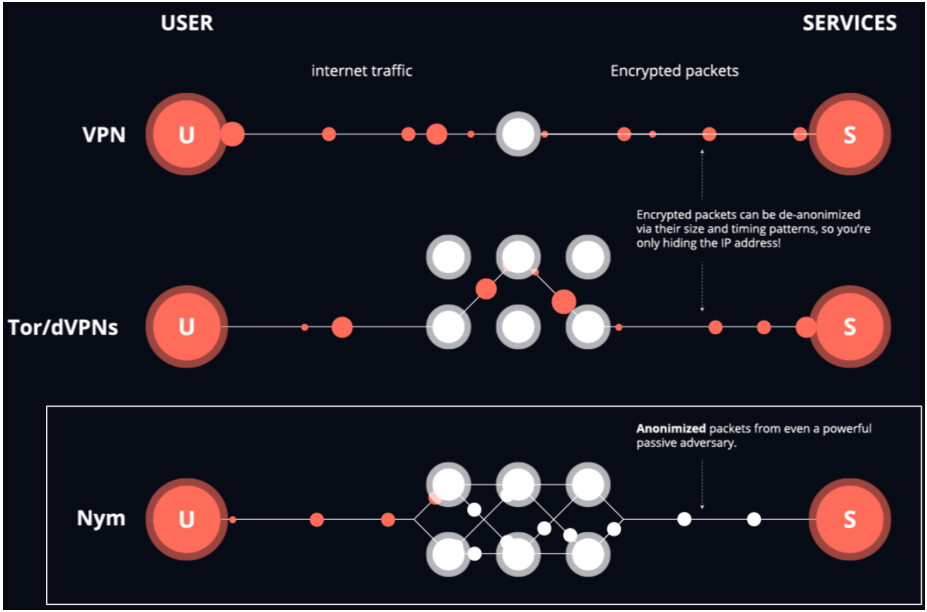
Sphinx Packets

Decentralized Header Construction

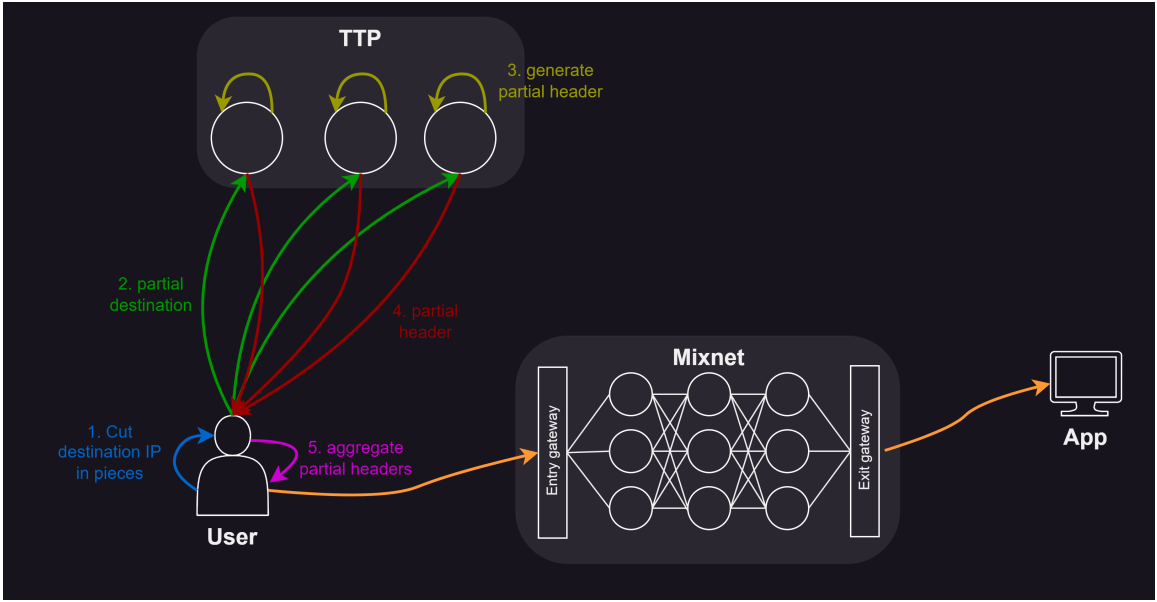
Aurélien Chassagne

February 18, 2025

Mixnet


USER
SERVICES
internet traffic
Encrypted packets
VPN
U
S
Encrypted packets can be de-anonimized via their size and timing patterns, so you're only hiding the IP address!
Tor/dVPNs
U
S
Anonimized packets from even a powerful passive adversary.
Nym
U
S

Schema overview



Desired properties

- Generic properties
  - **Correctness**: schema works without adversary
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  - **Efficiency**: Easy and fast to compute (e.g. XOR, hash, exponentiation,...)

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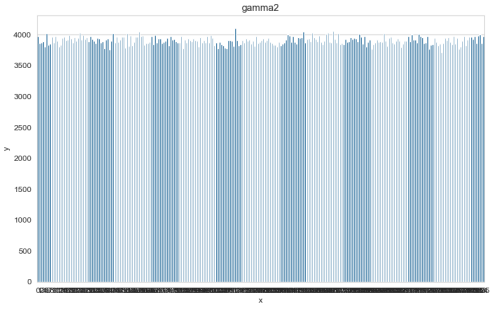
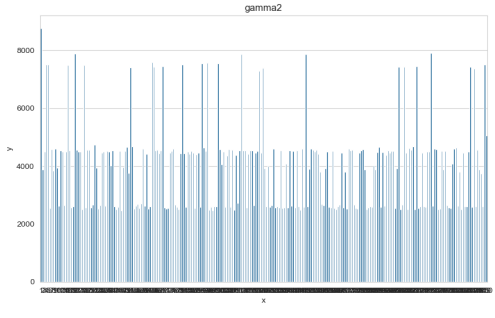
  - **Forward / reply Undistinguishibility**: Cannot distinguish forward from reply packet
  - **Replay attack resistant:**: Cannot reused previous packet
- Depends on the header
  - **Integrity**: Maximum size path
  - **Wrap-resistance**: Unable to increase the intial path
  - **Unlinkability**: Cannot link incoming and outgoing packet from a mixnode

Unlinkability compromised

Original schema

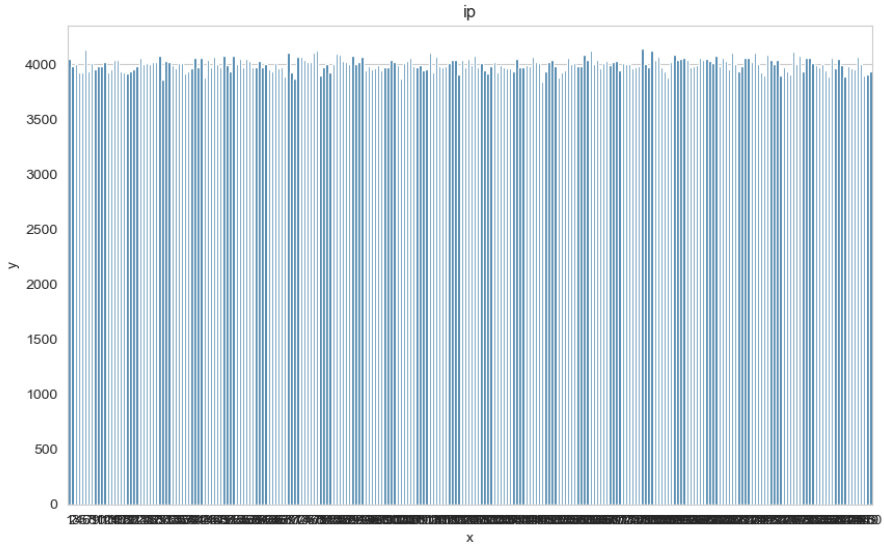


My schema



Unlinkability compromised

n_1	γ_1	n_2	γ_2	n_3	γ_3	IP



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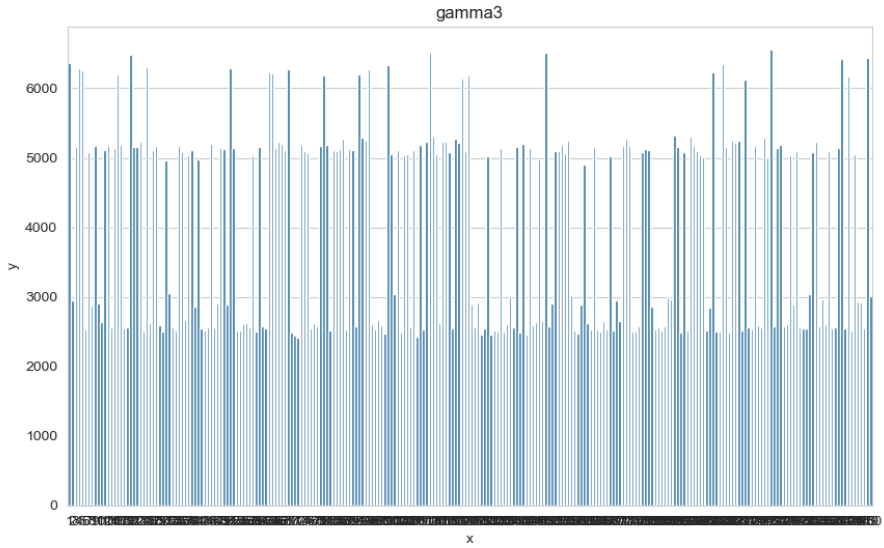

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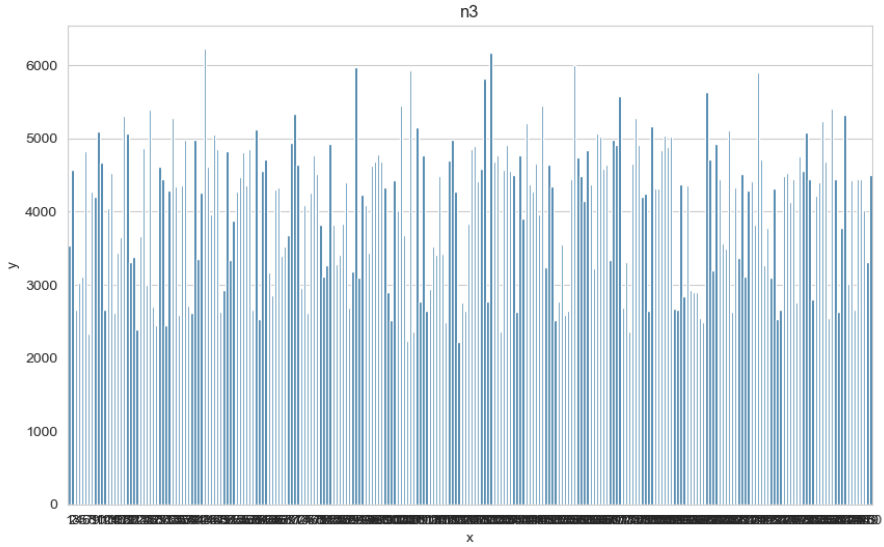

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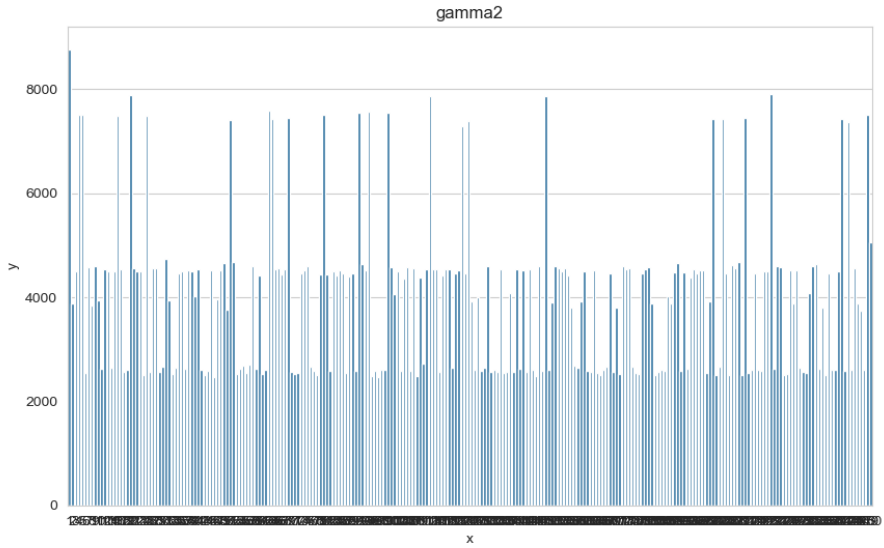

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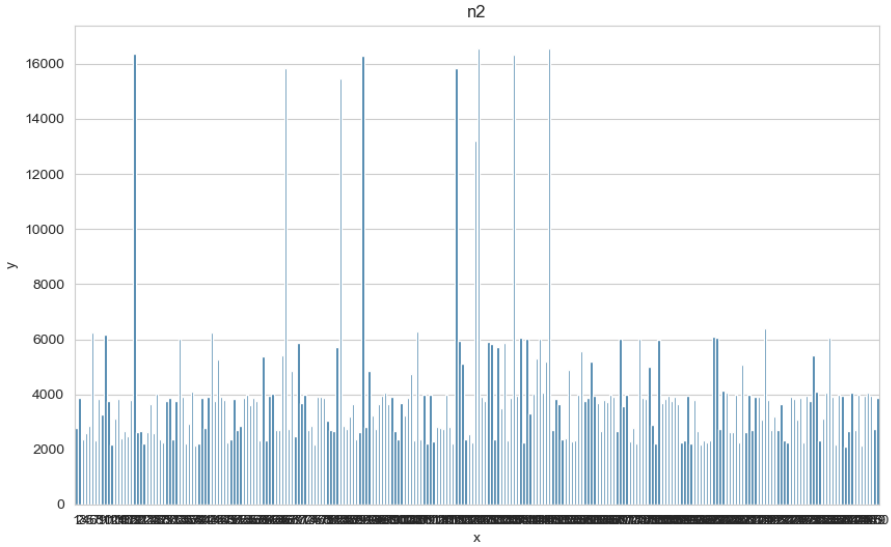

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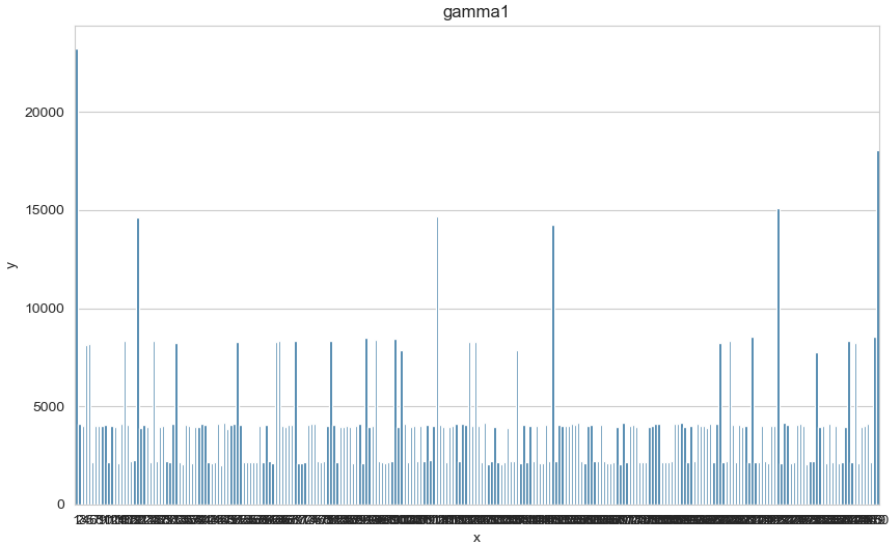

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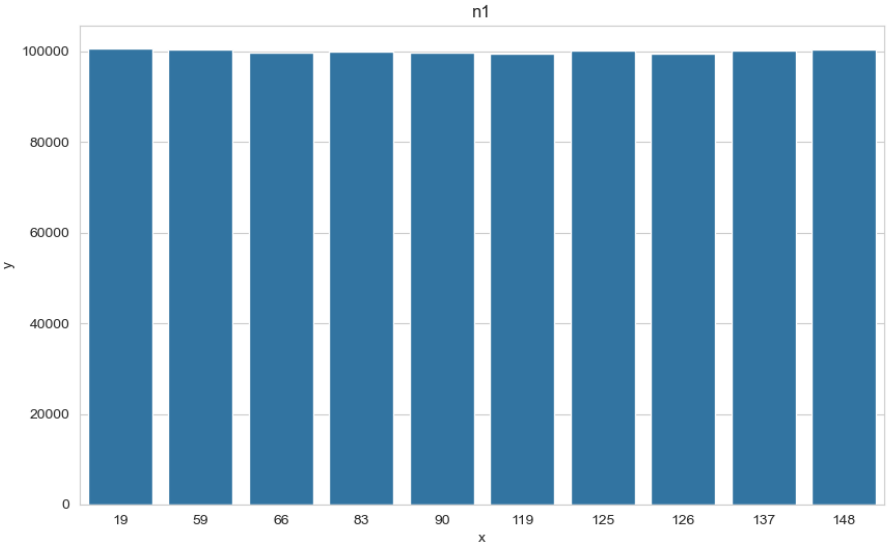

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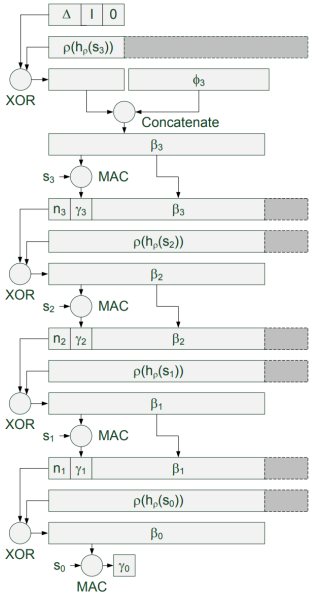

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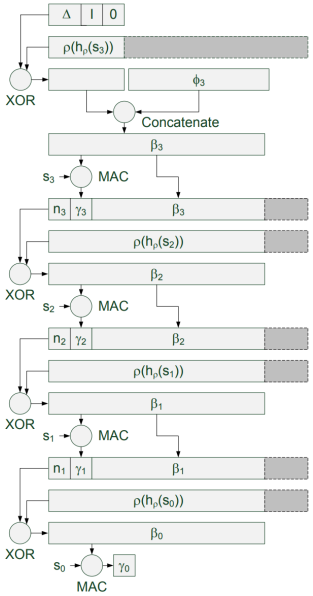

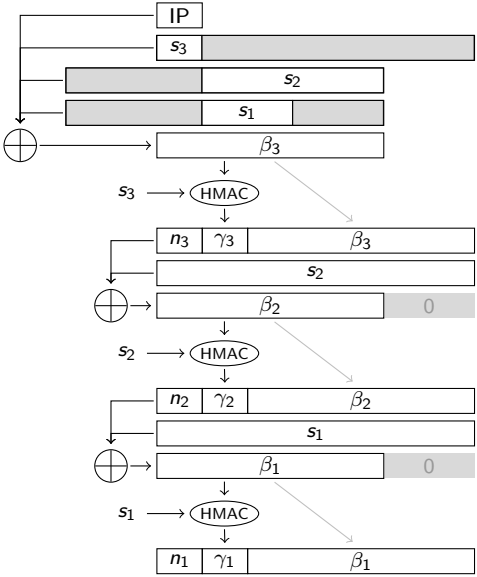

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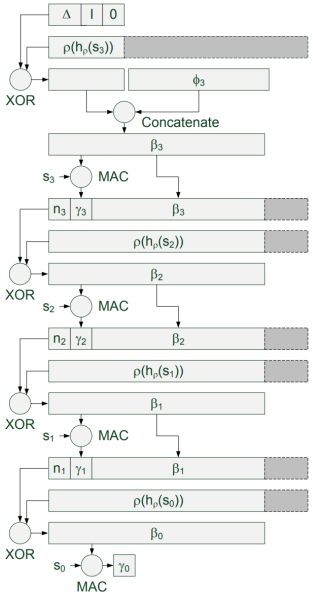

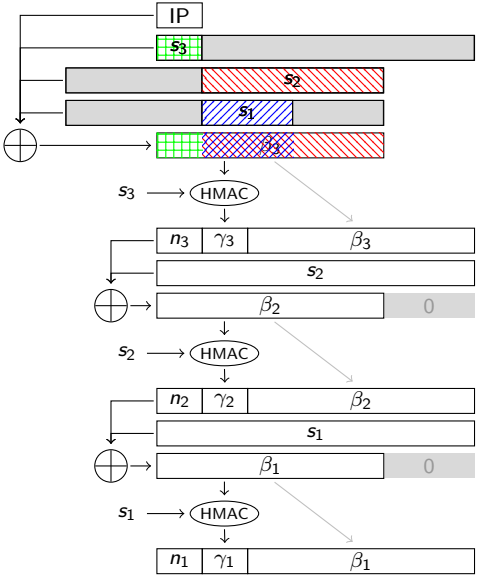

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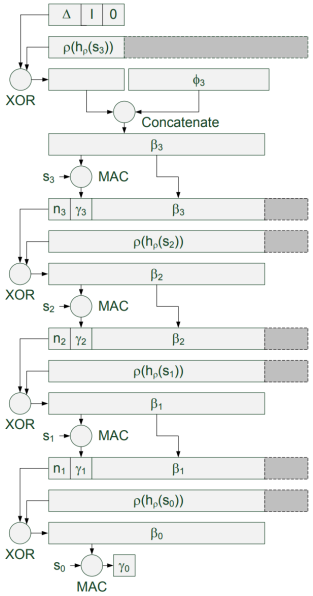

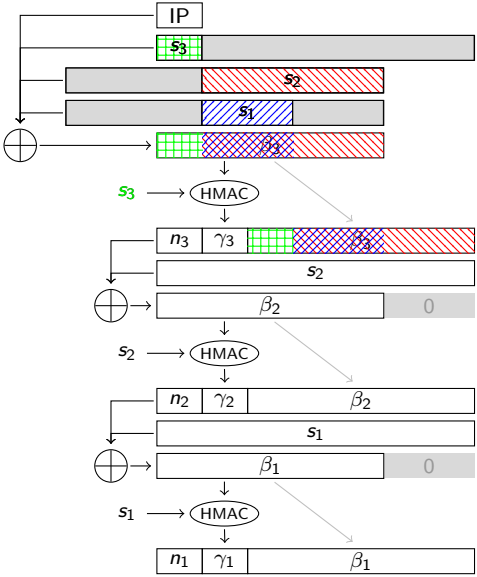

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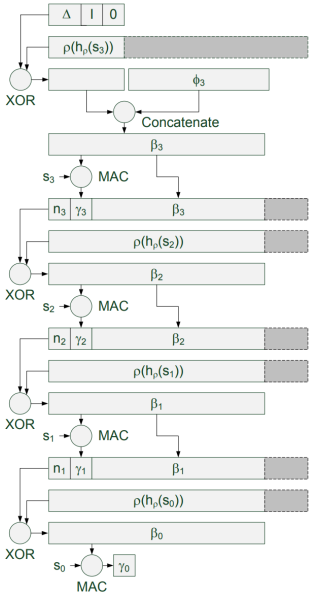

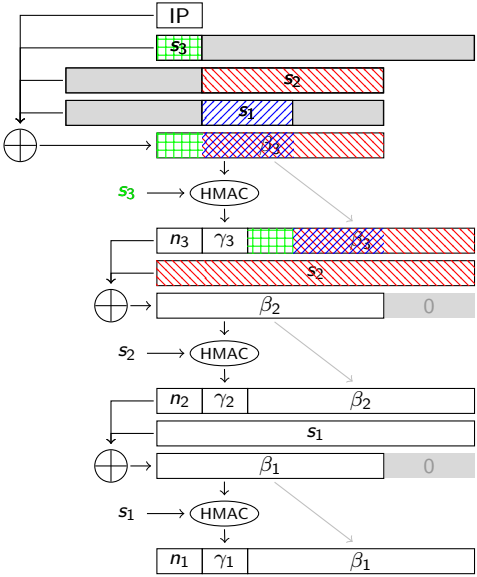

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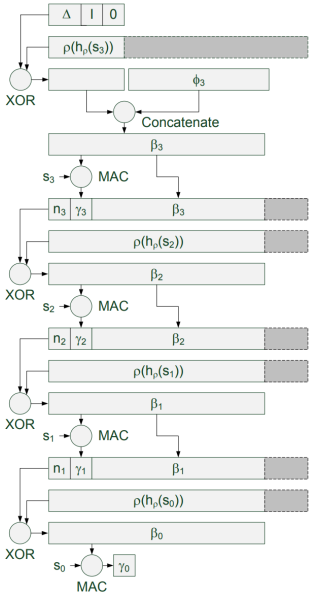

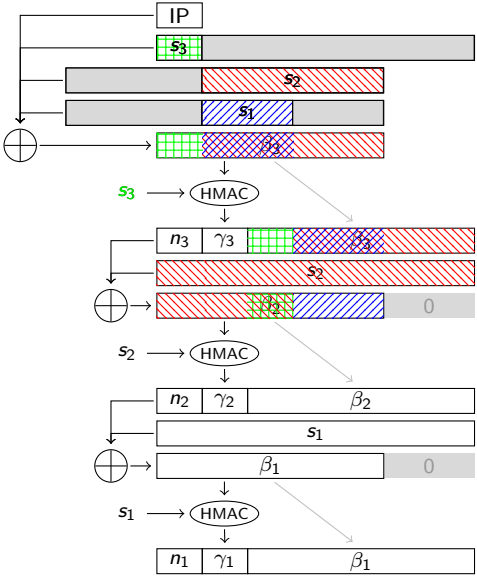

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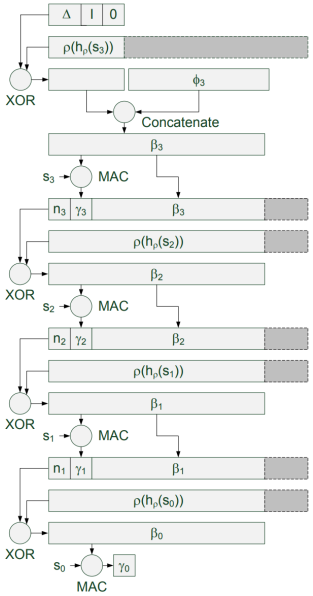

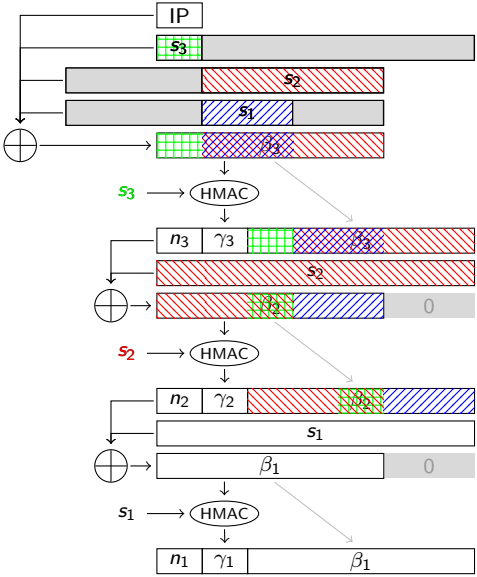

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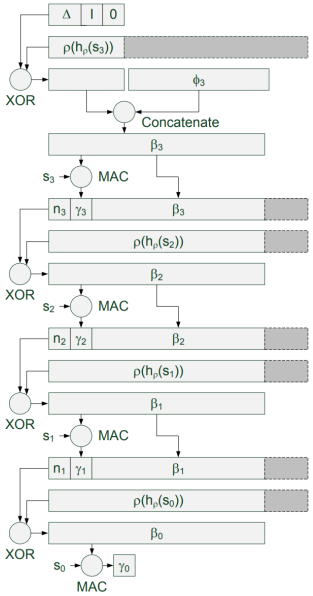

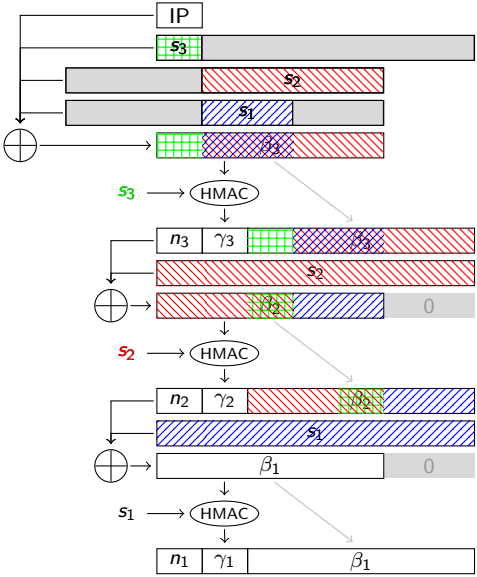

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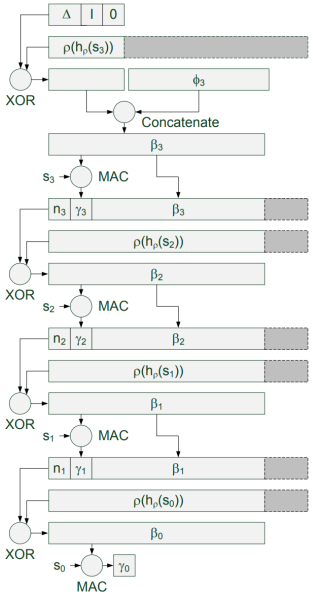

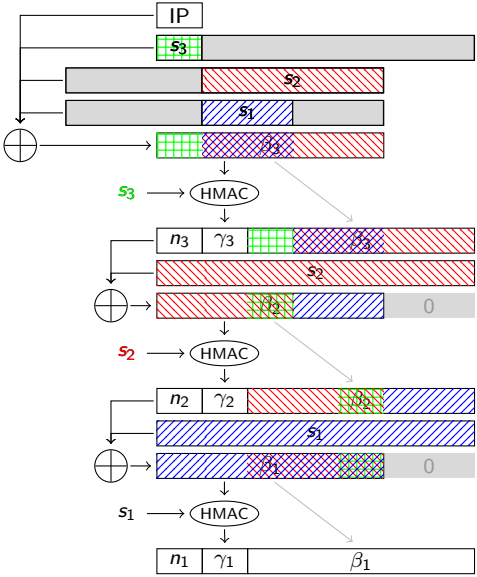

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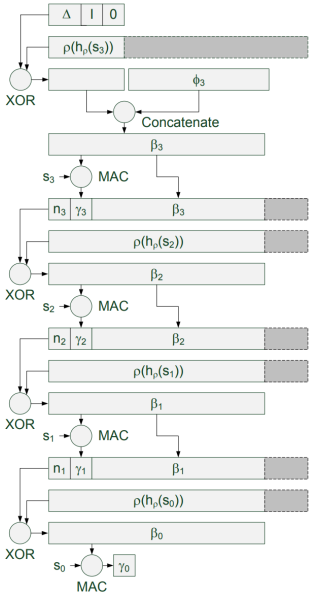
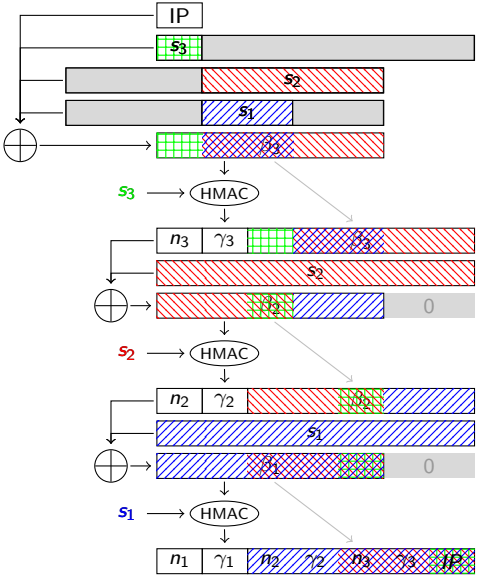
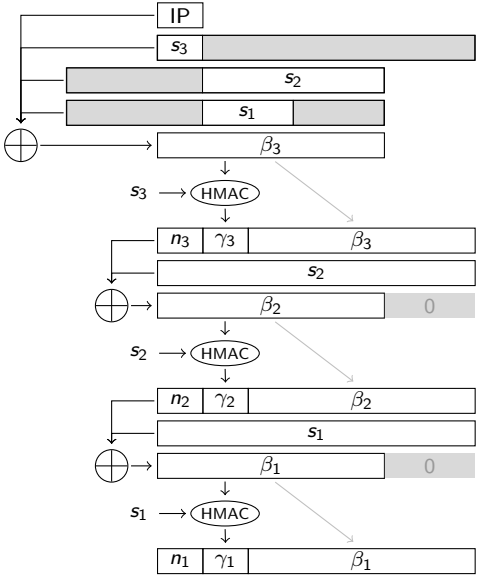




Adapting HMAC



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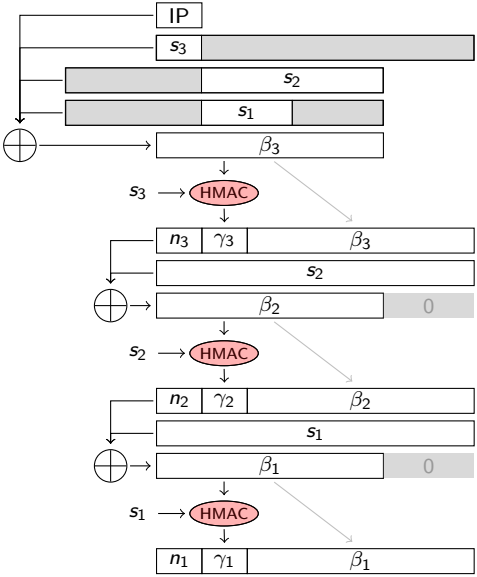

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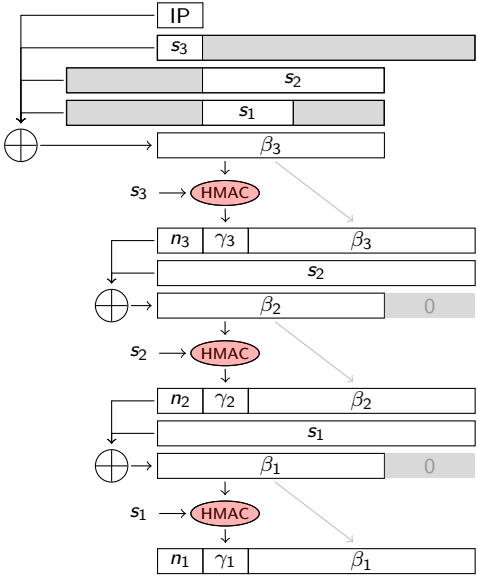

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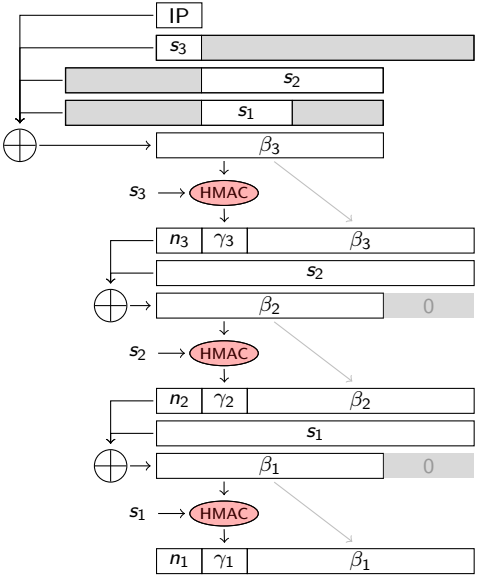

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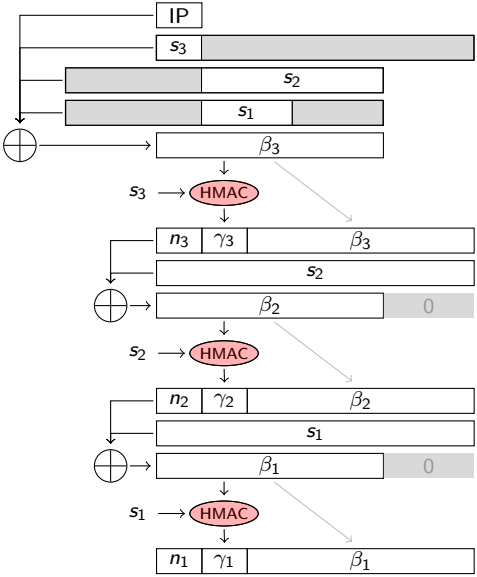

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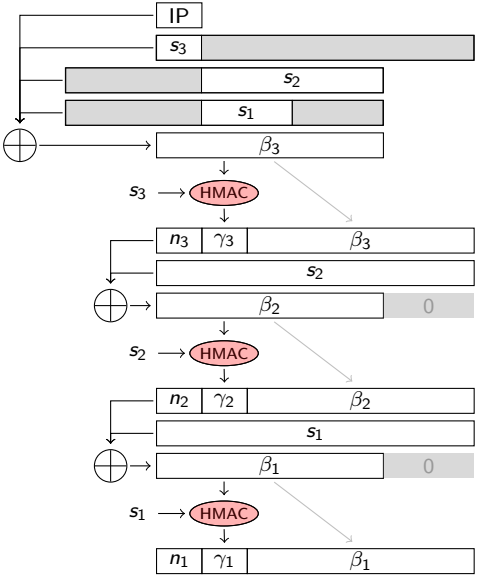

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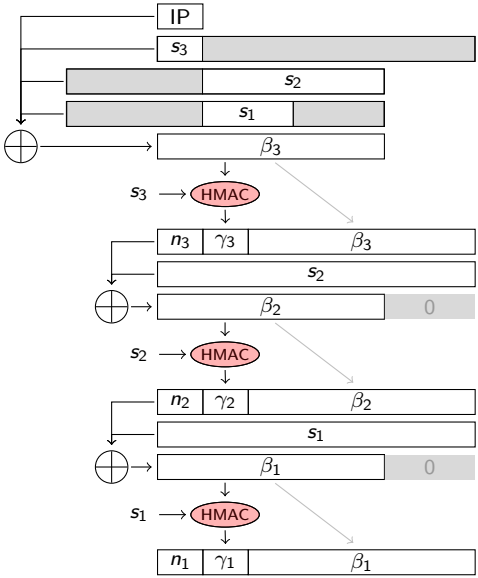
$$\begin{aligned}\mathcal{E}(m_1)\cdot\mathcal{E}(m_2) &= (g^{m_1} r_1^n)(g^{m_2} r_2^n) \bmod n^2 \\ &= g^{m_1+m_2}(r_1 r_2)^n \bmod n^2 \\ &= \mathcal{E}(m_1+m_2).\end{aligned}$$

Problem: Mix of different operations... order matters!



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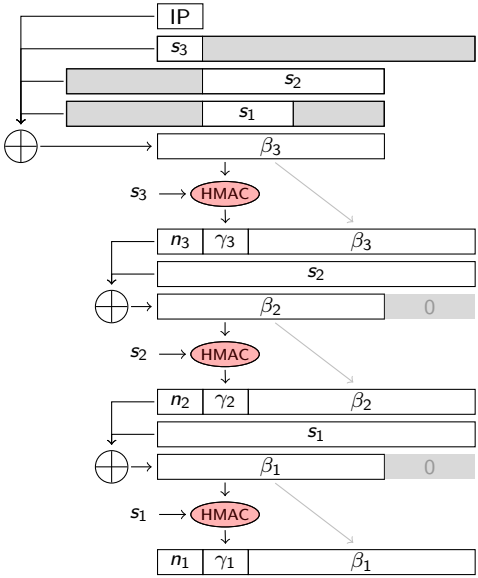
2. **ElGamal**

$$\mathcal{E}(m_1) \cdot \mathcal{E}(m_2) = (g^{r_1}, m_1 \cdot h^{r_1})(g^{r_2}, m_2 \cdot h^{r_2})$$
$$= (g^{r_1+r_2}, (m_1 \cdot m_2)h^{r_1+r_2})$$
$$= \mathcal{E}(m_1 \cdot m_2)$$

3. **Paillier**

Limitation: Increase ciphertext size...



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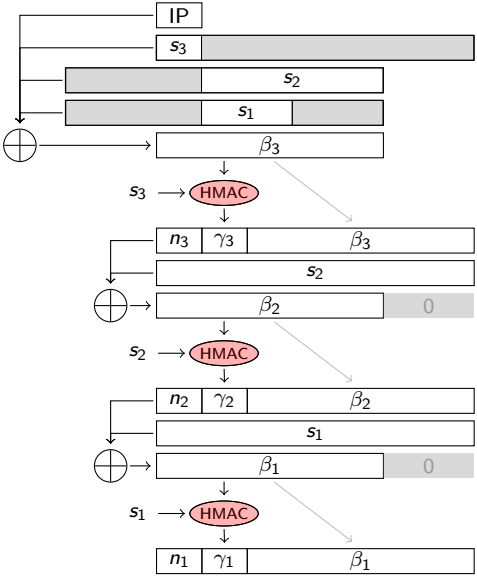
1. **RSA**

$$\mathcal{E}(m_1) \cdot \mathcal{E}(m_2) = m_1^e m_2^e \bmod n$$
$$= (m_1 m_2)^e \bmod n$$
$$= \mathcal{E}(m_1 \cdot m_2)$$

2. **ElGamal**
3. **Paillier**



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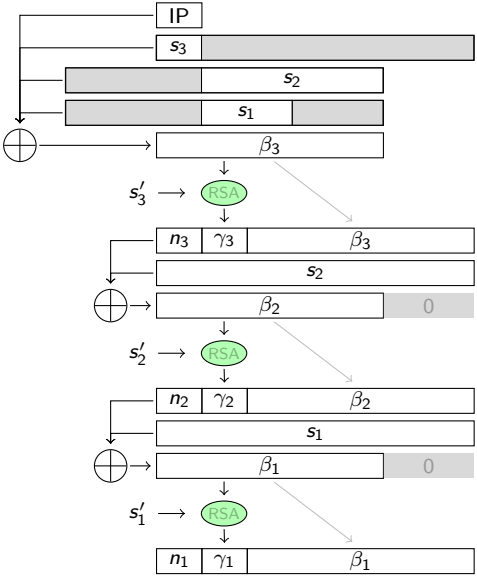
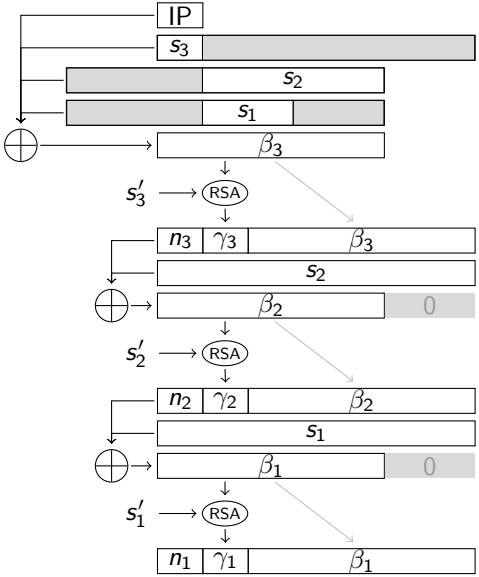
Selected solution: RSA for integrity tag

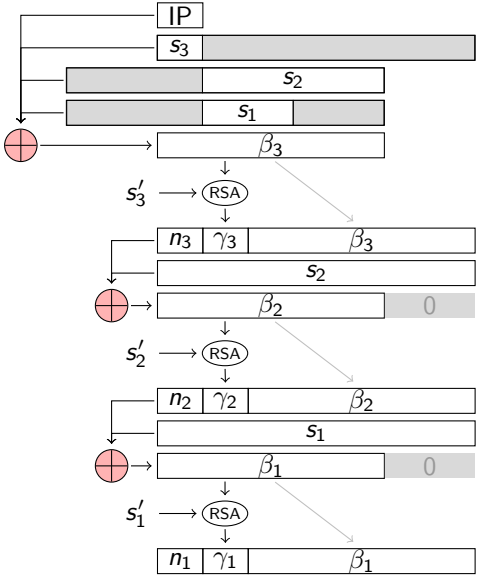
NB: s_i is different for each TTP but RSA required the same e...
Thus, create a new shared secret s_i' common to all TTP



Adapting XOR

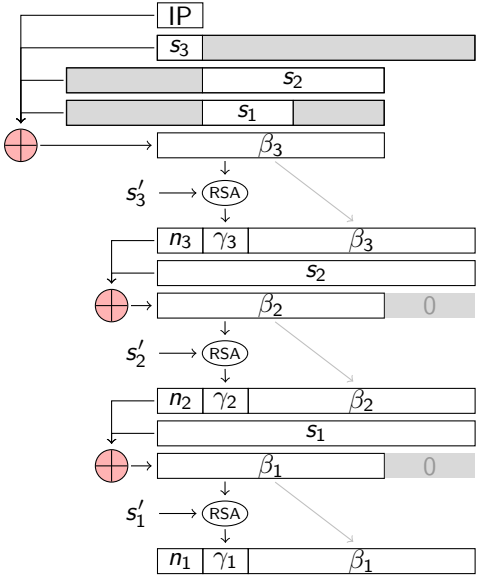


Adapting XOR



Adapting XOR

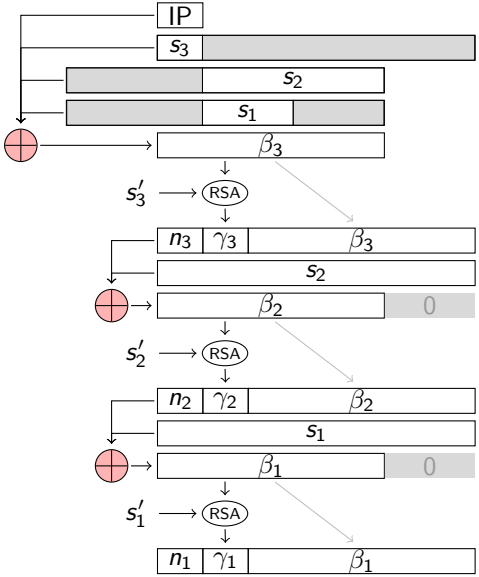
Since we use **RSA** for integrity tag γ_i



Adapting XOR

Since we use **RSA** for integrity tag γ_i

$$\begin{aligned}\mathcal{E}(m_1)\cdot\mathcal{E}(m_2) &= m_1^e m_2^e \bmod n \\ &= (m_1 m_2)^e \bmod n \\ &= \mathcal{E}(m_1 \cdot m_2)\end{aligned}$$



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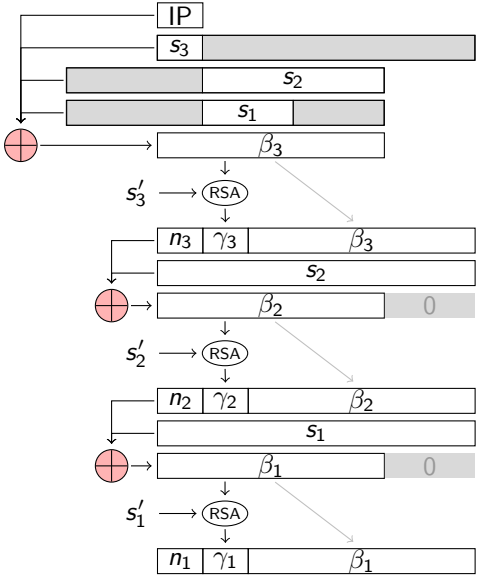
Modular multiplication of integrity tags gives integrity tag of headers' modular product.



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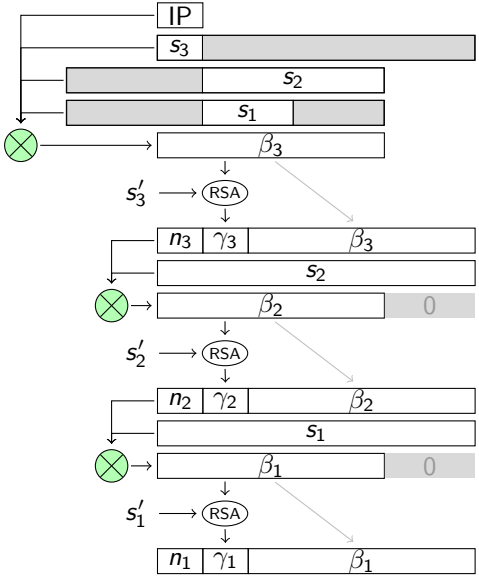
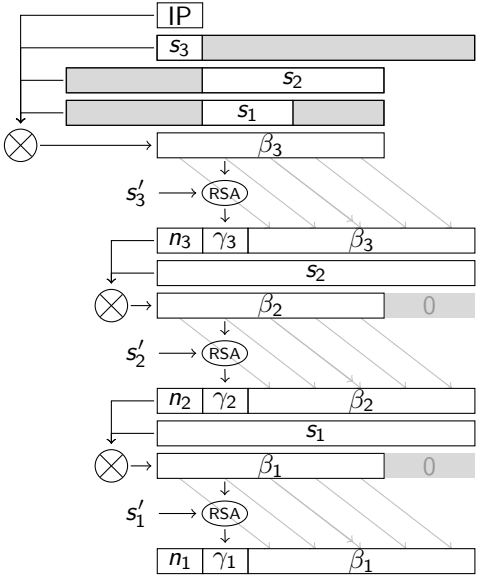
Modular multiplication of integrity tags gives integrity tag of headers' modular product.

Thus, header elements must be combined via modular multiplication rather than XOR.

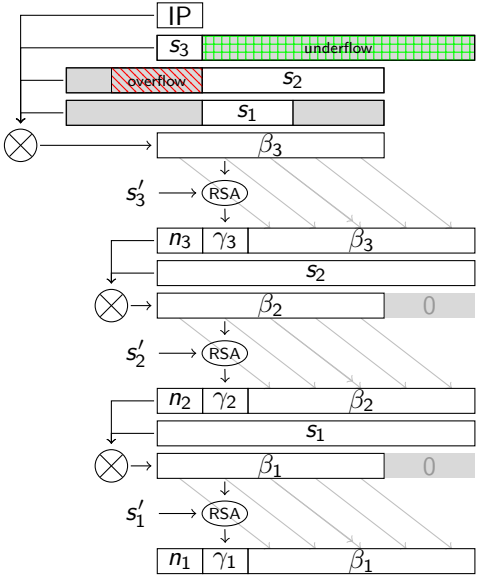


Handle overflows



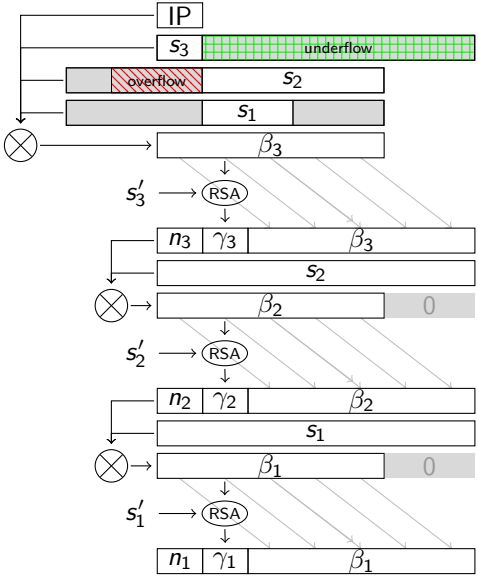
Handle overflows

- **Current Challenge: Overflow** issues



Handle overflows

- **Current Challenge: Overflow** issues
- Handling these issues is challenging. It may lead to **information loss** (further research is required).



Handle overflows

- **Current Challenge: Overflow** issues
- Handling these issues is challenging. It may lead to **information loss** (further research is required).
- **Proposed solution:** Simplify by **dividing data into small chunks** and processing each chunk modulo its size.