

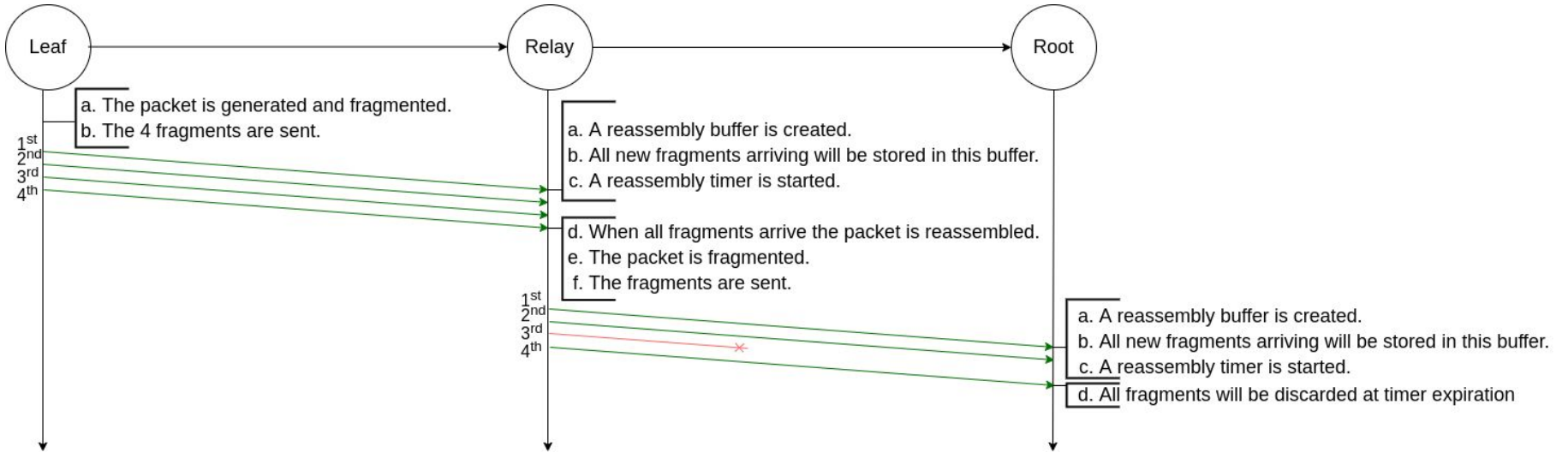
Fragment Forwarding, Forward Error Correction, Network Coding

Amaury Bruniaux

Georgios Z. Papadopoulos

RFC 4944: Fragment Forwarding

Example



3 main issues :

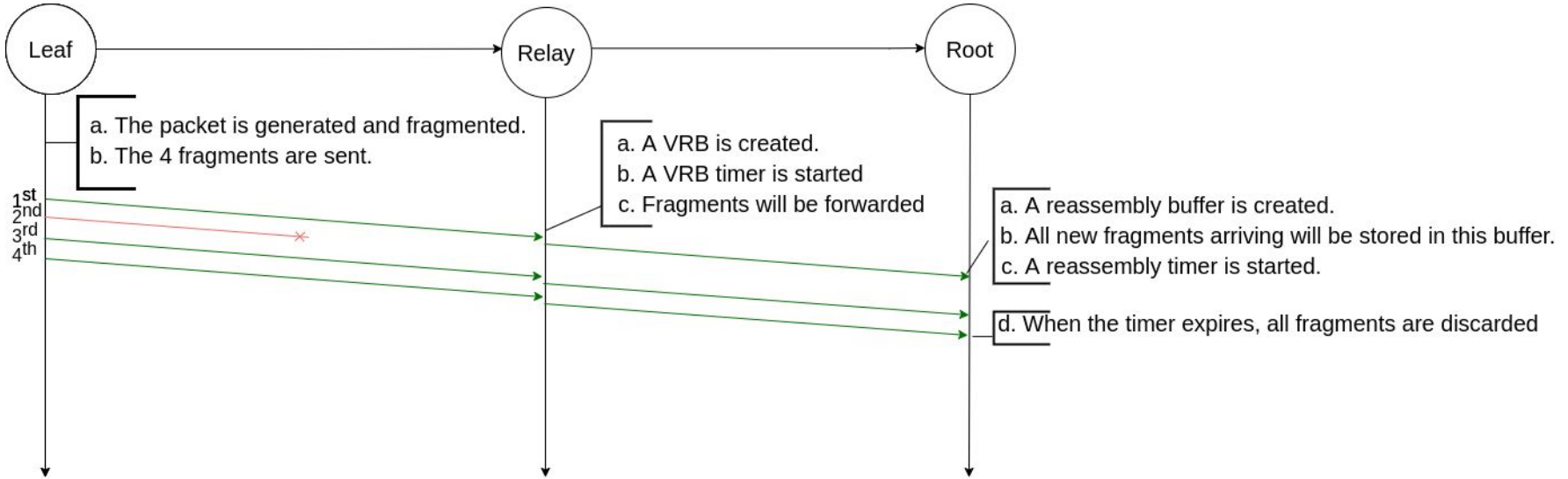
- Reassembling at each hop => Latency
- 1 lost fragment => whole packet is lost
- High memory usage

➔ **Latency and reliability could be improved** ➔

How to improve both ?

RFC 8930: Fragment Forwarding

Example



- Adds the VRB (Virtual Reassembly Buffer)

Decrease in latency and memory usage

Still one main issue : 1 lost fragment => the whole packet is lost

- Principle : Adding redundancy to transmissions in order to increase the odds of a successful first attempt
- 2 FEC types:
 - intra-frame: recover lost bytes of a fragment from redundant bytes
 - inter-frame: recover lost fragments from redundant fragments
- Our 3 inter-frame FEC propositions for 6LoWPAN fragmentation
 - XorFec
 - RFec
 - NCFec
- 1 State of the art article for LPWAN

XorFec

FEC with 1 additional fragment

- One additional fragment is added with the exclusive OR operator
- After the frames are received, if one is missing it is possible to recover it:
- $B = A \oplus (A \oplus B)$ with
 - A : XOR on original fragments received
 - B : lost fragment
 - $A \oplus B$: additional fragments

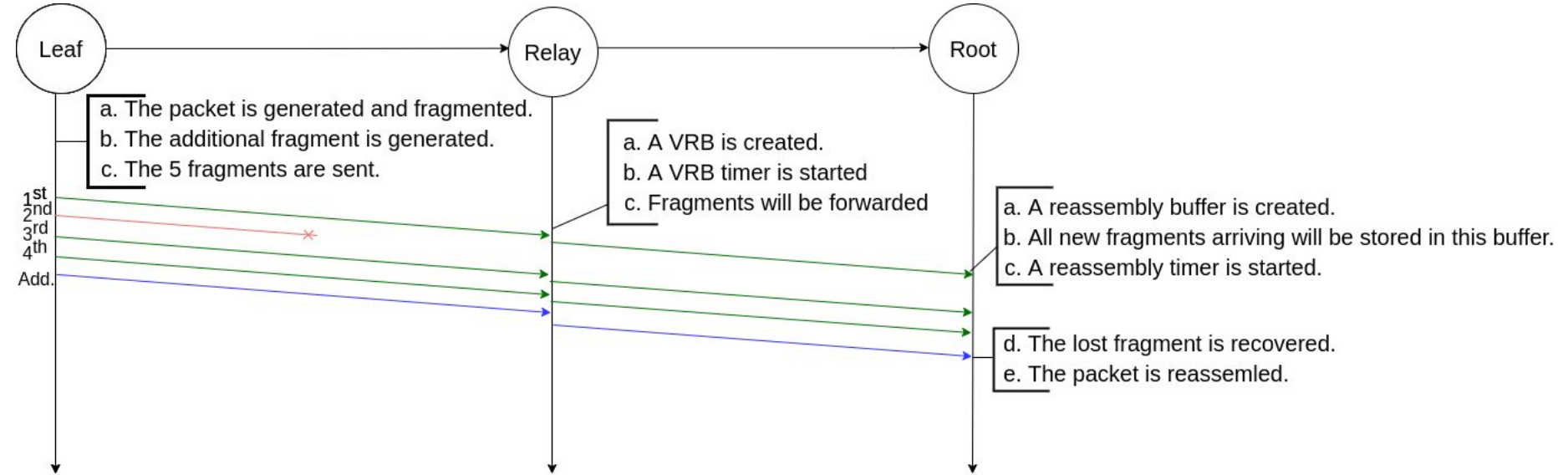
$$\boxed{1} \oplus \boxed{2} \oplus \boxed{3} = \boxed{\text{Add.}}$$

$$\boxed{1} \oplus \boxed{2} \oplus \boxed{\text{Add.}} = \boxed{3}$$

XorFec

FEC with 1 additional fragment

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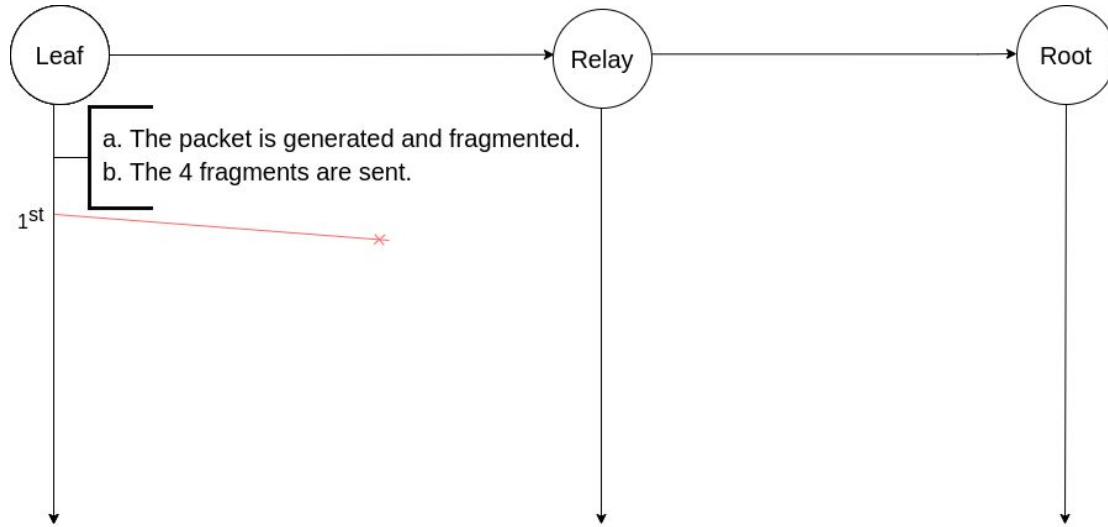
**Reliability
improvement**

**Only 1 fragment can be
recovered and the first
fragment cannot**

RFec

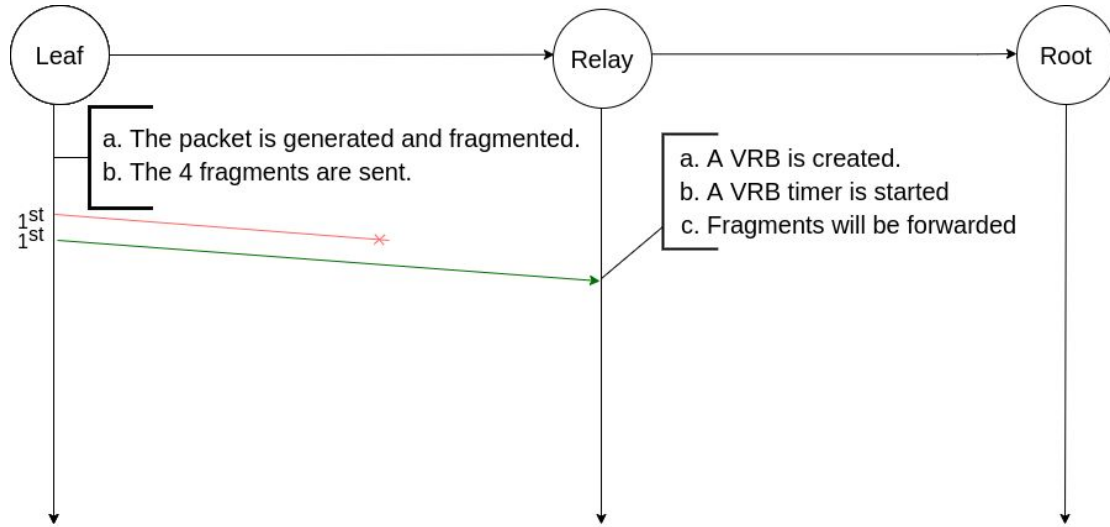
FEC with identical retransmission

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RFec

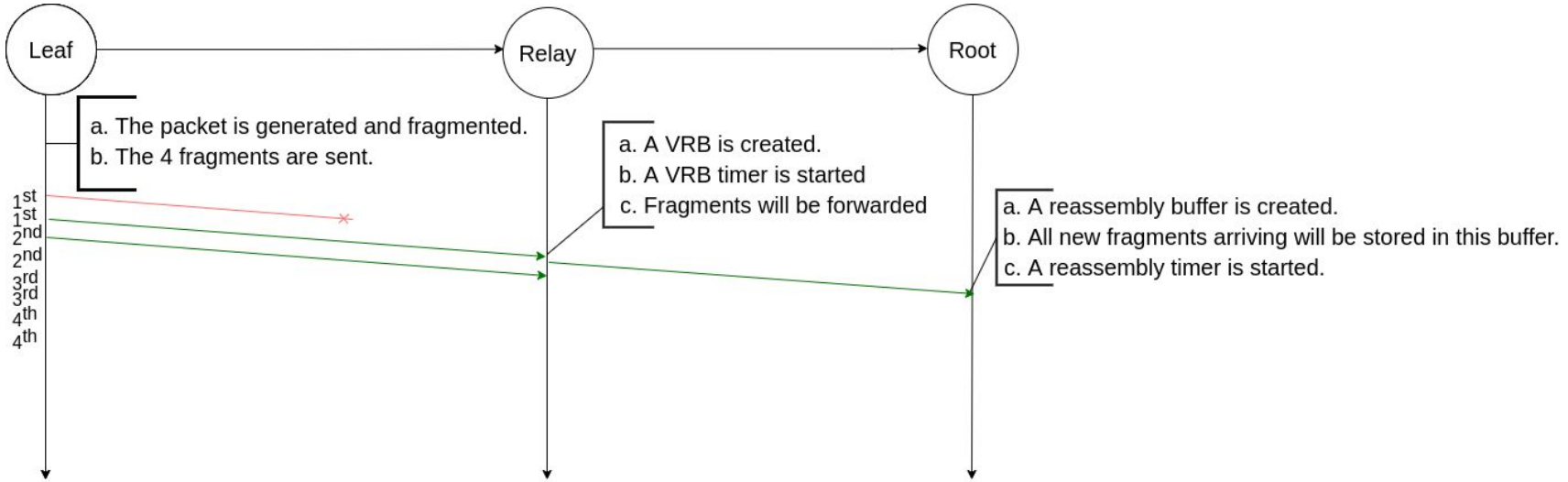
FEC with identical retransmission



RFec

FEC with identical retransmission

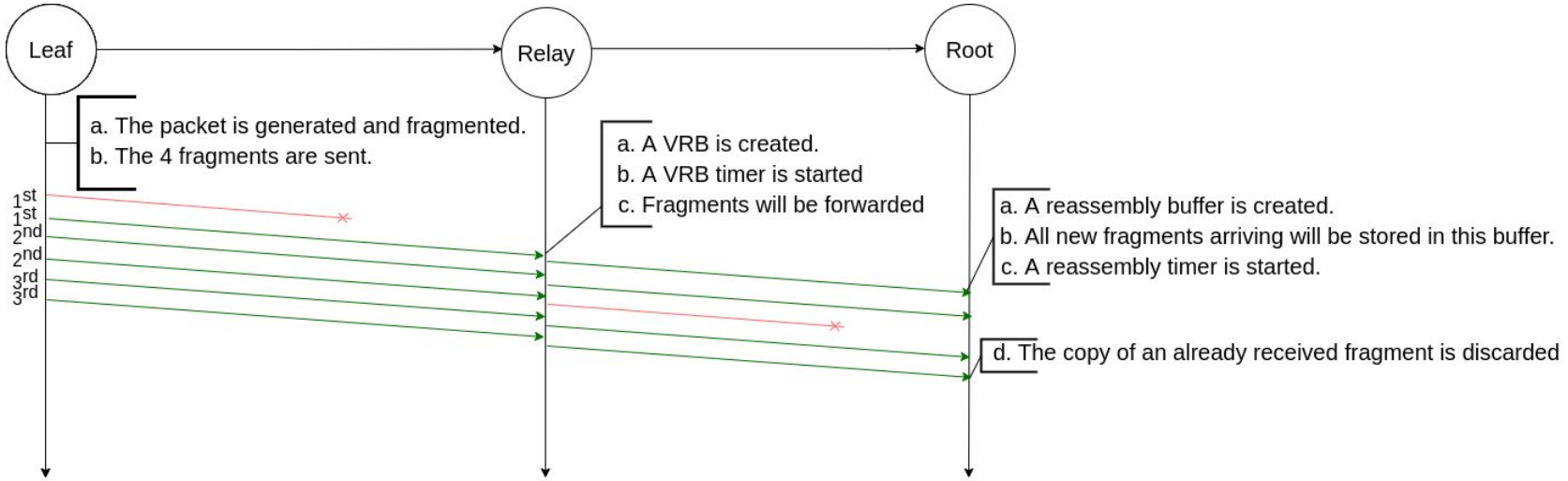
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RFec

FEC with identical retransmission

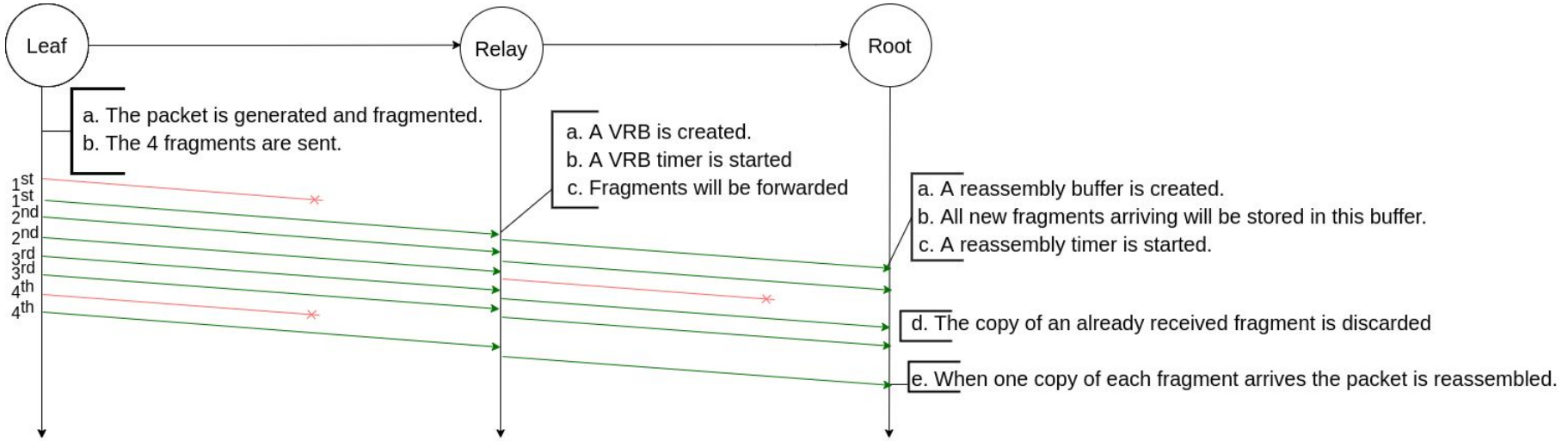
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RFec

FEC with identical retransmission

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**High reliability
improvement**

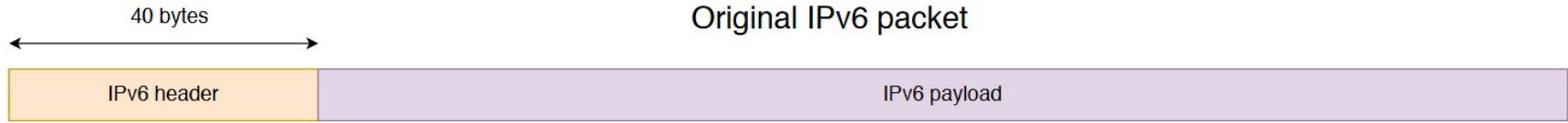


**High traffic
increasement**

NCFec

FEC with Network Coding

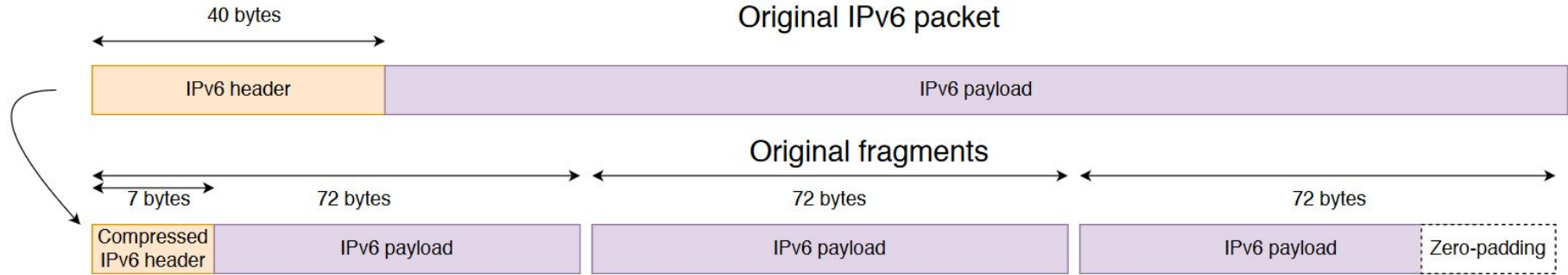
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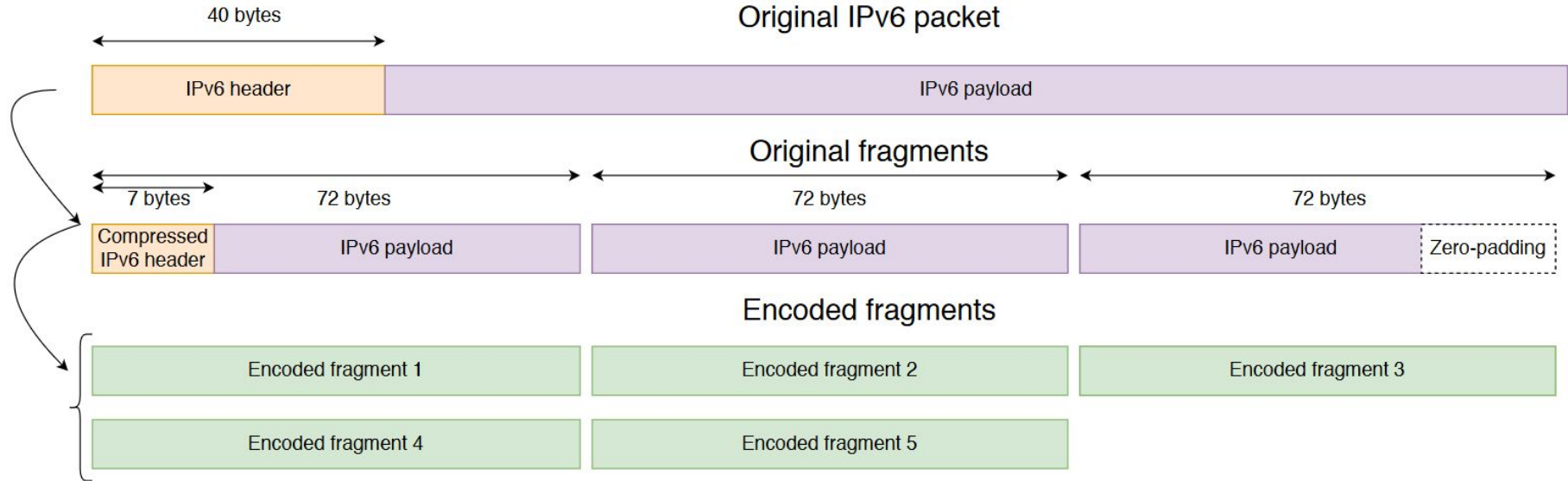


NCFec

FEC with Network Coding

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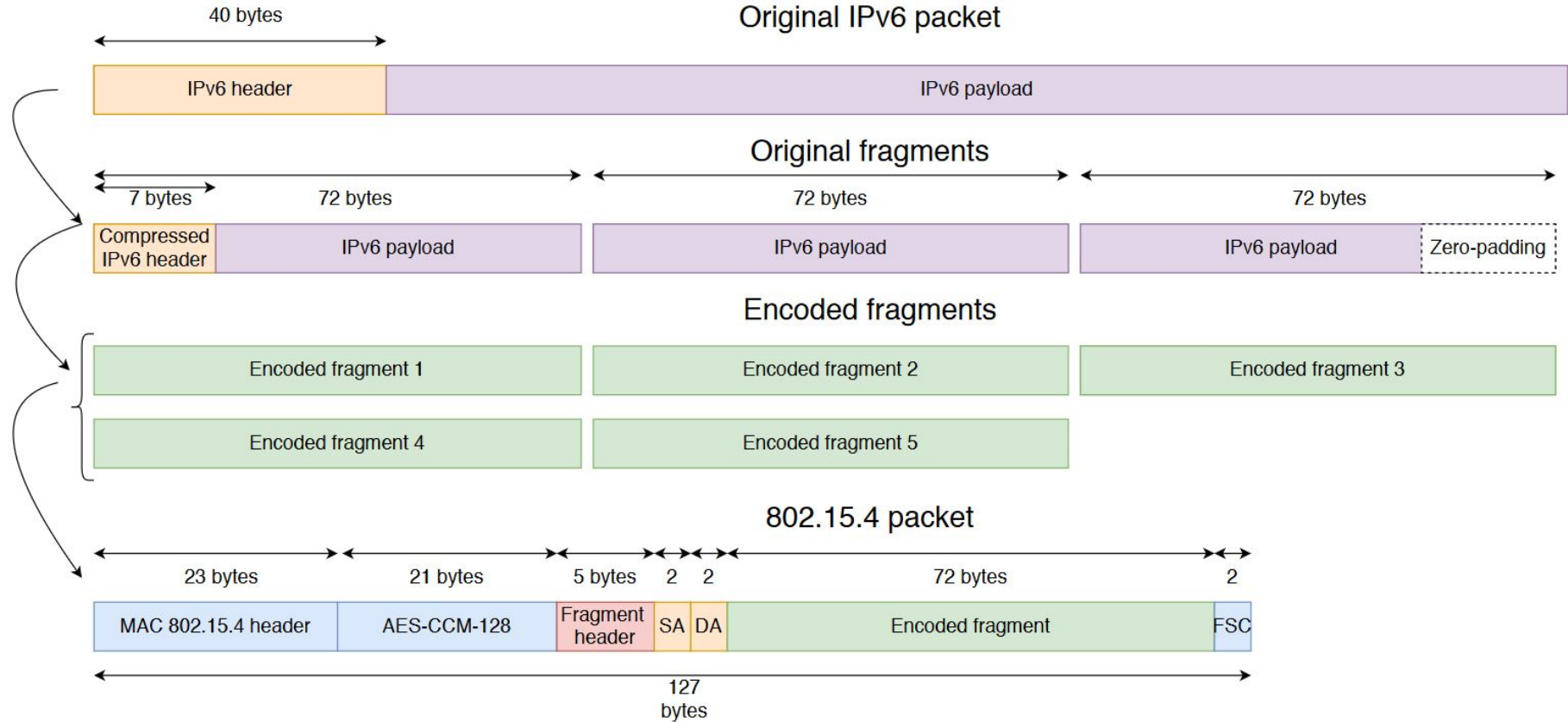


- The original m fragments can be obtained through decoding any m members of the M encoded fragments
- Encoding with finite field arithmetic

NCFec

FEC with Network Coding

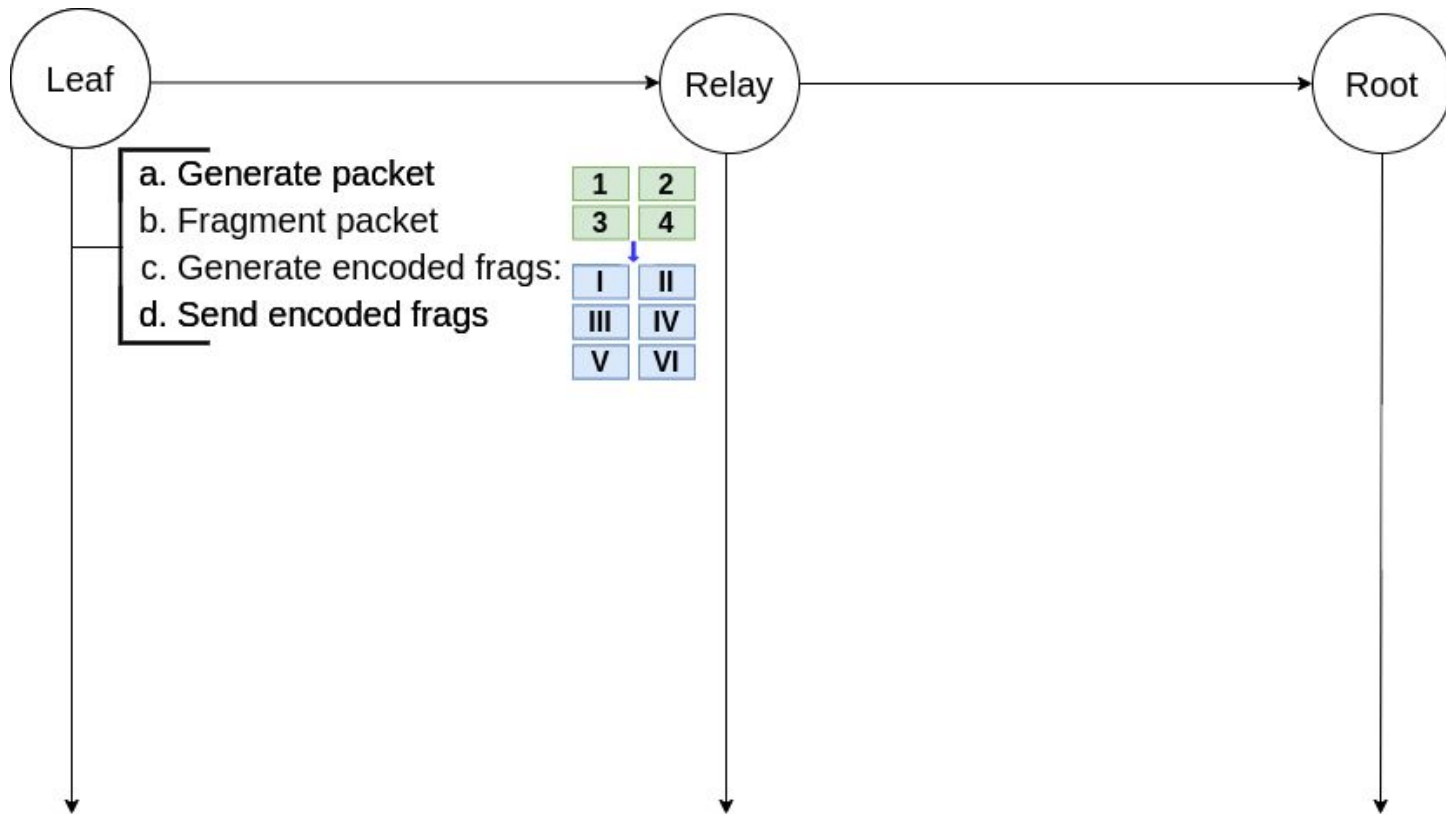
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NCFec

FEC with network coding

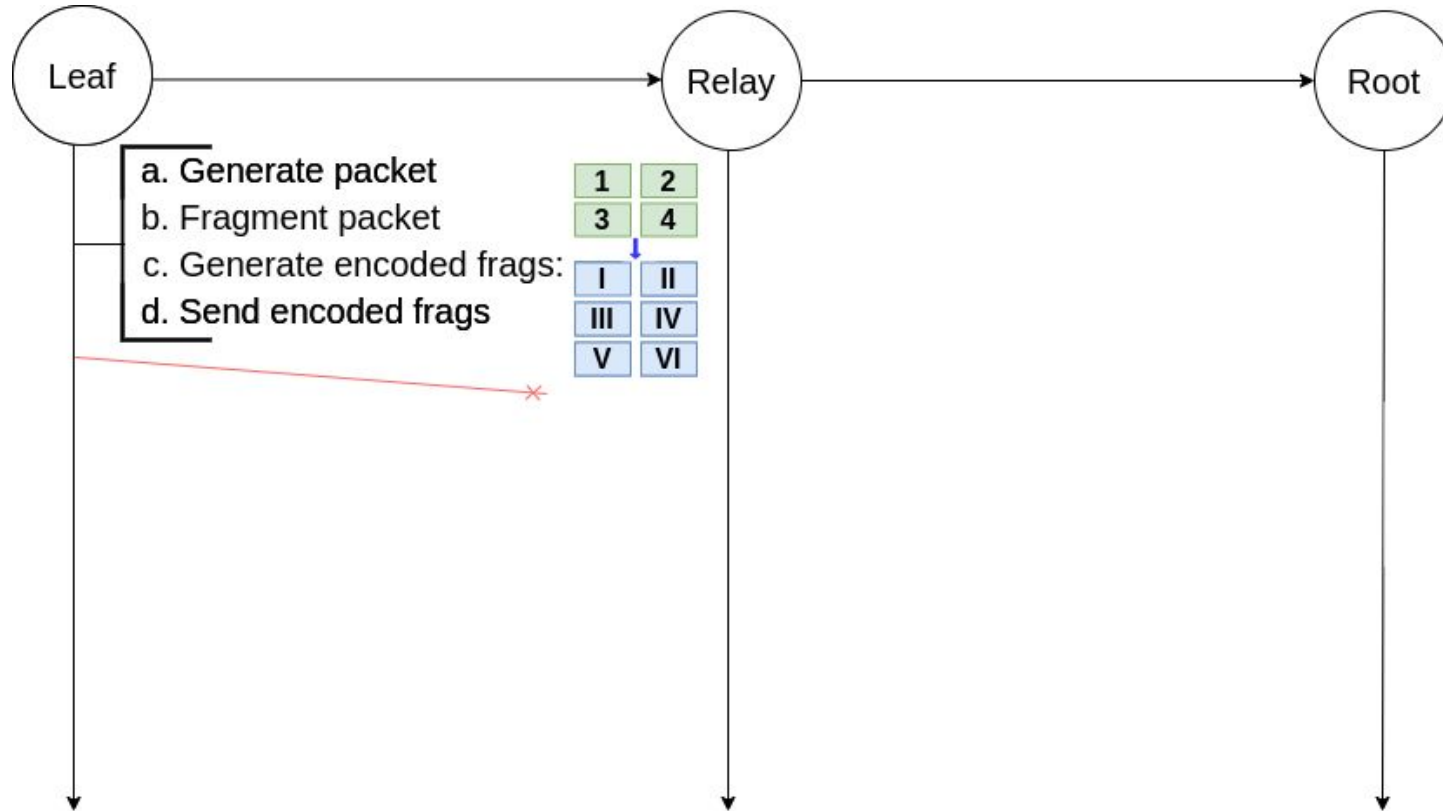
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NCFec

FEC with network coding

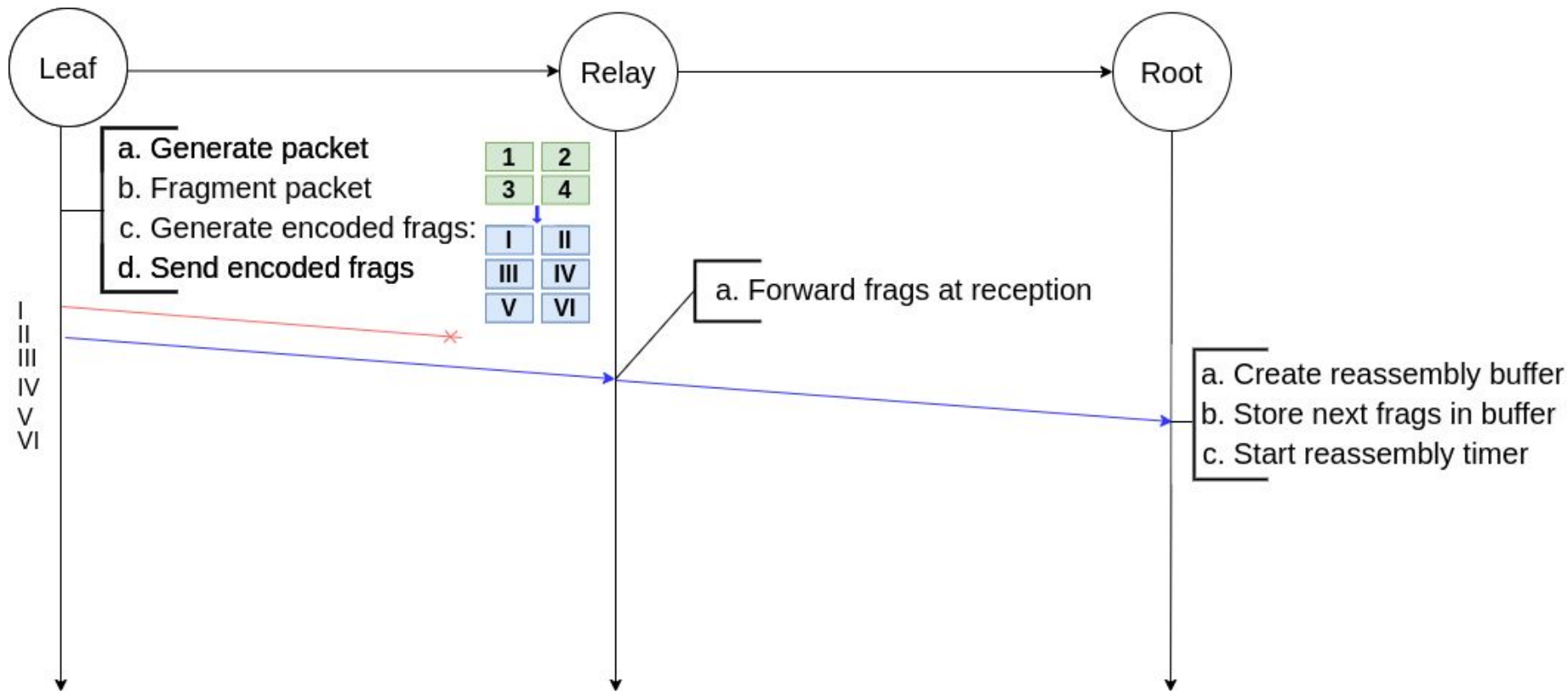
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NCFec

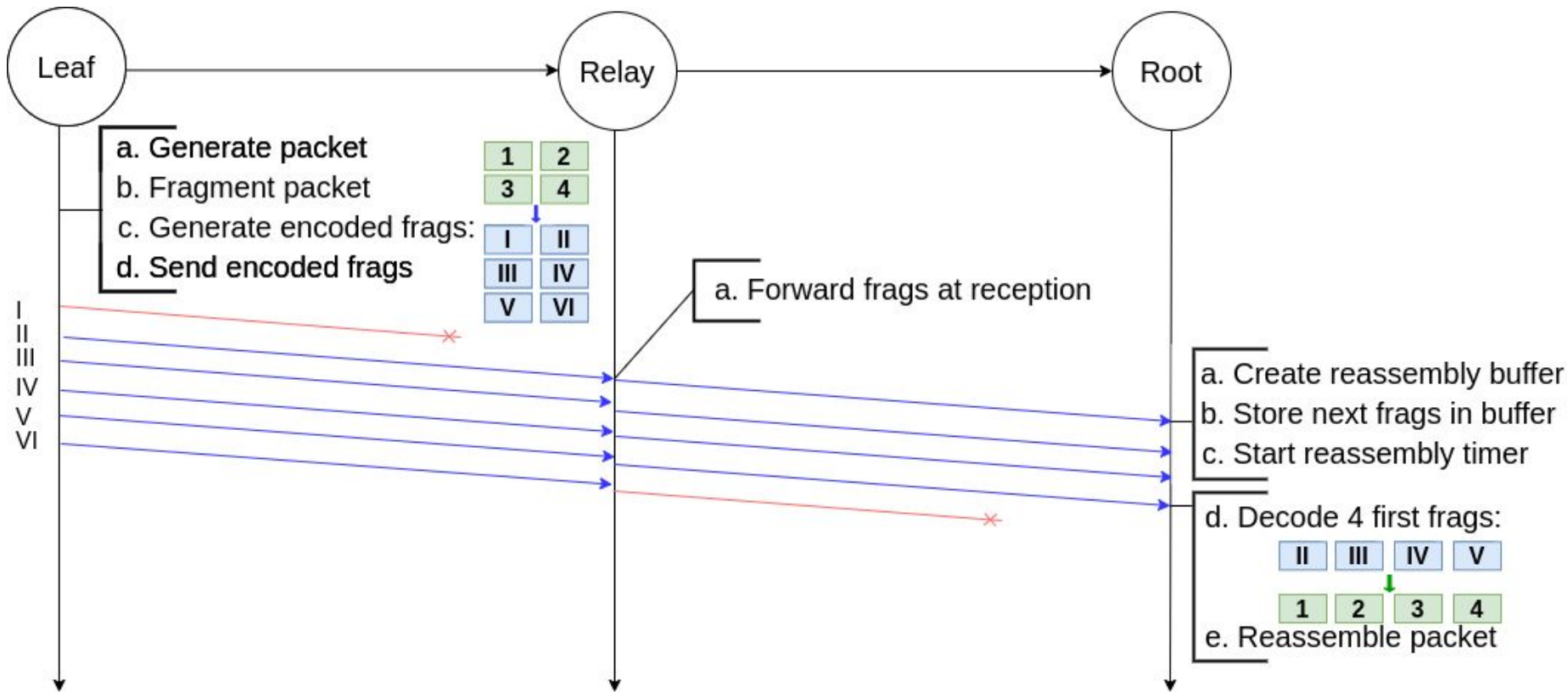
FEC with network coding

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NCFec

FEC with network coding



➔ Any fragment can be recovered => Reliability increase

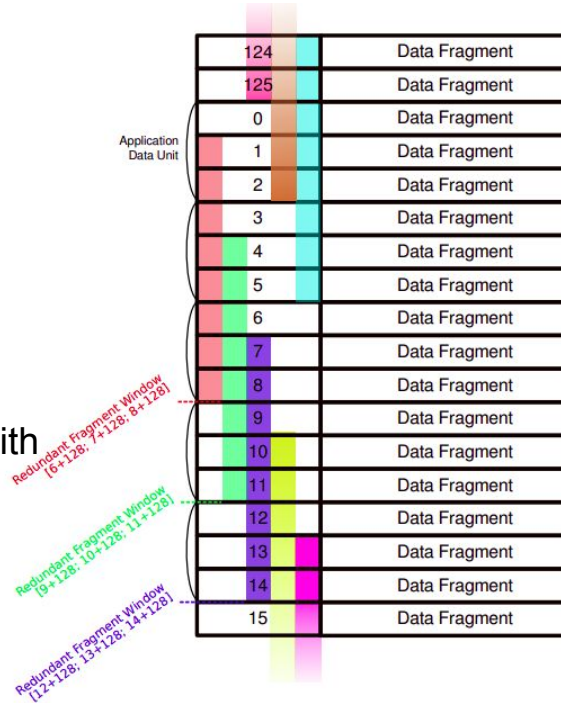
➔ Usage of resources: computing, memory, traffic

Thanks!

Fragmentation and Forward Error Correction for LoRaWAN small MTU net

Ulysse Coutaud, Martin Heusse, Bernard Tourancheau

- Nodes store a window of the last w fragments
- After each LORA packet, the node sends a redundancy fragment
- Redundancy fragments are created with XOR used on a subset of fragments from the window

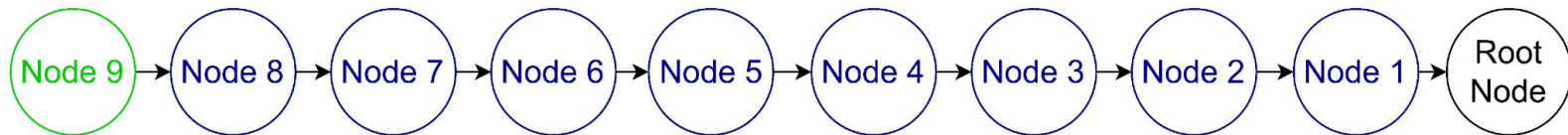


253	Redundant Fragment
0	Data Fragment
1	Data Fragment
2	Data Fragment
128	Redundant Fragment
129	Redundant Fragment
130	Redundant Fragment
3	Data Fragment
4	Data Fragment
5	Data Fragment
131	Redundant Fragment
132	Redundant Fragment
133	Redundant Fragment
6	Data Fragment
7	Data Fragment
8	Data Fragment
134	Redundant Fragment
135	Redundant Fragment
136	Redundant Fragment
9	Data Fragment
10	Data Fragment
11	Data Fragment
137	Redundant Fragment
138	Redundant Fragment
139	Redundant Fragment
12	Data Fragment
13	Data Fragment
14	Data Fragment
140	Redundant Fragment
141	Redundant Fragment
142	Redundant Fragment
15	Data Fragment

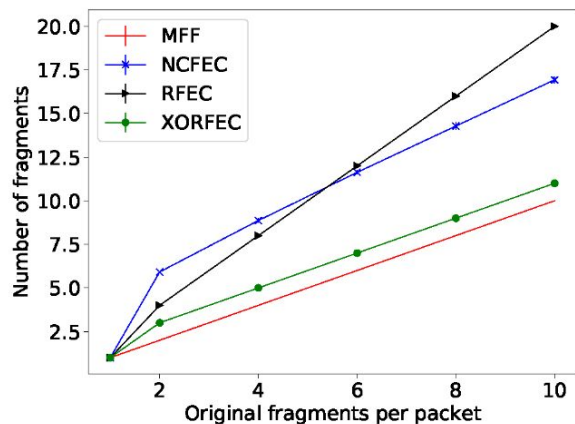
- The original m fragments can be obtained through decoding any m members of the M encoded fragments
- Linear code over $GF(2,8)$
- In order to encode M original fragments noted $\{K_0, \dots, K_{M-1}\}$ into N encoded fragments noted $\{L_0, \dots, L_{N-1}\}$:
 - Each encoded fragment f has a coefficient vector (f_0, \dots, f_{M-1}) where $f_i = f^{(i)}$
 - $L_f = f_0 * K_0 + f_1 * K_1 + \dots + f_{M-1} * K_{M-1}$ with the operations of $GF(2,8)$
- The encoding is done by inverting the matrix formed by the received fragments and multiplying by the vector of corresponding coefficients.

Appendix C: Performance evaluation

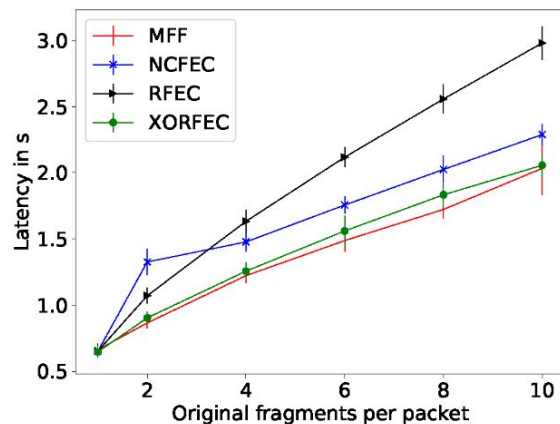
Link quality 0.65



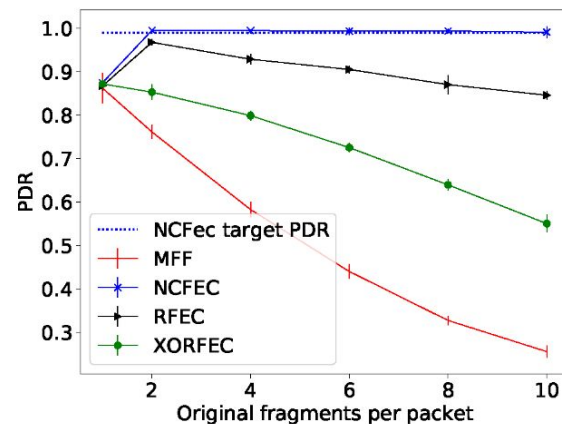
Results obtained with 6Tisch Simulator with a linear topology



(a) Fragments per packet.



(b) End-to-end latency.

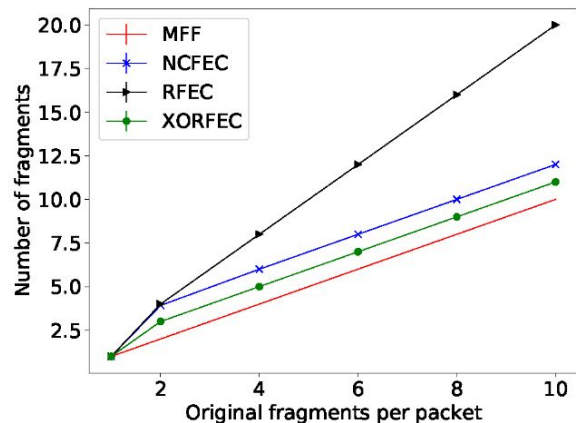


(c) End-to-end PDR.

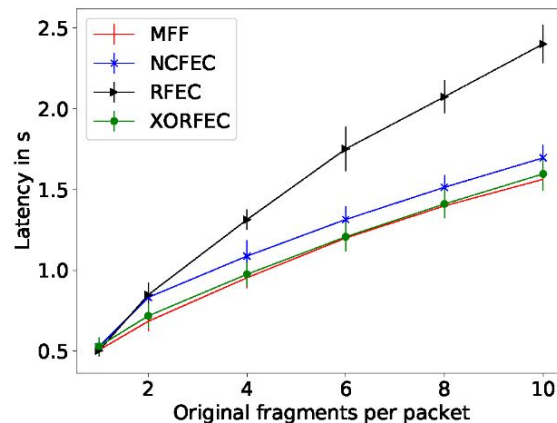
Appendix C: Performance evaluation

Link quality 0.85

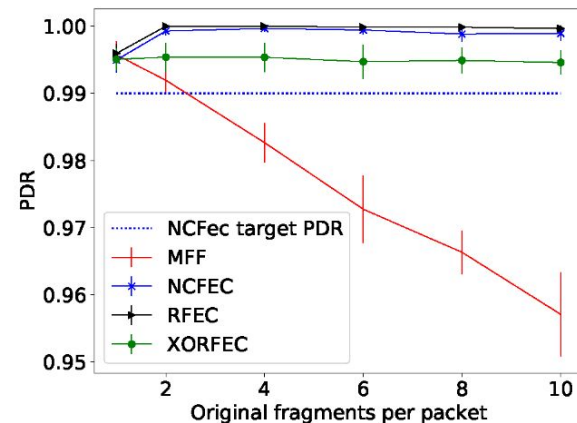
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(a) Fragments per packet.



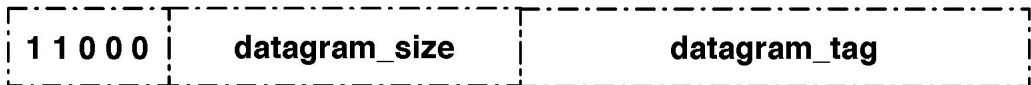
(b) End-to-end latency.



(c) End-to-end PDR.

Appendix D: NCFec Fragment header

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1



Standard fragment header

First Fragment Header

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

