Mobile Edge Computing Platform Deployment in 4G LTE Networks: A Middlebox Approach

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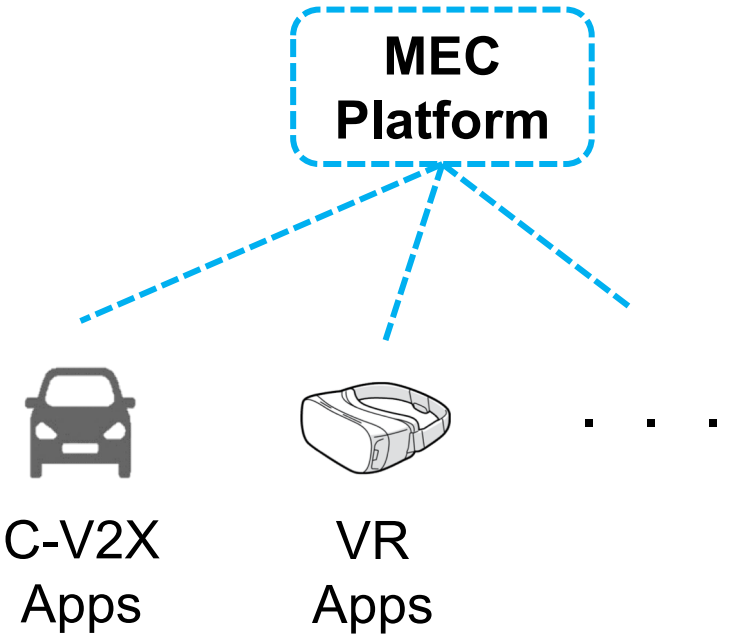
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Outline

- Introduction
- Background and Related Work
- Challenges and Design Ideas
- Prototype and Evaluation
- Conclusion

Introduction

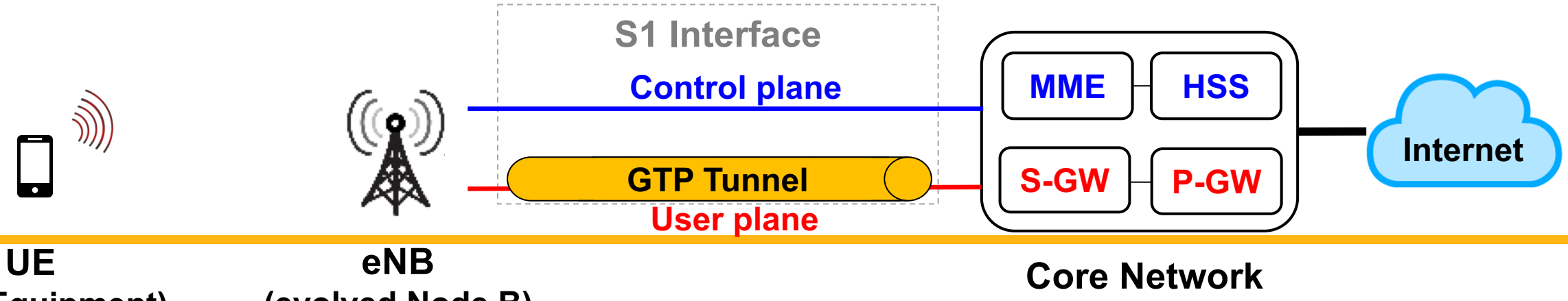
- Emerging low-latency apps in cellular networks
  - E.g., C-V2X (Cellular Vehicle-to-Everything), Virtual Reality (VR), etc.
- A key technology: Mobile Edge Computing (MEC)
  - Determined as a 5G feature by both ETSI and 3GPP
  - Providing a cloud computing platform at the network edge
- MEC: shortening latency with two major merits
  - Short end-to-end distance
    - Small propagation delay
    - No bottleneck/congestion from the Internet
  - Offloading services from the cloud



Background: 4G LTE Network

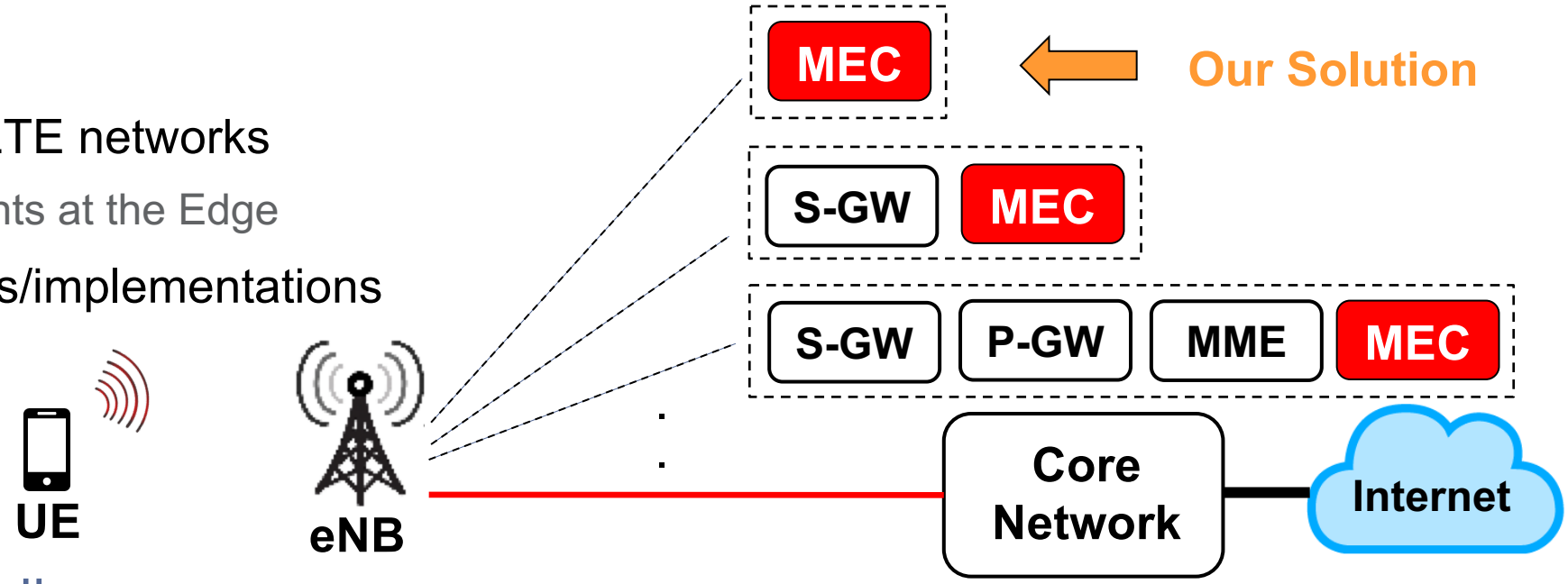
- Control plane: UE – RAN – MME/HSS
  - Functions: mobility, security, resource allocation
- User plane: UE – RAN – S-GW/P-GW
  - Routing data traffic between UE and Internet
  - Carried by GTP Tunnel
    - One tunnel is built for each UE's Internet traffic

MME: Mobility Management Entity
HSS: Home Subscriber Server
S-GW: Serving Gateway
P-GW: Packet Data Network Gateway
GTP: GPRS Tunneling Protocol



Related Work: MEC Deployment

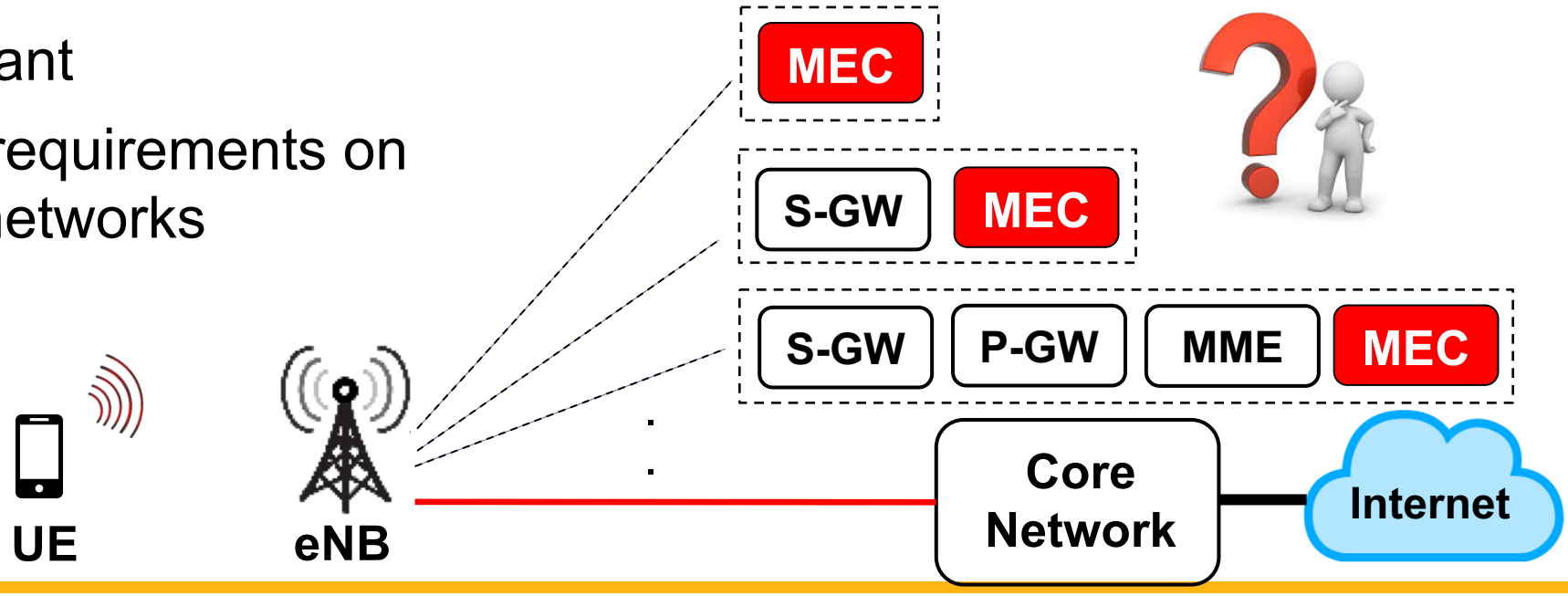
- ETSI standard[1]
  - Several options in LTE networks
    - Various components at the Edge
  - No concrete designs/implementations



- Other research studies
  - Several Surveys [2] [3] [4] : No examination of the MEC deployment in 4G networks
  - Existing deployment solutions[5] [6]: Not standard-compliant
    - Modifications on the eNB or/and the core network

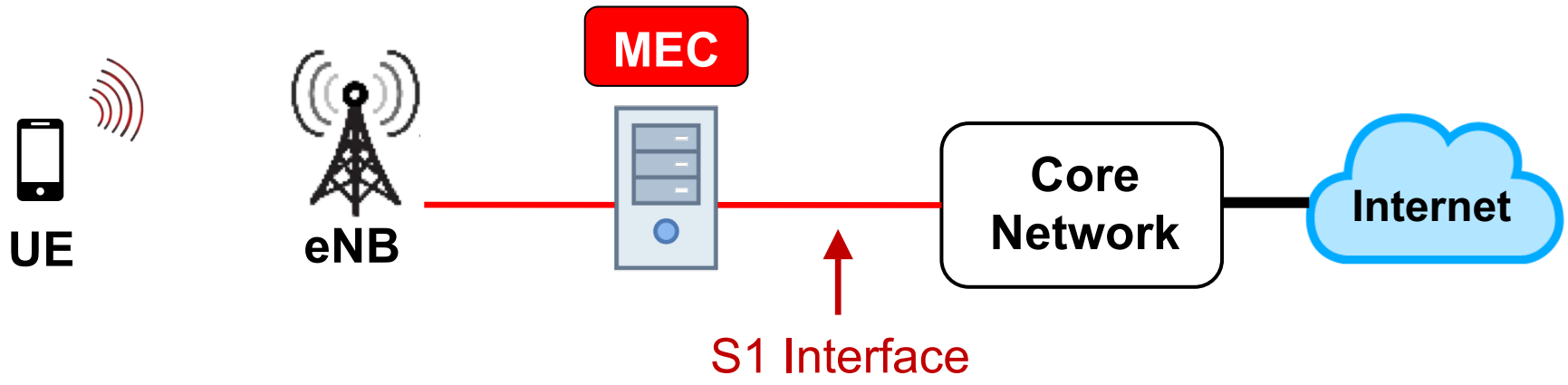
How to Deploy the MEC in LTE Networks?

- Goal: low costs, high deployment incentives
- Requirements
  - Standard-compliant
  - No modification requirements on eNB or/and core networks



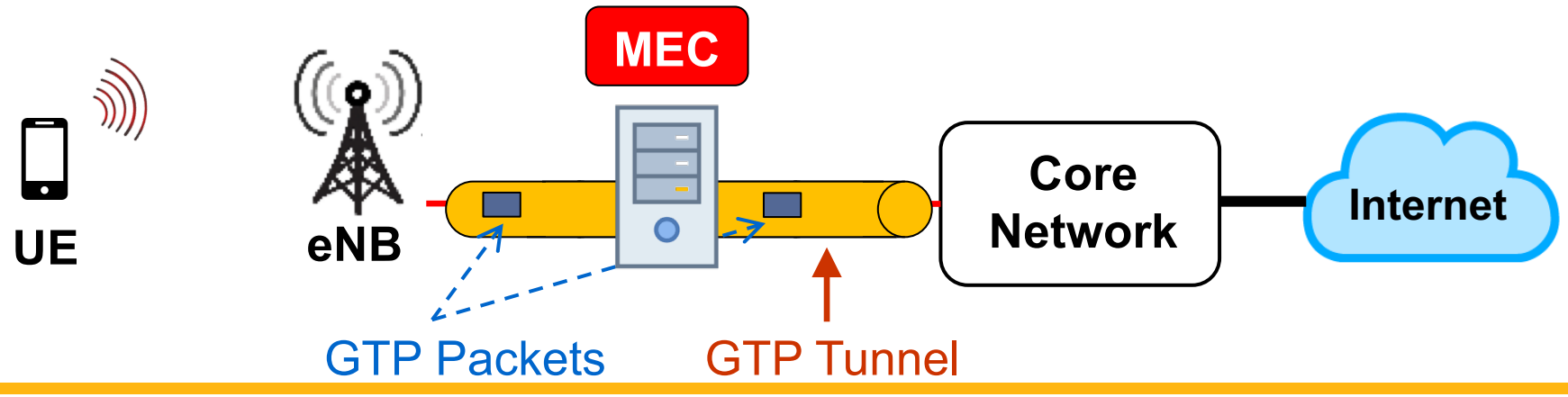
Key Idea: MEC Deployment as a Middlebox

- MEC platform sits on the S1 interface
  - Some traffic is routed to the MEC
  - The others pass through the MEC to reach the Internet
- A middlebox approach: transparent to the network architecture



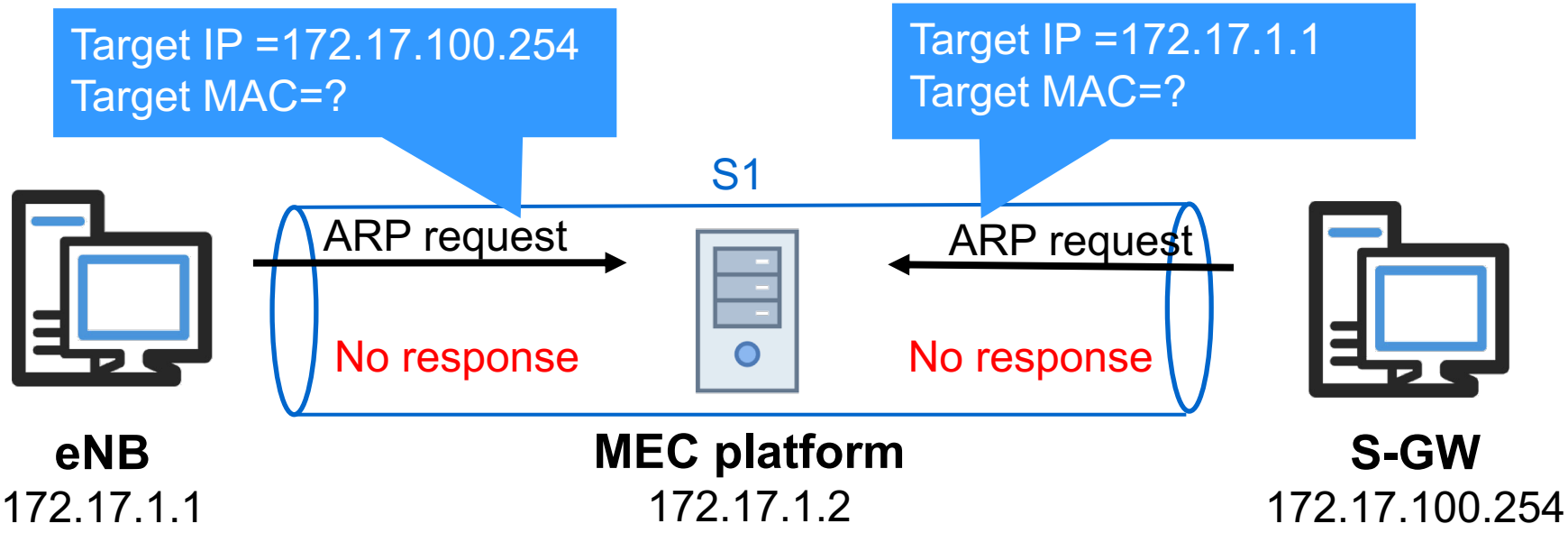
Challenges

- I. How to intercept and forward GTP packets?
- II. How to redirect data traffic to the MEC?
- III. How to enable MEC apps to serve GTP packets?
- IV. How to identify the GTP tunnel associated with each packet?



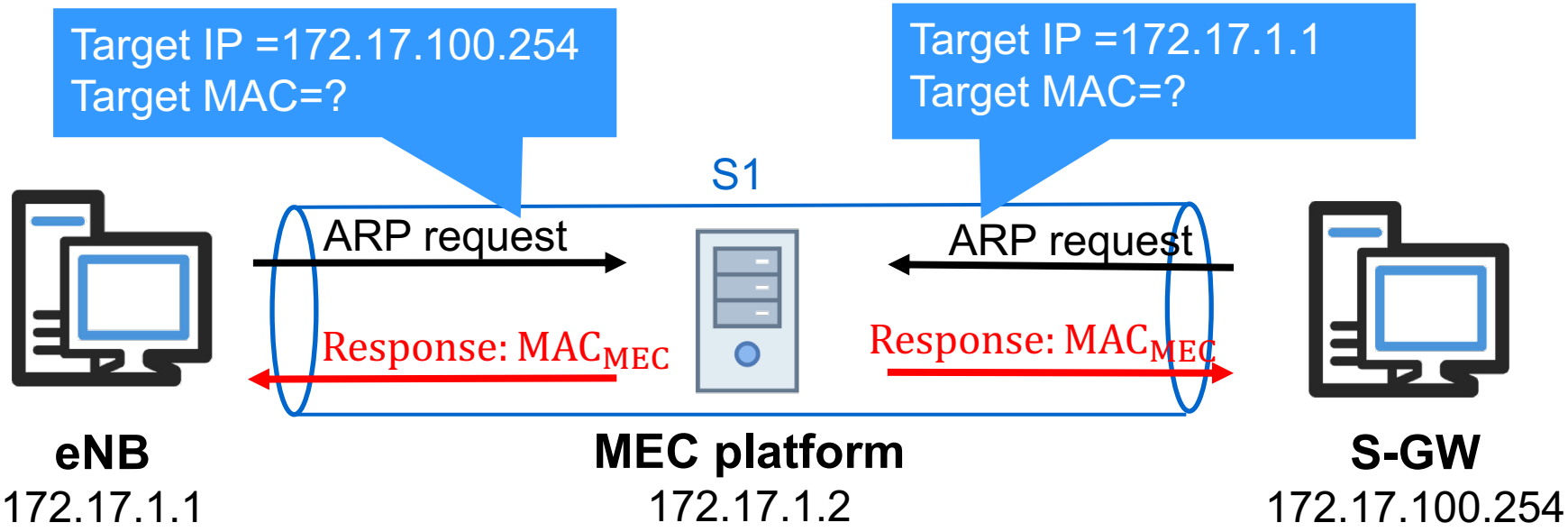
I. How to intercept and forward GTP packets?

- MEC divides S1 into two network segments
- No ARP response: eNB/S-GW doesn't know where to send packets



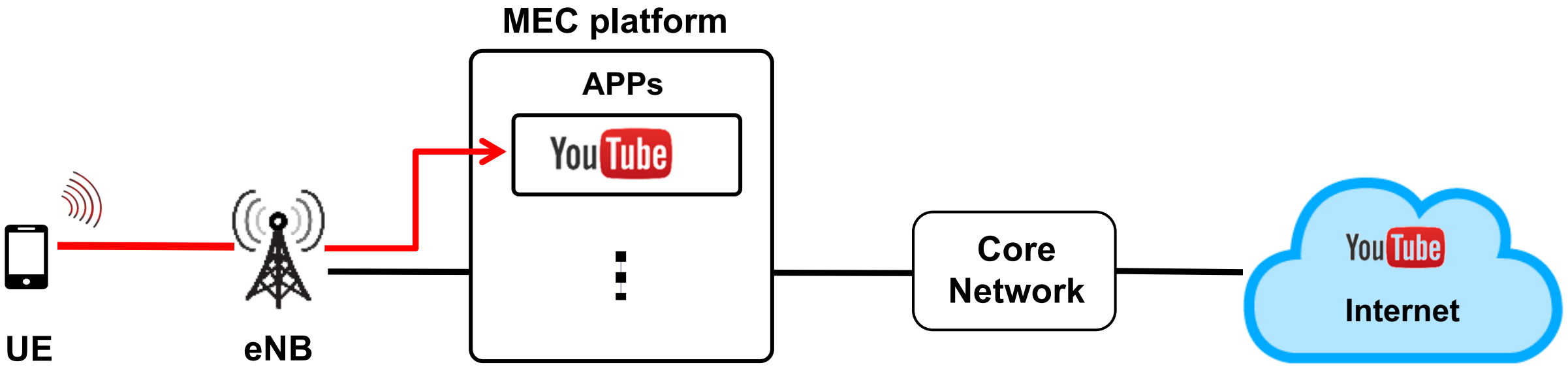
Solution: Proxy ARP

- MEC replies ARP requests
  - To eNB: MEC's MAC address ➔ S-GW's IP
  - To S-GW: MEC's MAC address ➔ eNB's IP



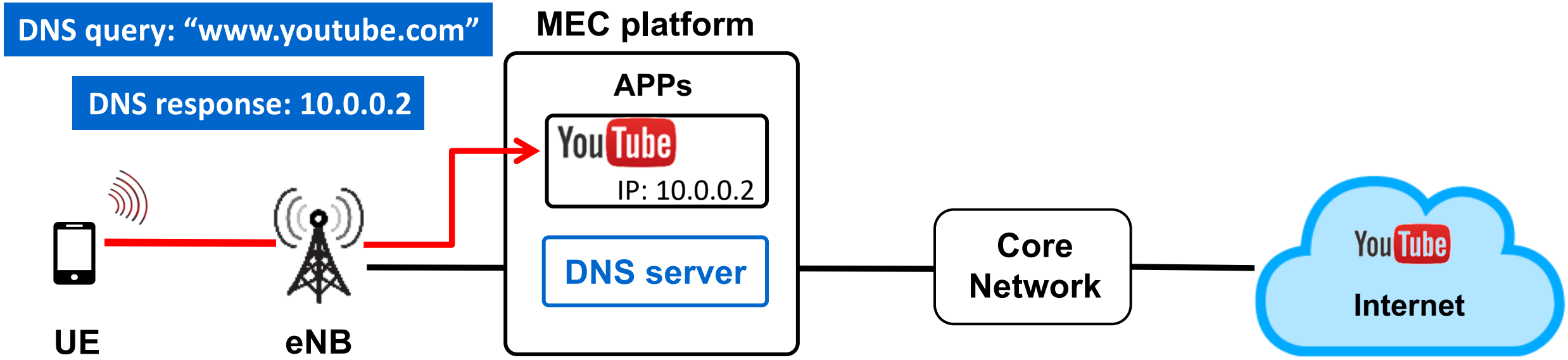
II. How to redirect data traffic to MEC?

- MEC needs to redirect UE's data packets to its app servers
  - Instead of forwarding them to the Internet
- Keep both apps and their servers work as usual



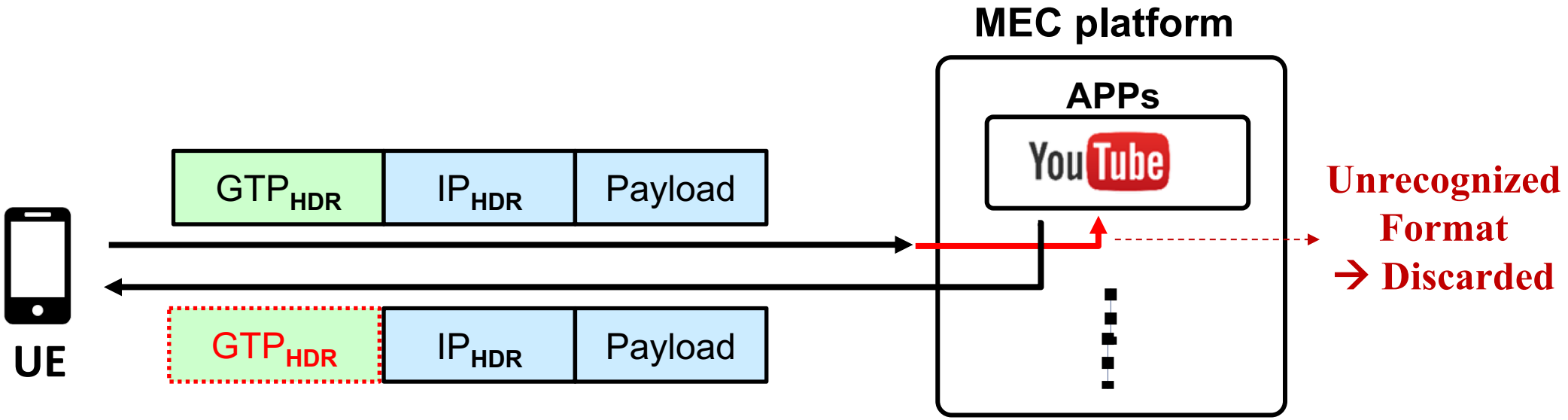
Solution: Traffic Redirection via DNS

- Intercept all DNS packets from UE
- Return local IP addresses in response to apps' domain names



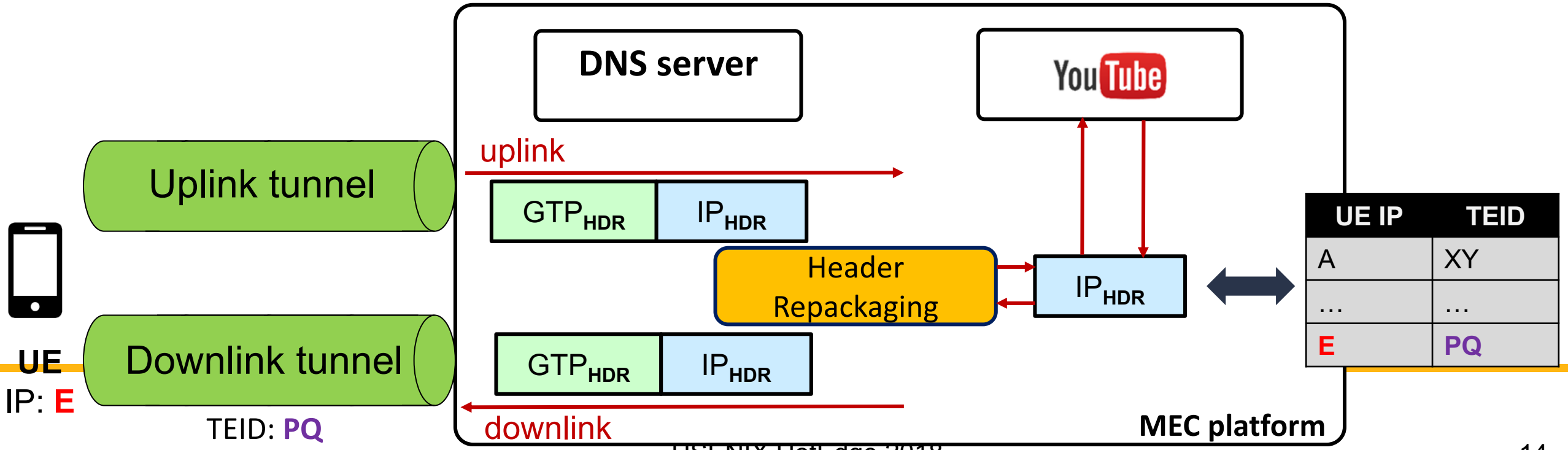
III. How to enable APPs to serve GTP packets?

- IP packets are carried by GTP tunnels
- App servers don't recognize GTP packets



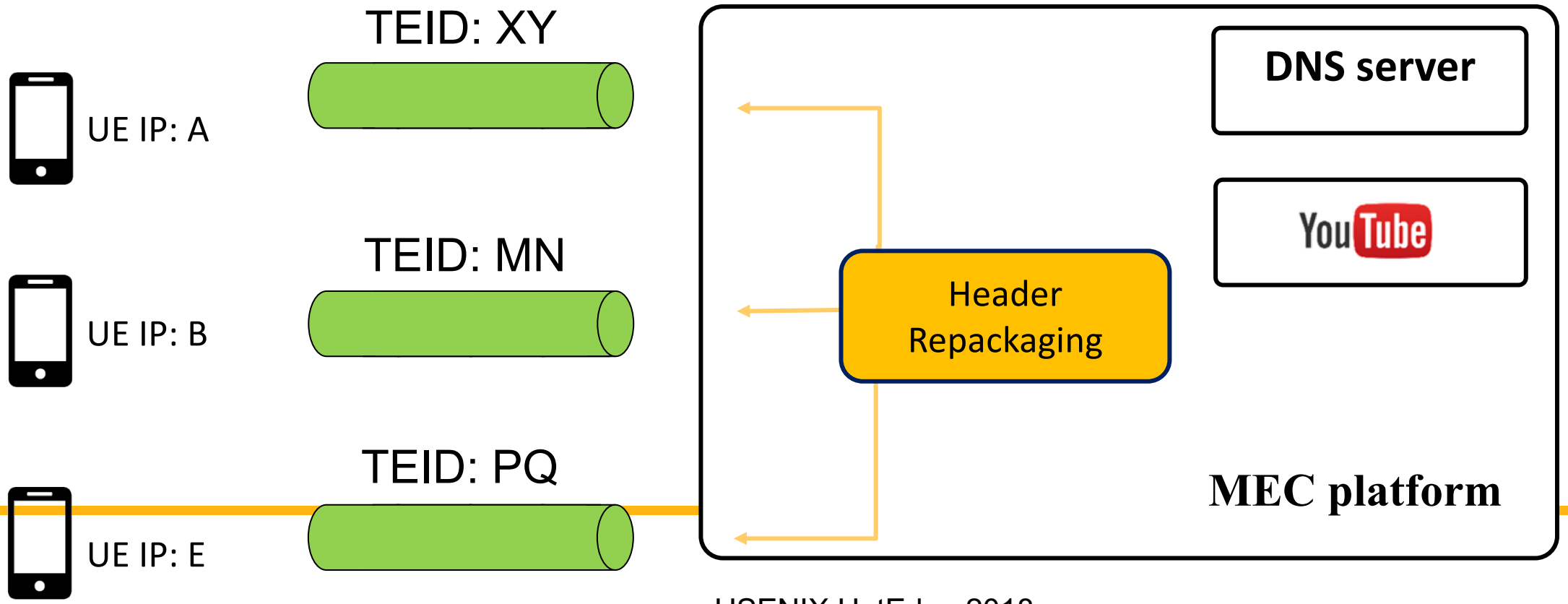
Solution: GTP header repackaging

- Strip off GTP headers before redirecting
- Maintain a dynamic table for each UE's tunnel
- Encapsulate GTP headers back after app server respond



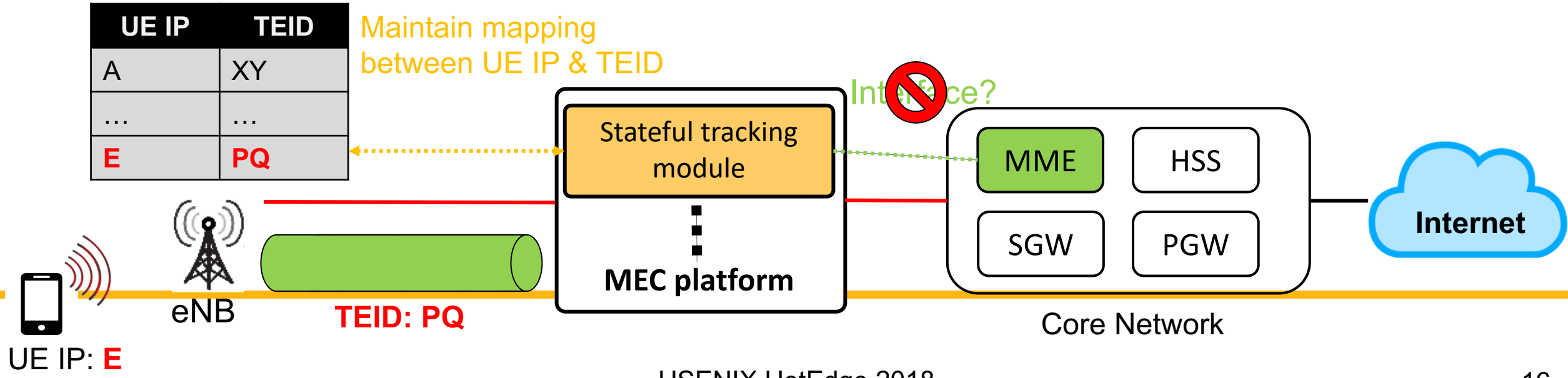
IV. How to identify tunnels for each UE

- GTP tunnels are dynamically built for each UE
- Encapsulating requires the correct mapping between IP and tunnel ID

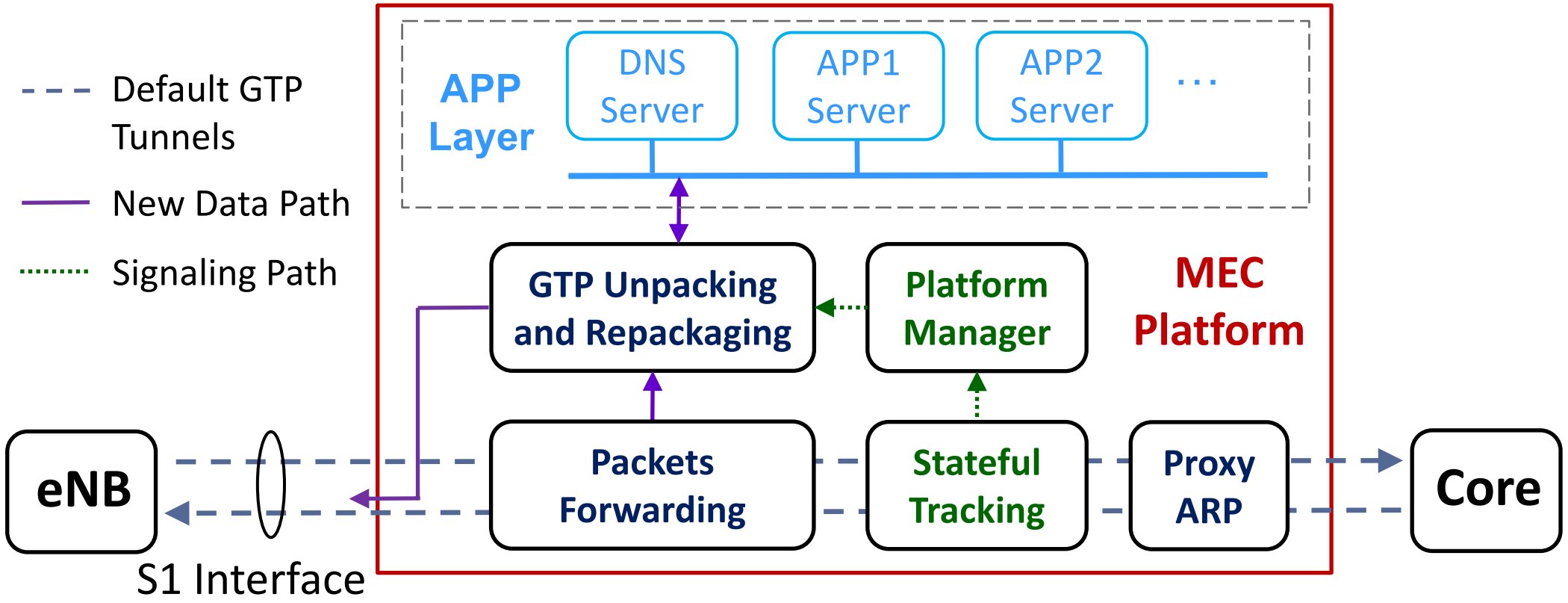


Solution: Stateful tracking of GTP tunnels

- UE info are maintained in the MME
- Prevent changes to the CN: communication between MEC and MME is prohibited
- Do stateful tracking when there is outgoing traffic instead

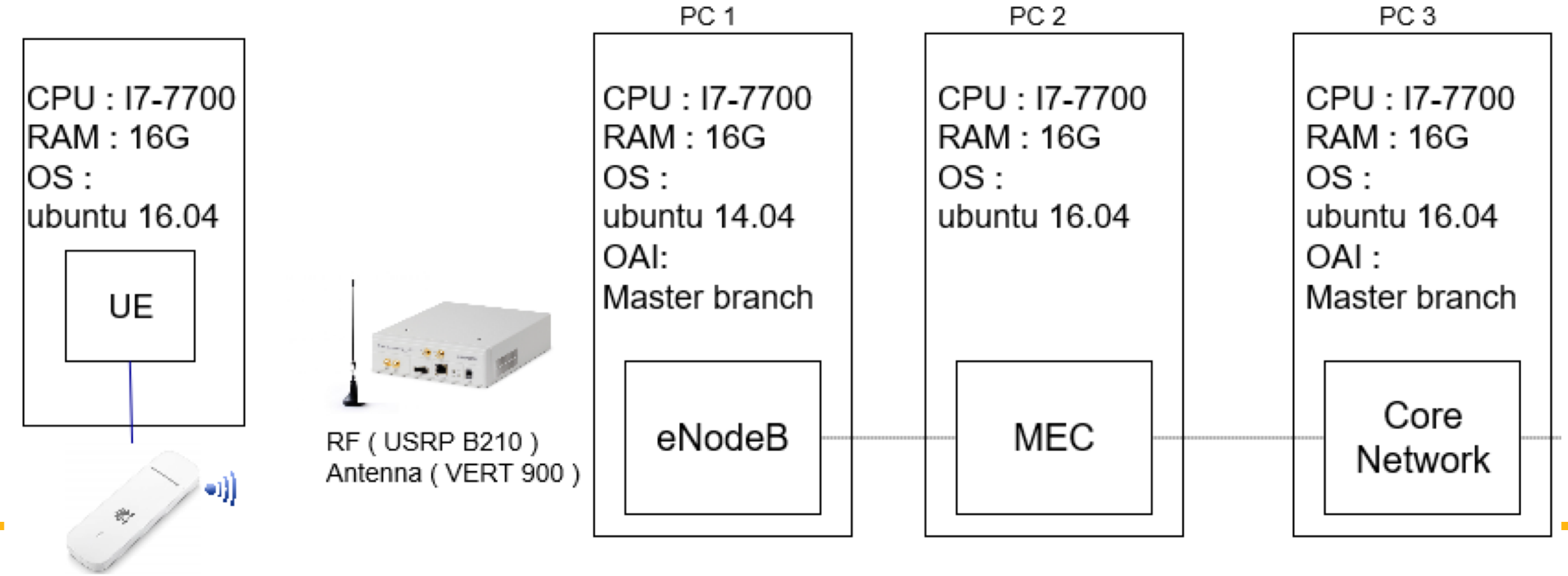


MEC Platform Architecture



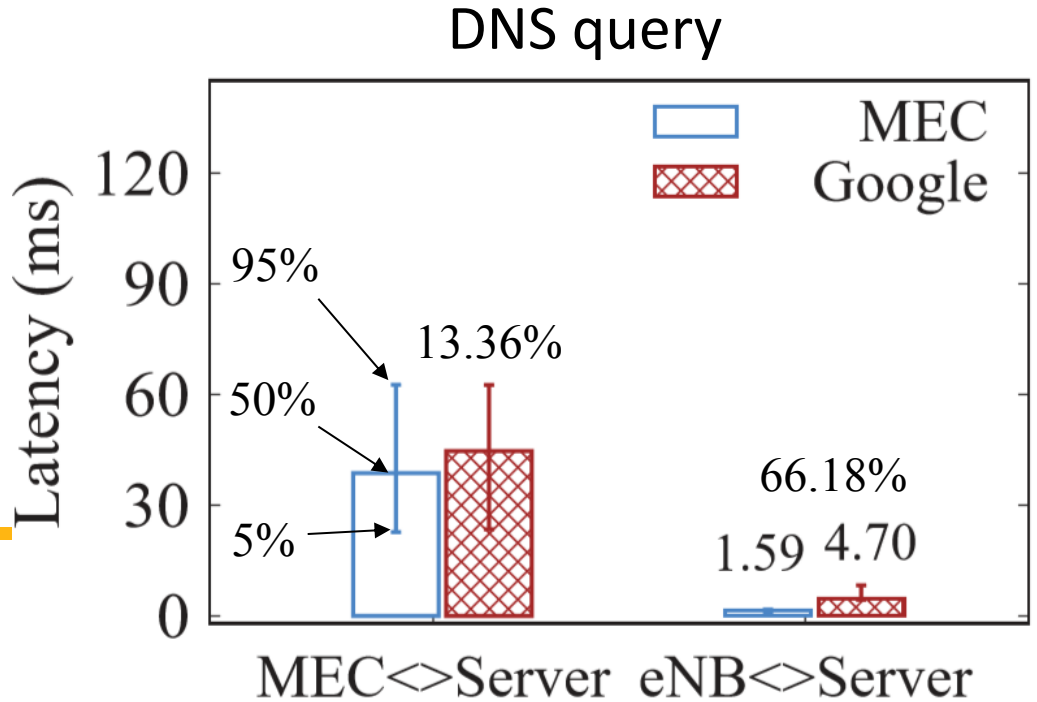
Prototype

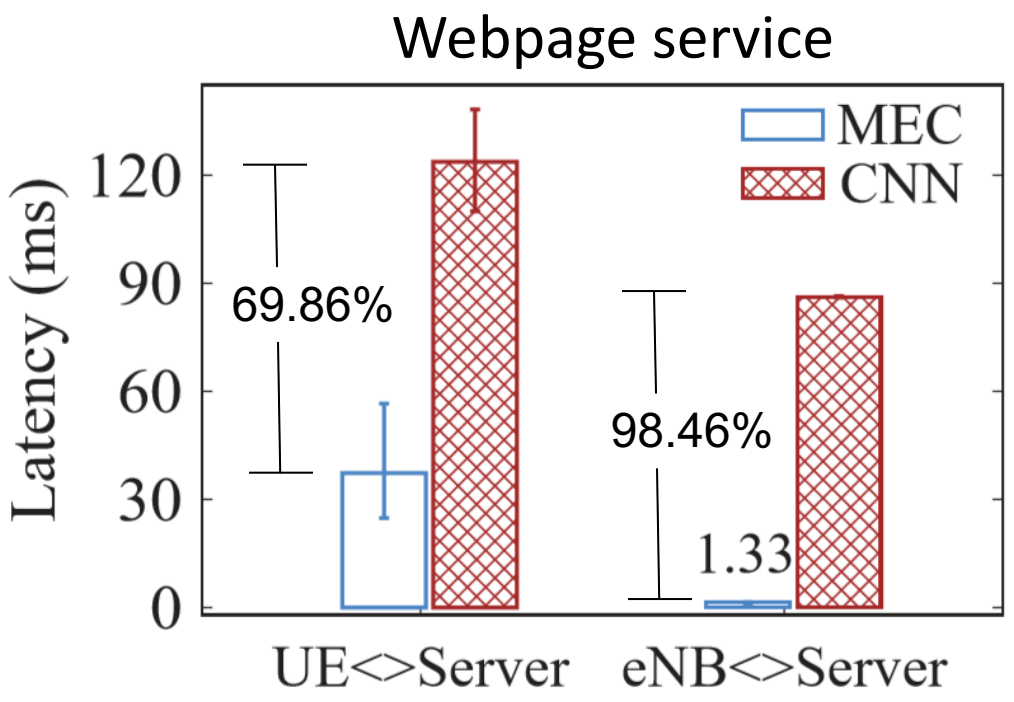
- Prototype with OpenAirInterface (OAI) cellular platform



Evaluation – Experiment #1

- Compare webpage response (CNN news) between cloned web server on MEC platform and on Internet
  - Results in different percentile(5%, 50%, 95%)
  - Overall latency vs. radio-link-omitted latency



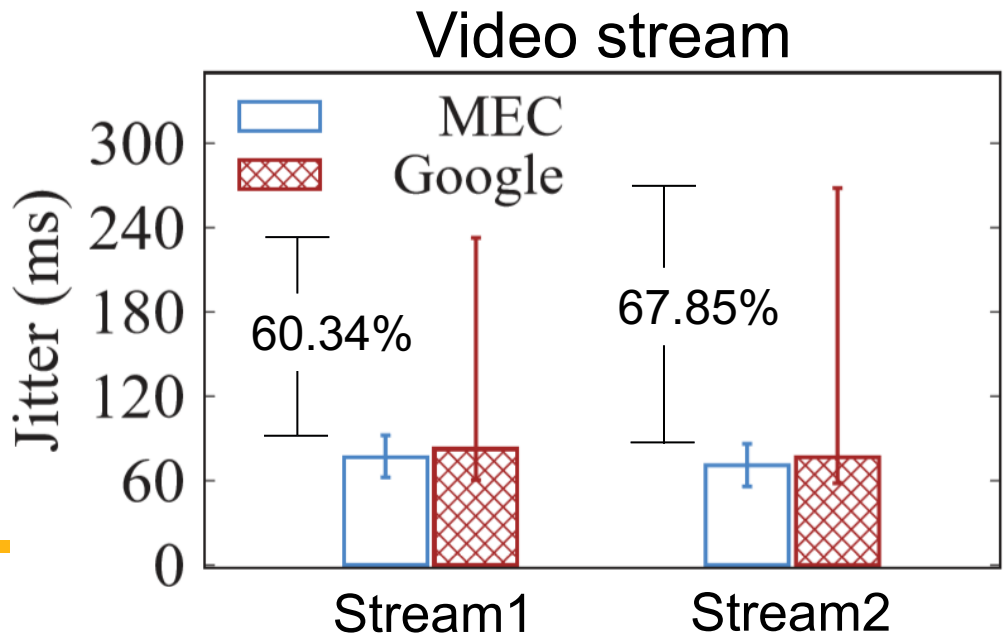


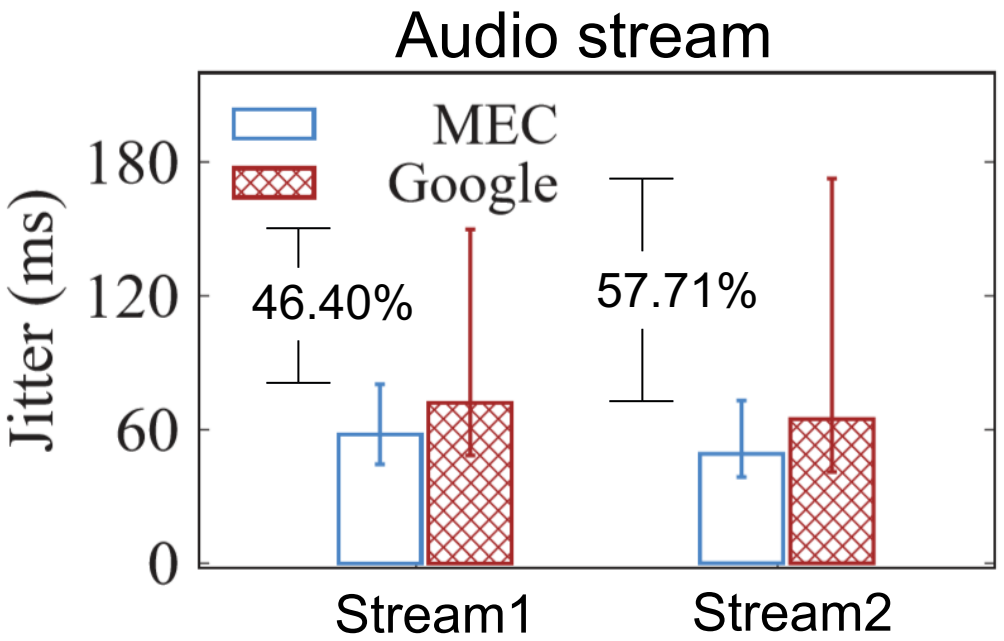
Evaluation - Experiment #2 (1/2)

- Video streaming from MEC and from Google Cloud Platform(GCP)
  - Using VLC media player
- Experiment settings:
  - RTP protocol
  - Streaming settings
    - Video: H264 codec, 24fps, 720p quality
    - Audio: MPEG codec, 128K bitrate

Evaluation - Experiment #2 (2/2)

- Results:
  - Stream 1: 512K video bitrate; Stream 2: 1M video bitrate
  - Packet jitter in different percentile





Discussion

- Scalability Challenges
  - Computing power demand for GTP packets
  - Context management for different eNBs
- Security and Billing
  - Third party content provider could imply malicious applications
  - Traffic does not travel through CN so billing and access control is necessary
- Mobility Management
  - Migrate application states and UE context during handover

Conclusion

- ✓ Enabled MEC with a middlebox approach in Cellular Networks
  - ➢ A Standard compliant solution
- ✓ Effectiveness of latency reduction
- ✓ Can be a reference design of the 5G MEC

Concluding Remarks

- A middlebox approach of MEC deployment in Cellular Networks
  - Standard-compliant, low costs, high deployment incentives
- Open issues
  - Scalability challenges
  - Multiple MEC apps and their state transfers
  - Mobility management
  - Security and billing
  - Fault tolerance
- Limitation: S1 interface cannot be confidentially protected
  - 3GPP standard: this confidentiality protection is vendor-specific
  - It is usually disabled by default

Thank you for your attention
Questions?

What if confidentiality protection is enabled on S1 interface?

- Enabling confidentiality protection on S1 interface is based on the operator's choice
- In practice, S-GW and eNB are usually placed in physically secured environment
- If ciphering function is enabled, operators need to allow MEC to acquire the security context of the S1 interface

Reference

[1] ETSI white paper 24: *MEC deployment in 4G, 5G networks*

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[4] MACH, P.,AND BECVAR, Z. *Mobile Edge Computing: A Survey on Architecture and Computation Offloading*. IEEE Communications Surveys and Tutorials 19, 3 (2017), 1628–1656.

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