AR/CG Network Traffic Classification in Programmable Dataplane

Alireza Shirmarz
Postdoc Researcher

Federal University of Sao Carlos (UFSCar)

Supervised
by
Prof. Fábio Luciano Verdi

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SMARTNESS

Augmented Reality (AR) & Cloud Gaming (CG)

Cloud Gaming (CG) Services

(1) Cloud Gaming Sessions:

(a) Control Session →
TCP (Signaling & Setup) - -

(b) Gameplay Session →
RTP/UDP (Real-Time Video & Input) - -

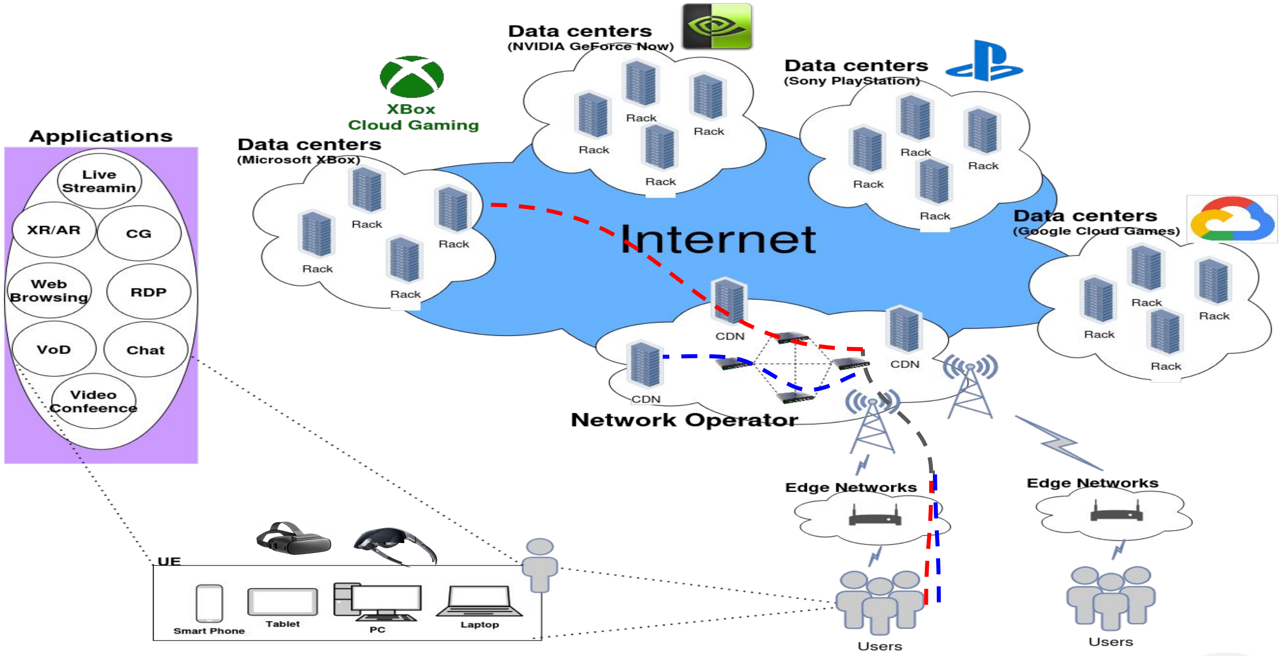
(2) VR/AR Integration:

(a) VR Glasses →
Merge AR with Cloud Gaming

(b) Blended Reality Experience →
Tighter Latency Demands

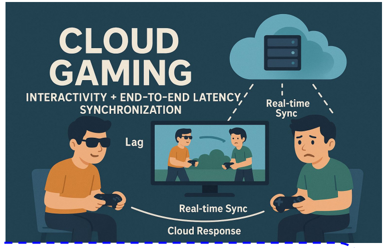
(3) CG/AR End-to-End Latency

(a) Propagation delay
(b) Interface delay
(c) **Queuing delay**



Augmented Reality (AR) & Cloud Gaming (CG)

- **Cloud Gaming & Augmented Reality Requirements**



- **Network D**
  - **Shared**
- **Dynamic F**
  - **AR/CG Flow Characteristics**
    - **Changing Endpoints:** IP/Port changes for security, CDN load balancing, and QoS adaptation
    - **Session Split:** Cloud Gaming often uses **TCP (control)** and **UDP (gameplay)** paths.

AR/CG Traffic
Identification & Prioritization

AR/CG Traffic Classification & Prioritization

SMARTNESS

- **Network Traffic Classification**
  - **Port-based**
    - Changing the port number (e.g. security and quality)
  - **DPI-Based**
    - Computational consuming method with limited computing resources
    - Encrypted traffic
  - **ML-based methods**
    - Dataset for statistical feature extraction
- **Network Traffic Prioritization**
  - **L4S (RFC 9330)**
    - ECN (RFC 9331)
    - Dual-Queue Coupled AQM for L4S (RFC 9332)

[1] A. Shirmarz, F. L. Verdi, S. K. Singh, and C. E. Rothenberg. From pixels to packets: Traffic classification of augmented reality and cloud gaming. In IEEE 10th International Conference on Network Softwarization (NetSoft), pages 195–203, 2024.

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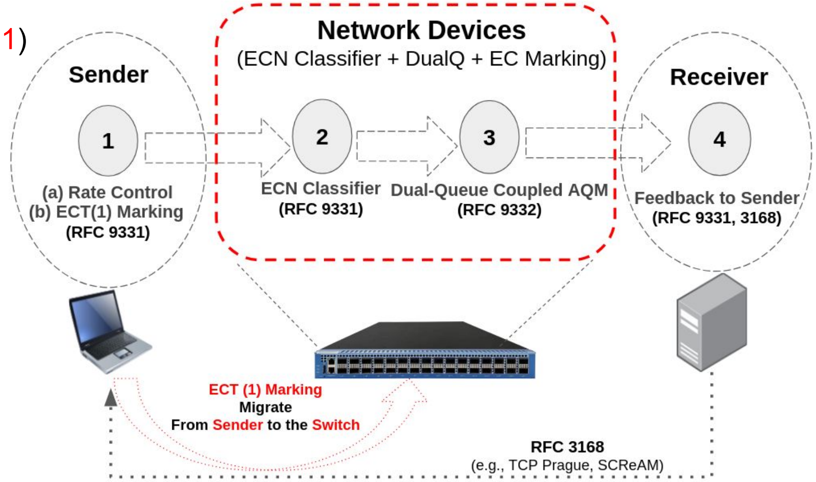
L4S: Low Latency, Low Loss, Scalable throughput

(1) L4S Architecture (RFC 9330–9332)

- **Sender:** Marks packets with **ECT(1)** (RFC 9330)
- **Network:**
  - **ECT(1) Classifier** → separates Classic / L4S flows (RFC 9331)
  - **Dual-Queue Scheduler** → Classic vs. L4S (RFC 9332)
  - **Marks EC (Congestion Experienced)**
- **Receiver:** Sends **feedback** to sender



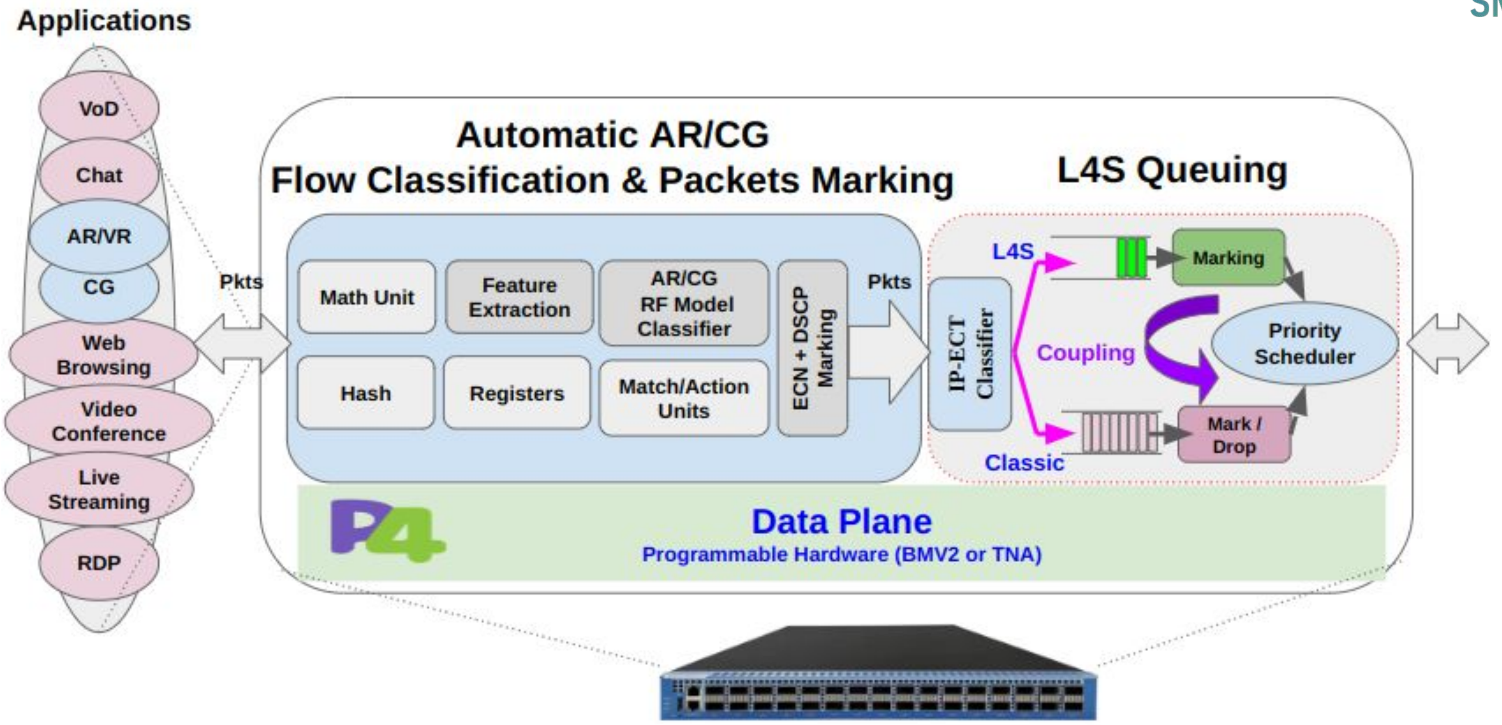
(2) Challenges

- Depends on **sender-side initiation**
- **ECT(1)** marking by CG platforms (e.g., Xbox) not always consistent
- **Shared network** → multiple apps with conflicting priorities

(3) Proposed Direction

- **Shift ECT(1) marking to network devices**
- Introduce **quantization** & **timing control** to minimize overhead

Automatic AR/CG Flow Classification & Prioritization



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Machine Learning (ML) Model Training/Evaluation

- **Datasets**
  - AR/CG/Other Apps pre-collected Dataset [1, 2]
- **Features** [1, 2]
- Packet Size (PS), Inter Packet Interval (IPI), Frame Size (FS), Inter Frame Interval (IFI)
- **Models**
  - Train/Eval → DT & RF [1, 2]
- **Hyperparameter**
  - Grid-Search (limited range 1 - 10) for DT/RF
    - max depth = 3
    - min samples split = 2
    - n estimators = 5 (for only RF)
- **DT/RF Model `*If-Then-Else*' Rule Extraction**
  - Convertor.py → *Input*: Rf.pkl , *Output*: Rules
- **Threshold Tuning**
  - PS, FS (bytes) → integer, round!
  - IPI, IFI (second) → Convert to nano second, integer, round!
- **Classification Output Encoding →** (Unclassified: 0), (AR: 1) , (CG: 2), and (Other: 3)
- **Aggregation in RF Classification→** Majority

TABLE I: Pruned DT/RF Model Evaluation

Model	Class	Acc (%)	Prec (%)	Rec (%)	F1_s (%)
DT	**AR**	86	88	98	92
	CG		67	97	79
	Other		90	78	83
RF	**AR**	94	93	98	95
	CG		80	97	88
	Other		93	88	90

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Network Flow Features

(1) Packet-based Features [1, 2]
- (a) Packet Size(PS)
- (b) Inter Packet Interval (IPI)

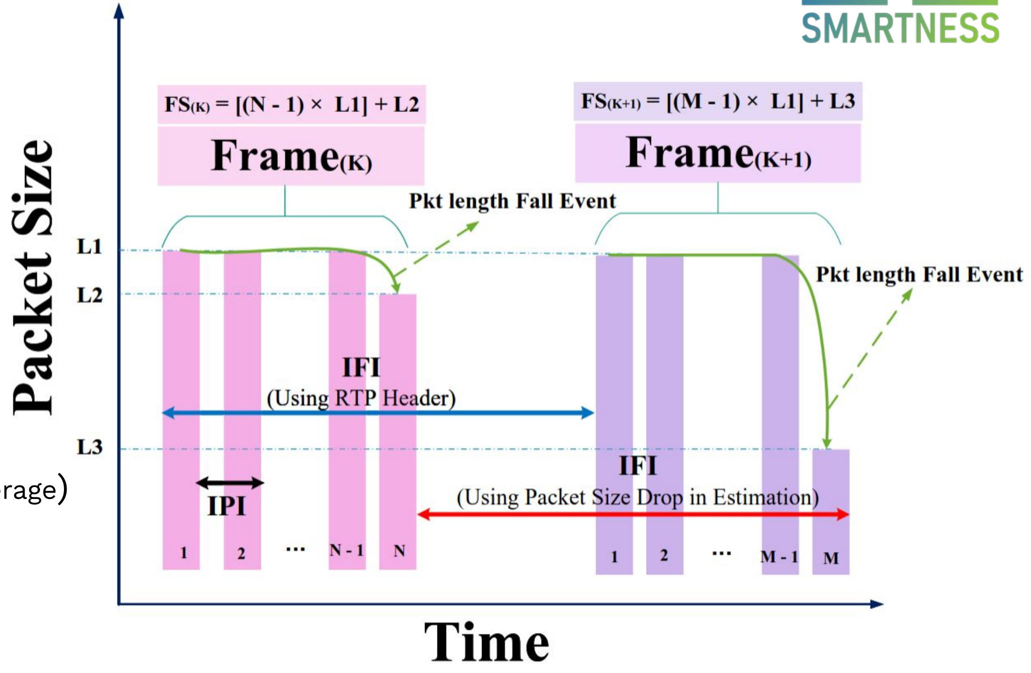
(2) RTP Frame-based Features [1, 2]
- (a) Frame Size(FS)
- (b) Inter Frame Interval (IFI)

(3) Flow Features [2]
- (a) Packet Feature Aggregation
- (b) **EWMA** (Exponentially Weighted Moving Average)

$$S_t = \alpha X_t + (1 - \alpha) S_{t-1}$$

where:

- S_t: current EWMA value
- X_t: current observation
- α: smoothing factor $(0 < \alpha \leq 1)$
- S_{t-1}: previous EWMA value



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Network Flow Features

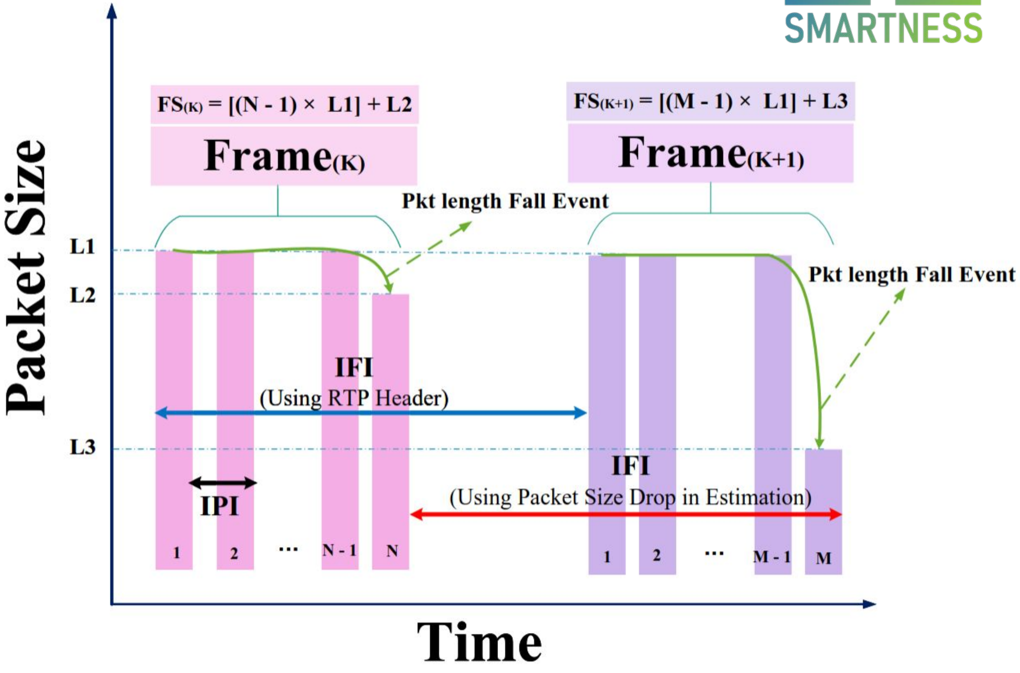
Features:

$$IPI_i = Timestamp(Pkt_{i+1}) - Timestamp(Pkt_i), i \geq 0$$

$$IFI_i = Timestamp(Frame_{i+1}) - Timestamp(Frame_i), i \geq 0$$

$$PS_i = Packet_i.IP.TotalLength$$

$$FS_K = \sum_{1}^{m} PS_i, \ where \ PS_i \ \in Frame_K$$



How to detect boundary of RTP Frames?

(1) *Packet Size Pattern*

(2) *RTP Header Marker Bit*

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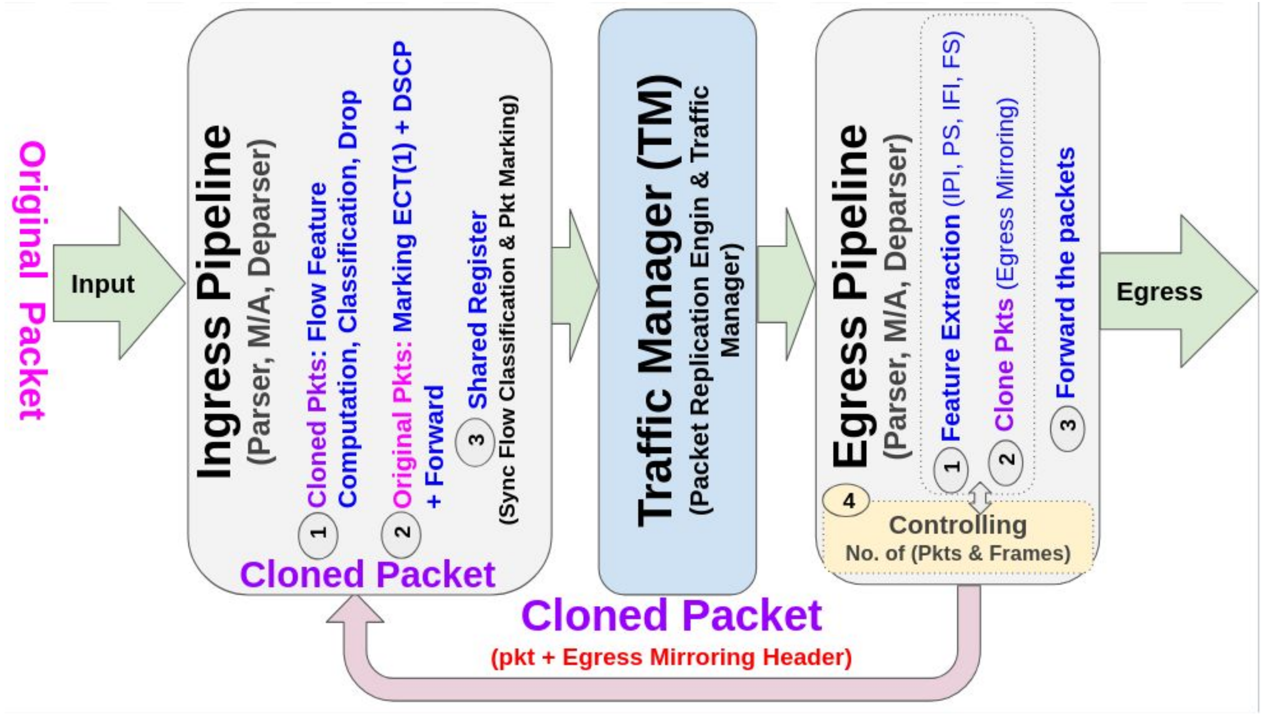
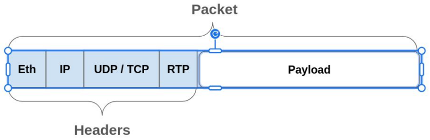
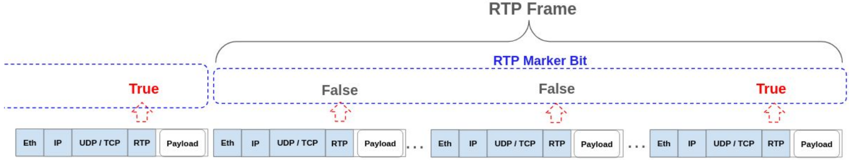
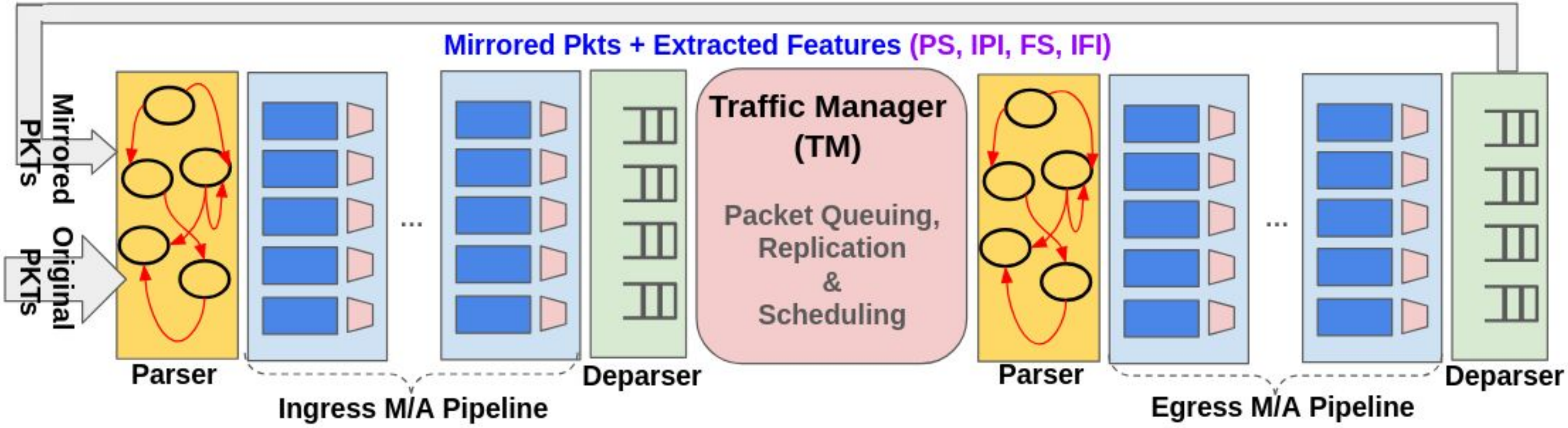
Decoupling Feature Extraction & Flow Classification



Deployment using P4 Pipeline & TNA







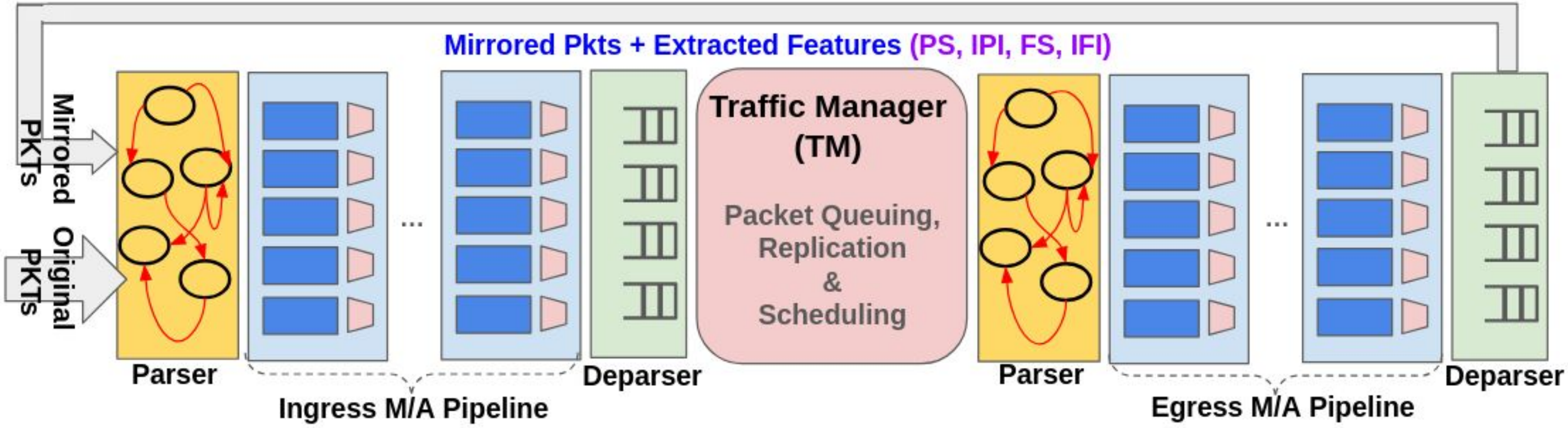
Deployment using P4 Pipeline & TNA

IPv4 & UDP & RTP
Headers

```
// IPv4
header ipv4_h {
    bit<4> version;
    bit<4> ihl;
    bit<6>  dscp;
     bit<2>  ecn;
    bit<16> total_len;
    bit<16> identification;
    bit<3> flags;
    bit<13> frag_offset;
    bit<8> ttl;
    bit<8> protocol;
    bit<16> hdr_checksum;
    ipv4_addr_t src_addr;
    ipv4_addr_t dst_addr;
}
```

```
// UDP
header udp_t {
    bit<16> srcPort;
    bit<16> dstPort;
    bit<16> length_;
    bit<16> checksum;
}
```

```
// RTP
header rtp_t {
    bit<2> version;
    bit<1> padding;
    bit<1> extension;
    bit<4> csrcCounter;
    bit<1> marker;
    bit<7> payloadType;
    bit<16> seqNumber;
    bit<32> Timestamp;
    bit<32> ssrcID;
}
```



Ingress Pipeline

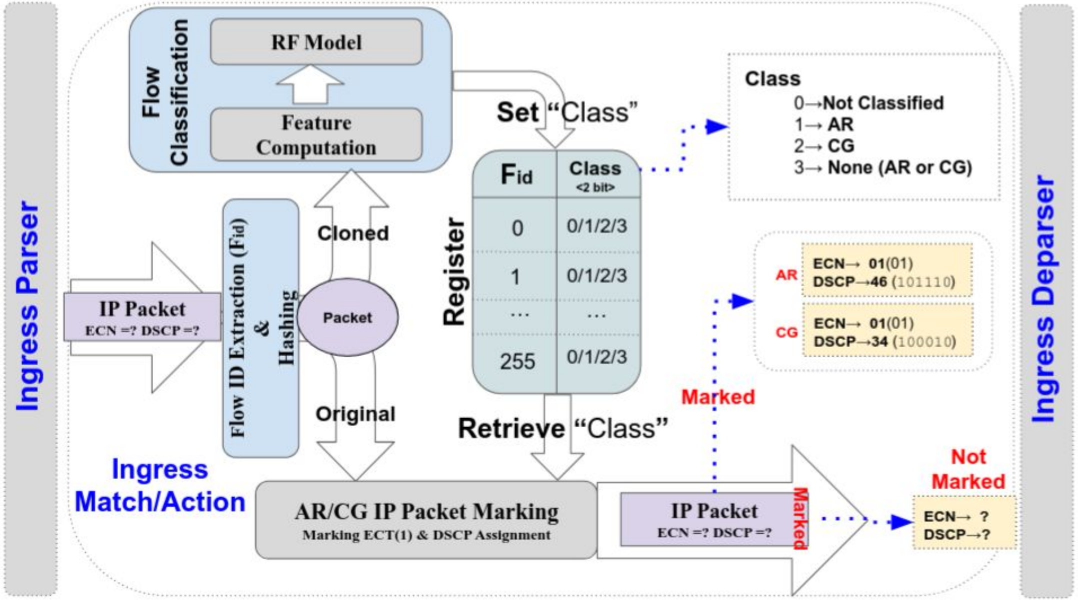


Fig. 2: Ingress Pipeline for Flow Classification & Packet Marking.

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Flow Features: Packet Features Aggregation

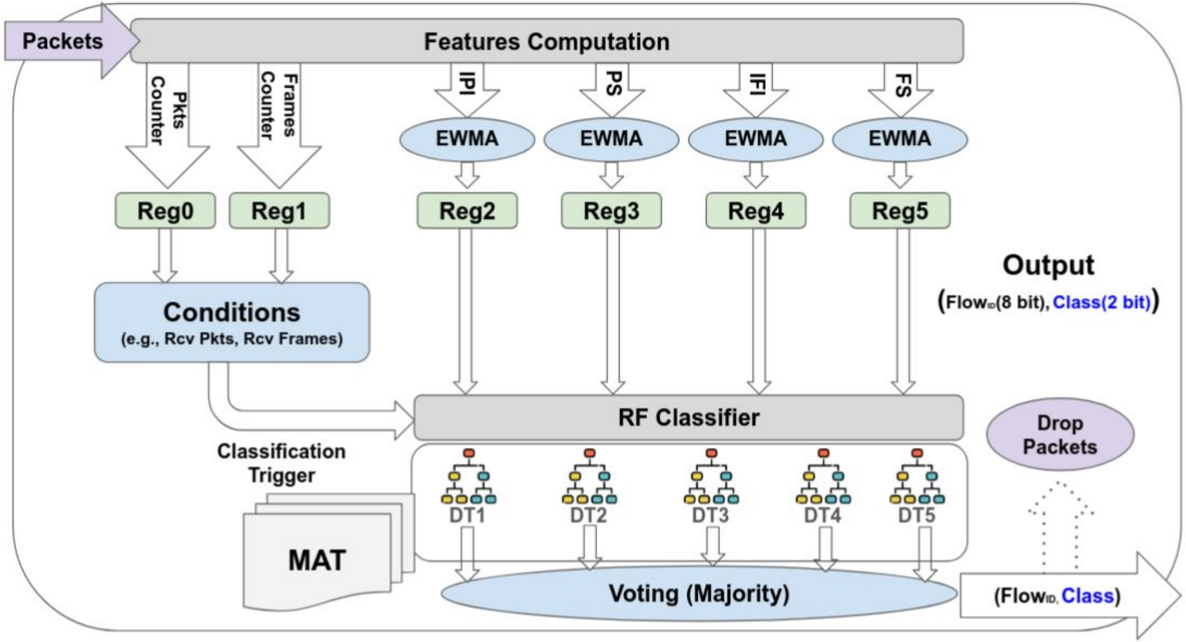

Fig. 3: Feature Computation & Flow Classification.

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Experimental Evaluation

- **Scenarios**
  - Run the Tcpreplay (in server 1) and collect by Tshark (in server 2)
  - Compare the Source (Pcap Pool) and collected PCAPs
    - **AR**→ DSCP = 46, ECN = 01
    - **CG**→ DSCP = 34, ECN = 01
    - **Other**→ DSCP = 50, ECN = 00
    - **Not Classified**→ DSCP = 0, ECN = 00

  - Collect 780 INT packets data including:
    - **T1**→ Timestamp departing from server2
    - **T2**→ Timestamp arriving to server2
    - Sum of Nodal Processing Time (during 1 second)
    - Sum of the processed packets

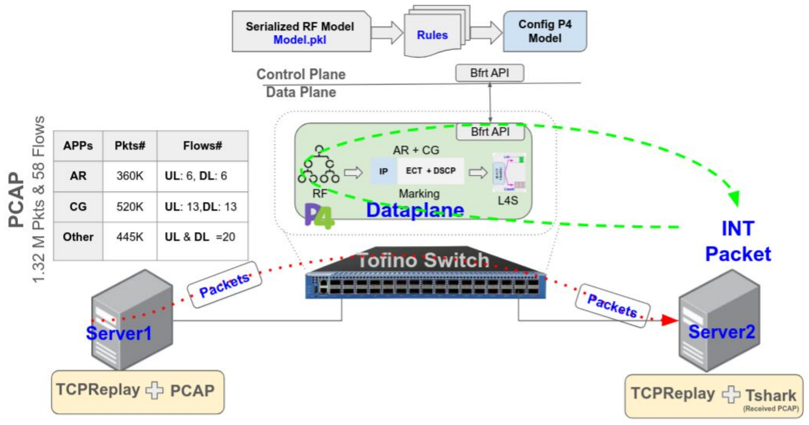

Fig. 4: Testbed for experimental evaluation. The red dotted line (red) shows the traffic path by TCPReplay flows. The dashed line (green) represents the path of INT packets.

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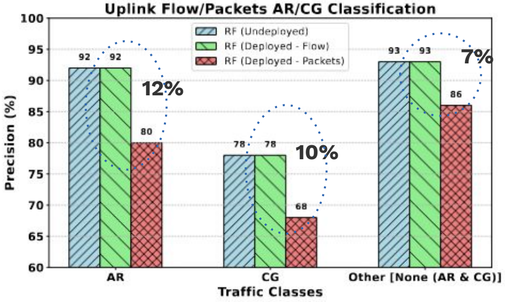
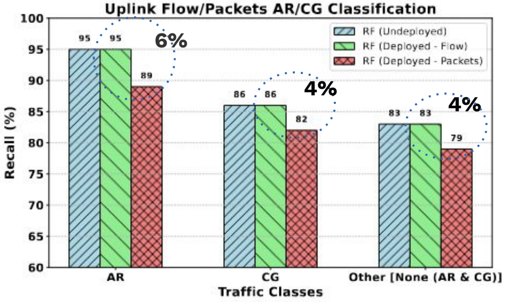
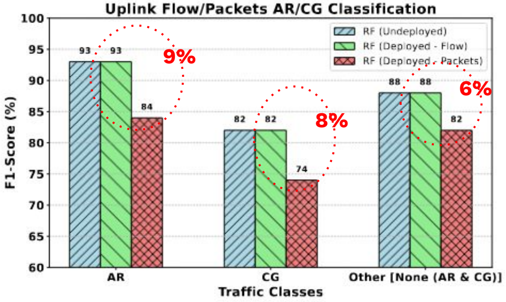
Flow/Packet Classification Performance



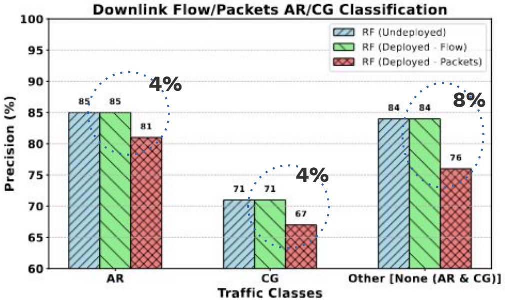
(a) Uplink Traffic Classification Precision



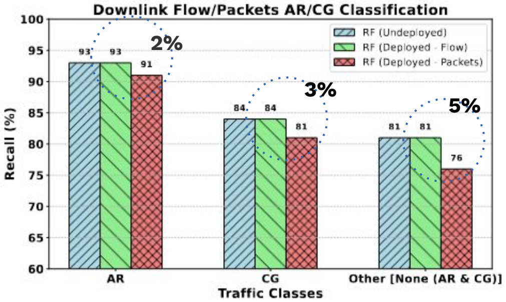
(b) Uplink Traffic Classification Recall



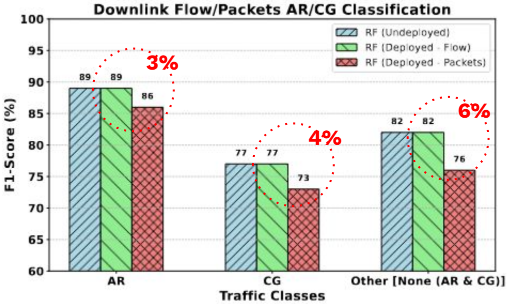
(c) Uplink Traffic Classification F1-Score



(d) Downlink Traffic Classification Precision



(e) Downlink Traffic Classification Recall



(f) Downlink Traffic Classification F1-score

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ECT(1) Marking Performance

TABLE III: ECT(1) Marking Analysis: TP, FP, and Not-Classified Packet Percentages and Counts.

	Perc. (%)		# Pkts		Total pkts (× 3)	
	UL	DL	UL	DL	UL	DL
TP (AR+CG)	89	92	720K	1683K	270K	610K
FP (Others)	15	9.2	200K	122K	445K	445K
Not-Class.	9	4.7	193K	86K	715K	1055K

Cost of Deployment

Classification Processing Time Overhead in Deployment

$$Time\ overhead = \frac{\frac{1}{N}\sum_{i=1}^{N}\left(T_{(\text{egress},i)} - T_{(\text{ingress},i)}\right)}{RTT}$$

TABLE IV: Classification/Marking Overhead vs Without Classification Data plane

	Avg	Std	P90	P95	P99
Without Class.	1.98^{-7}	1.44^{-7}	3.44^{-7}	3.47^{-7}	3.49^{-7}
Class. + Mark.	2.19^{-6}	3.79^{-6}	3.49^{-5}	3.72^{-5}	5.05^{-5}

Discussion

- **Classification Performance**
  - Packet misclassification→
    UL(AR: 16%, CG: 26%, Other: 18%) & DL(AR: 14%, CG: 27%, Other: 24%)
  - ECT(1) Misclassification→ UL:11%, DL: 8%
  - ECT(1) Misclassification→ UL:15%, DL: 9.2%
    - RF Model improvement in UL
      - ✓ Depending more likely on packet-based features!
    - RTP features effect on the video streaming
      - ✓ Downlink in AR/CG are Video Streaming and RTP-based features improved the classification performance
  - Non-classified Packets→ UL: 9%, DL: 4.7%
    - Deployment + Configuration (classification trigger) overhead!

Discussion

- **Time overhead**
  - Nodal Processing time increased!
  - Nodal processing time ratio to RTT is tiny!
  - Nodal Processing time rose 21.42 μs in average!

Achievements:

1- RTP Frame is available in programmable dataplane!
2- RF development using p4 pipeline
3- ECT(1) marking for L4S
4- L4S implemented with it!

Next Step:

1- Scheduling the L4S!
2- QUIC→ RoQ (a) CG framework, (b) tofino P4
3- Cloud Gaming framework QoE evaluation!
4- AR QoE evaluation!

Conclusion & Future Work

- **AR/CG Identification**
  - AR and CG are classified correctly with accuracy equals UL: 80%, DL: 78.3% in average.
  - ECT(1) Marking accuracy is UL: 89%, DL: 92% in average.
  - It is proving that AR/CG are differentiated from other streaming applications but they are confused in some cases!
- **Time Overhead**
  - Although nodal processing time increased but its ratio to RTT is negligible!
- The overhead of deployment in dataplane have direct effect on the QoS and QoE using the AR/CG applications!

Conclusion & Future Work

- **Packet & RTP Feature Extraction** + **Classification** + **ECT(1) Marking** were **entirely** developed in P4 pipeline with **TNA** architecture in **Tofino 2**.
- Average uplink classification degrades more than downlink after Tofino deployment (RTP + Pac
- Nodal processing time

We don't violate the physics law! So, we follow the necessary trade-off!

Future Work

- Concurrent classification & marking using 4 Tofino parallel pipelines!
- Selective packet cloning to minimize the overhead!
- AR/CG QoS/QoE evaluation with L4S integration
- L4S queue scheduling tailored to AR/CG application

Q&A

Thanks for Your Attention! + ACKs

Contact: Alireza Shirmarz
Website: https://alirezashirmarz.github.io
Email: ashirmarz@ufscar.br

LERIS Lab
https://leris.dcomp.ufscar.br

SMARTNESS
https://smartness2030.tech

Alireza Shirmarz Website
https://alirezashirmarz.github.io