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Studying DNS energy consumption

Sandoche BALAKRICHENAN

Problem Statement

- Why?
  - Corporate Social Responsibility – We would like to improve our understanding of the environmental impact of our “core business” technology - the DNS
  - Encrypted DNS traffic ≈ 23%[1] (as of 16th May 2024)
  - Cost of transition from UDP to encrypted communication does increase energy consumption[2]
- To the best of our knowledge - No prior studies focusing on measuring the energy impact of DNS infrastructure & protocol

[1] https://stats.labs.apnic.net/edns
[2] *Analysing the Energy Consumption of Security Protocols*

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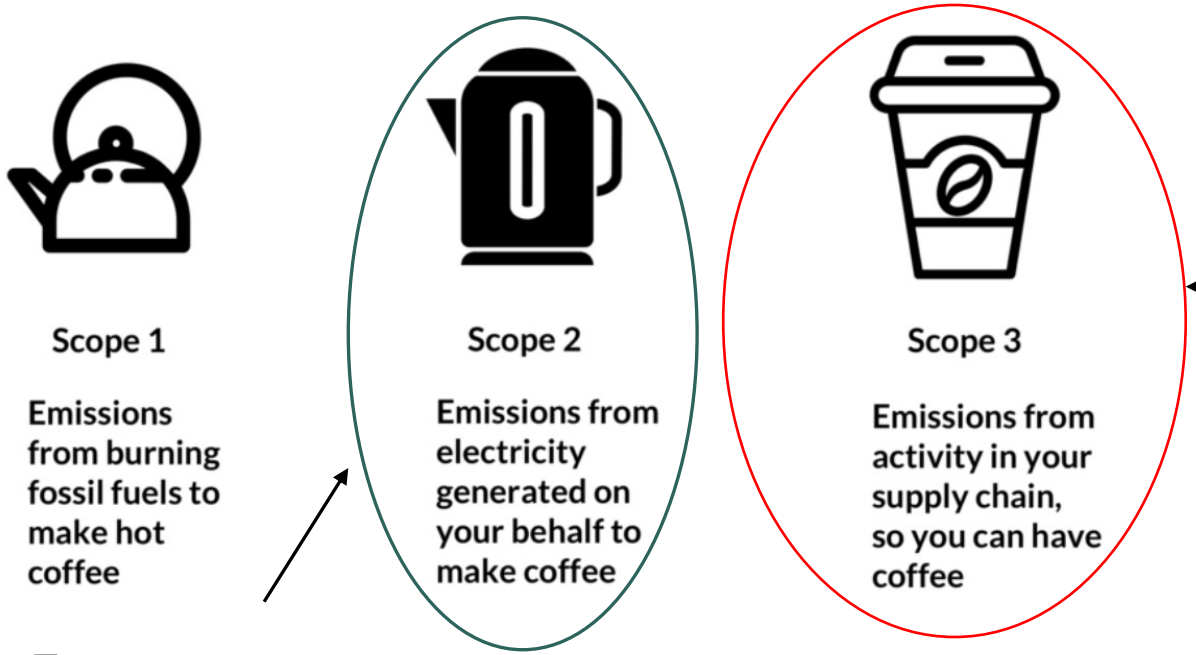
Afnic's work as its CSR effort

	Total Emission	Emission/DUM
2018	867 tCO2e	252 gCO2e
2022	690 tCO2e	153 gCO2e
2023	625 tCO2e	147 gCO2e ≈ 0.6 Km by Car



≈ 70% of the Carbon Footprint

Focus area

Source: The Greenweb foundation

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Work Done

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What do we want to do?

- Measure energy consumption at the authoritative server
- Measure energy consumption at the resolver
- Identify the tools and architecture for measurements
- Decide on the metrics to measure

What to measure?

- HW Energy utilisation
- Units to measure
  - Watts, KW, KWh

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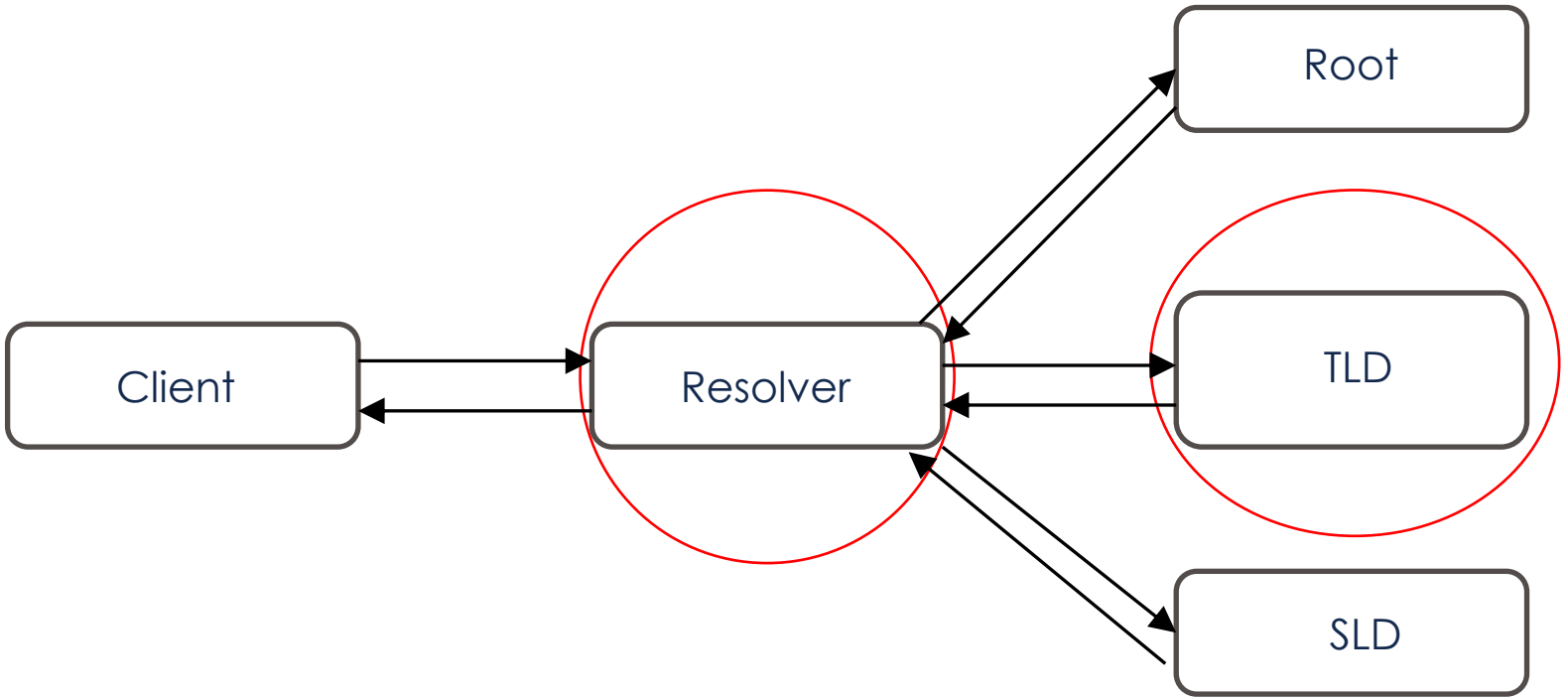
Where to measure?



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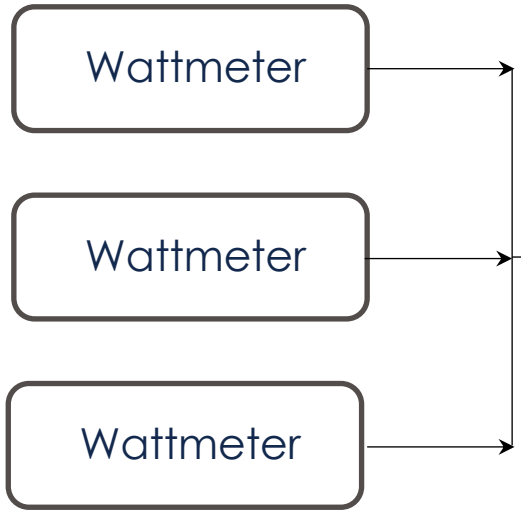
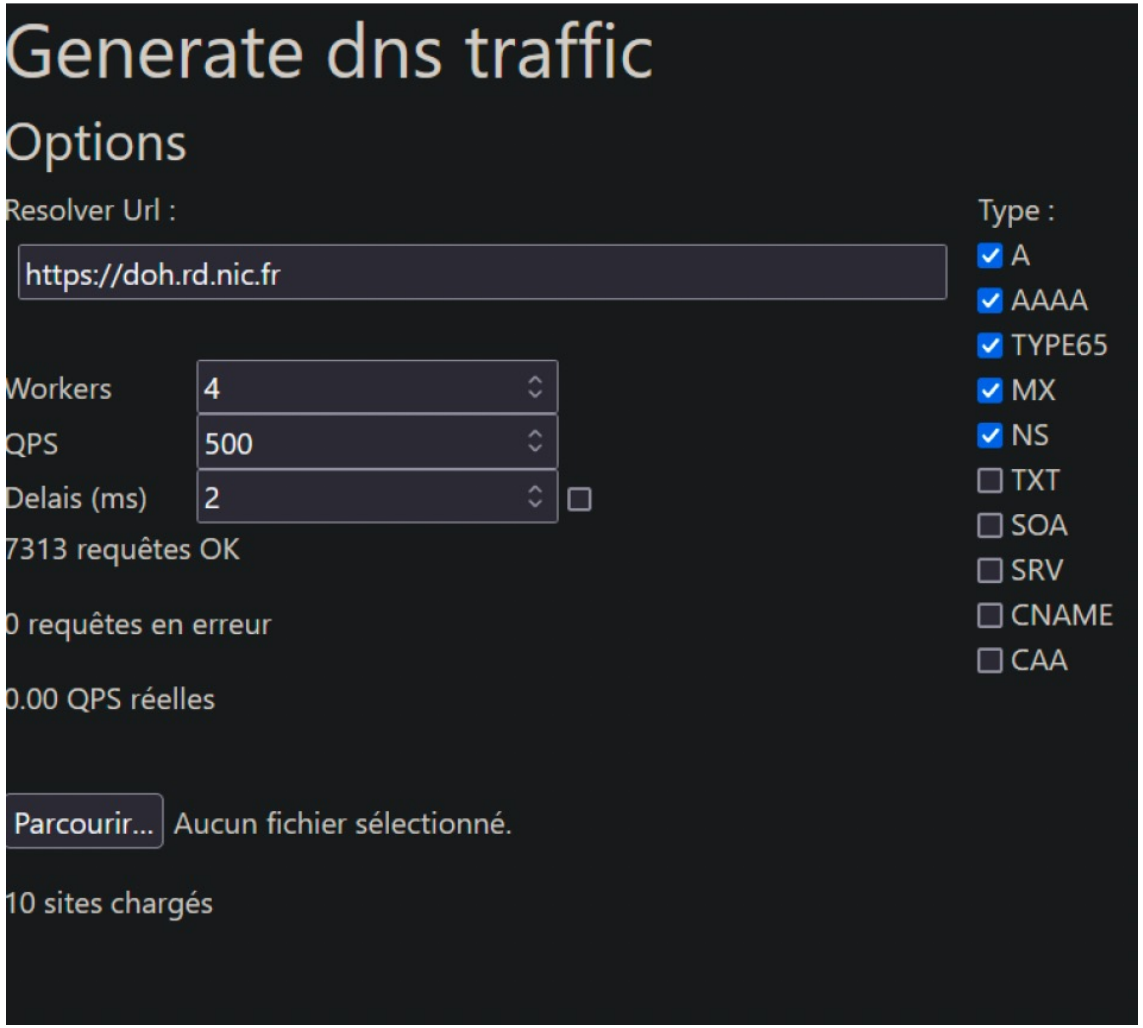
Authoritative Server measurements

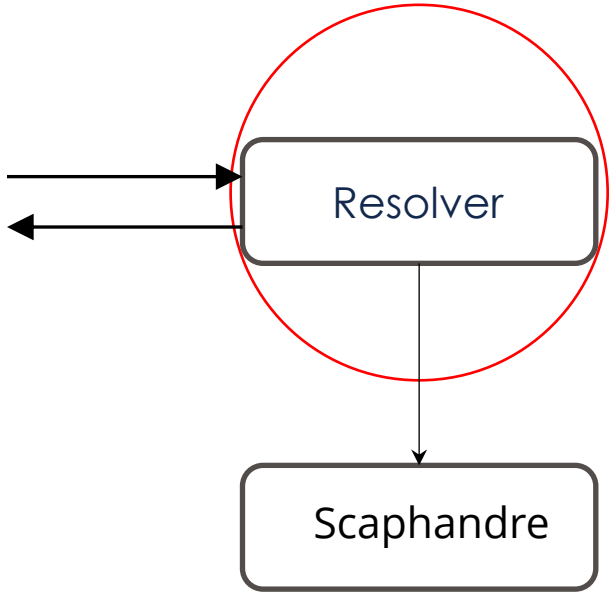
At Two of Afnic's Data Canters, the Authoritative Servers are attached with Wattmeter's



Grafana

Resolver measurements





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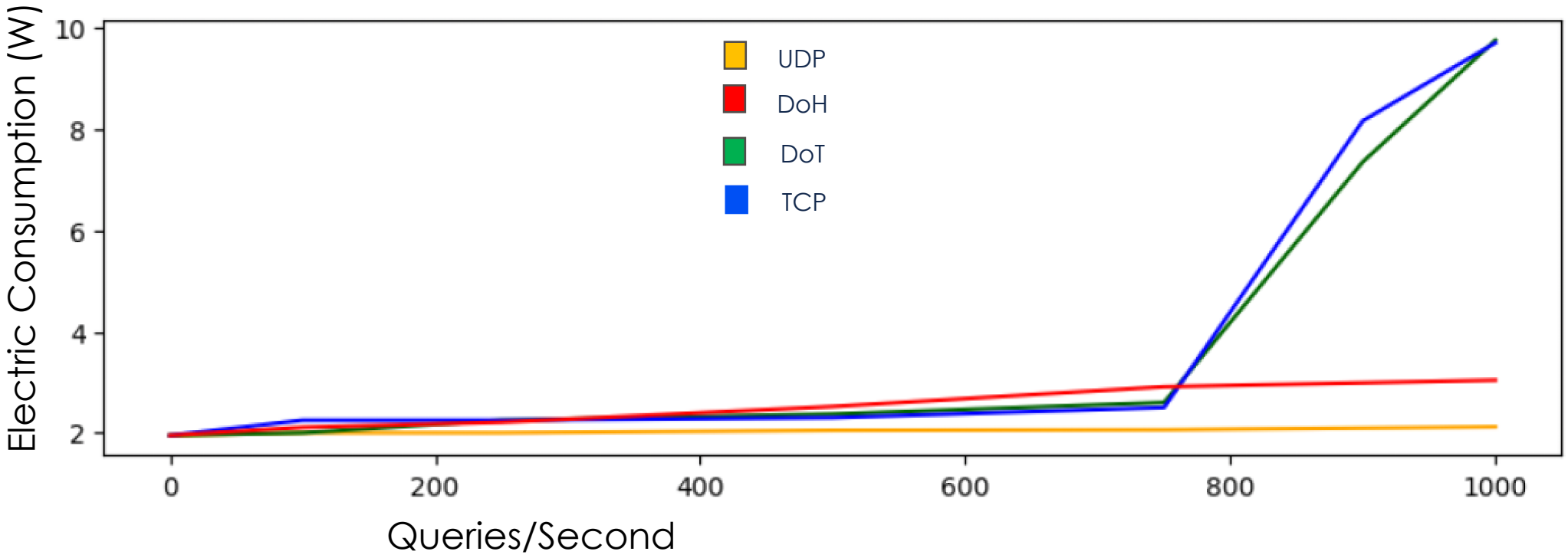
Resolver energy consumption



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Work in Progress

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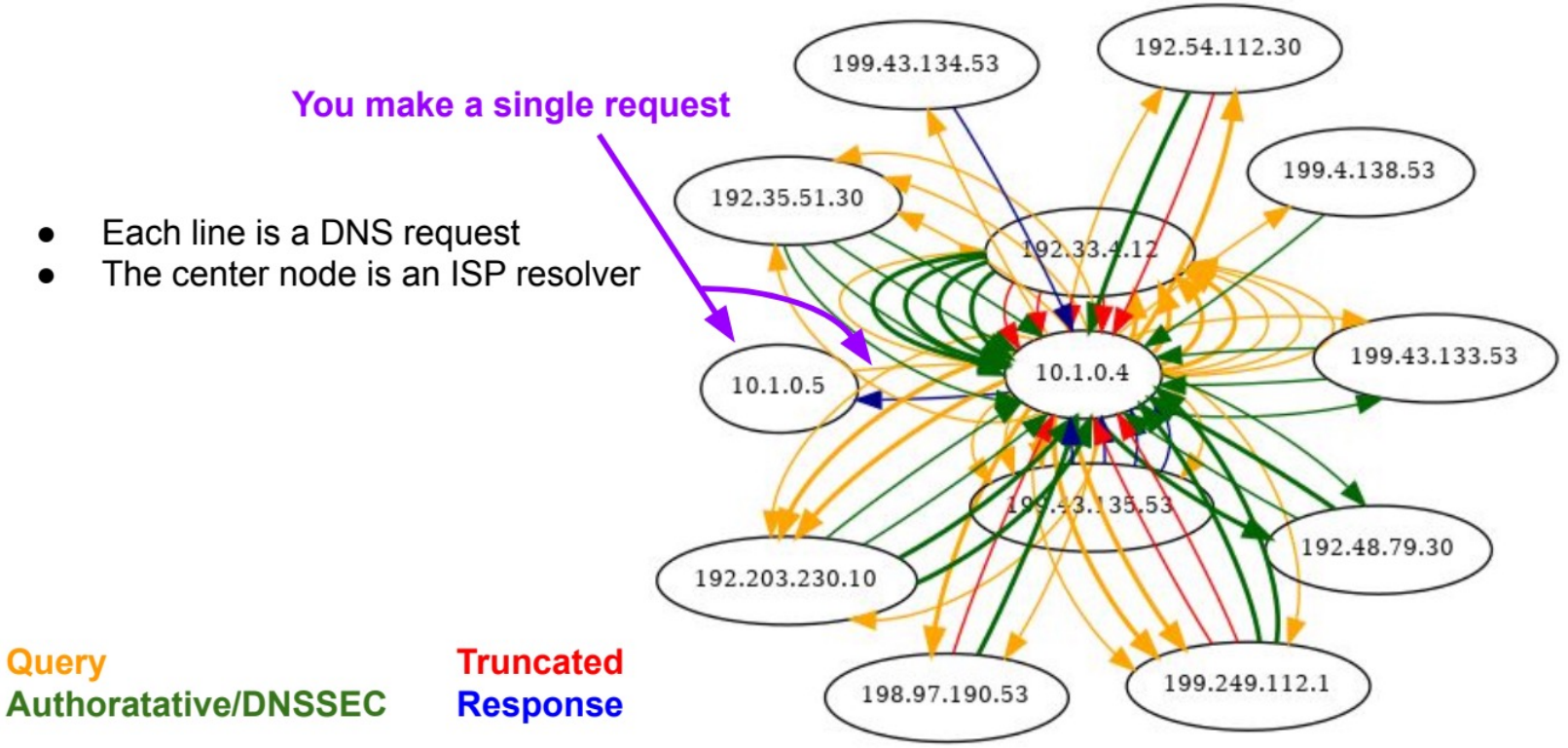
What do we want to do?

- Measure the energy consumption - UDP, TCP, DNSSEC, DoT & DoH
- Develop a mathematical model to estimate the number of packets and packet size for different DNS traffic types
- Benchmark the mathematical model results with the energy consumption in real resolvers/authoritative servers?
- Convert the consummation to CO2eq.

DNS Query/Response is too talkative

The example.com web page

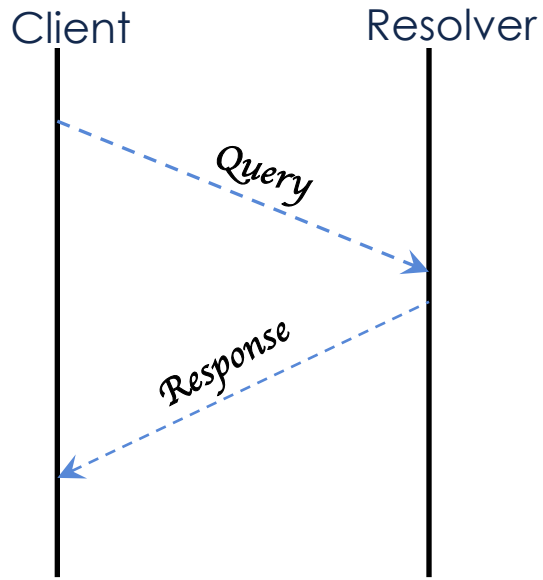
- Each line is a DNS request
- The center node is an ISP resolver



Source: DNS Deepdive (Wes Hardaker)

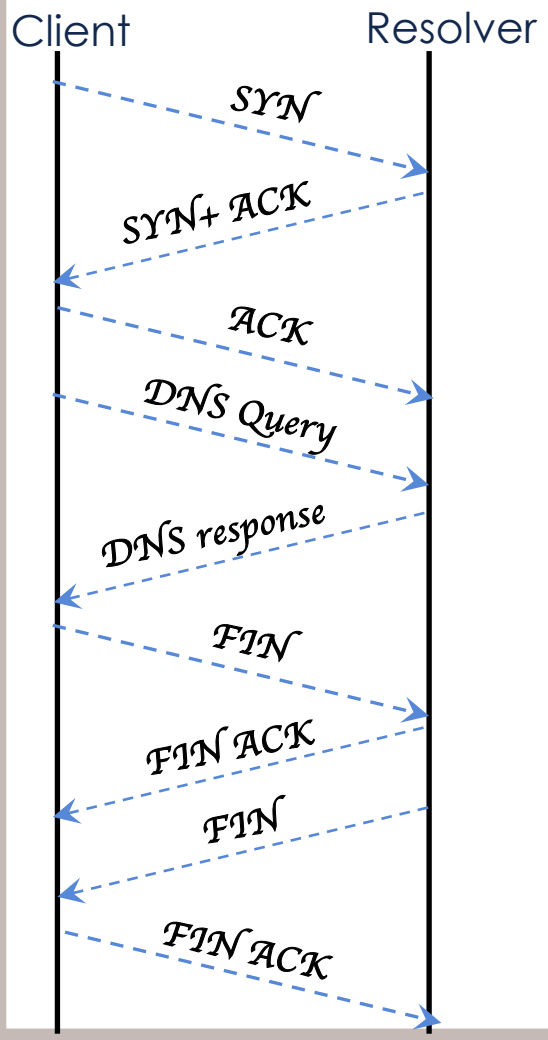
Estimating the number of packets – UDP

For a Query, total number of packets (N) transited over the network?



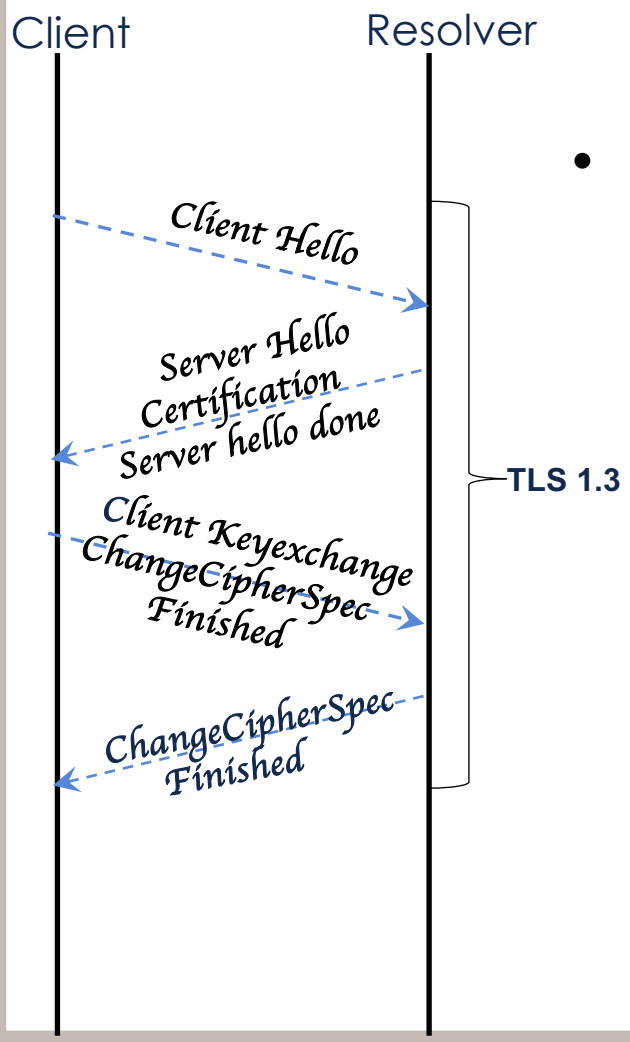
- Taking into account:
  - Same transport protocol used
  - Retransmission Coefficient: $\alpha = 0$ (Assuming no packet loss)
  - We set $\epsilon = 1 + \alpha$ (where $\epsilon = 1$, if there is no packet loss)
  - For resolving a domain name; $N = 2\epsilon$ (With Cache)
  - For resolving a domain name; $N = 8\epsilon$ (Without Cache) [$N = 2\epsilon + 3 * 2\epsilon$]

Estimating the number of packets - TCP



- TCP: $N = 11\ \epsilon$ (With Cache)
  - Connection phase (3 Packets); Closing Phase (4 packets)
  - DNS Query + Response = 2 Packets
  - ACK for DNS Query & Response = 2 Packets
  - Assuming ACK not piggybacked

Estimating the number of packets DoH



- DoH : Use TLS (TLS 1.3)
  - TLS adds 4 packets
  - DoH: N = TCP+TLS+HTTP/2
    - N= (3+4) ϵ + 2*(4+2+2) ϵ = 23 ϵ (With Cache)
    - N= (3+4) ϵ + 2*(4+2+2) + 3 *2 ϵ = 29 ϵ (Without Cache)
  - In addition
    - X.509 Certificates
    - RSA ≈ 1500B
    - ECDSA ≈ 800B

Estimating the Carbon footprint – UDP Packet

- Using Sustainable web design method:
    - 512B * 2 = 1024 B
    - 0.000001024 GB (1024B converted to GB)
    - Energy consumed = Bytes transferred * 0.81 kWh/GB
        - 0.000001024 * 0.81 = 0.00000082944 kWh
    - 0.00000082944 KWh * 442g/kWh = 0.00036661248 kg CO2e
    - 0. 82944 KWh (i.e. 100 0000 UDP resolution) ≈ 1.4 Km by Car

0.81 kWh – needed to transfer 1 GB of data (*Source: Sustainable web design research*)
442gCo2e/kWh – global carbon intensity to transfer 1 GB of data

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Fulfilling the CSR Role

- Forthcoming PhD programs on measuring and optimising DNS energy consumption

- We would like to collaborate with interested parties
    - Who operate DNS resolvers?
    - Researchers for mathematical modelling and measurements
    - Expertise in Energy measurements
    - DNS community

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Sandoche.balakrichenan@afnic.fr

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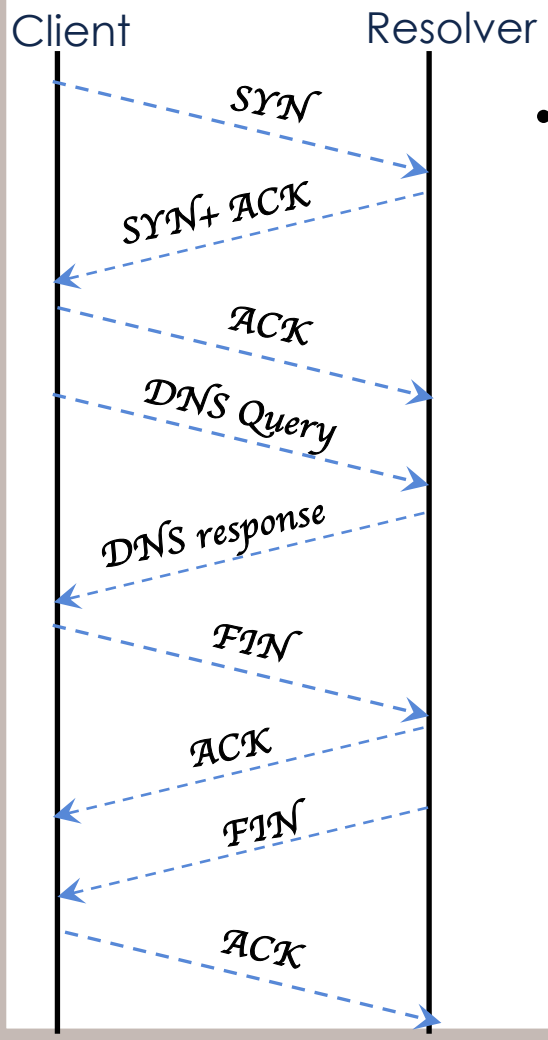
Estimating the number of packets - TCP



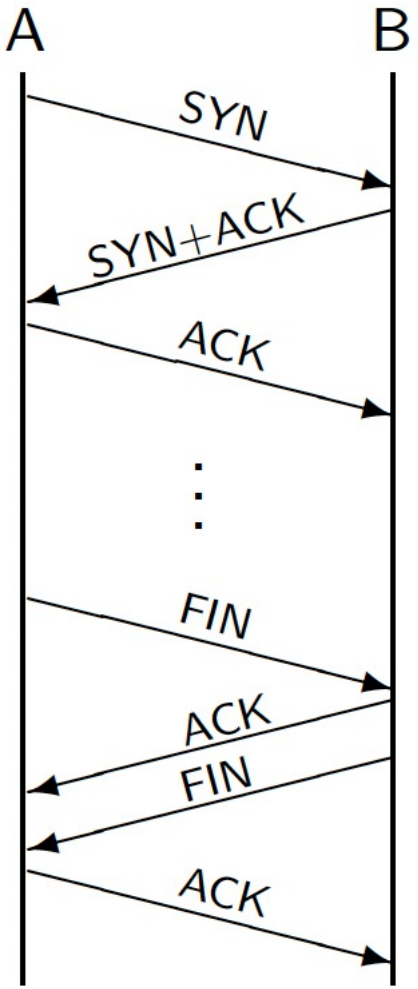
- TCP: $N = 9\epsilon$
  - Connection phase (3 Packets); Closing Phase (4 packets)
  - Assuming ACK not piggybacked
  - $L(P_Q)$: Query Payload; $L(P_R)$: Response Payload
  - MSS (Maximum Segment Size) = MTU – H_{IP} – H_{TCP} (H_{IP} : IP Header size & H_{TCP} TCP Header Size)

Estimating the Carbon footprint – TCP Packet

- Using Sustainable web design method:
  - 512B * 2 = 1024 B
  - 0.000001024 GB (1024B converted to GB)
  - 0.000001024 * 0.81 kWh/GB = 0.00000082944 kWh
  - 0.00000082944 KWh * 442g/kWh = 0.00036661248 kg CO2e
  - 0. 82944 KWh (i.e. 1000000 UDP Connection) ≈ 1.4 Km by Car

0.81 kWh/GB conversion to electricity usage
Convert this electricity use to carbon dioxide emissions
442g/kWh is the global average carbon intensity of electricity

Estimating the number of packets - TCP



- TCP: $N = \varepsilon \left(3 + 4 + 2 \left\lceil \frac{\mathcal{L}(\mathcal{P}_Q)}{MSS} \right\rceil + 2 \left\lceil \frac{\mathcal{L}(\mathcal{P}_R)}{MSS} \right\rceil \right)$
  - Connection phase (3 Packets) + Closing Phase (4 packets) = 7
  - Factor 2: Assuming ACK not piggybacked
  - $L(P_Q)$: Query Payload; $L(P_R)$: Response Payload
  - MSS (Maximum Segment Size) = MTU – H_{IP} – H_{TCP} (H_{IP} : IP Header size & H_{TCP} TCP Header Size)

What has been done? – Architecture for energy consumption measurements

Problem Statement

- As known to us - No prior studies focussing on measuring the energy impact of DNS infrastructure & protocol
- Why such a study is getting important now?
  - Encrypted DNS traffic ≈ 22.5%[1]
  - Cost of transition from UDP to encrypted communication does increase energy consumption[2]
  - Corporate Social Responsibility – We would like to improve our understanding of the environmental impact of our “core business” technology - the DNS

[1] https://stats.labs.apnic.net/ed
[2] https://www.locationaware.usf.edu/ongoing-research/technology/laisyc/

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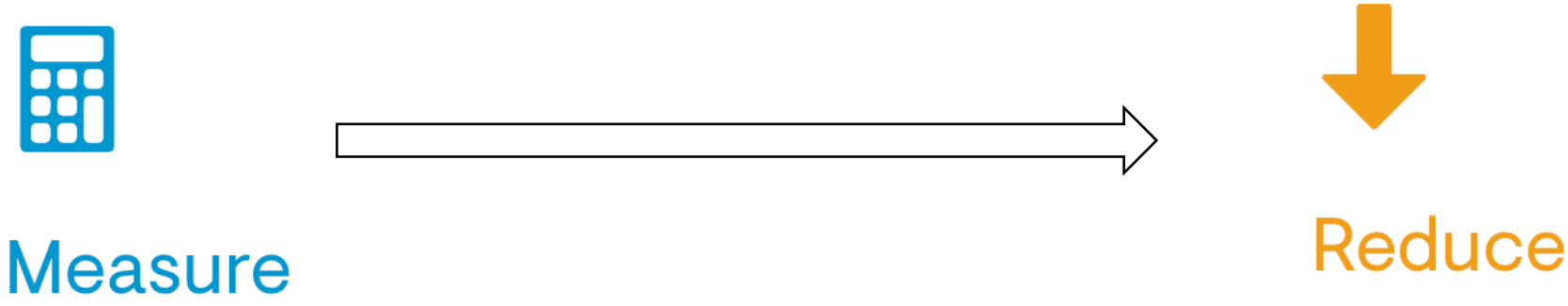
Objective of this study



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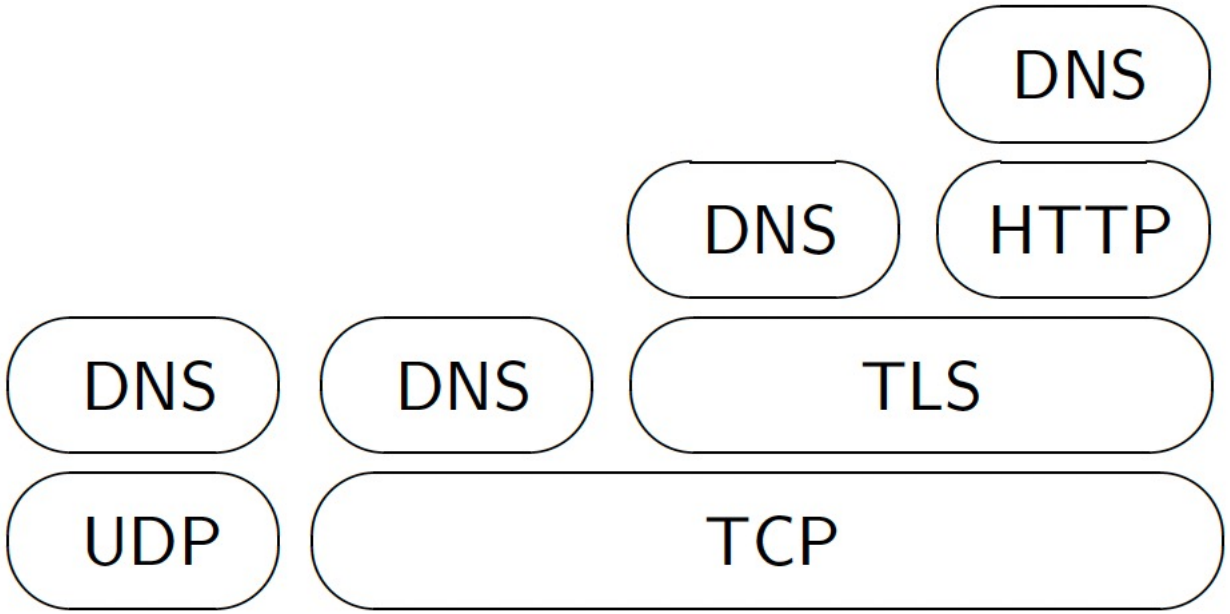
What we want to do?

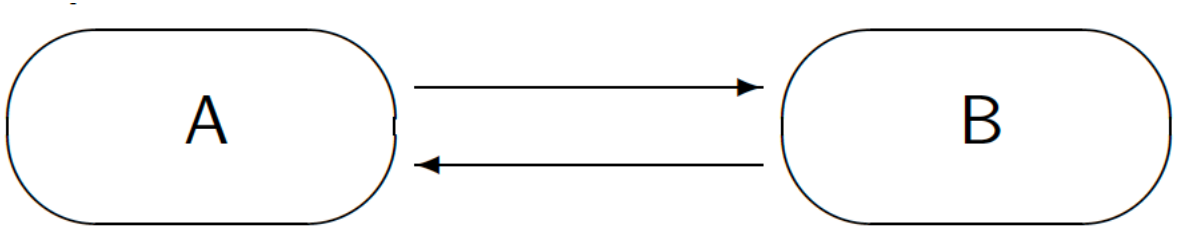
- Understand wire format for different DNS resolutions (UDP, TCP, DoT, DoH)
- Measure energy consumption at the authoritative server
- Measure energy consumption at the resolver
- Measure whether mechanisms such as DNS query name minimization reduces energy consumption
- Objective – To study whether the DNS community can play a role in reducing the carbon footprint of the DNS infrastructure

DNS, DoT and DoH protocol layers



Estimation of number of packets over the network (1/2)

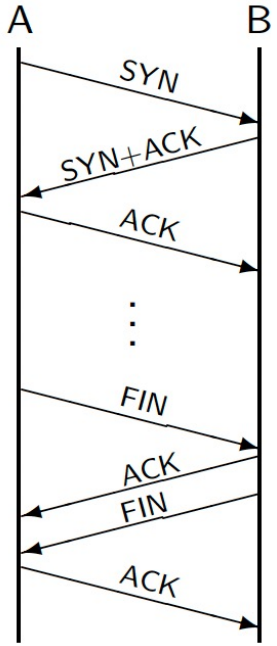
- *For a question, how many packets will transit over a network?*



- By summing
  - Same protocol over the link
  - Size of the packet limited by MTU
  - Replay Coefficient: $\propto \geqslant 0$ (linked to network disturbances)
  - We set $\epsilon = 1 + \alpha$ (where $\epsilon = 1$, if there is no network disturbances)

Estimation of number of packets over the network (2/2)

- For UDP, N = 2 ϵ
- For TCP, $N = \varepsilon \left(3 + 4 + 2 \left\lceil \frac{\mathcal{L}(\mathcal{P}_Q)}{MSS} \right\rceil + 2 \left\lceil \frac{\mathcal{L}(\mathcal{P}_R)}{MSS} \right\rceil \right)$



- The connection phase requires the exchange of 3 packets between machines A and B (:B: SYN, SYN+ACK, ACK)
- The closing phase requires 4 packets: FIN, ACK, FIN, ACK. This gives 3 + 4 = 7 packets to initialize and close a TCP connection.
- From here, all that remains is to determine the number of packets required to transmit the DNS question and DNS response payloads. L(PQ) (resp. L(PR)) is the length in bytes of the payload. Replay is defined with a replay coefficient $\alpha > 0$
- The number of packets required to transmit K bytes is linked to the MTU and, more specifically, to the MSS (maximum segment size), where $MSS = MTU - H_{IP} - H_{TCP}$ (H_{IP} is the size of the IP header and H_{TCP} the size of the TCP header)

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Fulfilling the CSR Role

- Forthcoming PhD program with IRT-SystemX and a collaboration with Télécom Sud Paris on measuring and optimising DNS energy consumption

- We would like to collaborate with interested parties
    - Who operate DNS resolver
    - Researchers for mathematical modelling and measurements
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Energy boundaries breakdown

Data Centers	Networks	User Devices
22%	24%	54%

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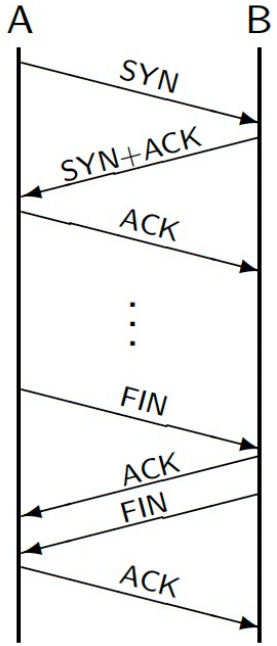
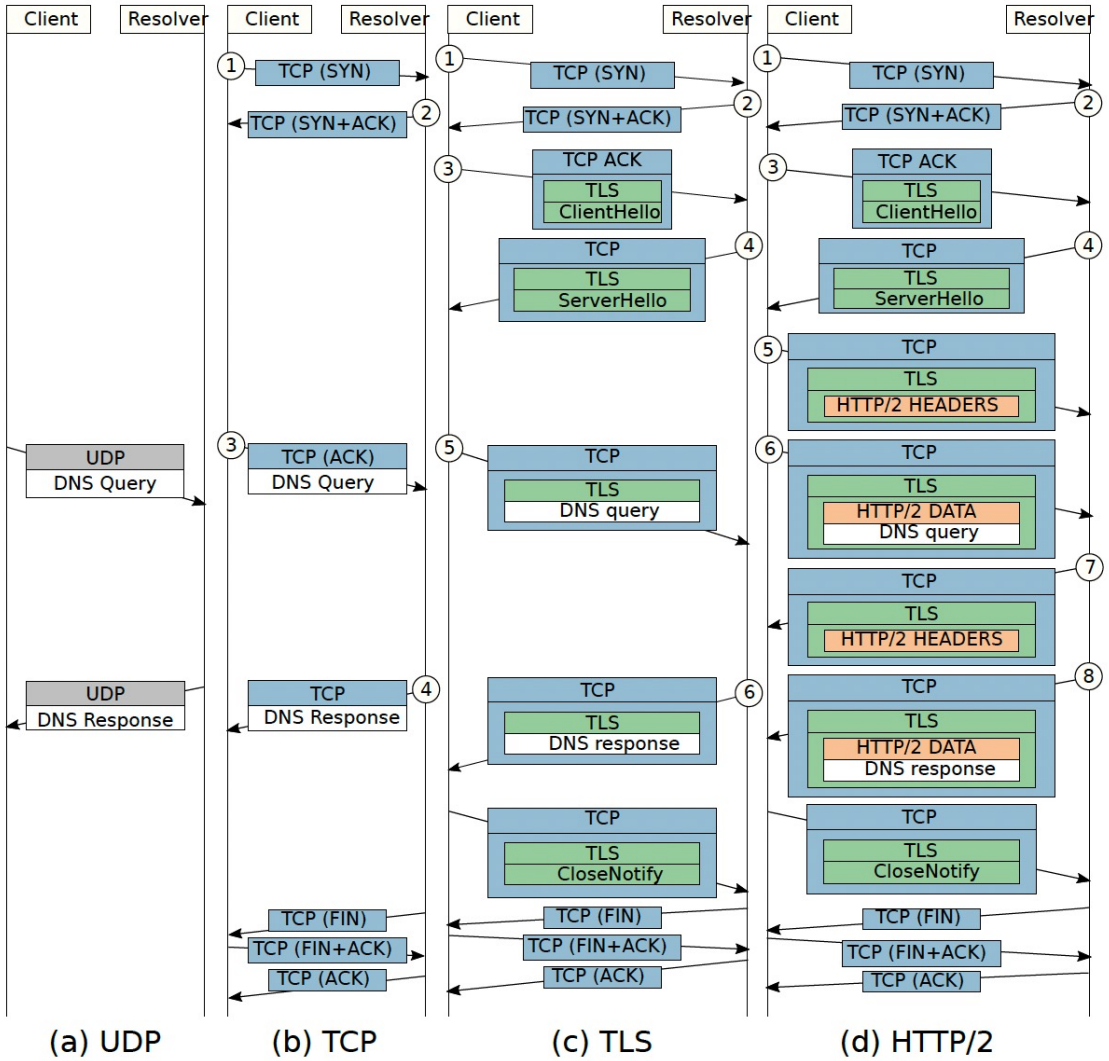
Appendix

What has been done? – Develop a mathematical model

- For UDP, N = 2 ϵ
- For TCP, $$N = \varepsilon \left(3 + 4 + 2\left\lceil \frac{\mathcal{L}(\mathcal{P}_Q)}{MSS} \right\rceil + 2\left\lceil \frac{\mathcal{L}(\mathcal{P}_R)}{MSS} \right\rceil\right)$$



What has been done? – Estimate the number of packet



What has been done? – Architecture for energy consumption measurements