In-Network Quality Control of IP Camera Streams

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Imagine a modern factory setup…

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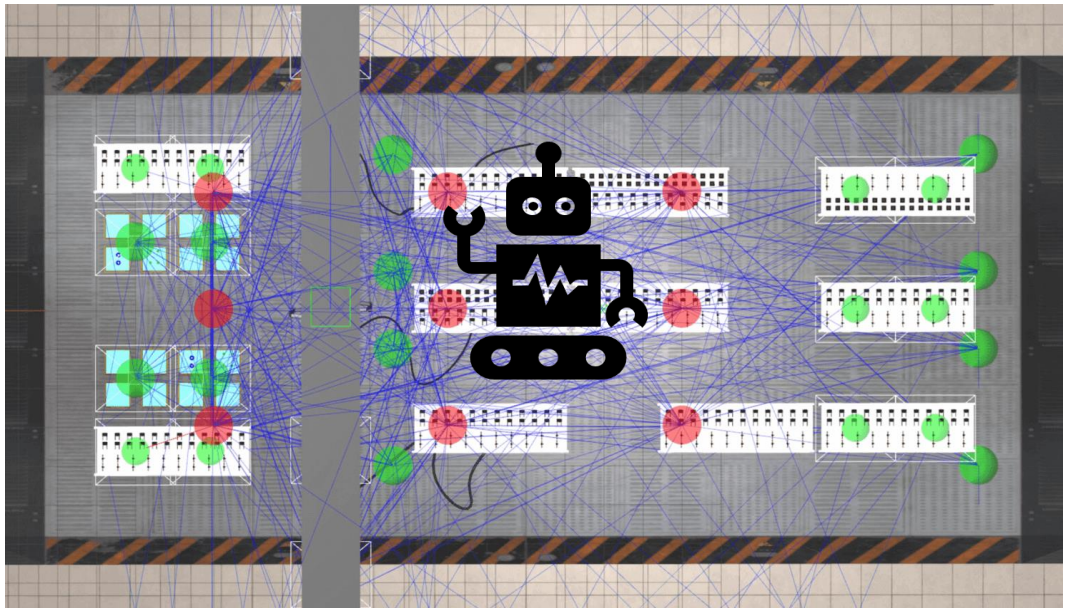

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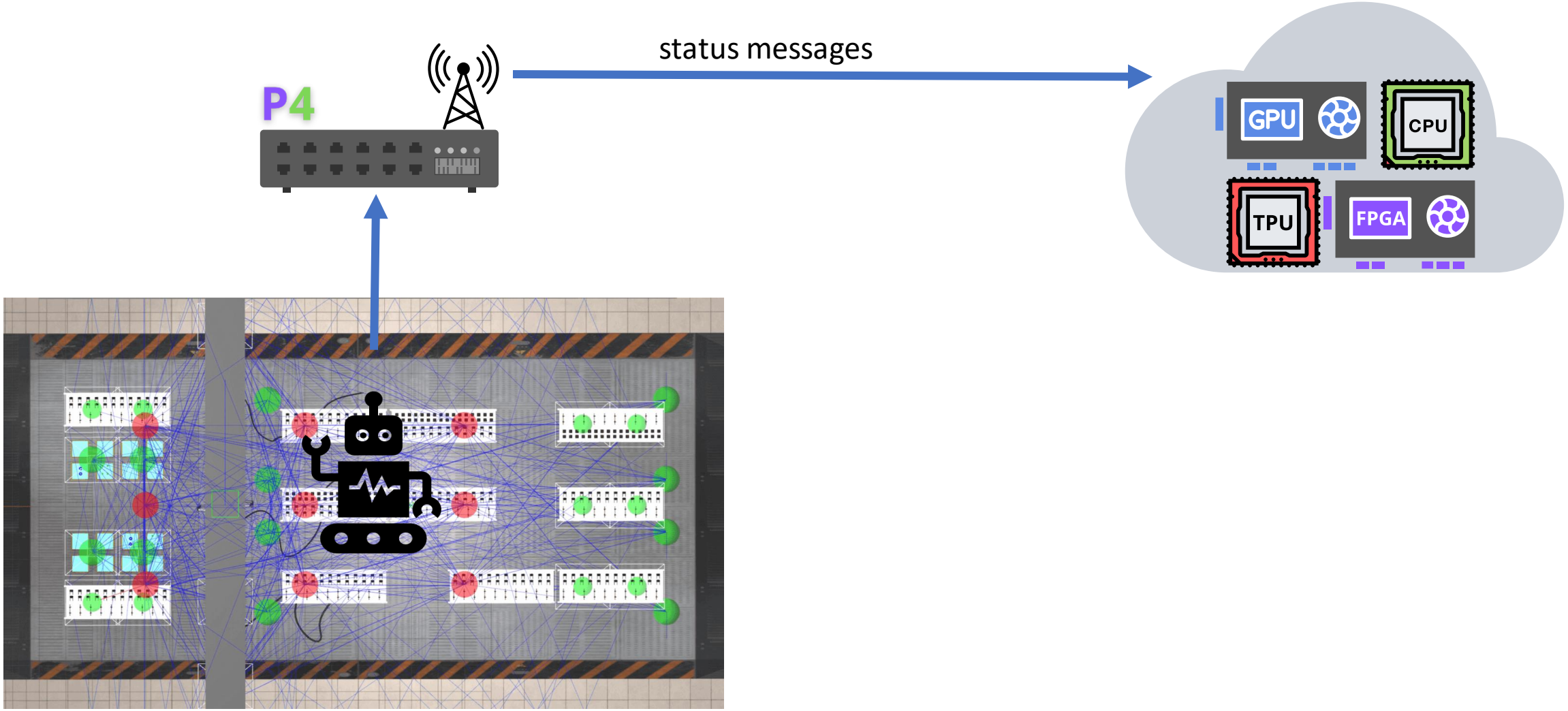

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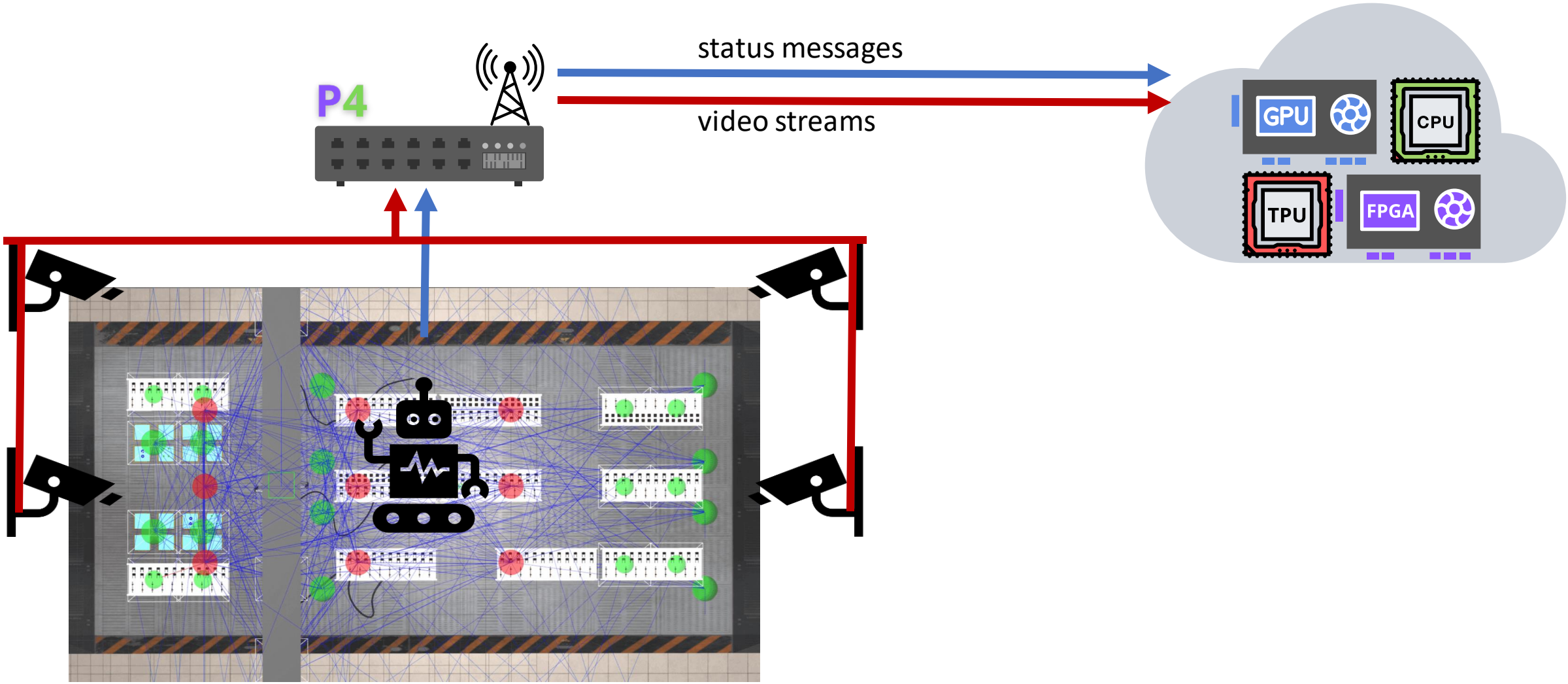
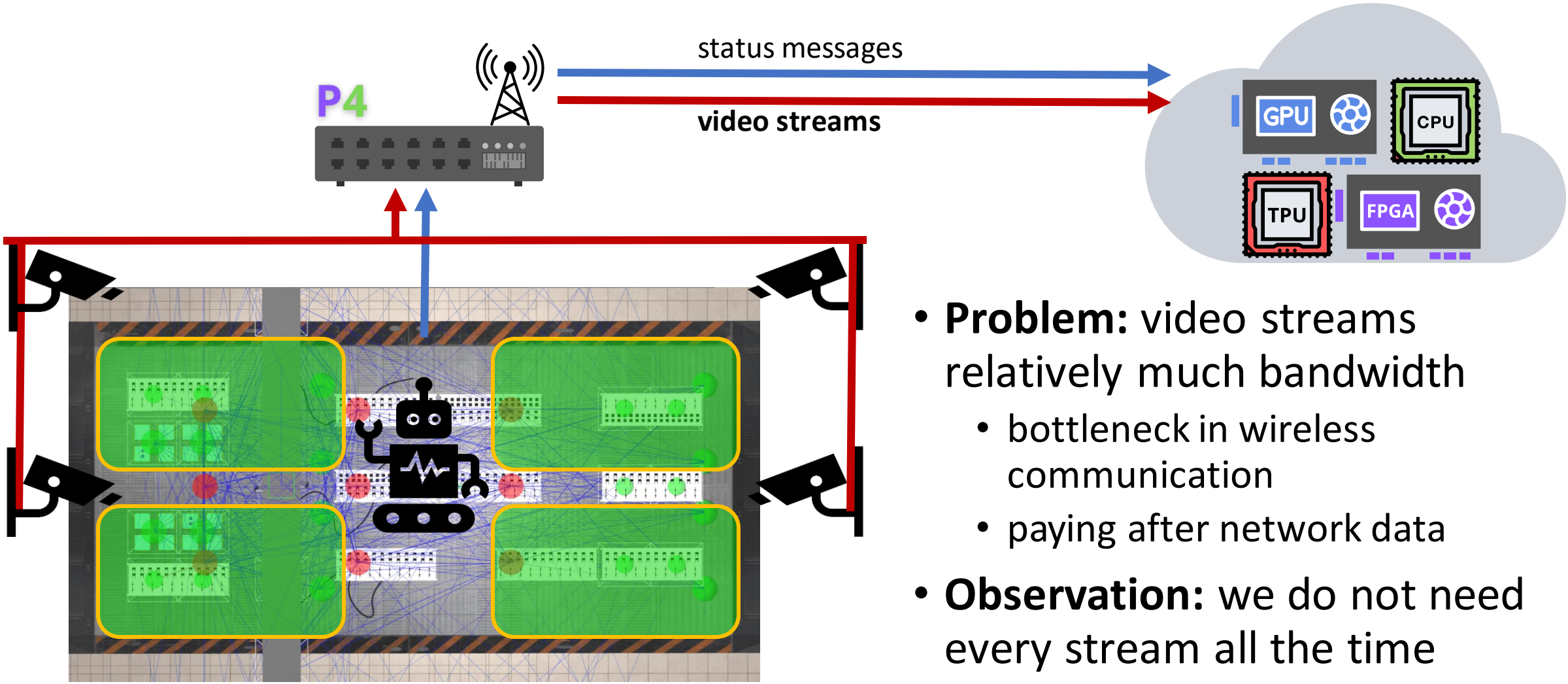
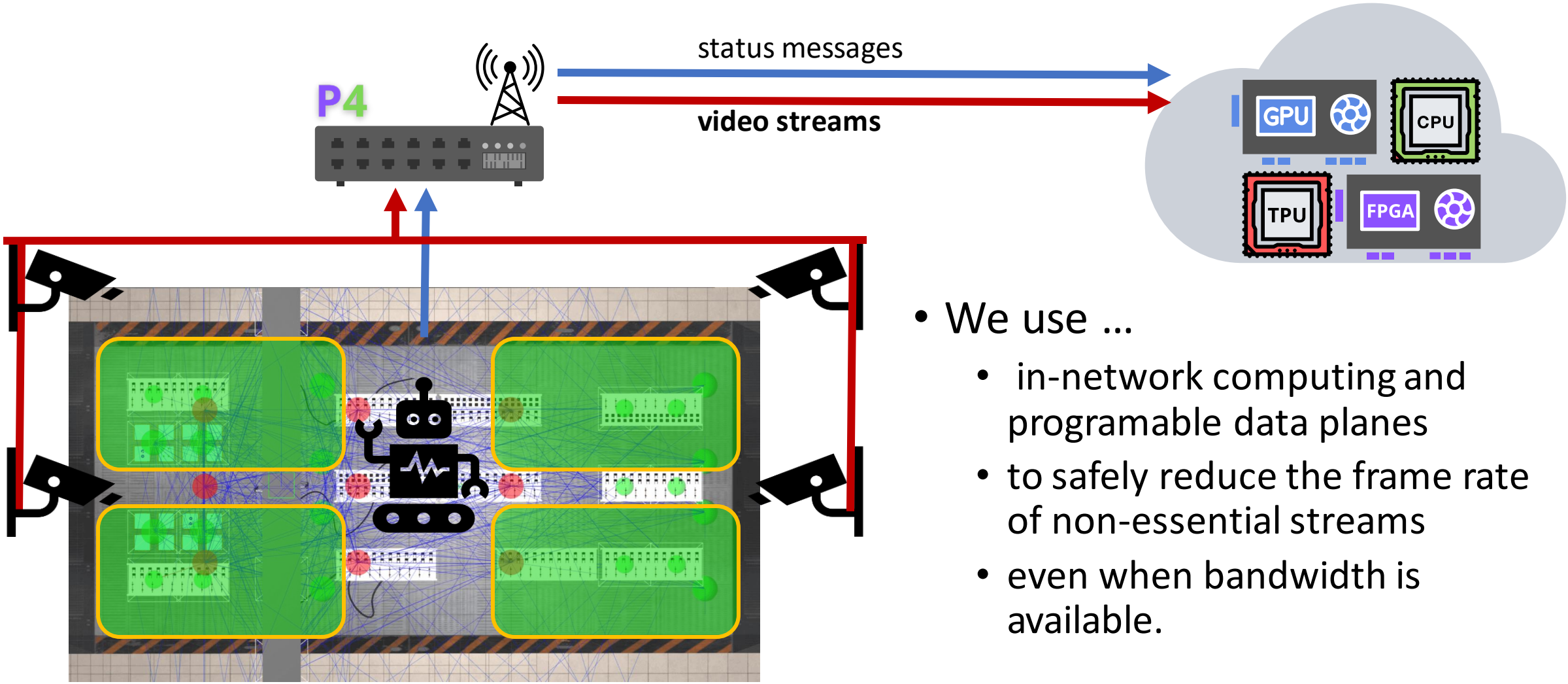


Motivation



- **Problem:** video streams relatively much bandwidth
  - bottleneck in wireless communication
  - paying after network data
- **Observation:** we do not need every stream all the time

Our Method



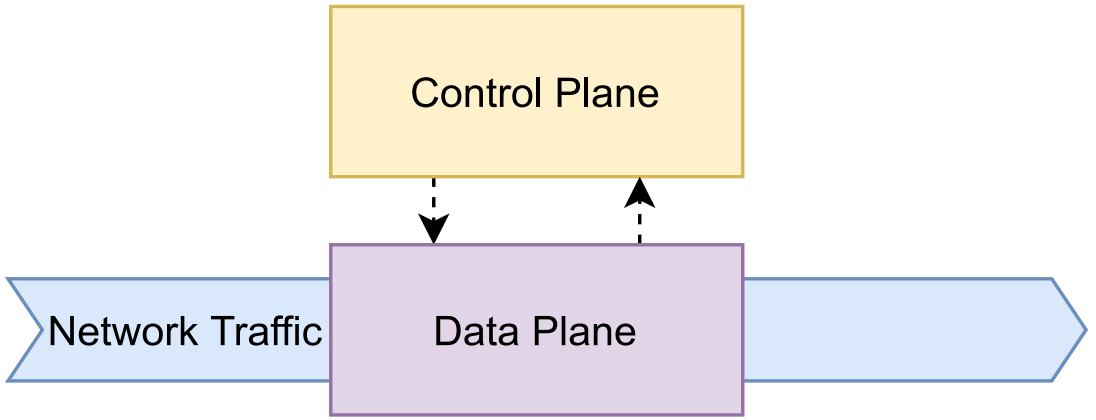
- We use …
  - in-network computing and programable data planes
  - to safely reduce the frame rate of non-essential streams
  - even when bandwidth is available.

Background

- Software-Defined Networking
- The P4 Language
- Video Streams

Background: Software-Defined Networking

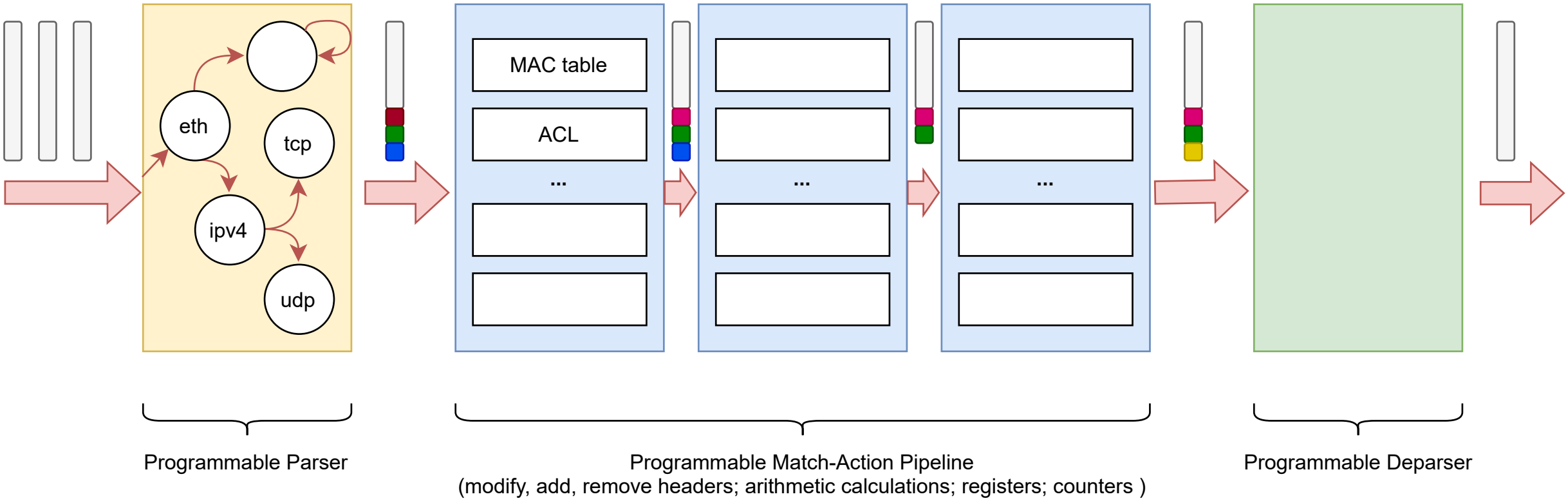
- Making the network behaviour programmable
- Separation of the Control Plane and Data Plane
  - The *data plane* is responsible for processing the individual networking packets.
  - The *control plane* updates the rules of the packet processing. (Relatively slow.)



Background: The P4 Language

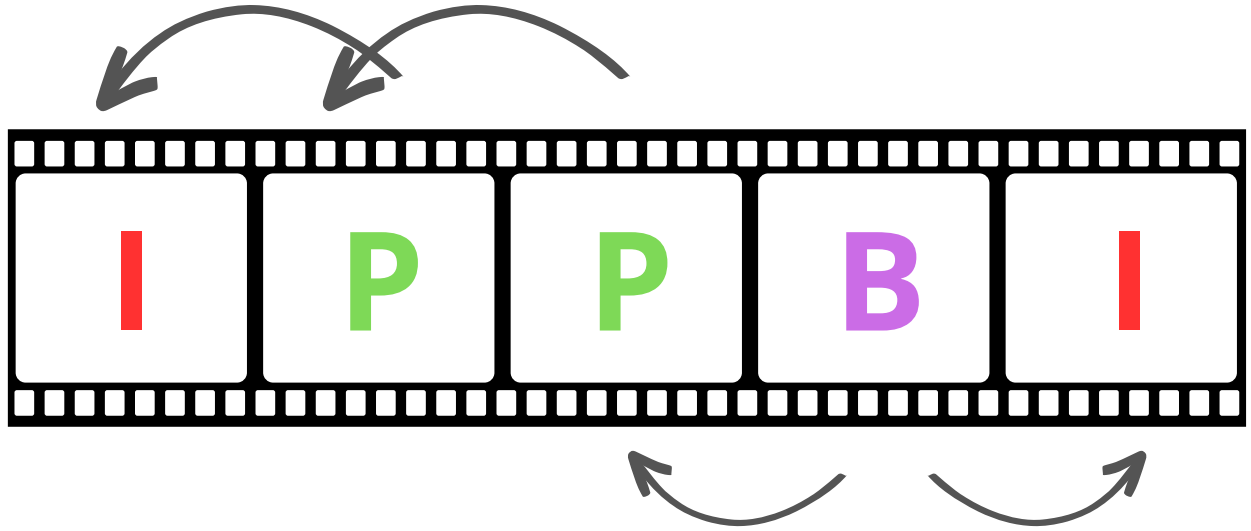
- First introduced in 2014
- Domain-specific language, design for data planes
- Describe the processing of a single packet
- Define custom headers, fields
- Use custom match-action tables
- Many different targets: software switch, smartNIC, ASIC switch …
- Main constraints:
  - No loops, no multiplication, …
  - No string operations
  - Variable-length headers are usually hard to handle
  - Other target/architecture-specific constraints...

Background: The P4 Language



Background: Video Streams

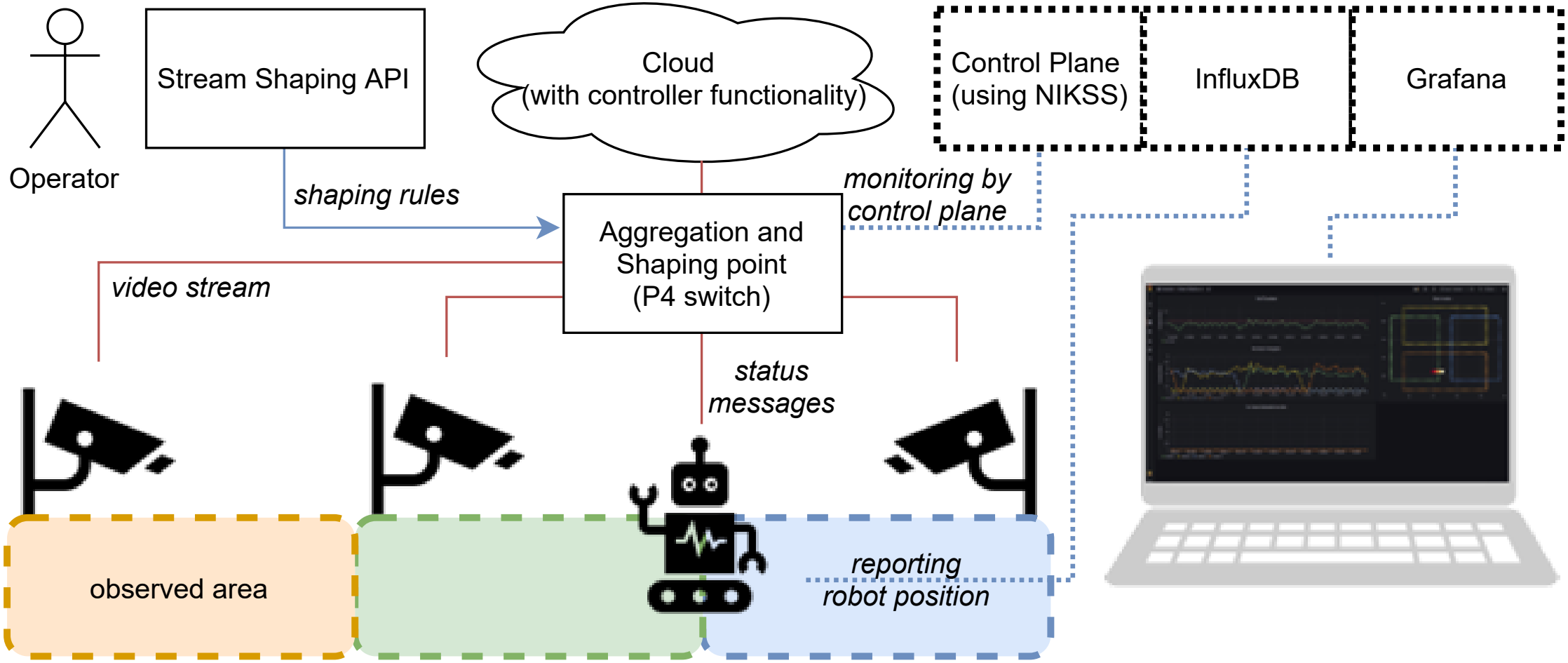
- H.265
- A sequence of frames
  - I-frames
  - P-frames
  - (B-frames)
- Packetisation:
  - If a frame is too big, it can be split among multiple packets (fragmentation units)
  - A start and end bit helps to locate the frame boundaries.



Solution

- Overview
- Data Plane Design

Solution Overview



Data Plane Design

Video packets

- Parse H.265 frame and packetisation information: start bit, end bit, frame type.
- Map source address to a stream ID.
- Read current from ***filtering_mode*** register. (*KEEP_ALL*, *DROP_P_FRAMES*)
- Track if we are inside a P-frame using the start- and end bits inside the ***is_p_frame*** register.
- Drop the packets belonging to a P-frame if required.
- (Additional telemetry for observability.)

Status messages

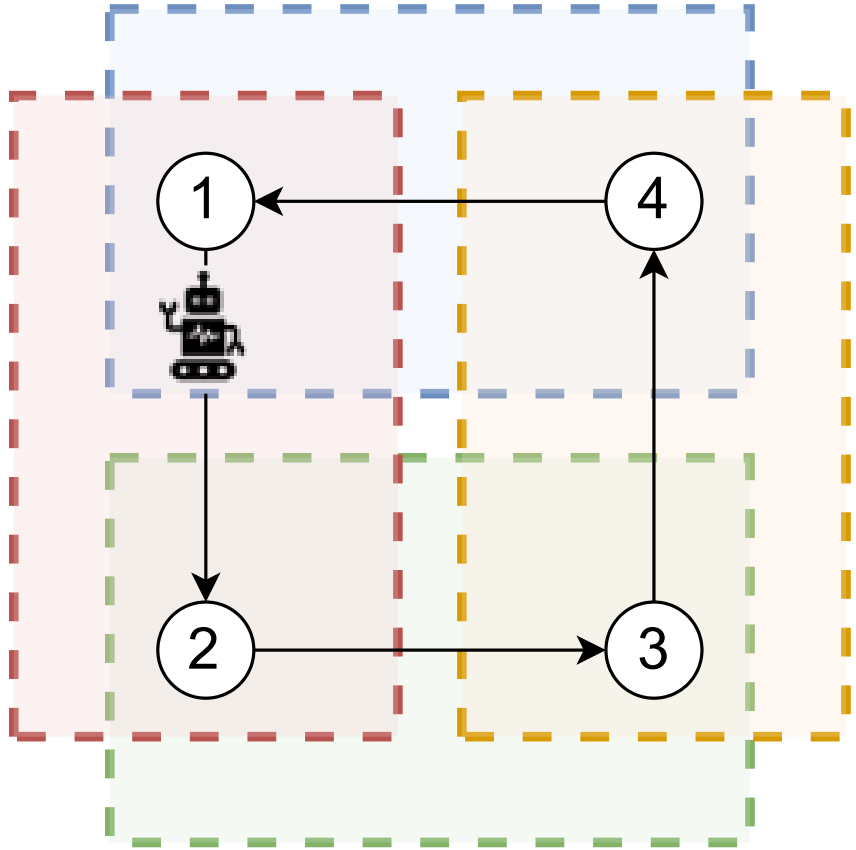
- We assume a simple UDP-based communication containing the *X* and *Y* coordinates of the robot.
- Update the ***filtering_mode*** register based on the *(X, Y)* coordinates and the provided rules.
- Forward the packet as usual.

Evaluation

- Demo Setup
- Traffic Patterns
- Discussion on Deployability

Evaluation: Demo Setup

- Prototype implementation: PSA-eBPF P4 backend with NIKSS
- Hardware setup:
  - IP camera (Reolink RLC-810A)
  - P4 programmable hardware: PCEngines APU4d4 + PSA-eBPF
- Single-server setup
  - VLC+FFmpeg (4 streams)
  - PSA-eBPF (same as before)
- Single simulated robot



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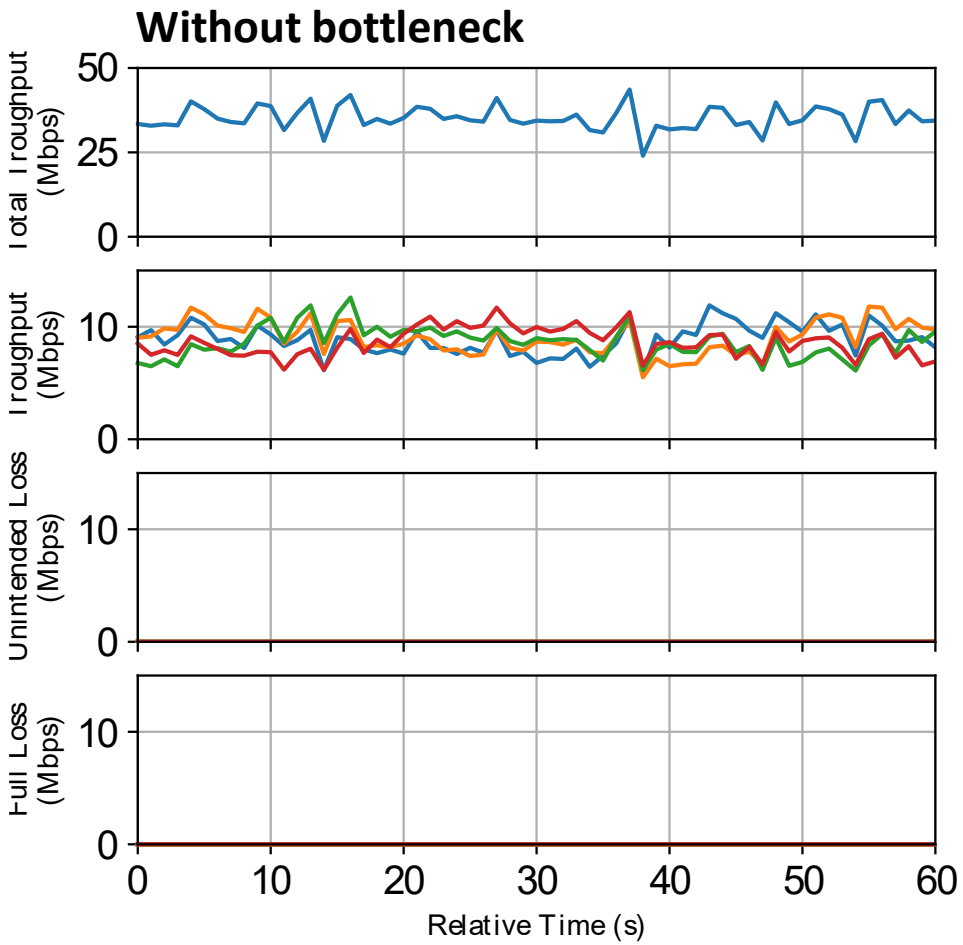

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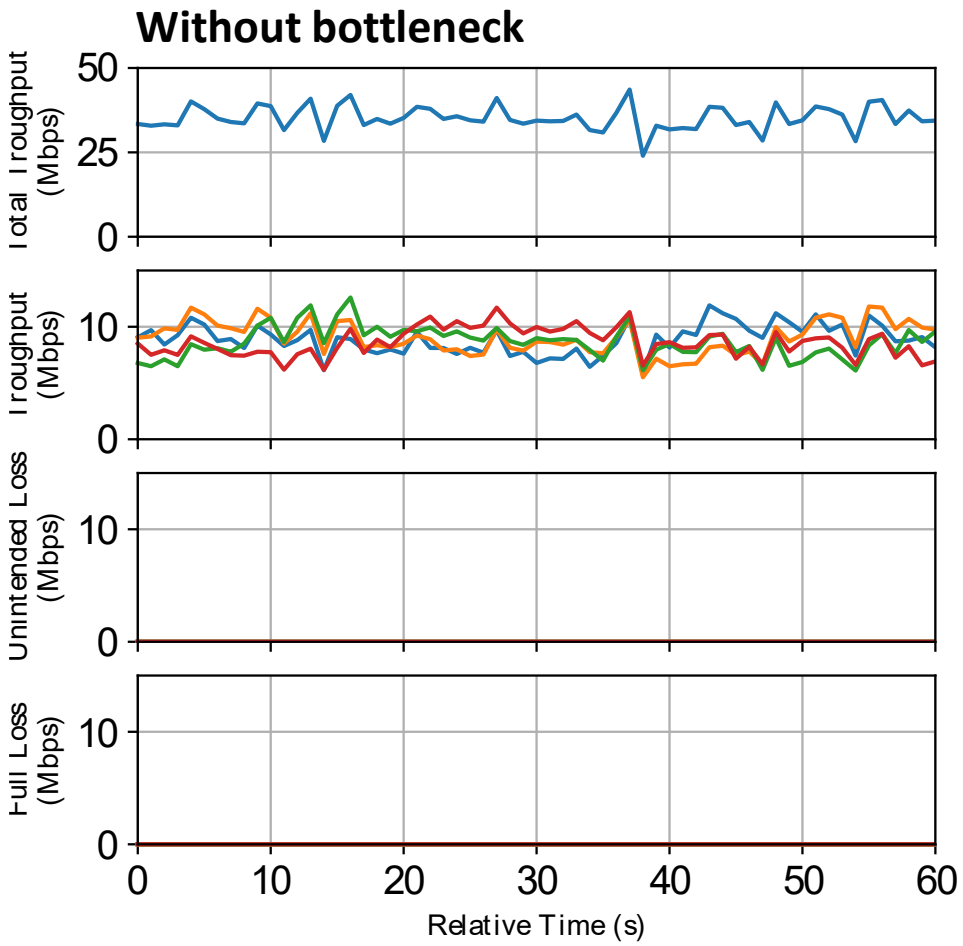
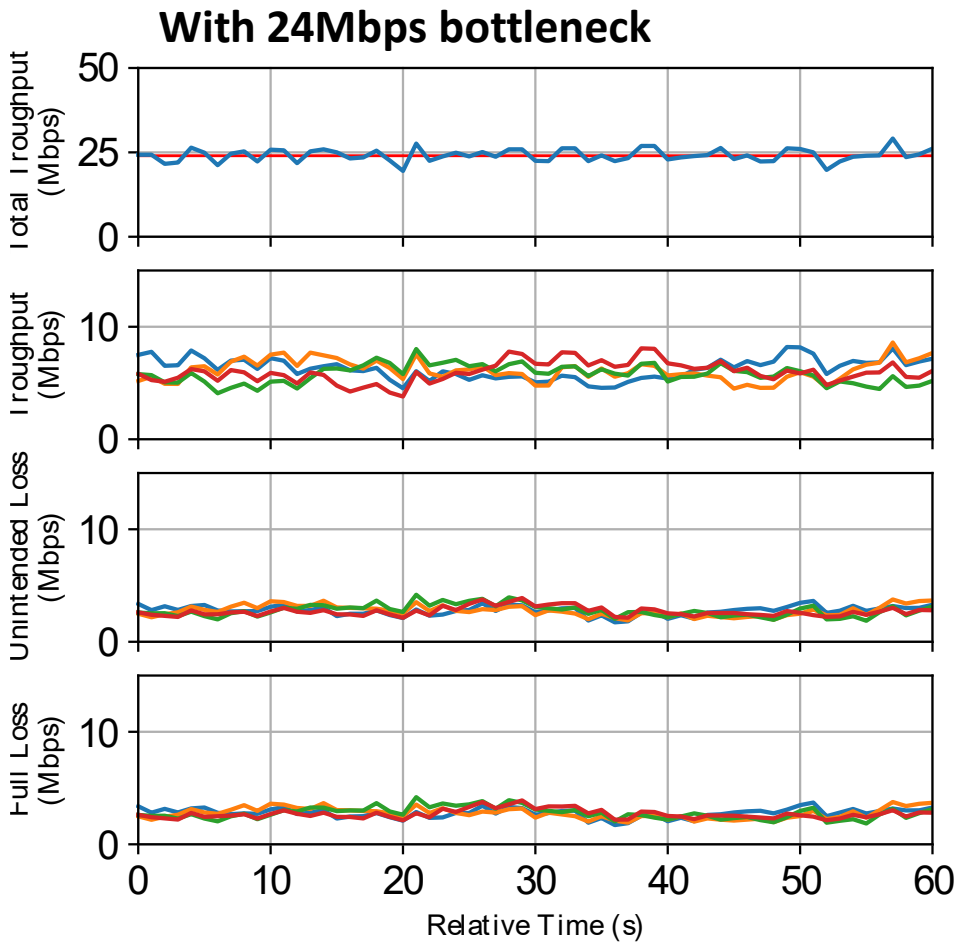
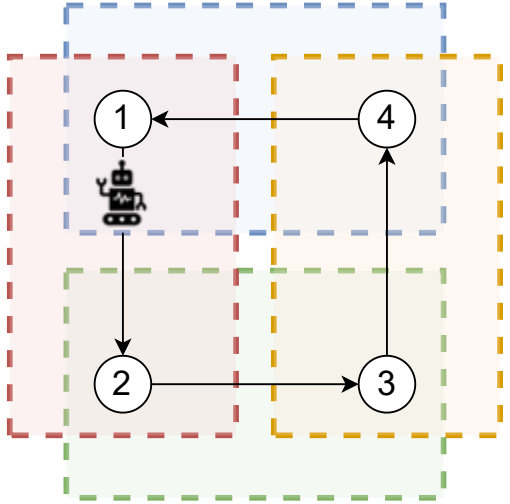




Evaluation: Traffic Patterns



Evaluation: Discussion on Deployability

- We use only 2 register arrays, and their size grows linearly with the number of streams.
- Filtering of P-frames is instantenious.
- Turning off the filtering is also instantaneous but the stream might only become distortion-free at the next I frame.
  - The frequency of I-frames can be configured.
  - The bounding boxes and rules can be adjusted.
- Can we use an Intel Tofino? Probably, but the use case does not require Tbps speed.

Summary and Future Work

- We build on the observation that not all video streams are required all the time in an industrial setup.
- We can leverage in-network computing and programmable data planes to safely reduce the frame rate of non-essential streams even when bandwidth is available.

- Future Work:
  - Investigate QoE metrics
  - How to efficiently encode rules using tables and registers?

Thank you for your attention!

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