

# New IP Sandbox

Leveraging Linux for the design of applications  
using New IP open platform

# Tutorial Overview

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- **Introduction and Setup**
- **Part 1: Introduction to New IP (motivation and format)**
  - Rationale for New IP
  - Address Innovation
  - New IP Contracts
  - New IP Design on Linux
- **Part 2: New IP Sandbox Test Environment**
  - Introduction to Linux namespaces and NeST topology creation platform.
  - NeST Design and Features
  - Platform for New IP Sandboxing
- **Part 3: Demonstration of the use cases**
  - Forwarding based on Asymmetric addresses
  - Developing Contracts latency-aware forwarding.
  - Platform Capabilities
- **Part 4: Service extensibility on New IP platform**
  - Extension scenario of latency-aware scheduling and forwarding for multiple time constraint streams.
- **Wrap up**

# Presenters

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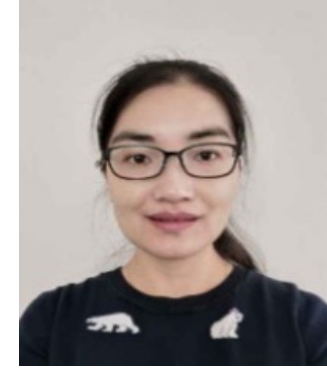
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Deepta and Shanshak (NITK) for support with tutorial and access to New IP VM

# Setup

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- Slides and VM for hands on portion of the tutorial
  - [Location in Github: <https://github.com/network2030/NewIP-Linux>]
- Access Cloud Account to VM
  - [Here]
  - [Download for your own use]

# New IP Overview

Basic Specification

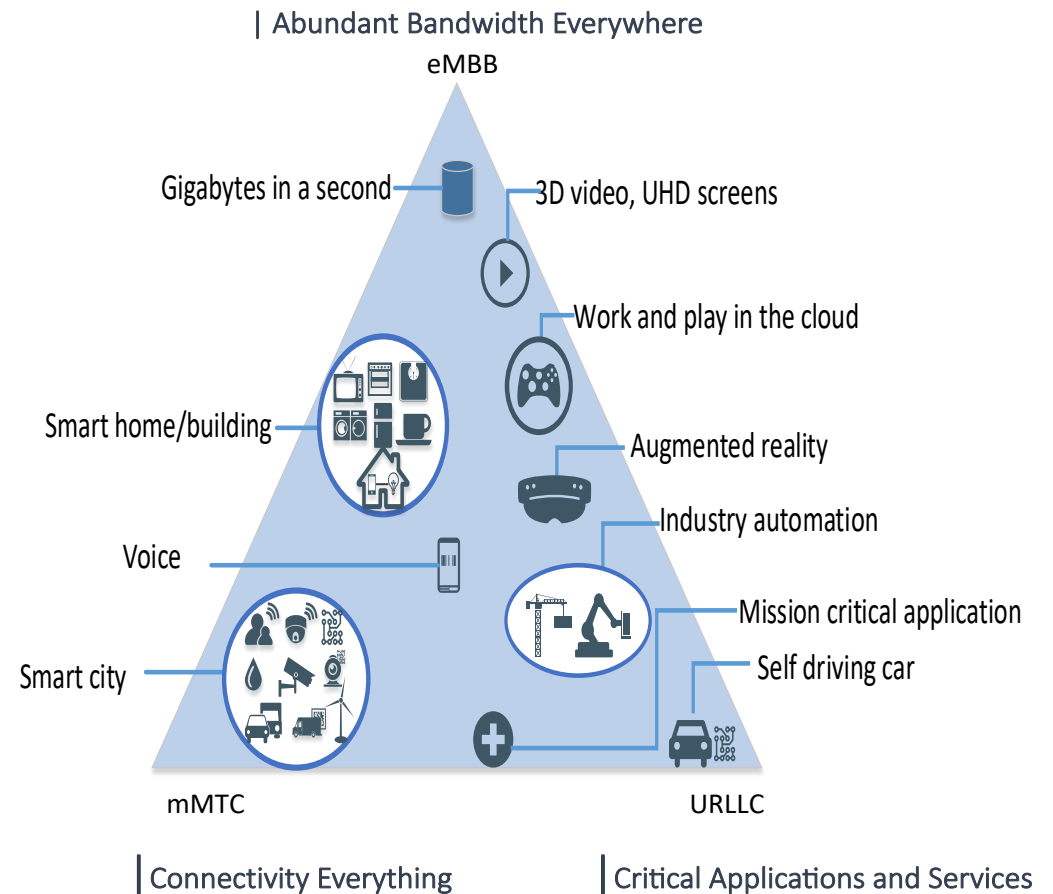
# Network Requirements

- Support for several billions of devices.
- Support for a variety of connections
- Support for terabytes of high-volume data streams

## Translating to Requirements on the Networks

- High reliability in machine-centric data delivery
- Fine-grained customization of traffic
- Guarantees of data delivery
  - Timeliness, quality, throughput
- Loss less flow of traffic between the endpoints
  - Reliability
- New Security aspects
  - Digital Sovereignty, Preservation of Privacy
- Digital Twins & Cyber physical systems.

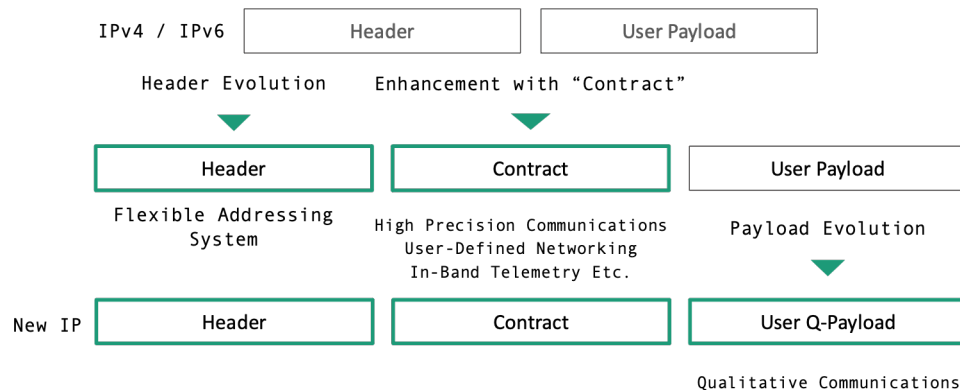
Understand impact of these requirements on the current network architecture



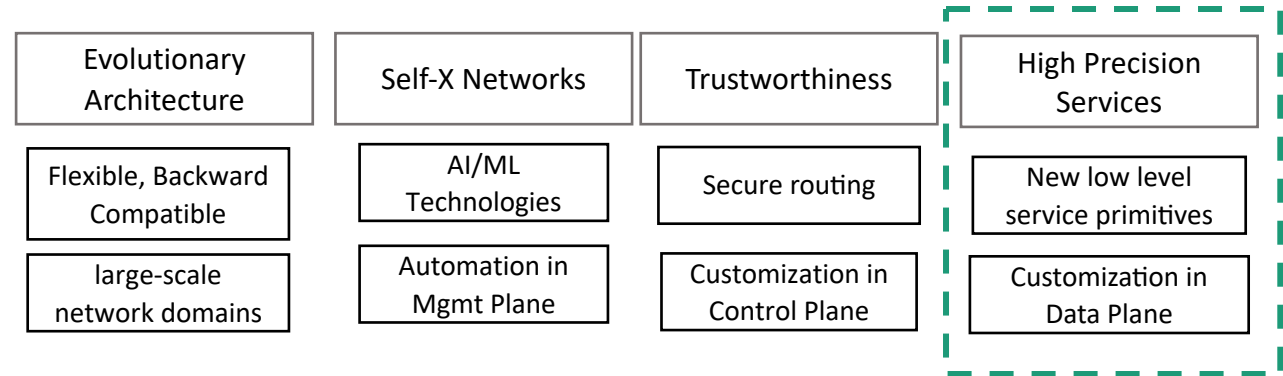
Source: ITU-T IMT-2020

# What is New IP?

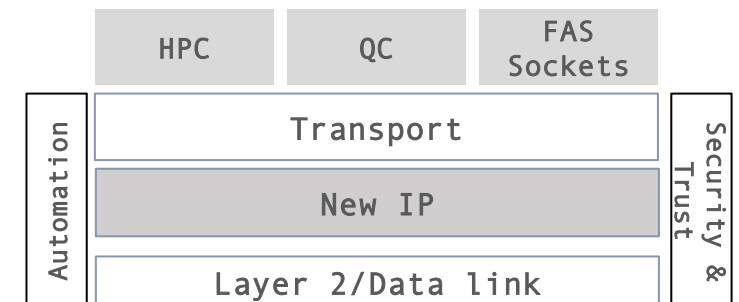
An abstraction of Network Technologies across different dimensions to enable next-gen application scenarios



An early stage of concept to support newer applications in evolutionary, flexible and programmable manner



Promotes Holistic approach vs Siloed approach: past few decades network innovation are driven by specific requirement within the constraints of current network architecture



# New Network Service Primitives

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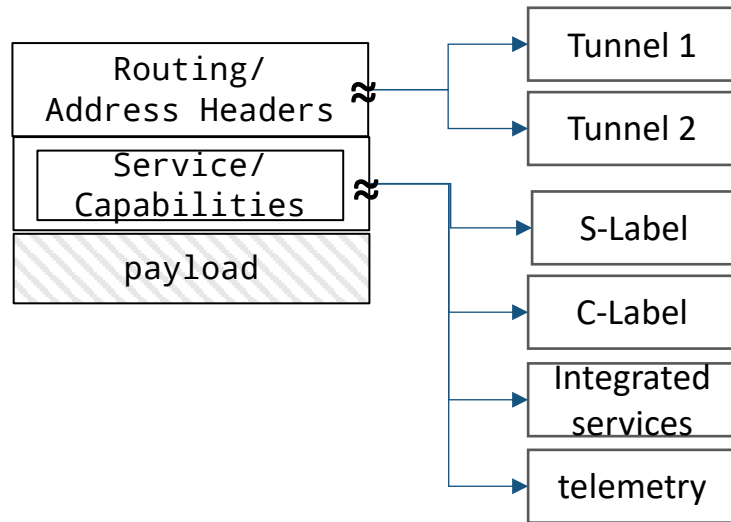
- Best Effort
  - Forward a traffic flow from a network node
- Differentiated services
  - Ingress - Enable classification, Police and mark traffic
  - Core – Queuing Dropping, Per-hop behavior (PHB) for minimum rate assurance, egress shaping and aggregate traffic
- Traffic Engineering
  - path selection based on constraints on bandwidth
- Limitations when dealing with newer applications
  - ✗ Fails to provide throughput guarantees
  - ✗ Fails to provide guarantees of maximum latency (in-time)
  - ✗ Fails to provide guarantees of precise latency (on-time)

•**Technical Specification:** "[New Services and Capabilities for Network 2030: Description, Technical Gap and Performance Target Analysis](#)" (October 2019)

•**Technical Report:** "[Network 2030 - Gap Analysis of Network 2030 New Services, Capabilities and Use cases](#)" (June 2020)



# Structured Headers lead to overheads



- Services continuously evolve using heterogeneous sets of protocols and functions
- Different methods of tunneling, load balancing, congestion control and Quality of Service, firewalls and intrusion detection systems.

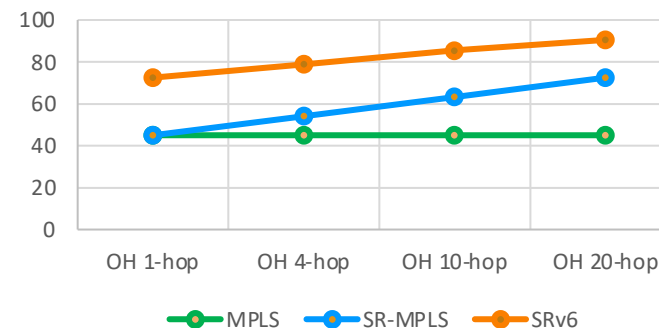
MPLS	bytes	MPLS-SR	bytes	SRV6	bytes
				IPv6 Encap	40
				SRH header	8
Transport Labels	4 to 12	Transport Labels	4 x SID count (upto 30)	transport SID	16 x SID count (upto 30)
Service Label	4	Service Label	4	ServiceSID	16
Outer IPv4 (for GTP)	20	Outer IPv4 (for GTP)	20	UDP Hdr	8
UDP Hdr	4	UDP Hdr	4	GTP	12
GTP	12	GTP	12	Inner User IP	20
Inner User IP	20	Inner User IP	20	User Transport	4
User Transport	4	User Transport	4	User Payload	4 to 1200
User Payload	4 to 1200	User Payload	4 to 1200		

$$transport\ OH\ \% = \frac{(Path_{oh})}{(Std_{hdr} + Path_{oh} + Pl)}$$

## Observations

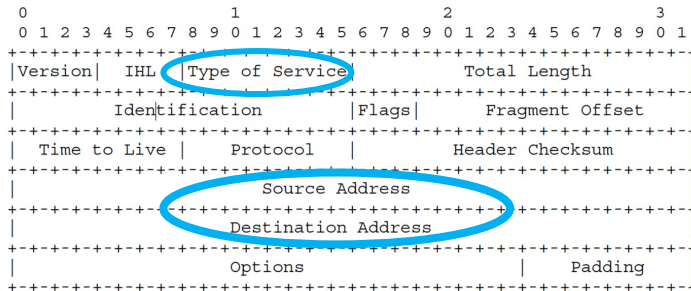
1. With Segment routing TE (MPLS or V6) overheads go up with No of hops.
2. General overhead for 4-byte packet is very high (with Std TCP/IP hdr included)
3. Segment routing TE vs MPLS has control plane complexity trade offs.

4-byte: Overhead in % of total length



Example: Transport Backhaul Path overhead

# Packet Formats - Services



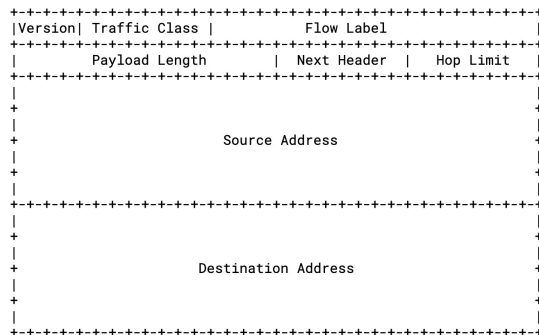
Missing Information for the Networks and Routers

Throughput for the media application

Latency for the underlying application requires

Other resource requirements the application may have – level of security, path, functions

Additional Primitives: Tracking, Receipt notification, Cost & Energy



Compound Service	Criteria	Use cases	Time scales*
Qualitative Service	Conditional to network state	High throughput multimedia such as Holographic applications	~ 40 ms
Holographic Type Communications	Coordinated, time dependence and high bandwidth	High bandwidth requirements, different encoding for teleconferencing vs 3D medical imaging	~30 ms
Digital Teleportation	Coordinated, synchronized,	Digital replicated live-environment	~30ms
Tactile communications	Time dependence and reliability (zero packet-loss)	Variable encodings of haptics, optionally high bandwidth requirements, fast responses.	< 10ms

# Packet Formats - Addresses

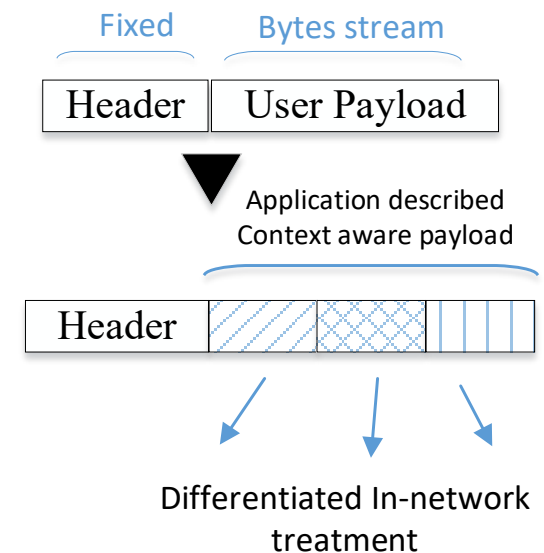
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- Private Networks are growing faster
  - Higher degree of customizations are required
    - Control: Managing internal networks like the Internet is not ideal.
    - Services: Different industries have different requirements.
- Addresses: There is no ideal fixed-length or format of an address
  - Smaller networks should not have to carry overheads of larger fixed-sizes
  - Smaller payloads + smaller headers improve energy efficiency.
  - Custom address structures protect networks from well-known vulnerabilities
  - Global Reachability  $\neq$  Global address space
  - Symmetrical addresses – should source/destination addresses must belong to same address family?

Diverse range of types of end hosts. E.g., IoT devices need energy efficiency, chunks of distributed media content needs descriptive addressing.

# Packet Format – Qualitative Payload

- Network is blind to Semantics associated with the packets
  - Payload itself is treated as raw, uninterpreted, unchangeable.
  - The tolerance to packet losses in the volumetric media applications is extremely low, and the problem
- Means to support Qualitative Communications
  - Network perceives the semantics of the packet payload, e.g., boundary, importance variation, relationship among different parts in the packet;
  - The unit of action taken by the network does not need to be on the entire packet.
  - E.g. achieving near linear throughput, if packet losses due to congestion are eliminated.



# Basic Structure of the New IP Packet

From these observations we conclude that the evolution of the network layer itself is necessary for innovations in the data plane and forwarding planes technologies.

Our proposal is very simple

1. It describes a packet format that evolves independently across several dimensions.
2. It maintains network layer as universal – accommodating all types of communications
3. Is backward compatible
4. The specification for the new packet format:

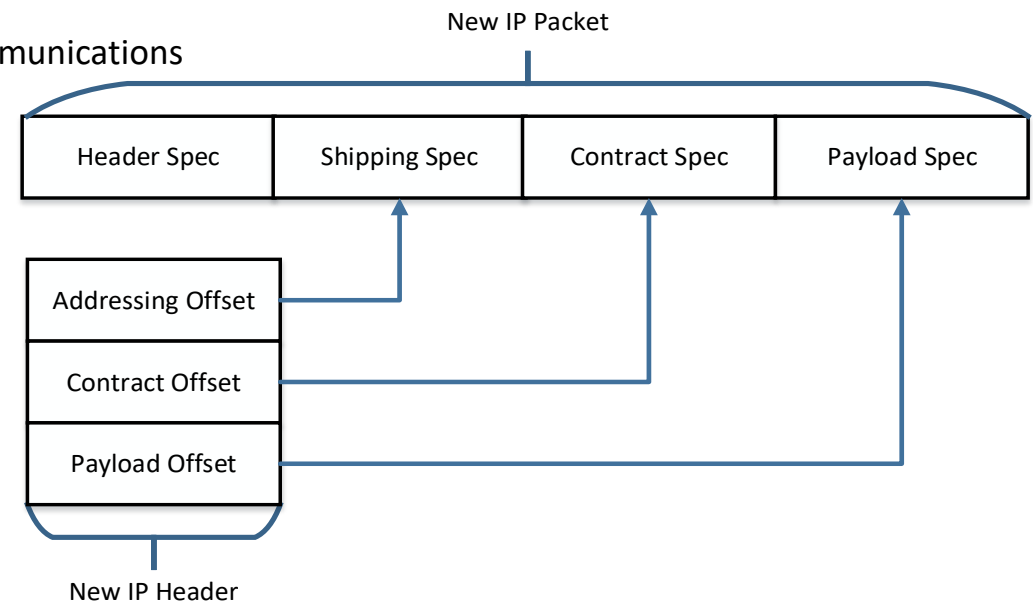
The structure is defined using the “Header Spec”

Shipping (Addressing and Reachability functions)

Contract Spec (service specific goals)

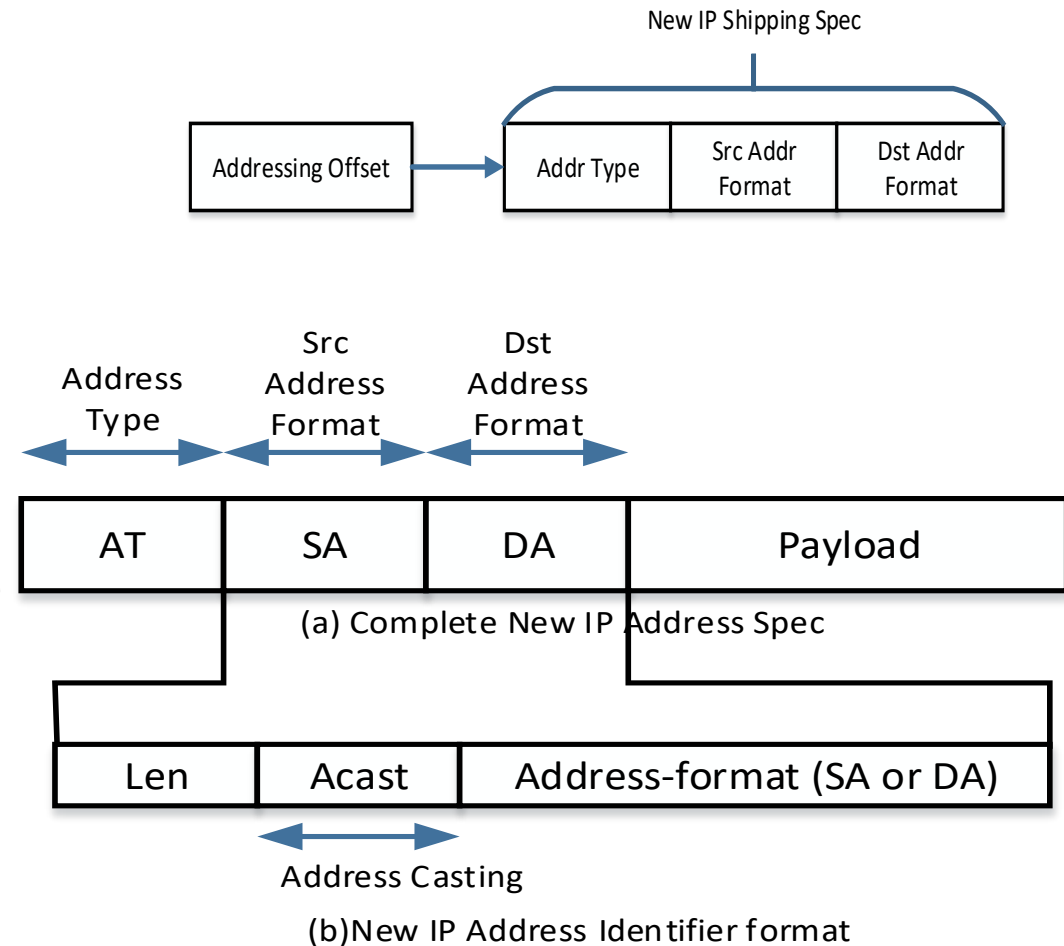
Payload Spec (packetization of user payload)

Header Spec is a very small header with offsets to other parts of the structure



# New IP Shipping Spec

- key features: (a) flexible address format scheme, (b) backward compatible, and (c) hybrid addressing.
- Hybrid addressing is supported by allowing both source and destination formats to be specified independently
- Address Type (AT) field is the first field routers or nodes look at.
  - For backward compatibility, AT will use reserved mnemonics such as IPV4, V6, MPLS etc. Then the remaining packet is the classic IP/MPLS.
  - Otherwise AT can reflect combination of source and destination address types.
- Address-cast (Acast) describes communication patterns such as unicast, groupcast, multicast, coordinated-cast etc.



# New IP Shipping Spec Examples

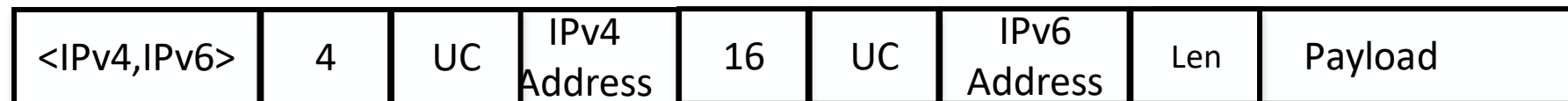
- Backward Compatibility

For example, IPv4 and MPLS in New IP

- In these cases AT will use reserved mnemonics such as IPV4, V6, MPLS etc. Then the remaining packet is the classic IP/MPLS.



- Asymmetric Addresses in Shipping Spec



# New IP- Contract

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- A contract is service specification of a service associated with the packet.
- It can be optional. Then the contract offset will be set as NA.
- Event and Conditions specify when Action take place. – tremendous potential for the research and development of data plane technologies
- It can be composed of one or more clauses; Each clause will be a high-level data plane action. For example, in order to support Ultra-Reliable Low Latency (uRLLC) in 5G, two contracts C1 and C2 can be used.
  - C1 contract clause indicates the BoundedLatency action, and clause
  - C2 has action NoPktLoss i.e., the low latency and reliability are to be met.

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```
<Contract> := <Contract clause>
              | <Contract clause> AND <Contract>

<Contract clause> := <Contract ECA>
                    | <Contract ECA> OR <Contract clause>

<Contract ECA> := <Event, Condition, Action>
                  | <Metadata>
                  | <Event, Condition, Action> <Metadata>
                  | <Action>
                  | <Action><Metadata>
```

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```
<Action> := <BoundedLatency>
            | <OnTimeDelivery> | <Coordinate>
            | <NoPktLoss> | <PktMonitor>
            | <ReportInsuringParty>
            | [...]
```

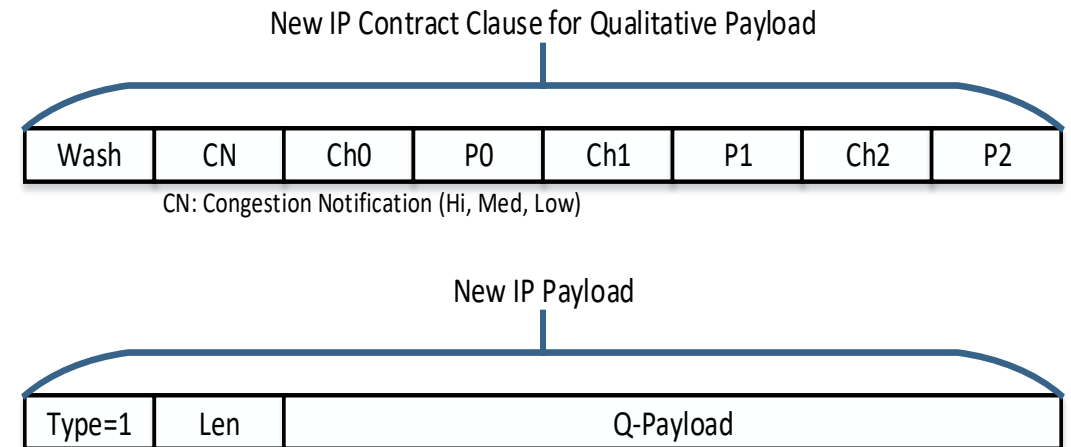
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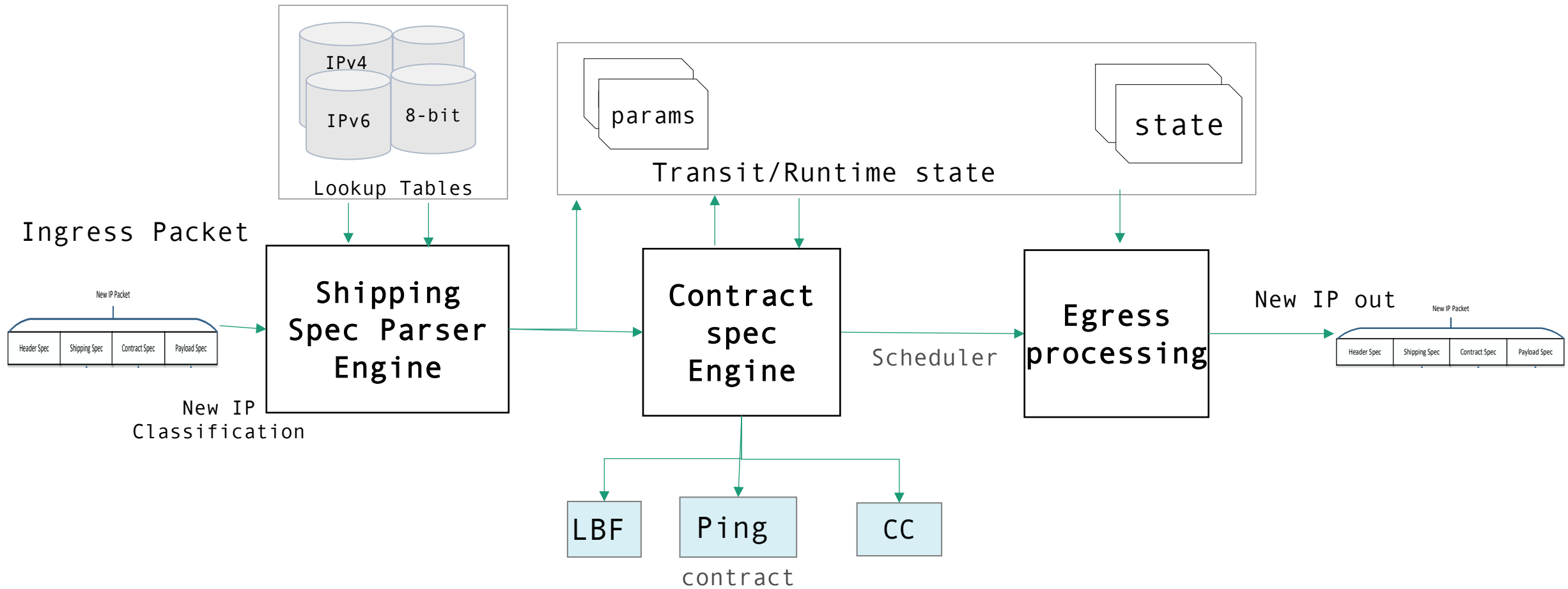
# New IP – Q-Payload

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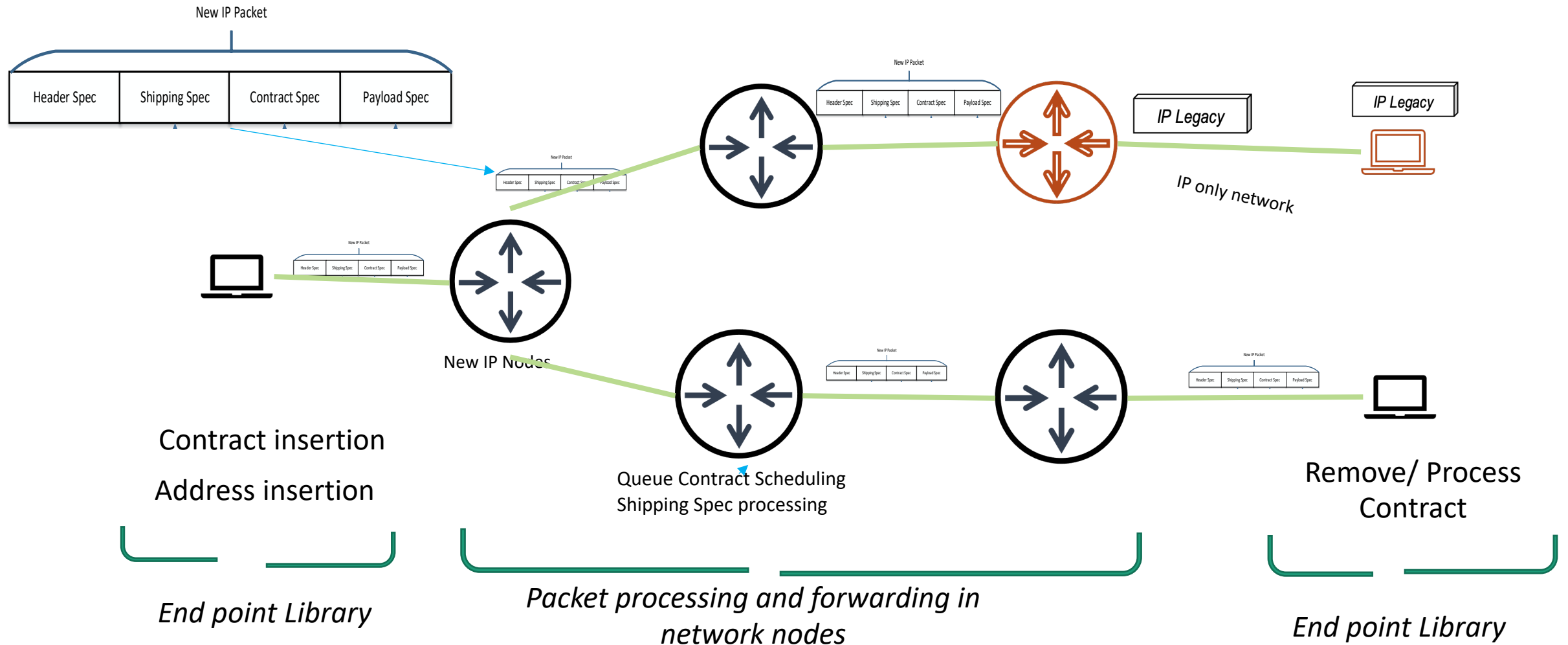
- The Payload specification is used to support qualitative payload.
- The Type field indicates whether it is a traditional or Q-payload.
- Q-payload itself needs support from Contract Specification to describe actions on Q-payload.
- For example
  - Wash: a generic operation to arbitrarily or selectively remove the bits/bytes inside the packet payload. For example, remove every 8th bit, remove every fifth byte, etc.
  - Repair and Recover: can salvage lost portions from the residual payload based on context present along with the action.
  - Enrich: The re-insert lost portions with locally cached chunks when the network condition improve.



# New IP Packet Processing Pipeline



# Realizing Proof of Concept



# Design Principles

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- Since New IP Packet format is new and carries a lot of intelligence, it was important to understand those processing overheads from
  - Design and over all implementation framework perspective
  - From performance and ease of development
- More Focus on packet processing/ not hardware
- Emphasis on Fast and flexible test and verification environment
- Our Platform choice – Linux with network name spaces
  - Reuse not reinvent
  - Linux gave us a very stable environment and a plethora of tools and features.
  - Very short learning curve
- NeST provides meets all the above design considerations

# References

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- Technical Specification: "[New Services and Capabilities for Network 2030: Description, Technical Gap and Performance Target Analysis](#)" (October 2019)
- Technical Report: "[Network 2030 - Gap Analysis of Network 2030 New Services, Capabilities and Use cases](#)" (June 2020)
- R. Li, K. Makhijani and L. Dong, "New IP: A Data Packet Framework to Evolve the Internet : Invited Paper," 2020 IEEE 21st International Conference on High Performance Switching and Routing (HPSR), 2020, pp. 1-8, doi: 10.1109/HPSR48589.2020.9098996.
- K. Makhijani and L. Dong, "Asymmetric Addressing Structures in Limited Domain Networks," 2021 IEEE 22nd International Conference on High Performance Switching and Routing (HPSR), 2021, pp. 1-7, doi: 10.1109/HPSR52026.2021.9481811.
- [IEEE GLOBECOM 2019: Richard Li, "IP: GOING BEYOND THE LIMITS OF THE INTERNET"](#)

# New IP Use cases

Lijun

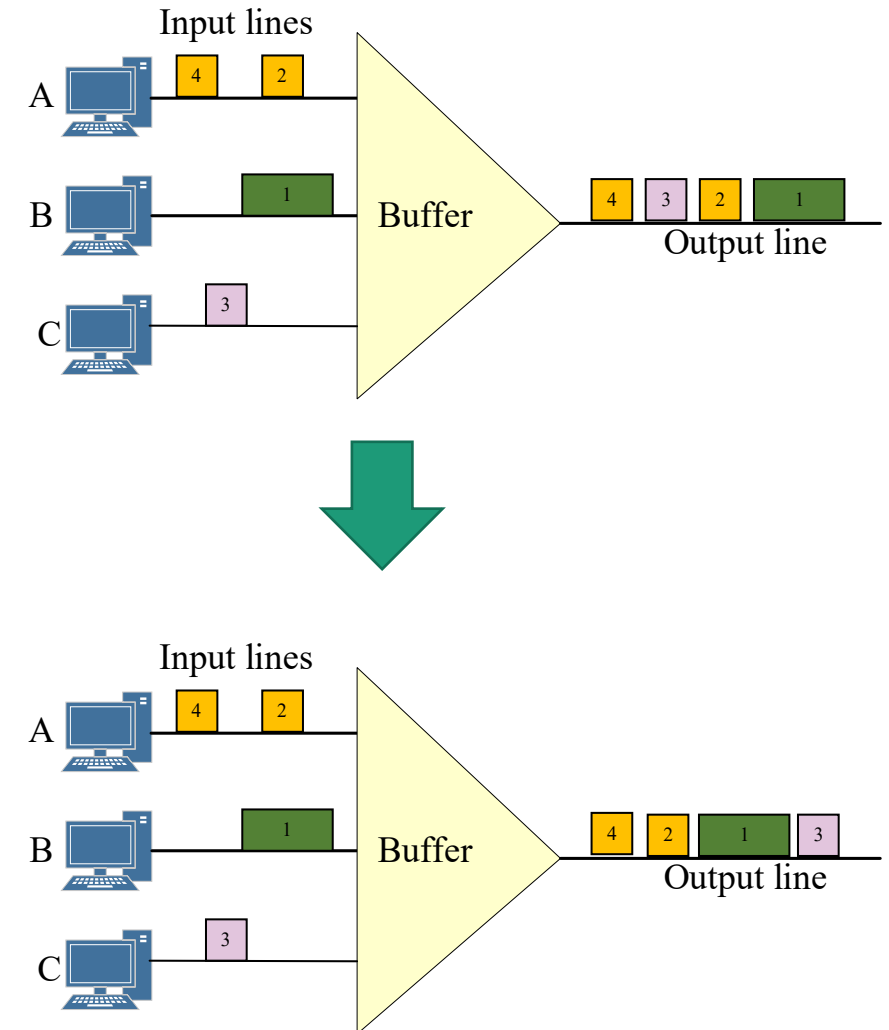
# Part II: Some Examples of New IP Use Cases

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- Optimal Latency Guarantee for Multiple Concurrent Packets
- Qualitative Communication
- Information Exchange Oriented Vehicle Clustering
- And many more

# Statistical Multiplexing to Computational Multiplexing

- Statistical multiplexing does not work at a packet level. They do not distinguish among packets on whether they are latency-sensitive or not, thus do not treat the latency-sensitive packets differently.
- Compared to statistical multiplexing in the current Internet, a computational multiplexing concept is proposed in New IP.
  - For a latency-sensitive packet, the precise location in the outgoing queue based on its time constraint can be computed, such that the scheduling order of all latency-sensitive packets can be determined.
  - Computational scheduling takes into consideration of per-packet timing data at a finer granularity as compared to flow-level granularity.
  - With computational multiplexing, simultaneously arriving packets on same output ports are scheduled deliberately in order to satisfy their deadlines if they are specified in the packets.





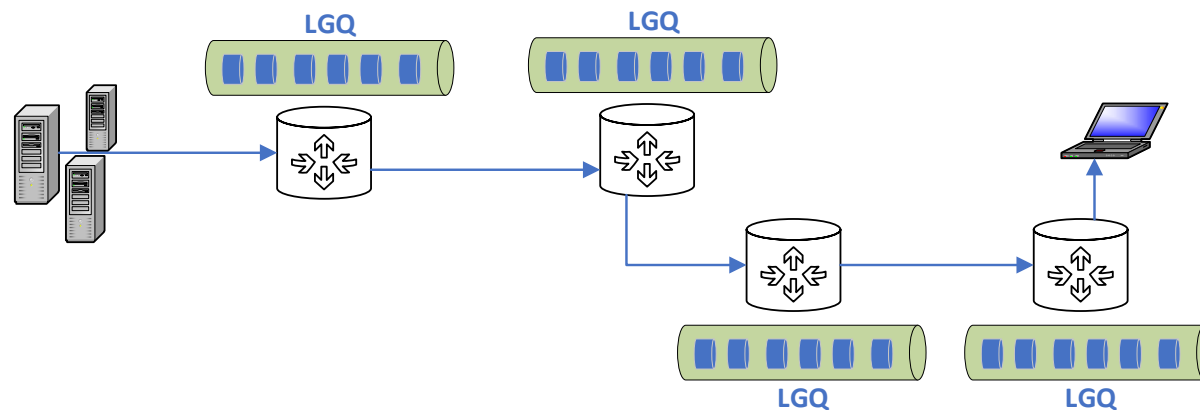
# New IP Contract Design

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- We take advantage of the Contract Spec that is defined in New IP to inform the intermediate network nodes that a packet forwarding requires end-to-end in-time guarantee. We design the corresponding Contract Clause (*InTimeGuarantee*) in the Contract Spec as follows to achieve the latency guarantee of packet delivery at finest granularity:
  - Action: deadline-aware scheduling, with the optimal algorithm proposed in the following of the paper, the packets specified with *InTimeGuarantee* are able to meet their corresponding end-to-end deadlines.
  - Metadata includes: (1) budget: it denotes the residual budget before the packet deadline runs out and is considered unsuccessful. (2) hop: it denotes the residual number of hops towards destination. Given the routing path is configured, and the total number of hops between the source and destination is fixed.

# Dedicated LGQ for Latency Guaranteed Packets

- At each router, there is a dedicated queue for latency guaranteed packets, called latency guarantee queue (LGQ)
- All packets forwarded by the router with *InTimeGuarantee* contract clause are put in LGQ. The packets in LGQ have the highest priority to be scheduled compared to other packets without deadline constraints.



# Motivation

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- From a router's perspective, it may have more than one packet (multiple packets) that require latency guarantee. The scheduling of those packets matters.
  - If FIFO is adopted, some packets in LGQ may miss the deadline.
  - The time that a packet spent at a router before it is forwarded to the next hop (called as **dwel time**) includes
    - Processing delay: likely fixed (we do not consider in the document)
    - Queueing delay: affected by packet scheduling in LGQ.
    - Transmission delay: affected by the size of the packet, proportional to the packet size.
- The **average dwel time determines averagely how long a packet stays in a router** before its last bit gets transmitted completely.
- Although previously proposed scheduling policy may be able to satisfy the deadline requirements of the packets, they did not consider how transmission delay affects the scheduling.
- A packet scheduling algorithm that adopts the computational multiplexing enabled by New IP could be designed, which **considers both the packet transmission delay and deadline requirement, achieve the minimal average dwel time.**

Packets	Deadline	Transmission Time
p1	10	5
p2	14	2
p3	15	1
p4	6	3

# Step by Step to Illustrate TDMS

Line 2: sort packets by decremental order of transmission time

Packets	Deadline	Transmission Time
p1	10	5
p4	6	3
p2	14	2
p3	15	1

Outer loop 1

TDMS	Deadline	Transmission Time
p2	14	2

Total transmission time of set  $J_1$  is  $5+3+2+1=11$ , the last packet in the TDMS schedule must be the packet with the largest transmission time that meets its deadline, which is p2.

Outer loop 2

TDMS	Deadline	Transmission Time
p1	10	5
p2	14	2

Total transmission time of set  $J_2$  is  $5+3+1=9$ , the last packet in the TDMS schedule must be the packet with the largest transmission time that meets its deadline, which is p1.

Outer loop 3

TDMS	Deadline	Transmission Time
p4	6	3
p1	10	5
p2	14	2

Total transmission time of set  $J_3$  is  $2+1=3$ , the last packet in the TDMS schedule must be the packet with the largest transmission time that meets its deadline, which is p4.

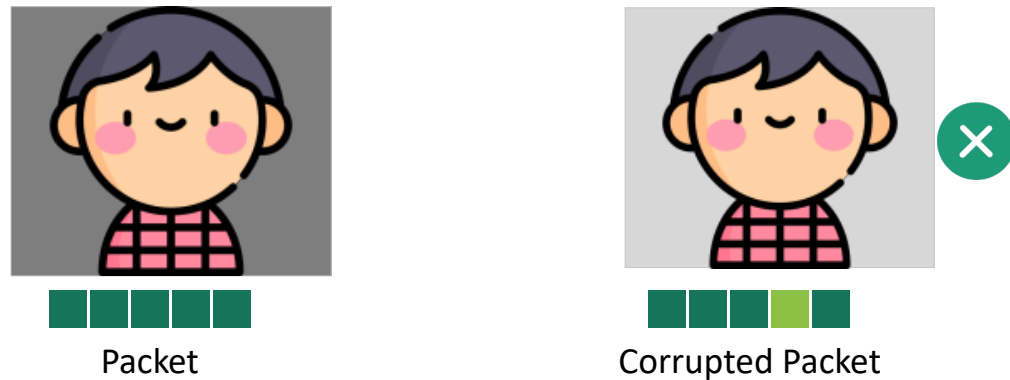
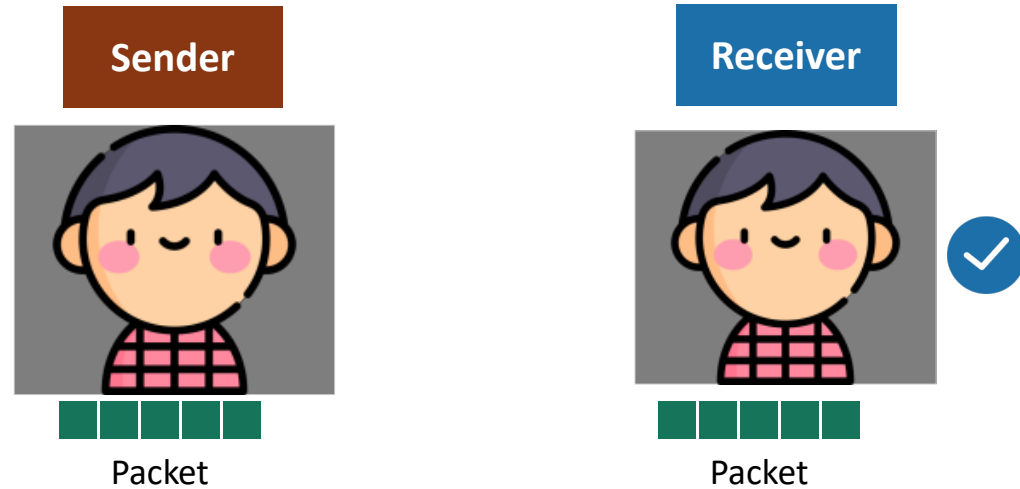
Outer loop 4

TDMS	Deadline	Transmission Time
p3	15	1
p4	6	3
p1	10	5
p2	14	2

Total transmission time of set  $J_4$  is 1. The only left packet is p3, which is put in the very front of the queue. Return TDMS.

TDMS achieves minimal average dwell time, which is  $(1+4+9+11)/4=25/4=6.25$

# Integrity of Packet



## Syntax

What is received  What is sent

Every bit and byte has the same significance to routers/switches

## Good for

- File/Document Transfer
- Banking, Shopping

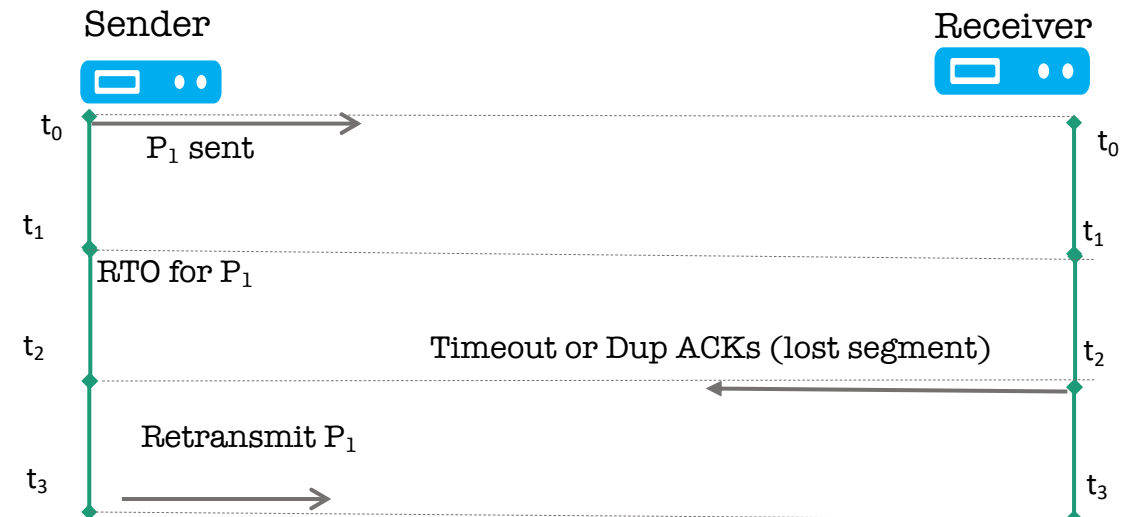
## Overkill for some applications

- Video
- Holograms

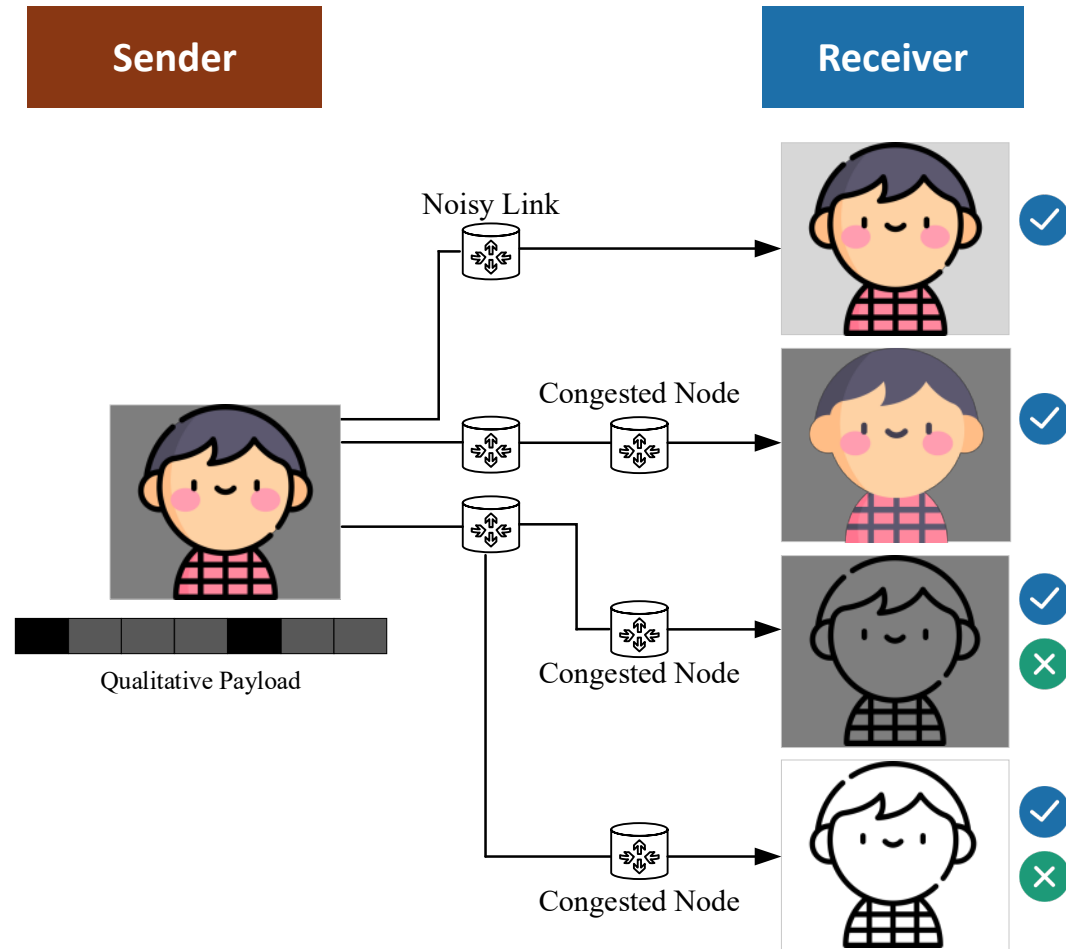
# Cost of retransmissions due to packet dropping

- 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.



# Qualitative Communication: A structure of bits and bytes



## Semantics

What is received  What is *maximally meant*

In payload, bits and bytes are not equally significant. Instead, they are different in their entropies

Less significant bits and bytes may be dropped

Partial or degraded, yet useful, packets may be repaired and recovered before being rendered

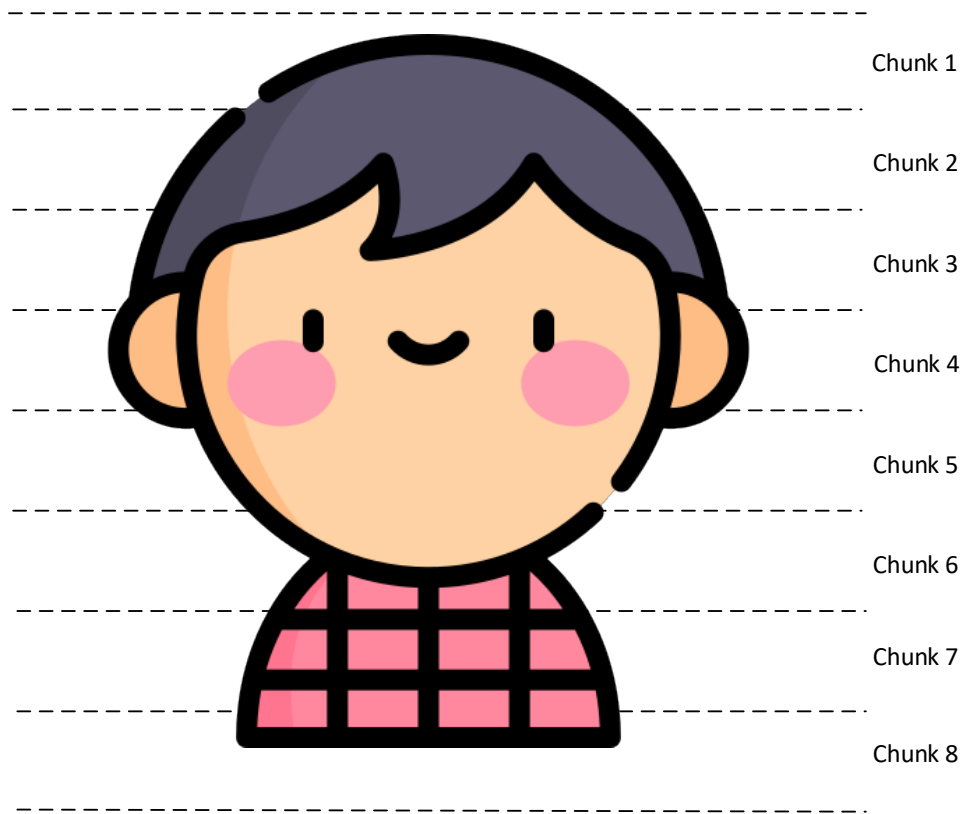
## Good for

- Large volume of image-like data
- Holographic type communications
- Media with digital senses
- Disaster Environment

# Qualitative Communication: an example for illustration only

## User Data Payload: Divided into 8 chunks.

Original Qualitative Payload Sent by Sender



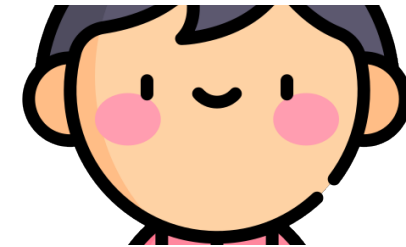
## Contract:

**Event:** Congested **OR** Radio Unstable

**Action:** Packet Wash

**Meta-Data:** Chunk 1, Chunk 2, chunk 6, Chunk 7, Chunk 8

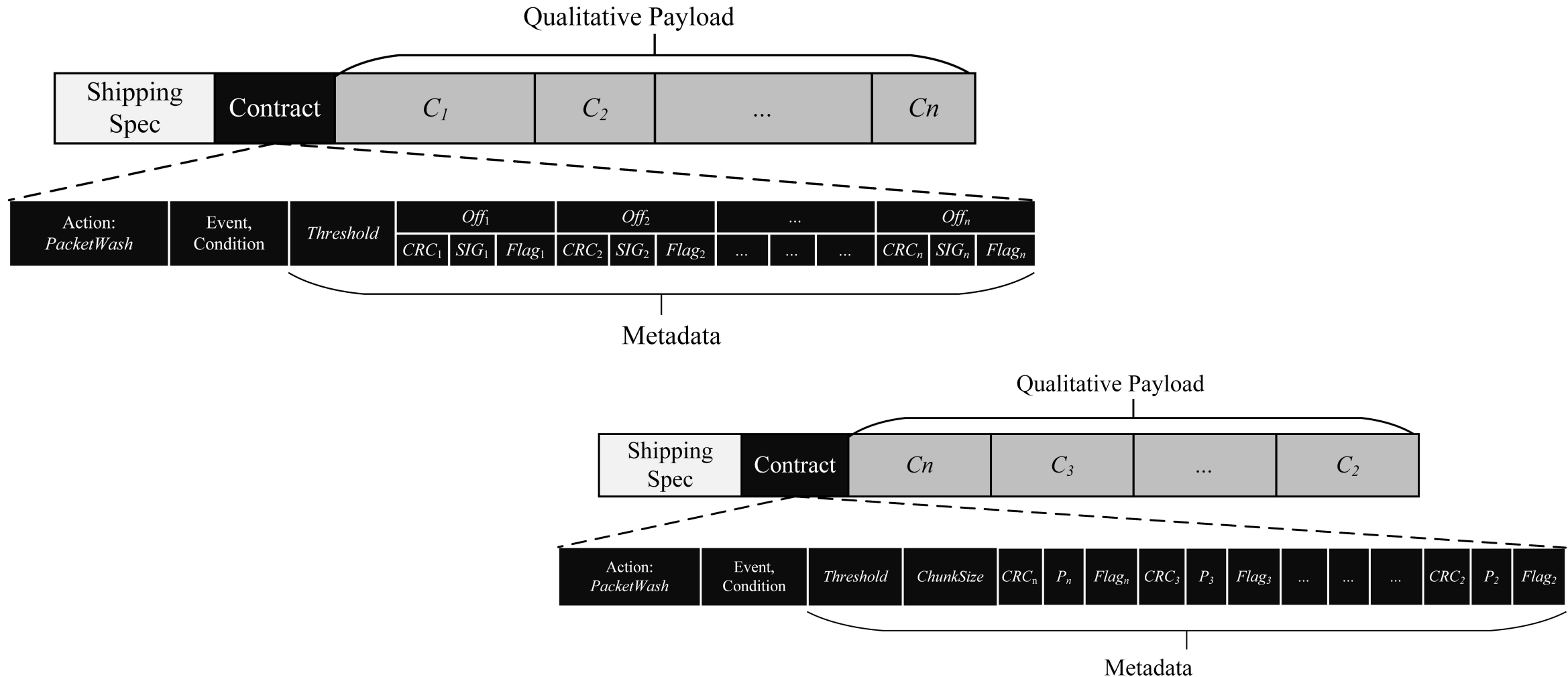
On congested node: after cut



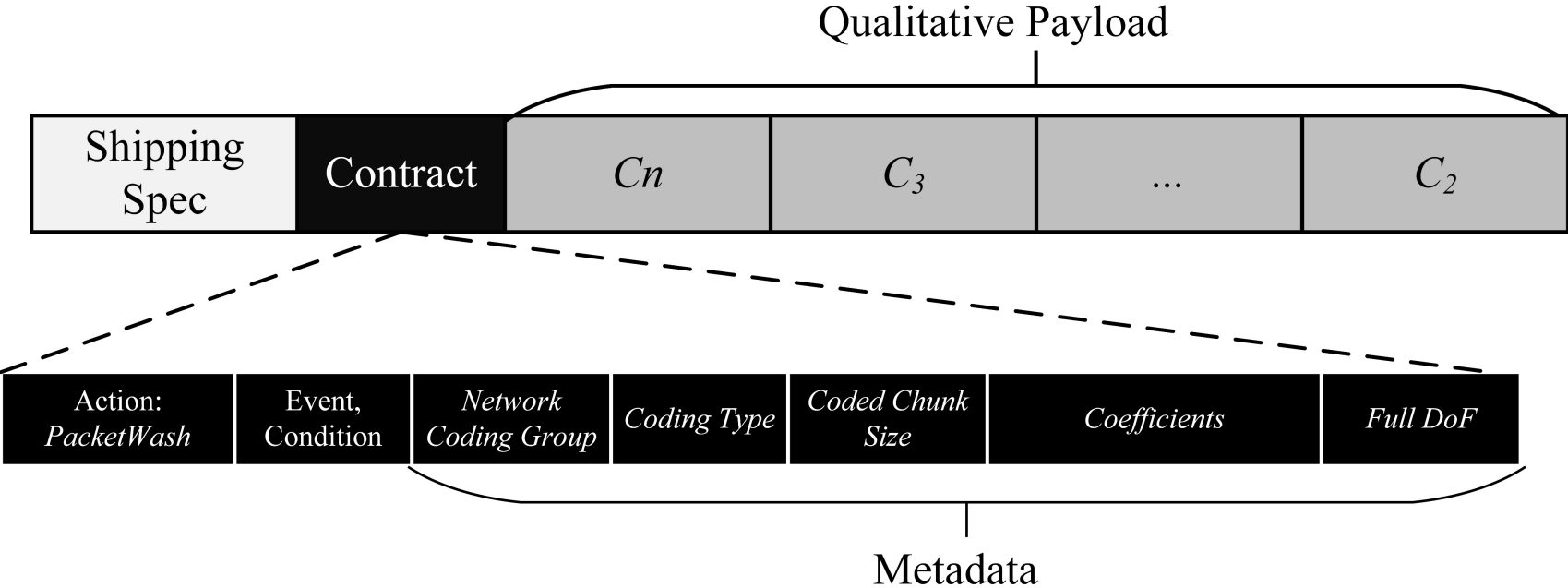
**Packet Wash is preferred to drop-and-retransmit**



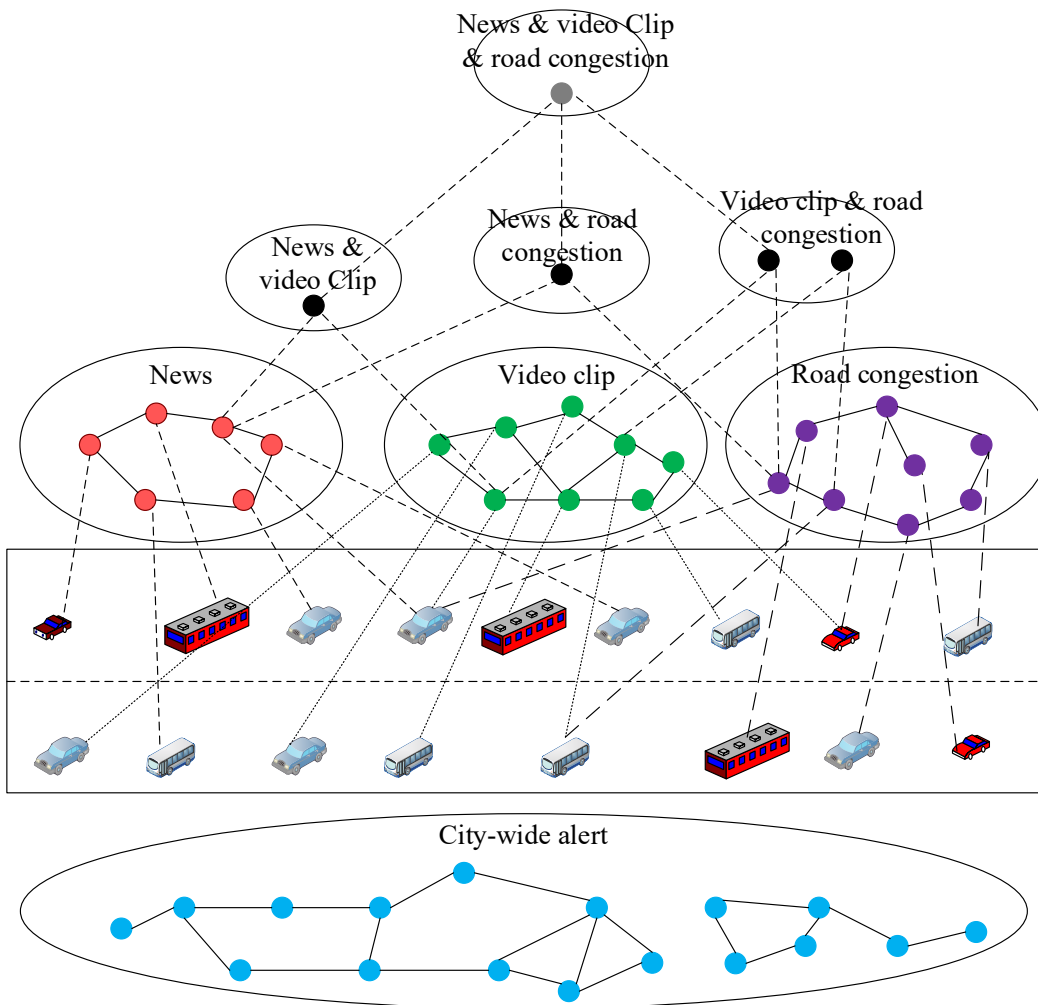
# Significance based packetization



# Random Linear Network Coding based packetization



# New IP Enables Information Exchange Oriented Vehicle Clustering



- Some vehicle may not have access to the infrastructure and needs other vehicle with Wifi or cellular interface to relay its data request to the infrastructure nodes and the data sent from the infrastructure nodes.
- An information topic based clustering builds a collaborative vehicular system for information exchange being delegated to those vehicles that have infrastructure access and are willing to provide the service to other neighboring vehicles.

**Action: forward to cluster head**

**Metadata: content identifier, topic name, cluster tag, aggregation permitted**

**Source: requesting vehicle IP address**

**Destination: content host IP address (could be set to cluster head IP address)**

New IP packet for information request

**Metadata: content identifiers, aggregation performed**

**Source: cluster head IP address**

**Destination: content host IP address**

New IP packet for aggregated requests

**Metadata: content identifier, offset in payload for corresponding data.**

**Source: requesting vehicle IP address**

**Destination: content host IP address (could be set to cluster head IP address)**

New IP packet for concatenated data

# References for Future Reading

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