PhD Thesis

EFFICIENCY AND SECURITY IN PEER-TO-PEER STREAMING PROTOCOLS

DOCTORADO EN INFORMÁTICA (RD99/11)
DEPARTMENT OF INFORMATICS
UNIVERSITY OF ALMERÍA
SPAIN

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Supervisors

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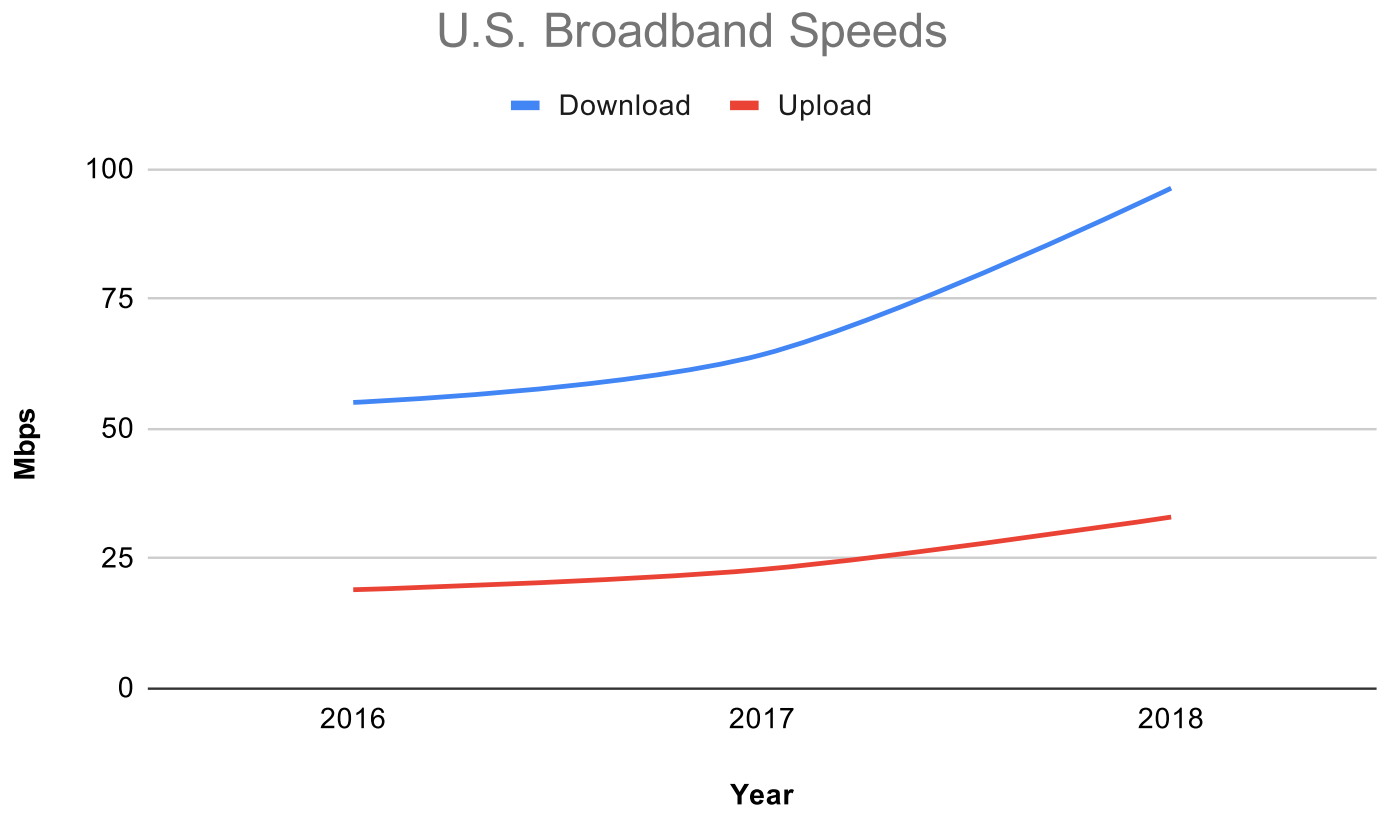
DR. VICENTE GONZÁLEZ RUIZ

November 11, 2019

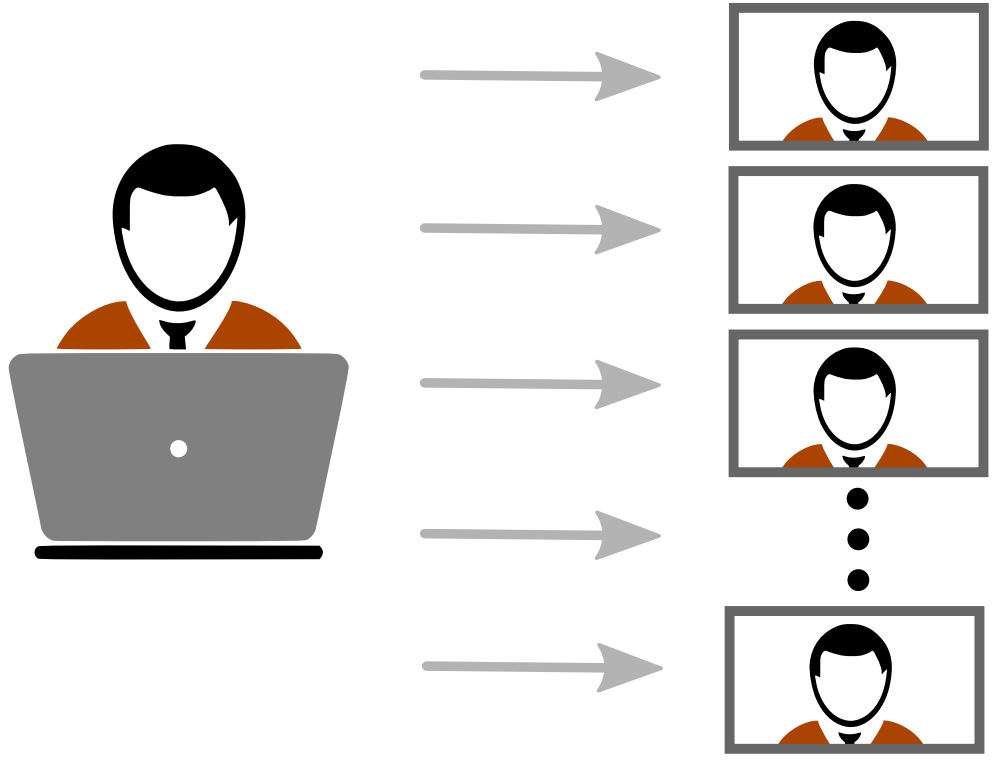
INTERNET HAS CHANGED THE WAY WE COMMUNICATE



Source: https://www.speedtest.net/reports/

HIGH QUALITY STREAMING TO THE LARGEST NUMBER OF USERS

with lowest cost in the shortest possible time



OUTLINE

- **INTRODUCTION**
  - Background
  - Research Questions
- **PEER TO PEER STRAIGHFORWARD PROTOCOL**
  - An application-layer protocol that provides real-time broadcasting on the Internet
- **SECURITY**
  - Pollution Attacks
  - Strategies applied to Traditional Networks
  - Strategies applied to Software Defined Networks
- **EFFICIENCY**
  - NAT Traversal using Collaborative Port Prediction
  - Runing P2PSP on Embeded Devices
- **CONCLUSIONS**
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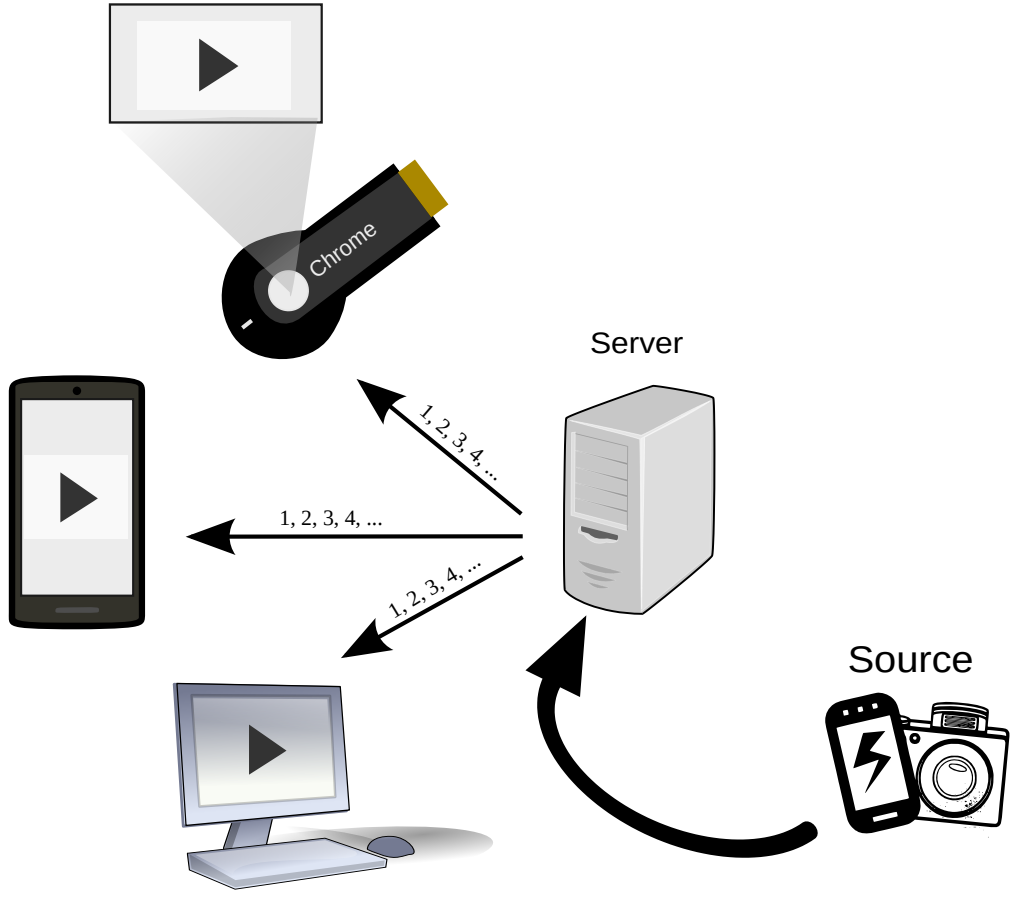
MOST POPULAR SOLUTIONS

CLIENT-SERVER MODEL



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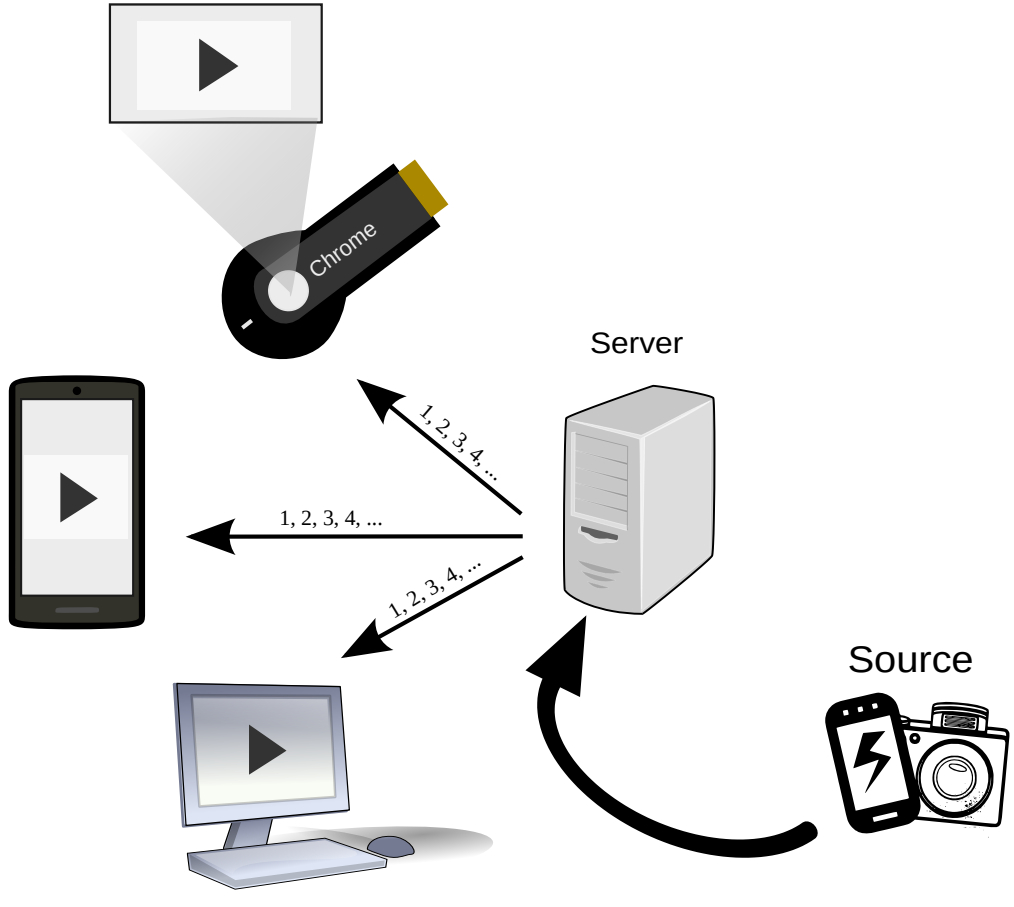
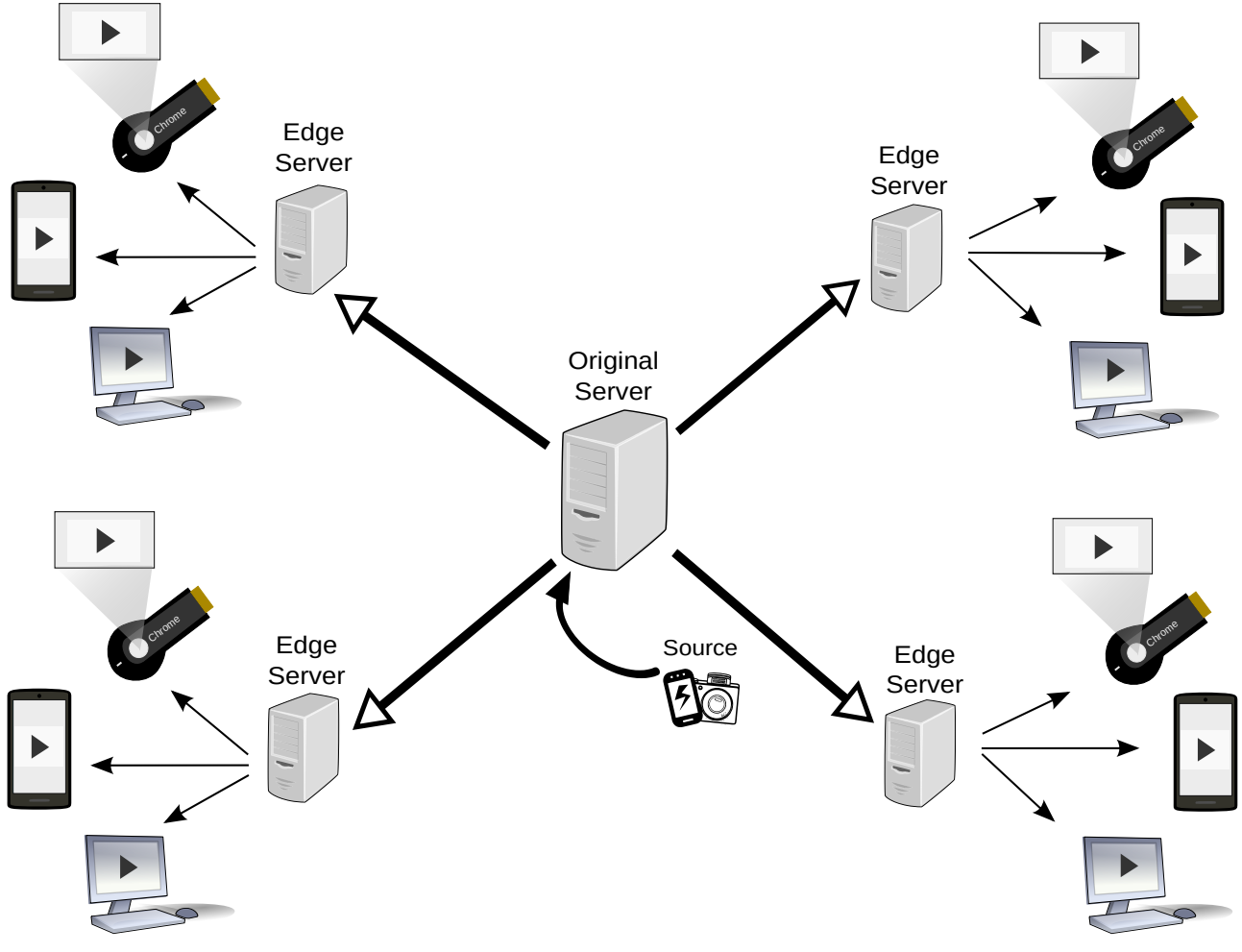


It is not scalable without replication

MOST POPULAR SOLUTIONS

CONTENT DELIVERY NETWORKS



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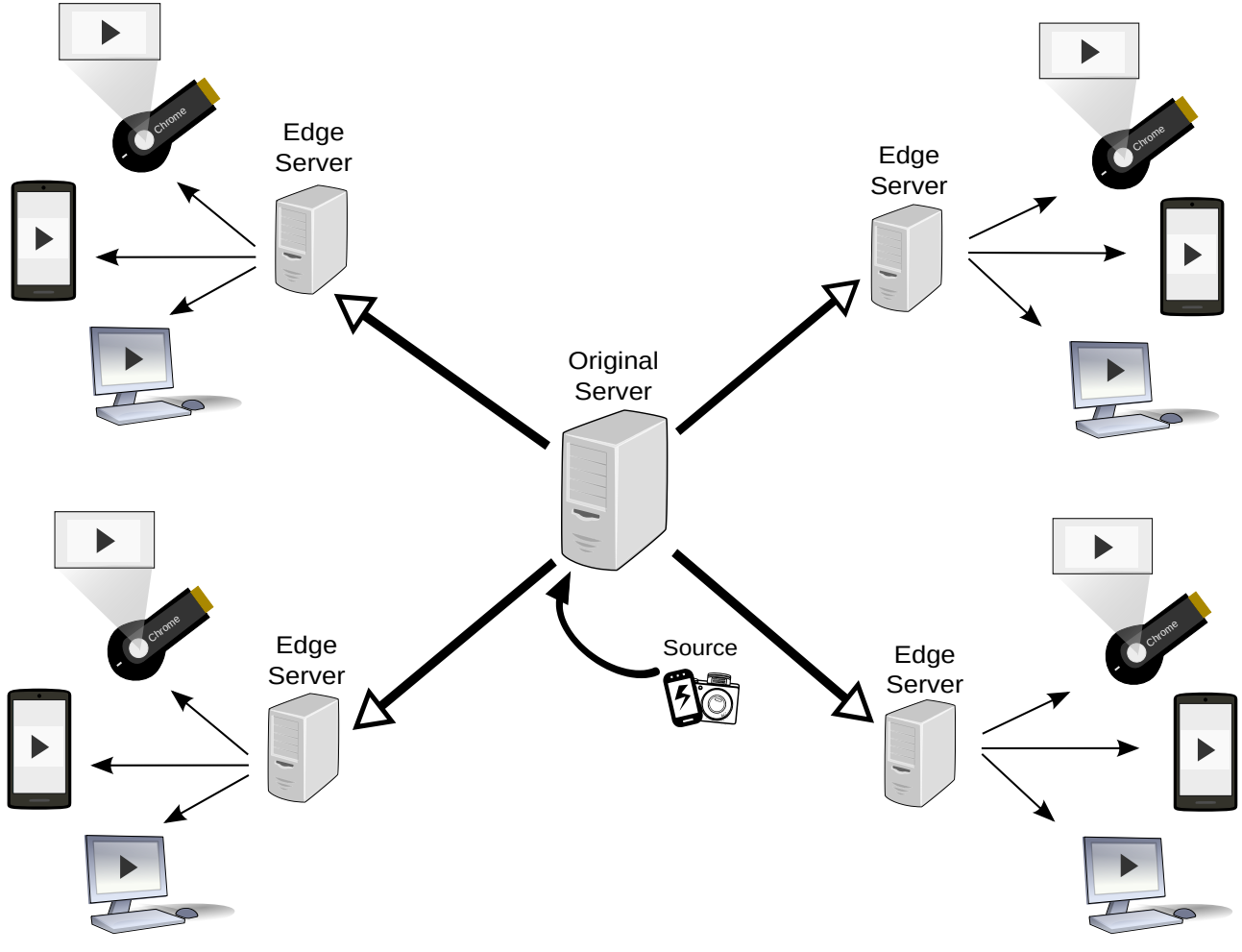
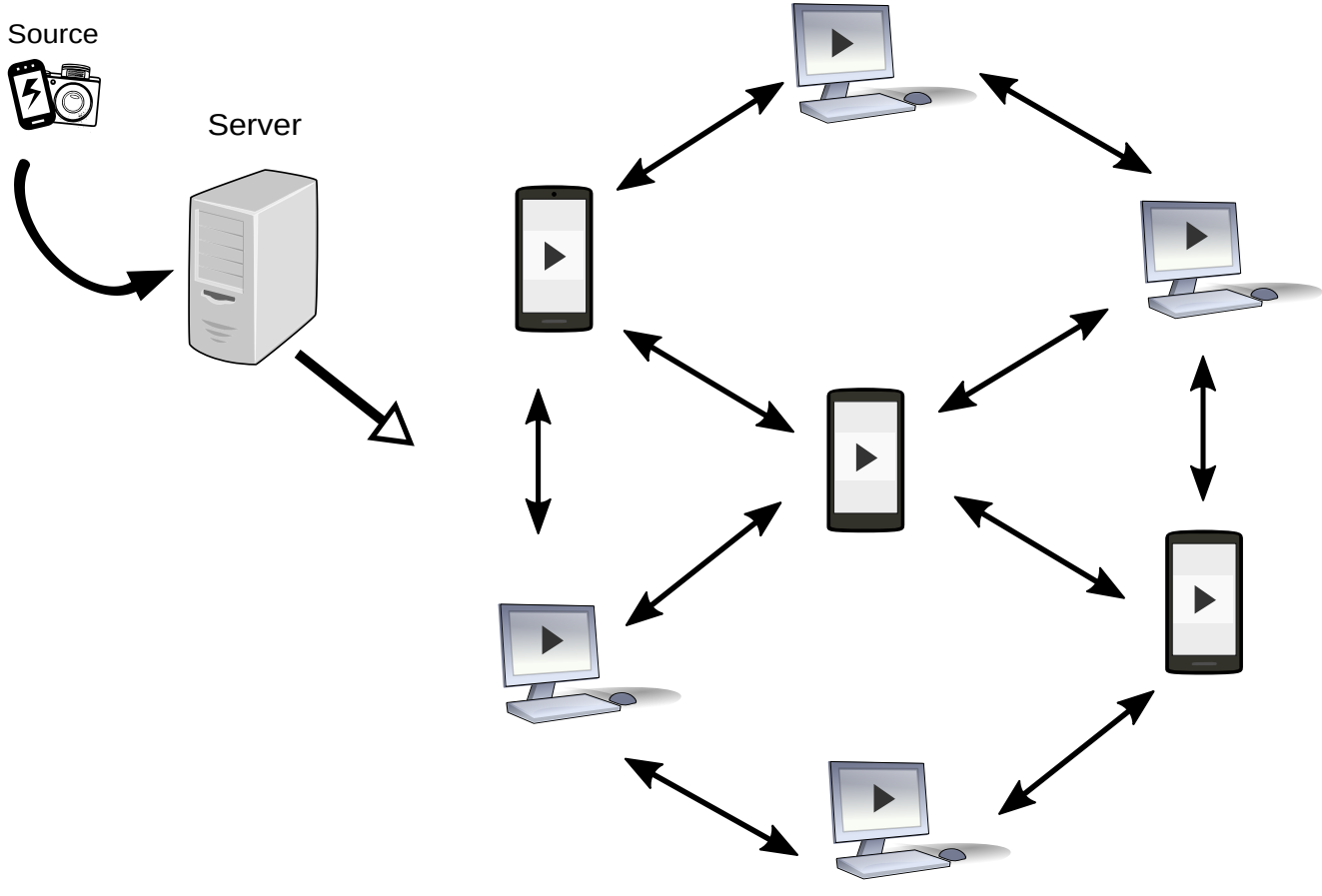


Significant increase in the cost of the infrastructure

ALTERNATIVE SOLUTION

PEER-TO-PEER NETWORKS



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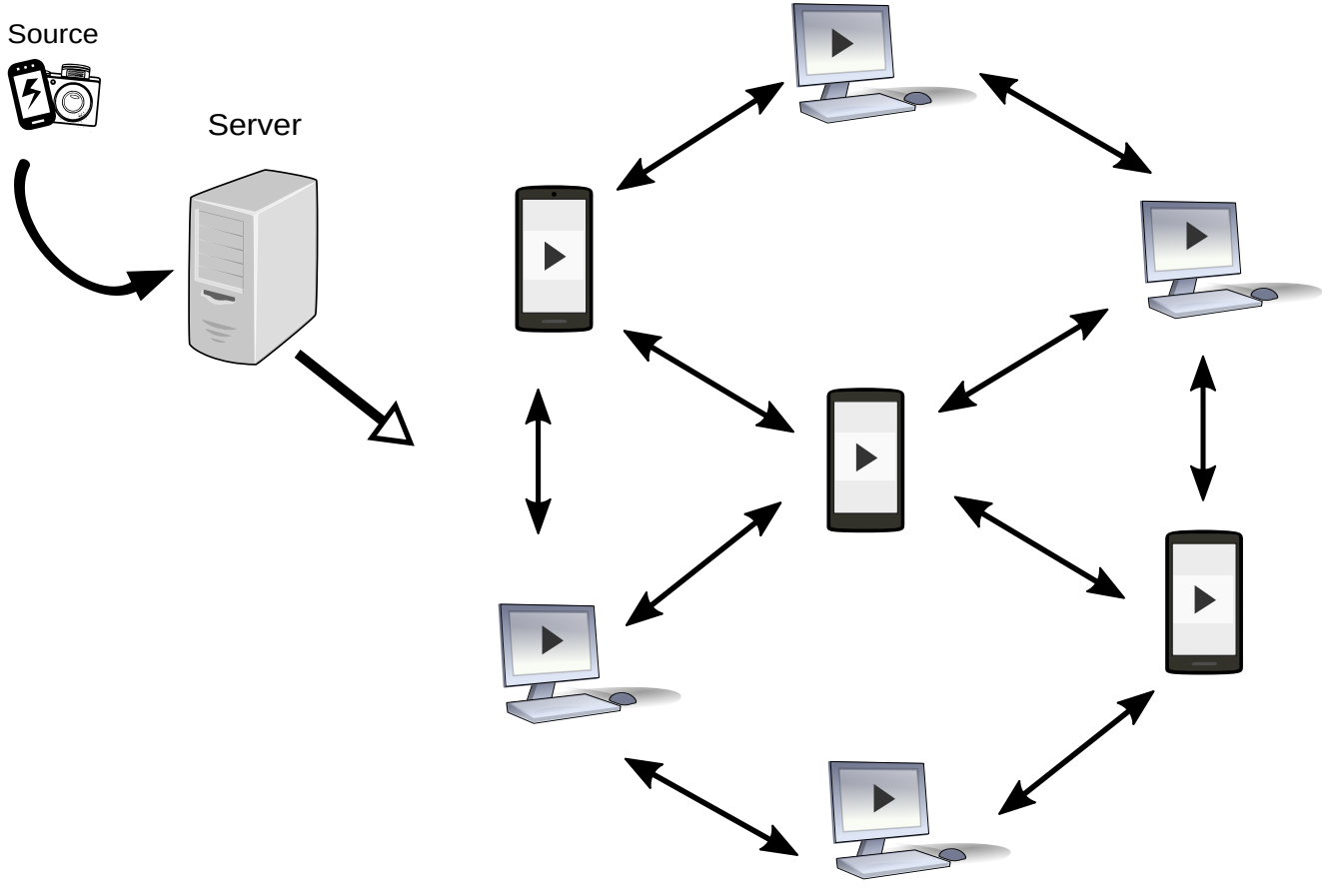
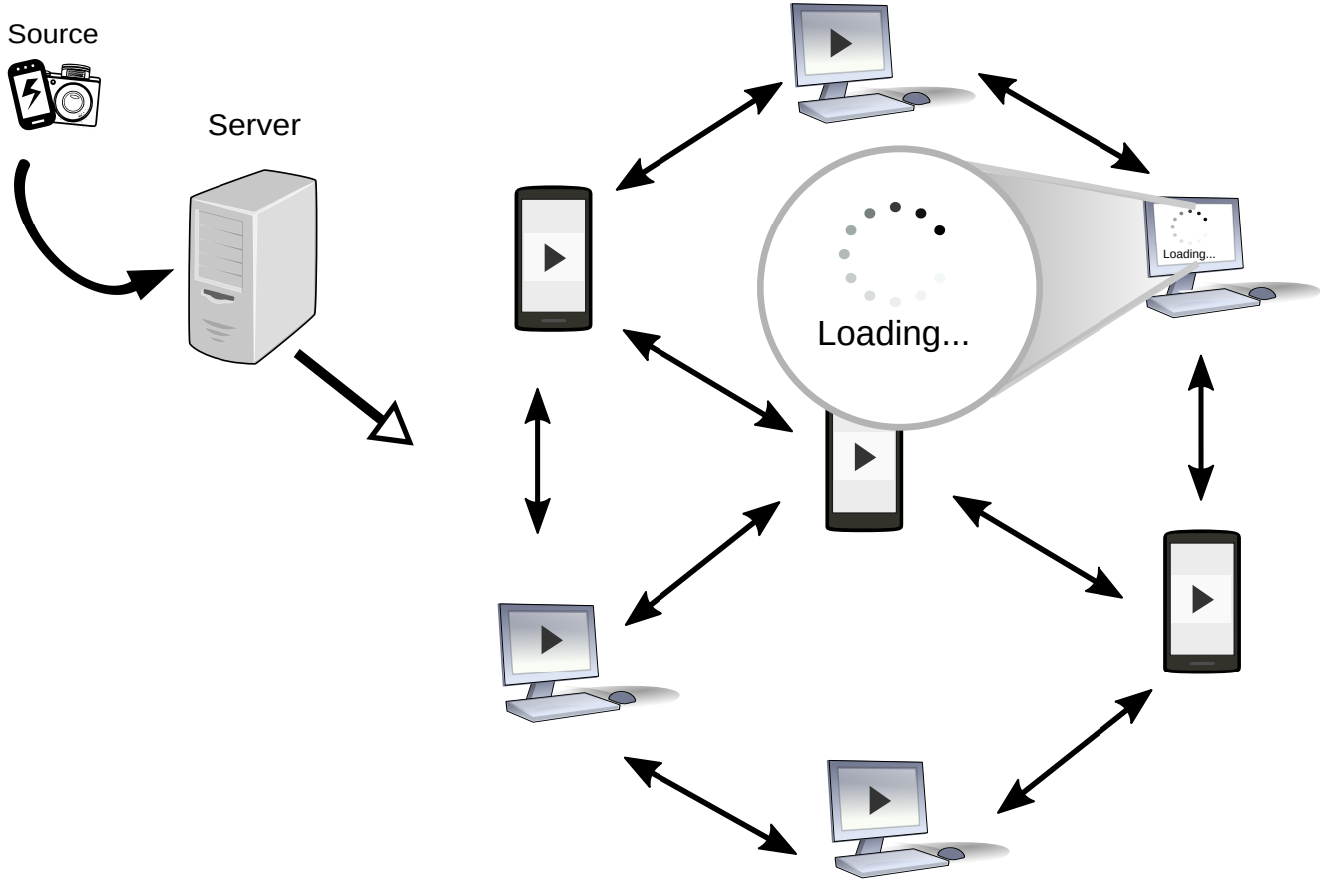


Latency, Security, Network Limitations, Client Resources

PEER-TO-PEER NETWORKS

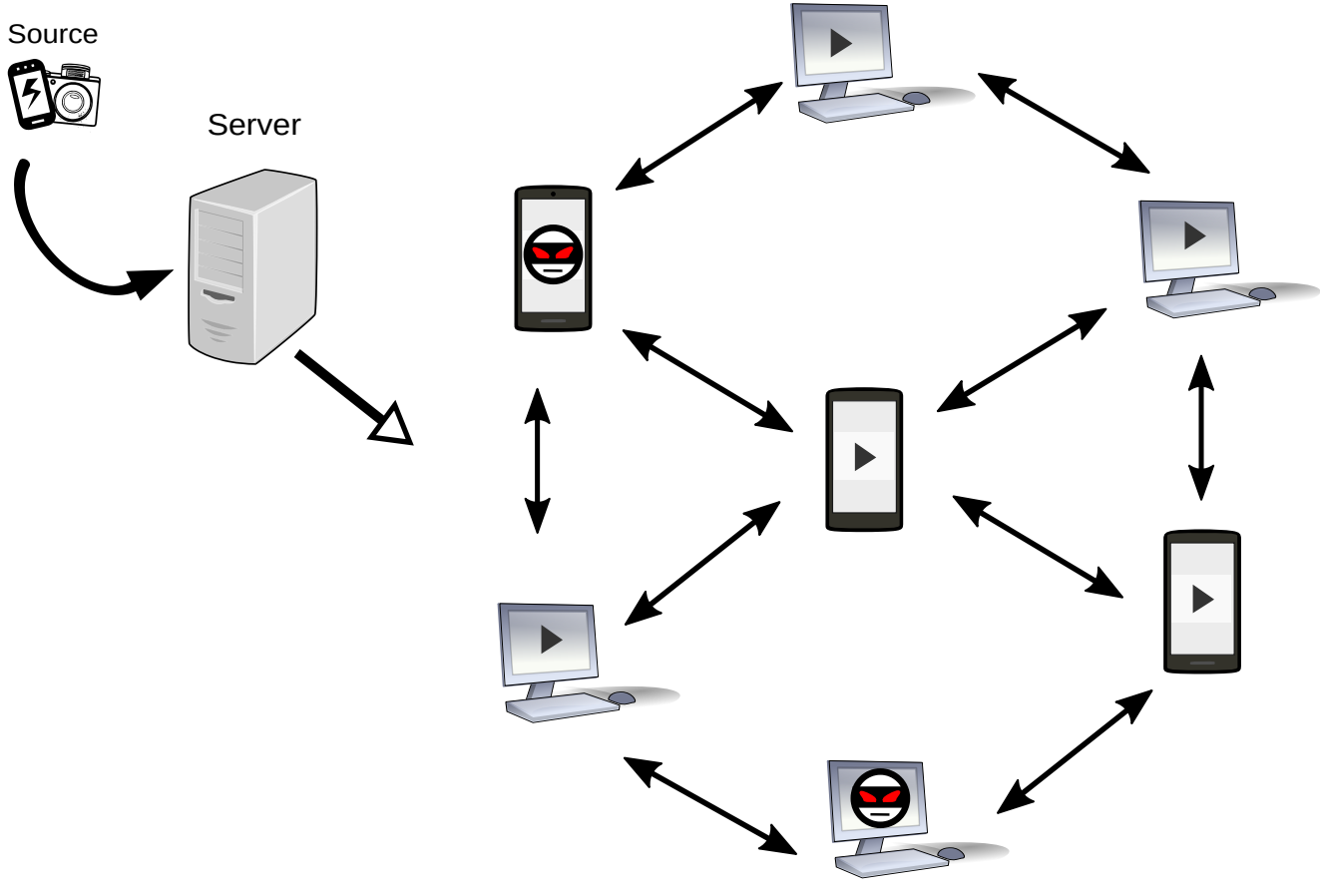
PROBLEMS: LATENCY



Because of its distributed approach, sometimes there is a considerable delay from when the content is generated until users play it.

PEER-TO-PEER NETWORKS

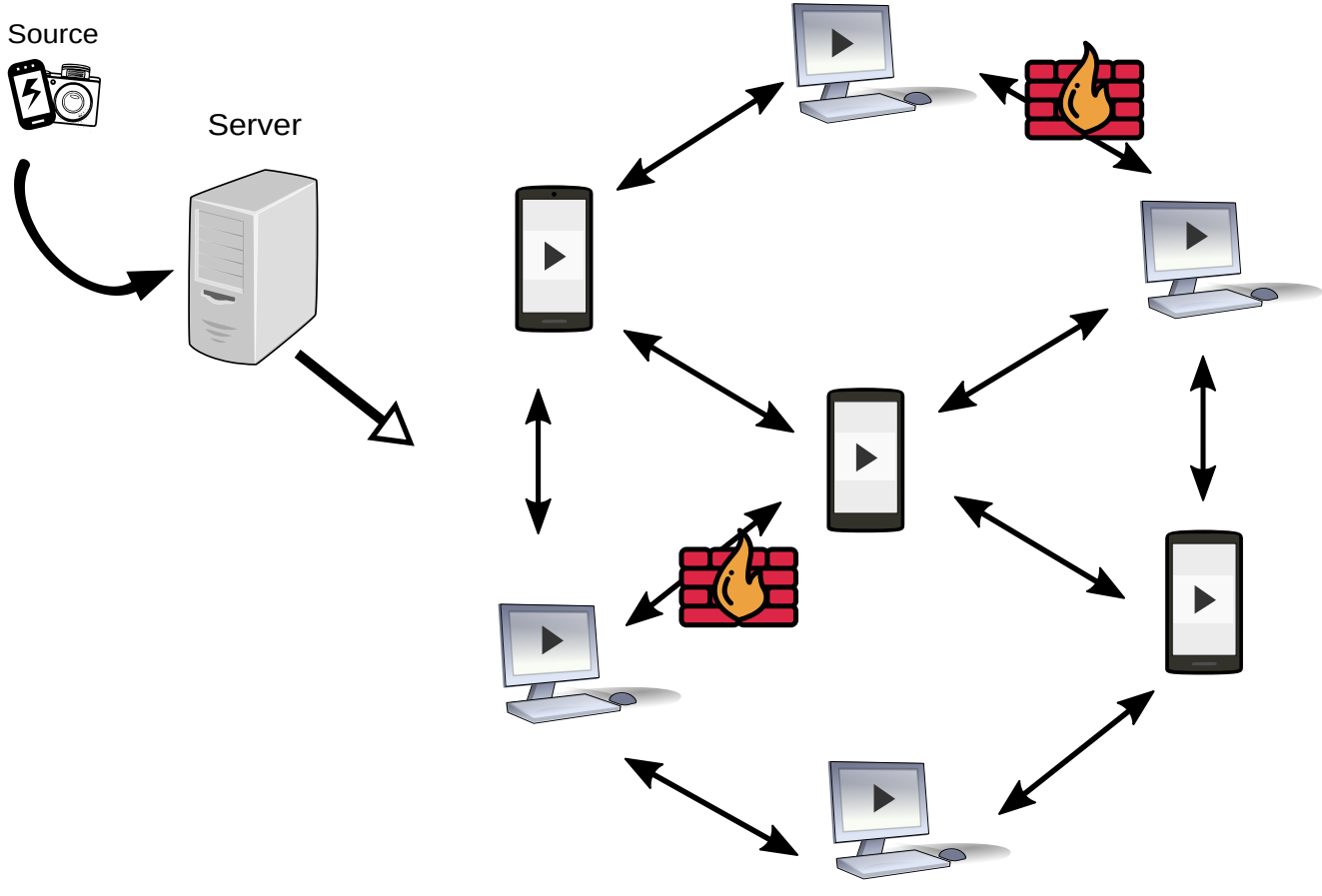
PROBLEMS: SECURITY



The anonymity provided by most P2P networks leads to malicious peers attacking in different ways: denial of service attacks, poisoning of content, avoiding sharing their resources, etc.

PEER-TO-PEER NETWORKS

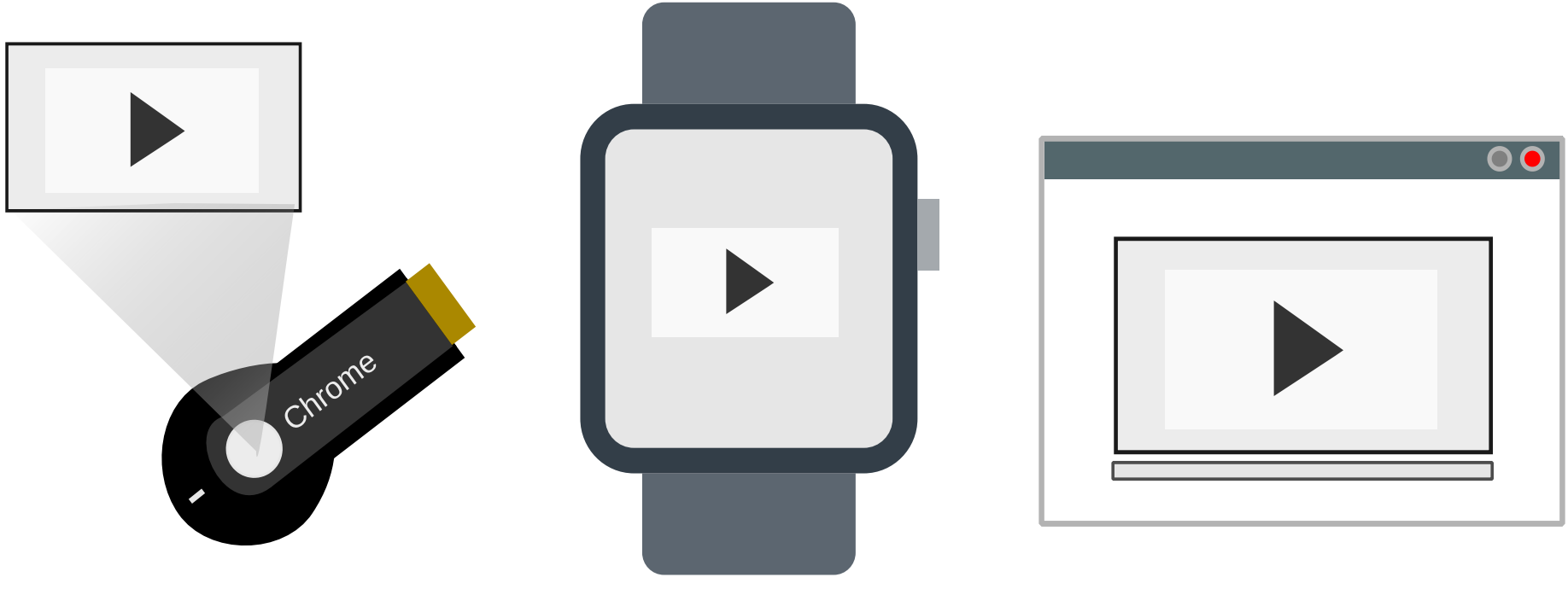
PROBLEMS: NETWORK LIMITATIONS



Limitations in networks caused by peers behind NATs and firewalls.

PEER-TO-PEER NETWORKS

PROBLEMS: CLIENT RESOURCES



The complexity of most of the P2P applications, result in they can not be executed on some types of devices. Especially in those with low resources.

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Would our protocol be straighforward enough to be run on low-resource devices?

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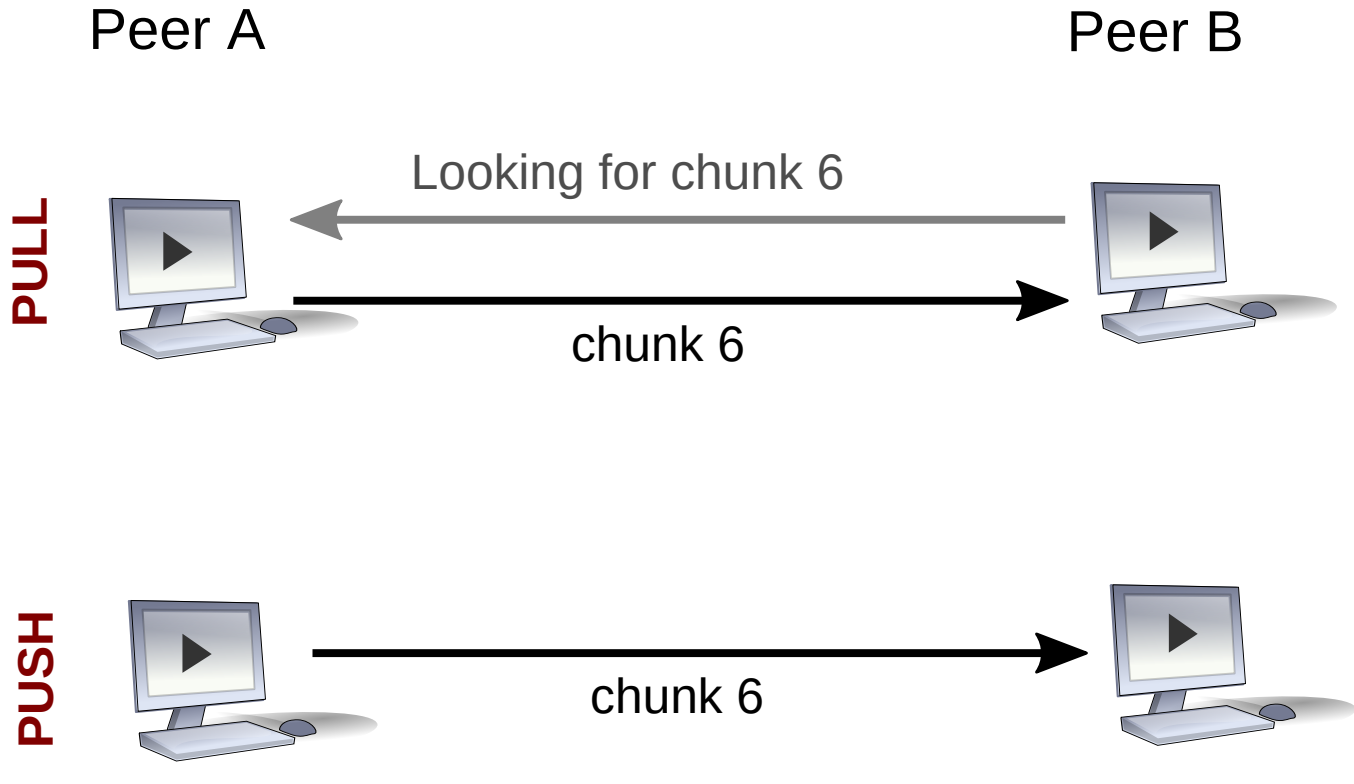
PULL-MODEL VS PUSH-MODEL

GOAL: REDUCE LATENCY BY KEEPING IT AS SIMPLE AS POSSIBLE




P2PSP
Peer to Peer Straightforward Protocol

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- AN OPEN-SOURCE (GNU GPL V3) IMPLEMENTATION IS AVAILABLE ON GITHUB.

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HOW DOES A P2PSP SYSTEM WORK?

An open-source implementation is available on GitHub

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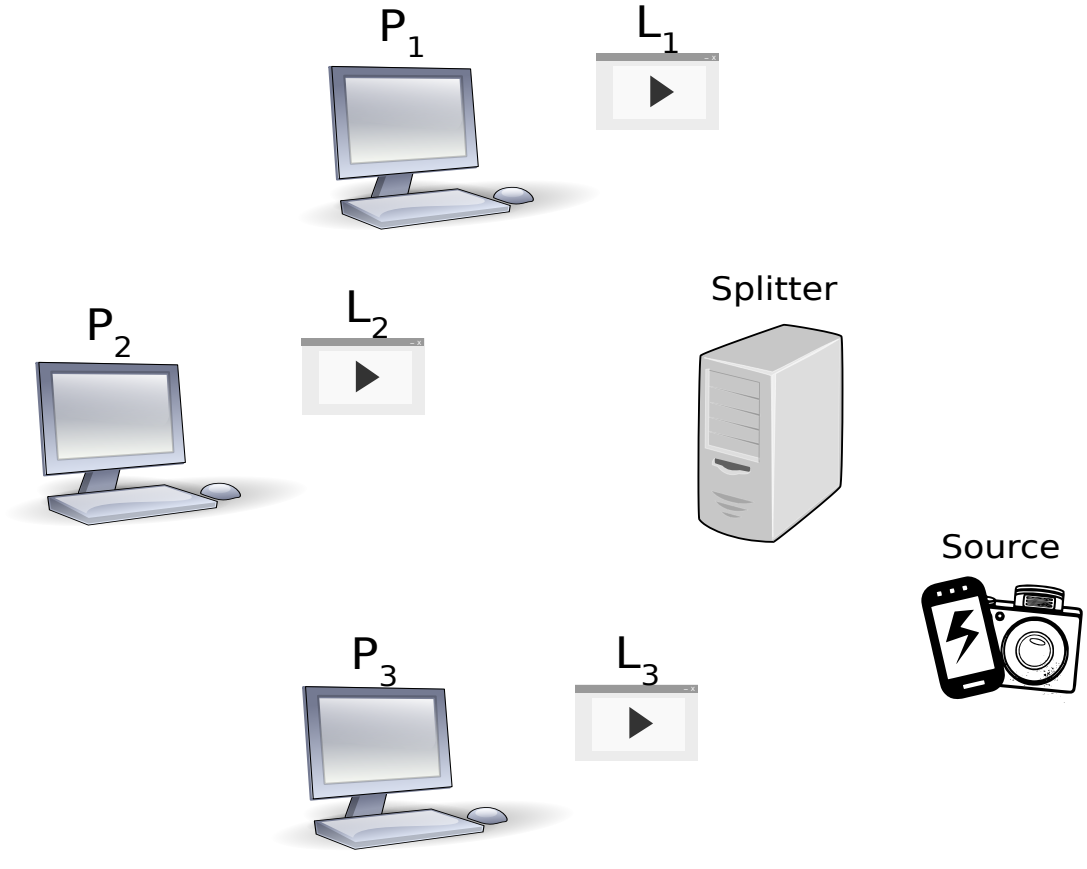

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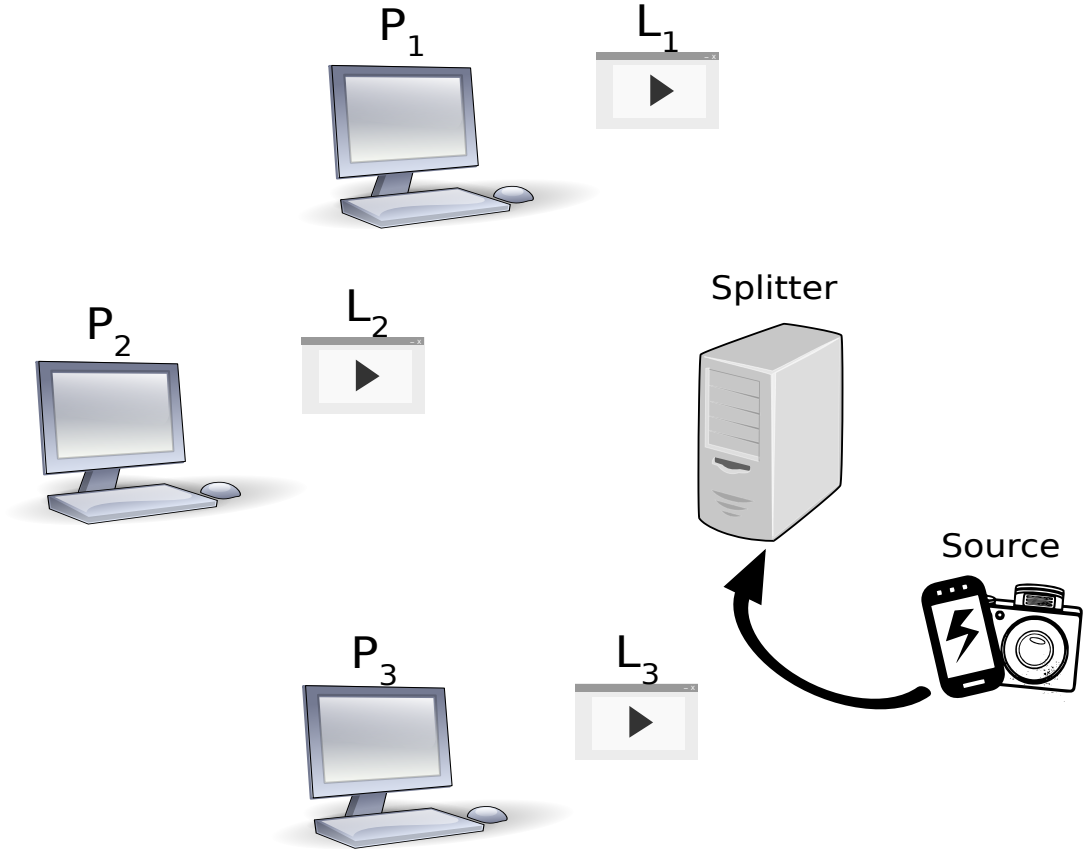

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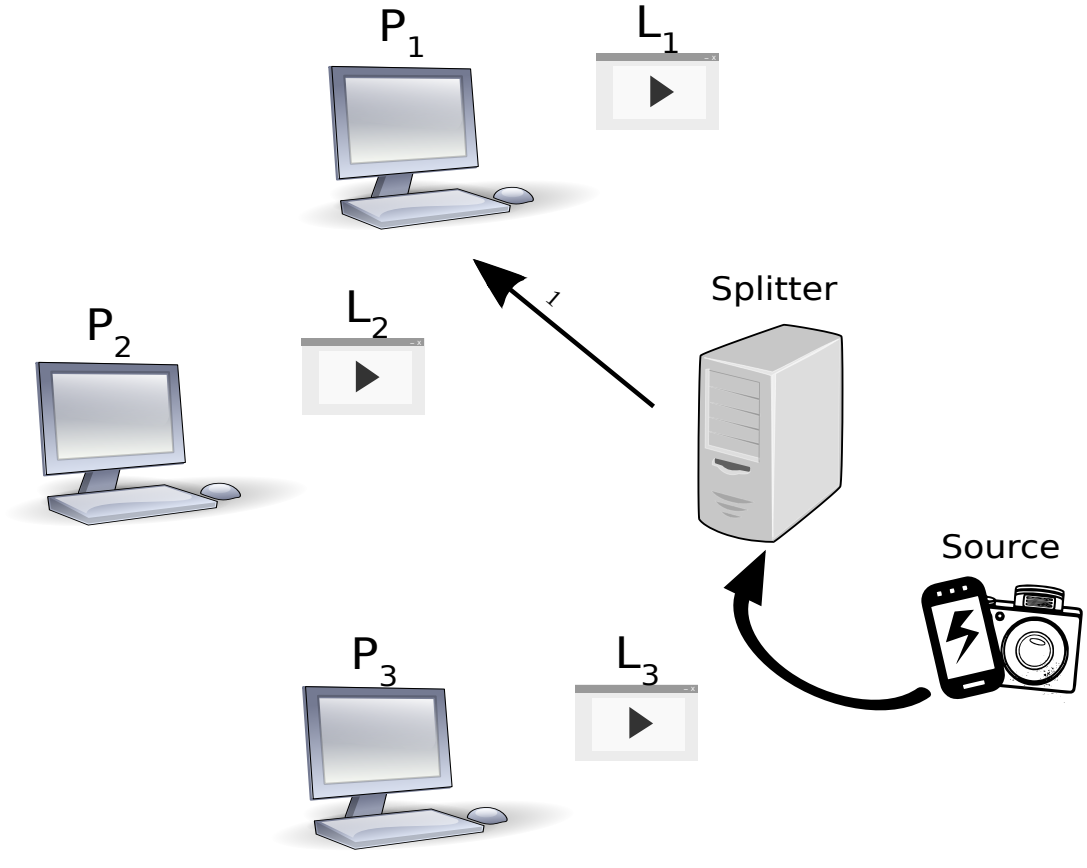

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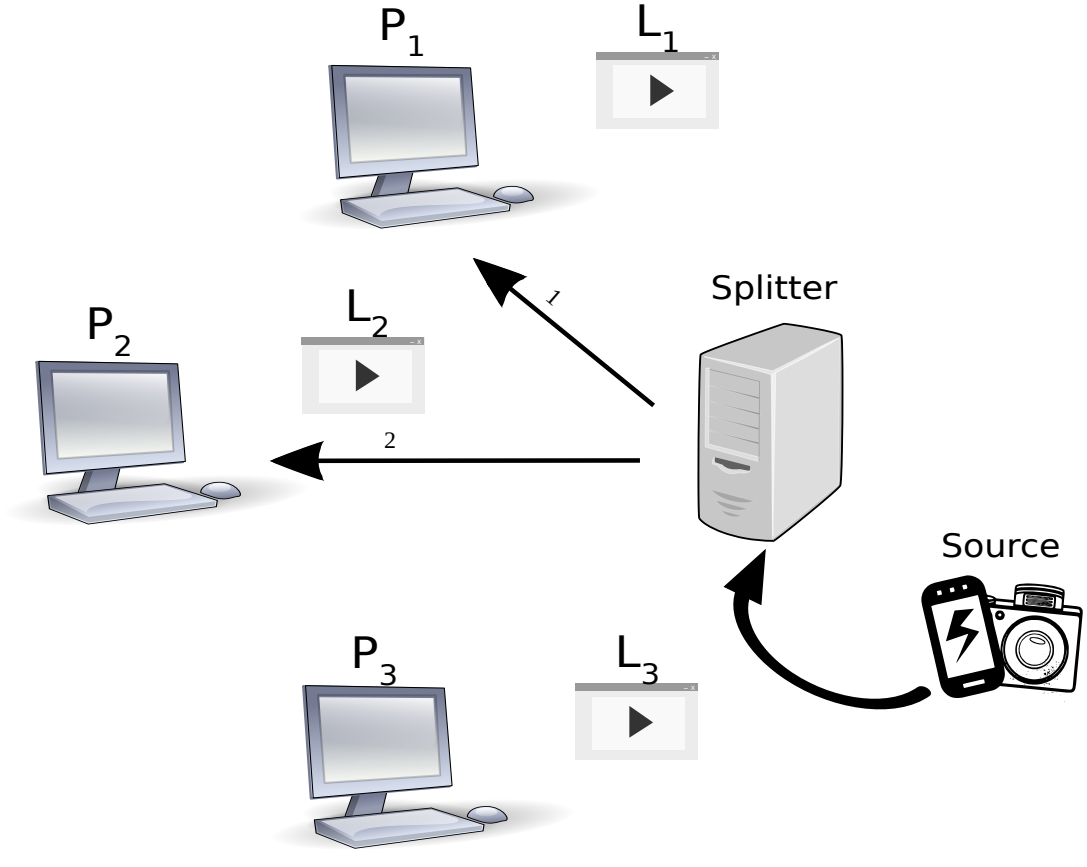

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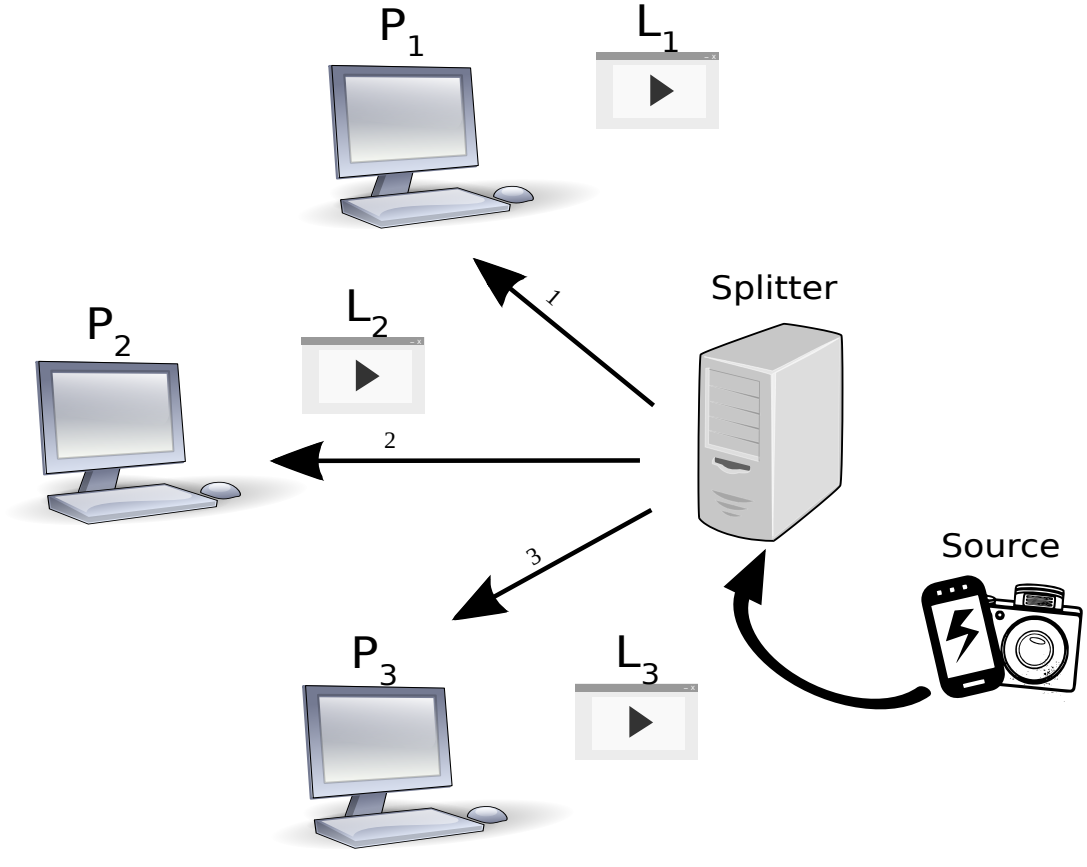

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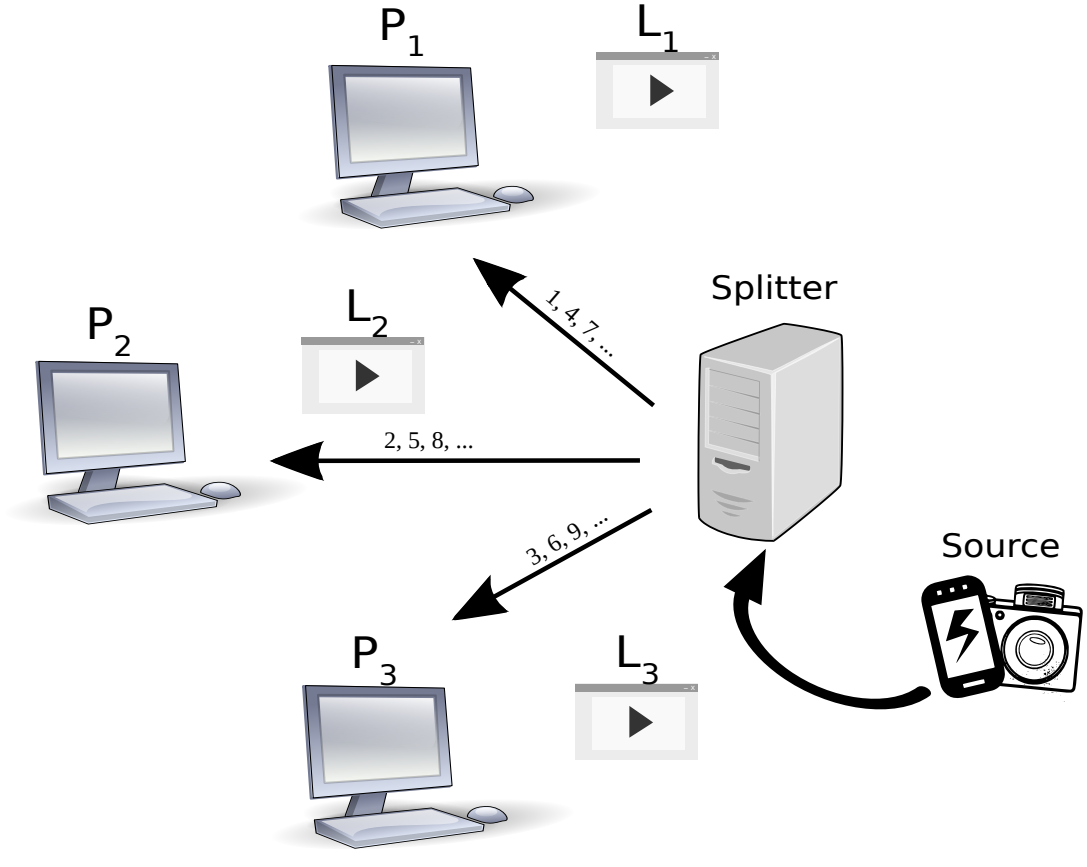

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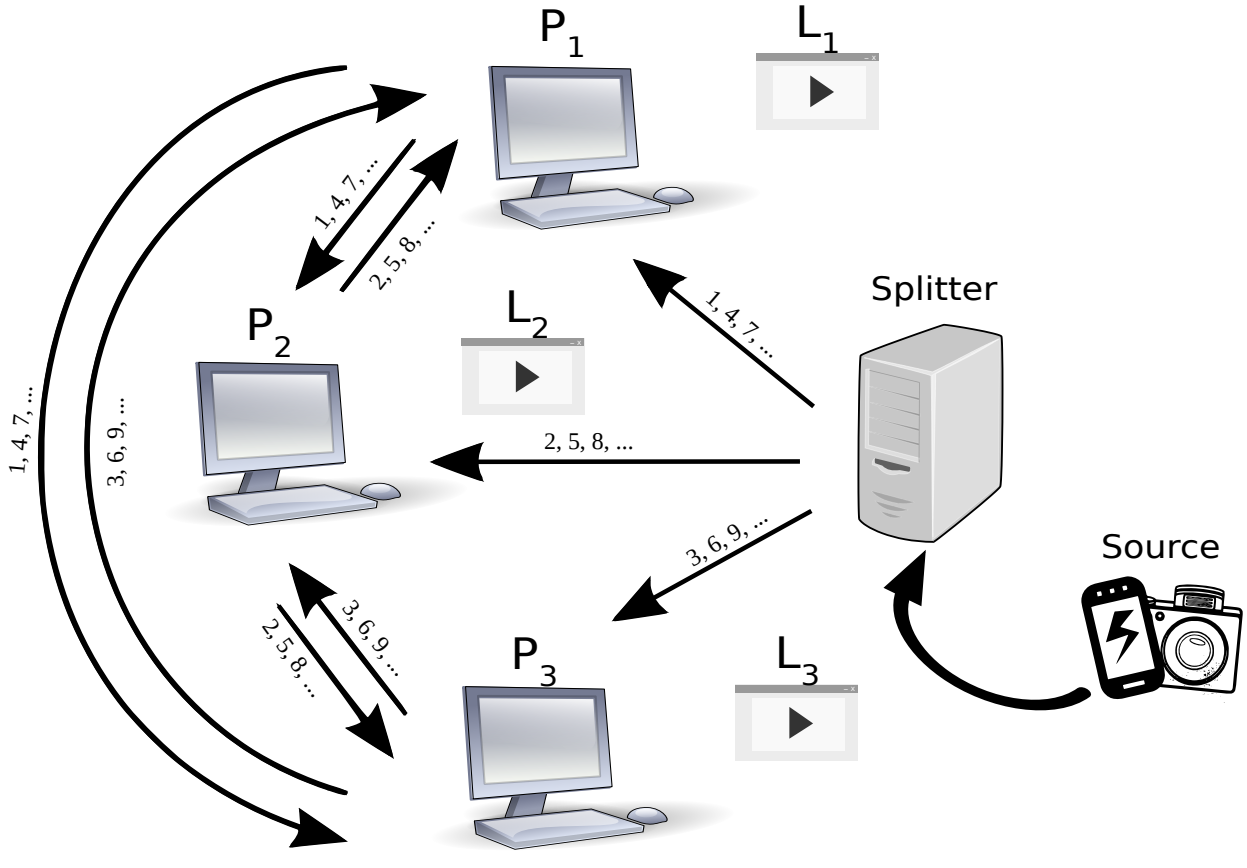

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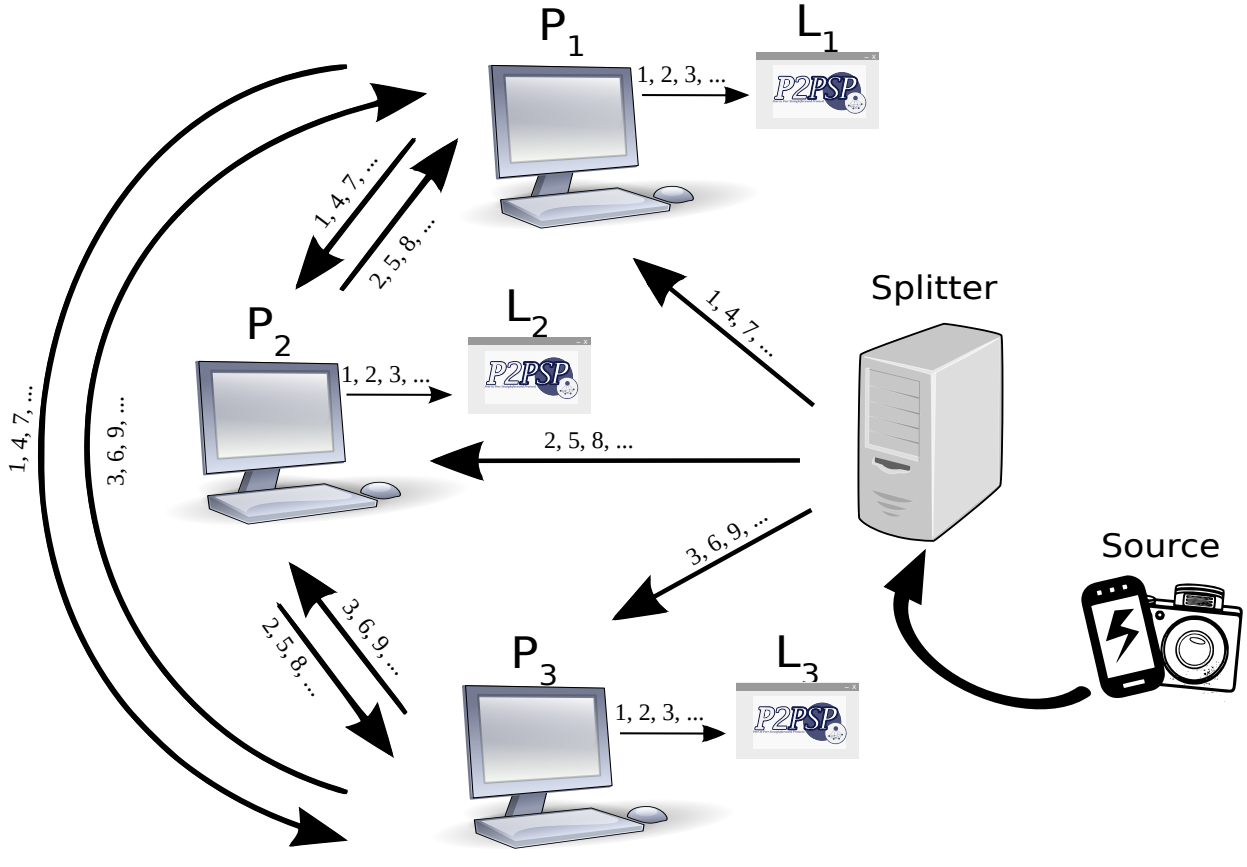

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4. PEERS SEND THE STREAM TO THE PLAYER.

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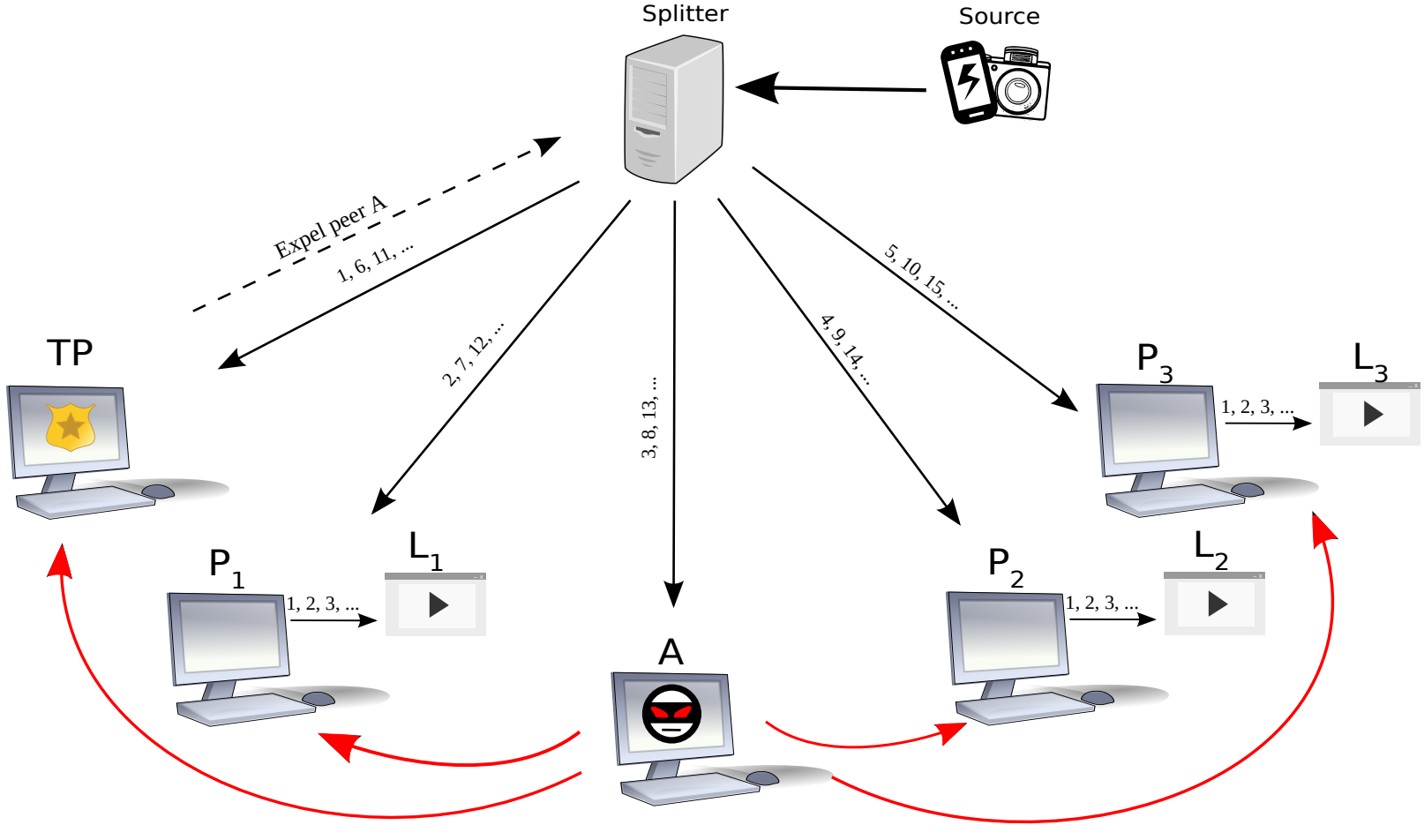
POLLUTION ATTACKS

Pollution attacks consist of a peer or a set of peers modifying the content of the stream.
Can be done in different ways.

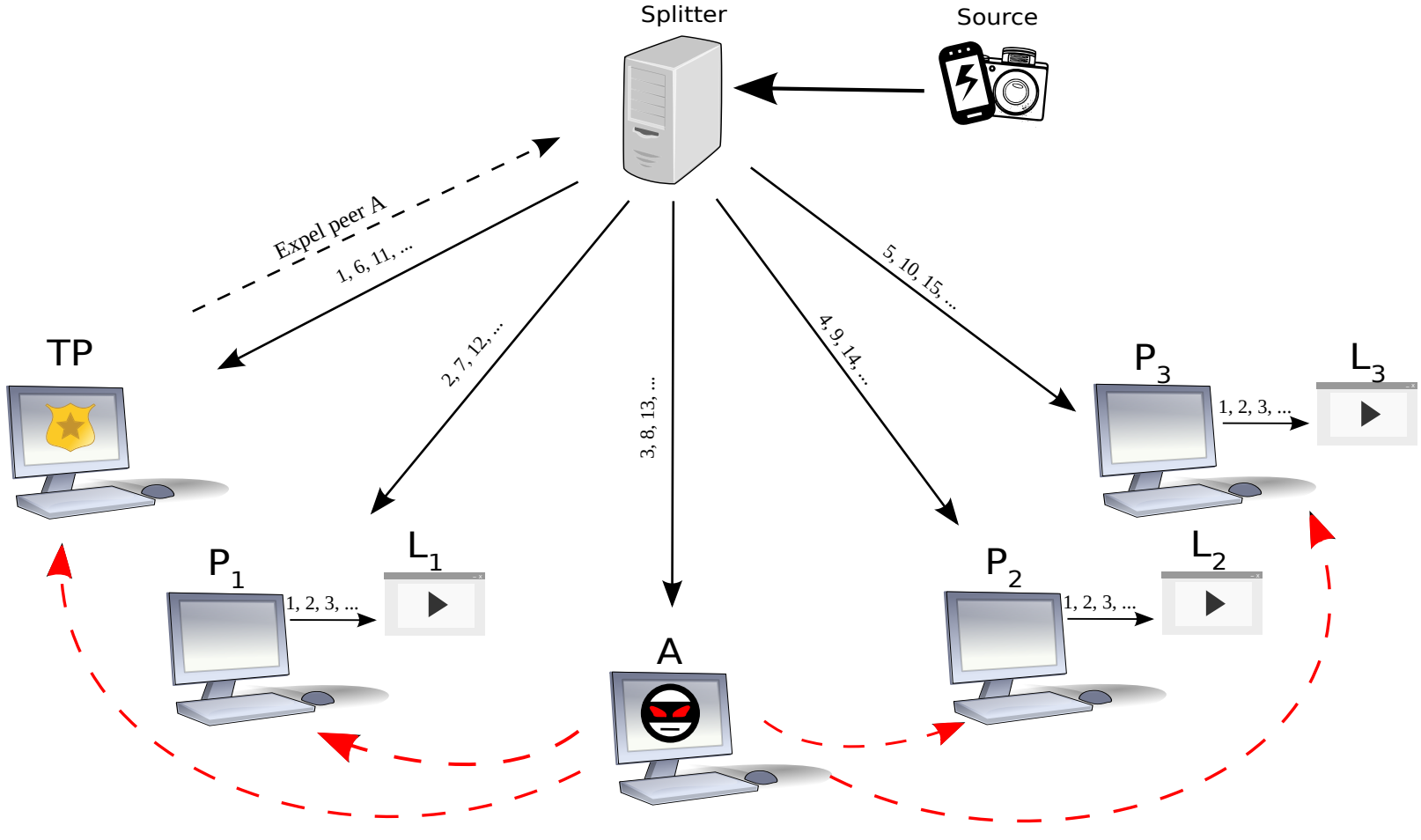
POLLUTION ATTACKS

Persistent attack: an attacker poisons every chunk received from the splitter and sends them to the entire team.



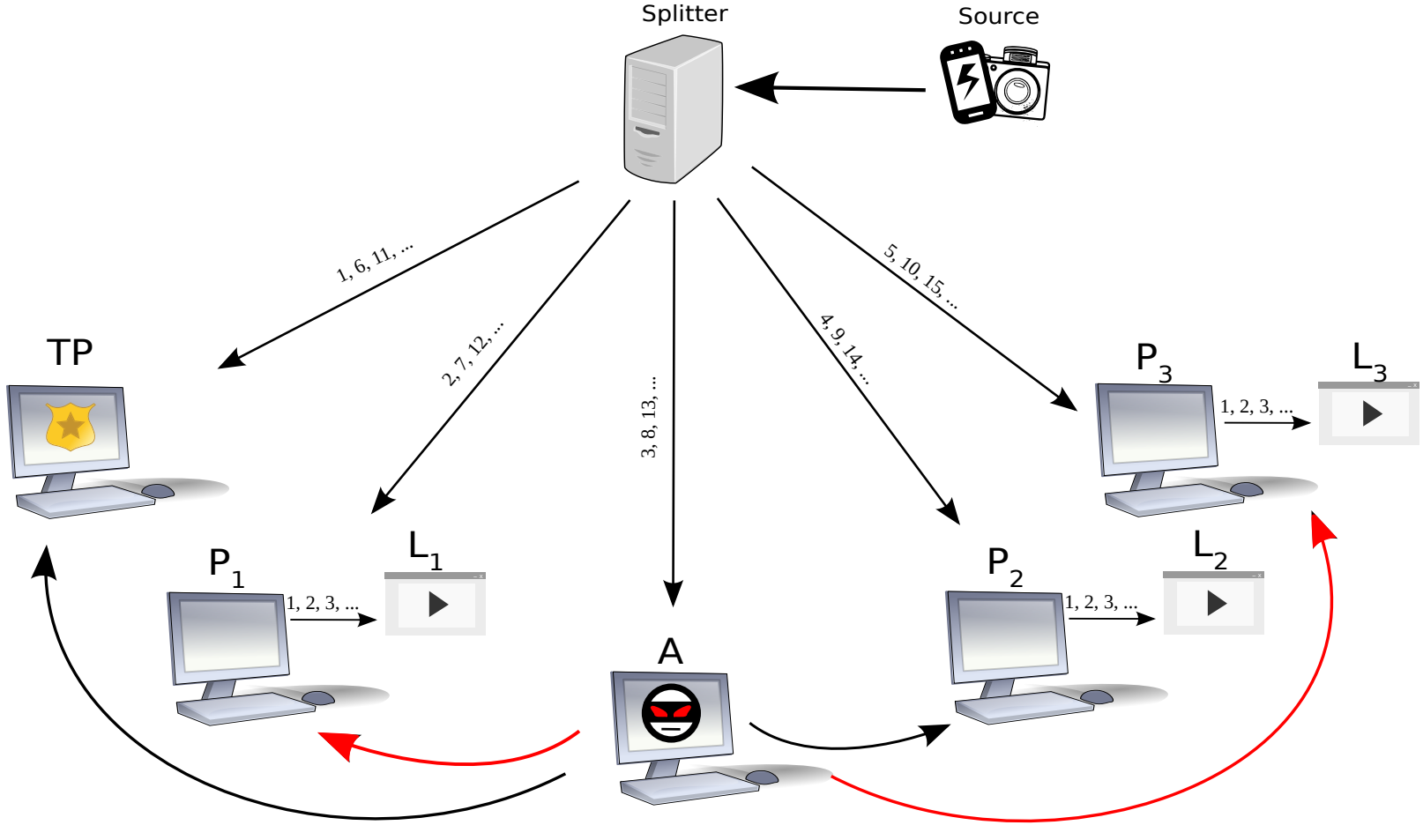
POLLUTION ATTACKS

On-Off attack: the attacker only poisons some chunks but not others.



POLLUTION ATTACKS

Selective attack: poisoning chunks intended for only one peer or a small subset of peers.



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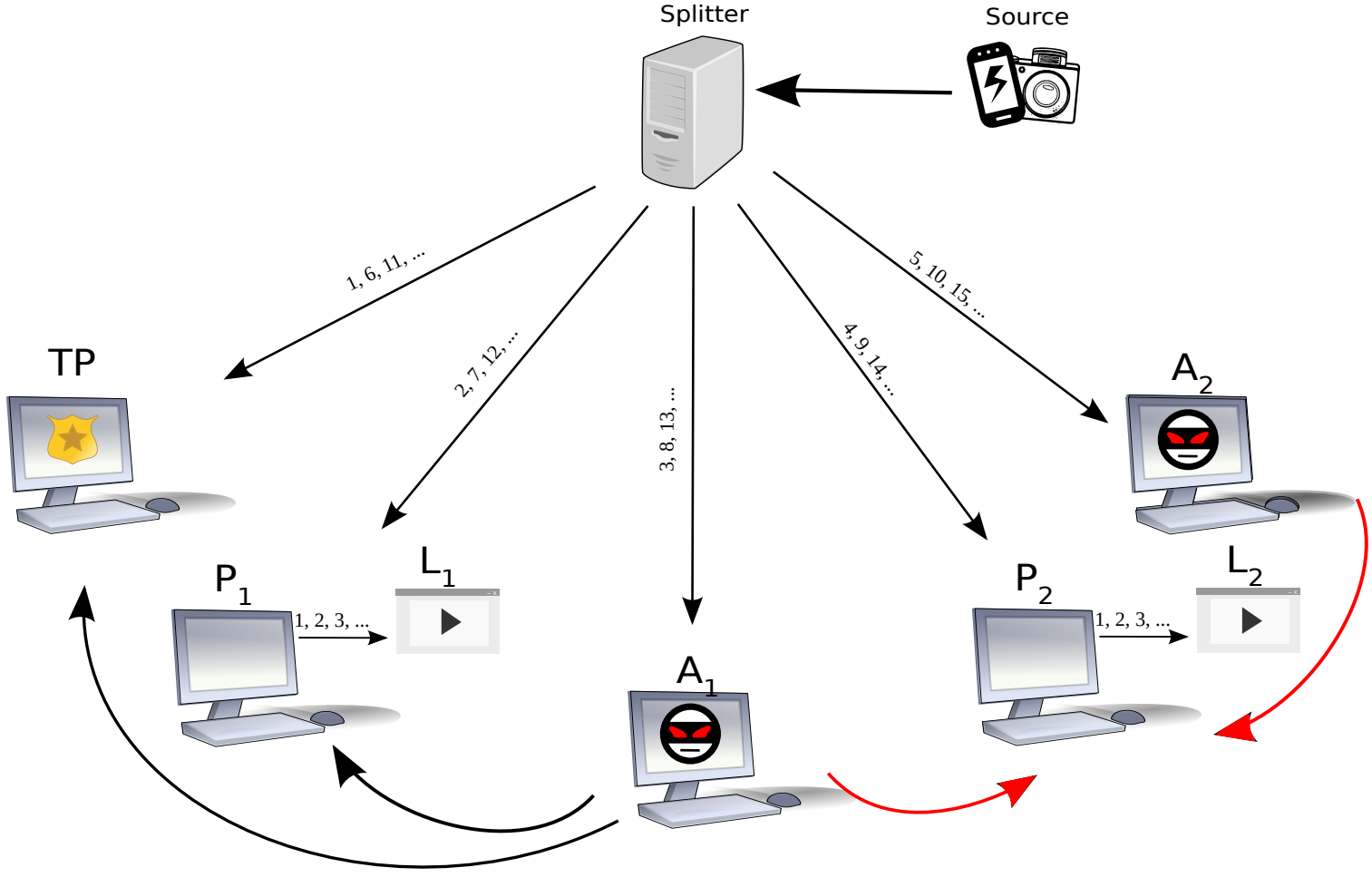
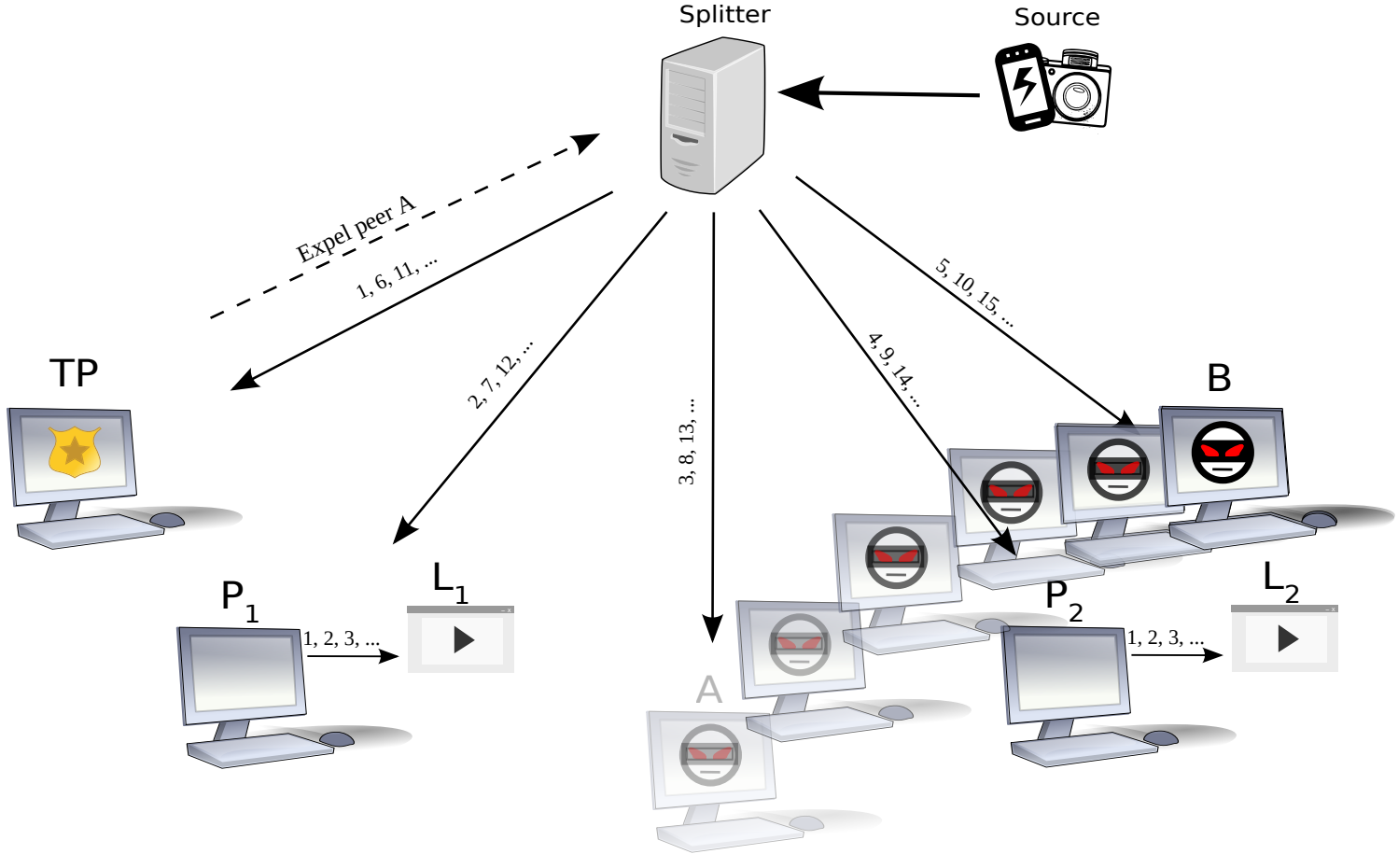
Collaborative attack: several attackers may collaborate to produce Selective and On-off attacks on a large set of peers.



POLLUTION ATTACKS

Hand-wash attack: leaving the team and returning to continue the attack with another alias.



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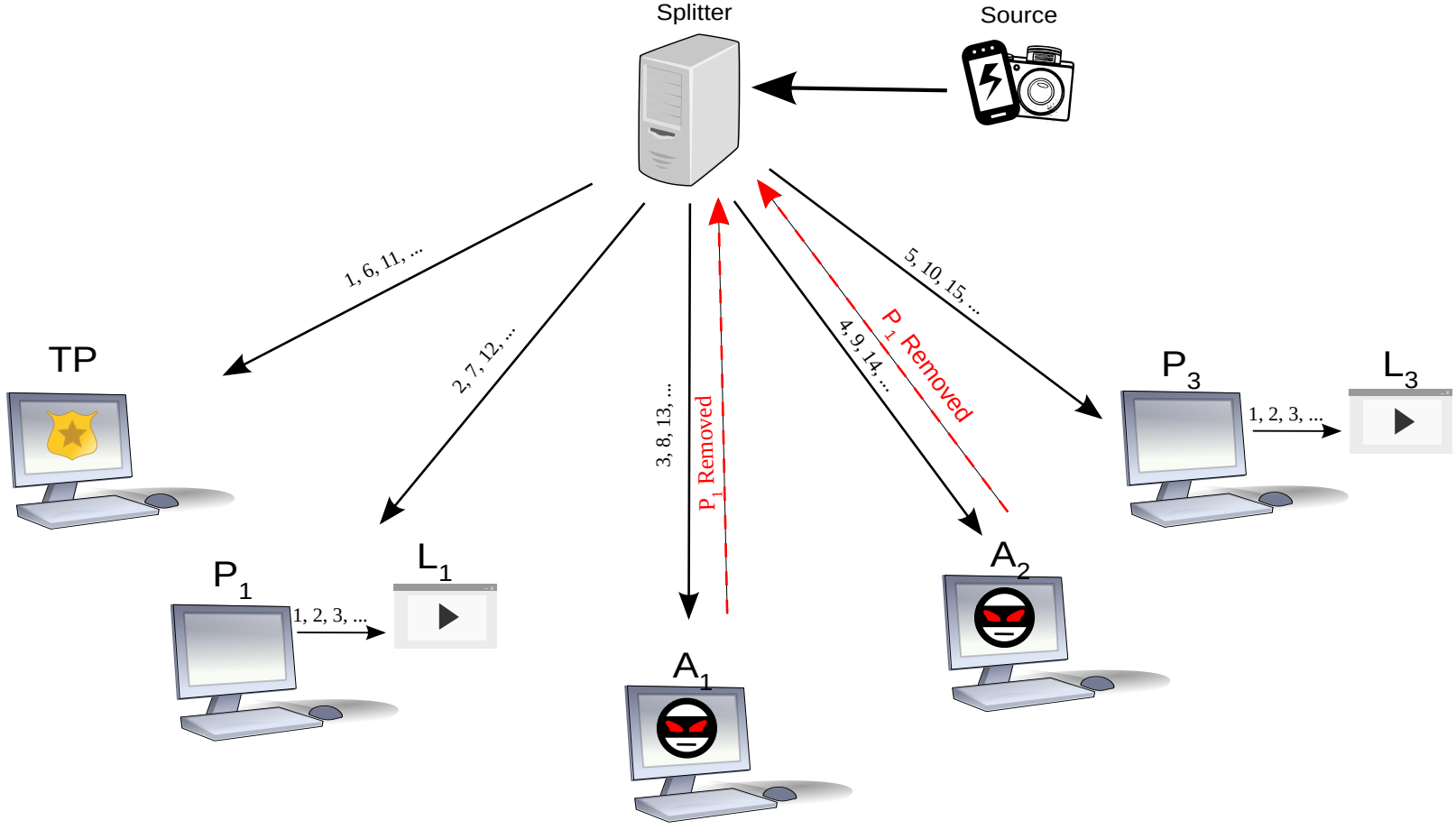
Bad-mouth attack: blaming other regular peers of sending poisoned chunks or not sending chunks.



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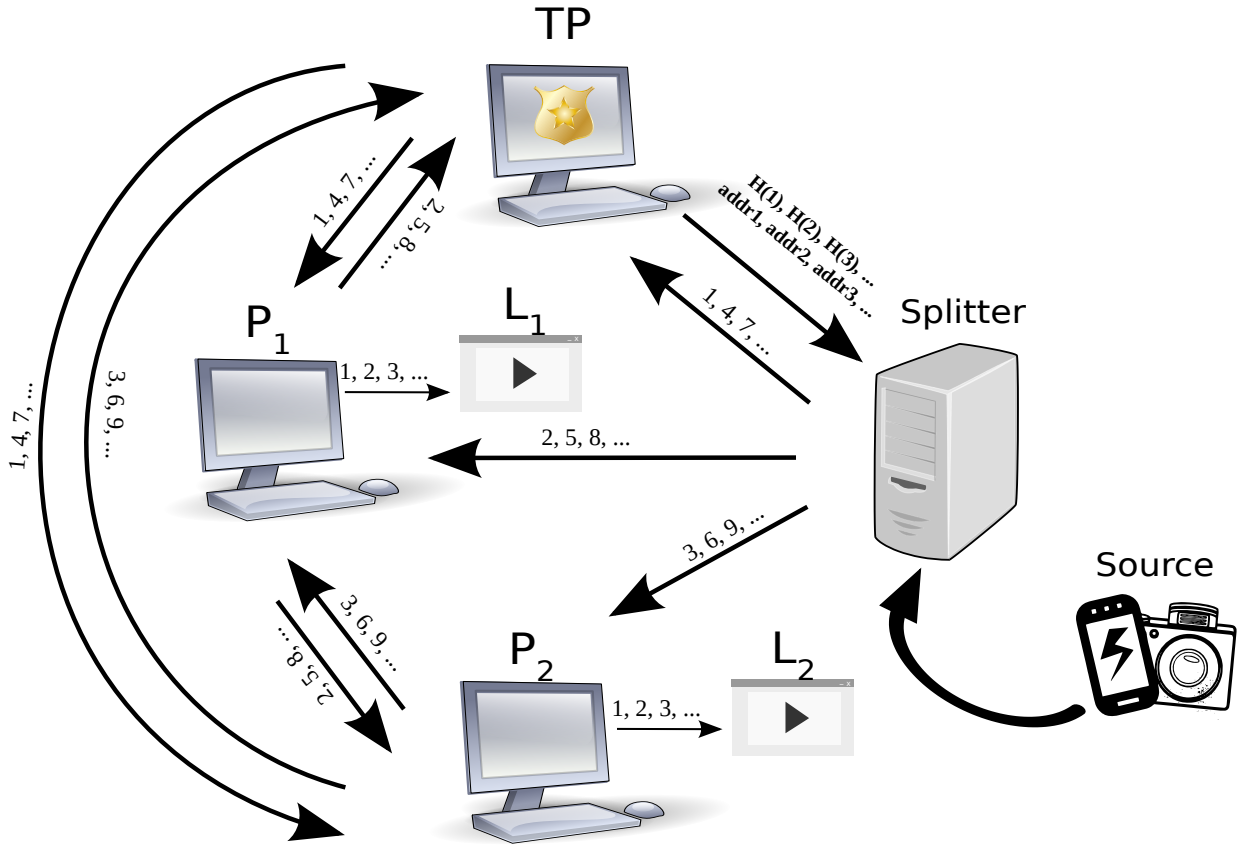
STRATEGY BASED ON TRUSTED PEERS

HOW DOES IT WORK?



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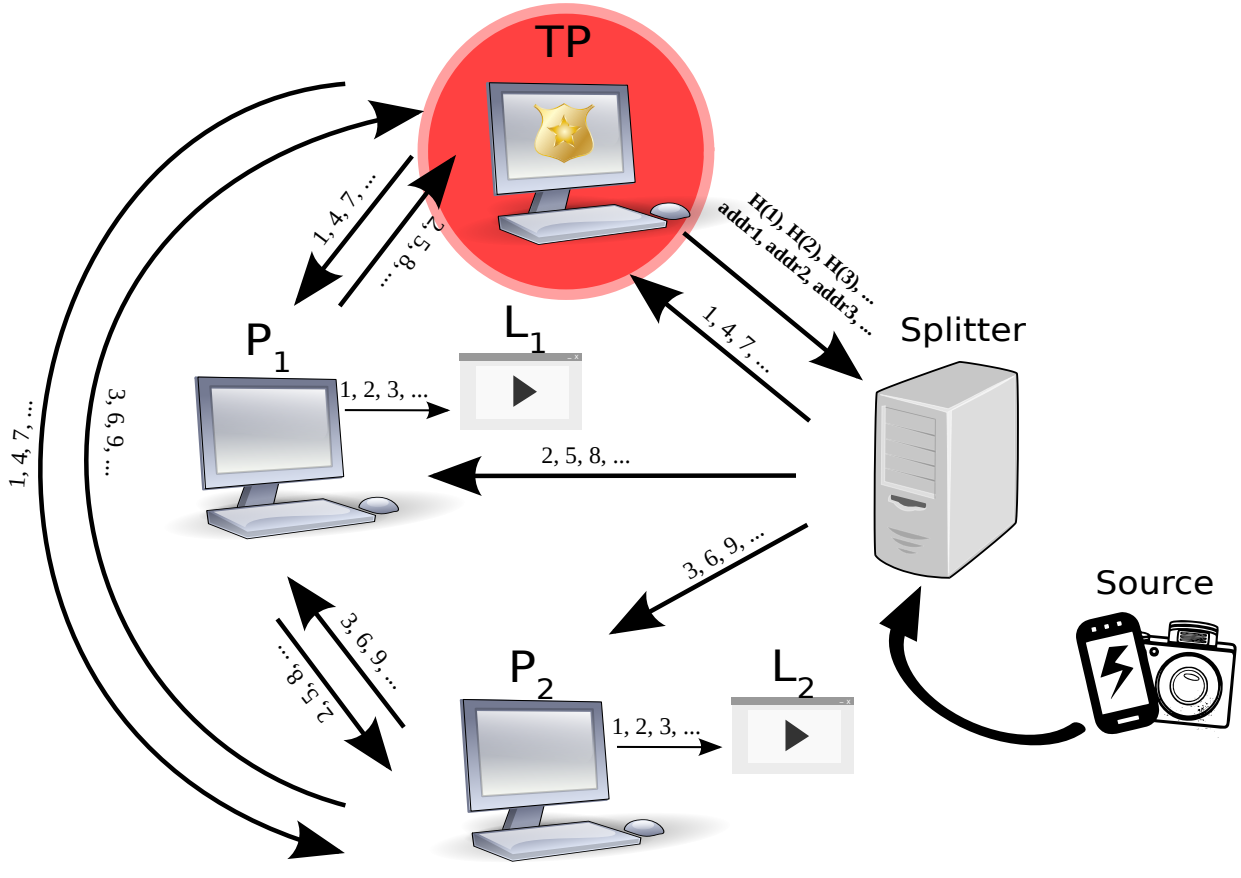

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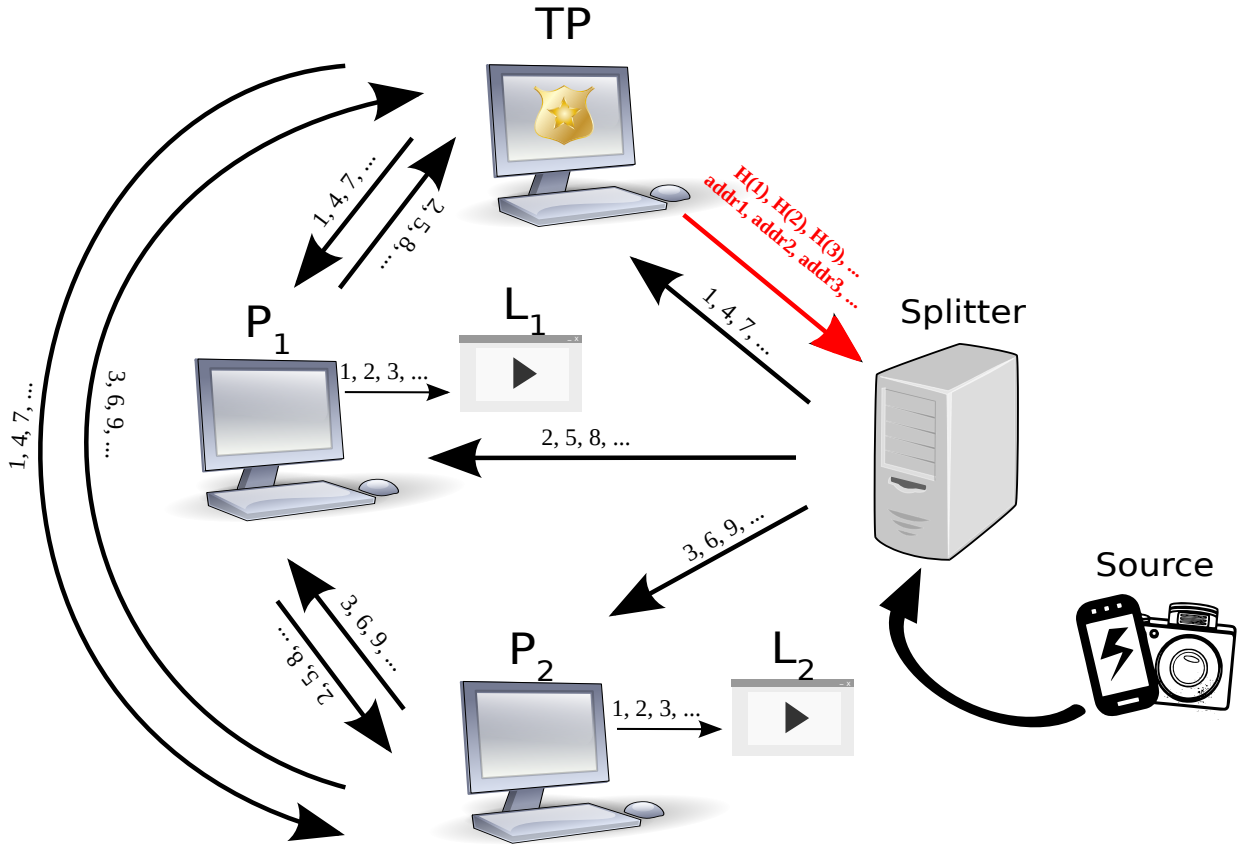

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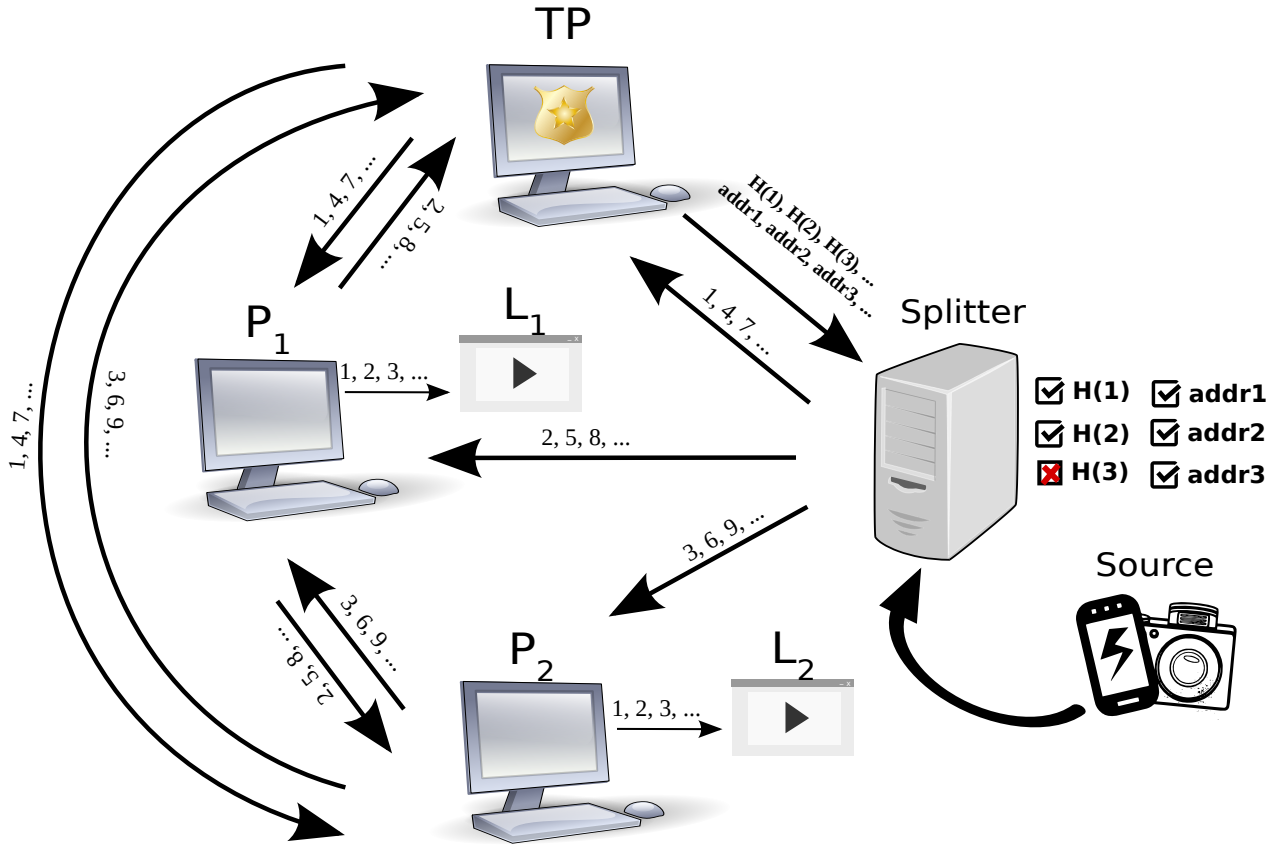

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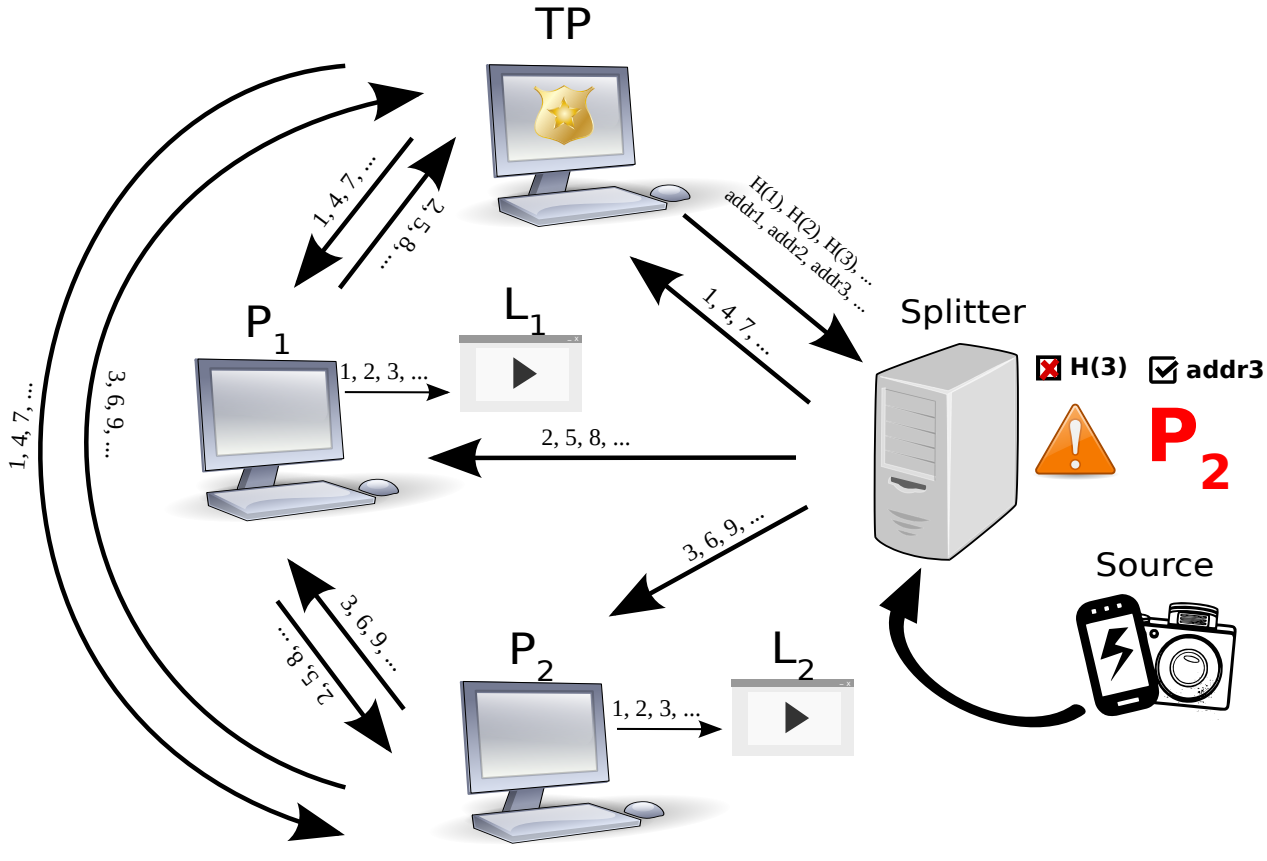

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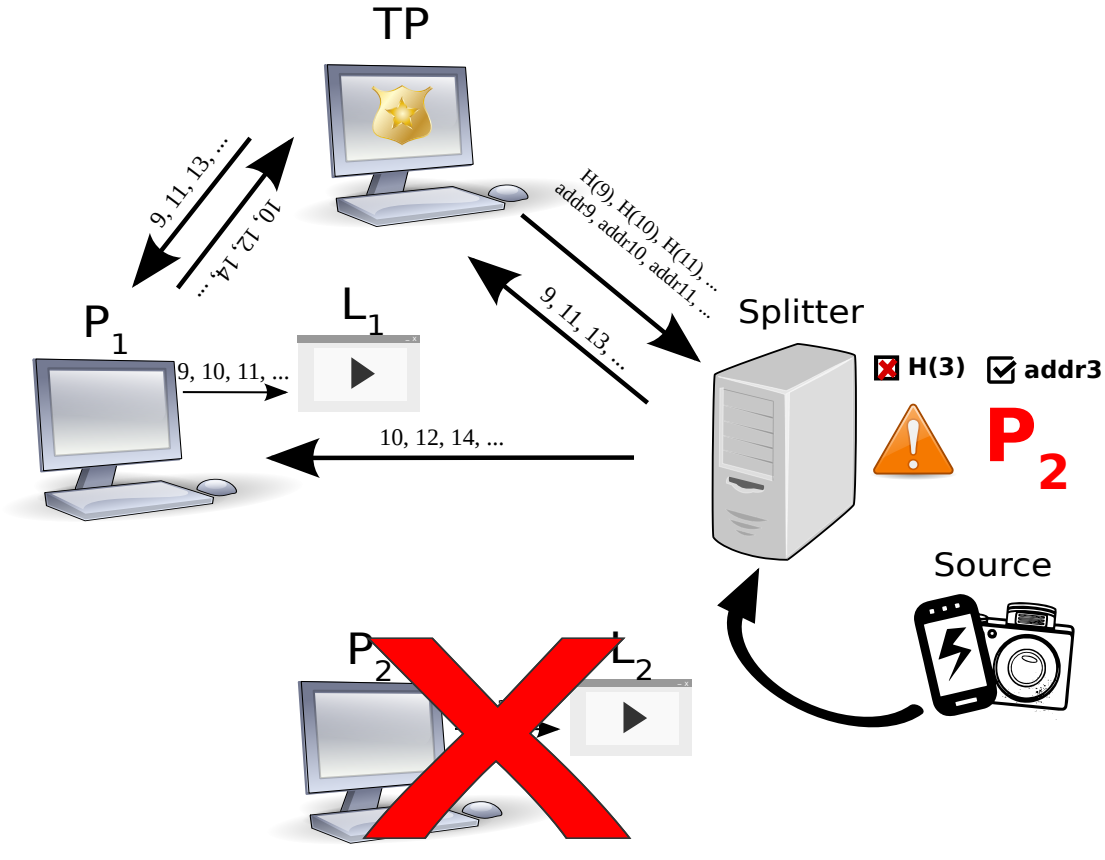

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STRATEGY BASED ON TRUSTED PEERS

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- Peers don't know if they are being poisoned.

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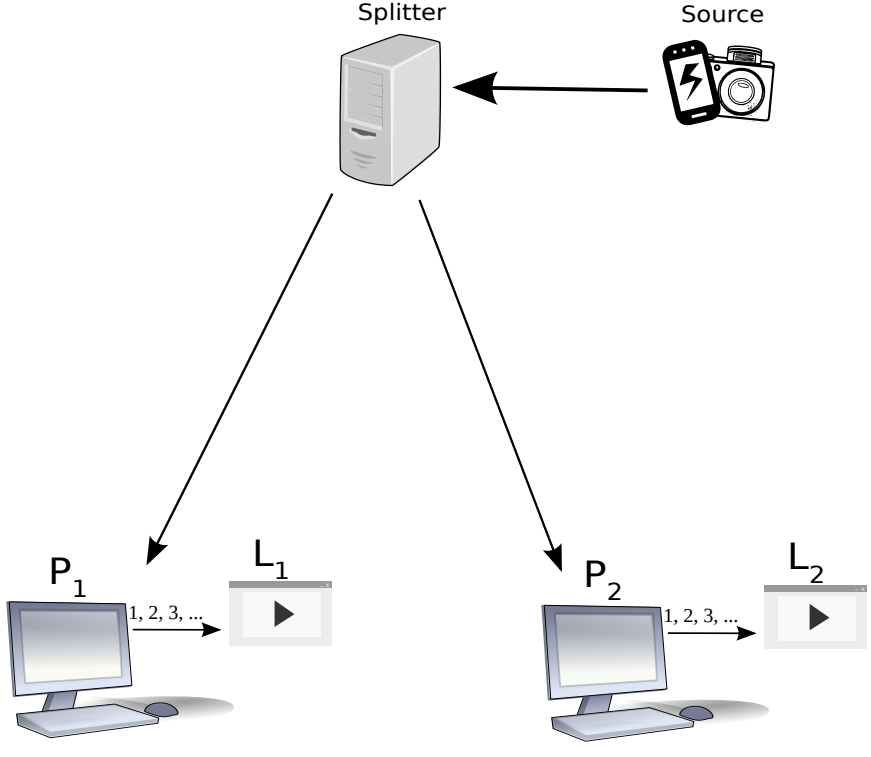
- Peers don't know if they are being poisoned.
- If an attacker knows who the trusted peers are the system is completely vulnerable to **Selective Attacks**.

STRATEGY BASED ON TRUSTED PEERS AND DIGITAL SIGNATURES

IT HAS BEEN DESIGNED TO MITIGATE THE SELECTIVE ATTACK AND TO IDENTIFY POISONED CHUNKS BY USING DIGITAL SIGNATURES. THE BEHAVIOR RULES ARE:



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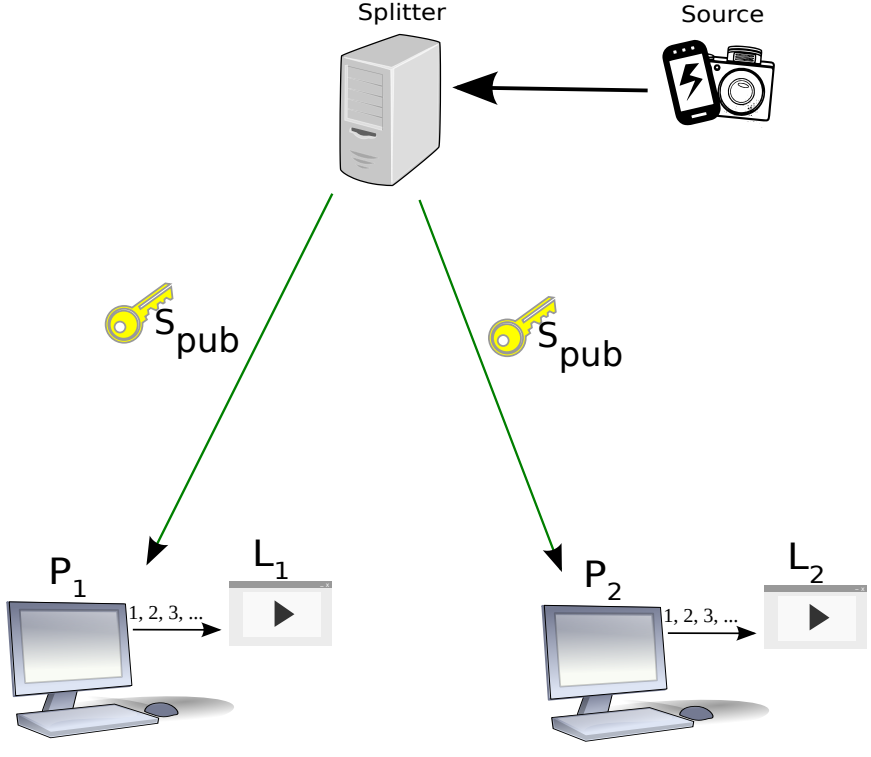

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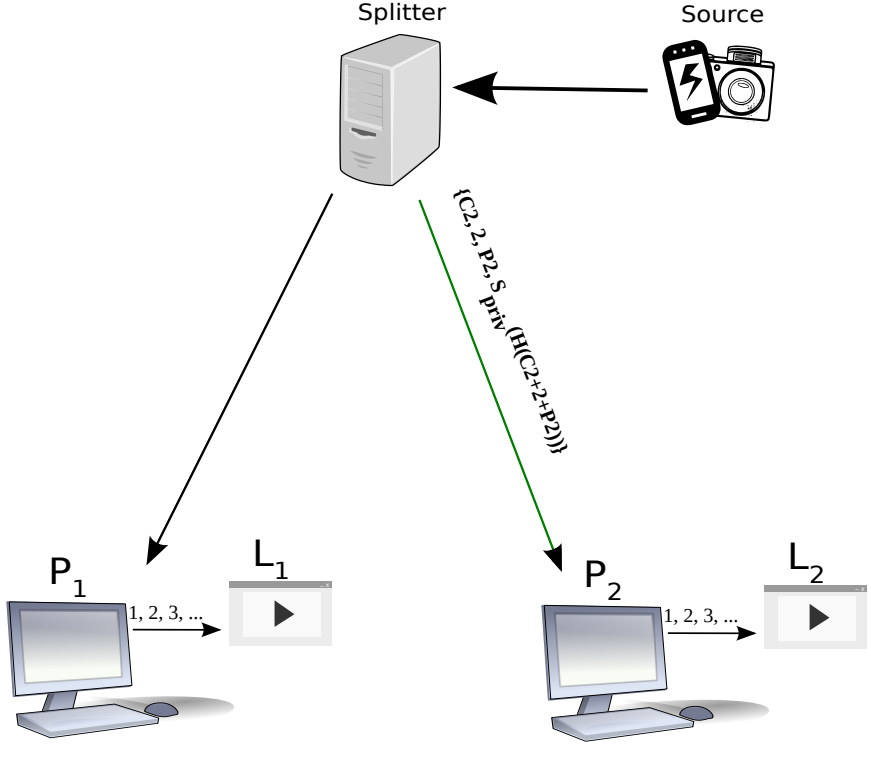

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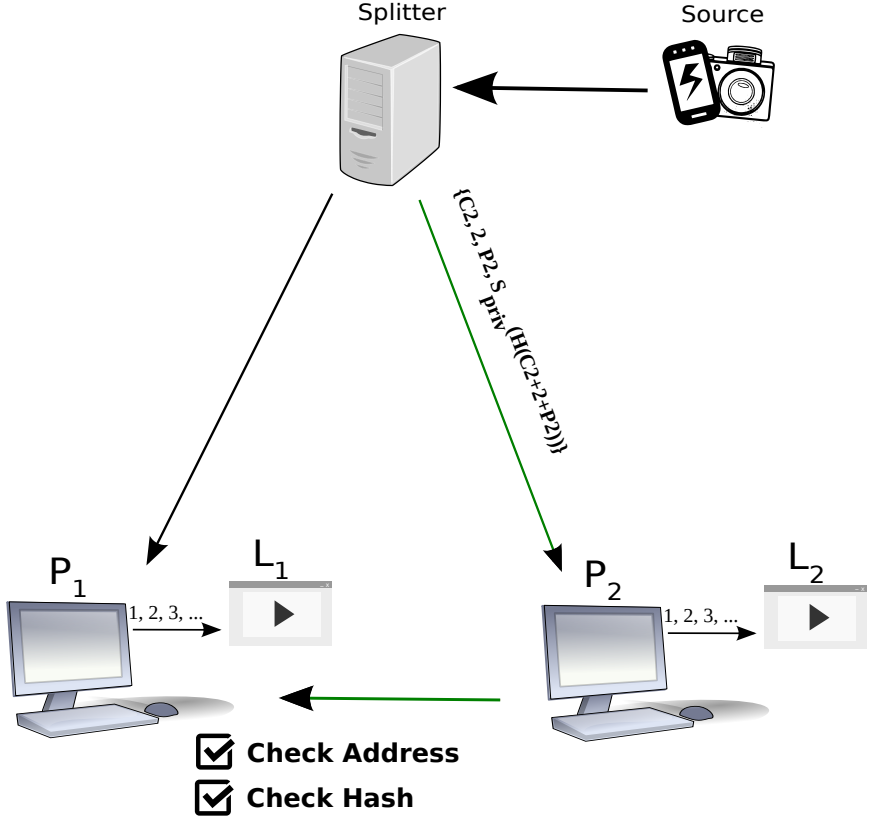

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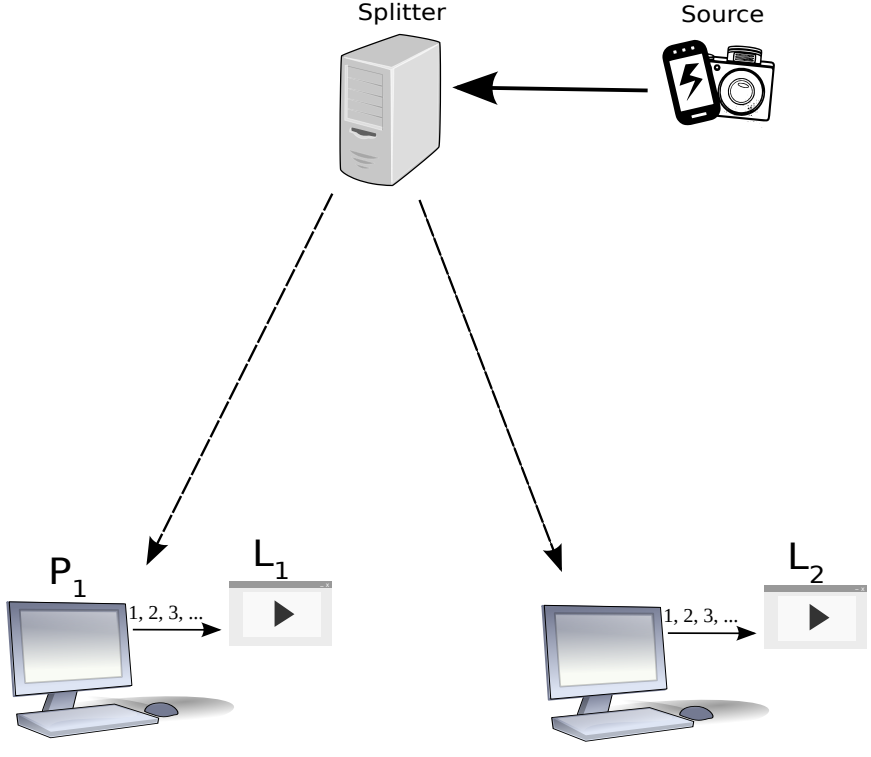

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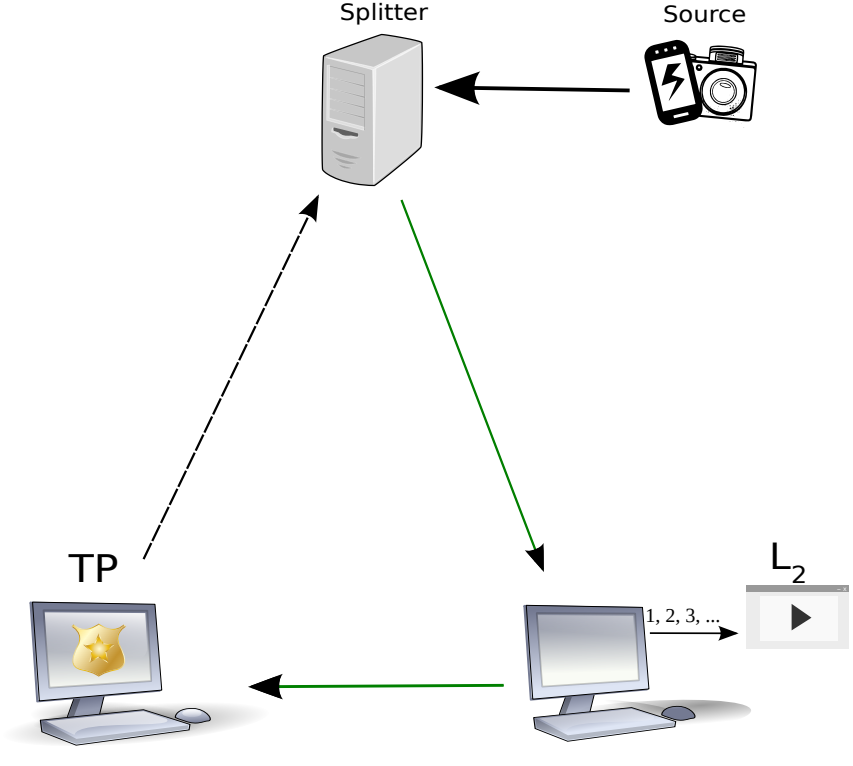

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5.PEERS REMOVED BY ANY TP ARE DIRECTLY EXPELLED BY THE SPLITTER AFTER A RANDOM TIME.

STRATEGY BASED ON TRUSTED PEERS AND DIGITAL SIGNATURES

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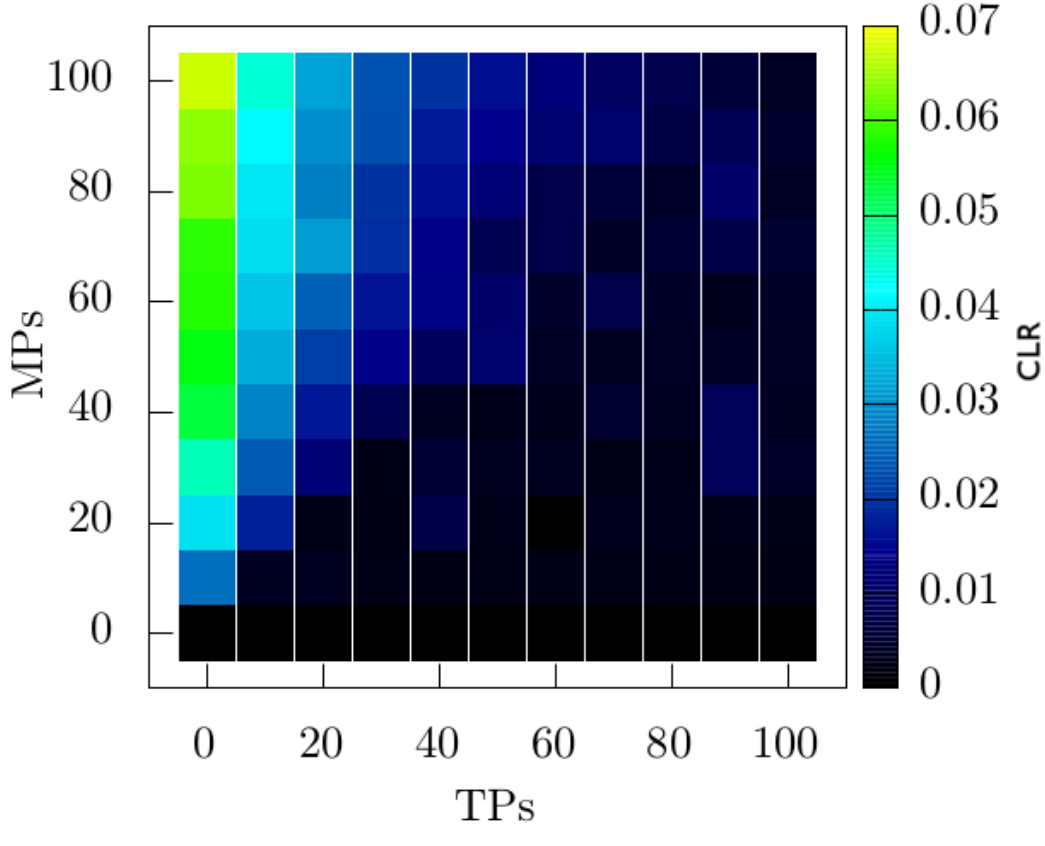
- **CAN TRUSTED PEERS EXPEL THE BAD GUYS BY FOLLOWING THESE BASIC RULES?**

EXPERIMENTAL RESULTS

RESULTS OBTAINED BY SIMULATION [WAR-GAMES]

Persistent, Selective and Collaborative Attack



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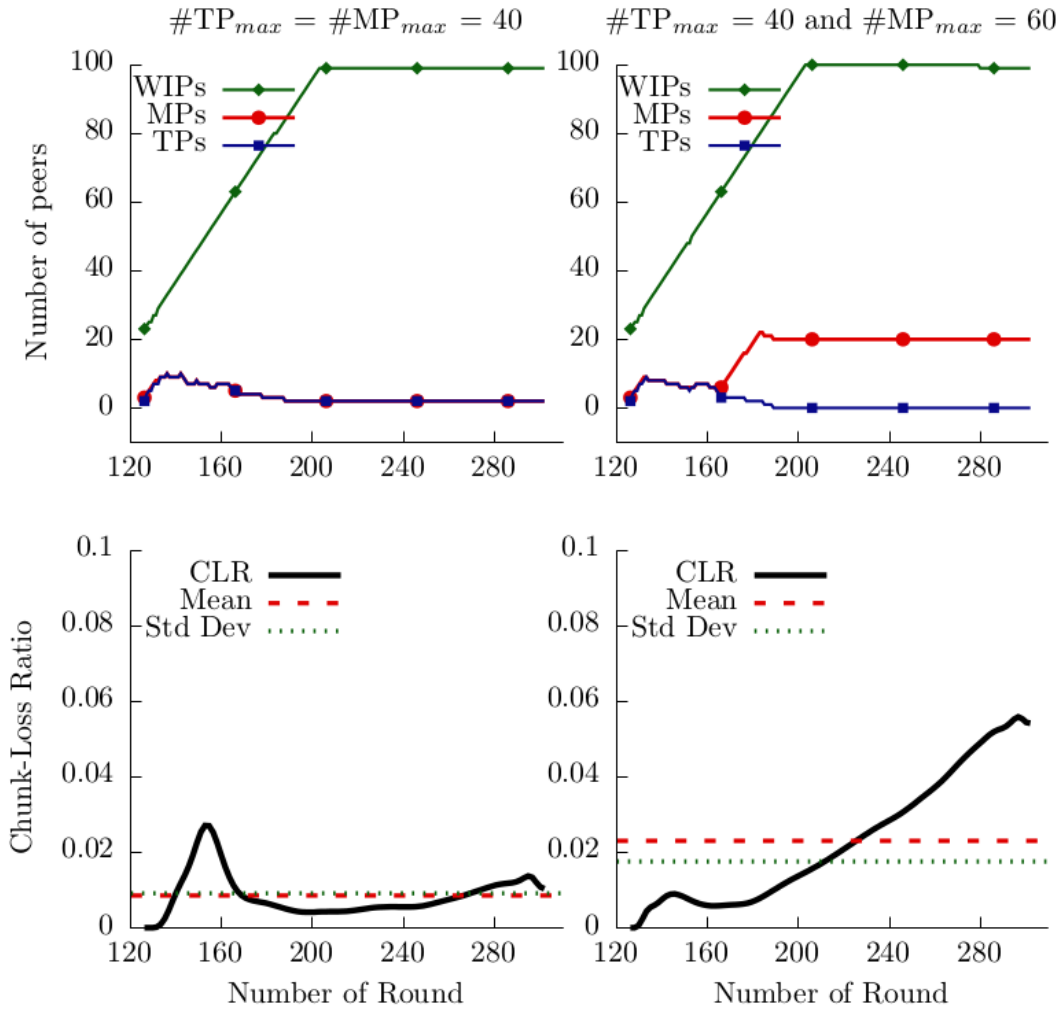

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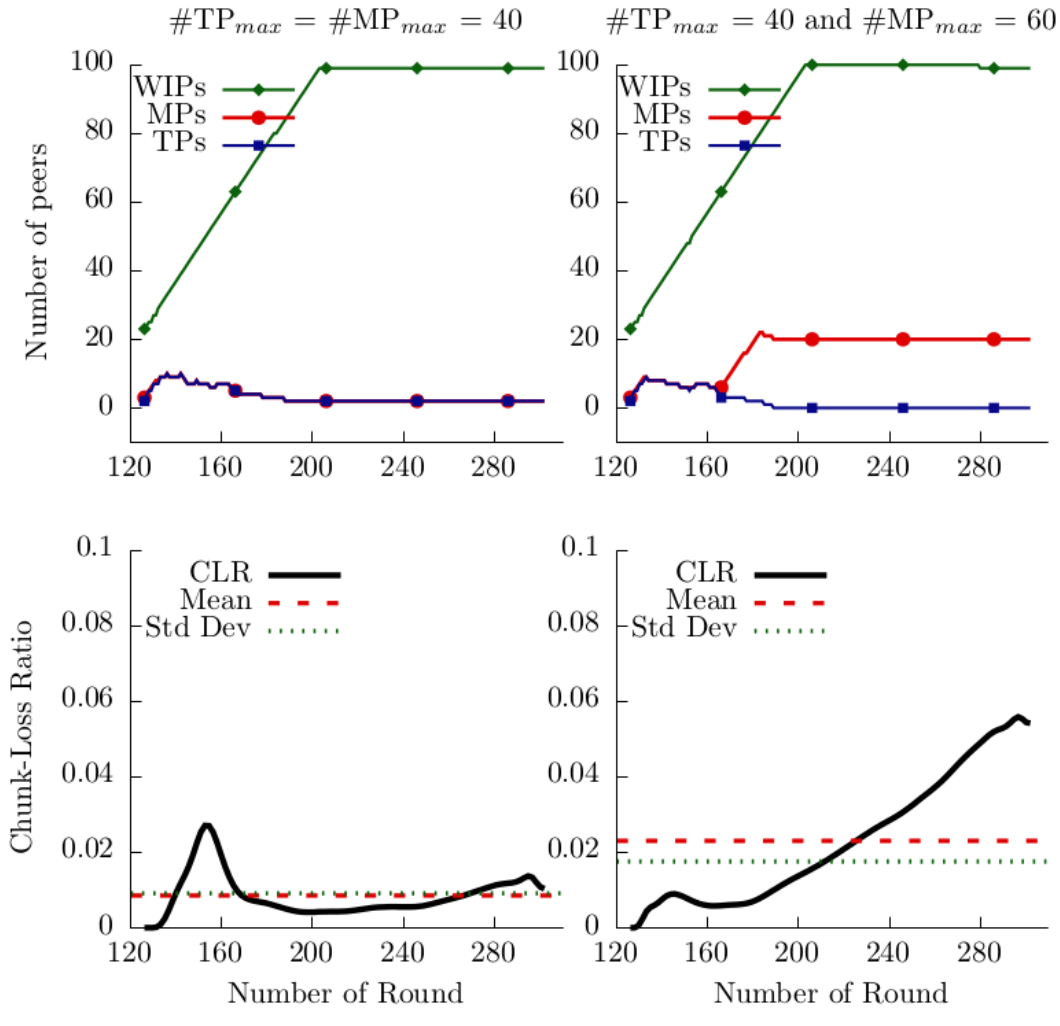

Trusted peers as unique defense strategy is not appealing when the number of MPs is large

A HARD MULTI-OBJECTIVE OPTIMIZATION PROBLEM

Attackers and defenders have to solve a multi-objective optimization problem and each decision made by one part may have a countermeasure by the other part

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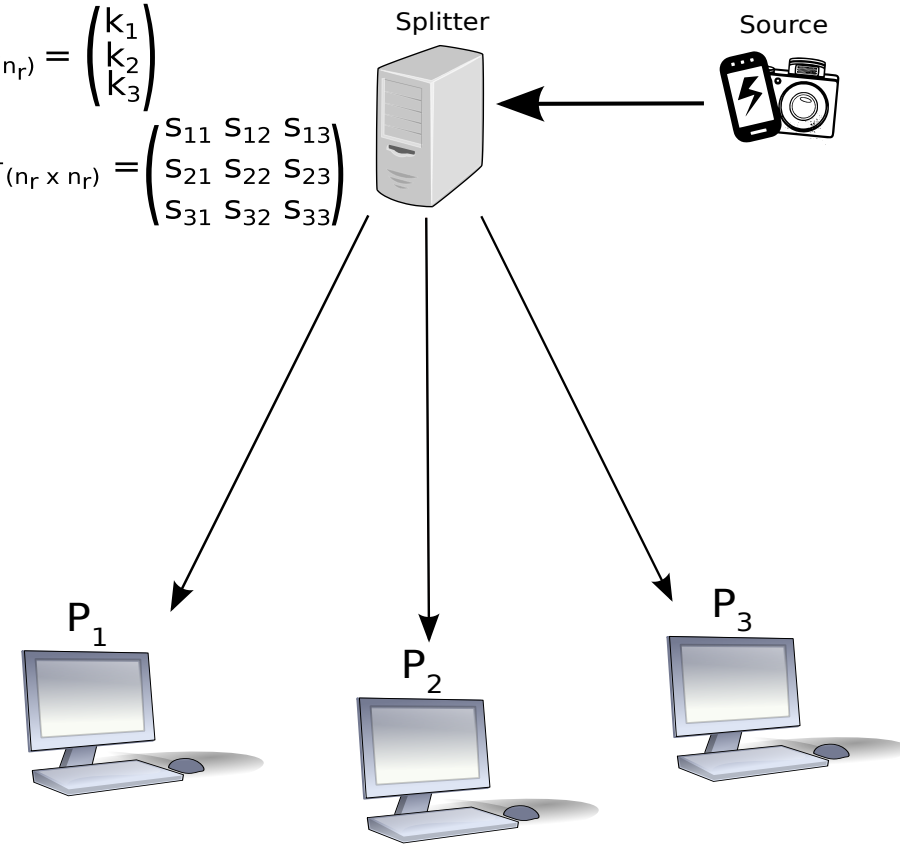
WHO ARE THE GOOD/BAD GUYS?

STRATEGY BASED ON TRUSTED PEERS AND SHAMIR'S SECRET SHARING

THE MAIN IDEA IS VERY SIMPLE: “IF YOU WANT TO REMAIN IN THE TEAM YOU MUST HAVE A GOOD BEHAVIOR WITH AT LEAST T PEERS”. THE BEHAVIOR RULES ARE:

$$K^{r+1}_{(n_r)} = \begin{pmatrix} k_1 \\ k_2 \\ k_3 \end{pmatrix}$$

$$A^{r+1}_{(n_r \times n_r)} = \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{pmatrix}$$



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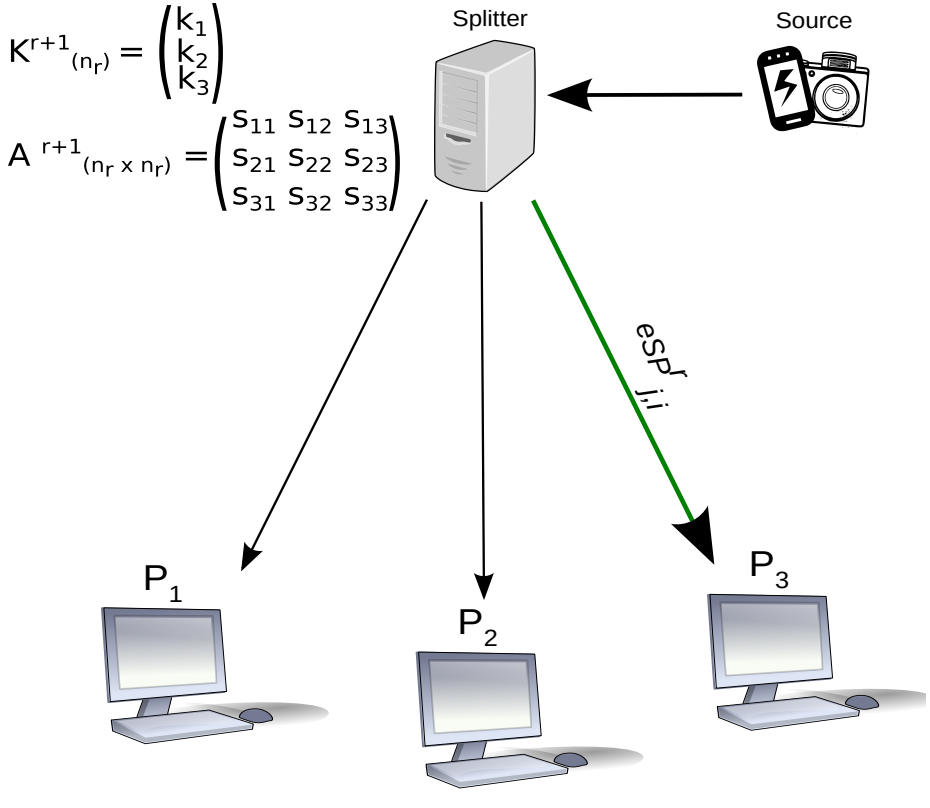

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$$eSP^r_{j,i} = \{eCH^r_{j,i},\ SH^{r+1}_i\}$$
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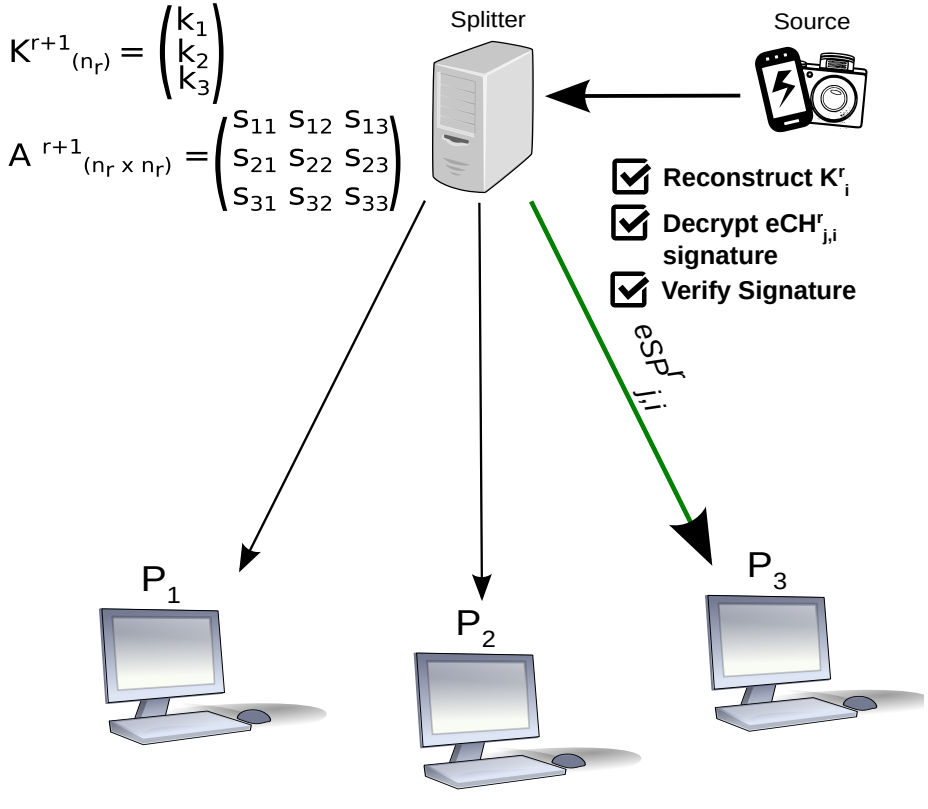

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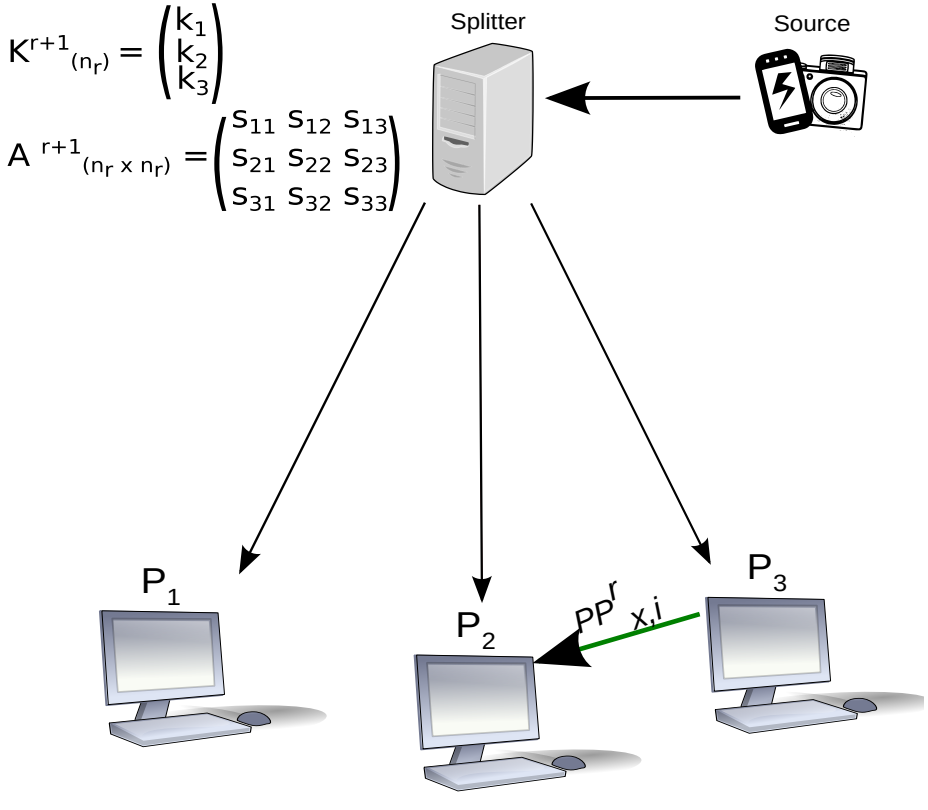

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3.THE PEER SENDS THE MESSAGE DECRYPTED.

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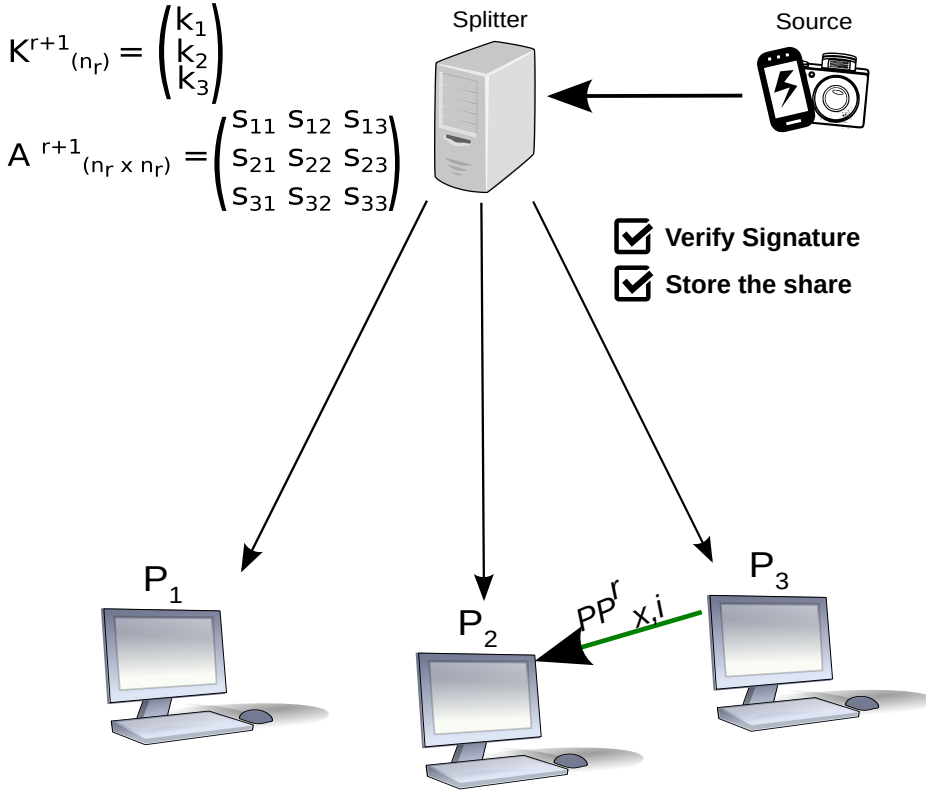

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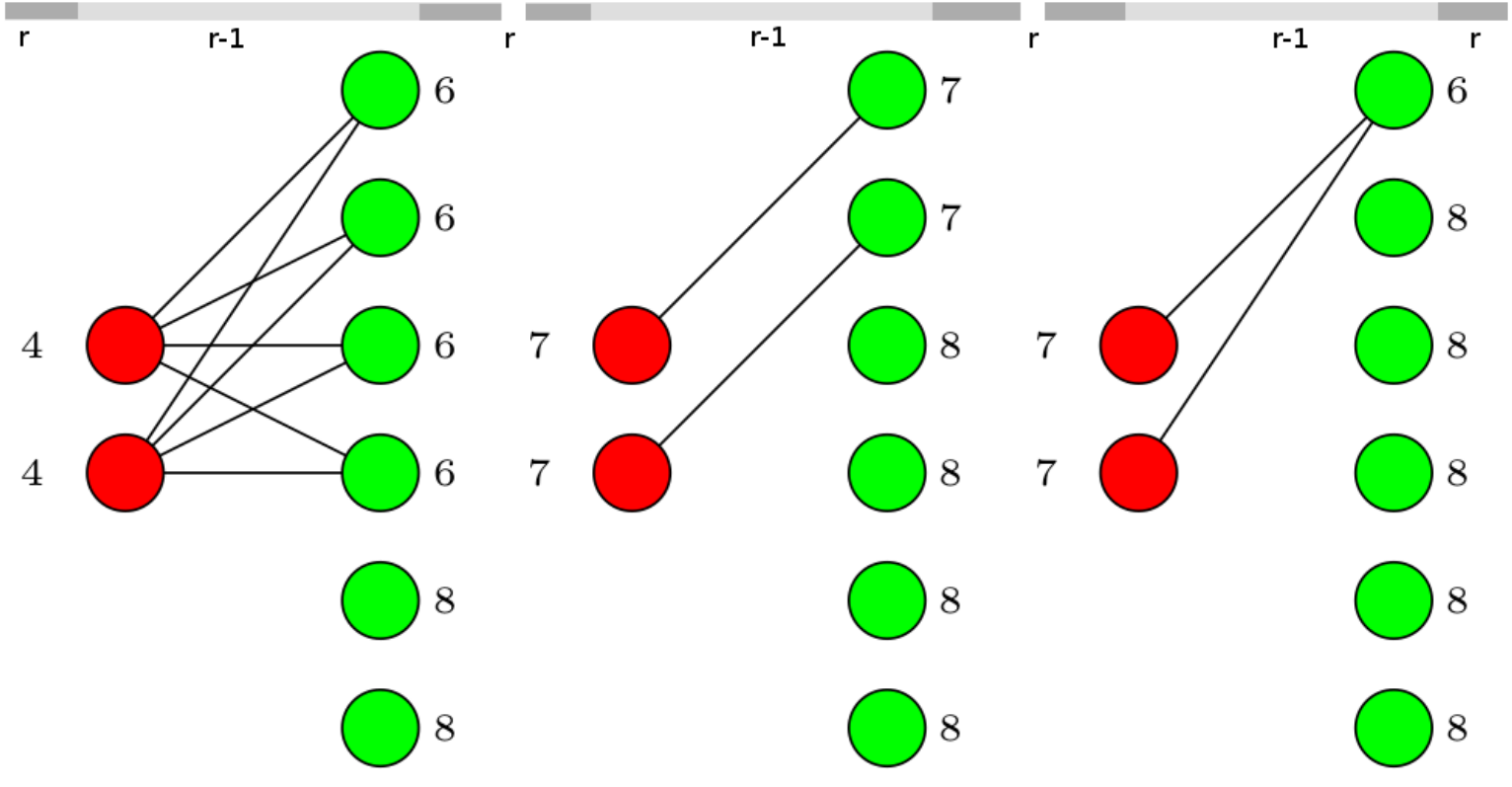
4.THE PEER VERIFIES THE MESSAGE AND SAVES THE SHARE.

THEORETICAL RESULTS

RESULTS OBTAINED AFTER A THEORETICAL ANALYSIS: $\mathrm{MPs} <= N/2$



(a) One MP to many (b) One MP to one (c) Many MPs to one

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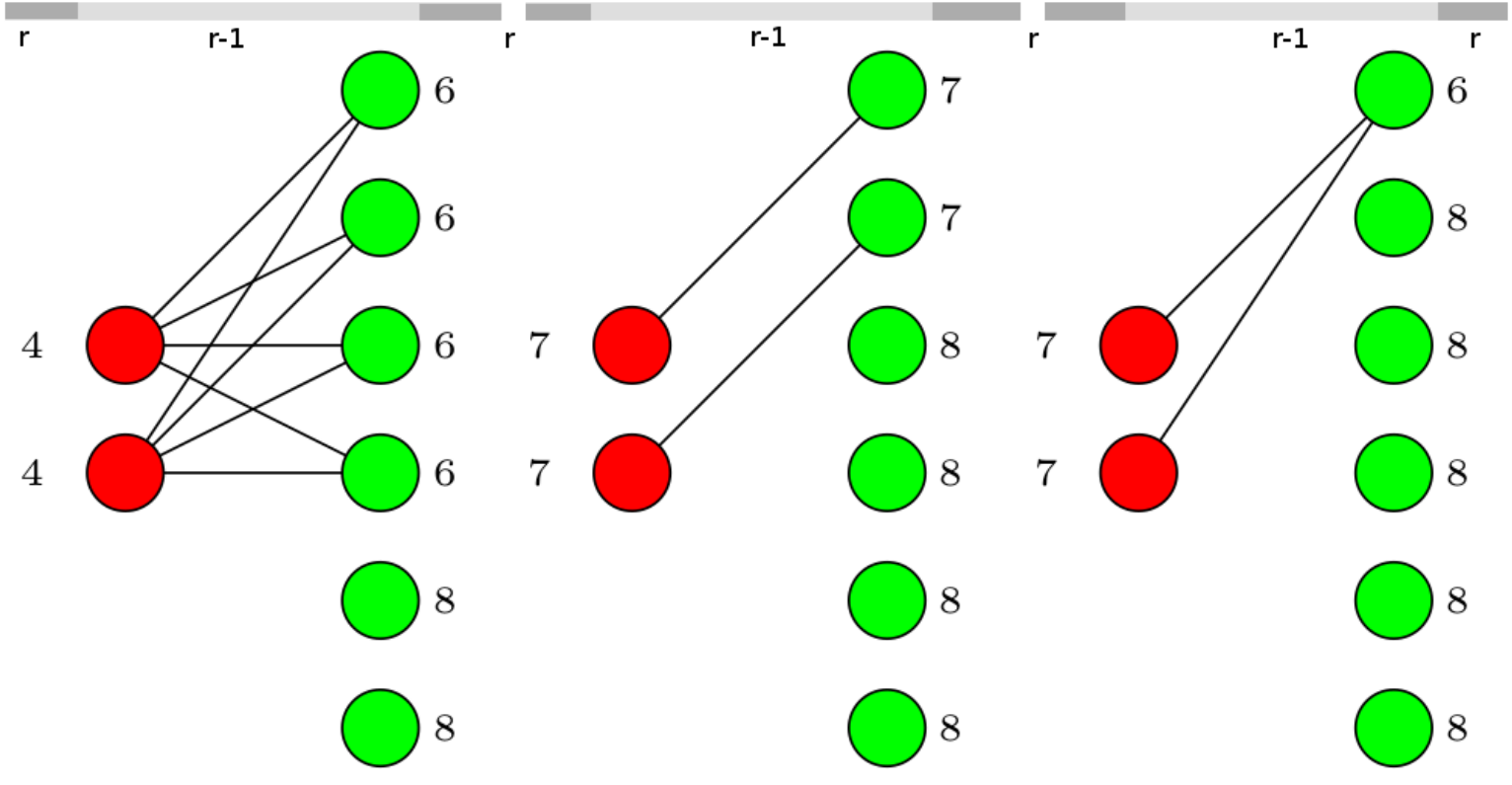


(a) One MP to many (b) One MP to one (c) Many MPs to one

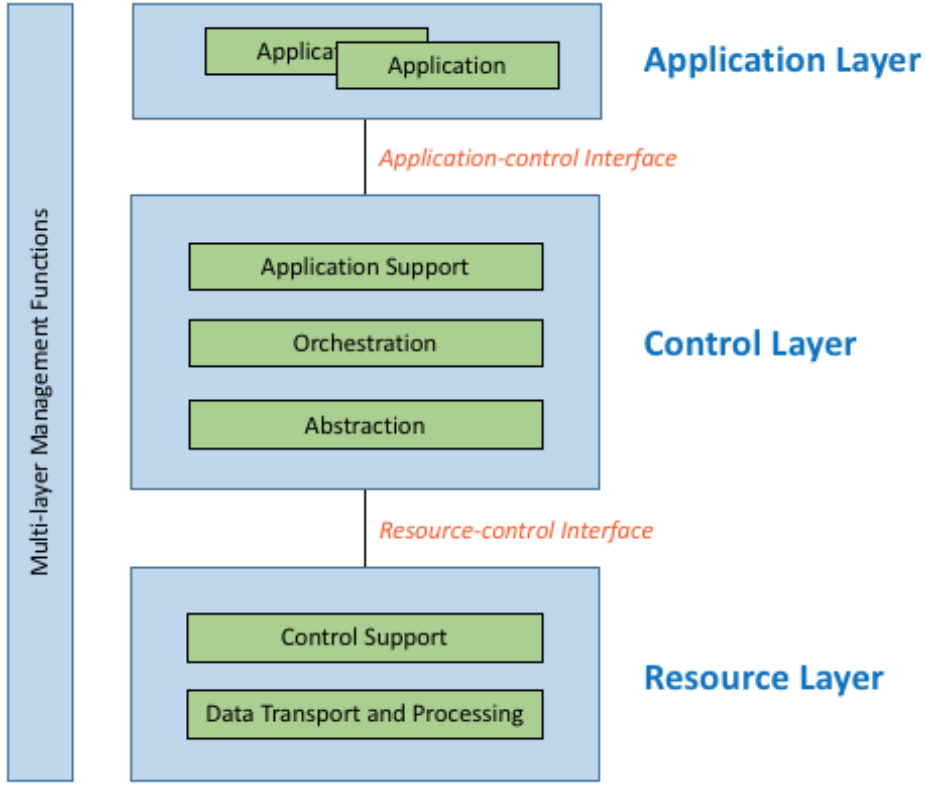
Most severe attack is fully mitigated with only one Trusted Peer

OUTLINE

- INTRODUCTION
  - Background
  - Research Questions
- PEER TO PEER STRAIGHFORWARD PROTOCOL
  - An application-layer protocol that provides real-time broadcasting on the Internet
- **SECURITY**
  - Pollution Attacks
  - Strategies applied to Traditional Networks
  - Strategies applied to Software Defined Networks
- EFFICIENCY
  - NAT Traversal using Collaborative Port Prediction
  - Runing P2PSP on Embeded Devices
- CONCLUSIONS
  - Key Results and Future Work

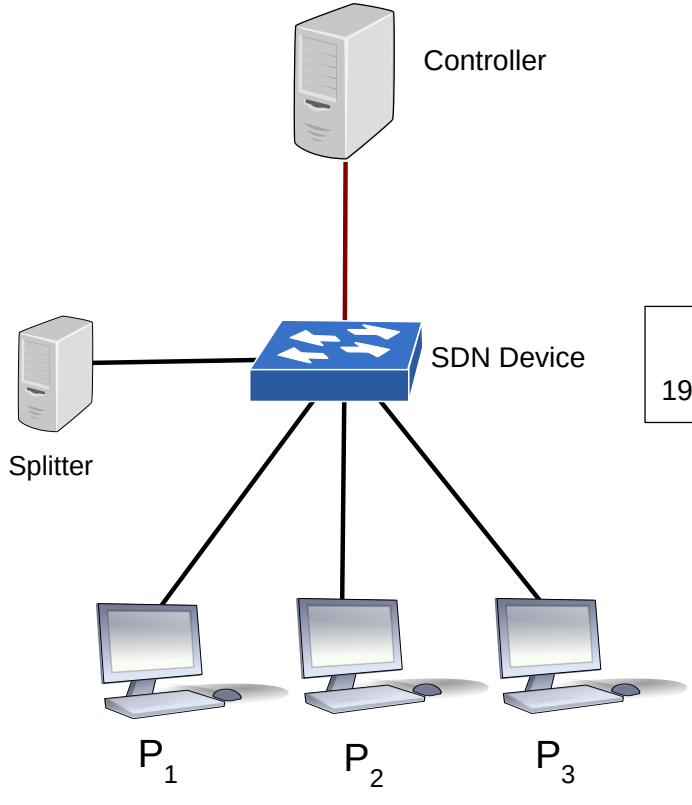
SOFTWARE DEFINED NETWORKS

SDN ARCHITECTURE



SOFTWARE DEFINED NETWORKS

P2PSP PROPOSAL



Ryu Controller
Scrambling table:
(.1,.1), (.2,.3), (.3,.2)

Splitter
192.168.0.99

OF Switch

P_1
192.168.0.1

P_2
192.168.0.2

P_3
192.168.0.3

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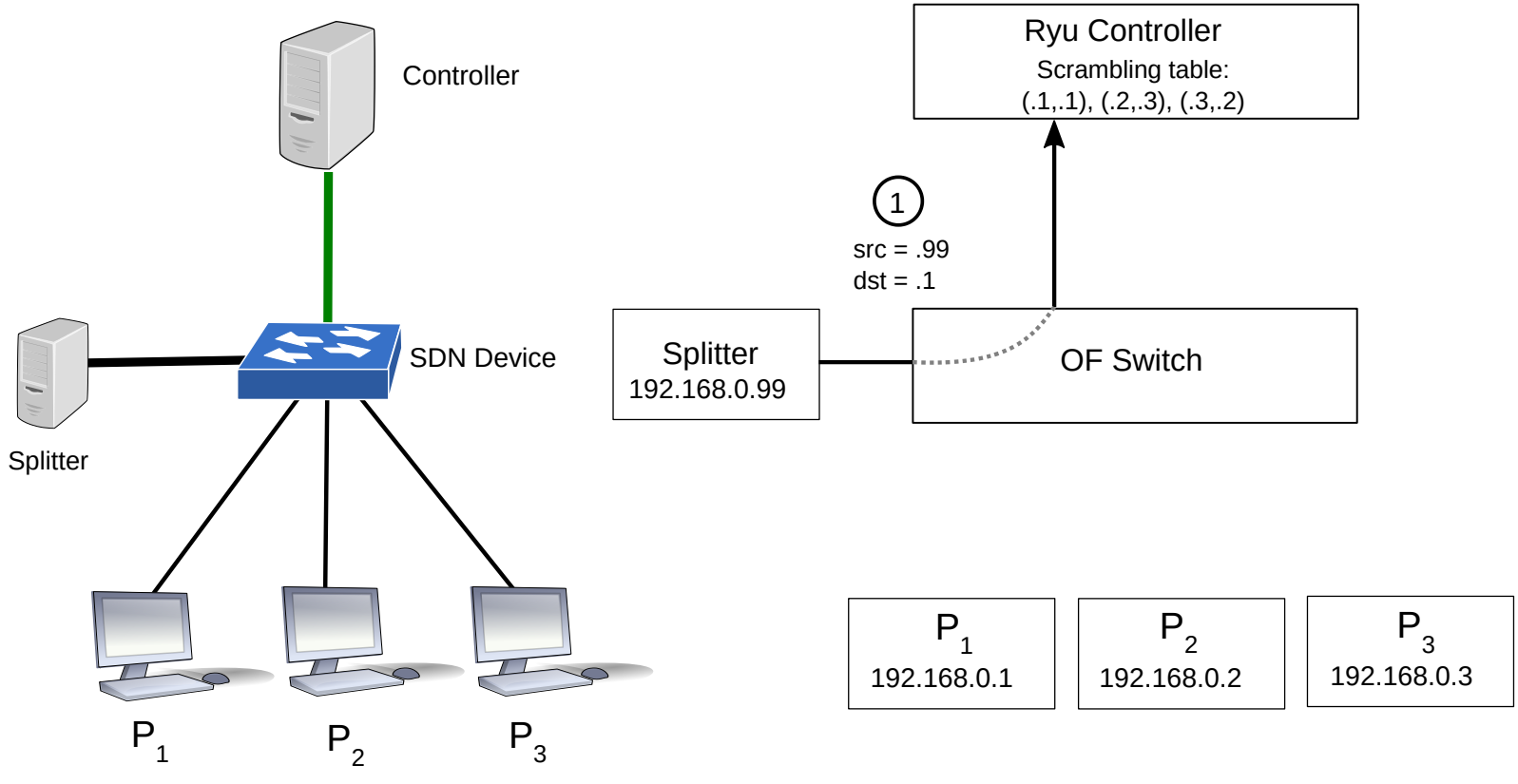

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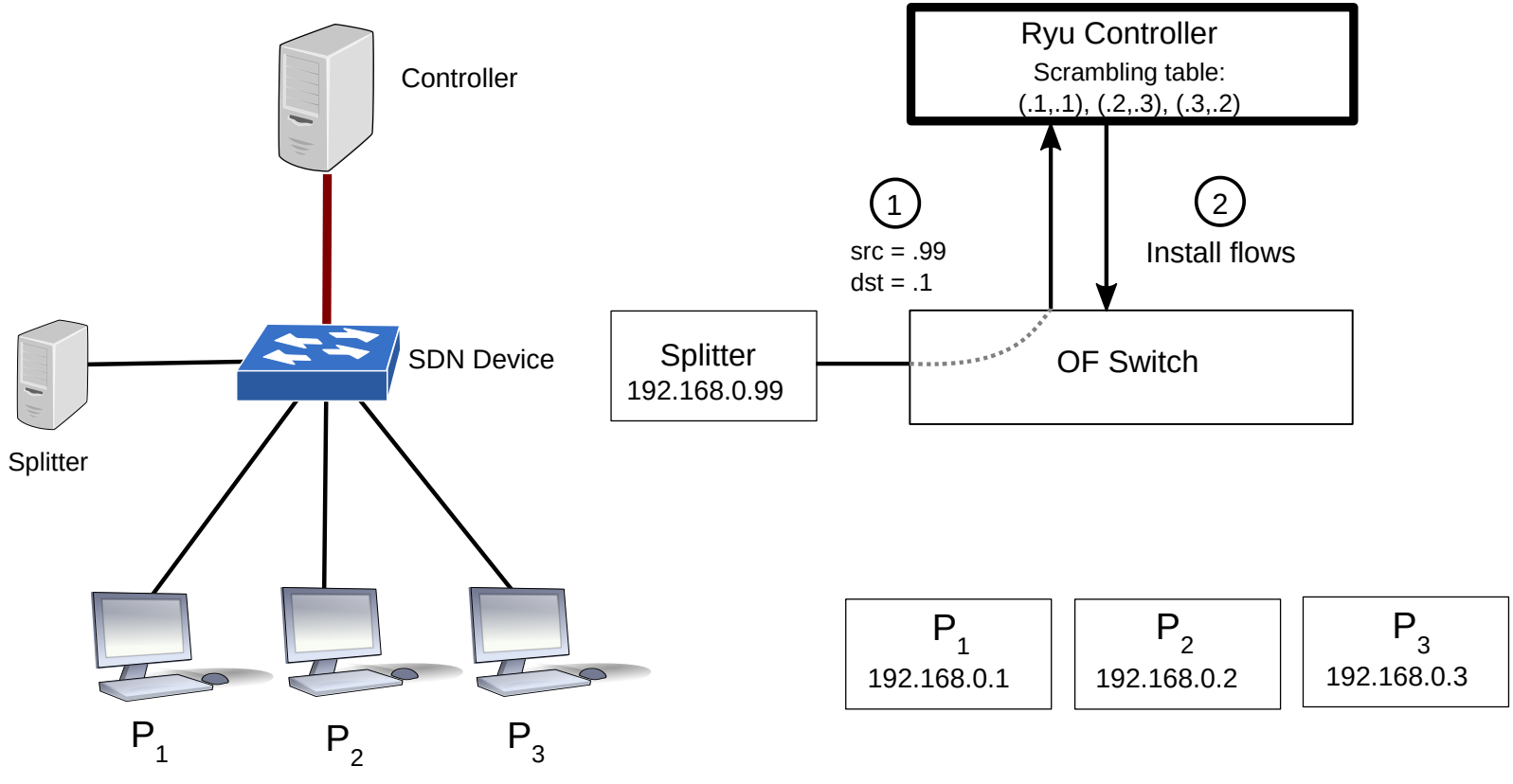

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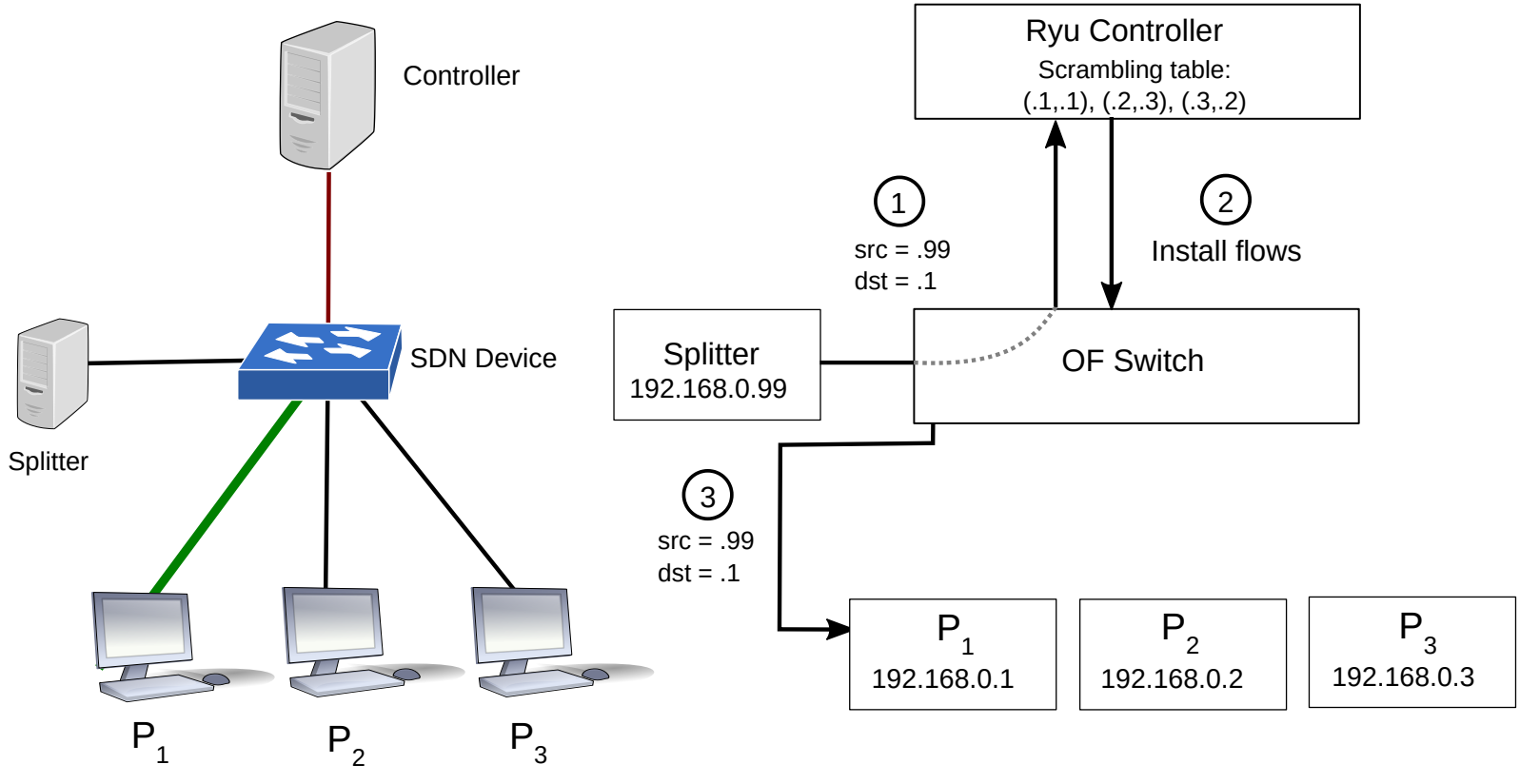

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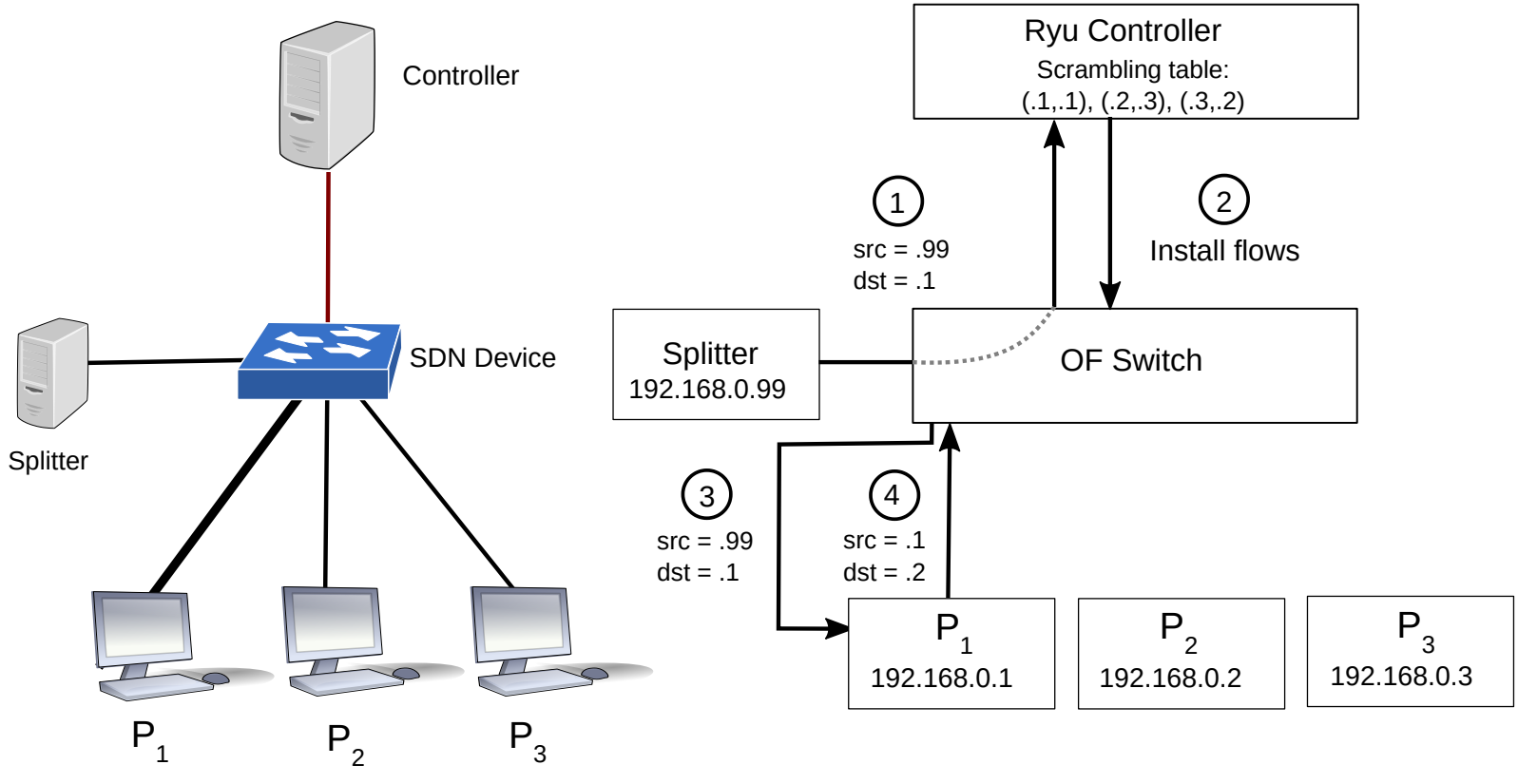

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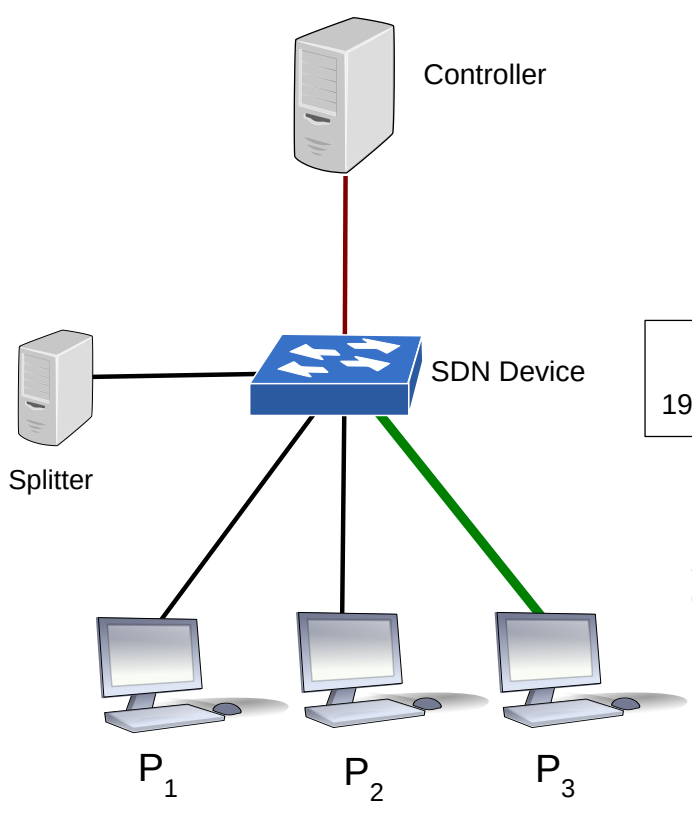
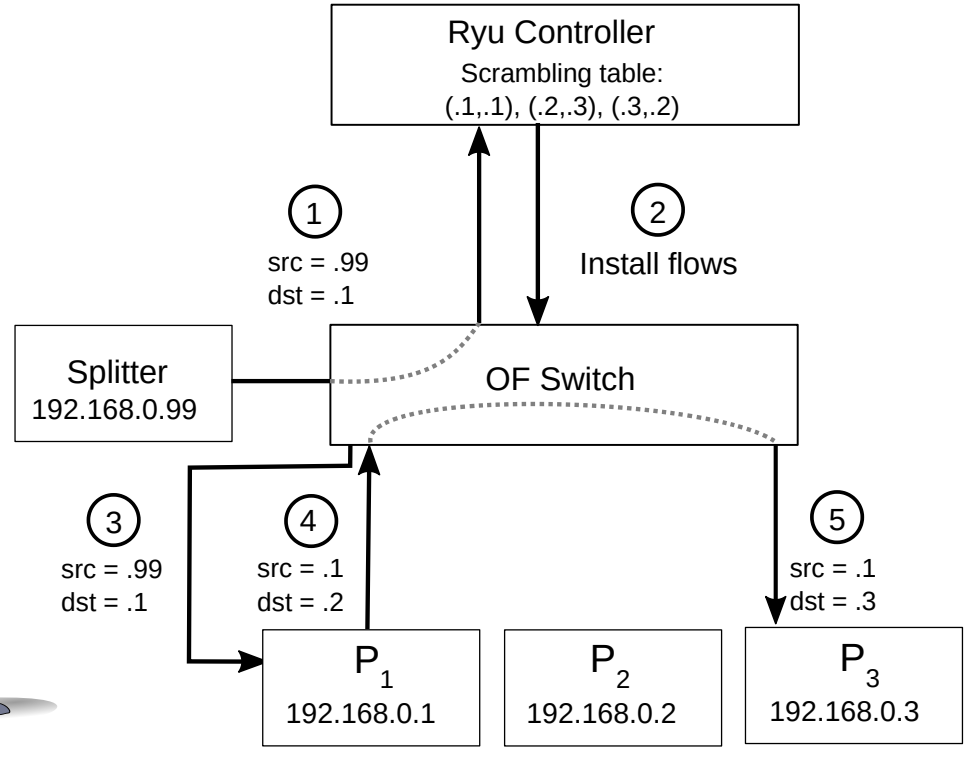
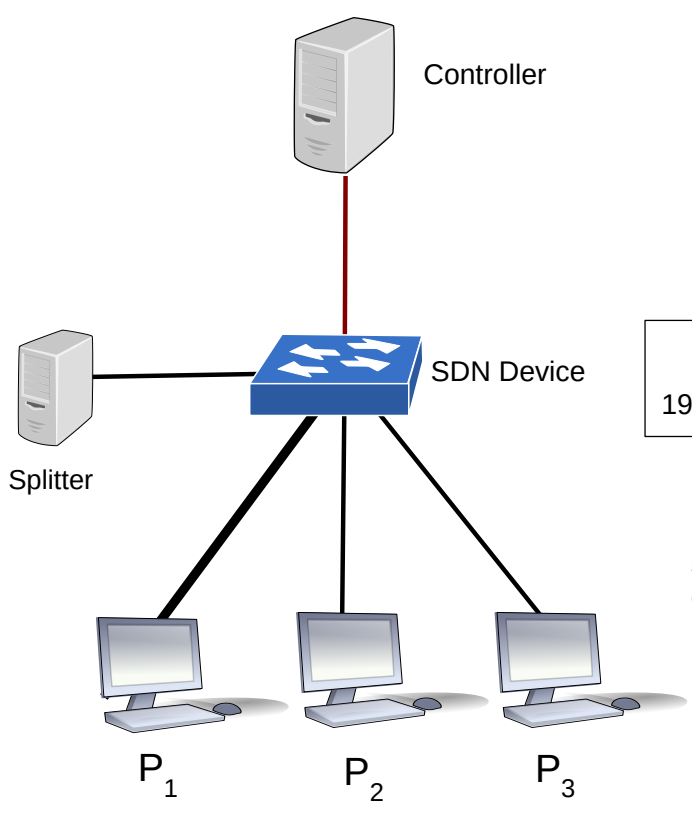
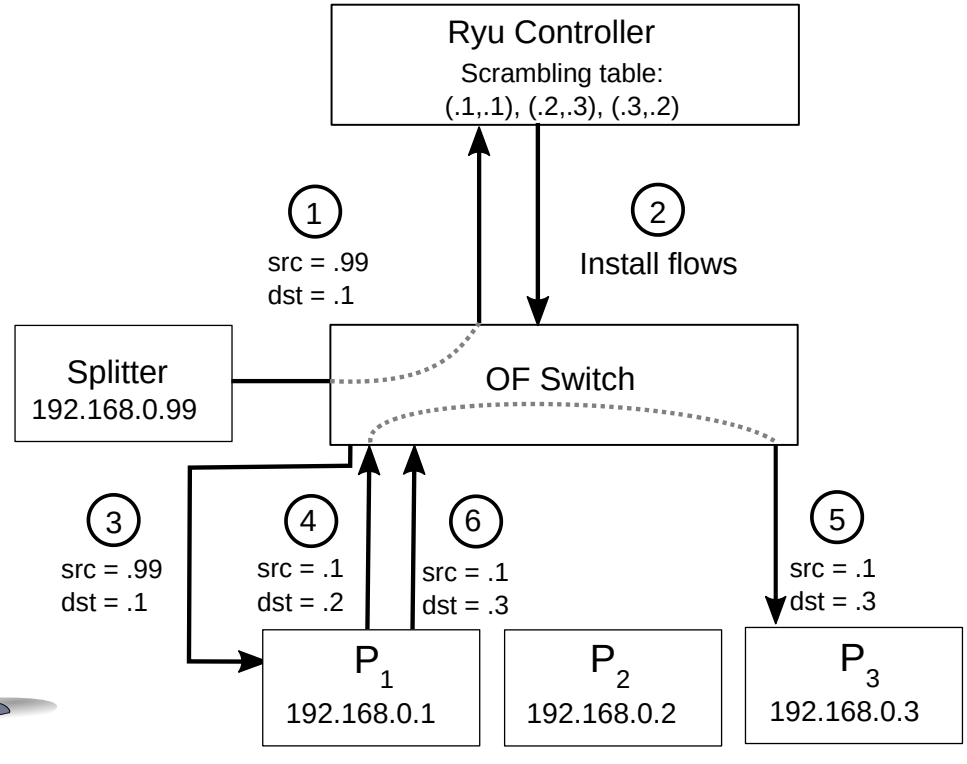




SOFTWARE DEFINED NETWORKS

P2PSP PROPOSAL





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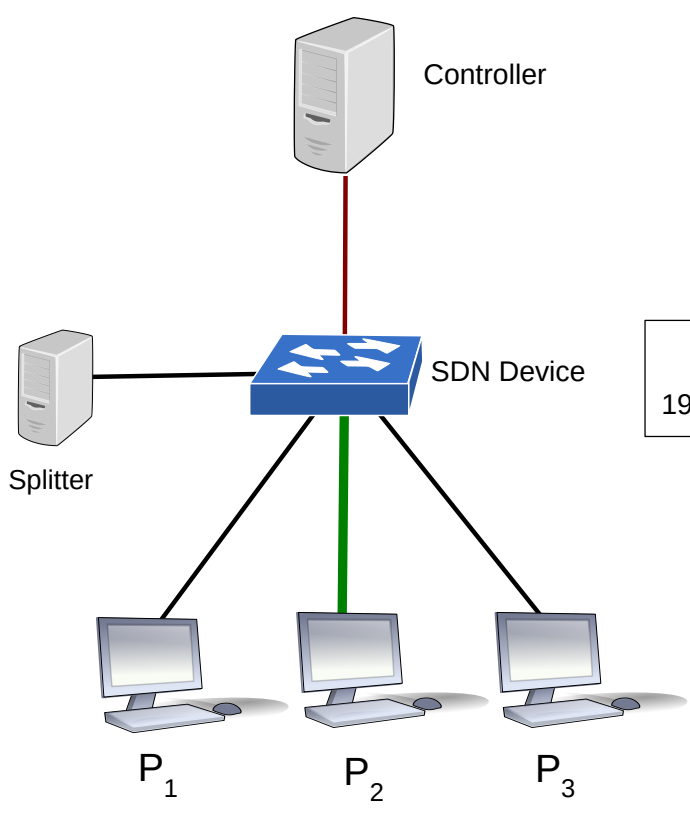
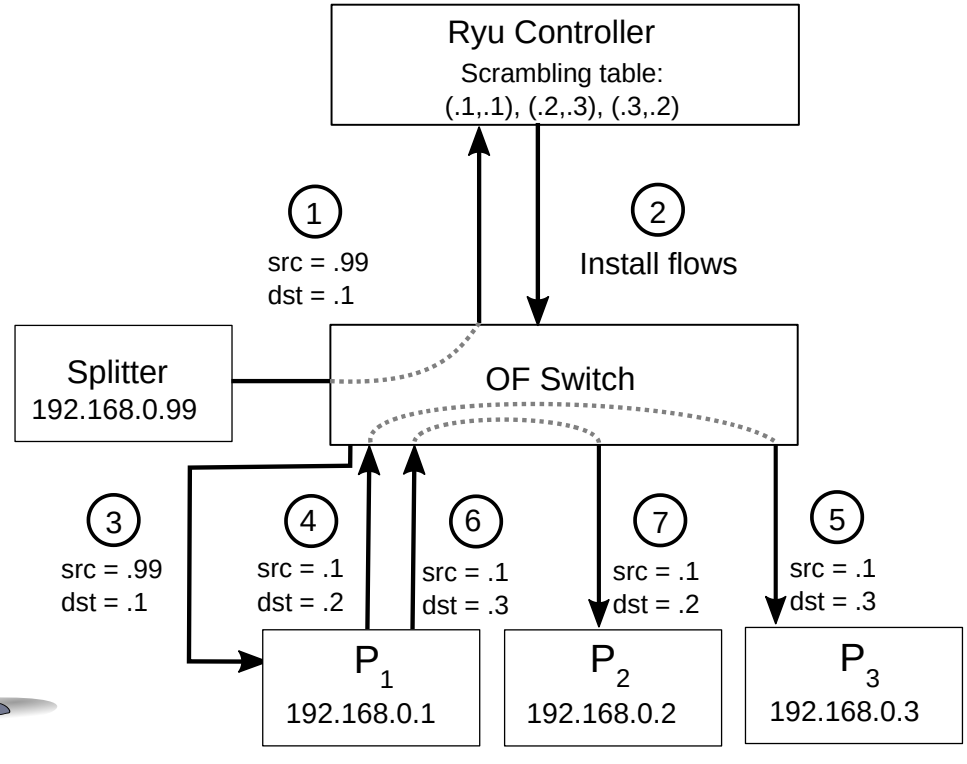
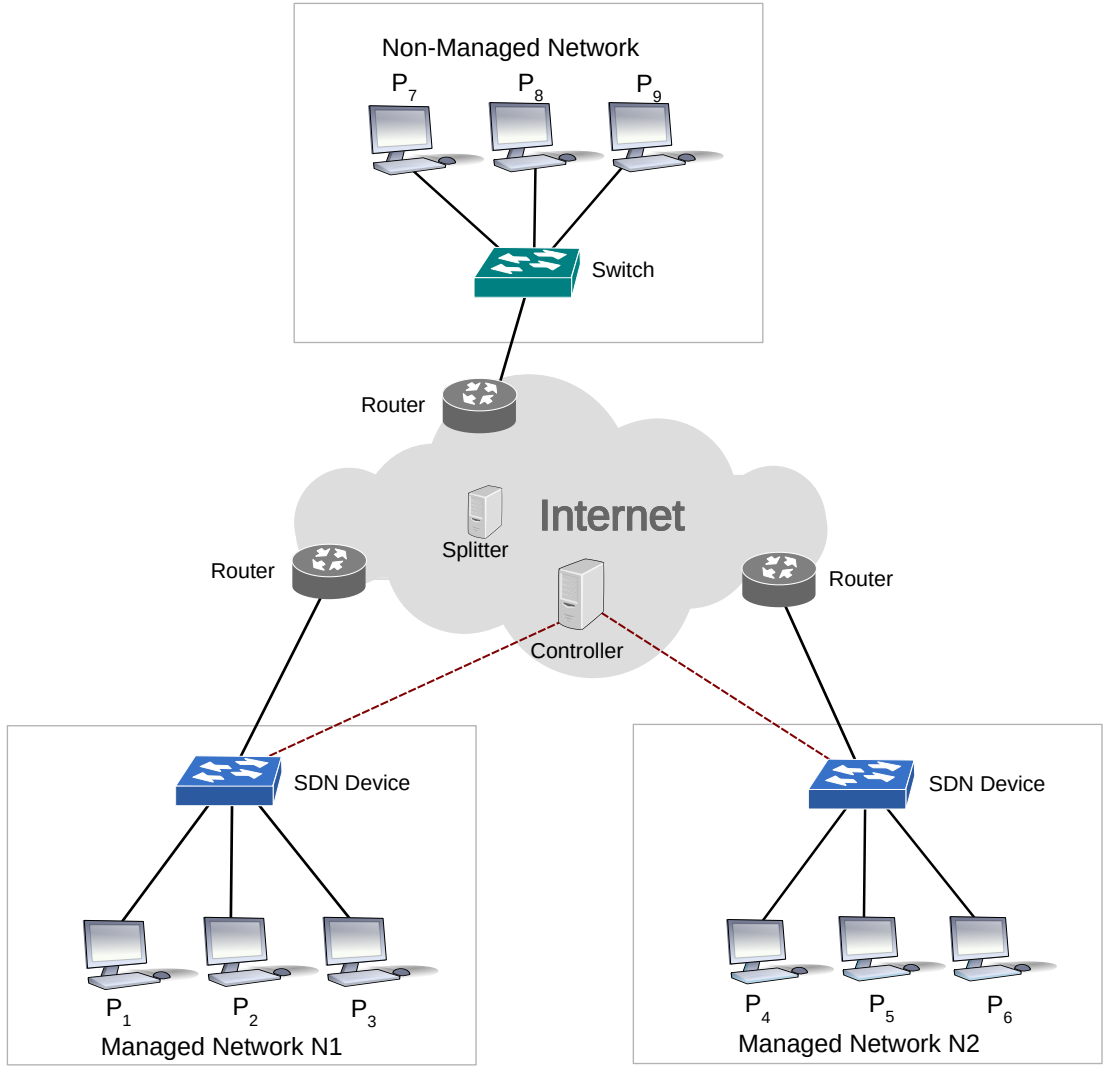




SOFTWARE DEFINED NETWORKS

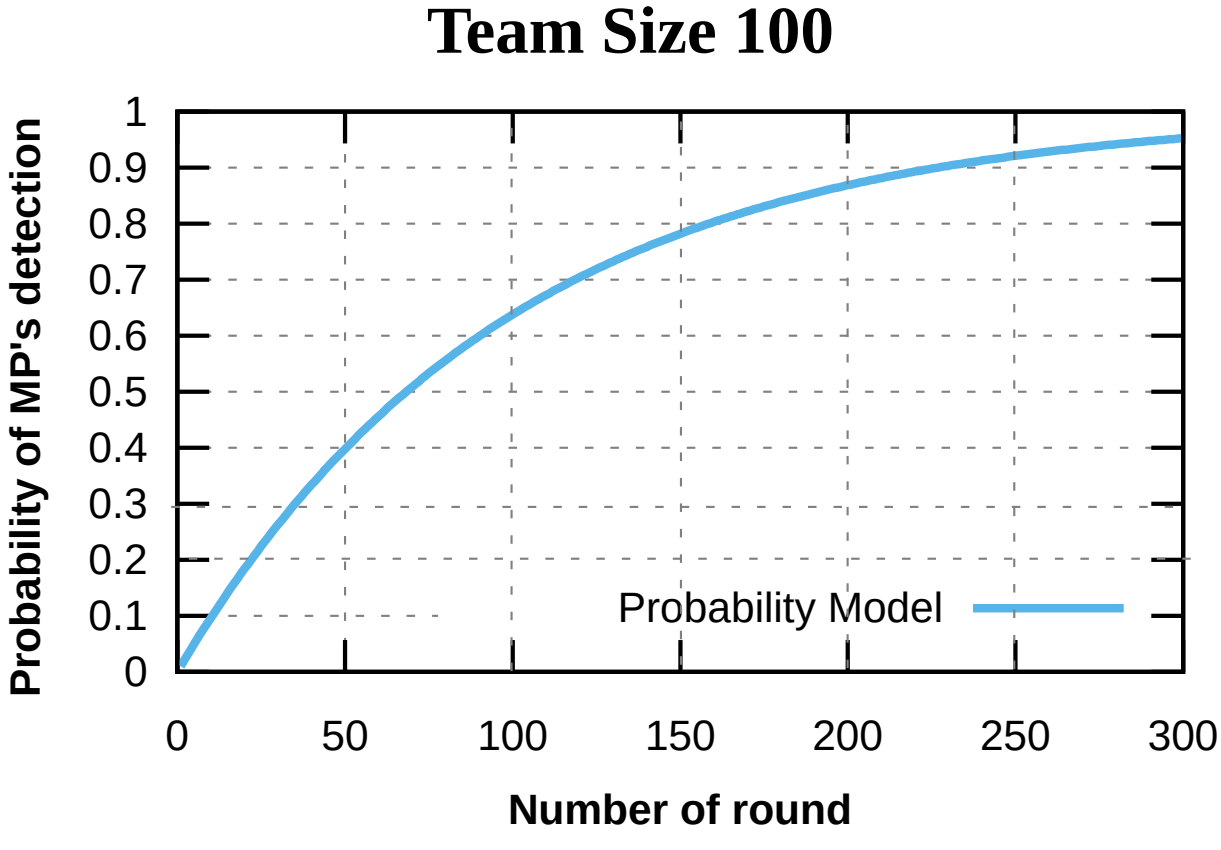
It also works under hybrid environments



DETECTION PROBABILITIES

MODEL

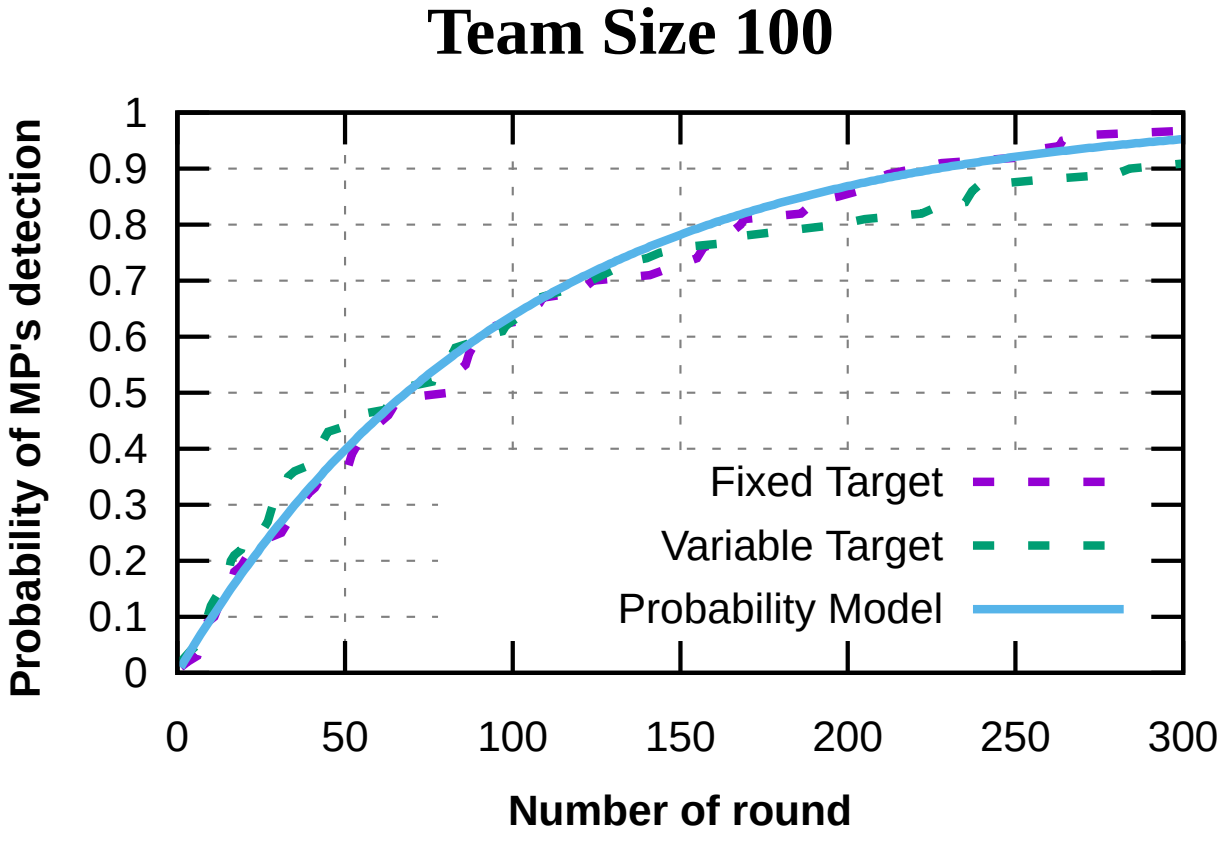
$$p = \sum_{r=1}^{N} \left(\left(\frac{Z-2}{Z-1} \right)^{(r-1)} \times \frac{1}{Z-1} \right)$$



EXPERIMENTS

Team size: 10 to 100 | **Samples:** 100 | **Period:** 1 | **Cases:** Fixed and Variable attacks.

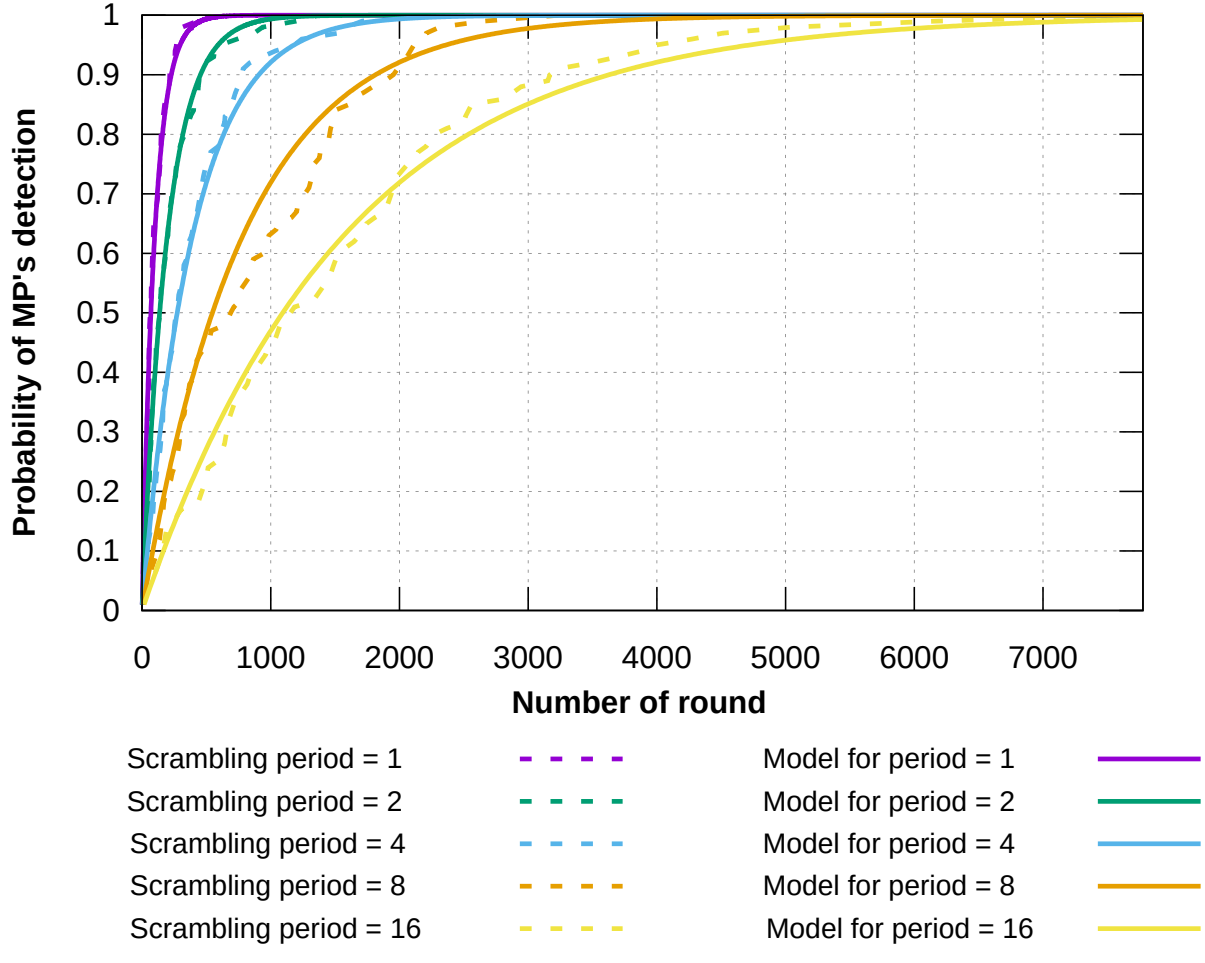
An open-source implementation is available on GitHub



EXPERIMENTS

Modifying the scrambling period

Team Size 100



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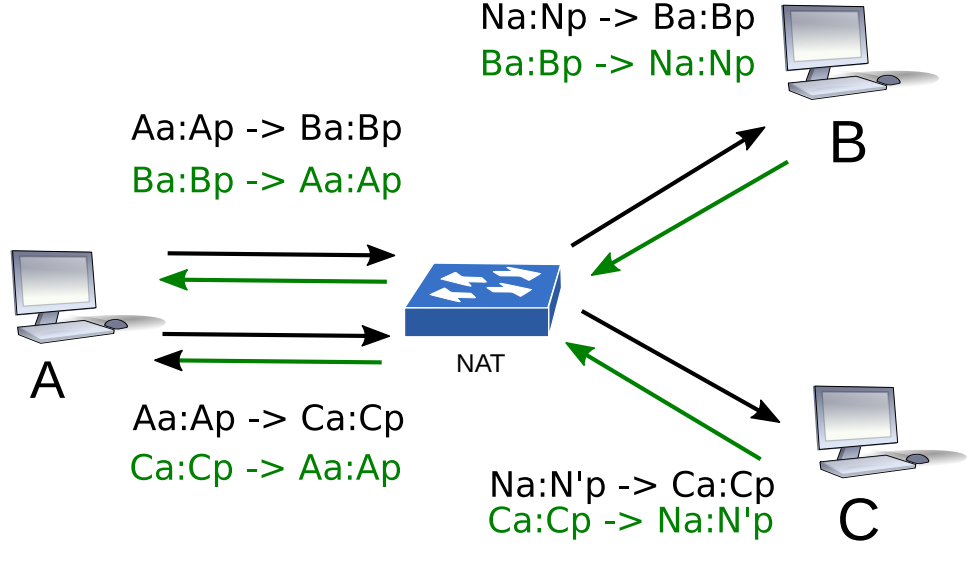
NAT TRAVERSAL

NAT

It is a method of remapping one IP address space into another by modifying network address information



SYMMETRIC NAT

Each request from the same internal endpoint to a destination endpoint is mapped to a unique external endpoint; if the destination change, a different mapping is used.

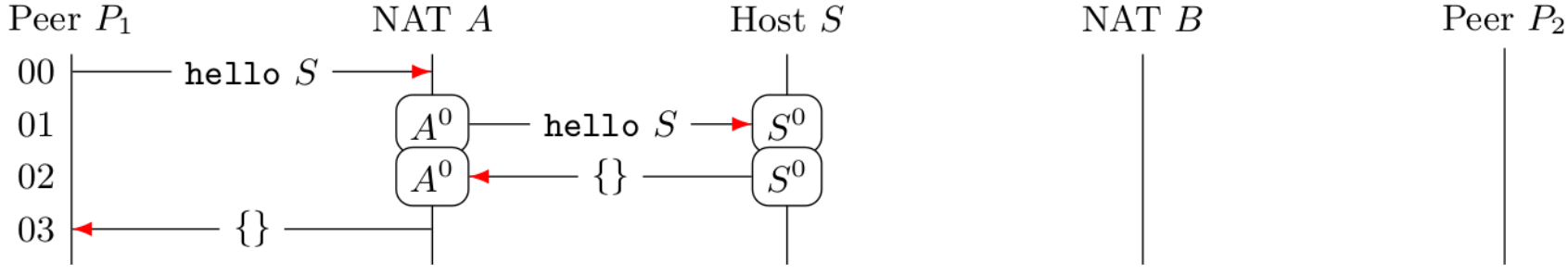
NAT TRAVERSAL

PEERS COMMUNICATION ISSUES

Peer P_1 NAT A Host S NAT B Peer P_2

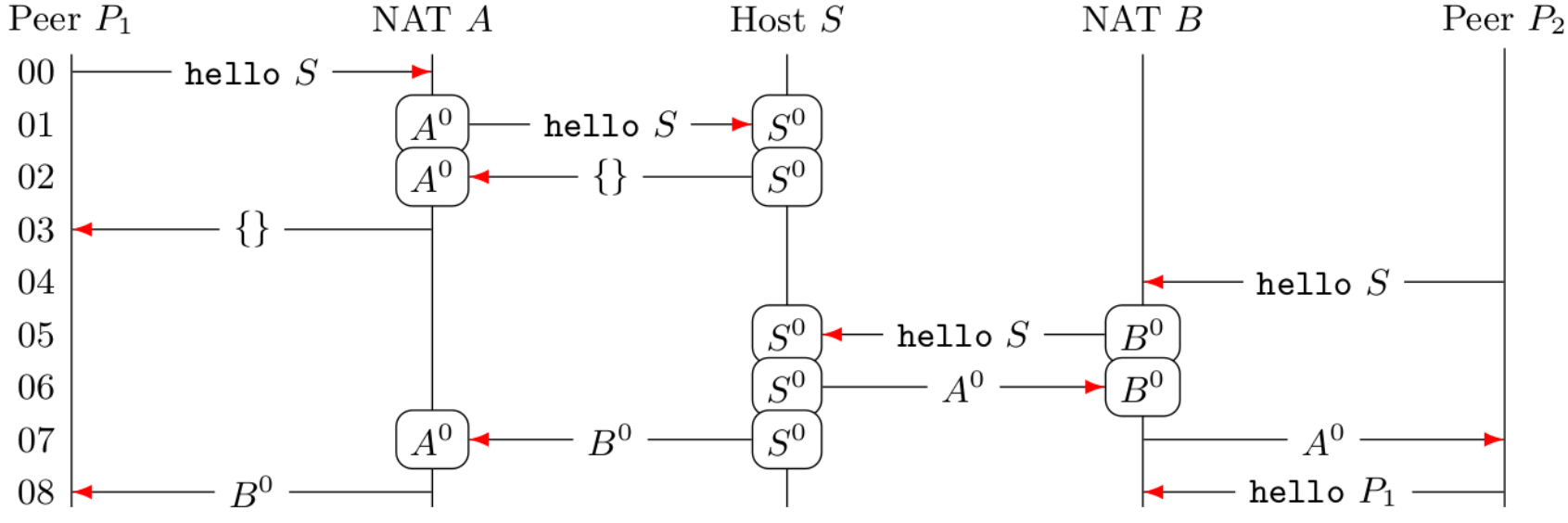
NAT TRAVERSAL

PEERS COMMUNICATION ISSUES



NAT TRAVERSAL

PEERS COMMUNICATION ISSUES



NAT TRAVERSAL

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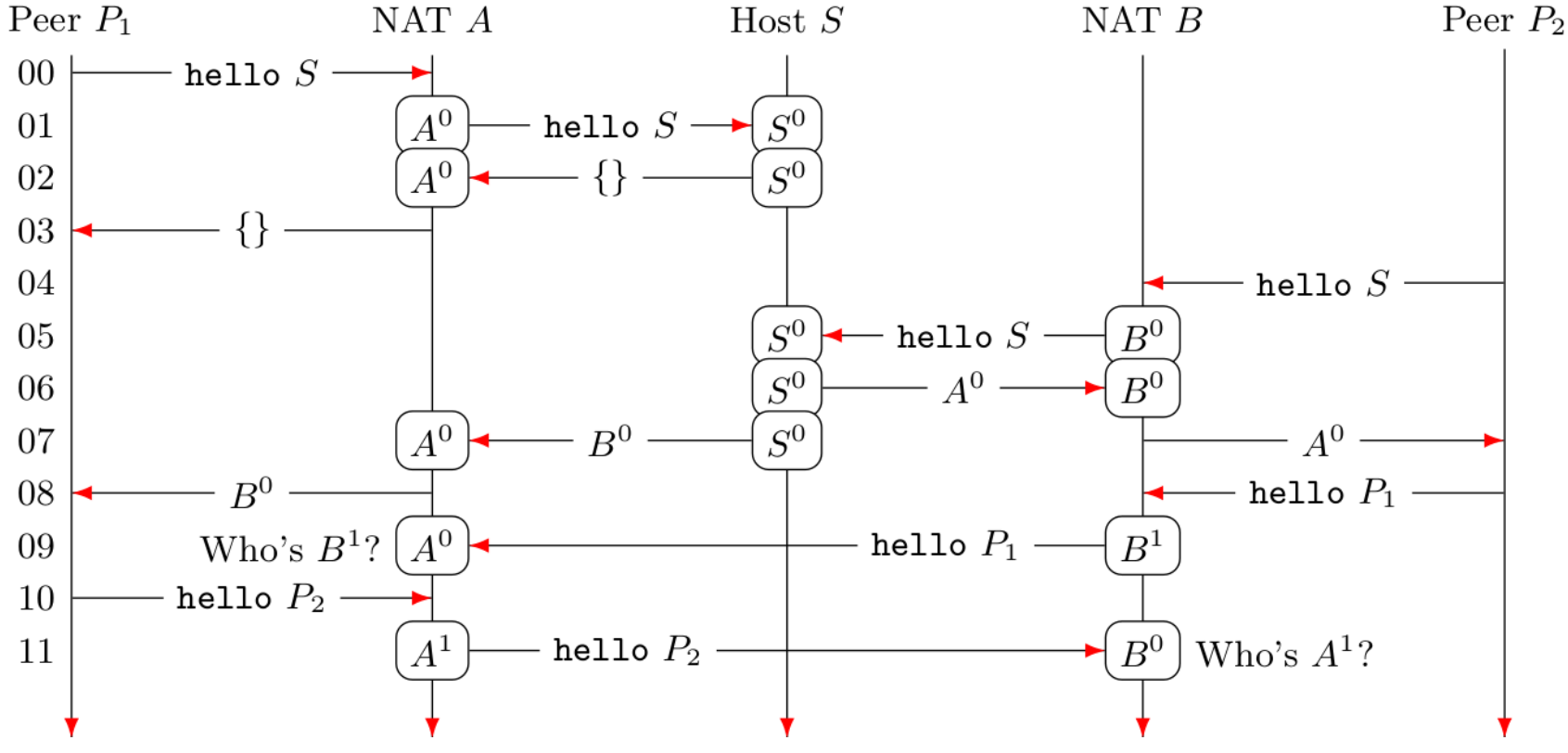

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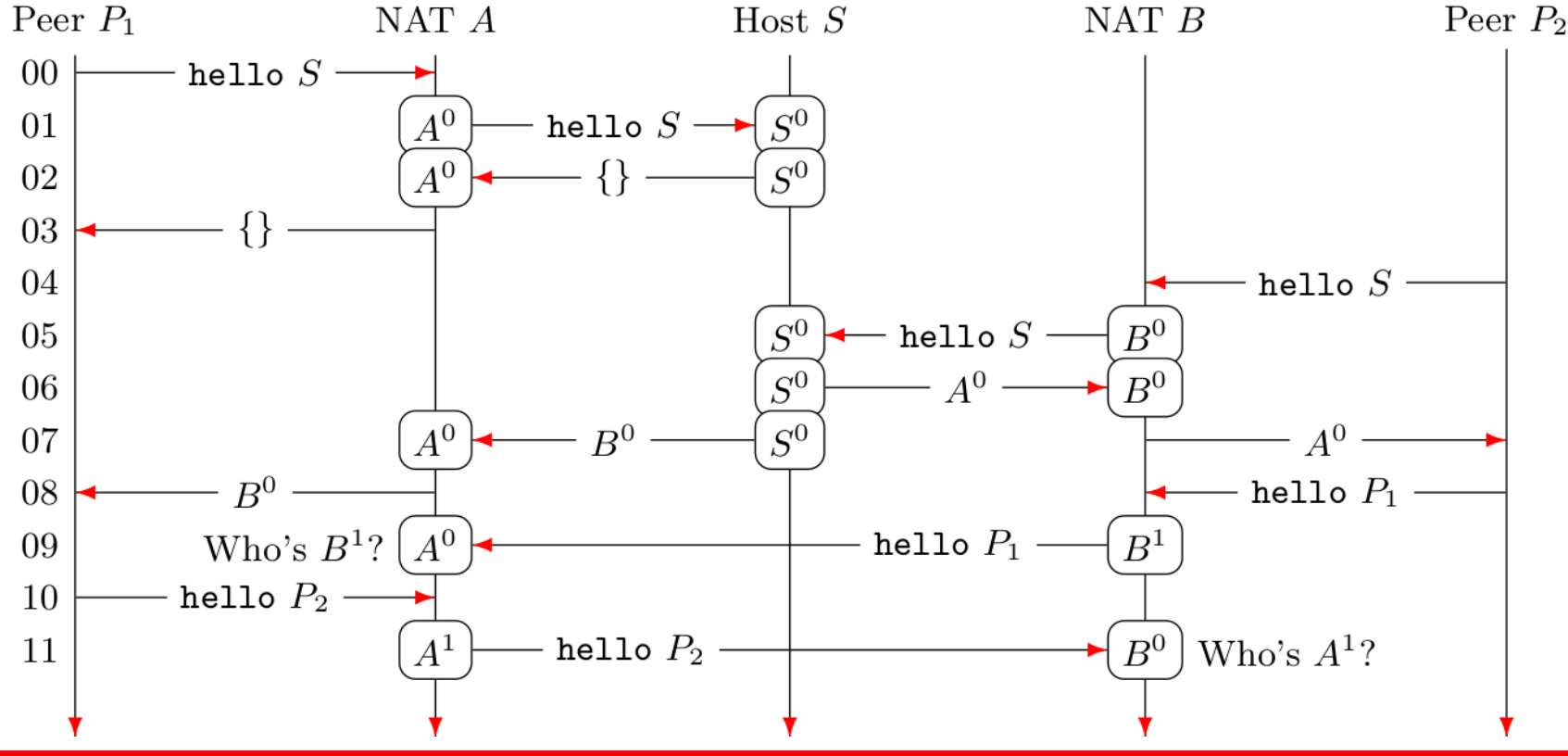

NAT device A does not have a translation entry for endpoint B_1, and NAT device B does not have a translation entry for endpoint A_1

COLLABORATIVE PORT PREDICTION

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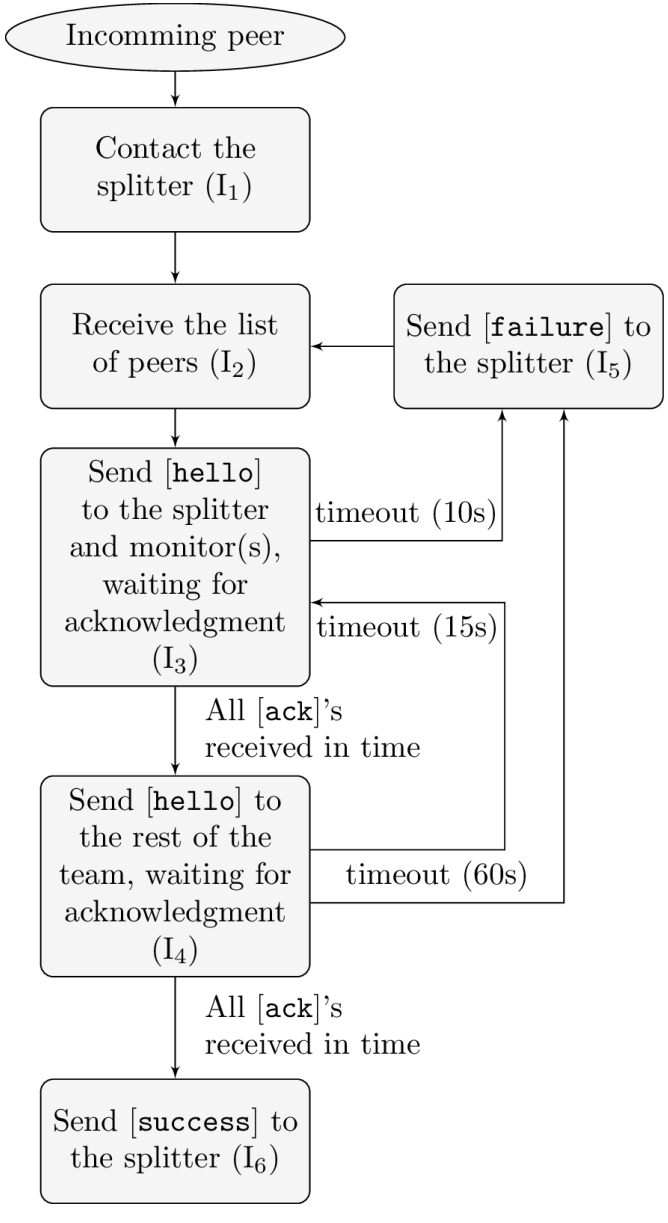

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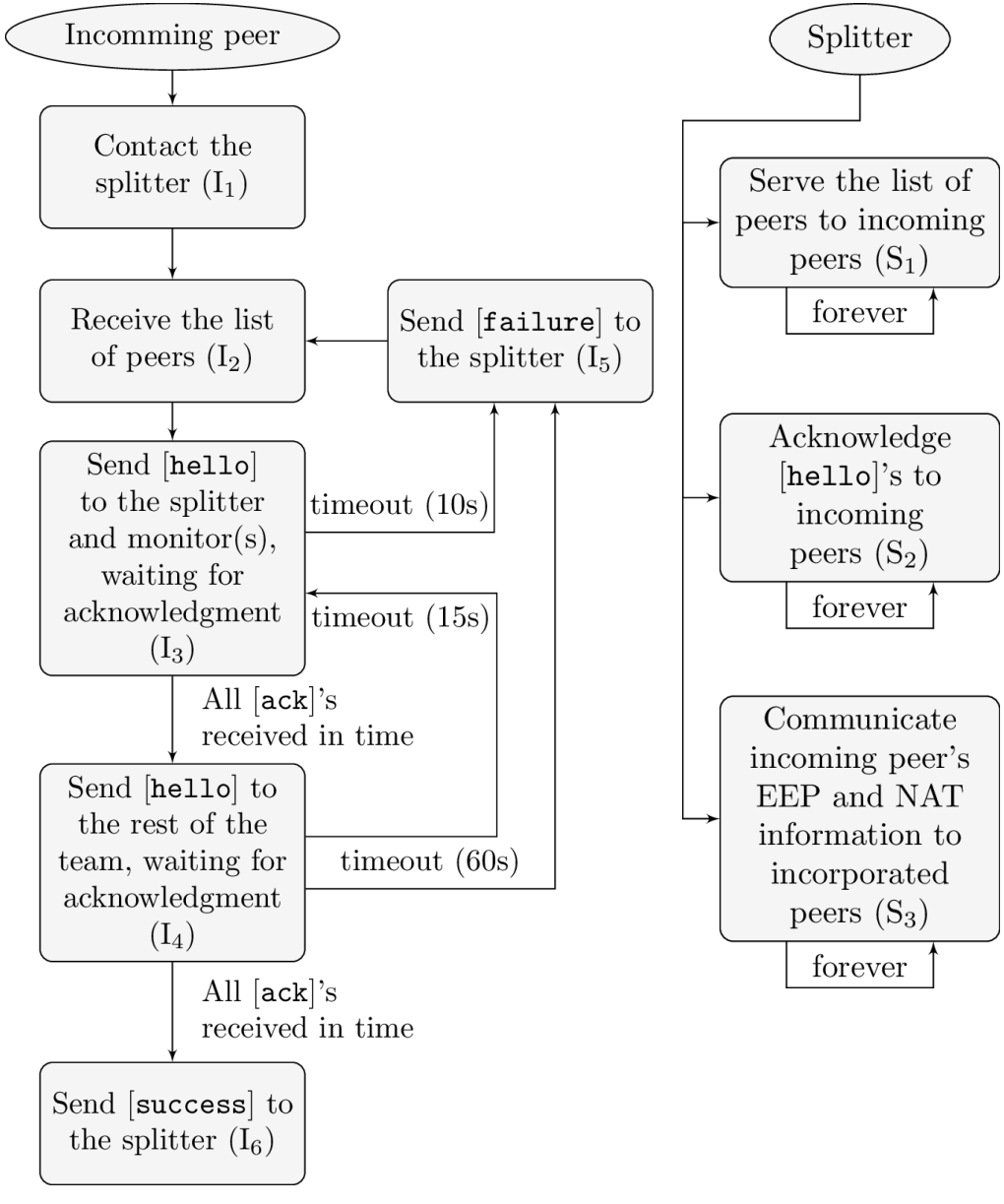
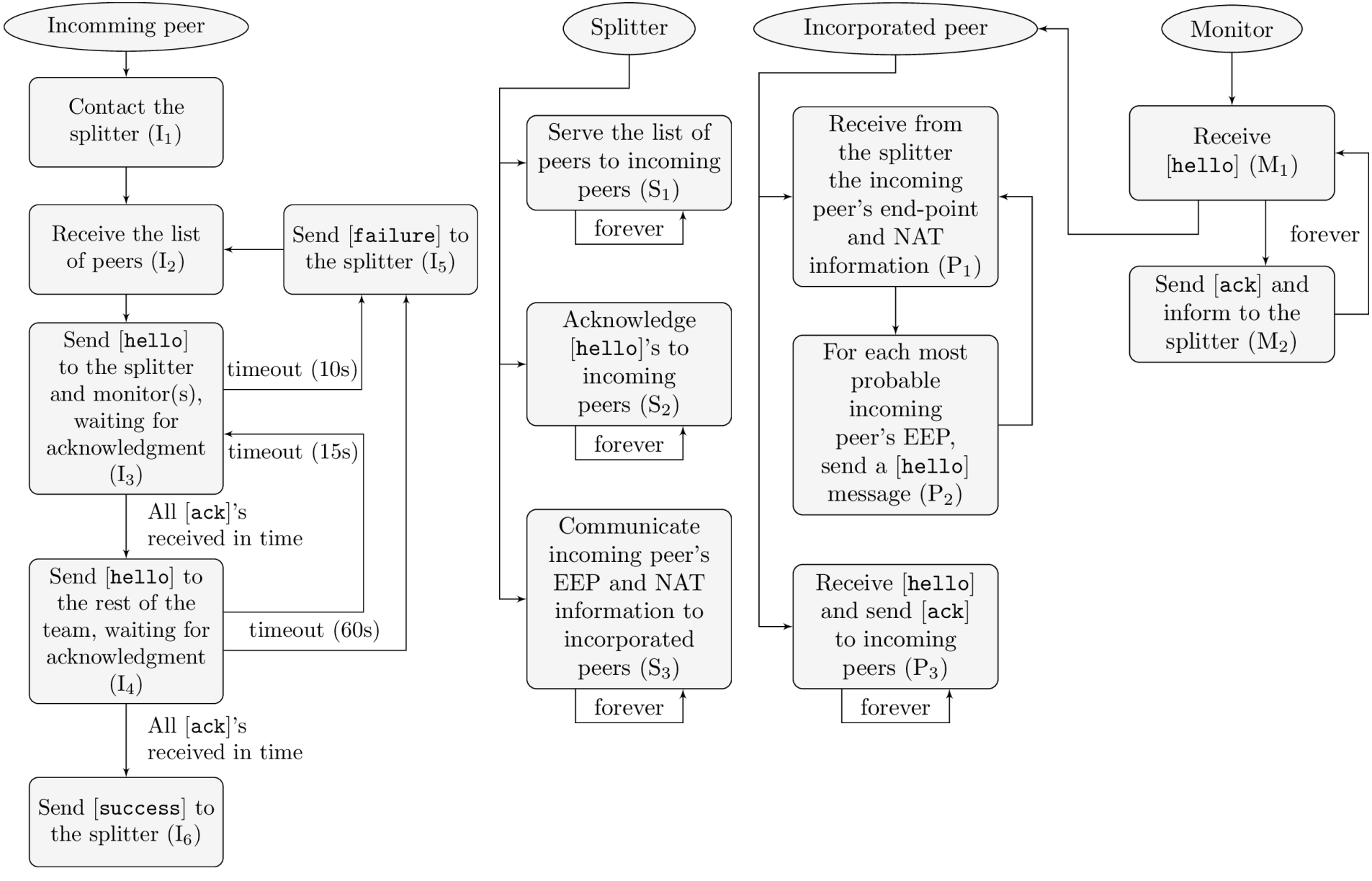
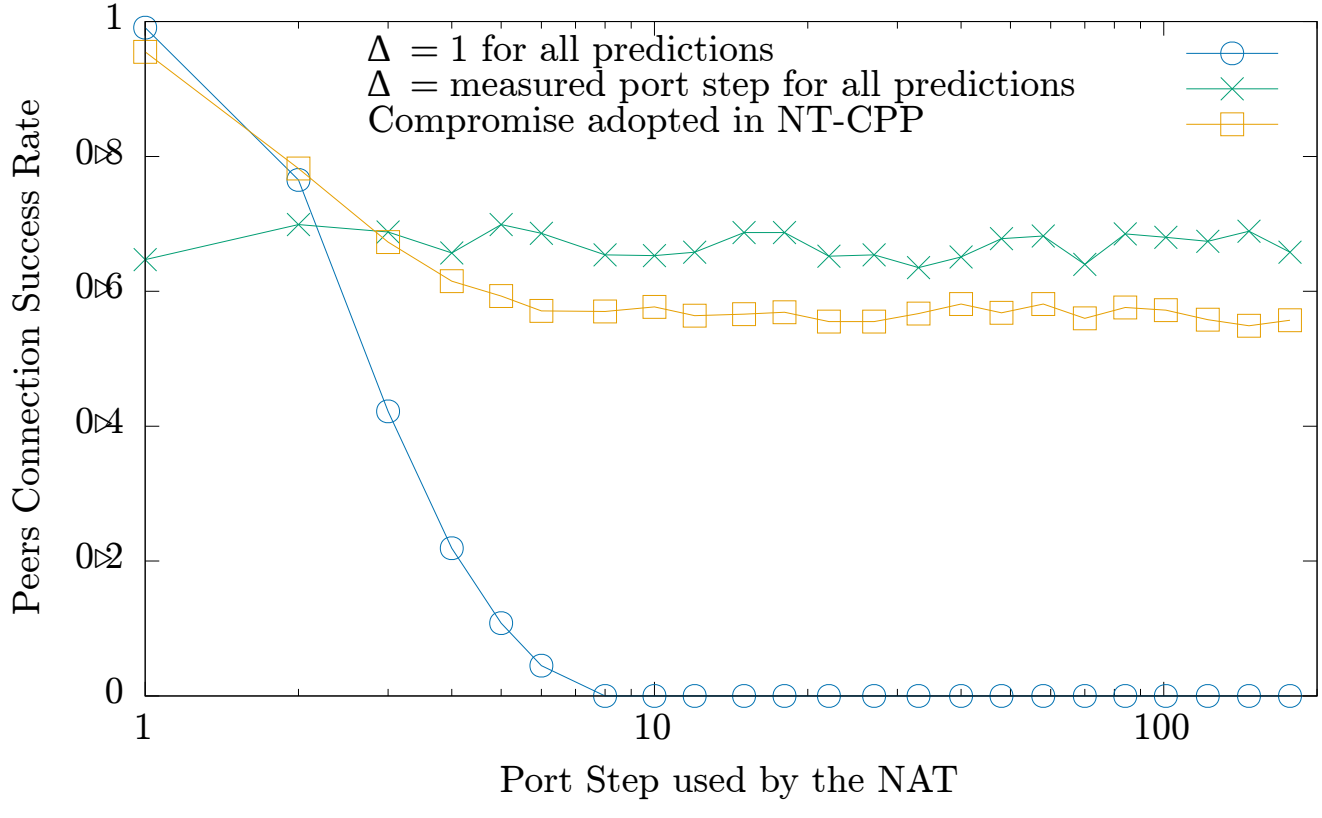


COLLABORATIVE PORT PREDICTION



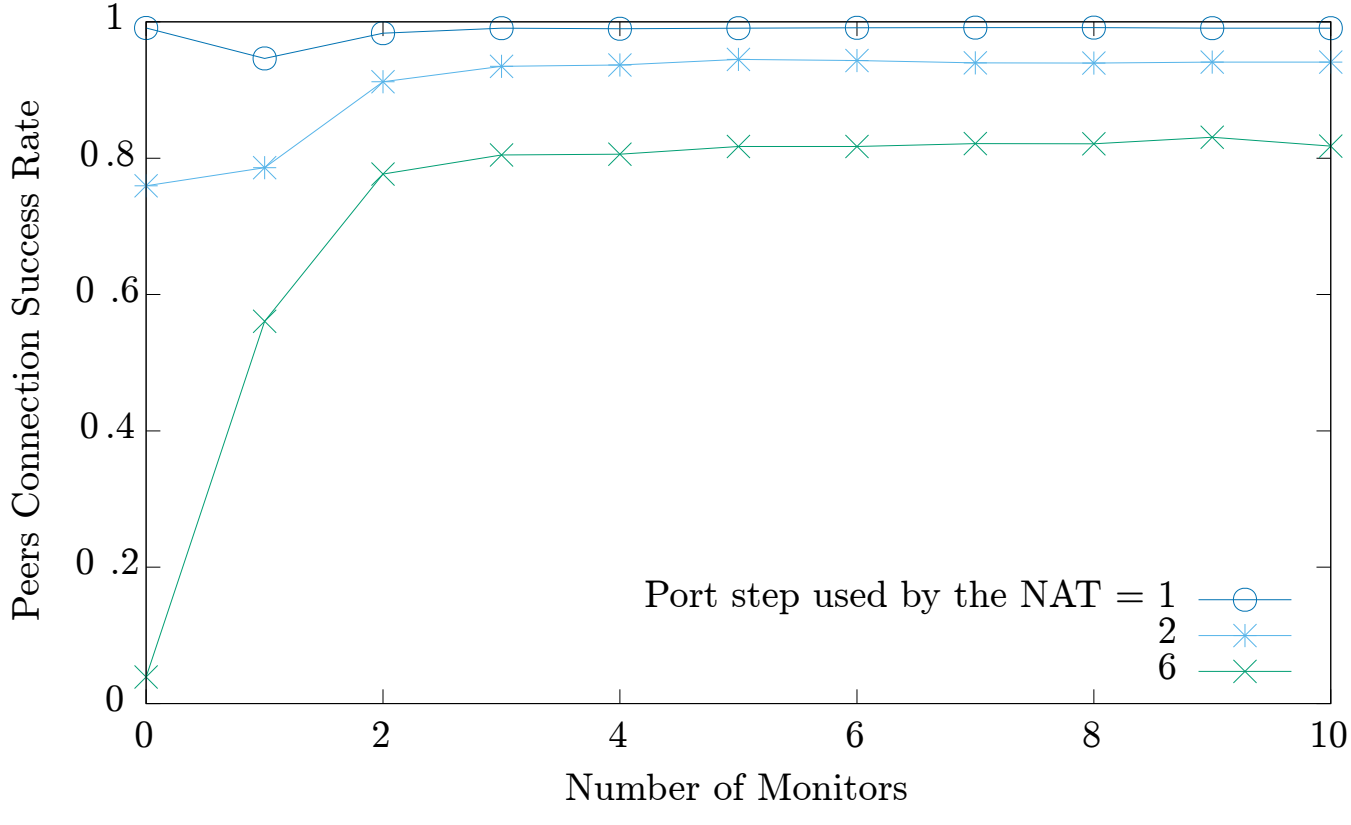
EXPERIMENTS

Port step: [1 to 200] | **Monitors:** 1 | Port predictions $n = 20$



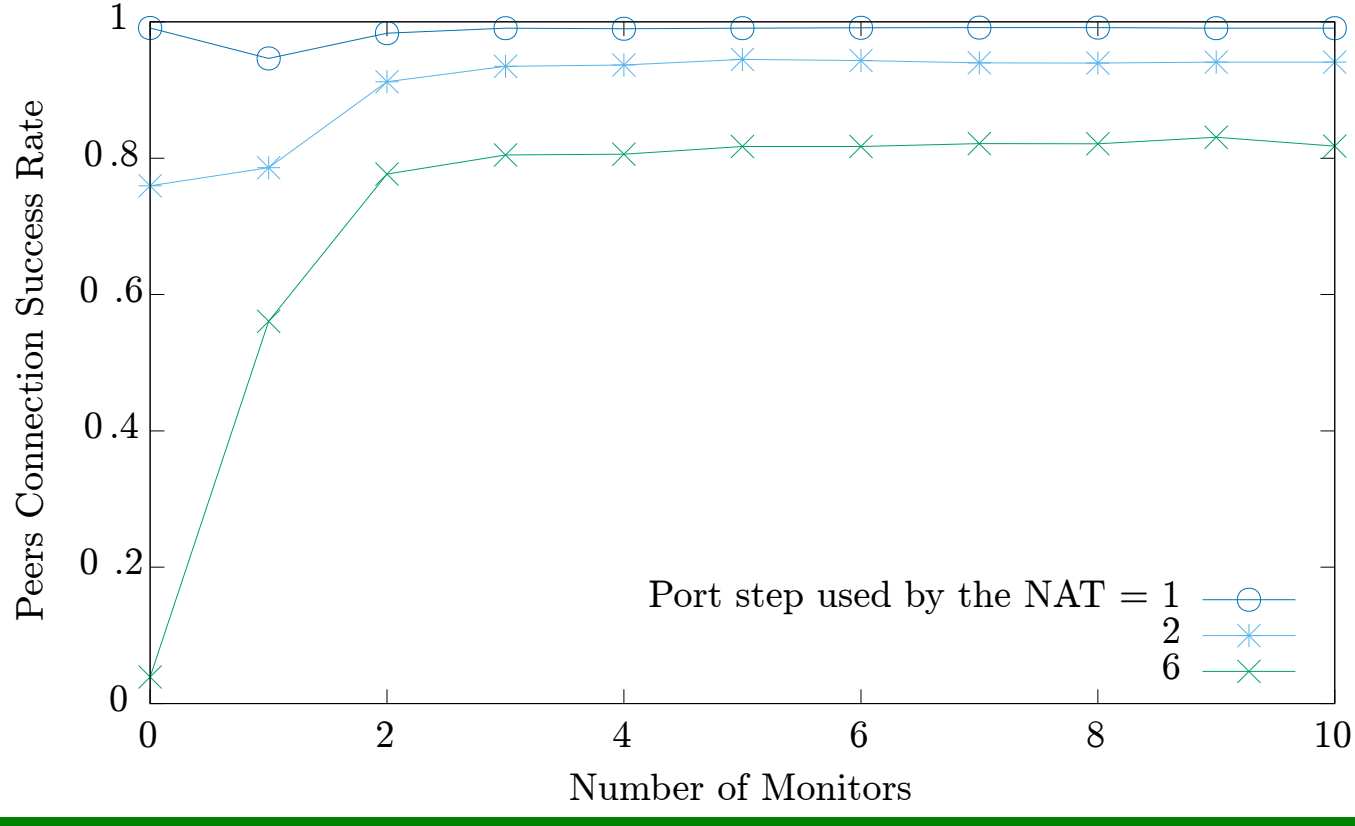
EXPERIMENTS

N : [1 to 10] | **Port step:** [1 to 6] | Port predictions $n = 20$



EXPERIMENTS

N : [1 to 10] | **Port step:** [1 to 6] | Port predictions $n = 20$



Only two monitor peers collaborating leads to higher traversal success rates

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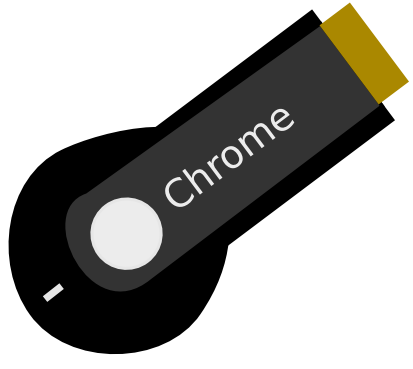
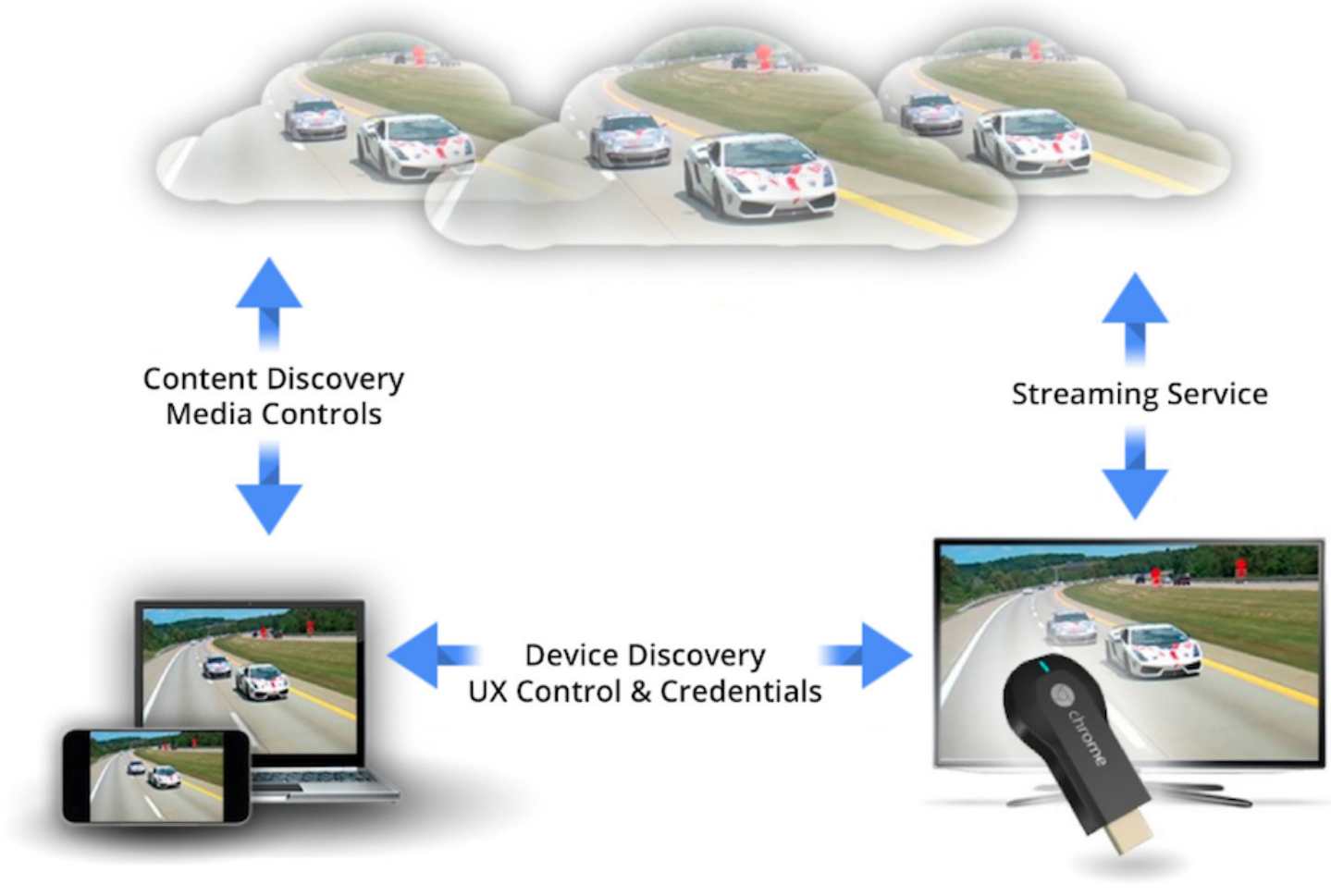
GOOGLE CHROMECAST

Google Chromecast (GC) is a device designed as small dongle, which enable users with a mobile device or personal computer to play Internet-streamed audio-visual content on a high-definition television through mobile and web apps that support the Google Cast technology.



HOW DOES IT WORK?



BUILT-IN TECHNOLOGIES

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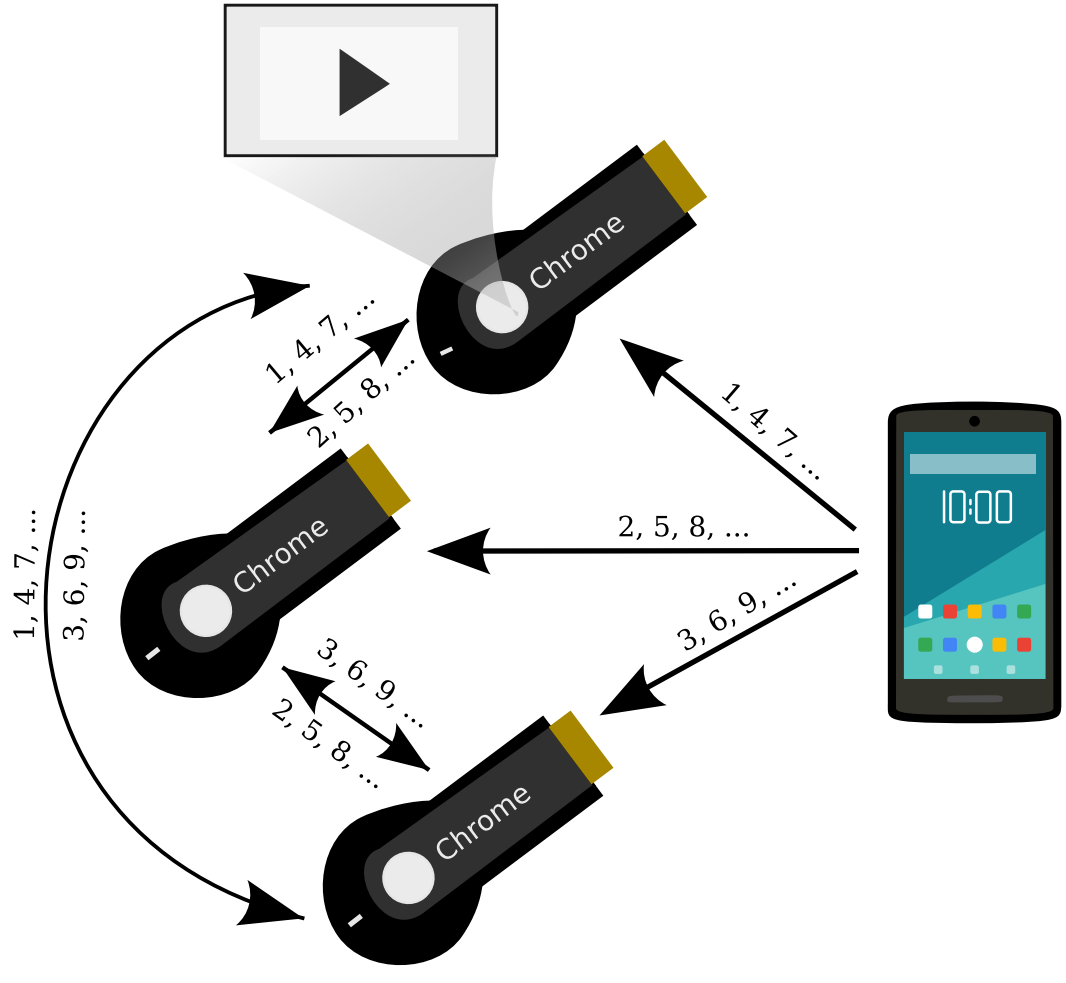
MSE

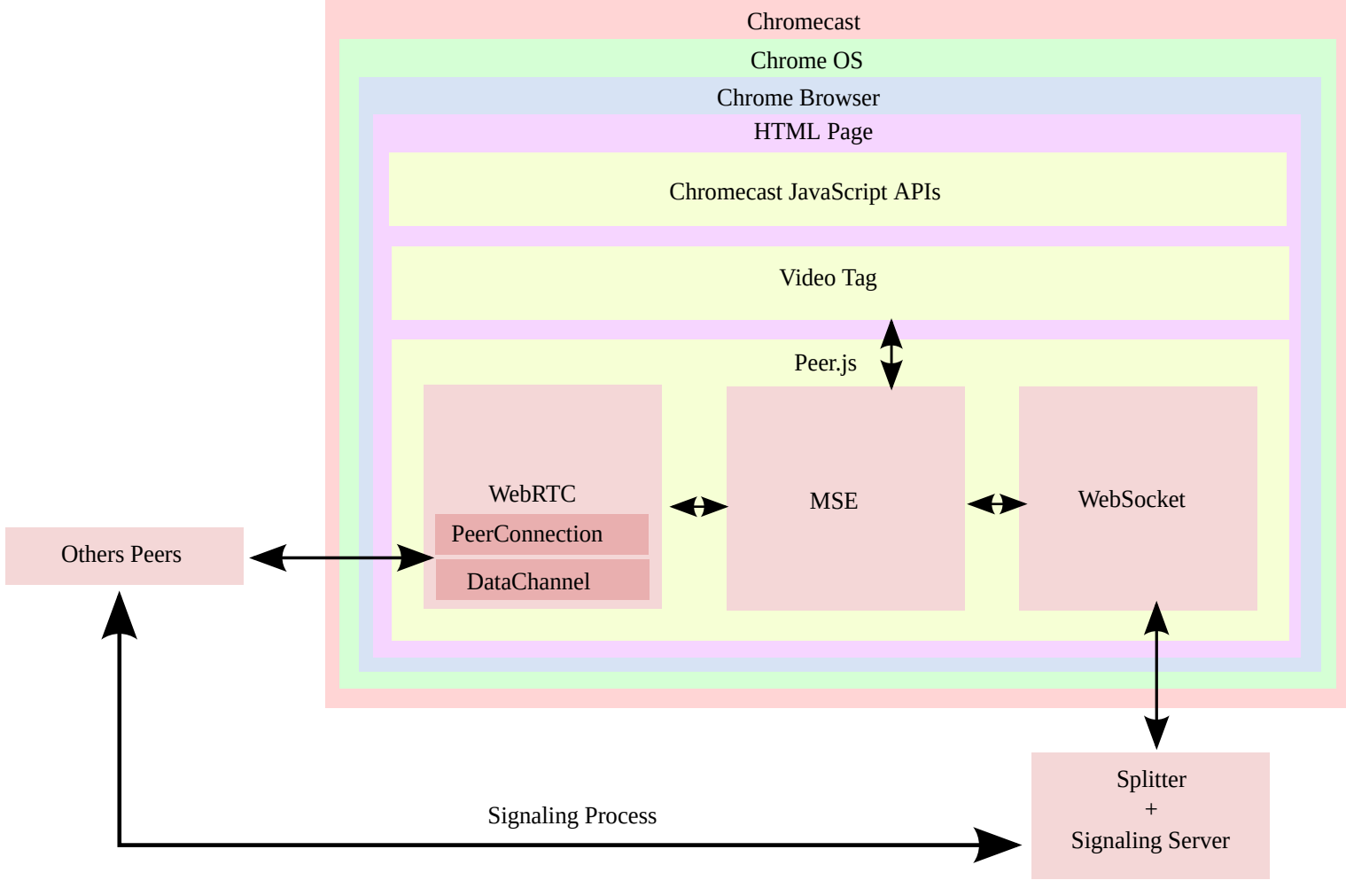
DEVELOPMENT

A P2PSP CHROMECAST TEAM



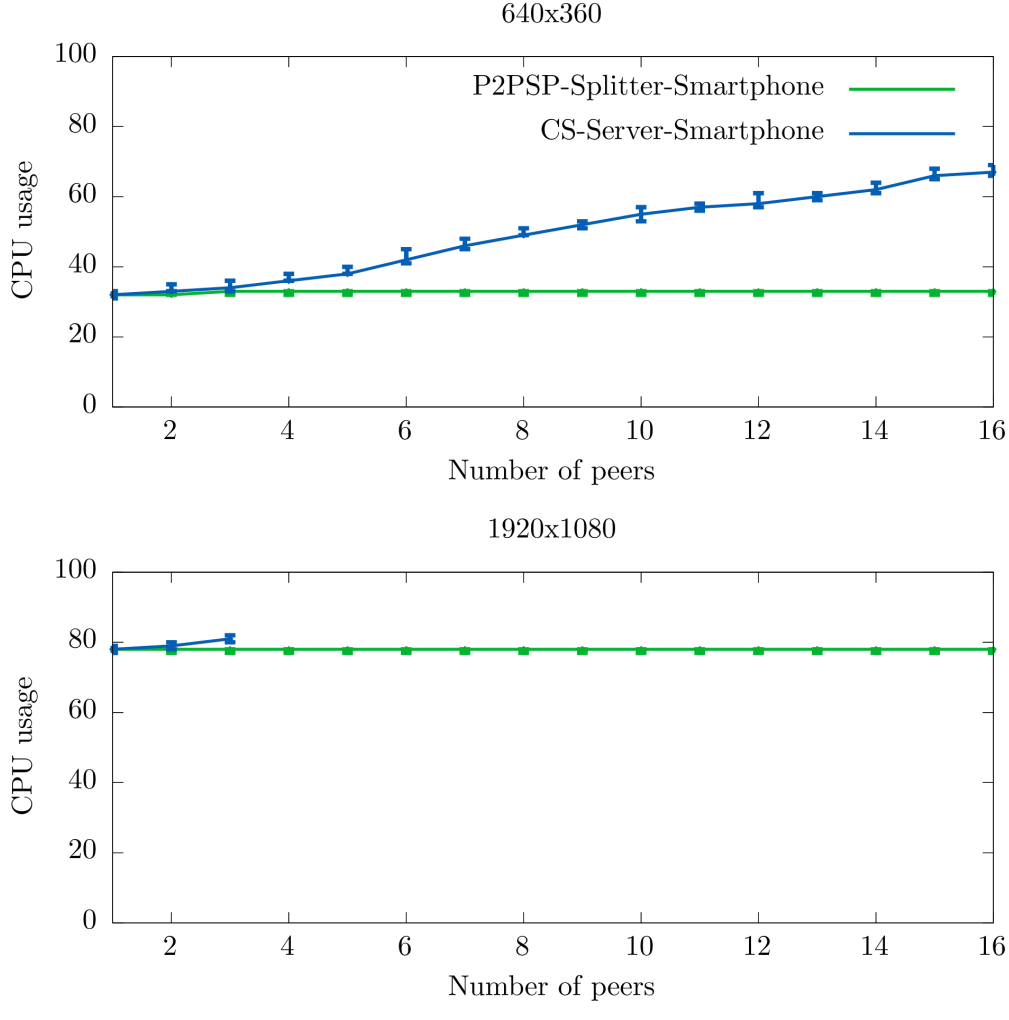
DEVELOPMENT

P2PSP CHROMECAST PEER ARCHITECTURE



EXPERIMENTS

Streaming a MP4 (H.264 + AAC) video at 24 FPS. Resolutions: 640x360 and 1920x1080



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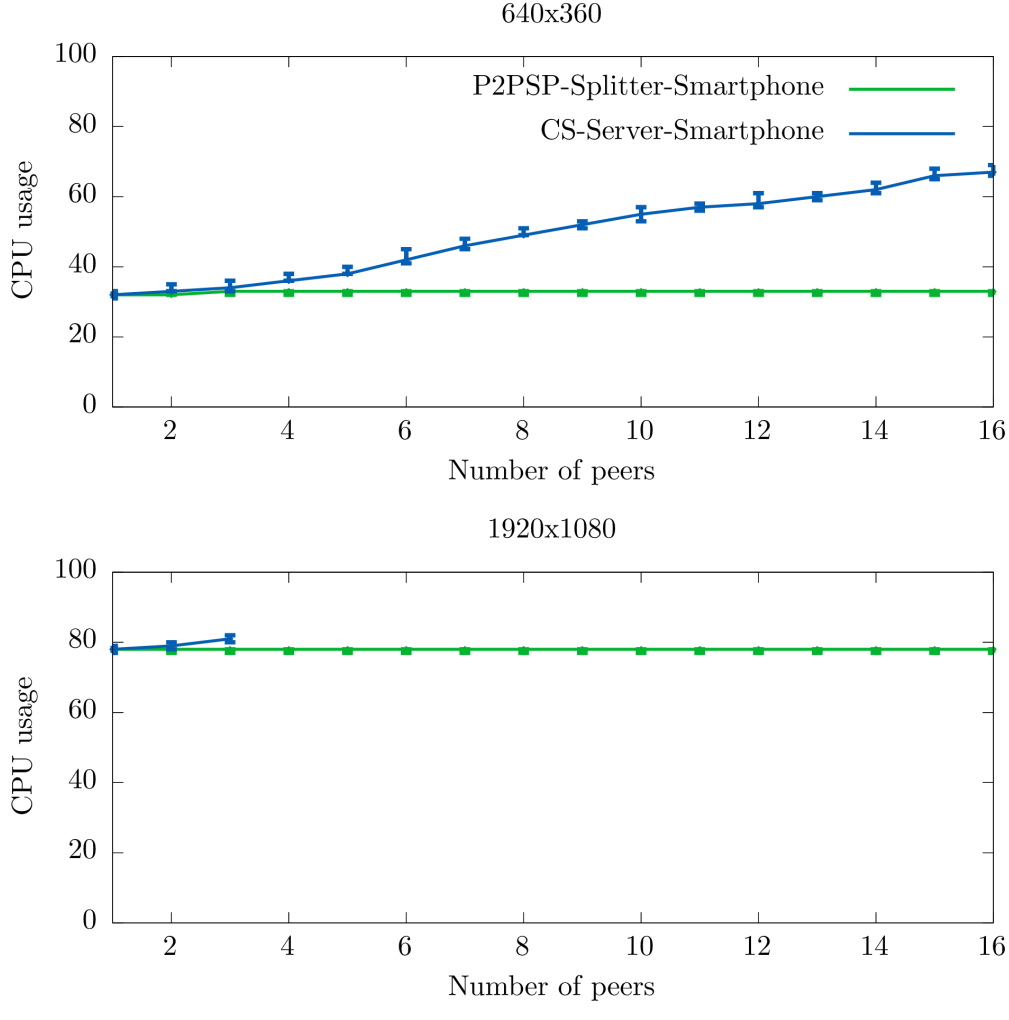

Number of peers receiving the media increases significantly in comparison with a CS model

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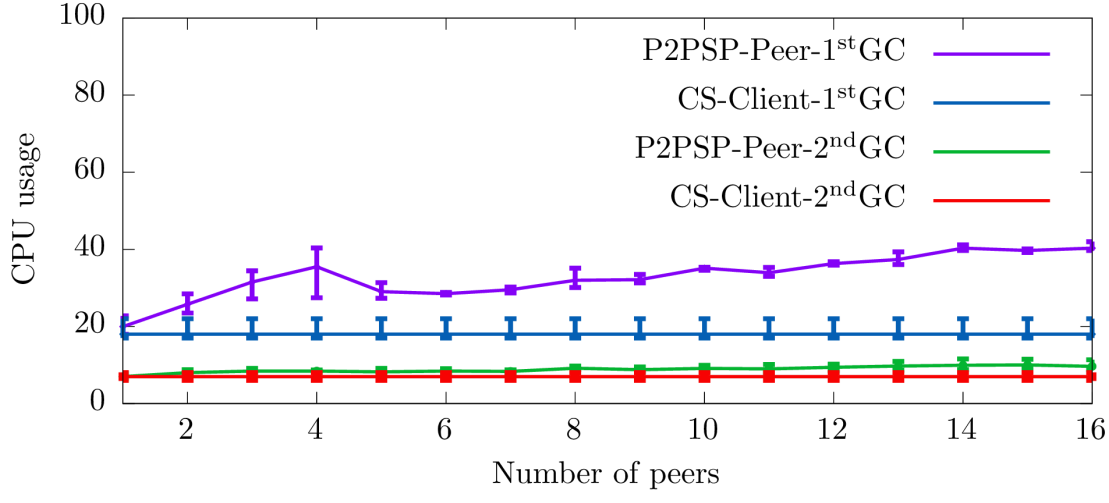
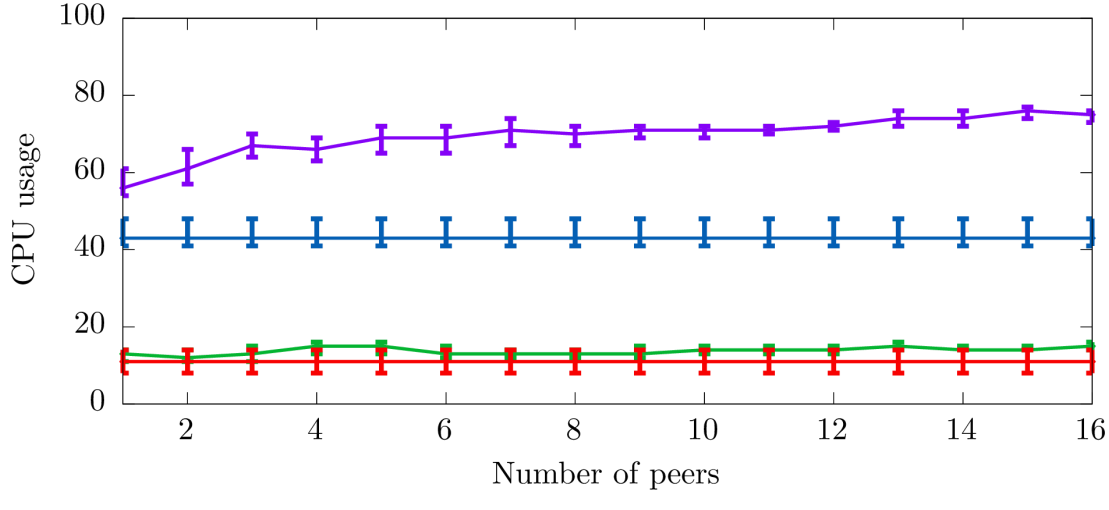
640x360



1920x1080



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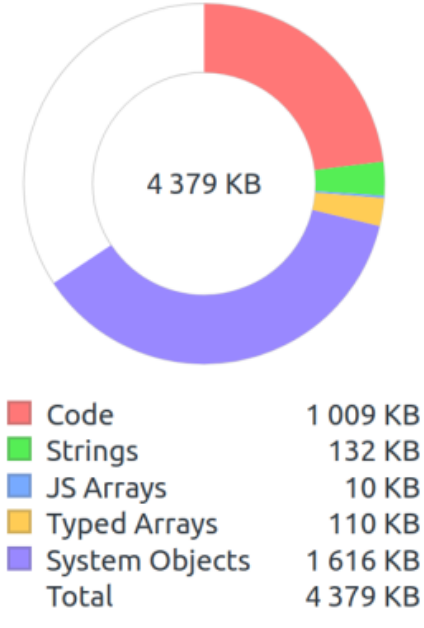
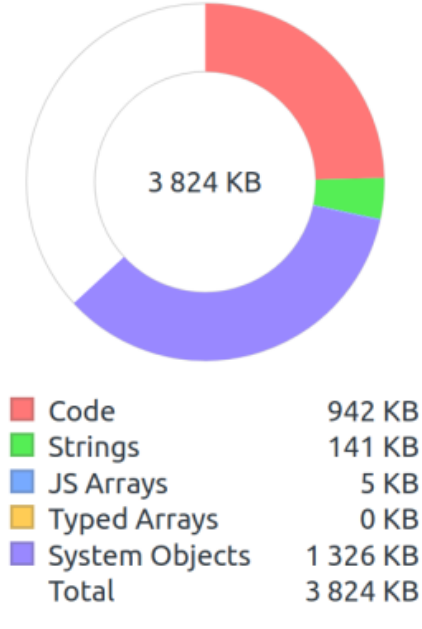


(a) P2PSP model.



(b) CS model.

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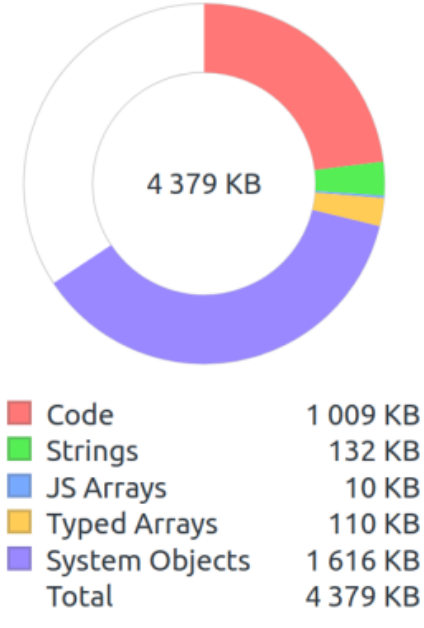

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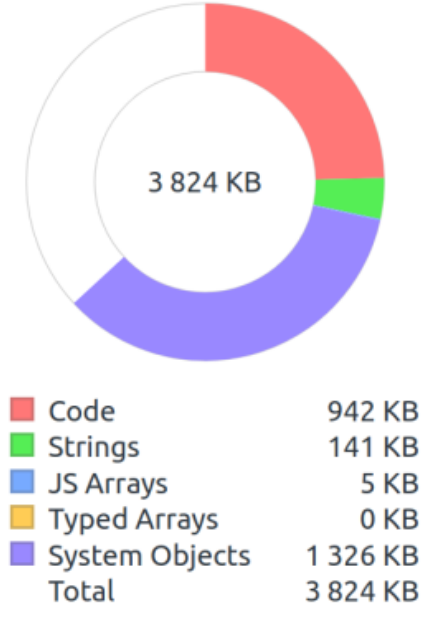

(b) CS model.

A peer can run on a GC improving the QoE of the user when connected to an HDMI TV

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3. We got a implementation of the **P2PSP running on embedded devices** aiming of avoiding third-party media servers, in order to decrease the cost of the streaming and increase the degree of privacy.

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1. Our experimental results show that **using only trusted peers** as a defense strategy is not appealing when the number of malicious peers can be large.

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2. The most severe possible **attack is fully mitigated**. For the remaining attacks, we can improve effectiveness to face them increasing the number of TPs.

3. Deterministic quick MP detection, not only in pure SDN environments but also in mixed environments where some peers are on the Internet and others are under managed networks.

PUBLICATIONS

INTERNATIONAL JOURNALS (JCR)

1. Medina-Lopez, C., Mertens, M.B., Gonzalez-Ruiz, V. & Casado, L.G. (2019). Reducing streaming cost while increasing privacy: A case study on a smartphone and chromecast using peer-to-peer technology to skip third-party servers. IEEE Consumer Electronics Magazine, DOI: 10.1109/MCE.2018.2880810. 8, 50–55 Impact factor JCR 2018: 3.273. **Journal ranking: 10/52 (Q1) in Computer science, Hardware & Architecture.** 76/265 (Q2) in Engineering, Electrical & Electronic. 29/88 (Q2) in Telecommunications.

2. (Under Review) Medina-Lopez, C., Casado, L.G, Yuansong Qiao & Gonzalez-Ruiz, V. An SDN Approach to Detect Targeted Attacks in P2P Fully Connected Overlays. International Journal of Information Security. **Impact Factor JCR 2018: 1.822. 44/107 (Q2) in Computer science, Software Engineering.** 42/104 (Q2) in Computer science, Theory and Methods. 92/155 (Q3) Computer science, Information systems.

3. (Under Review) Medina-Lopez, C., García-Ortiz J.P, Martinez, J.A, Casado, L.G, Gonzalez-Ruiz, V. NAT Traversal in P2P Networks using Collaborative Port Prediction. Peer-to-Peer Networking and Applications. **Impact Factor JCR 2018: 2.397. 70/155 (Q2) Computer science, Information systems.** 41/88 (Q2) Telecommunications.

PUBLICATIONS

INTERNATIONAL CONFERENCES WITH DOI

1. Medina-López, C., González-Ruiz, V. & Casado, L. (2017). On mitigating pollution and free-riding attacks by Shamir's Secret Sharing in fully connected P2P systems. In Wireless Communications and Mobile Computing Conference (IWCMC), 2017 13th International, 711–716, DOI: 10.1109/IWCMC.2017.7986372. IEEE.**GGS Rating: B, GGS Class: 3**.

2. Medina-López, C., Shakirov, I., Casado, L. & González-Ruiz, V. (2017). On pollution attacks in fully connected P2P networks using trusted peers. In Intelligent Systems Design and Applications, 144–153, DOI: 10.1007/978-3-319-53480-0. Springer, Cham, Porto. **CORE 2016: rank C.**

3. Medina-López, C., Casado, L. & González-Ruiz, V. (2015). Pollution Attacks Detection in the P2PSP Live Streaming System. In International Joint Conference. CISIS 2015. Advances in Intelligent Systems and Computing, 401–410, DOI: 10.1007/978-3-319-19713-5 34. Springer International Publishing. **CORE 2014: rank B.**

PUBLICATIONS

OTHER INTERNATIONAL CONFERENCES

1. Medina-López, C. (2015). Participation as a speaker. In GSoC 2015 Lightning Talks, **Google Inc., SunnyVale, CA. USA**

2. Medina-López, C., García Ortiz, J.P., Naranjo, J., Casado, L. & González-Ruiz, V. (2014). IPTV using P2PSP and HTML5+WebRTC. **In 4th W3C Web and TV Workshop**, 5, IRT, W3C, Munchen, Germany

PUBLICATIONS

NATIONAL CONFERENCES

1. Medina-López, C., González-Ruiz, V., Casado, L.G., Naranjo, J. & García-Ortiz, J.P. (2015). Ejecutando peers p2psp en google chromecast. In Actas VI Jornadas de Computación Empotrada, 123–129, Cordoba

2. Medina-López, C., Naranjo, J., García-Ortiz, J.P., Casado, L.G. & González-Ruiz, V. (2013). Execution of the P2PSP protocol in parallel environments. In G.B. y Alberto A. Del Barrio Garcia, ed., Actas XXIV Jornadas de Paralelismo, 216–221, Madrid

PUBLICATIONS

OTHER PUBLICATIONS PRODUCED DURING THE ELABORATION OF THIS THESIS

1. Andujar, A. & Medina-López, C. (2019). Exploring New Ways of eTandem and Telecollaboration Through the WebRTC Protocol: Students' Engagement and Perceptions. International Journal of Emerging Technologies in Learning (iJET), 14, 200–217

2. Medina-Lopez, C., Casado, L.G. & Gonzalez-Ruiz, V. (2015). P2PSP: un protocolo de red sencillo como herramienta para el aprendizaje basado en proyectos. Experiencias Docentes en Redes de Computadores, 1, 35–41

THANKS!

Google Summer of Code