Packet Level Resilience for the User Plane in 5G Networks

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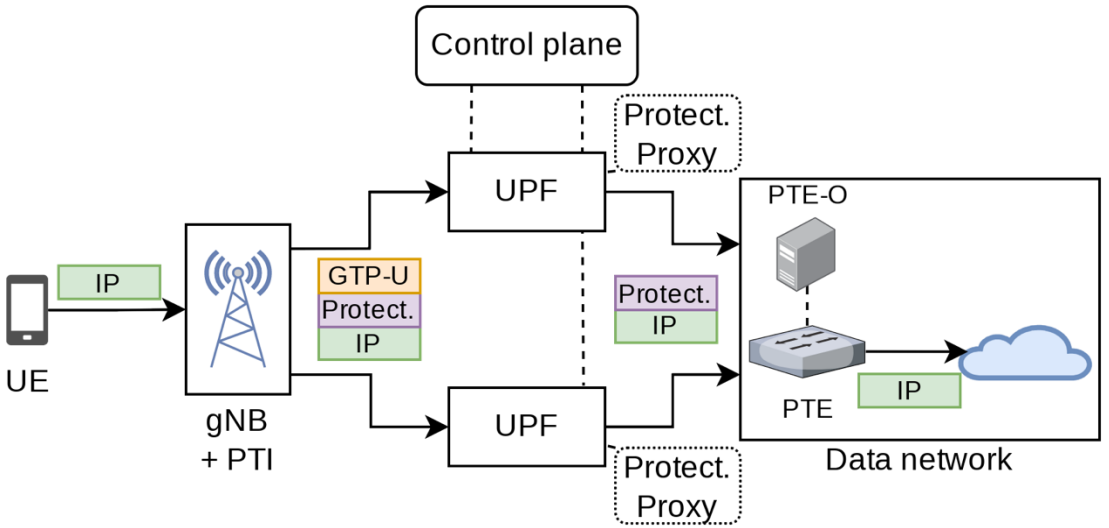

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Motivation

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- Packet loss is detrimental to smart factories and autonomous robots
- 5G and beyond technologies are used to provide connectivity to such applications
- Connectivity may fail due to power outages, fiber cuts, hardware defects, link disruptions, …
- Mechanisms such as Fast ReRoute (FRR) provide failover with redundant links
  - Reacting on a sub-microsecond scale
  - → For mission-critical applications, a smaller restoration time is required

Leverage a 1+1 protection scheme to achieve ultra low packet loss in 5G networks

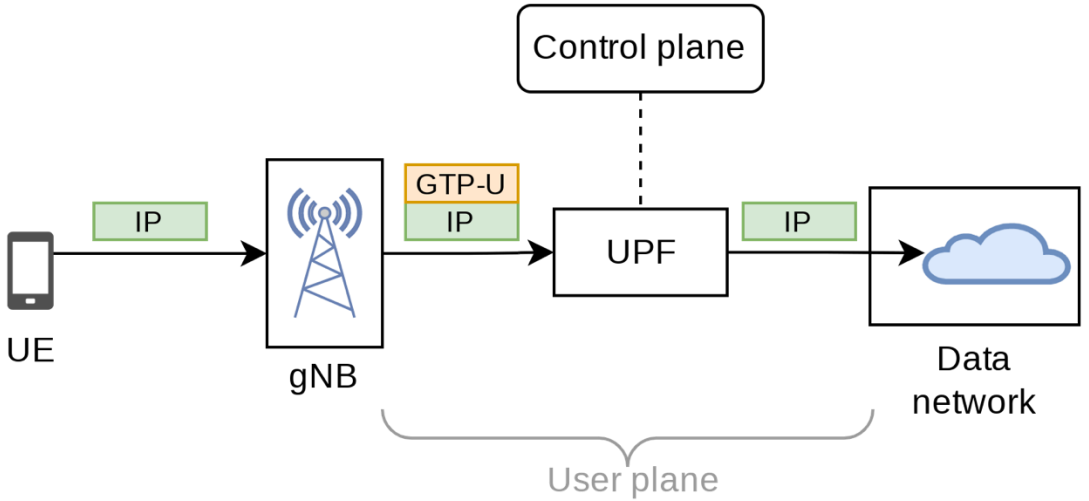
Components in the 5G Architecture

User equipment (UE)

- E.g., mobile phones
- Wants to communicate with the Internet
- Connects to the gNB

gNodeB (gNB)

- Inside Radio Access Network (RAN)
- Encapsulates traffic from UE in a GPRS Tunnel (GTP-U)
  - Addresses the User Plane Function (UPF)



Core network divided into two parts

- Control plane
- User plane
  - UPF forwards packets from authenticated UE to data network (e.g., the Internet)
  - UPF decapsulates GTP-U

If the UPF fails, the UE often needs to reconnect, or the session needs to be handed over

The Packet Replication, Elimination, and Ordering Function (PREOF)

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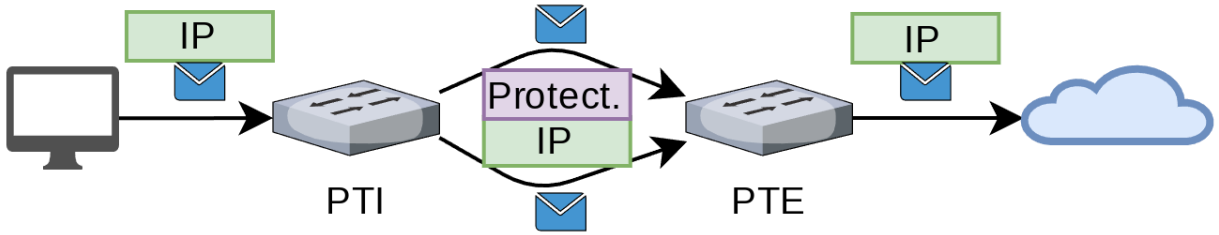
Mechanism to enable real-time applications with extremely low data loss and bounded latency

- Standardized by the DetNet IETF working group

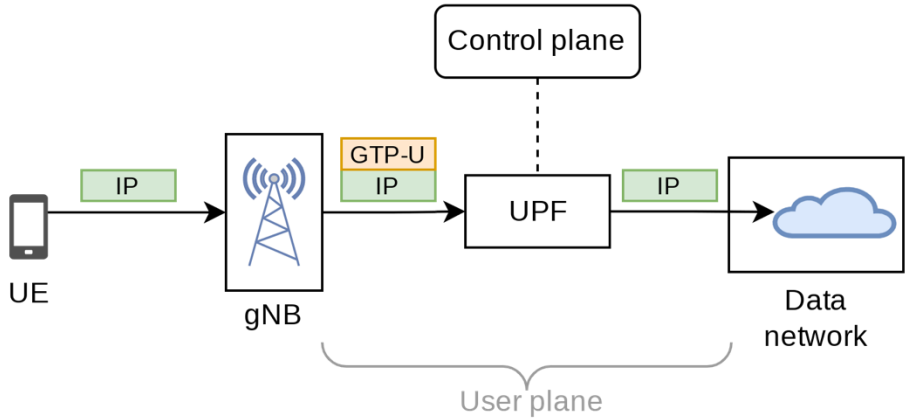
1+1 protection scheme

- Packets are replicated at a Protection Tunnel Ingress (PTI) node
  - Sent over multiple disjoint paths towards a Protection Tunnel Egress (PTE) node
  - Encapsulated with sequence number and tunnel destination information
- PTE eliminates duplicates and forwards one packet copy towards its destination
  - Ordering function ensures that forwarded packets are delivered in-order

→ PREOF achieves packet level resilience



Packet Level Resilience for the User Plane (I)



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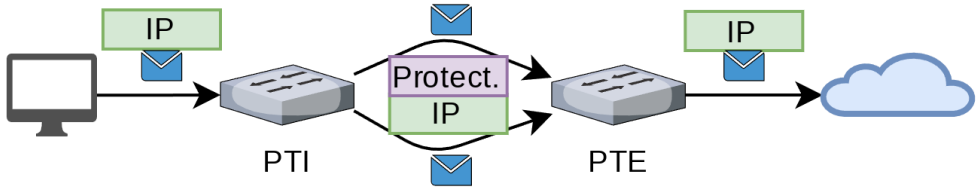

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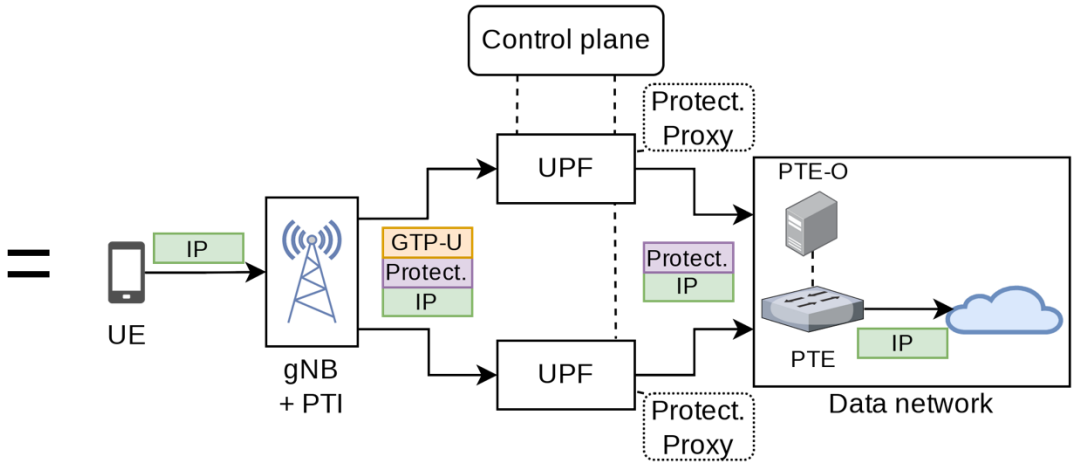
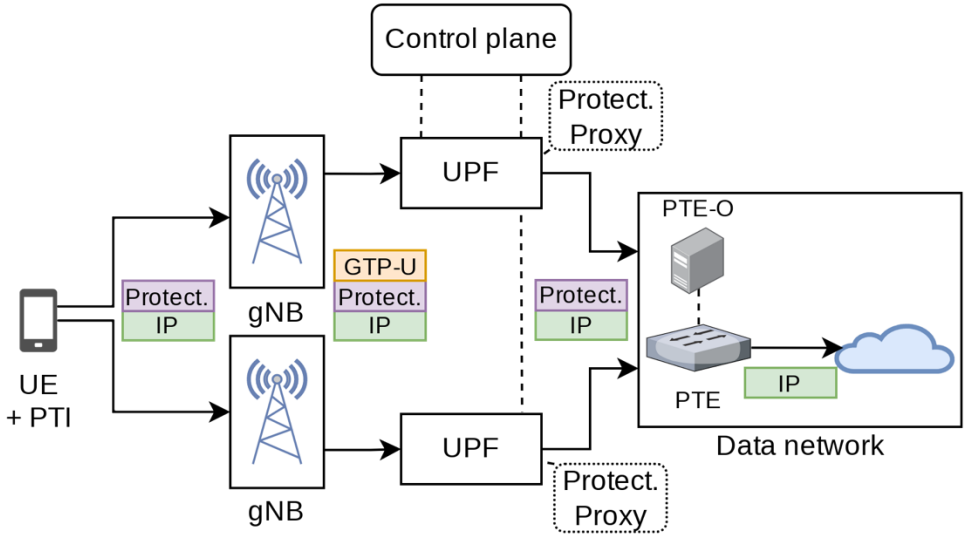


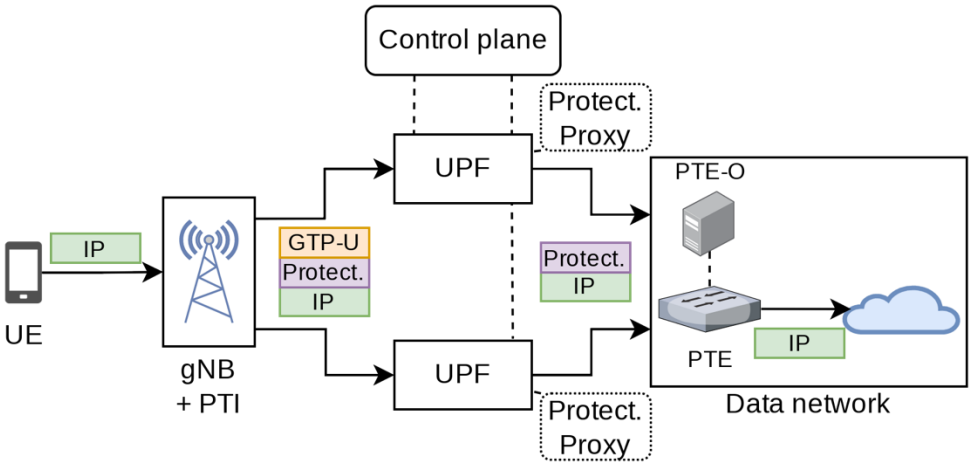


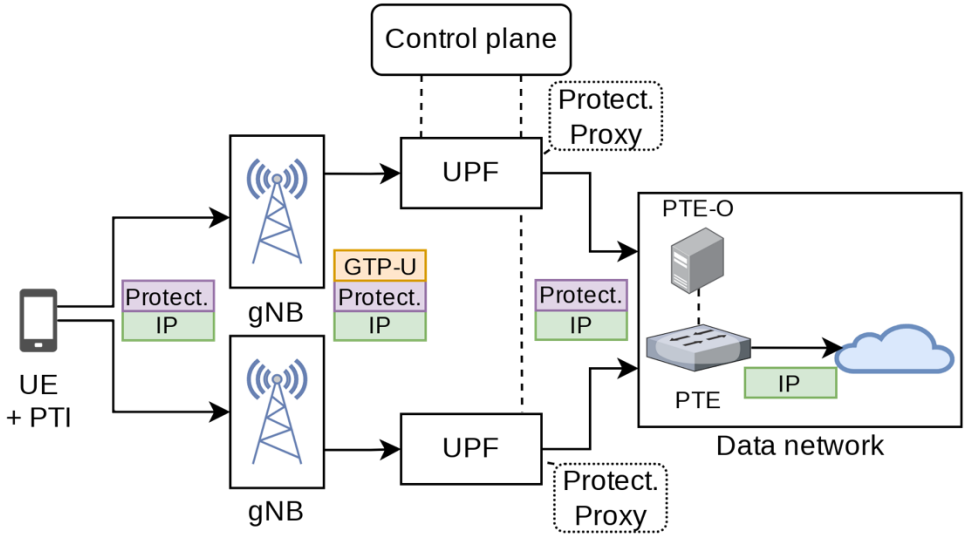
PTI Location

PTI and PTE are integrated into the 5G components using redundant UPF paths

Where to place the PTI?

- Approach 1: Locate PTI in the gNB
- Approach 2: Locate PTI in the UE

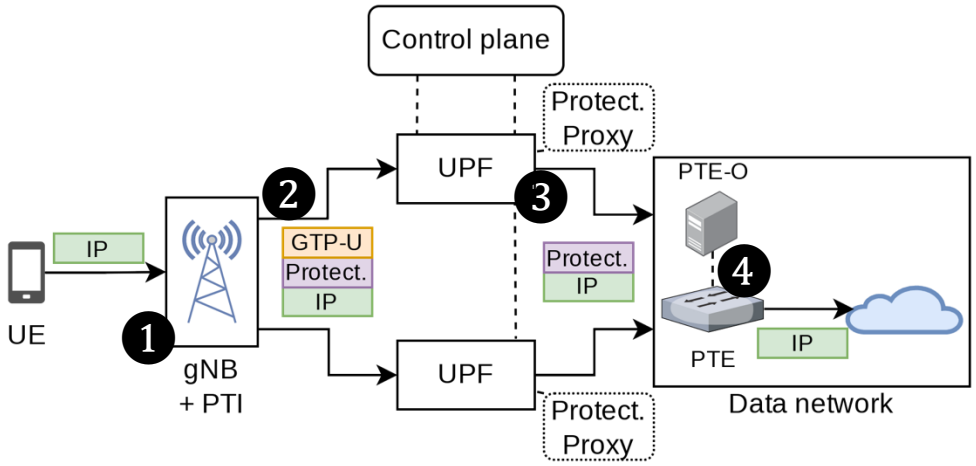


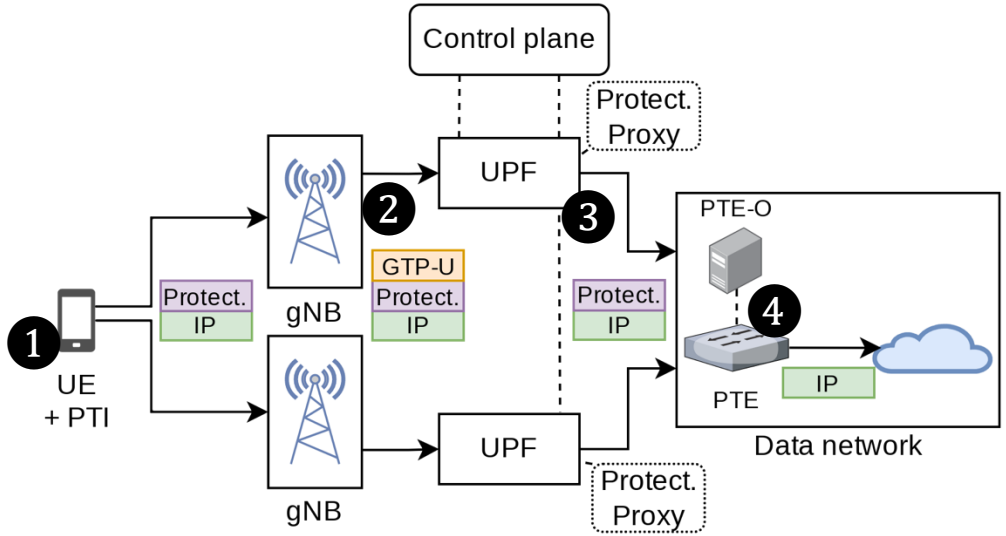


Packet Level Resilience for the User Plane (II)

Concept

1. PTI encapsulates with protection information and forwards to UPF (via gNB)
2. gNB adds GTP-U encapsulation and forwards to UPF
3. UPF removes GTP-U encapsulation and forwards to PTE
4. PTE applies elimination and ordering function and forwards to data network
   - Elimination function may be offloaded





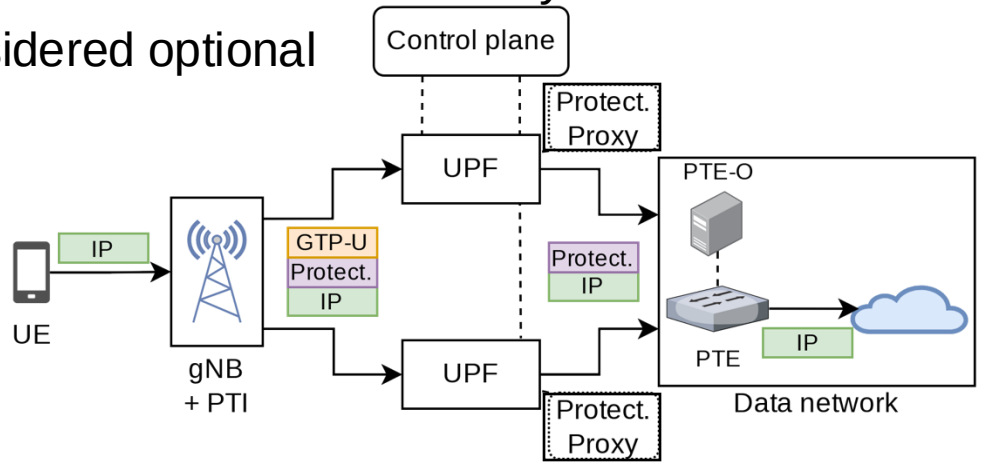
The Protection Proxy

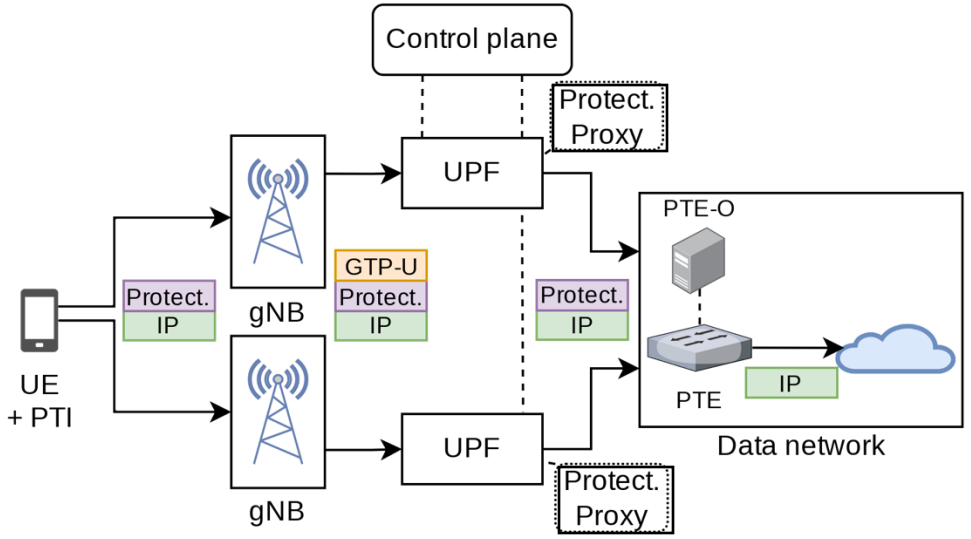
UPF may apply additional traffic engineering mechanisms based on IP header from UE

- Not directly accessible because of protection encapsulation
- → Employ a protection proxy to avoid modifications to UPF
  - Proxy parses protection and IP header
  - Applies traffic engineering mechanism based on that

Protection proxy and offloaded ordering function increase latency

- Not desired in an ultra-low latency environment
- → considered optional



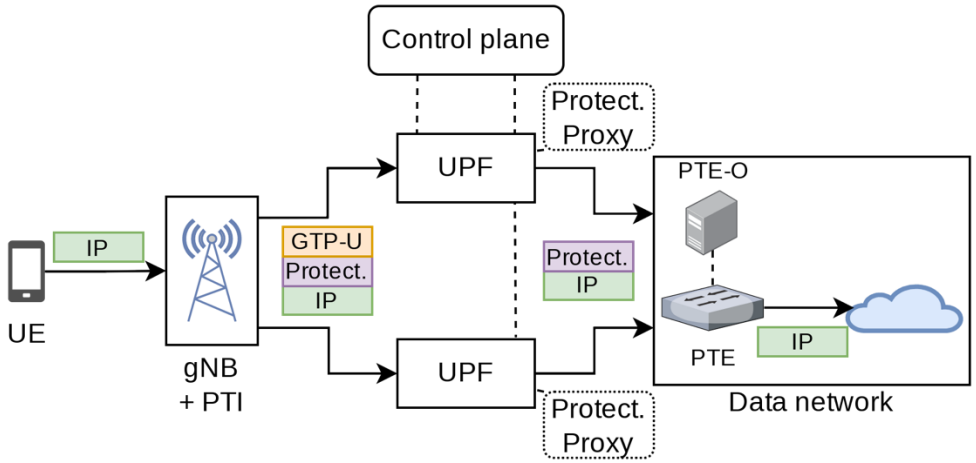


PTI Location (II)

PTI in the gNB

- Protects in case of a UPF failure
- Transparent for the UE
- gNB typically has more powerful hardware
- Replication is more feasible

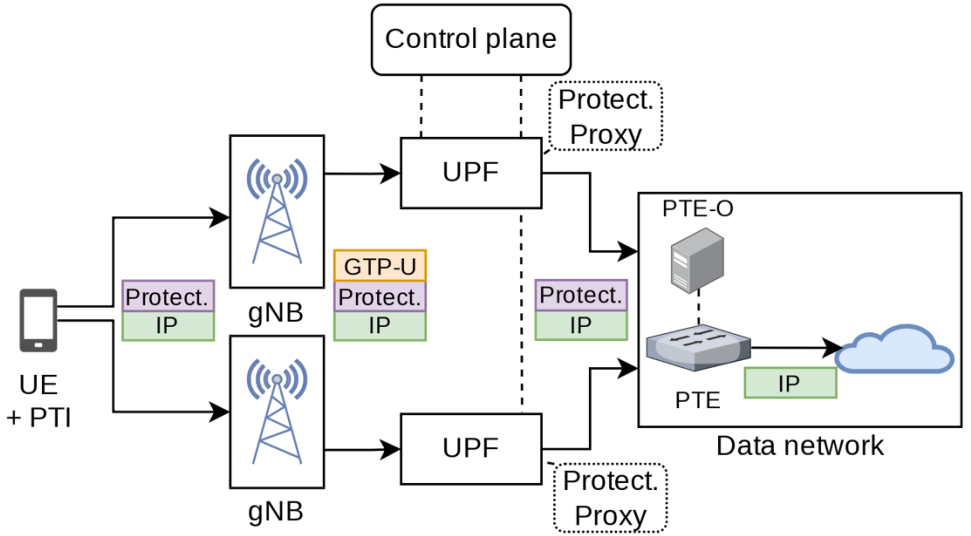
→ Less resilient but more feasible



PTI in the UE

- Protects in case of a UPF or gNB failure
- More load on UE
- UE must replicate and encapsulate
- Multiplies traffic on wireless link (not cost-efficient)

→ More resilient but also more expensive



Conclusion

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Existing 5G networking equipment is extended with a packet replication and elimination function

Two approaches

- Placing replication function into gNB
  - Less resilient but more feasible, requires additional standardization
- Placing replication function into UE
  - More resilient but also more expensive

Optional proxy for…

- Traffic engineering in UPF
- Ordering mechanism (packet buffer)

Future work

- Provide an implementation, e.g.,
  - Using P4 programmable hardware for replication and elimination
  - Using offloading techniques such as eBPF / DPDK for protection proxy and ordering function

Any Questions?

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