Florent HARDY

Profiling and Optimizing Programmable Networks' Power Consumption

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Work setting

GARDEN

- Project financed by the Agence Nationale de la Recherche (JCJC)
- Study power consumption of **Programmable Networks**

Master's Internship

- Study power consumption of **Programmable Switches** (Tofinos)
- Groundwork for thesis

Programmable Networks

Control plane programmability

- SDN = Software defined network
- (Centralized) controller

Data plane programmability

- Redefine how packets are processed
- P4 programming language
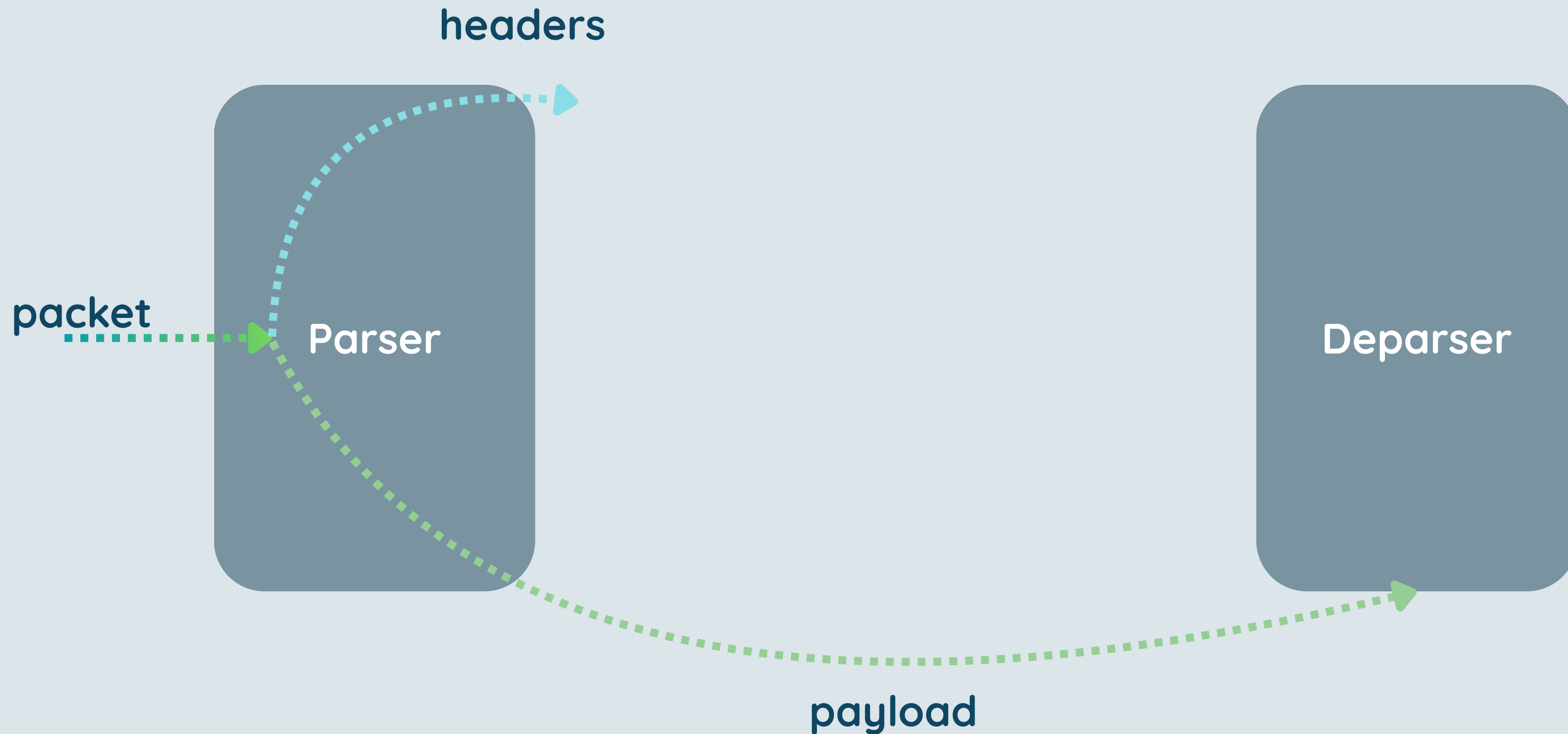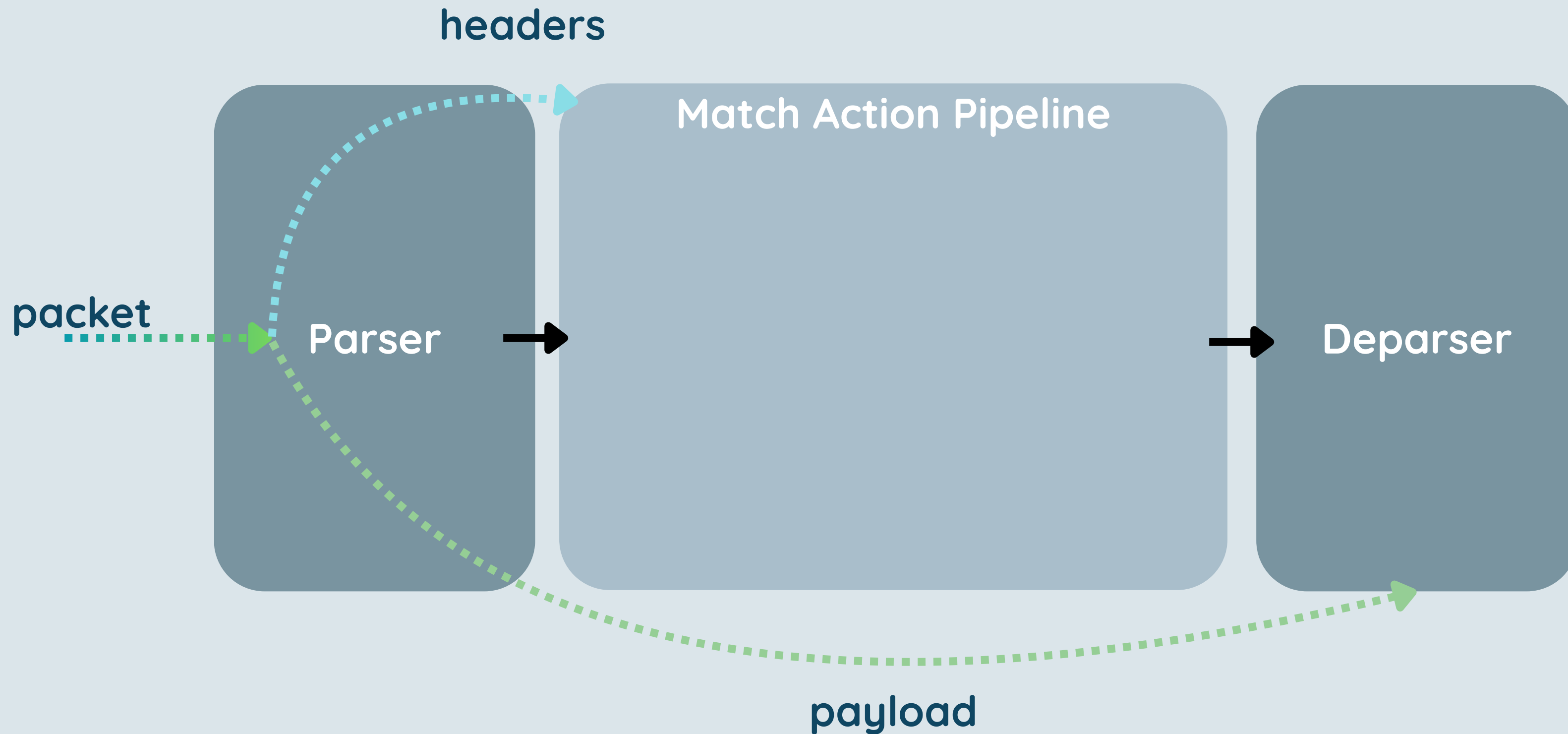 - P4-programmable switches (Tofino)

Tofino

Parser

Deparser

Tofino

headers

packet

Parser

Deparser

payload

Tofino

packet

headers

Parser

Match Action Pipeline

Deparser

payload

Tofino

Tofino

packet → **Parser** → **Match Action Pipeline**

headers

Match Action Unit ... **TCAM** **SRAM** MAU

→ **Deparser**

payload

TCAM = Ternary CAM (longest prefix matches)

SRAM = Static RAM (exact matches)

Why?

(3) : ~ 10% of global electricity consumption

France ICT CO_2[1] 100%

Core Networks 4%

Datacenters[2] 46%

Networks 27%

Terminal production & usage (Phones, TVs...) 50%
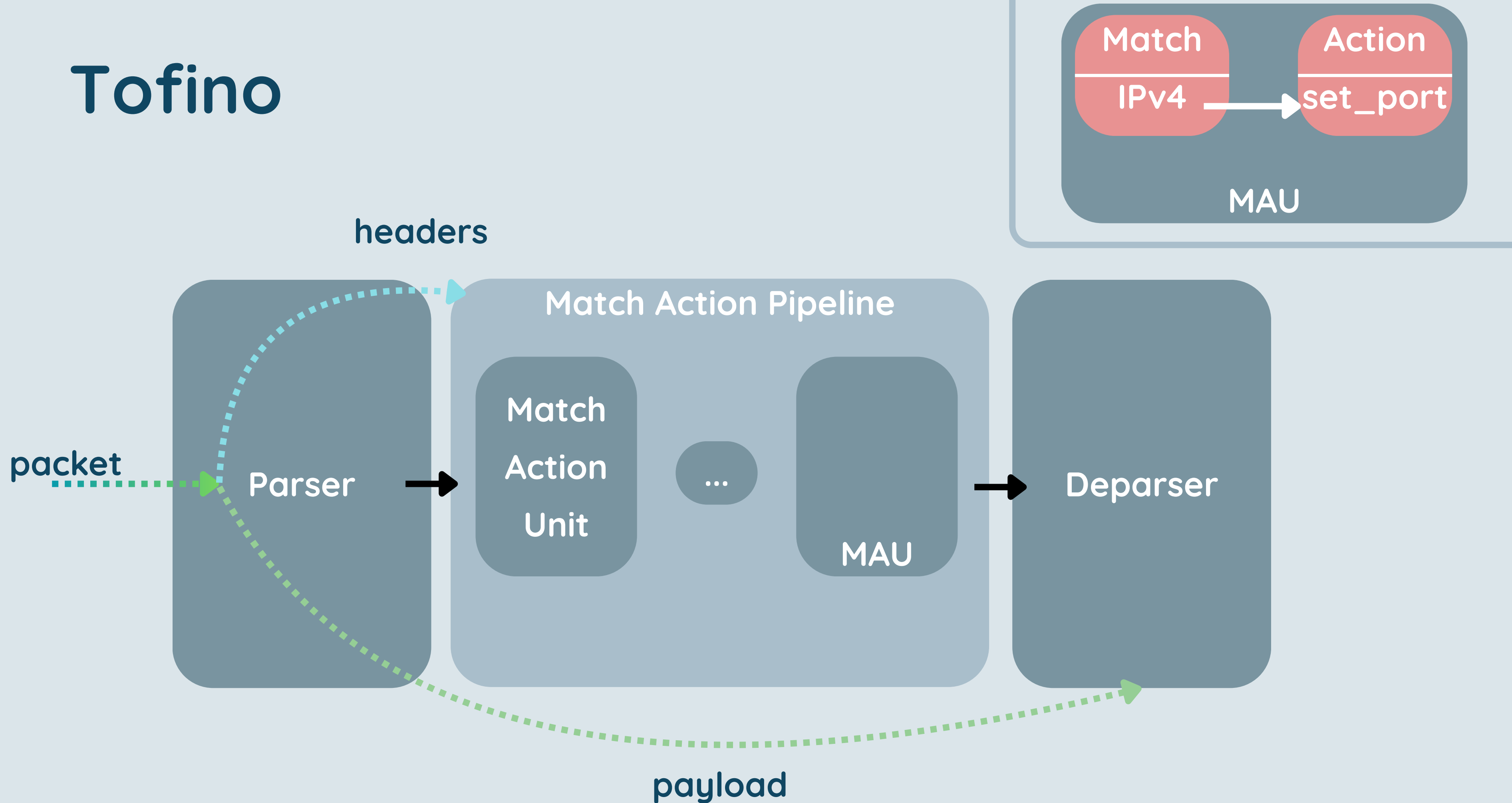
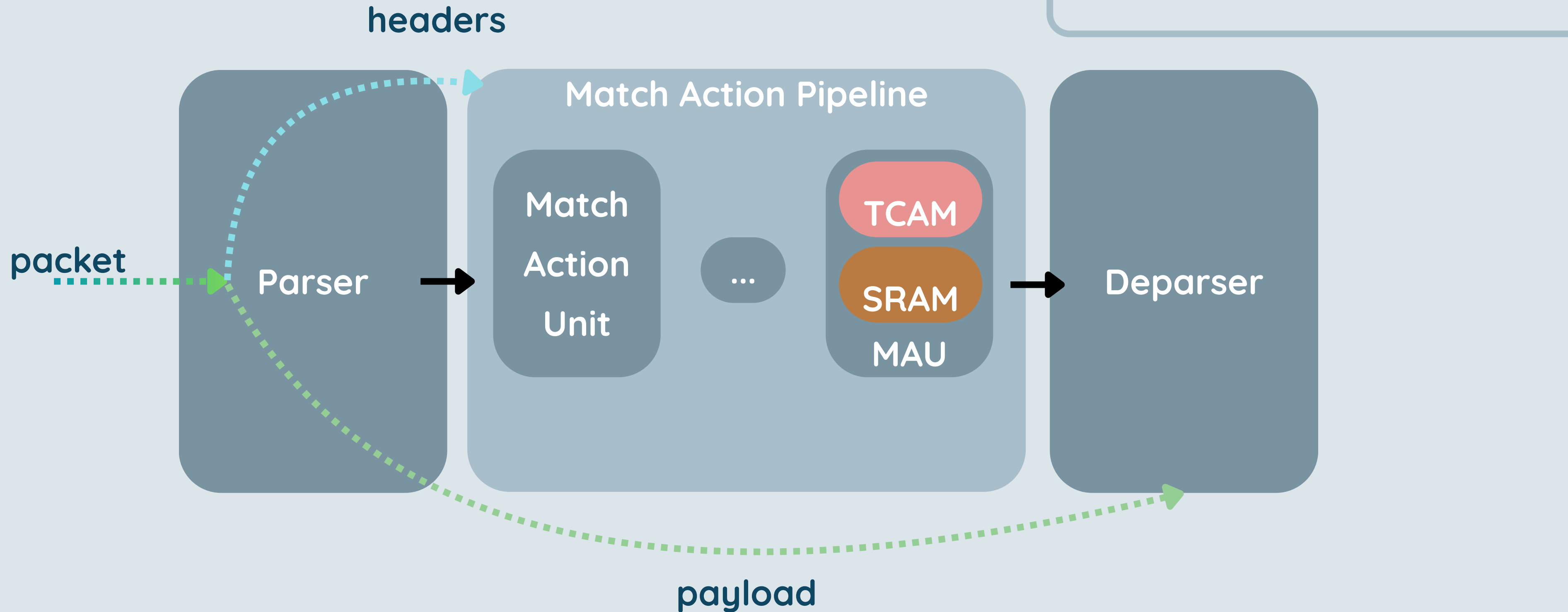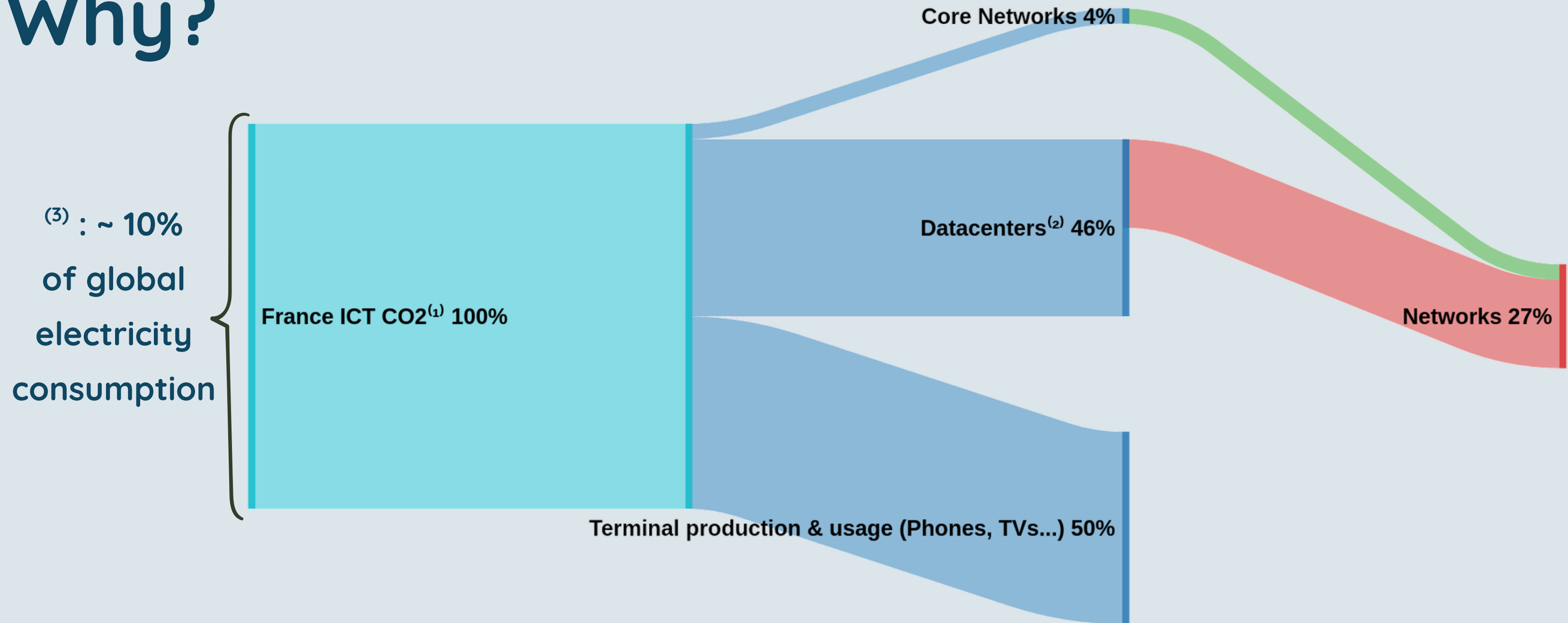[1] : Actualisation des chiffres de l'impact du numérique en France, Government agencies (ADEME, Arcep), 09/01/2025
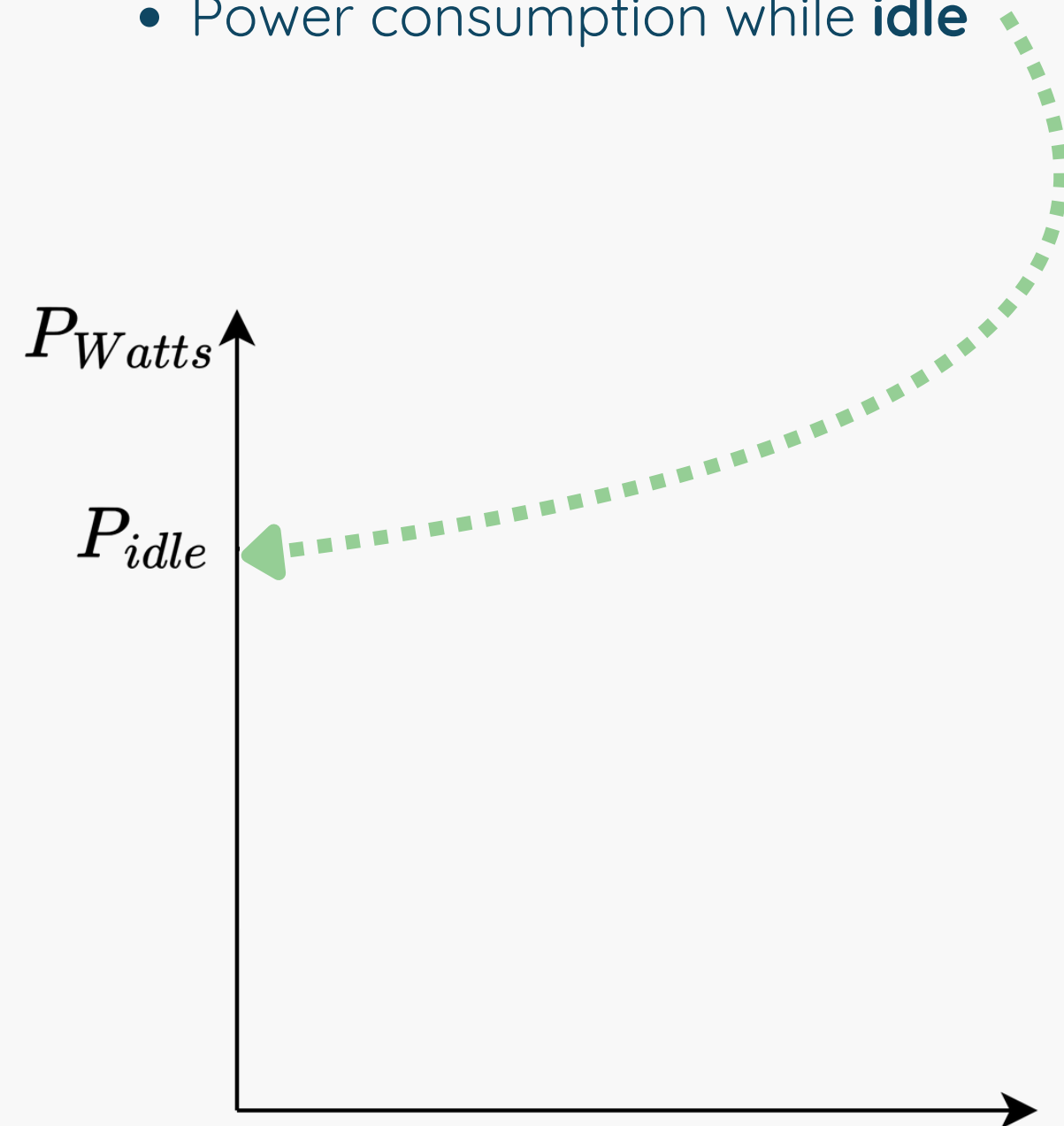
[2] : Achieving Energy Efficiency in Data Centers Using an Artificial Intelligence Abstraction Model, T. Wang et al., IEEE Transactions on Cloud Computing, 2018

[3] : Electricity Consumption by ICT: Facts, trends, and measurements, Erol Gelenbe, 2023

State of the art
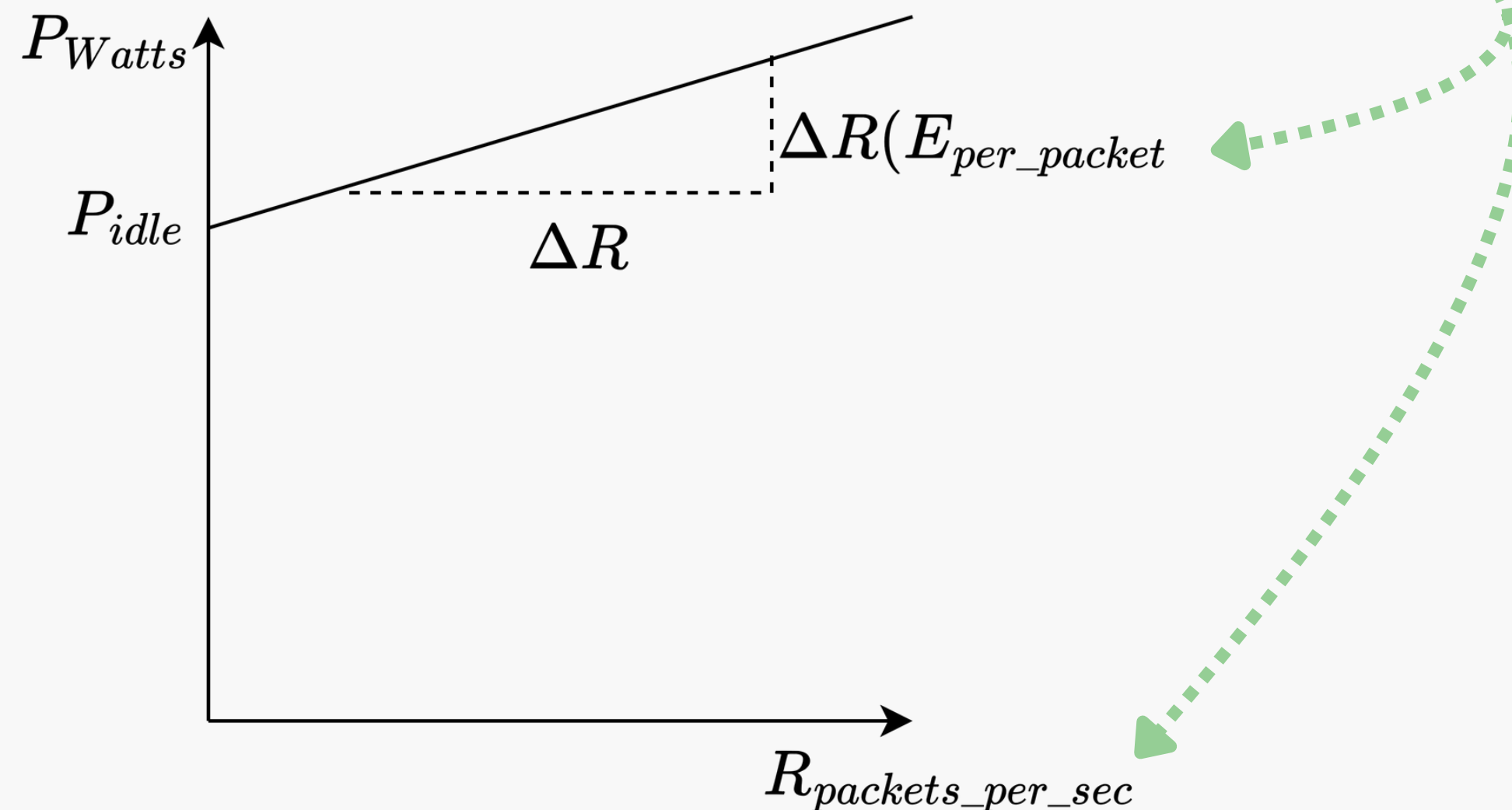
Modeling switch power consumption

- Power consumption while **idle**

P_{Watts}

P_{idle}

State of the art

Modeling switch power consumption
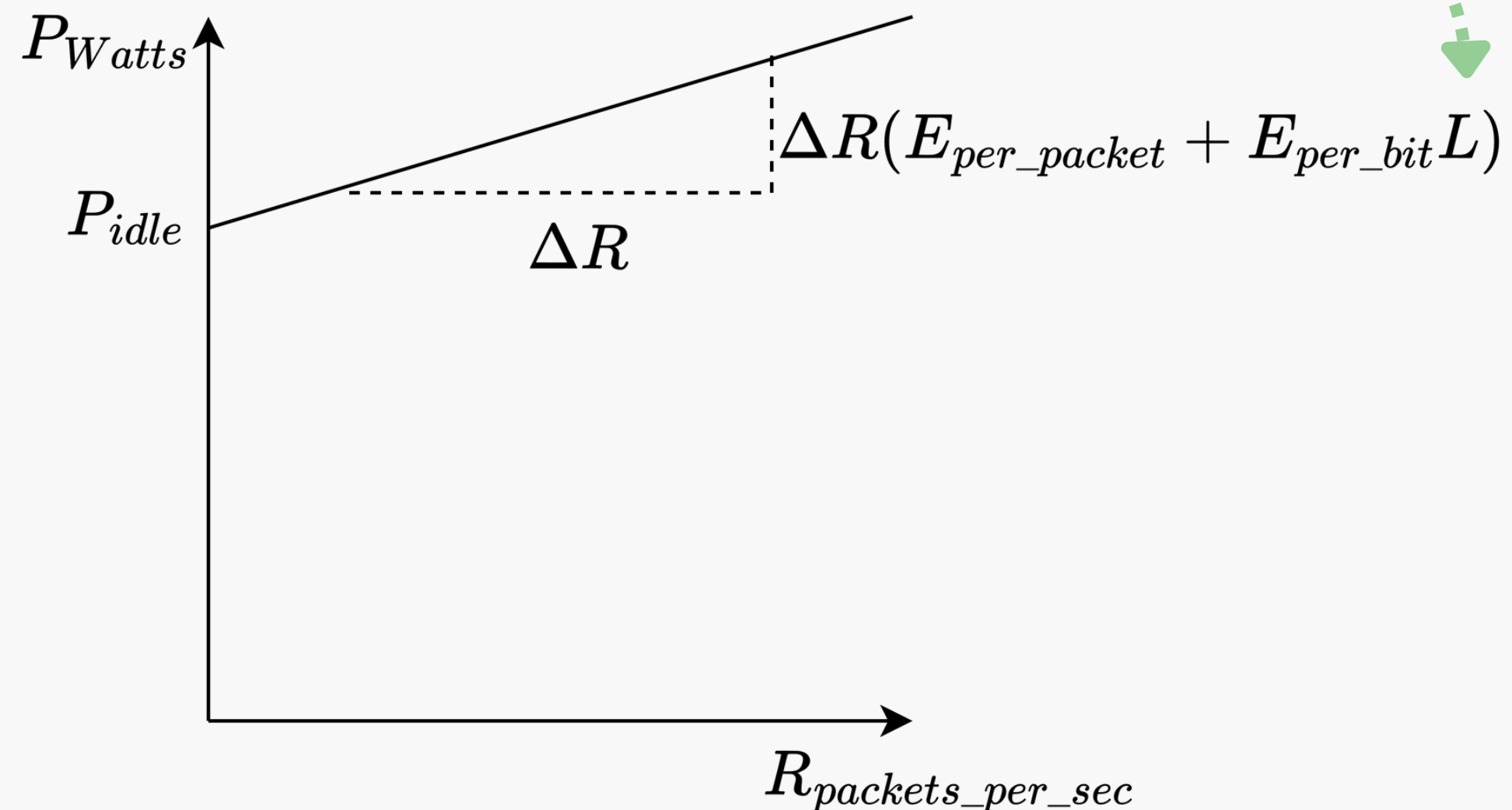
- Power consumption while idle
- Power consumption depending on **input packet rate**

State of the art

Modeling switch power consumption

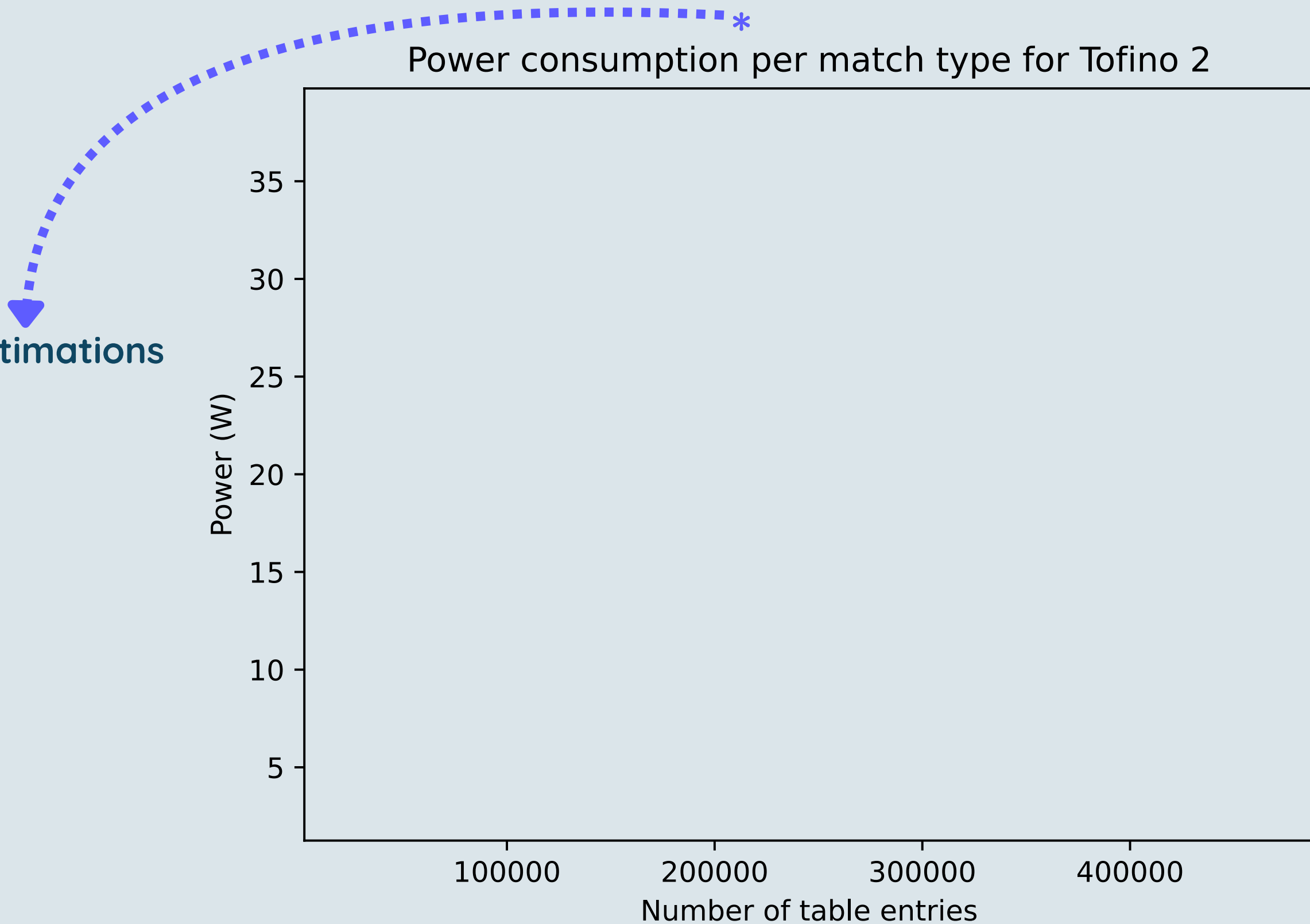- Power consumption while idle
- Power consumption depending on input packet rate
- Power consumption depending on **packet size**

$$\Delta R(E_{per\_packet} + E_{per\_bit}L)$$

$$\Delta R$$

$$P_{Watts}$$

$$P_{idle}$$

$$R_{packets\_per\_sec}$$

What is missing?

* : According to compiler estimations

Power consumption per match type for Tofino 2 *

Power (W) vs Number of table entries

What is missing?

* : According to compiler estimations

Power consumption per match type for Tofino 2

*

Legend:
- ✖ alpm
- ● lpm

longest prefix match

TCAM only

Y-axis: Power (W) — values: 5, 10, 15, 20, 25, 30, 35

X-axis: Number of table entries — values: 100000, 200000, 300000, 400000

What is missing?

* : According to compiler estimations

Power consumption per match type for Tofino 2

TCAM & SRAM
(algorithmic) longest prefix match

TCAM only

Legend:
- alpm (×)
- lpm (●)

Y-axis: Power (W) — 5, 10, 15, 20, 25, 30, 35
X-axis: Number of table entries — 100000, 200000, 300000, 400000

What is missing?

* : According to compiler estimations

TCAM & SRAM

(algorithmic) longest prefix match

TCAM only

Power consumption per match type for Tofino 2

*

Legend:
- **✕** alpm
- **●** lpm

Y-axis: Power (W) — 5, 10, 15, 20, 25, 30, 35

X-axis: Number of table entries — 100000, 200000, 300000, 400000
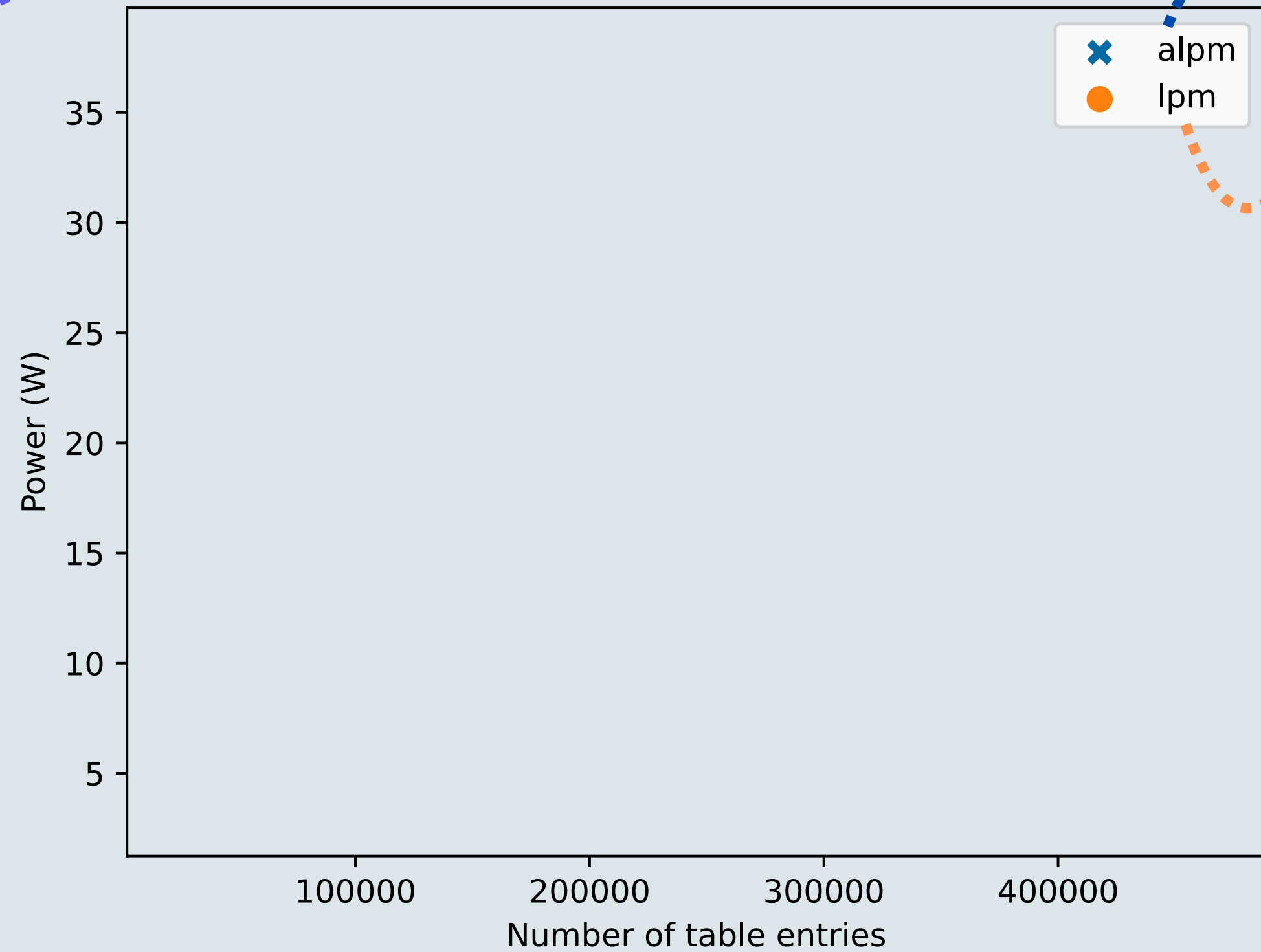
What is missing?

* : According to compiler estimations

Power consumption per match type for Tofino 2

TCAM & SRAM
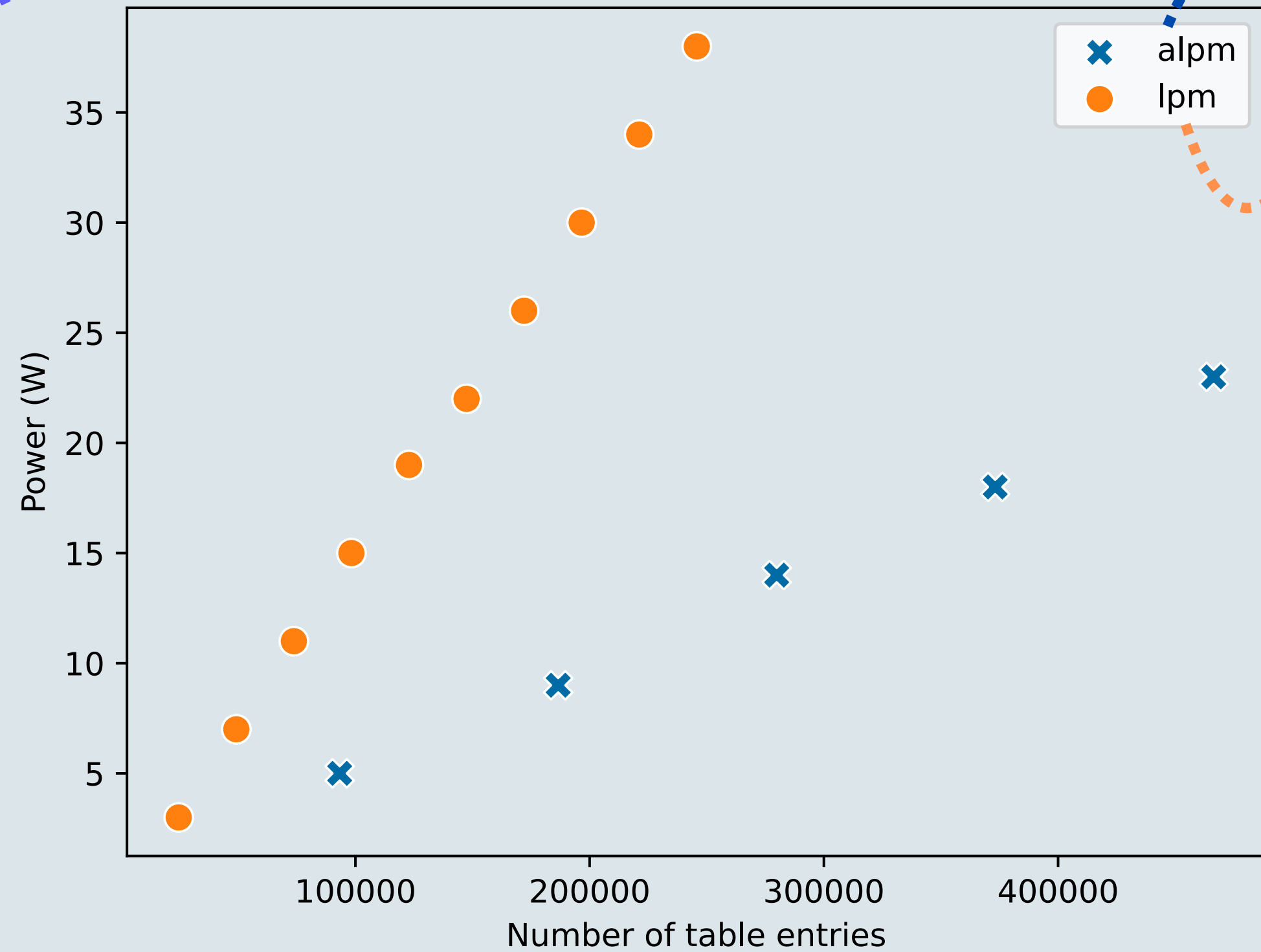(algorithmic) longest prefix match

TCAM only

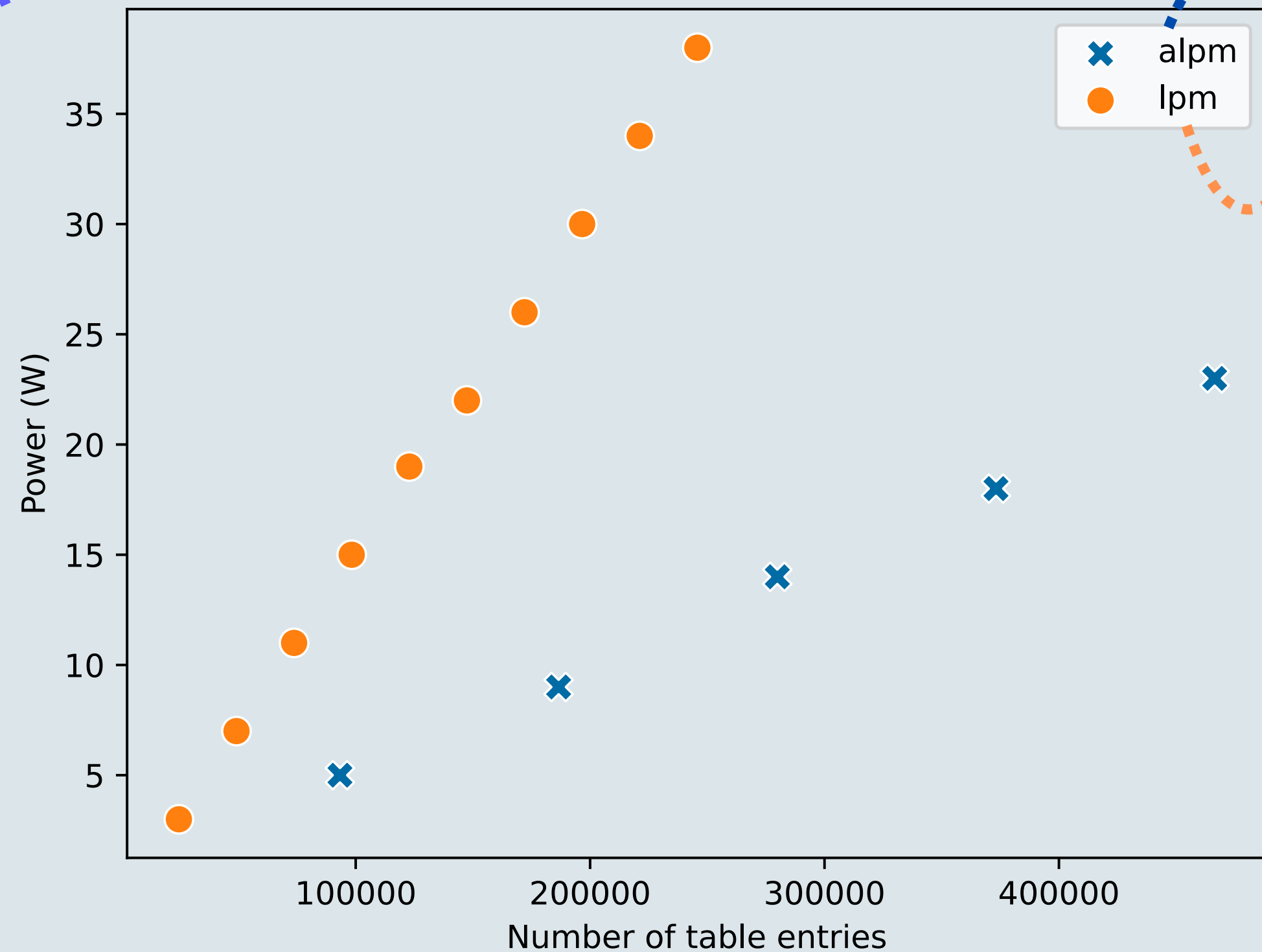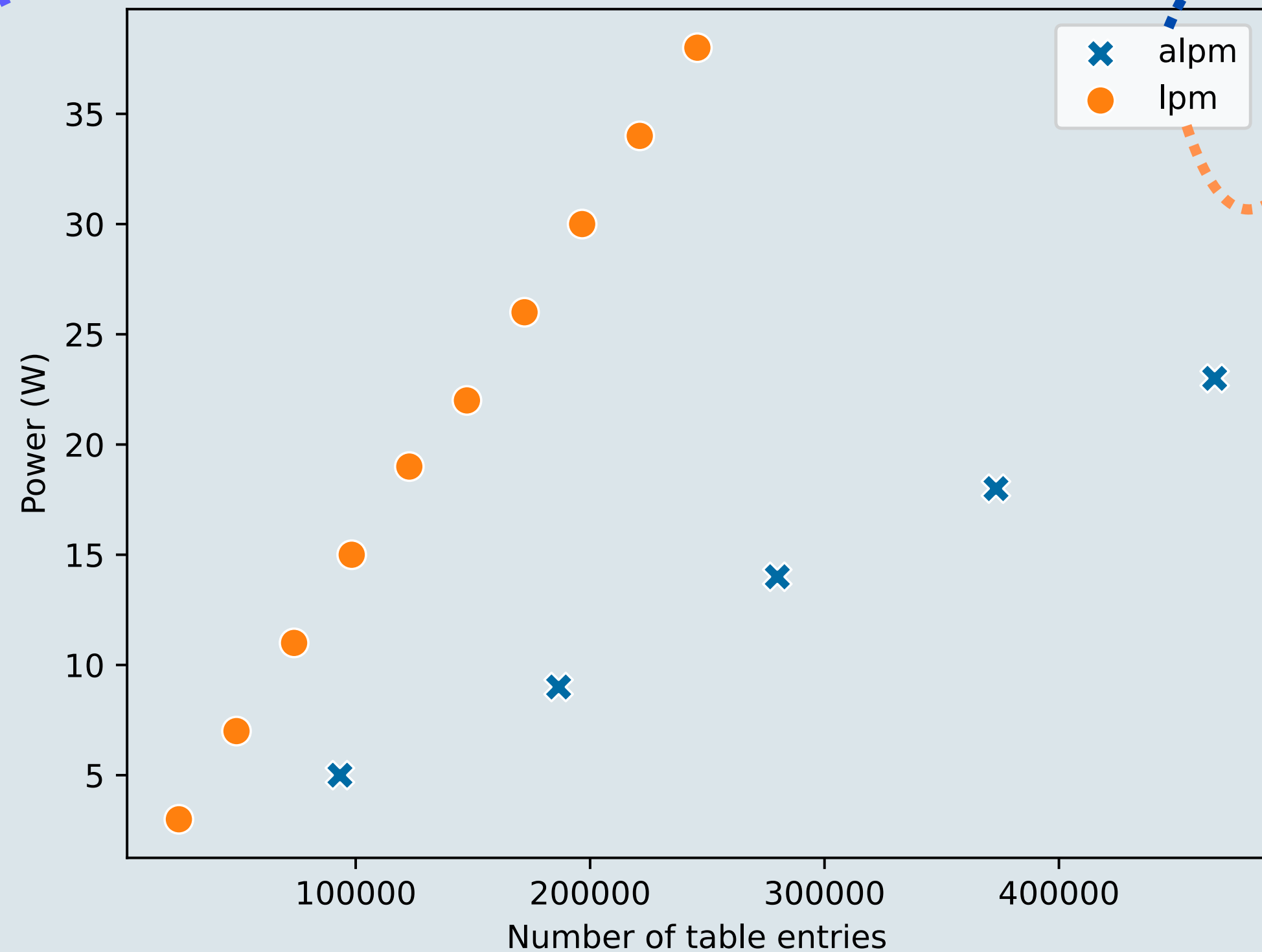$$P = P_{idle} + \quad R \times (E_{per\_packet} + E_{per\_bit} L)$$

What is missing?

*: According to compiler estimations

Power consumption per match type for Tofino 2

TCAM & SRAM
(algorithmic) longest prefix match

TCAM only

Legend:
- × alpm
- ● lpm

X-axis: Number of table entries
Y-axis: Power (W)

$$P = P_{idle} + R \times (E_{per\_packet} + E_{per\_bit}L) + E_{per\_TCAM} \times \boxed{TCAM} + E_{per\_SRAM} \times \boxed{SRAM} \boxed{+?}$$

Methodology

How to find the missing levers + ?

- List every possible lever
  - TCAM/SRAM usage
  - Parser length
  - ...
- Create P4 codes highlighting each lever
  - alone
  - in combination with other levers
- Parse compiler artefacts...
  - Memory mapping
- ...to create a dataset

Use the dataset to train a model

Modeling

- **98 parameters** (only 30 or so are actually useful)

- Dataset of **585 p4 programs**

- Random forest → **96% accuracy**

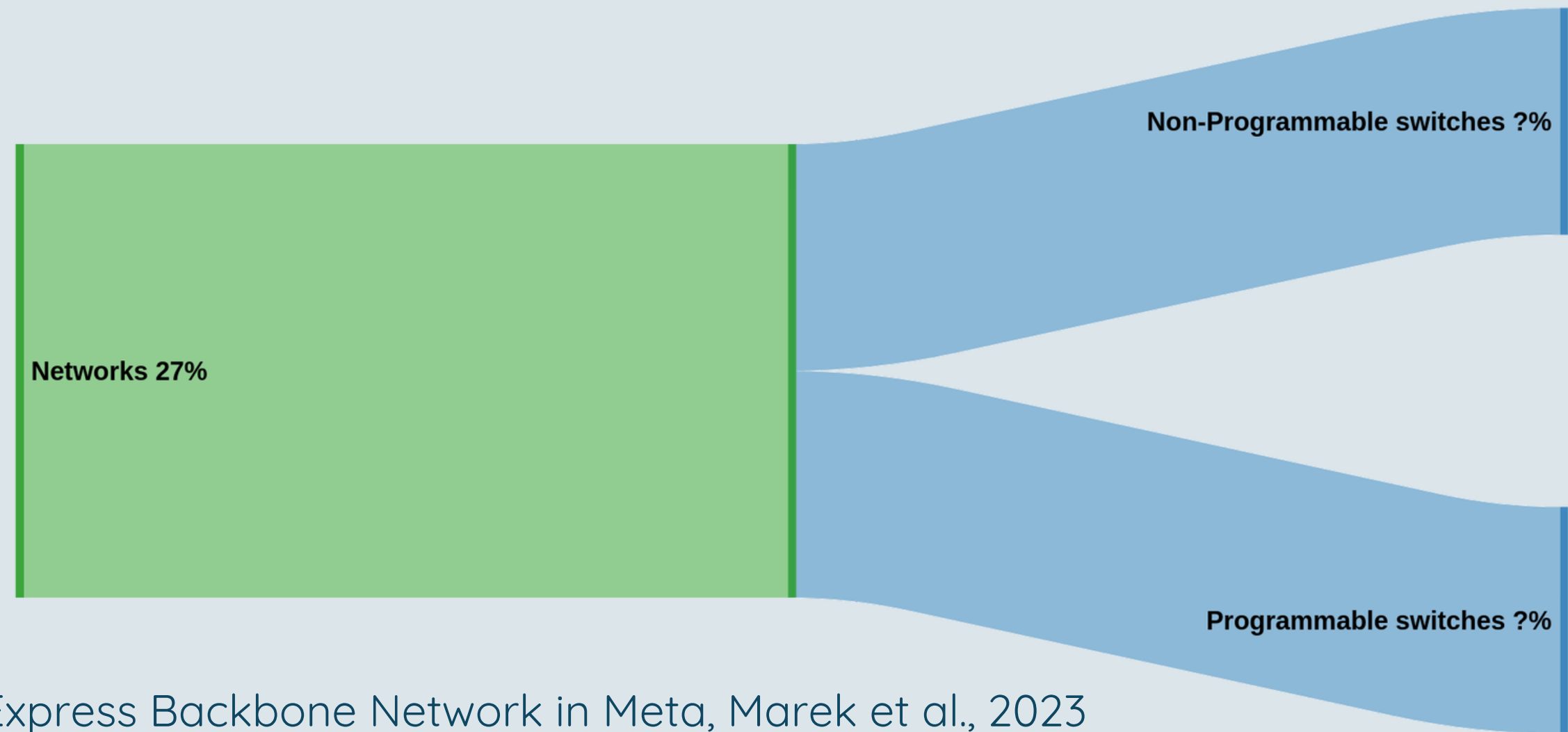## Permutation feature importance results
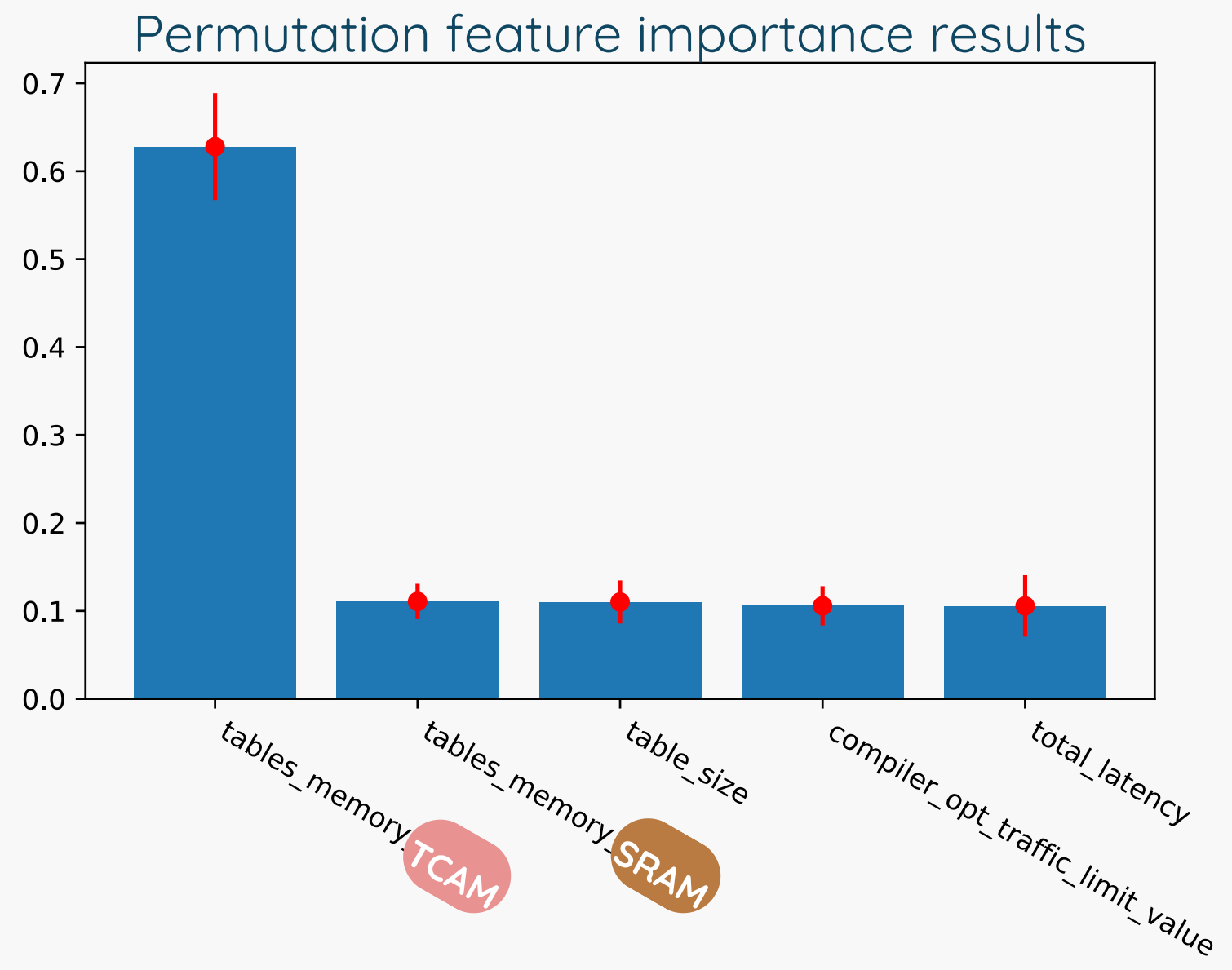
Next steps ?

Optimising P4 code

- Try out optimisation techniques

- Running benchmark on Tofinos
  - Helping grid5000 with the integration of Tofinos

- Collecting data

- Compare results

Bonus slides

Why?

Networks 27%

Non-Programmable switches ?%

Programmable switches ?%

Programmable switch uses :

- **Meta** : EBB: Reliable and Evolvable Express Backbone Network in Meta, Marek et al., 2023
  - "Programmable Switch"
- **Alibaba** : Cetus: Releasing P4 Programmers from the Chore of Trial and Error Compiling, Li et al., 2022
  - Tofino
- Data Center Switch Silicon Evolves, Omdia, 2019
  - 2019 : Programmable switches accounted for **10% of Data Center switch purchases**

State of the art

Modeling switch power consumption

- Power consumption while **idle**
- **Input packet rate** & packet size
- Energy consumption (**per bit** & **per packet**)

$$P_{Watts}$$

$$\Delta R(E_{per\_packet} + E_{per\_bit}L)$$

$$P_{idle}$$

$$\Delta R$$

$$R_{packets\_per\_sec}$$
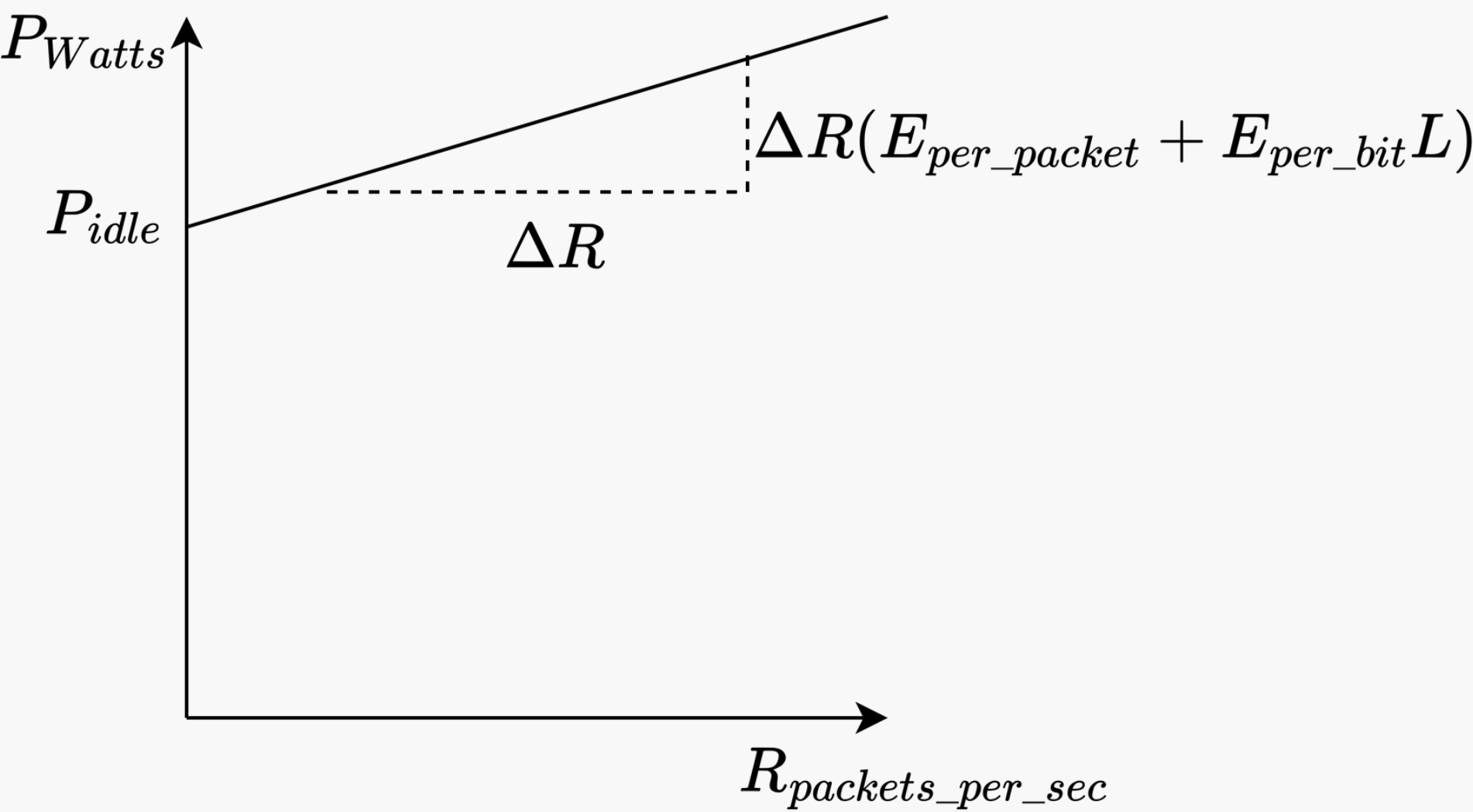
Switch	E$_{per\_packet}$	E$_{per\_bit}$
Tofino [1]	7.21 nJ	1.72 pJ
NetFPGA [2]	57.3 nJ	124 pJ
Edge Switch [3]	1571 nJ	1175 pJ

[1]: Power Modelling Framework for Network Switches, Jackie Lim

[2]: An empirical model of power consumption in the NetFPGA Gigabit router, Vishwanath et al.

[3]: Modeling Energy Consumption in High-Capacity Routers and Switches, Vishwanath et al.