets.



Benefits of In-Packet Network Coding

- The sender can add some ratio of redundancy in the packet payloads.
- The remainder of the payload can be cached by the receiver and are useful for future decoding.
- When network congestion happens, the intermediate router does not need to decide which chunk to drop, it can randomly select as many chunks as needed until the outgoing buffer permits to contain the packet.
- There is no need for priority in this context and not need to track which specific chunk has been lost.



Side-Effects of Qualitative Packetization

- Since Qualitative service is a new packetization scheme,

  Payload integrity must be preserved (network never interprets user payload)

- While we do not propose a format of Qualitative packet:
  - Chunk Offset - Now each Chunk is an independent entity other than forwarding header. Relative offset from the start may be used to delineate chunks.
  - Encryption – over payload is not helpful in this scheme, it must be at chunk level
  - Checksum – similarly, checksum independence is necessary.

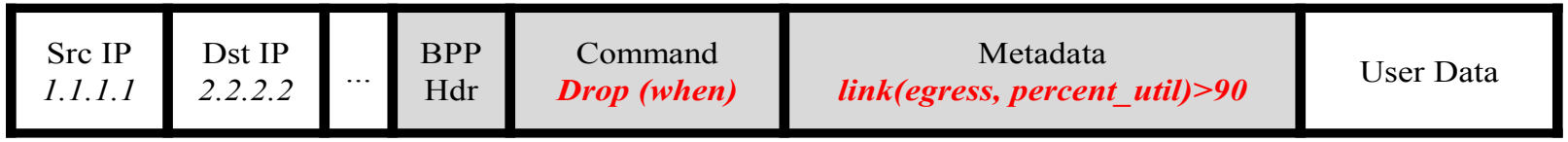
Agenda

- Motivation & Concept
  - Traditional means of dealing with retransmission.
  - Qualitative Service
  - New Packetization
- Qualitative Service Techniques
  - Qualitative Service Framework
  - Generic PacketWash Operation
  - Adaptive Rate Control
  - In-Packet Network Coding
- **In-Network Qualitative Packet Processing**
  - **BPP Based Implementation Strategy**

Background: Big Packet Protocol

- Presented at NEAT'18 Workshop (prior work)
- Positioned as new data plane for forward-looking new and emerging applications.
- Processing of packets is guided by commands and metadata carried in the packet to define packet and flow behavior
  - BPP Supports QoS, reservations, forwarding decisions, operational visibility
  - Nodes act on SLO metadata, affect forwarding decision depending on local conditions, conduct measurements, assess network/path conditions, ...

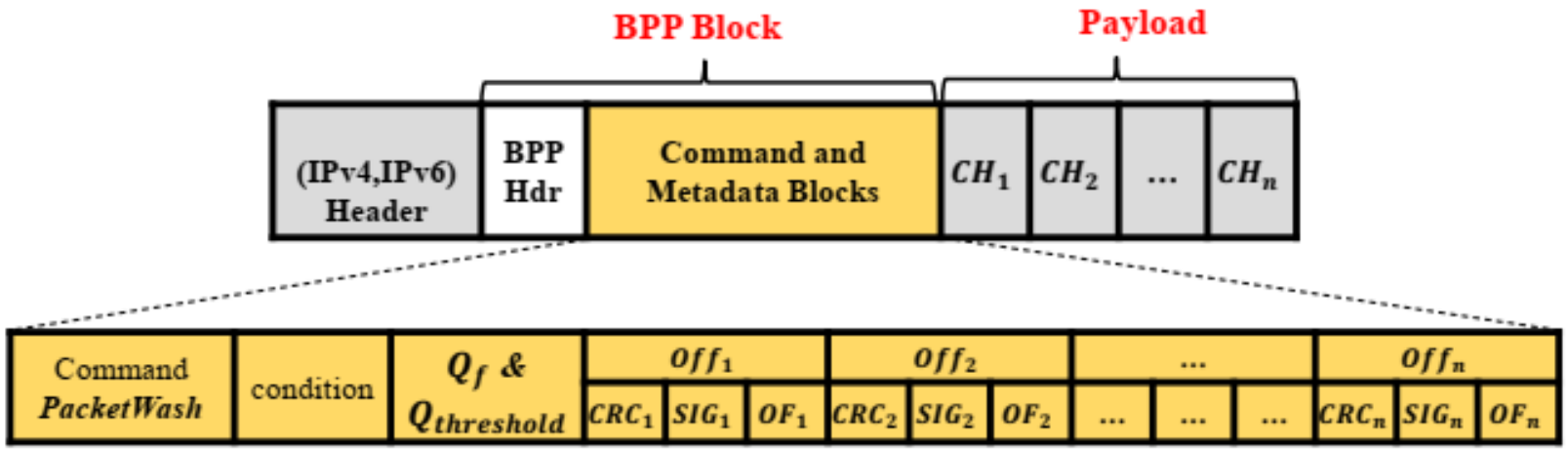
Generic BPP Packet Format



Why not extend this to realize PacketWash operation…

Qualitative Service via PacketWash in BPP

```
PacketWash:
        if (network(congested) >= 80%)
            if (Qf< Qthreshold) then
               trim(Payload, CHn) else drop
            else forward_normal
```



Recall Packetwash… Trim, forward_normal, drop are PW **actions;** Q_f and$Q_{thresh,}$ map to **entropy rules**, and CH_1 + CH_2… CH_n form **Qualitative Packet**

Summary

- Qualitative Service Motivation: A proposal to consider packet chunk as a logical unit and defined qualitative service in the context. Defined Qualitative packet, entropy, and description of chunks.
- New Paradigm: Although we used cost of retransmissions in the network as motivation, the scope is much broader. We explored new challenges of encryption, checksums etc.
- Framework: An end to end Qualitative service framework and building blocks
- Realization: touched upon three different schemes: PacketWash, Adaptive rate control, and in-packet network coding: each with different benefits.
- In-network support: BPP specific suitability, a new directive and its formalization
- Future work – Have performed transport layer evaluation, introduced as basic service in FG-NET-2030.


Q&A

Backup

Related Work: Example 1

FlexCast: Graceful Wireless Video Streaming,

S. Aditya, S. Katti, ACM MobiCom'11

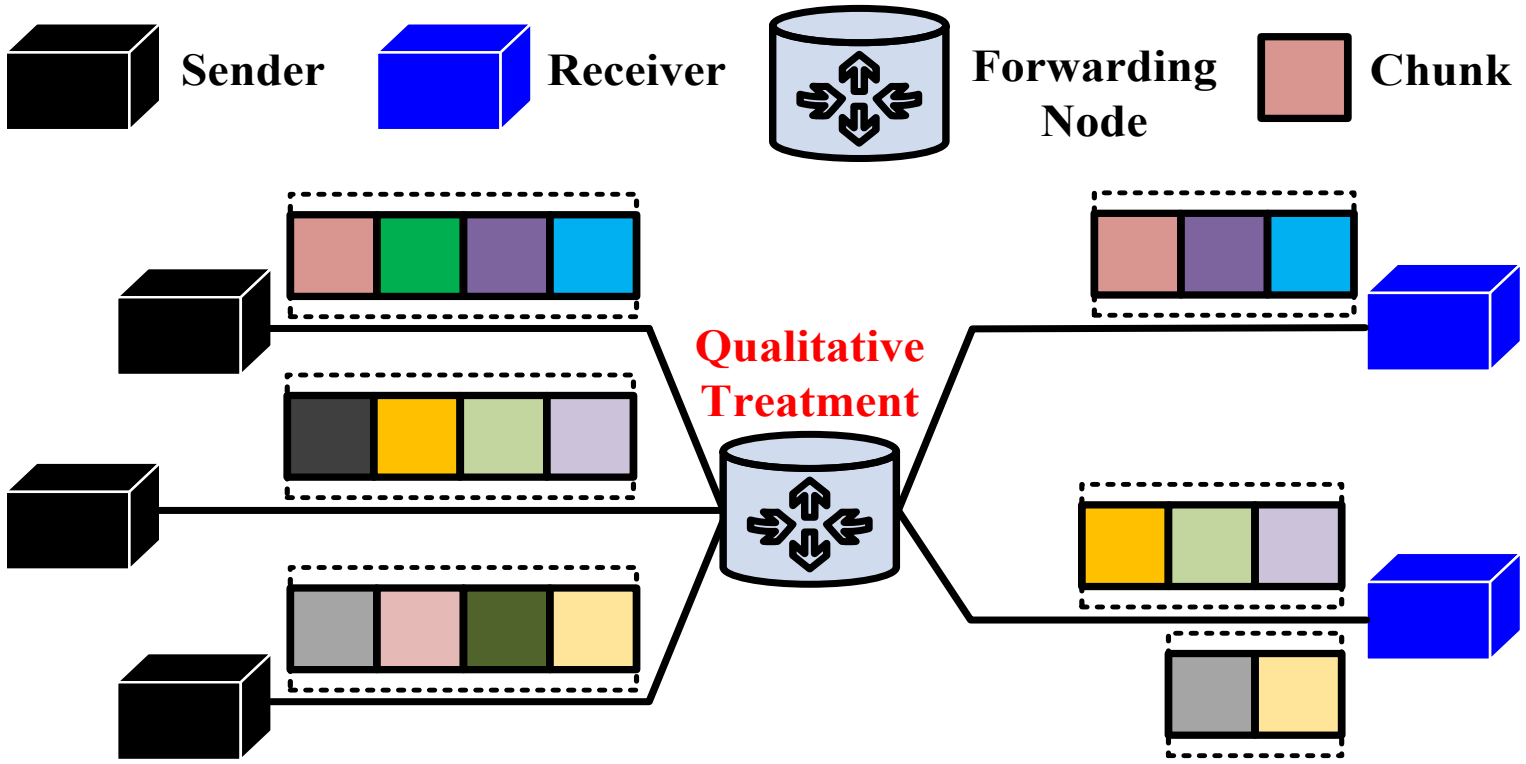
- Key idea: scalable rate-less code so that the more packets are received, the better the video representation
- Basically, the sender aggressively transmit, and if bits are dropped over the wireless channel, then it does not matter. The more received bits translate into a higher resolution
- For broadcast/multicast, this allows to transmit a potentially high rate, and receivers will get whatever their connection allows.

Related Work: Example 2

Re-architecting datacenter networks and stacks for low latency and high performance,

M. Handley et al, ACM SIGCOMM 2017 & Catch the Whole Lot in an Action: Rapid Precise Packet Loss Notification in Data Center, P. Cheng et al, USENIX NSDI 2014

- Specific context, namely that of the data center
  - In particular, the requirements are DC specific, namely fast transmission (therefore very shallow buffers, therefore a high risk of packet drops when congestion)
- Packets have two roles – two layers of information:
  - Transmit payload
  - Signal that the sender is still transmitting at some rate, and therefore sender should request more packets
- Papers propose to drop the payload but keep the header!
  - So that re-transmission can be requested right away (no time-out, and the congested link does not go idle due to transport backing off)
  - Lossless network for metadata!
  - To allow for receiver-based congestion management (in the SIGCOMM paper)


Sender
Receiver
Forwarding Node
Chunk
Qualitative Treatment

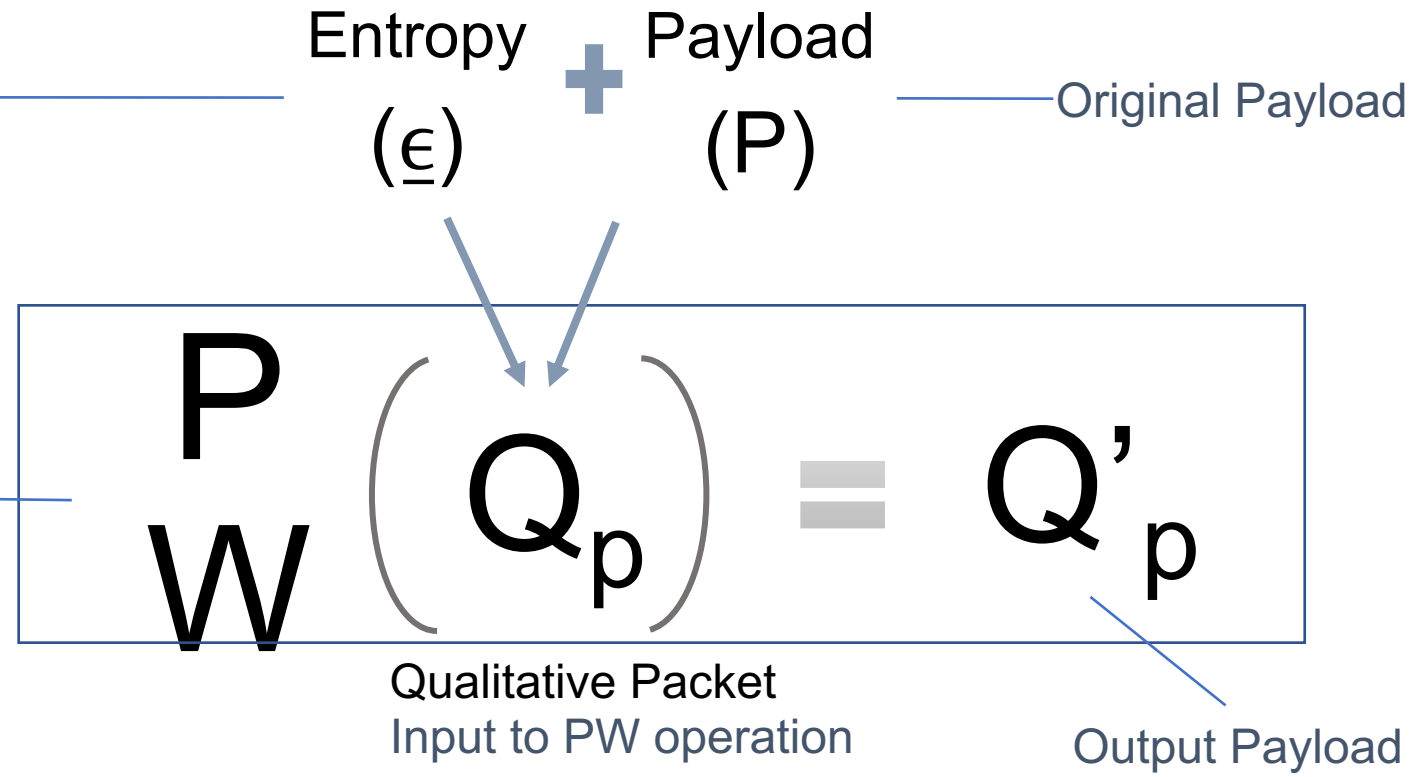
Generalized Packet Wash Concept

Entropy: Rules

- Quality of different parts of payload (significance/priority)
- Rules to alter the packet

PackWash: Action

- PacketWash Operation on a Qualitative Packet.
- e.g. may reduce the size of a packet while retaining most of the information



Formal Definition of Packet Wash Directive

- **conditional-directive**: Packetwash only makes sense if the outcome is likely that the packet will reach the receiver.
- **q-entropy function**: The rules of how to treat a packet are carried as Entropy (based on the significance-factors associated with chunks).
- **Resource-resolution/Incentive**: We reward Qualitatively treated packets by bumping their priority.
- **latency-constraint**: If a qualitative packet is determined to arrive late at the destination even after qualitative treatment or at the cost of processing, then it is worth to drop it.