Title: *Effect of Mixing Processes on End-to-End Latency in Mix Networks*

Author: Mahdi Rahimi, COSIC, KU Leuven

Abstract:
Mix networks enhance anonymity by routing client packets through intermediary hops, where deliberate delays are introduced for traffic mixing. While this process strengthens privacy, it also increases end-to-end latency—particularly in scenarios where messages span multiple packets. This poster explores how mixing strategies can be tuned to manage and minimize latency in mix networks, without compromising anonymity guarantees. The discussion builds on insights from recent works on latency-aware and packet-aware routing [1]–[3], offering a foundation for designing more efficient anonymous communication systems.

References.

[1]. Rahimi, Mahdi. "CLAM: client-aware routing in mix networks." In *Proceedings of the 2024 ACM Workshop on Information Hiding and Multimedia Security*, pp. 199-209. 2024.

[2]. Rahimi, Mahdi. "Larmix++: Latency-aware routing in mix networks with free routes topology." In *International Conference on Cryptology and Network Security*, pp. 187-211. Singapore: Springer Nature Singapore, 2024.

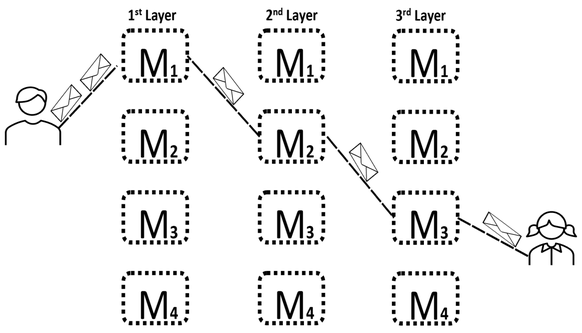
[3]. Rahimi, Mahdi. "PARSAN-Mix: Packet-Aware Routing and Shuffling with Additional Noise for Latency Optimization in Mix Networks." In *International Conference on Applied Cryptography and Network Security*, pp. 159-188. Cham: Springer Nature Switzerland, 2025.

Mahdi Rahimi
COSIC, KU Leuven, Leuven, Belgium
CANS 2024, Cambridge, UK
25 September 2024

Effect of mixing process on end-to-end latency in mix networks

Background and Motivation

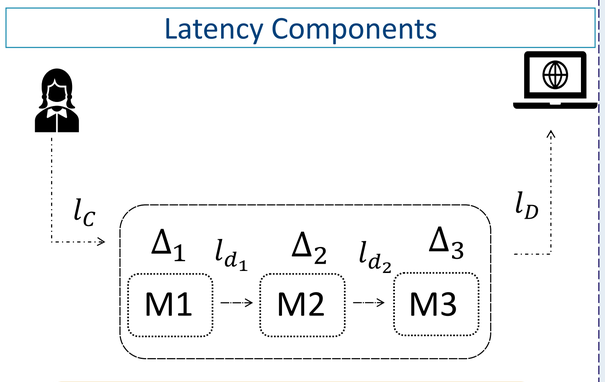
Mix Networks



High degree of anonymity
Decentralized (like NYM)
Scalable

High end-to-end latency

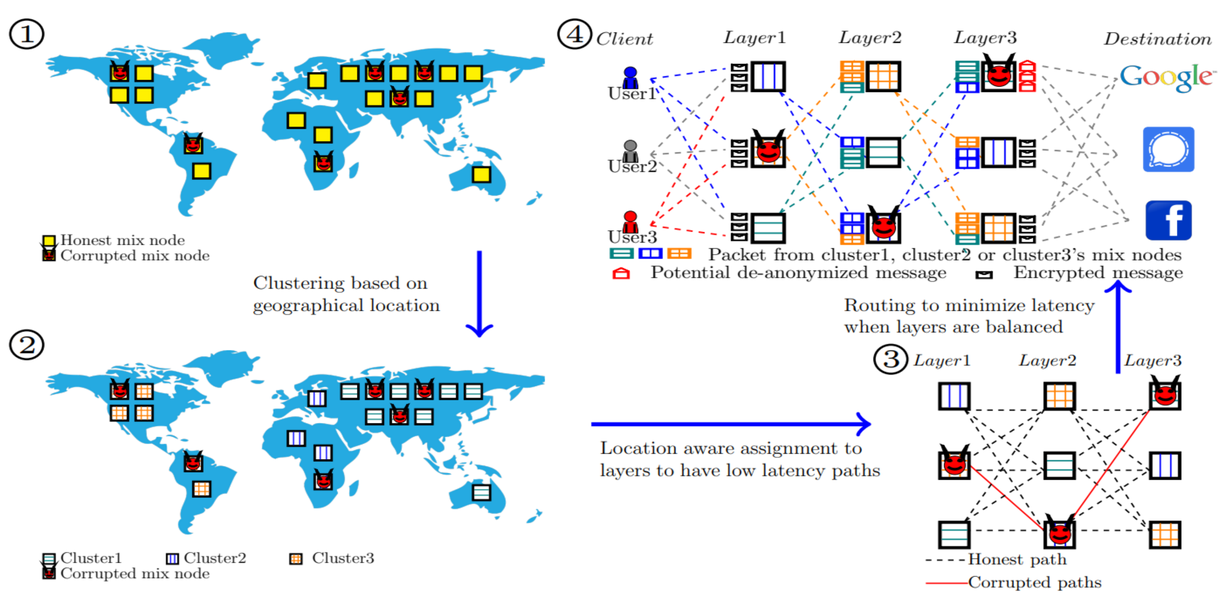
Latency Components



Propagation delay: $l_C + l_{d_1} + l_{d_2} + l_D$.
Mixing delay: $\Delta_1 + \Delta_2 + \Delta_3$.
Processing delay: negligible.

Propagation delay + Mixing delay → End-to-end latency

Propagation Delay Management (LARMix, NDSS 2024)

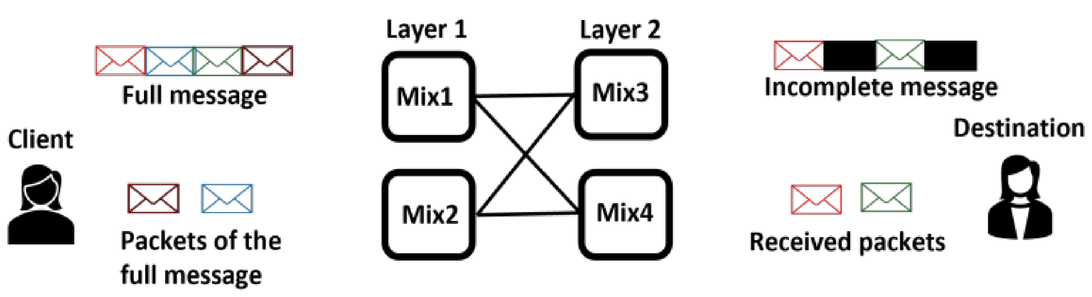


LARMix proposes node assignment and selection to ensure link delays within mixnet ($l_{d_1} + l_{d_2}$) are not very high.

Mixing Process Effects

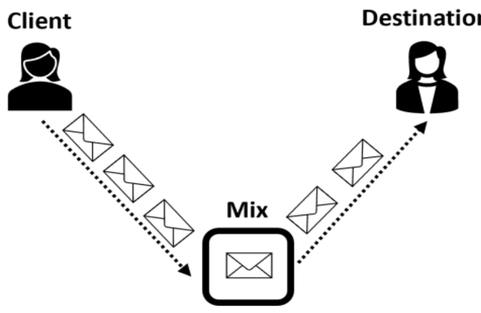
Propagation delay:
Manageable by bypassing high latency links (LARMix 2024).

Mixing process:
Its effect is not clear. It may prolong packets with unexpected delays.



The destination should receive all packets to be able to discover the message.

Single Mix Scenario



λ: paramter in EXP(λ)
n: number of packets
$H_n = \sum_{k=1}^{n} \frac{1}{k}$

Average of latency

$$\frac{H_n}{\lambda}$$

α percentile of latency

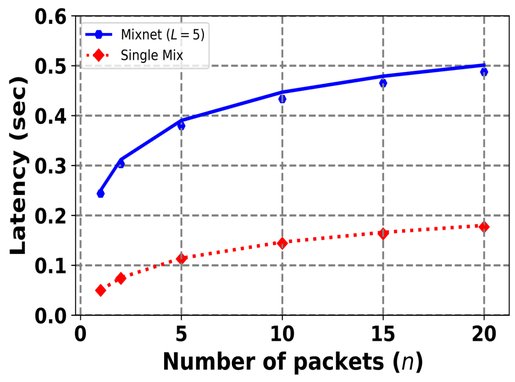
$$t_\alpha = \frac{\log\left(\frac{1}{1-\alpha^{\frac{1}{n}}}\right)}{\lambda}.$$

The higher the $\frac{1}{\lambda}$ or n the higher the latency, this holds similarly for a network of mixnodes as well.

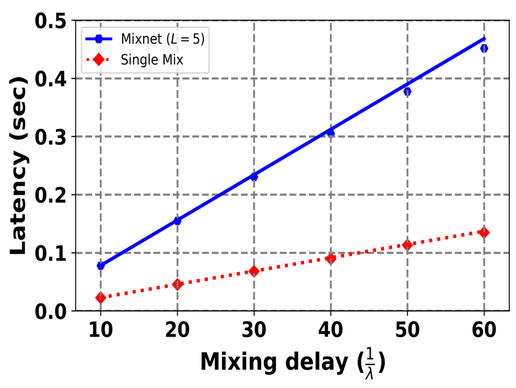
Results

Average Latency

Effect of number of packets

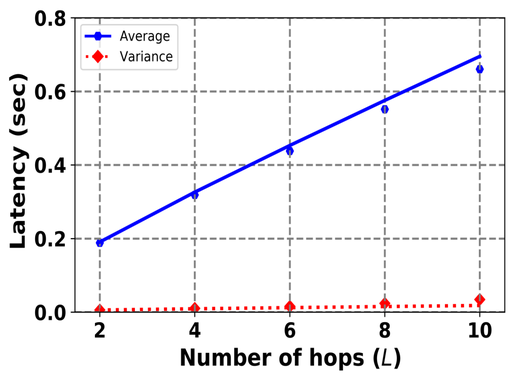


Effect of the average mixing delay

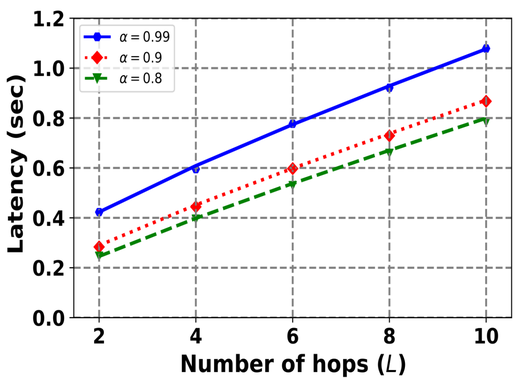


Effect of Hops Count on Latency

Average and variance

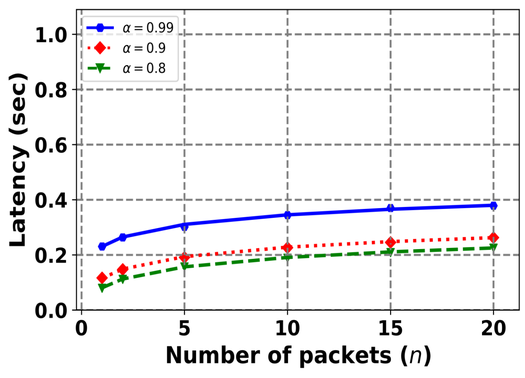


α percentile

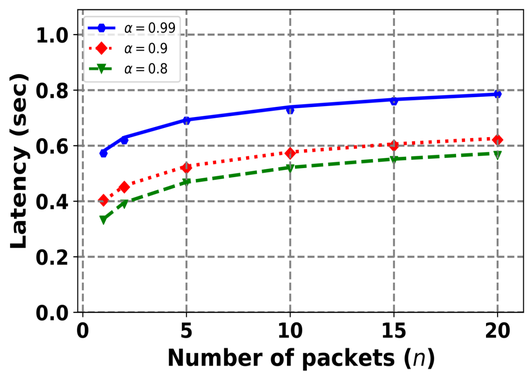


α Percentile of Latency

Single mix



Mixnet



Conclusions

High latency in mix networks can be attributed to mainly: 1) propagation delays 2) delay caused by mixing process.

Mixing process, on the other hand, may impose high latency specifically when number of packets increases.

LARMix (NDSS, 2024) provides latency reduction within mixnet link delays, resolving high propagation latency.

Mixing process will eventually be managed using methods proposed in this project.

Acknowledgments
This work is partially supported by CyberSecurity Research Flanders.

COSIC