Enabling Flexibility of Traffic Split Function in LTE-WiFi Aggregation Networks through SDN

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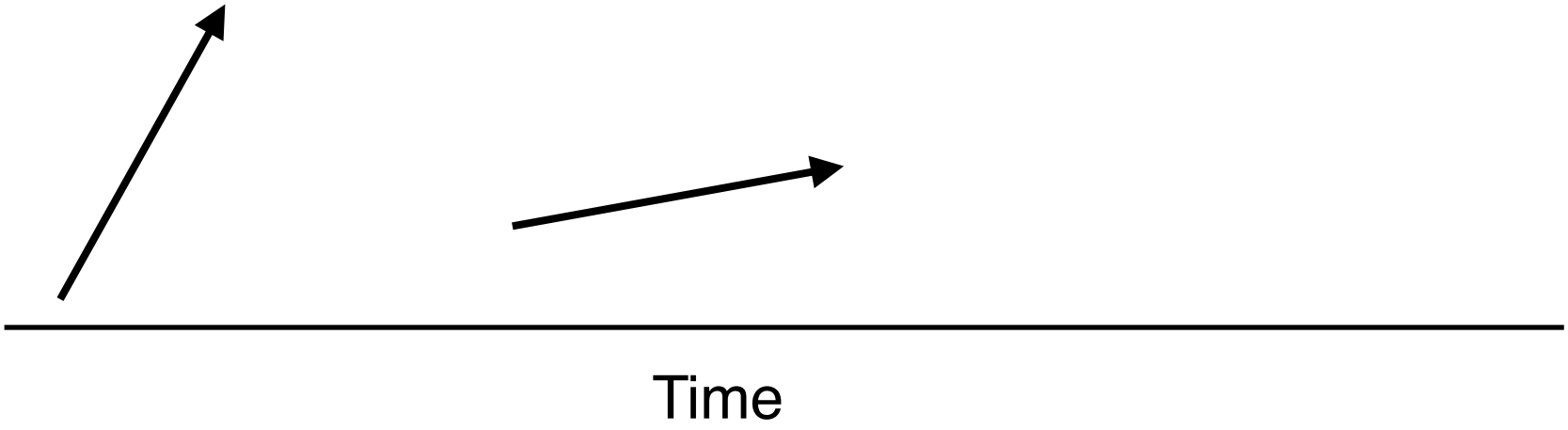
Trends in current cellular networks



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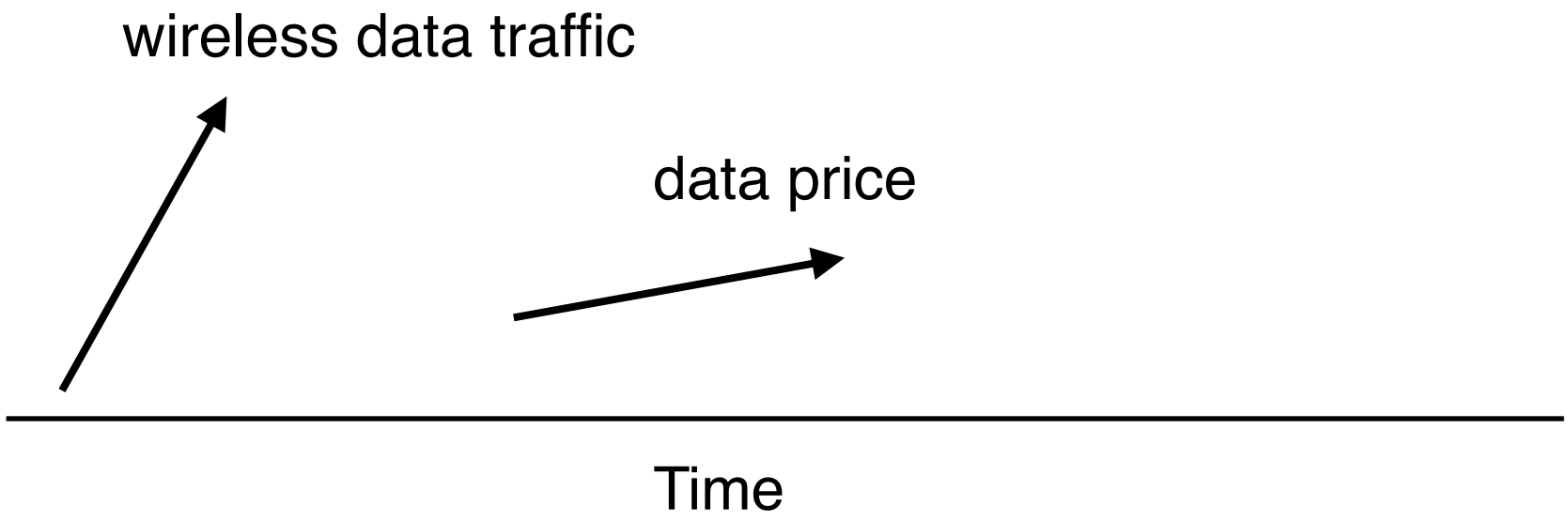

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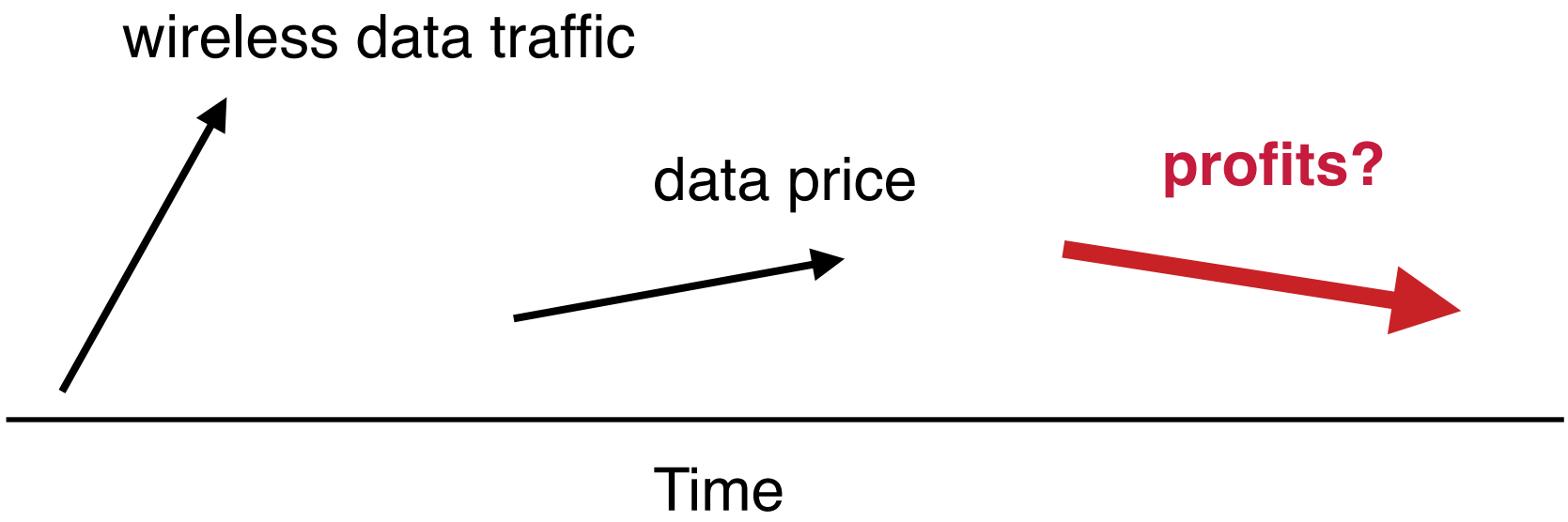

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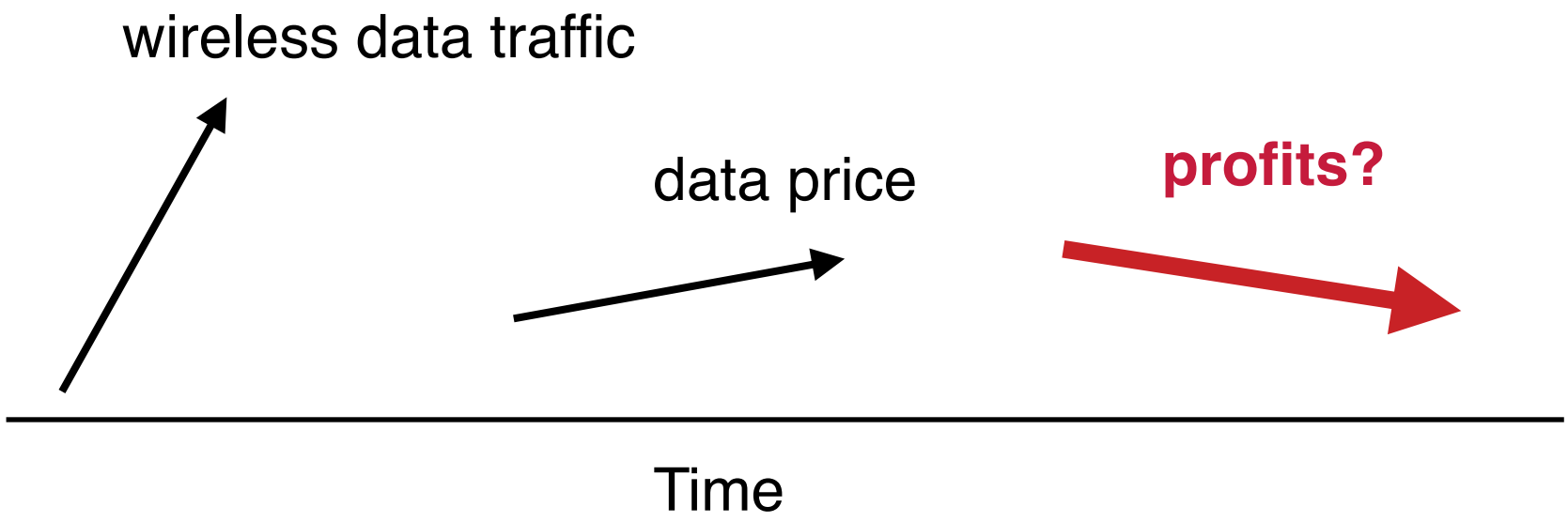
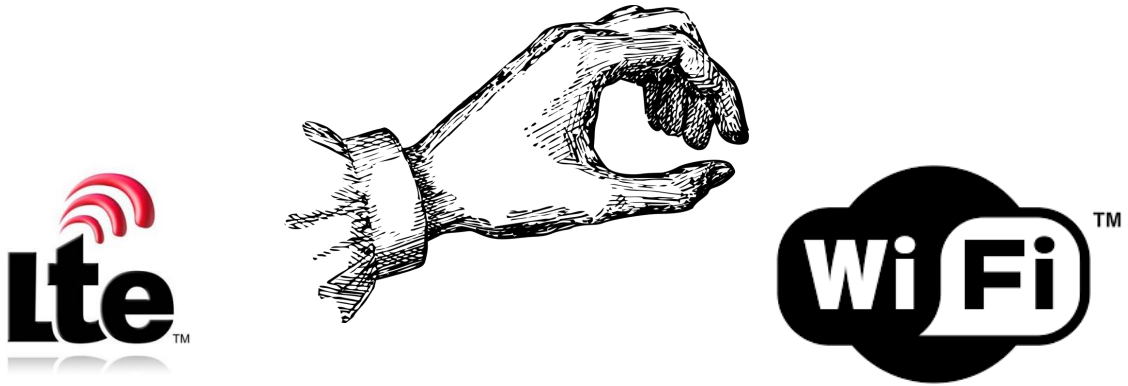


- Mobile Network Operators need cost-effective solutions for capacity expansion

LTE operators' interest in unlicensed operation



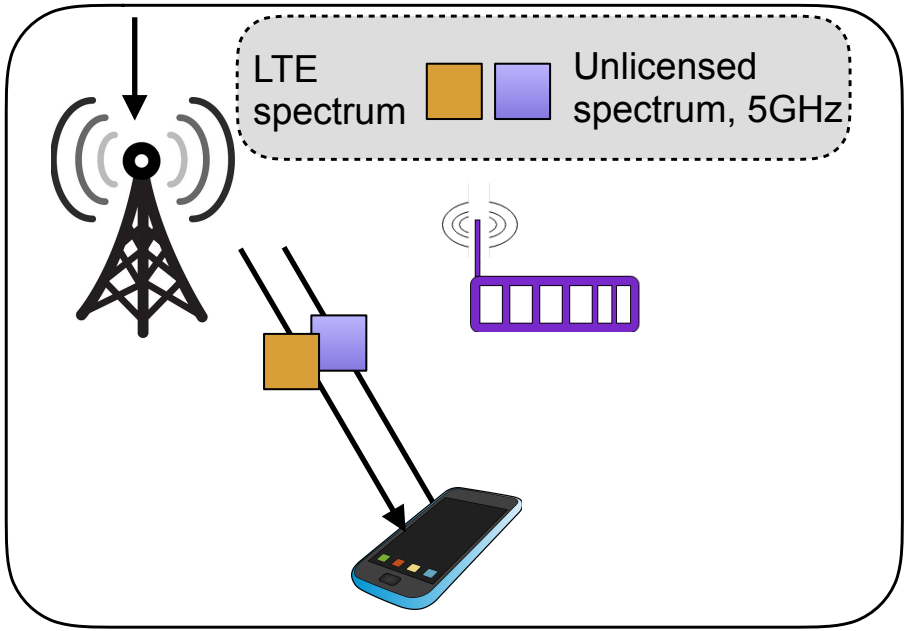
- Spectrum: free resource (no license fees)
- Unlicensed WiFi network: ubiquitous infrastructure, mature technology well accepted by public

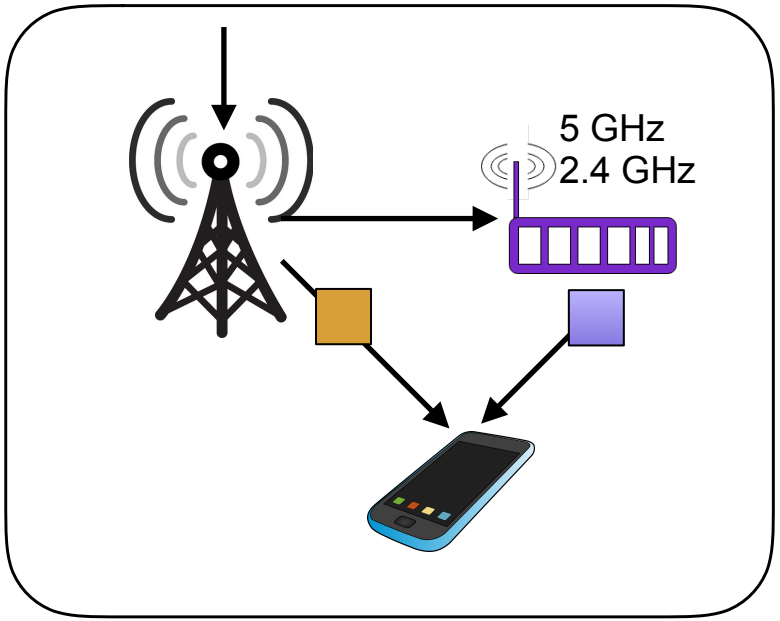
Several options to use unlicensed spectrum

- Spectrum of WiFi
  - ✓LTE-Unlicensed,
  - ✓Licensed-Assisted Access LAA,
  - ✓MulteFire
- WiFi itself
  - ✓LTE/WiFi aggregation LWA
  - ✓Wifi offloading

Several options to use unlicensed spectrum

- Spectrum of WiFi
  Coexistence is a big challenge!
- WiFi itself
  Lower throughput improvement





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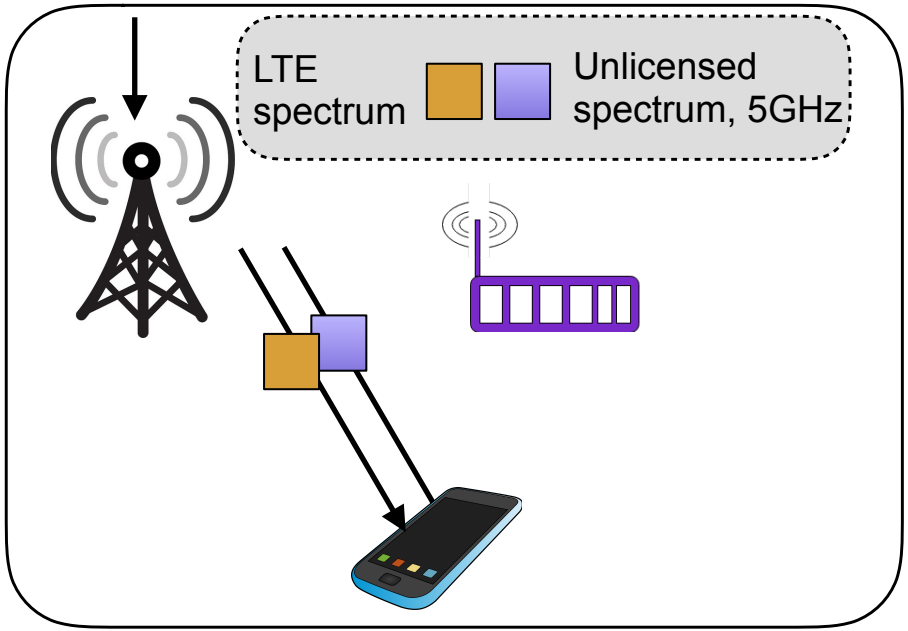
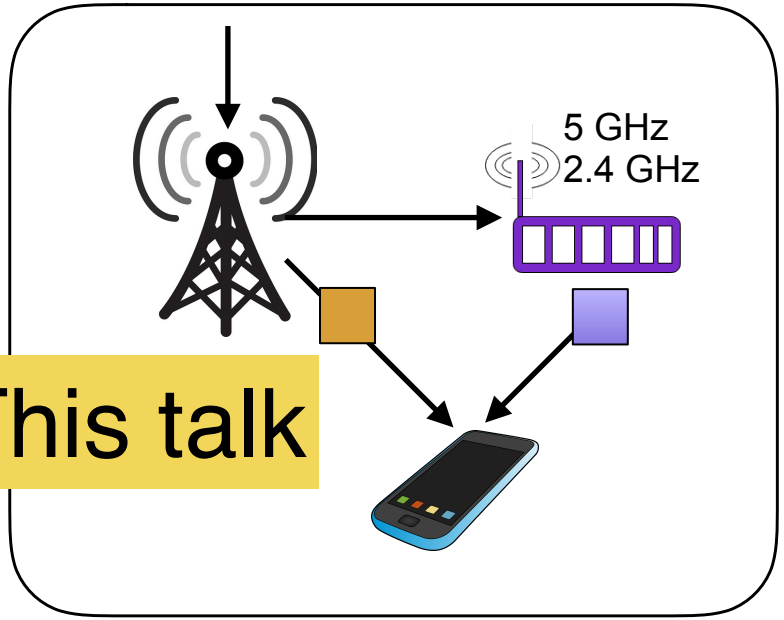
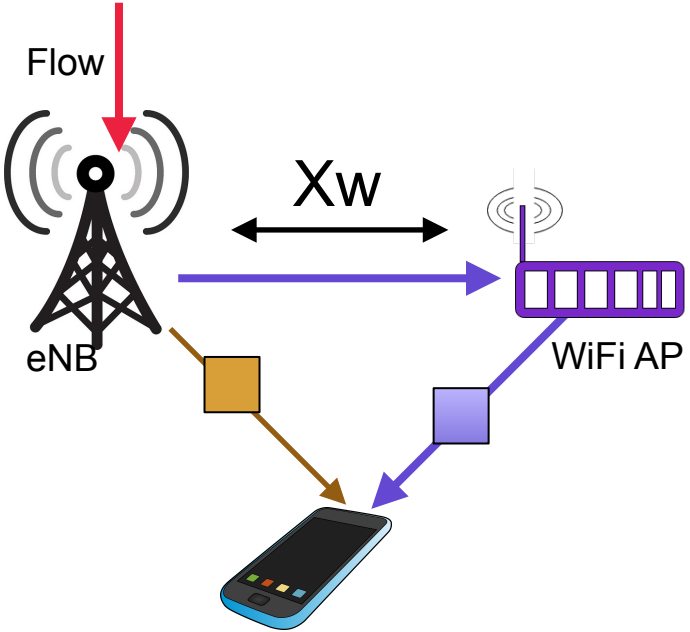




LWA: LTE-WiFi Aggregation



- 3GPP Release 13, dual connectivity
- Already existing **carrier-WiFi** APs
- Direct interaction between the eNB and WiFi
- Traffic splitting at the eNB
- Xw: data and control messaging
- How to split the traffic?

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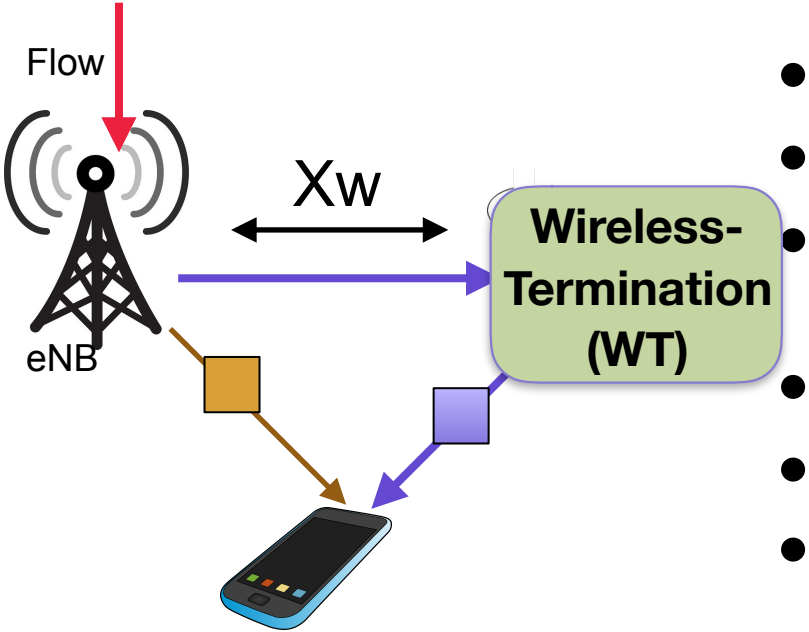

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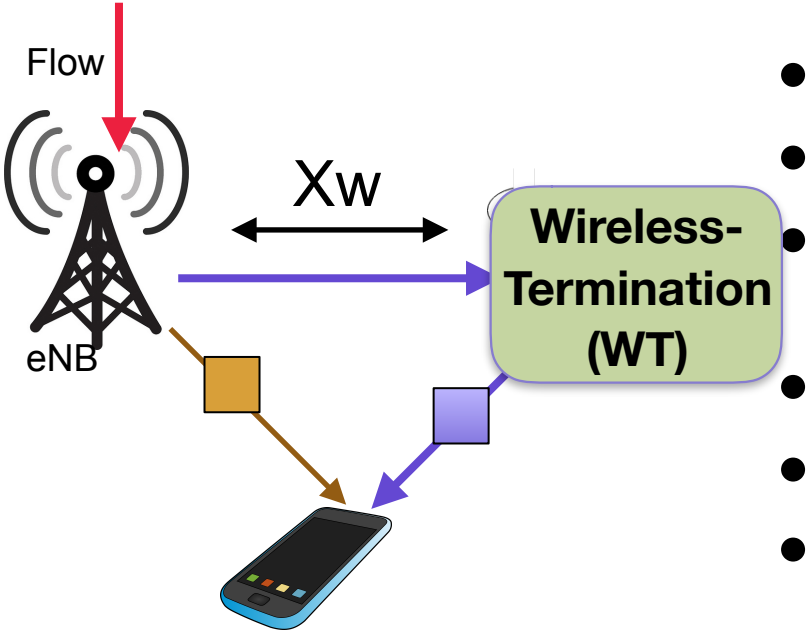

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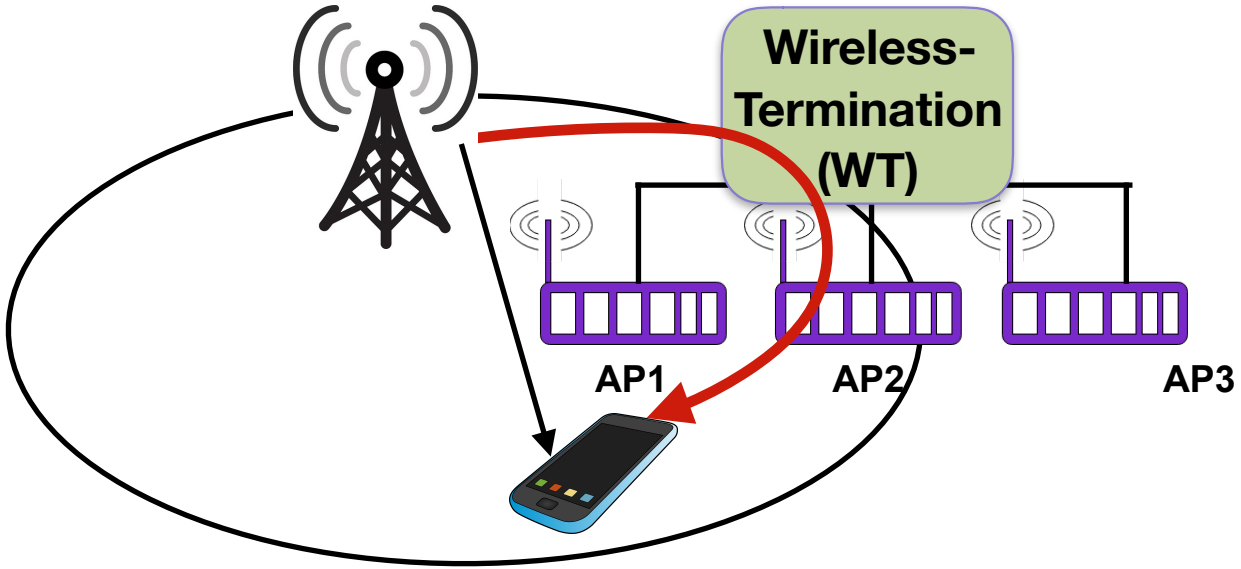
LWA does not define how this splitting should be performed.

Traffic splitting might be suboptimal



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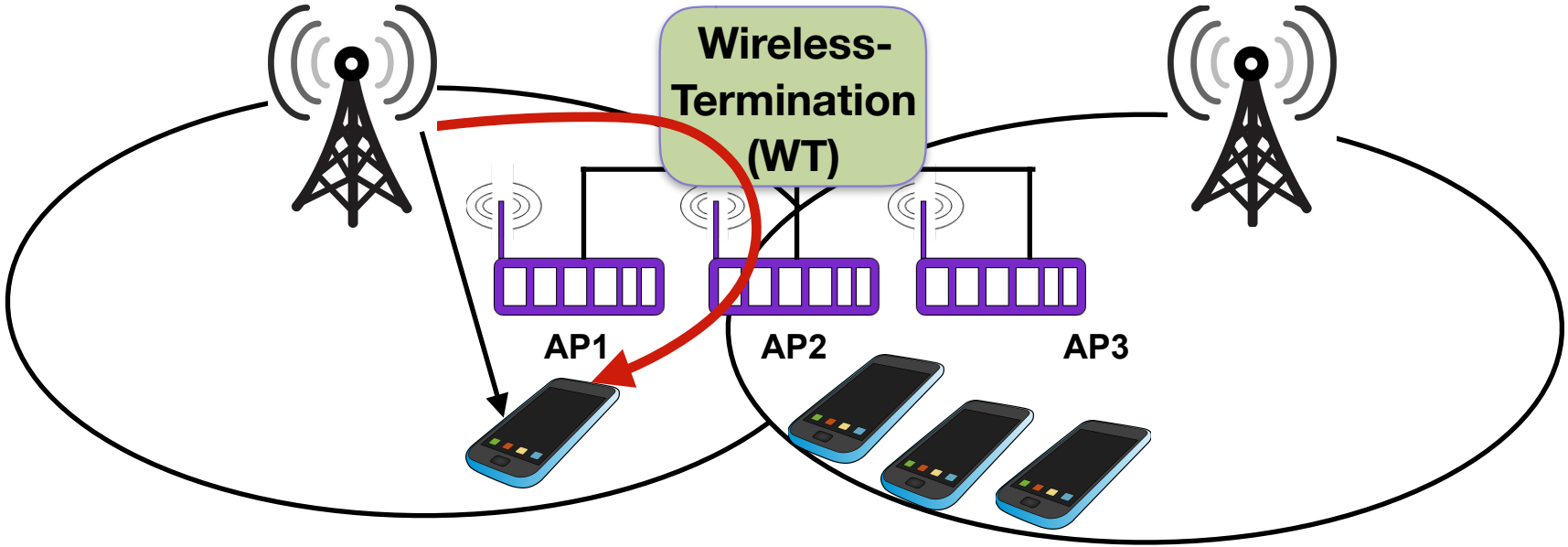

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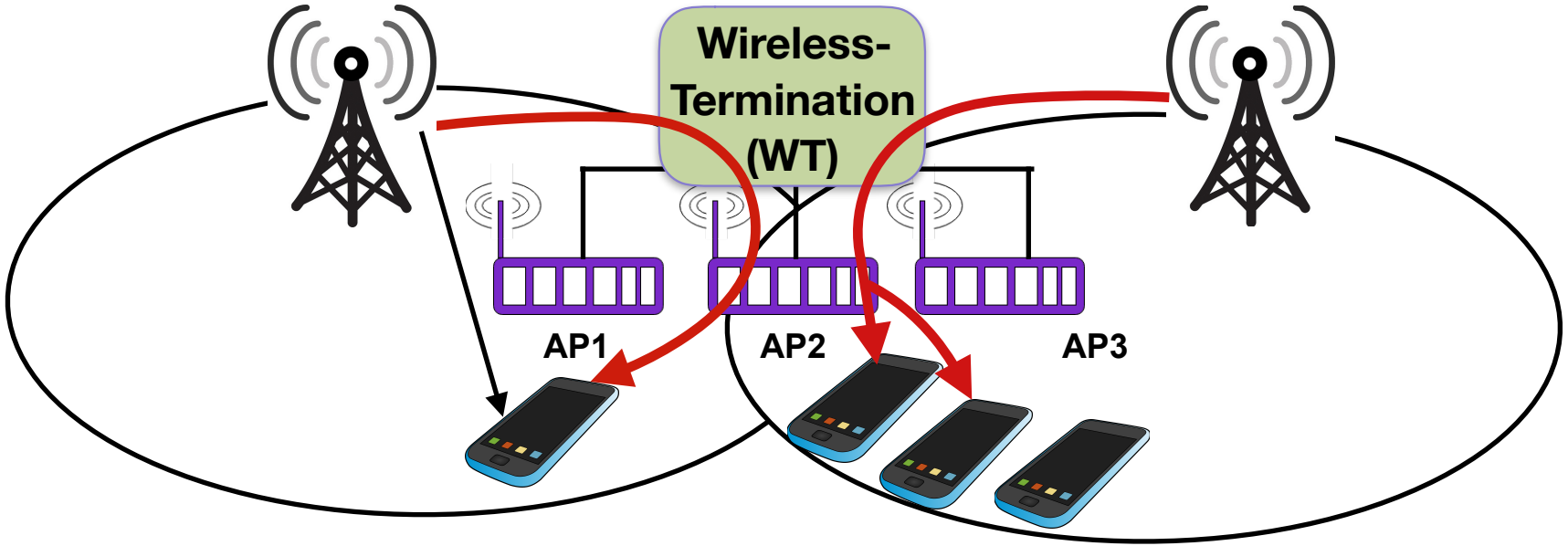

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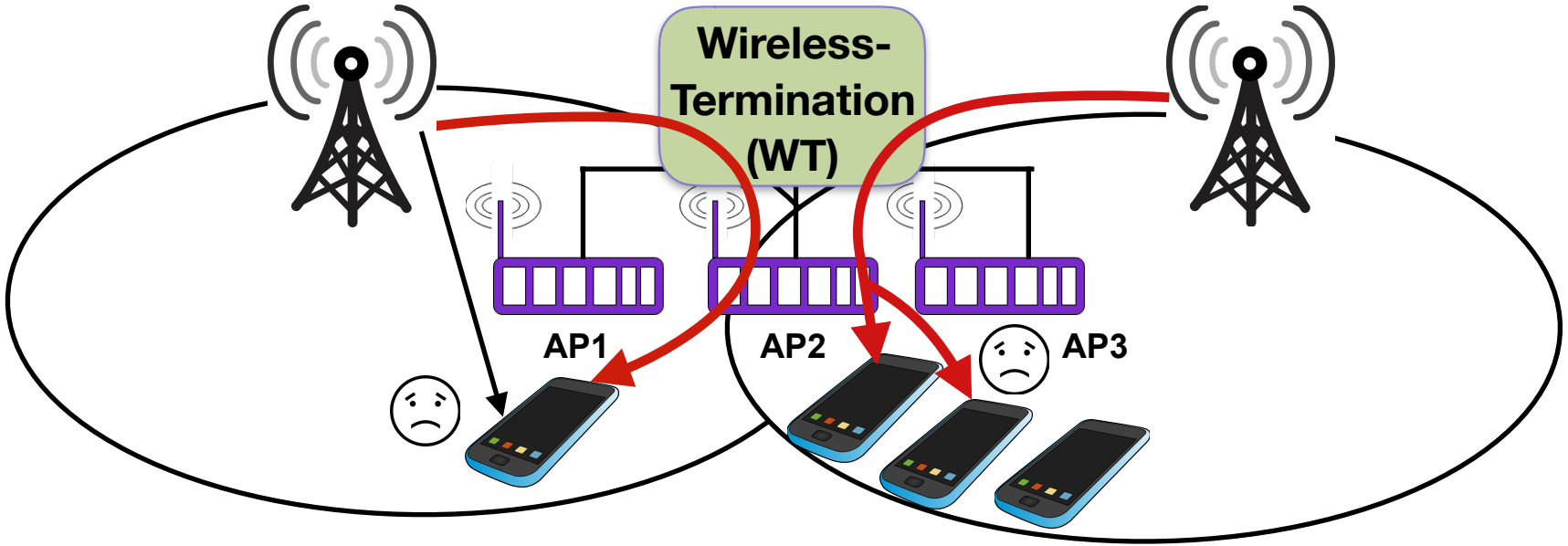

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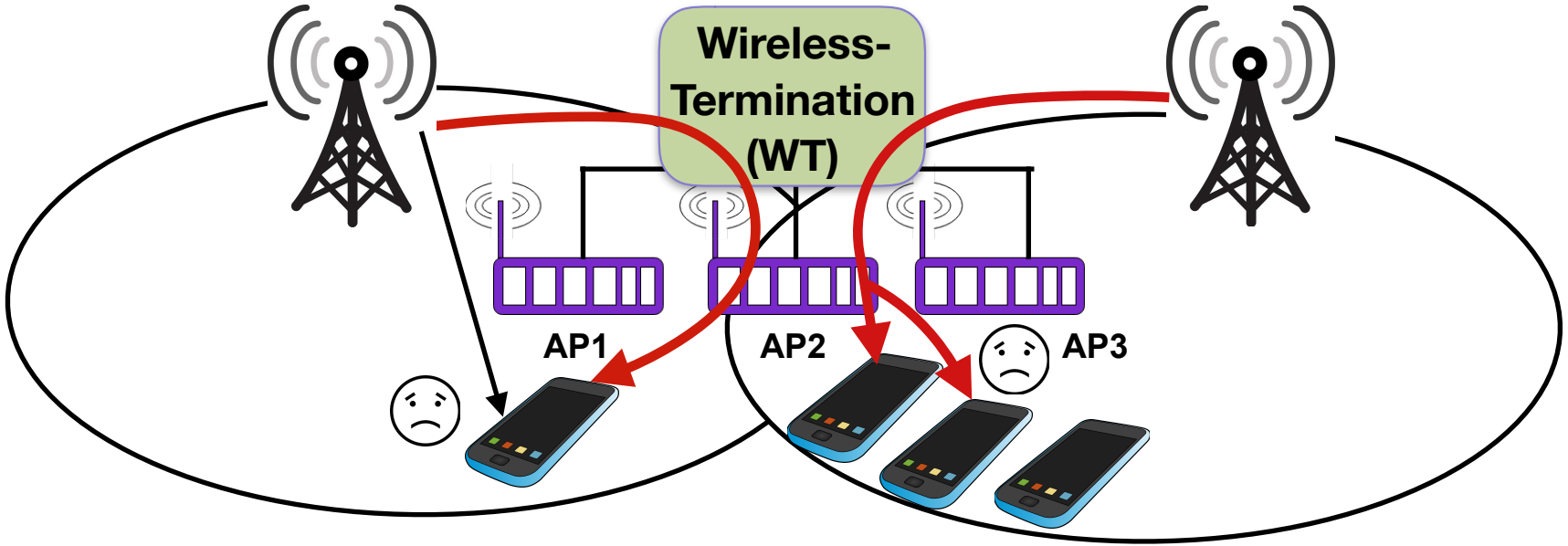
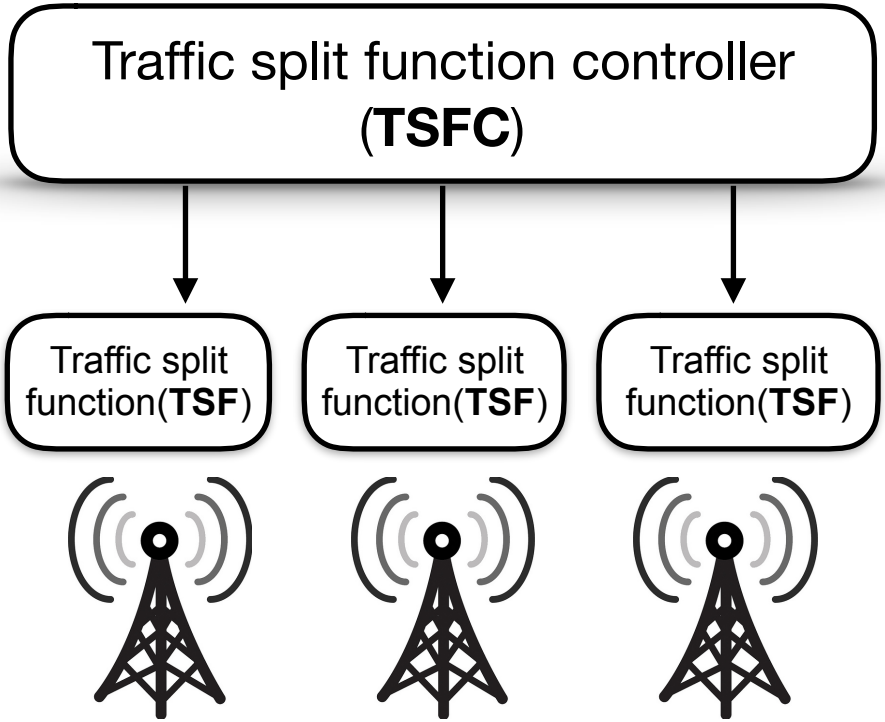


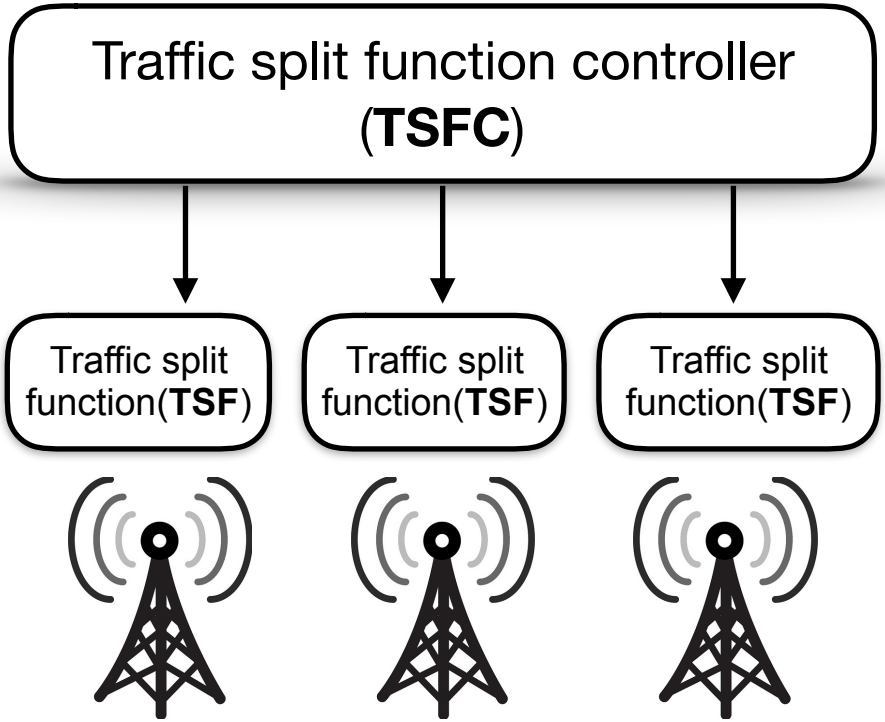
- Expected capacity cannot be realized!
- Multiple eNBs connected to the same AP

Central the traffic split function decision



- Our idea: centralise the traffic split function decision

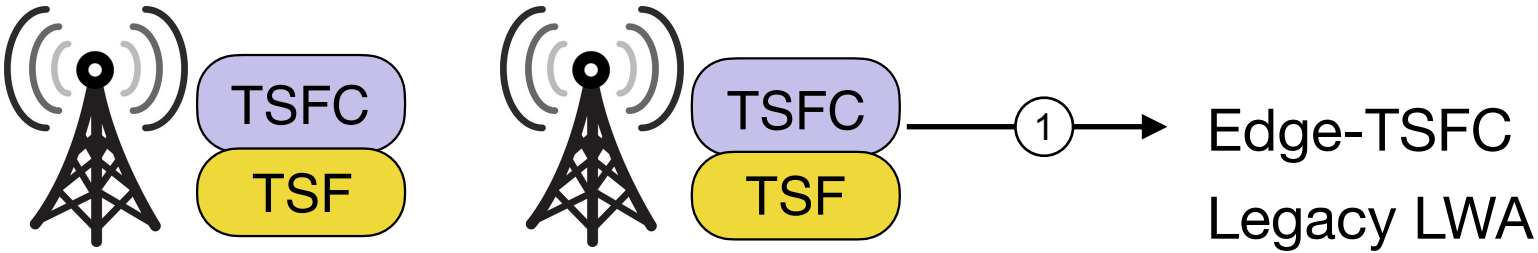
Central the traffic split function decision



- Our idea: centralise the traffic split function decision

- Centralization gain
- More flexibility
- Cheap, simple edge-devices
- In line with the C-RAN trend
- Possible with SDN idea

Where to locate the TSFC?



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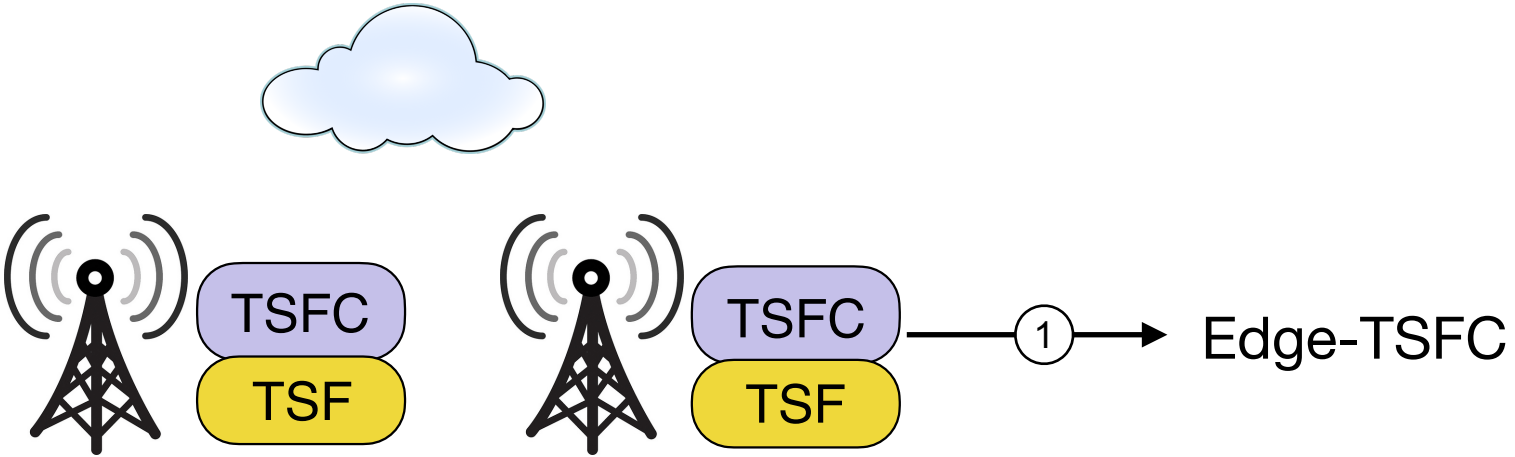

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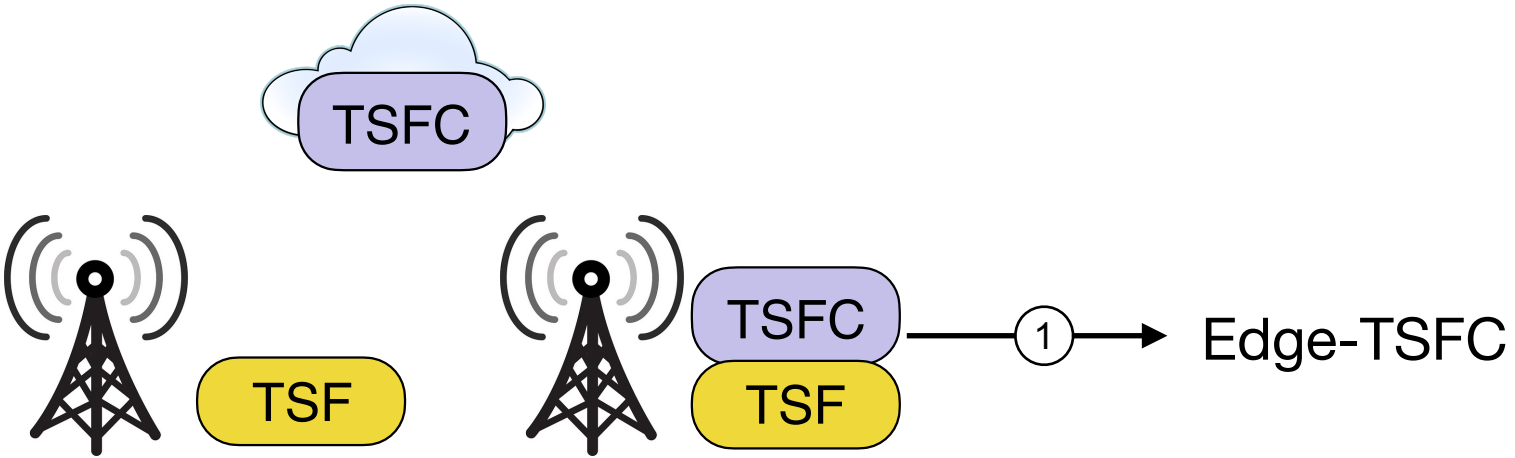

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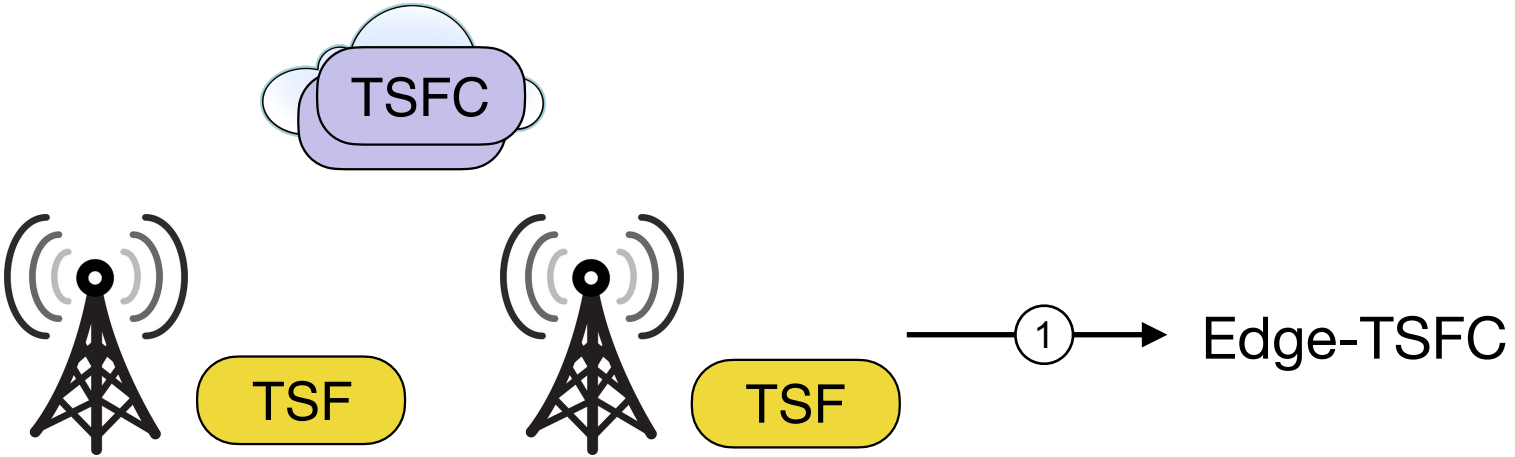

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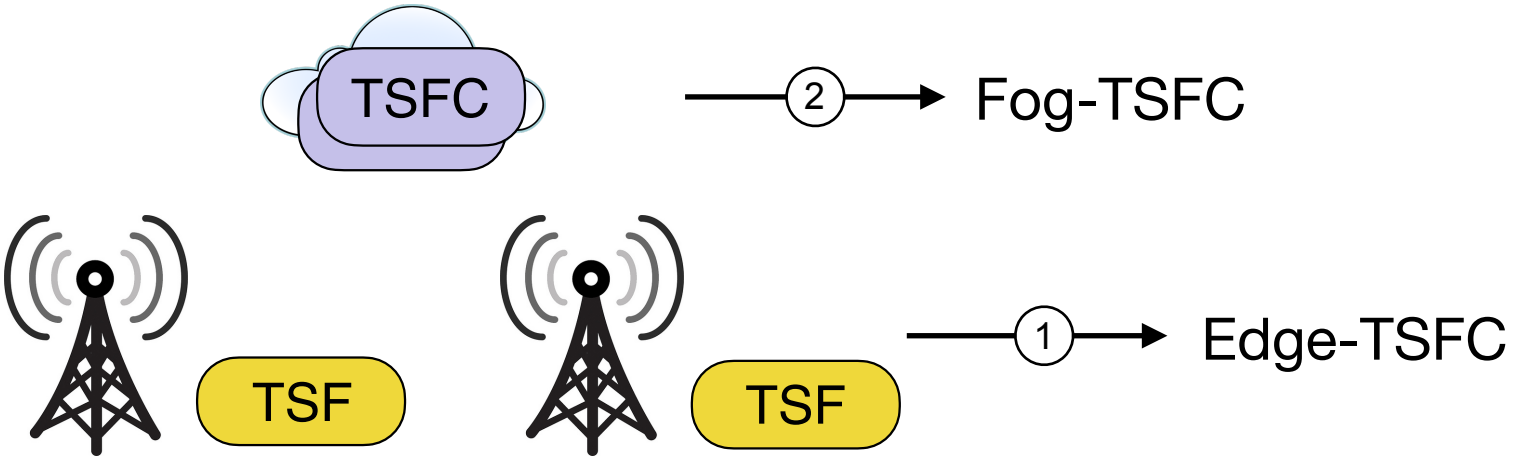

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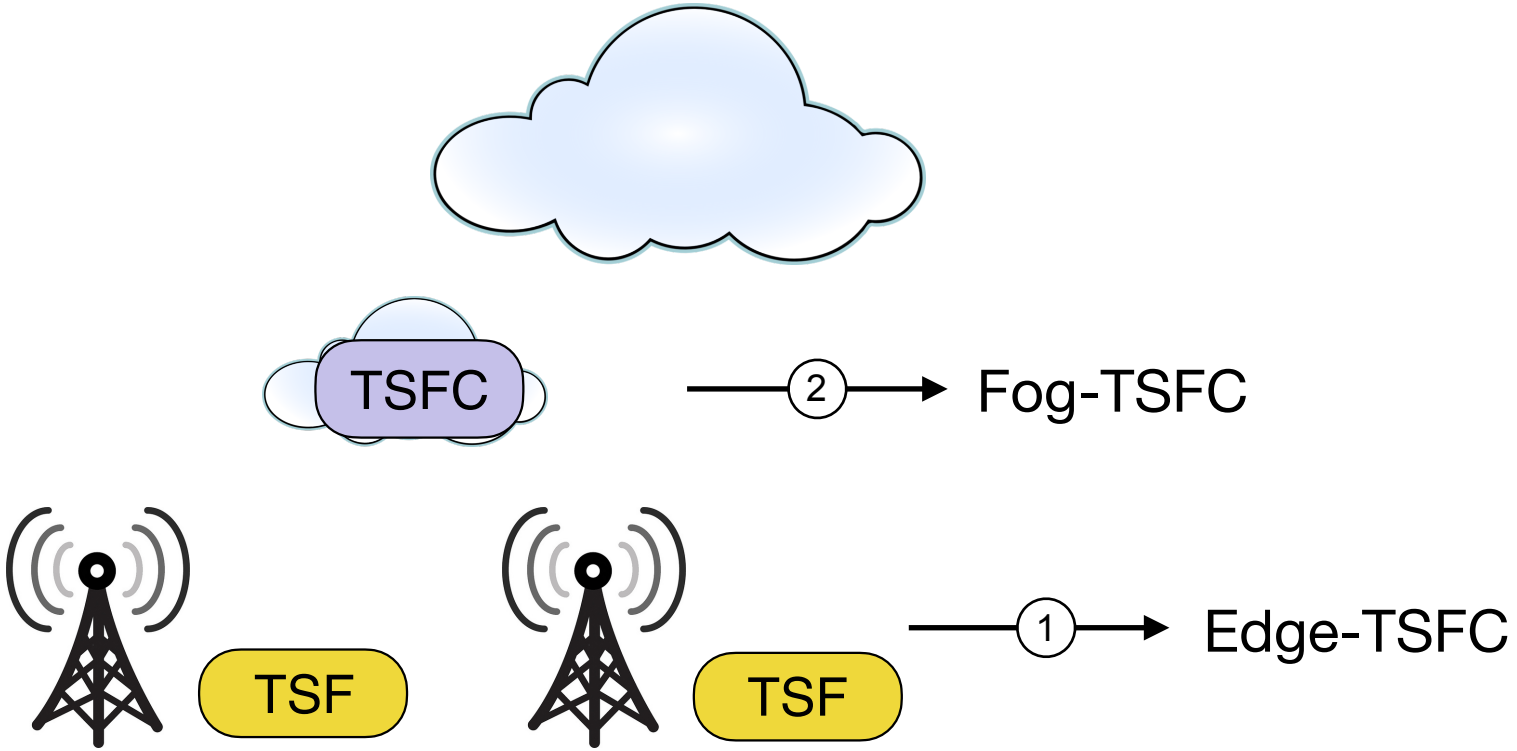

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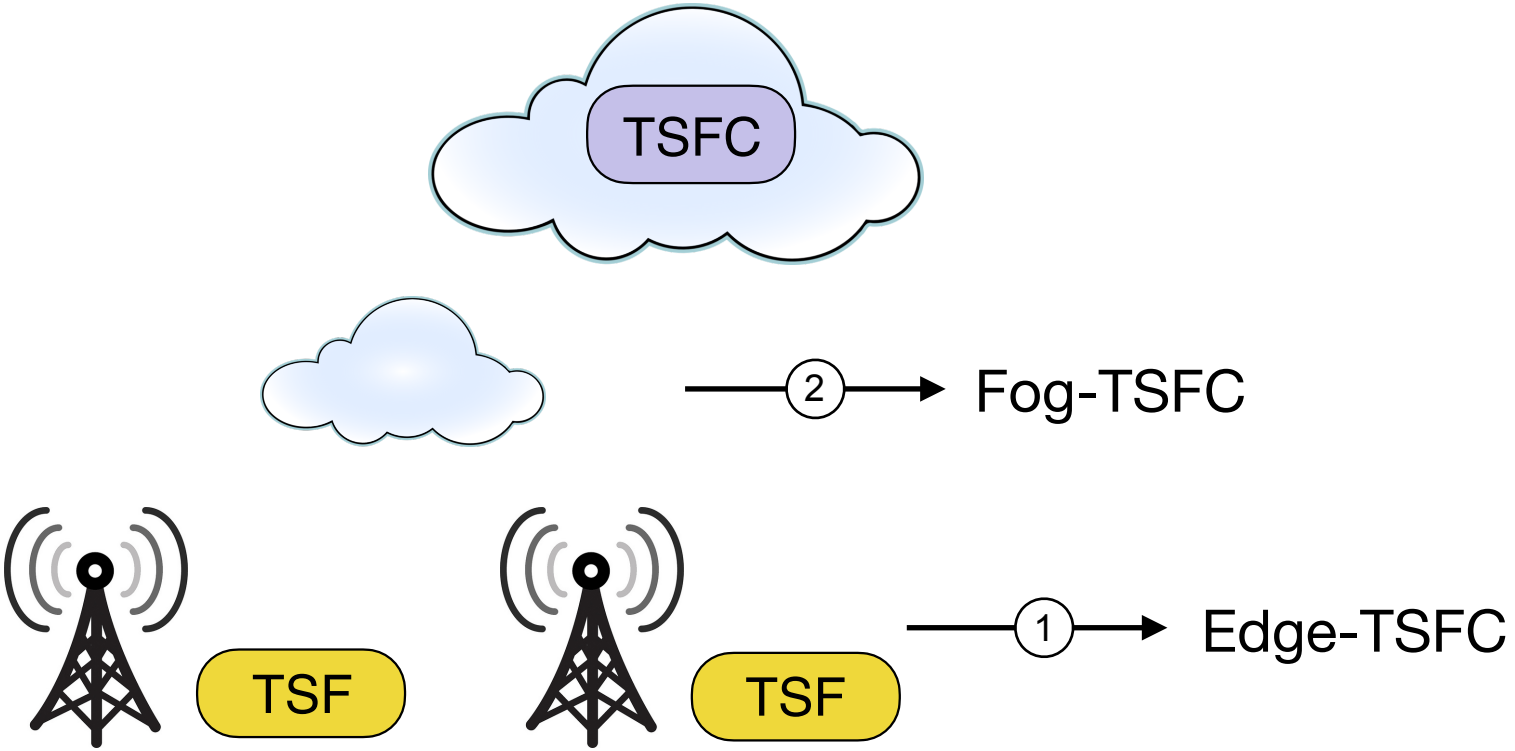

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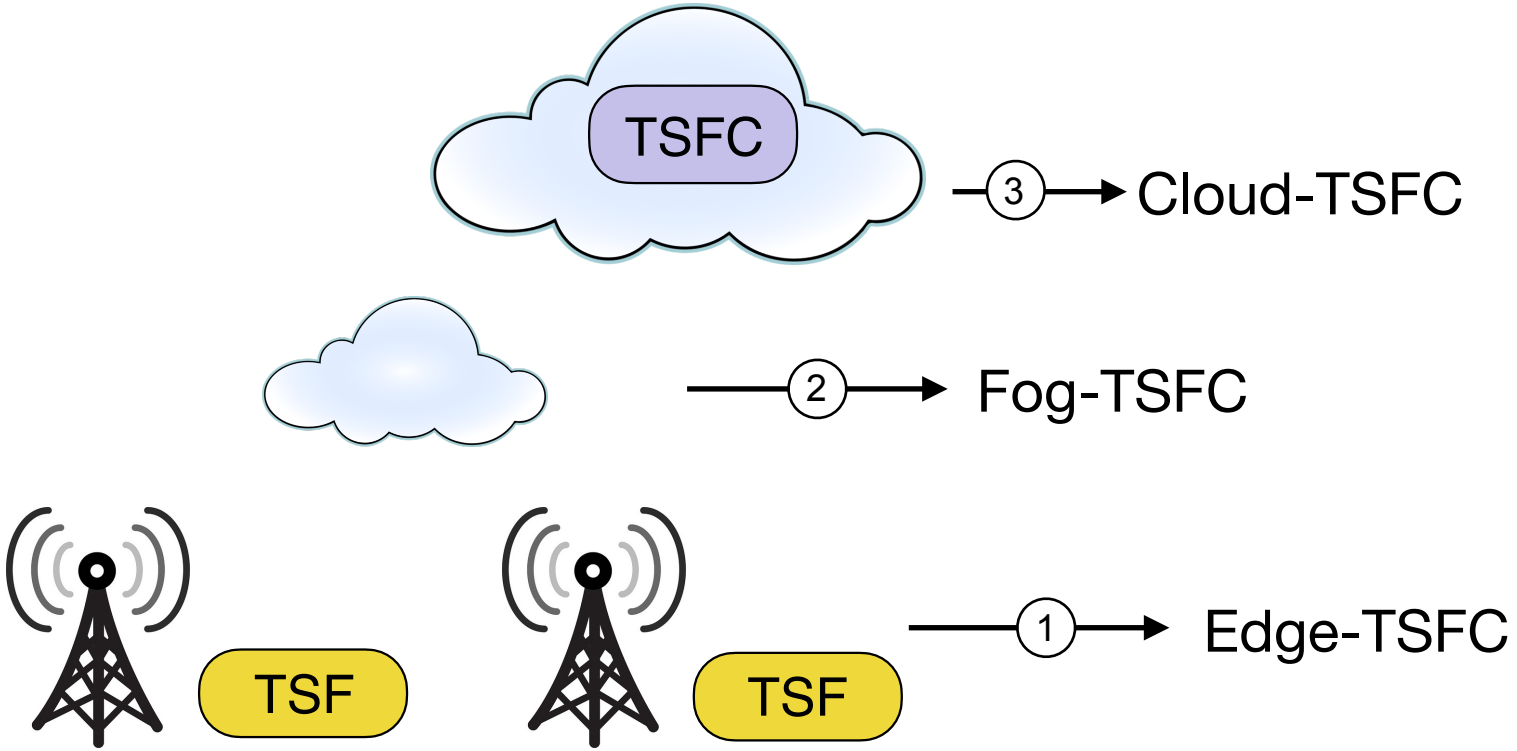

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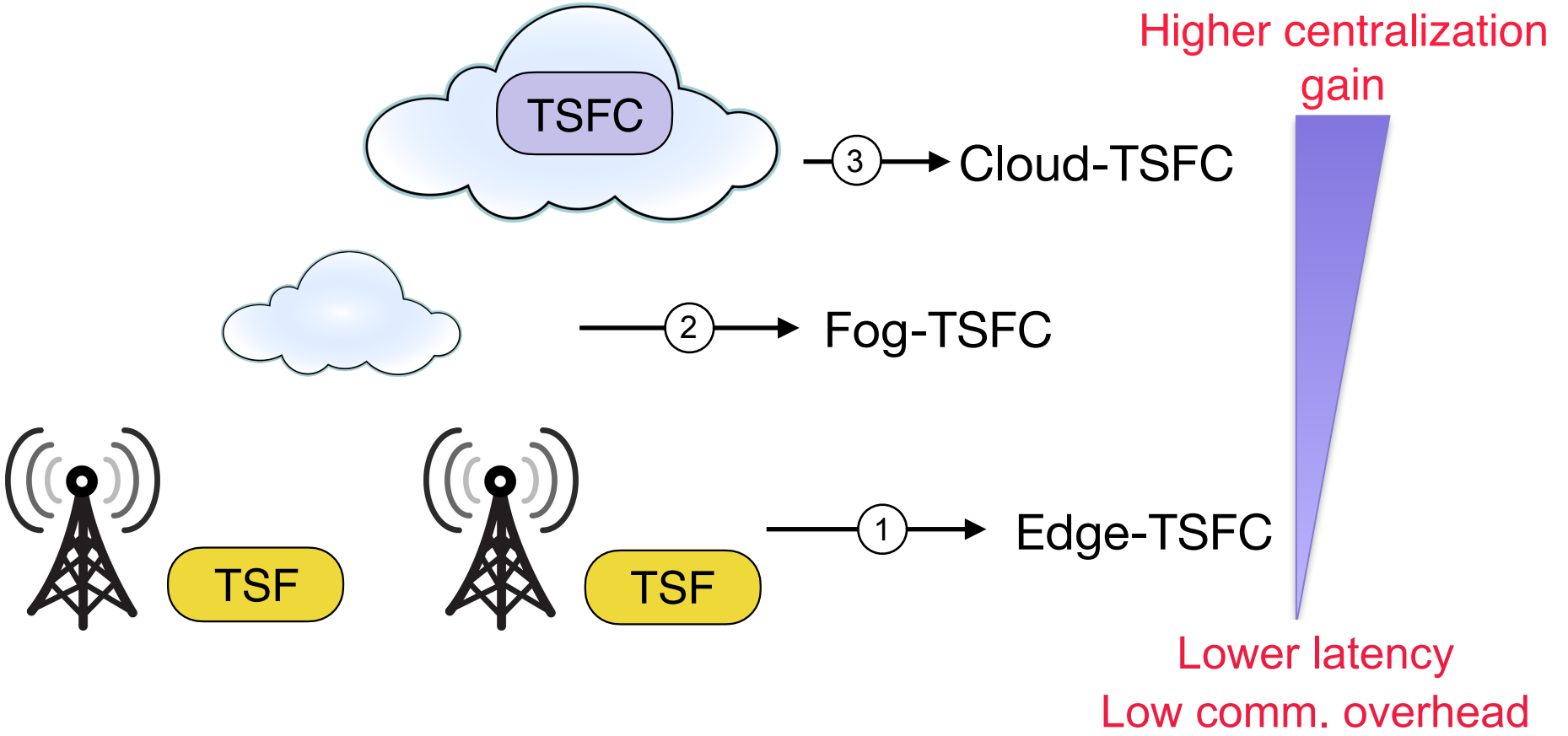

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- Understand
  - how decoupling TSFC from TSF changes the architecture and operation of LWA
- Determine
  - key parameters affecting controller, i.e., TSFC, placement
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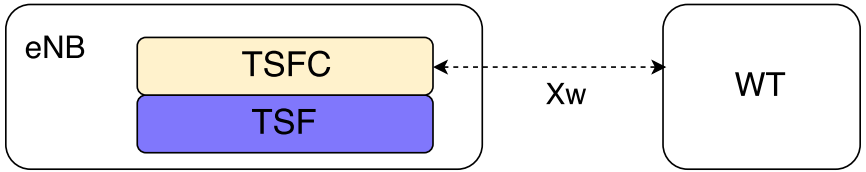
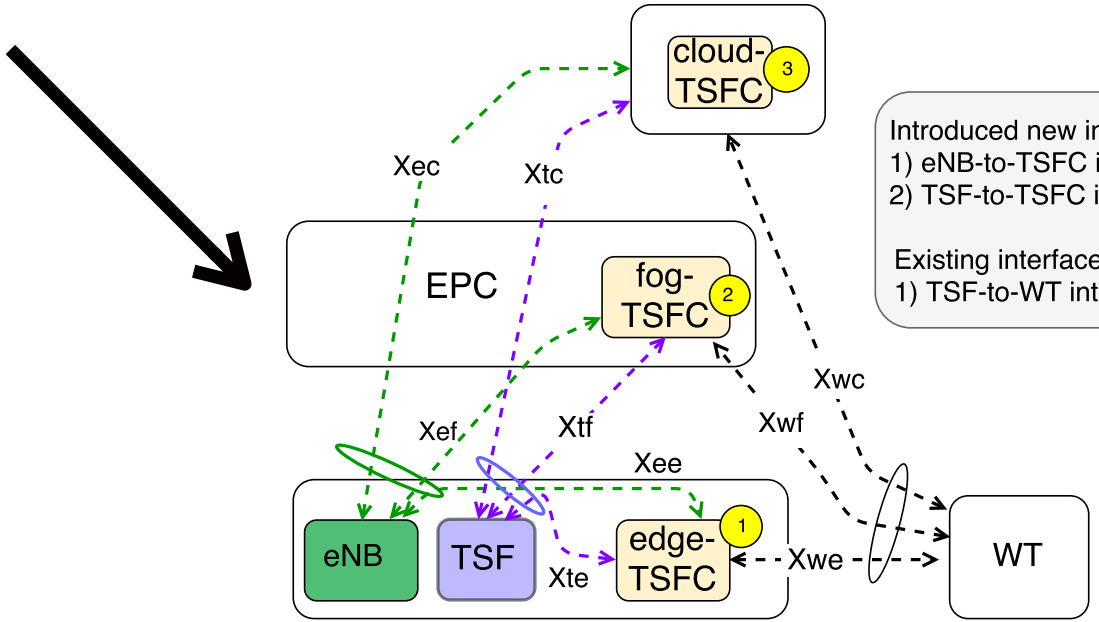
Change in the architecture



New interfaces are needed



Introduced new interfaces:
1) eNB-to-TSFC interface (Xef, Xec, Xee)
2) TSF-to-TSFC interface (Xte, Xtf, Xtc)

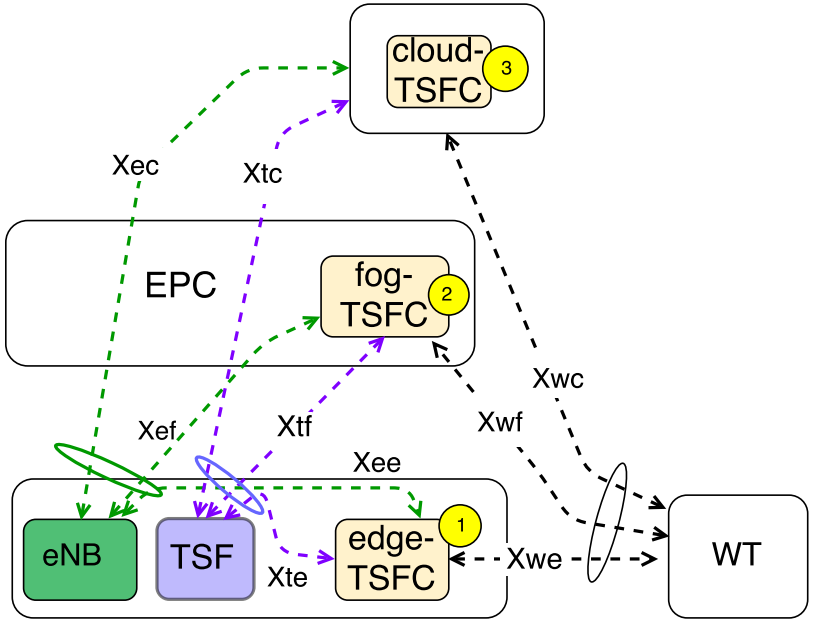
Existing interfaces:
1) TSF-to-WT interface (Xwe, Xwf, Xwc)

Flexibility but new interfaces

- **Xe interface**: eNB-to-TSFC communication
  - Three instances: Xe**e**, Xe**f**, Xe**c**

Edge Fog Cloud

- **Xt interface**: TSF-to-TSFC communication
  - Three instances: Xte, Xtf, Xtc
  - Difference interface delays

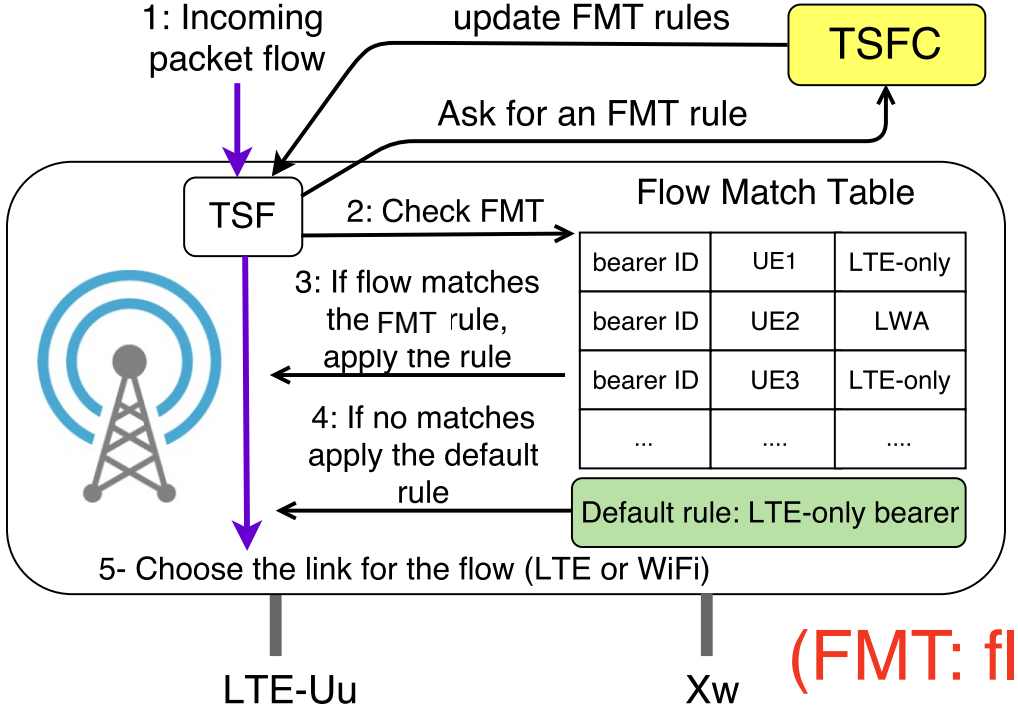


Flexibility but new interactions

- TSFC has **two tasks**:
  - ✓**mode assignment**: LTE-only or LWA mode
  - ✓**traffic split**: for LWA mode, how to deliver packets

- TSFC may perform these tasks in **two modes**:
  - ✓**reactive**: upon every change trigger the r-TSFC
  - ✓**proactive**: acts only periodically p-TSFC

Flexibility but new data structures



(FMT: flow match table)

Mode assignment in edge/fog/cloud TSFC

- rTSFC: every time a new flow is created, trigger rTSFC
- cloud-TSFC:
  - ✓not scalable
  - ✓impractical for short-lived flows or highly mobile users
- fog-TSFC:
  - ✓similar problems with cloud-TSFC
  - ✓depends on number of eNBs controlled by a fog-controller

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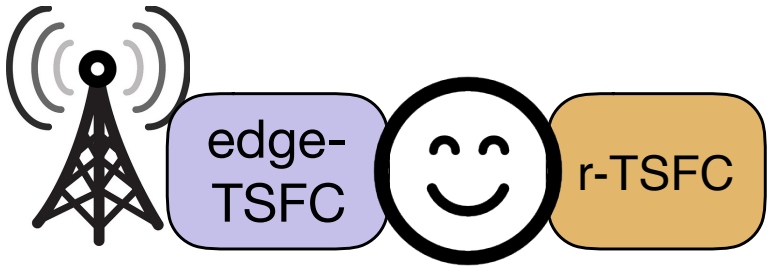

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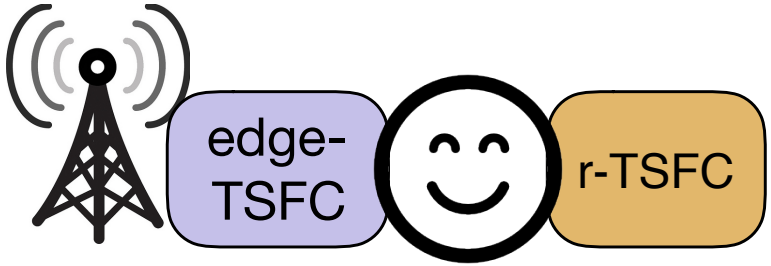

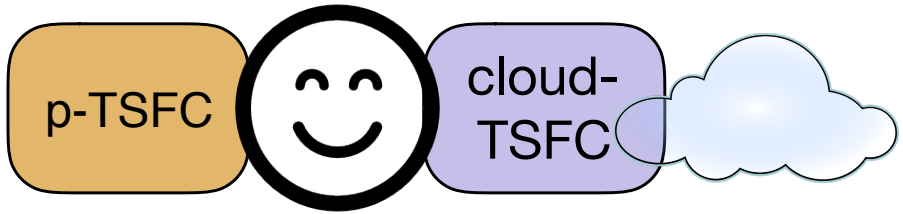

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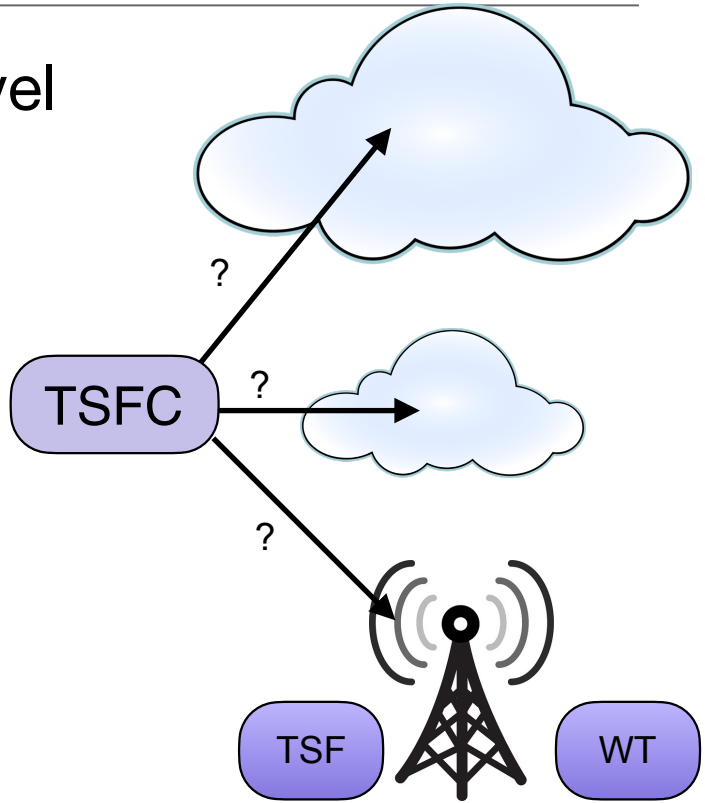
Where to deploy the TSFC?

- depends on the targeted reactivity level
  - ✓small-scale changes
  - ✓medium-scale changes
  - ✓Long-term changes



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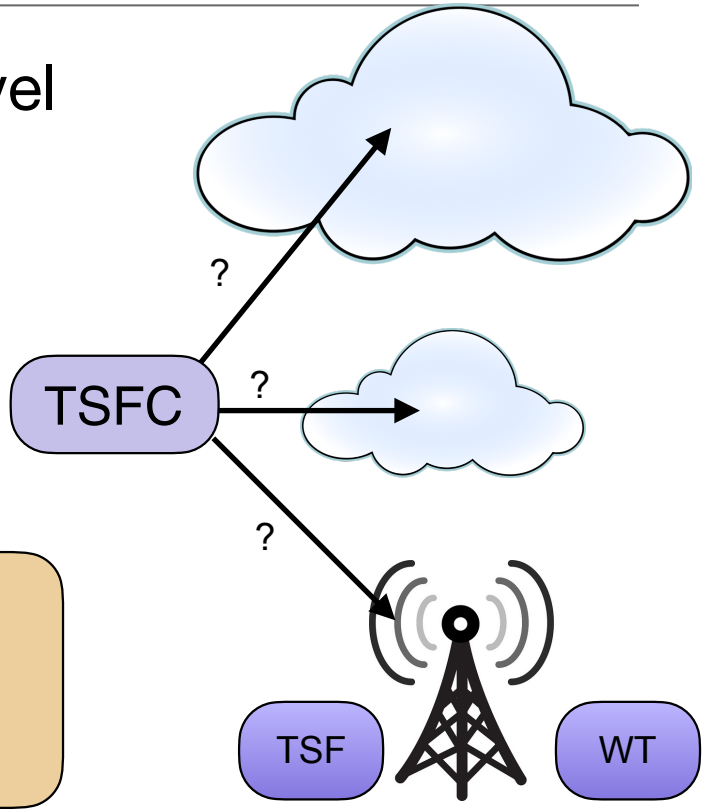
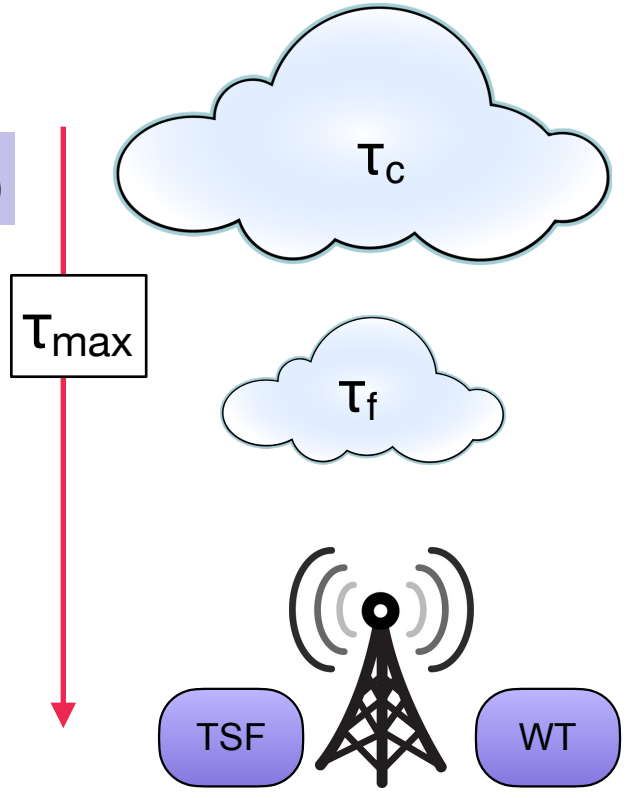


controller delay budget (τ_{max}): time period the system state remains static considering a target reactivity level

Cloud-first assignment

- controller delay budget τ_{max}
- if $\tau_{max} >= \tau_c$ then cloud-TSFC
- else if $\tau_{max} >= \tau_f$ then fog-TSFC
- else: edge-TSFC

$\tau_c = 2\max(Xwc, Xec, Xtc)$



Parameters affecting controller placement

controller delay budget: $\tau_{max} = \min(\ldots,\ldots,\ldots)$

- Small-scale:

  ✓channel coherence time, flow duration

- Medium-scale:

  ✓channel decorrelation time due to shadowing, flow duration

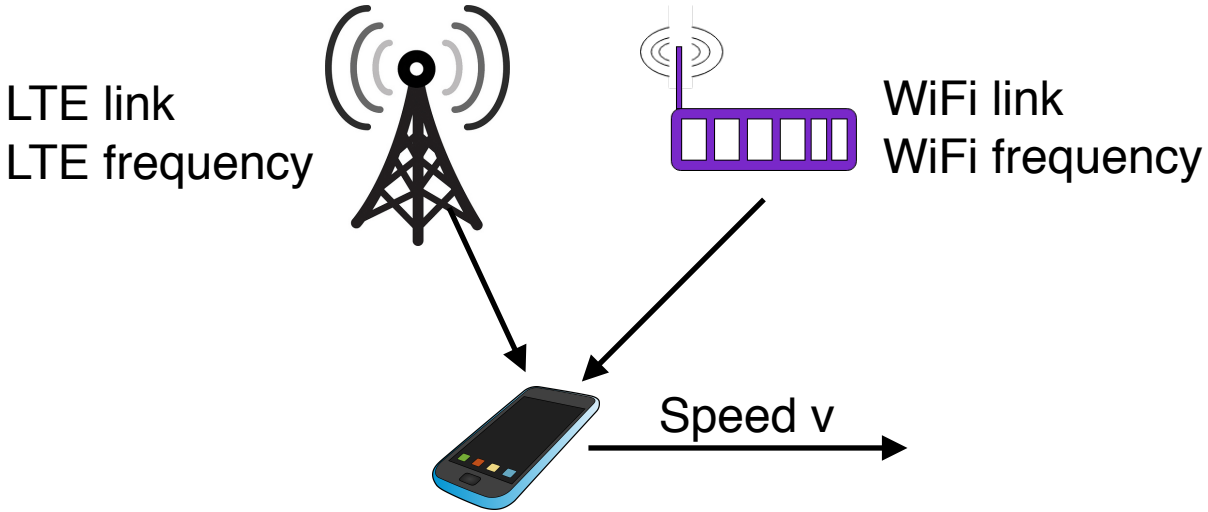
- Long-time scale:

  ✓time to handover, flow duration

React to even small scale changes

- channel coherence time, flow duration

controller delay budget: $\tau_{max} = \min(\tau^{l}_{c}, \tau^{w}_{c}, \tau_{f})$ where $\tau_{ch} \approx c/fv$



React to medium scale changes

- channel decorrelation time due to shadowing, flow duration
  - $\tau_{max} = \min(\tau^{l}_{sh}, \tau^{w}_{sh}, \tau_f)$ where $\tau_{sh} \approx d_{sh}/v$
  - d_{sh}: de-correlation distance of shadowing

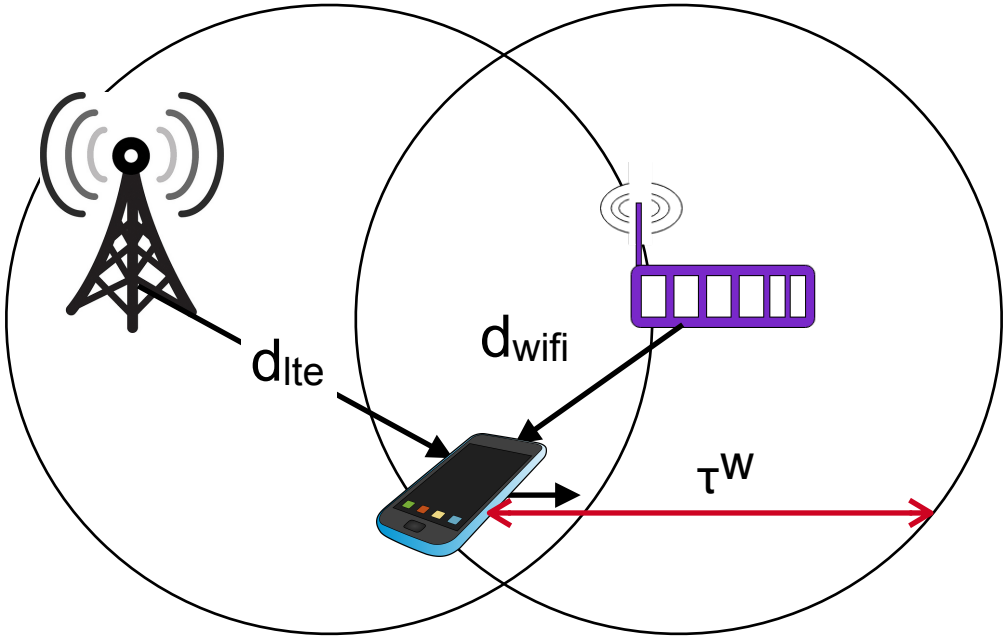
TABLE 3: Decorrelation distances d_c for highway and urban scenarios.

Scenario	LOS	OLOS
Highway	23.3	32.5
Urban	4.25	4.5

T. Abbas, K. Sjoberg, J. Karedal, and F. Tufvesson, "A measurement based shadow fading model for vehicle-to-vehicle network simulations," International Journal of Antennas and Propagation vol. 2015.

React to long term changes

- time to handover, flow duration: $\tau_{max} = \min(\tau^w, \tau^l, \tau_f)$



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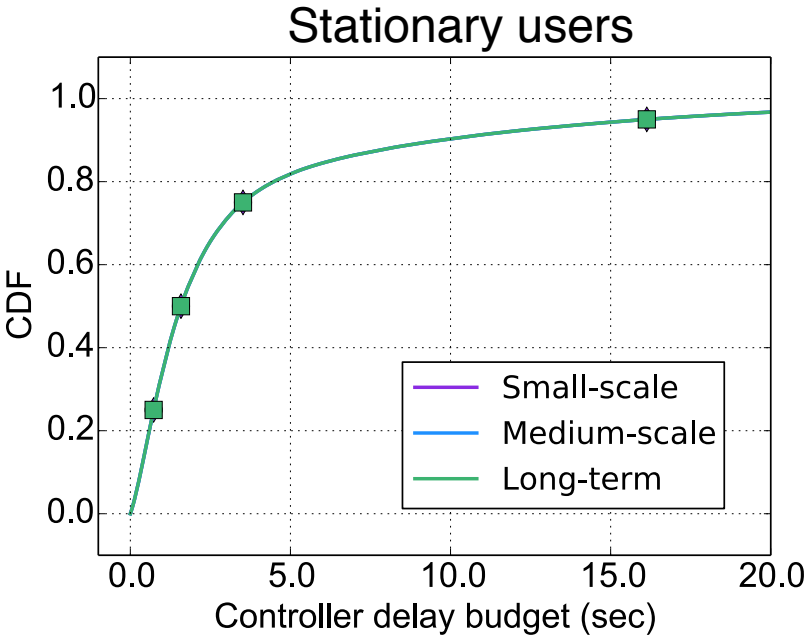
Preliminary analysis

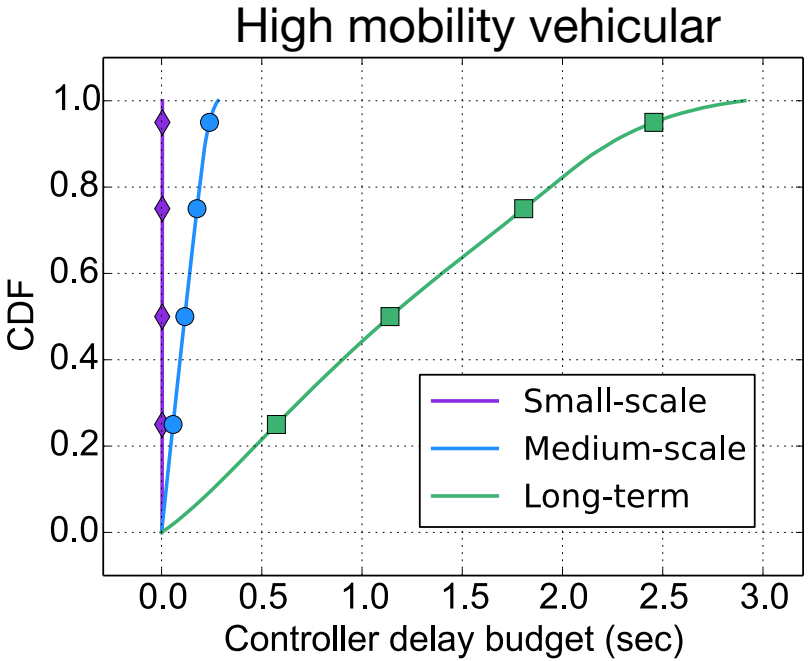
- Monte-Carlo simulations in Python (10^6 realizations)
- CDF of flow durations in [Yang15], a dataset collected from Chinese nw. operator
- Mobility according to [Maternia16]

  ✓static, low pedestrian, medium (slow vehicle), high (fast vehicle)
- LTE frequency: 2.3 GHz, WiFi: 2.4 and 5 GHz
- Edge, fog, cloud interface delays: (5, 10, 50 ms)

- J. Yang, W. Li *et al.*, “Characterizing and modeling of large-scale traffic in mobile network,” in *IEEE WCNC* 2015
- M. Maternia, S. E. El Ayoubi *et al.*, “5G PPP use cases and performance evaluation models,” *5G PPP*, 2016.

Empirical CDF of controller delay budget

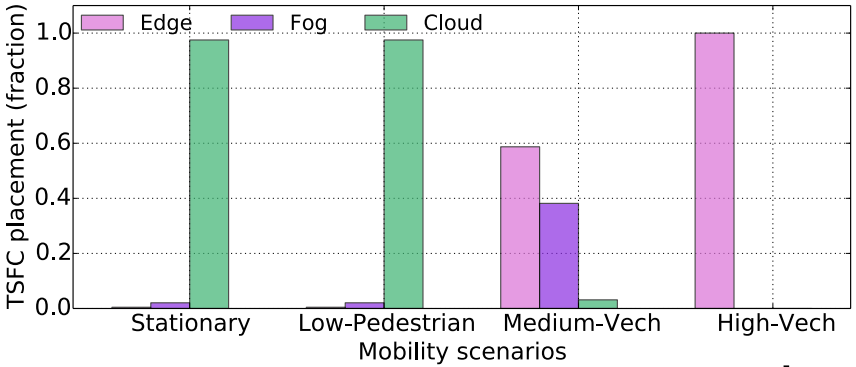




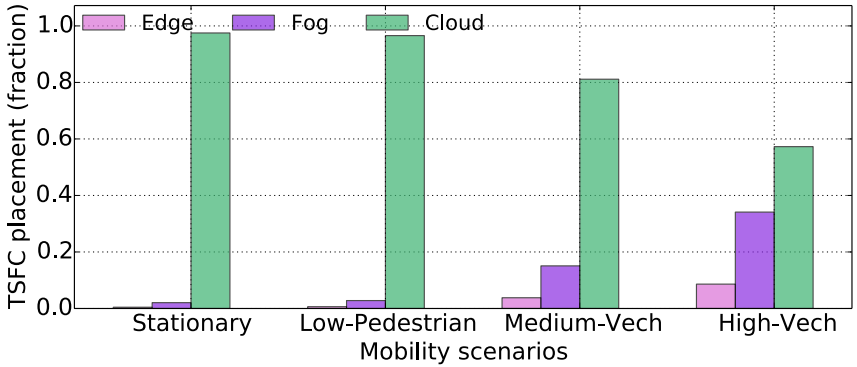
- flow duration determines the budget
- channel dynamics determines the budget

Location of TSFC (WiFi@2.4 GHz)

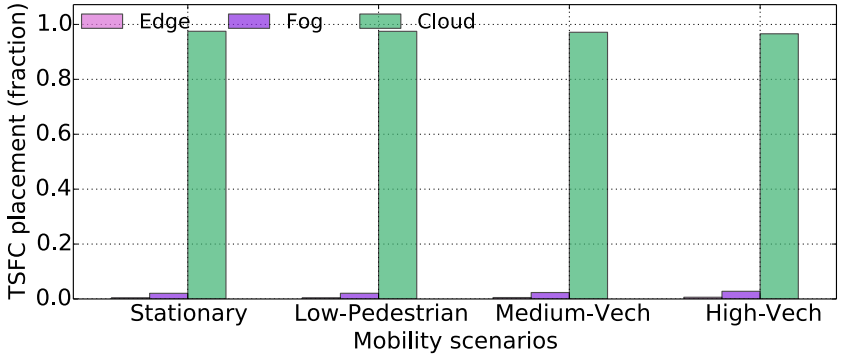
Small scale



Medium scale

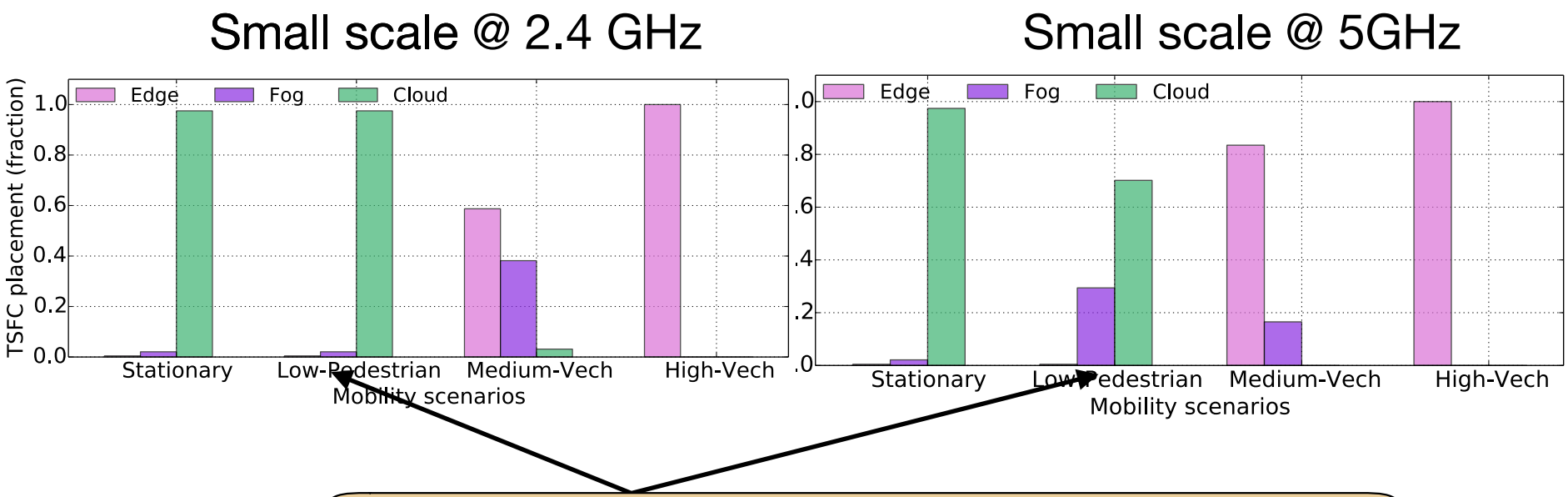


Long-term



- Fraction of times TSFC is placed in cloud, fog, or edge

Location of TSFC (WiFi@5 GHz)



Similar but lower controller delay budget as channel@5GHz changes faster

Summary and future work

- A flexible LWA architecture with SDN
- Change in the architecture and operation
- Promises higher centralisation gains:

  ✓future work to quantify the gains

  ✓future work to develop a traffic split function and evaluate using NS-3 simulations and prototype experiments

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Enabling Flexibility of Traffic Split Function in LTE-WiFi Aggregation Networks through SDN

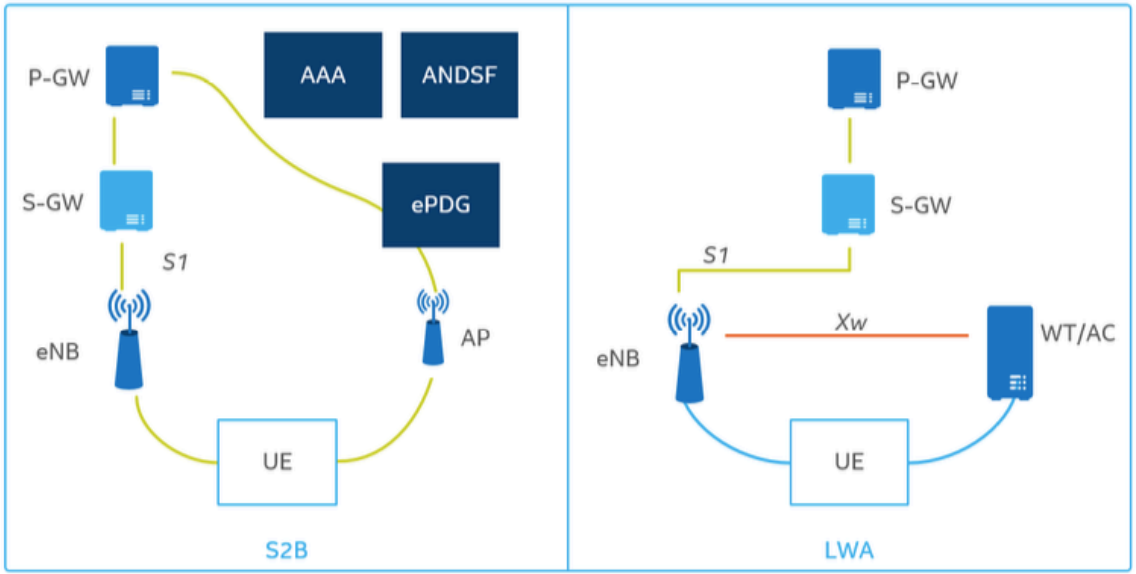
Suzan Bayhan and Anatolij Zubow, TU Berlin

Thank you!

Backup slides

LTE-WLAN interworking vs. LWA

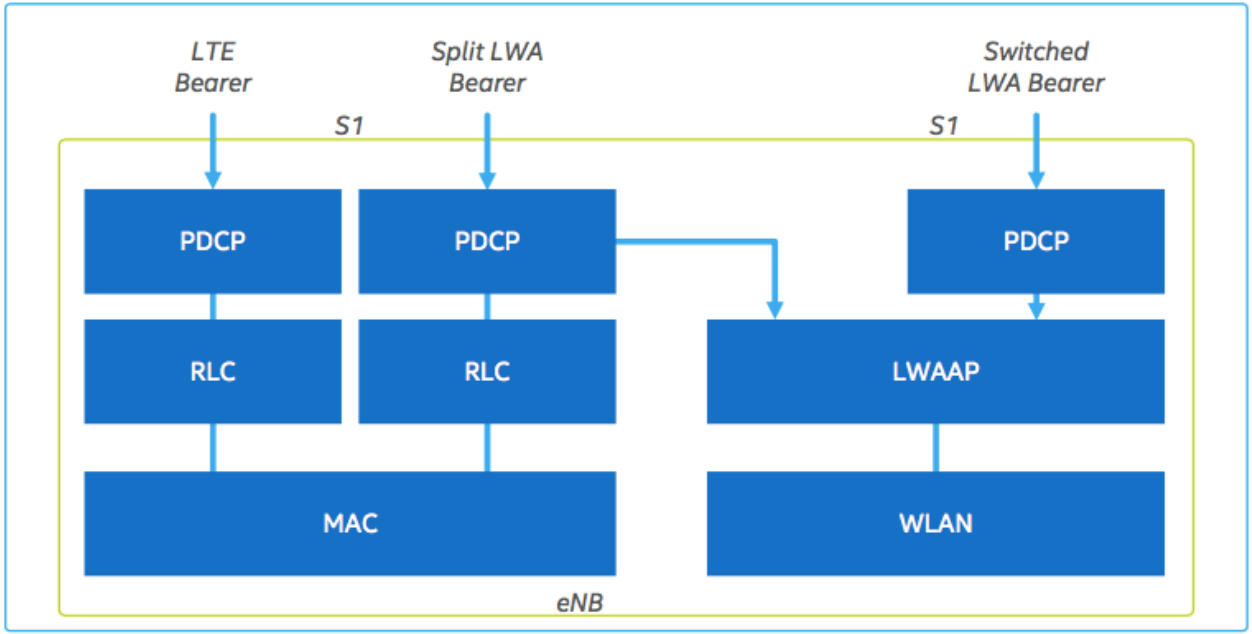
FIGURE 1. S2B (LTE/WLAN INTERWORKING VIA UNTRUSTED WLAN ACCESS) AND LWA (LTE-WLAN AGGREGATION) NETWORK ARCHITECTURE



- Figure source: https://www.intel.com/content/dam/www/public/us/en/documents/white-papers/unlicensed-lte-paper.pdf

PDCP level aggregation

FIGURE 2. LWA (LTE-WLAN AGGREGATION) USER PLANE ARCHITECTURE



- Figure source: https://www.intel.com/content/dam/www/public/us/en/documents/white-papers/unlicensed-lte-paper.pdf