NJIT®
New Jersey Institute of Technology

THE ELISHA YEGAL BAR-NESS CENTER FOR WIRELESS COMMUNICATIONS AND SIGNAL PROCESSING RESEARCH

Fog-Aided Wireless Networks

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Joint work with
Ravi Tandon

Towards 5G Systems

Cloud processing: centralization

Edge processing: localization

Towards 5G Systems

Cloud processing: centralization

→ cloud radio access network (C-RAN)

Edge processing: localization

→ edge caching

Towards 5G Systems

Cloud processing: centralization

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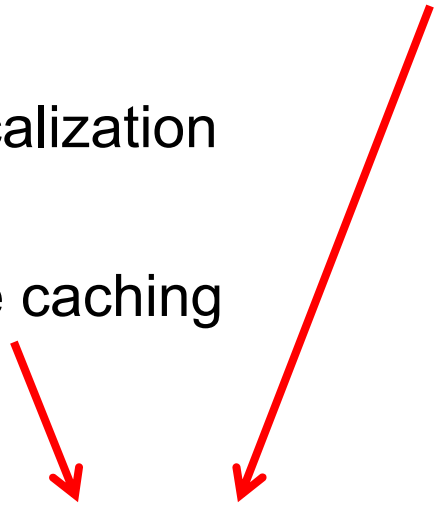
Edge processing: localization

→ edge caching



Fog-RAN (F-RAN): cache-aided C-RAN

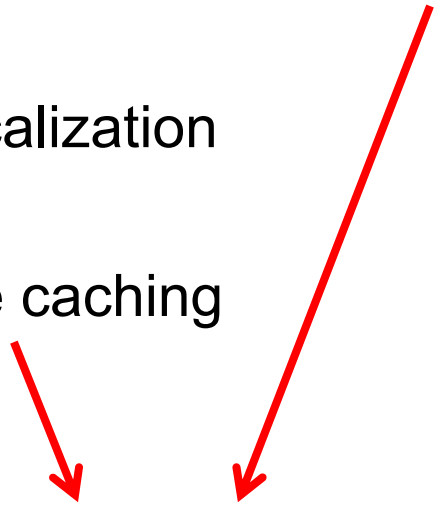
Towards 5G Systems

Cloud processing: centralization

→ cloud radio access network (C-RAN)

Edge processing: localization

→ edge caching

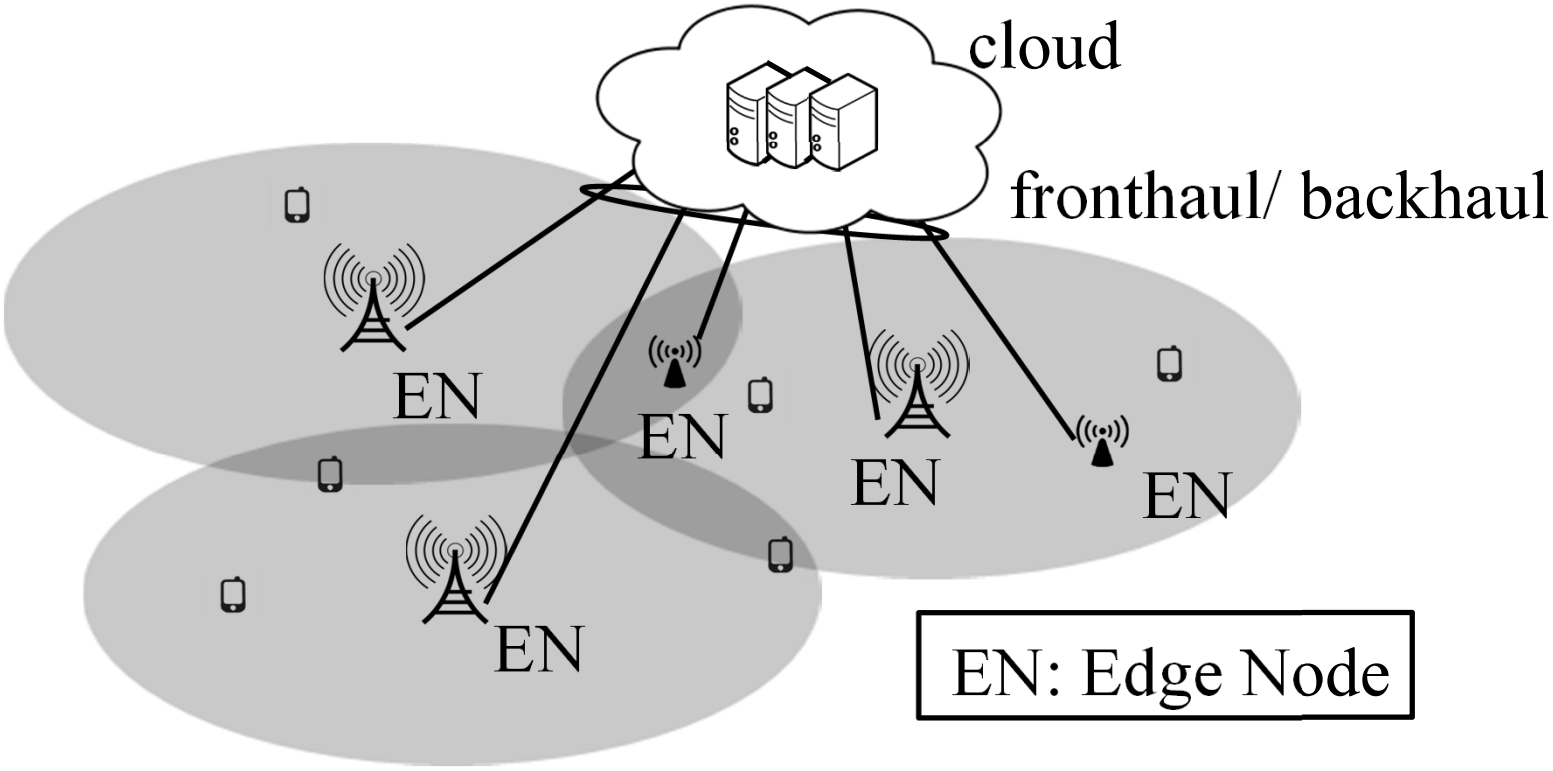


information-theoretic analysis of

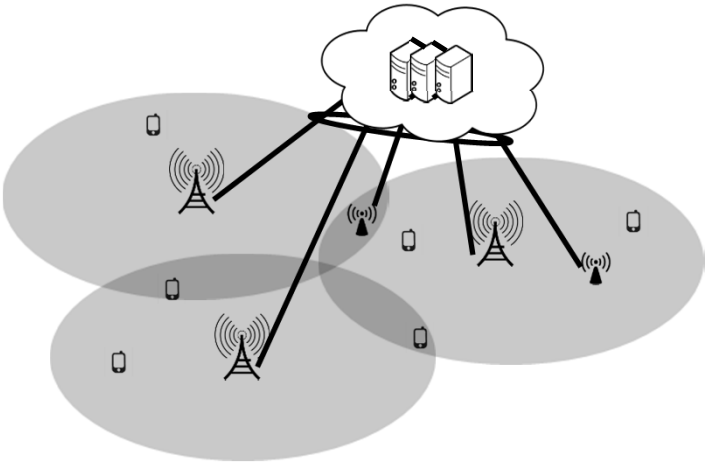
Fog-RAN (F-RAN): cache-aided C-RAN

Cloud Radio Access Network (C-RAN)

Centralization of network functionalities via virtualization



Cloud Radio Access Network (C-RAN)

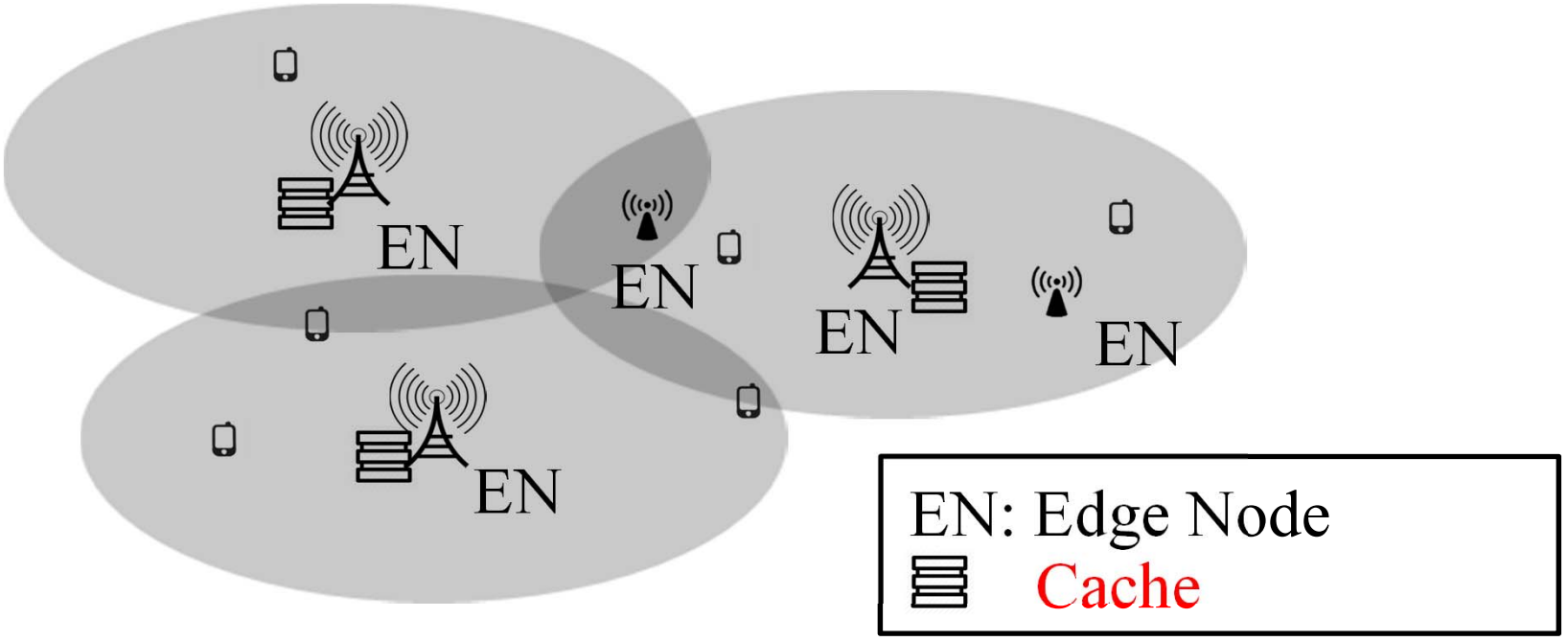


- Reduced CAPEX and OPEX
- Greening and statistical multiplexing
- Interference management

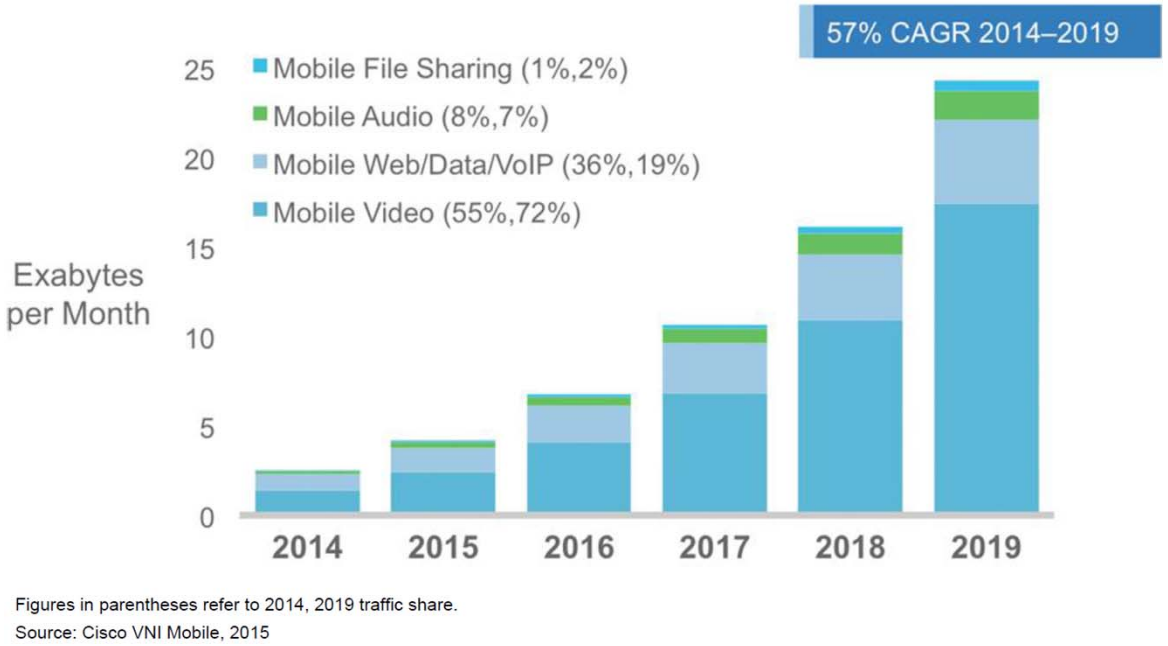
- Fronthaul/ backhaul overhead
- Latency

Edge Caching

- Storage of popular content at the edge



Edge Caching

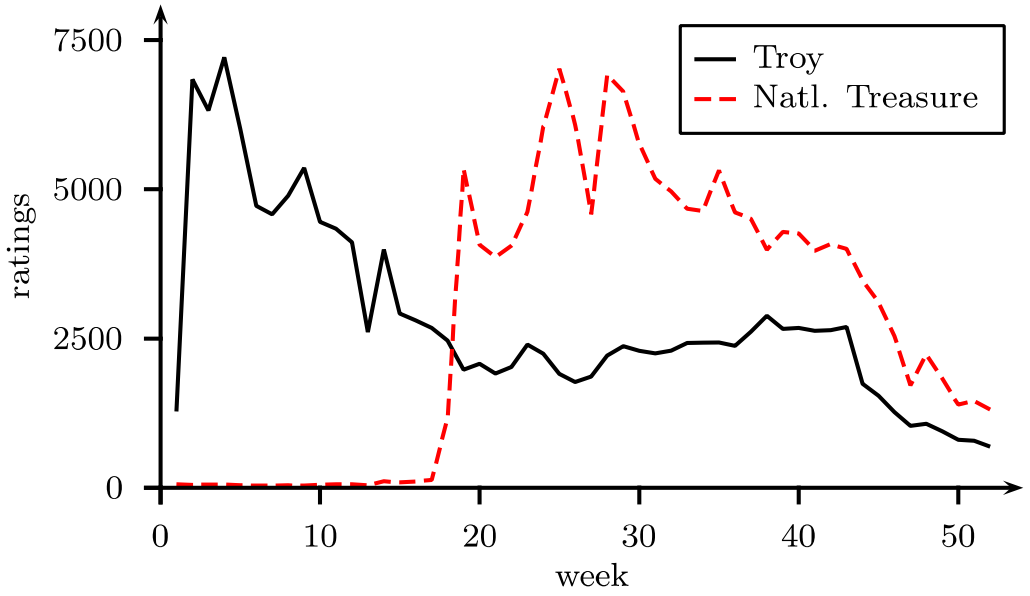


Figures in parentheses refer to 2014, 2019 traffic share.
Source: Cisco VNI Mobile, 2015

- Video-on-demand is driving wireless traffic growth
- Predicted to account for almost ¾ traffic by 2019

Image source: Cisco (2015)

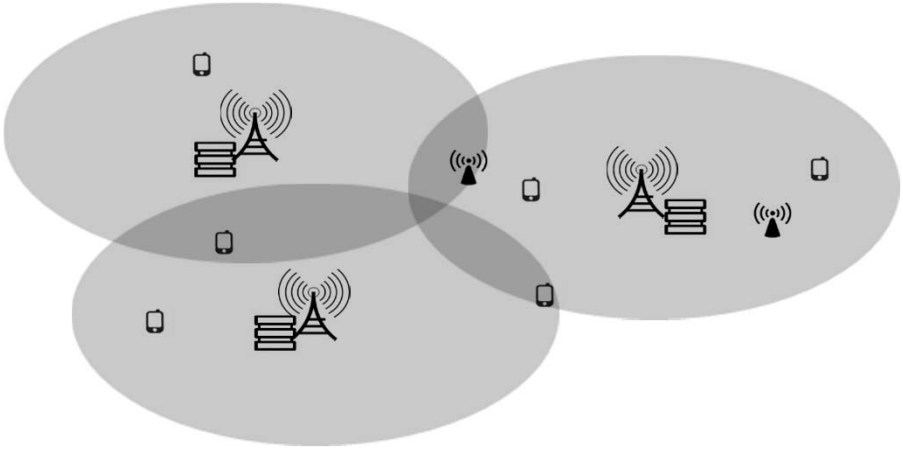
Edge Caching



- Content popularity is slowly time-varying and hence predictable

Image source: Pedarsani et al. (2013)
Data source: netflixprize.com

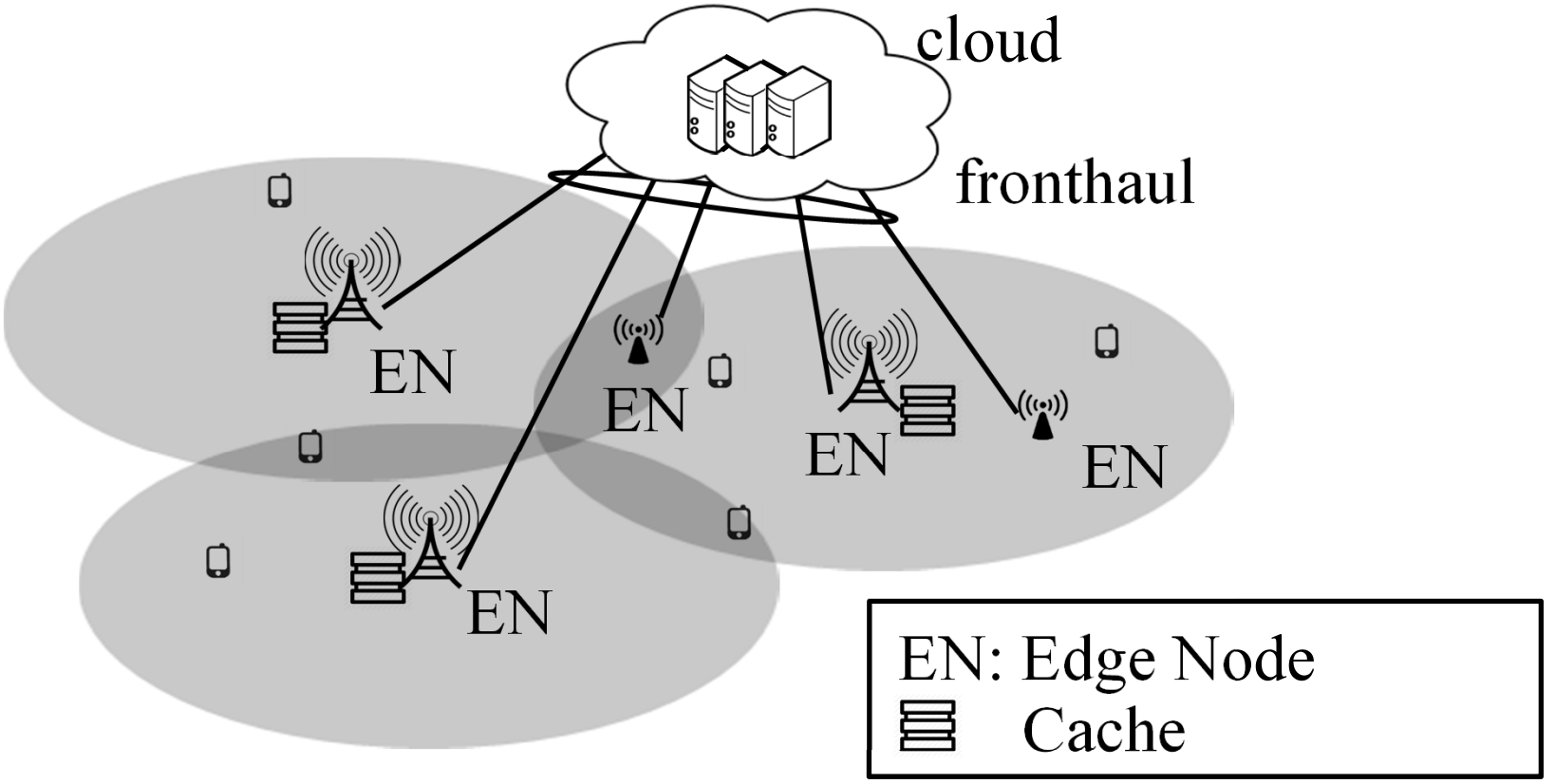
Edge Caching



- Reduced backhaul overhead
- Reduced latency

- Interference limited
- Unable to support generic traffic requirements

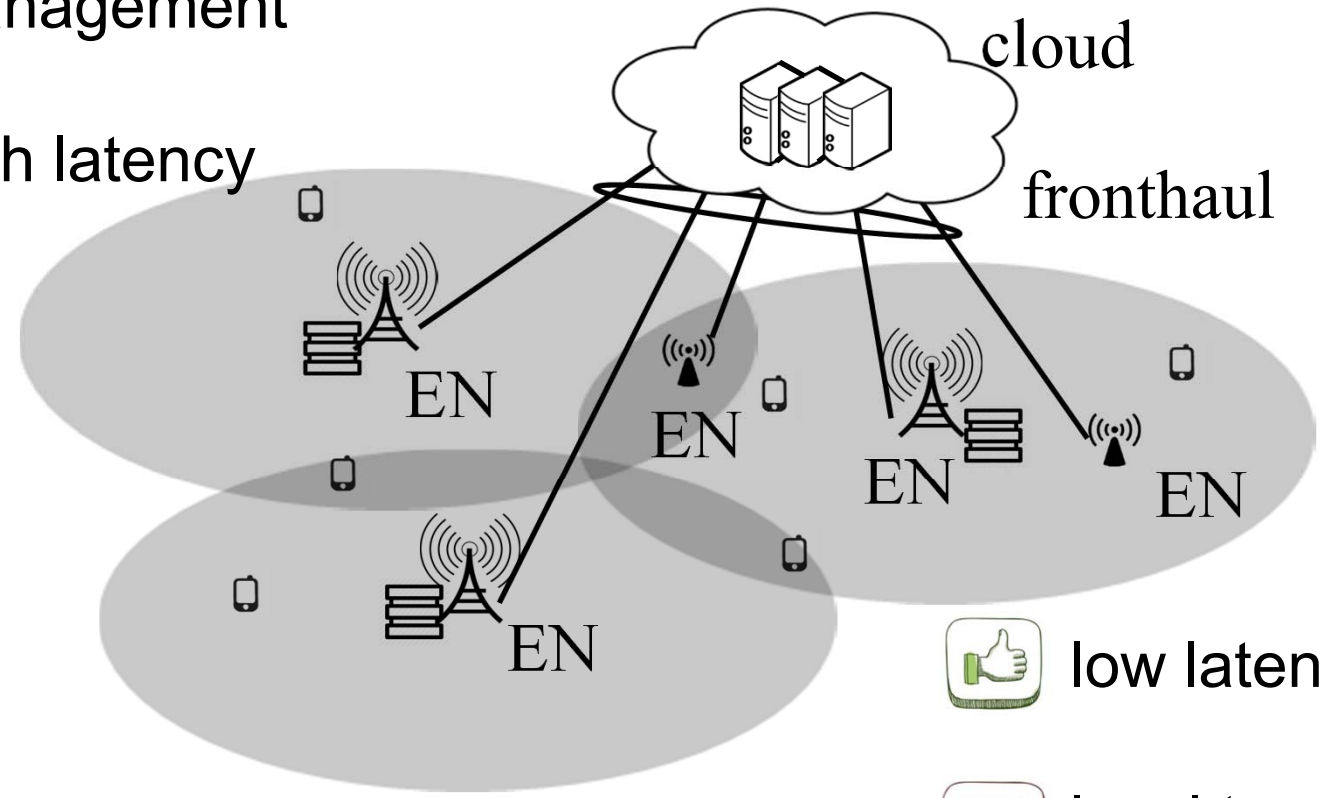
Fog-RAN (F-RAN)



Fog-RAN (F-RAN)

centralized interference management

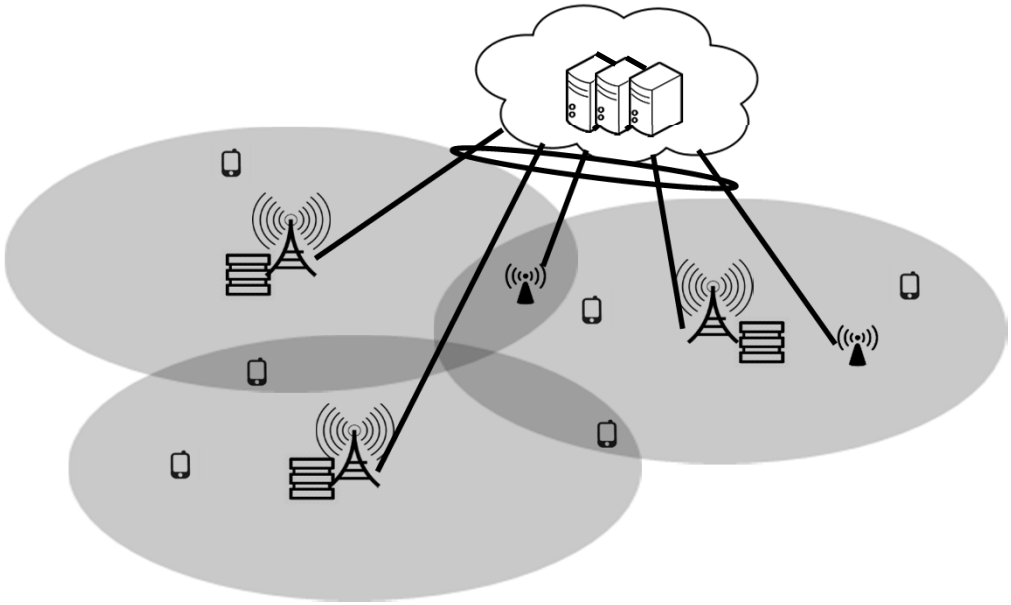
high latency



low latency

local transmission

Fog-RAN (F-RAN)



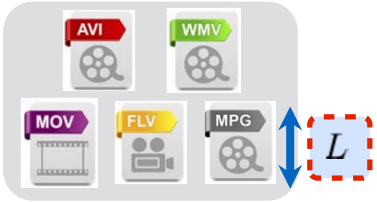
- Optimal operation of an F-RAN: complex design problem across cloud, fronthaul and edge segments
- Focus: *Information-theoretic model and performance metric* to obtain fundamental insights

System Model

Key F-RAN Parameters

N : # of popular files

L : size of a File



Set of popular files

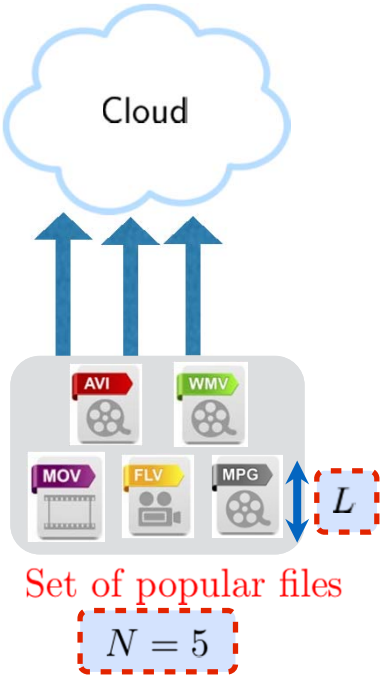
$N = 5$

System Model

Key F-RAN Parameters

N : # of popular files

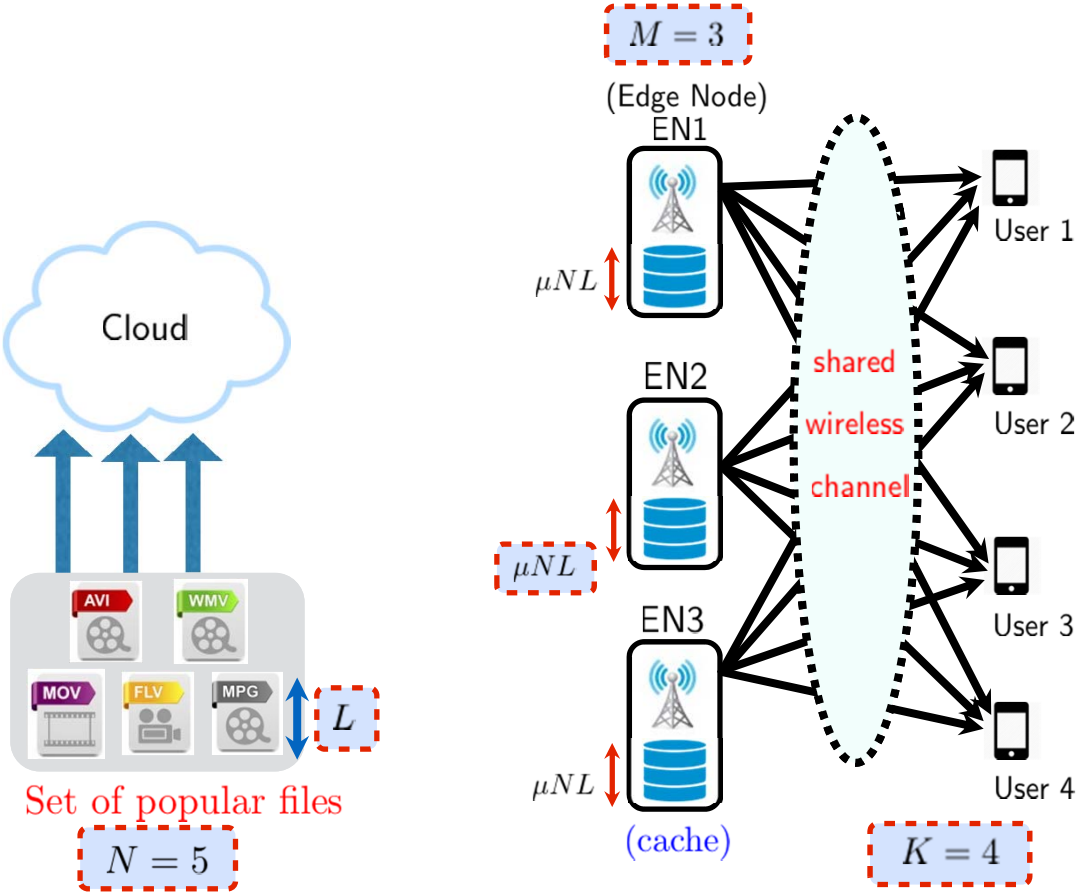
L : size of a File



System Model

Key F-RAN Parameters

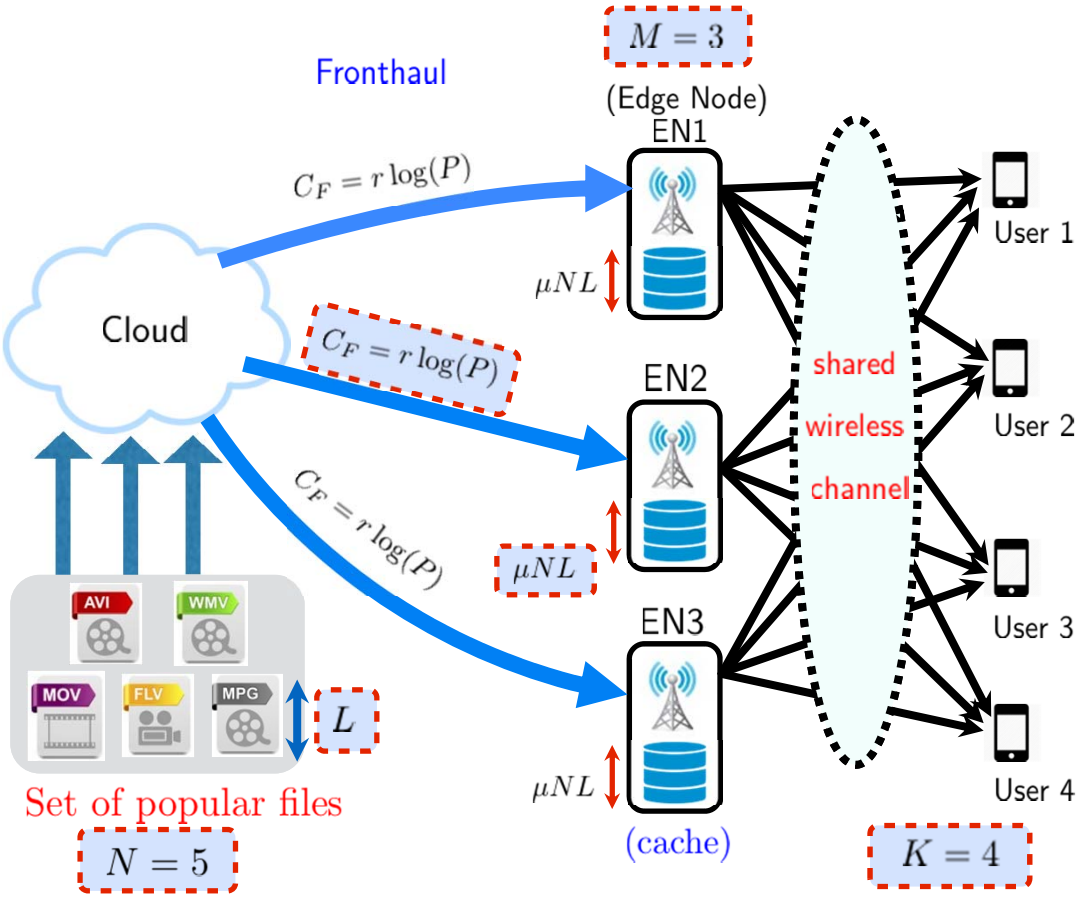
N : # of popular files	M : # of edge nodes (ENs)	K : # of users
L : size of a File	μNL : cache storage capacity	



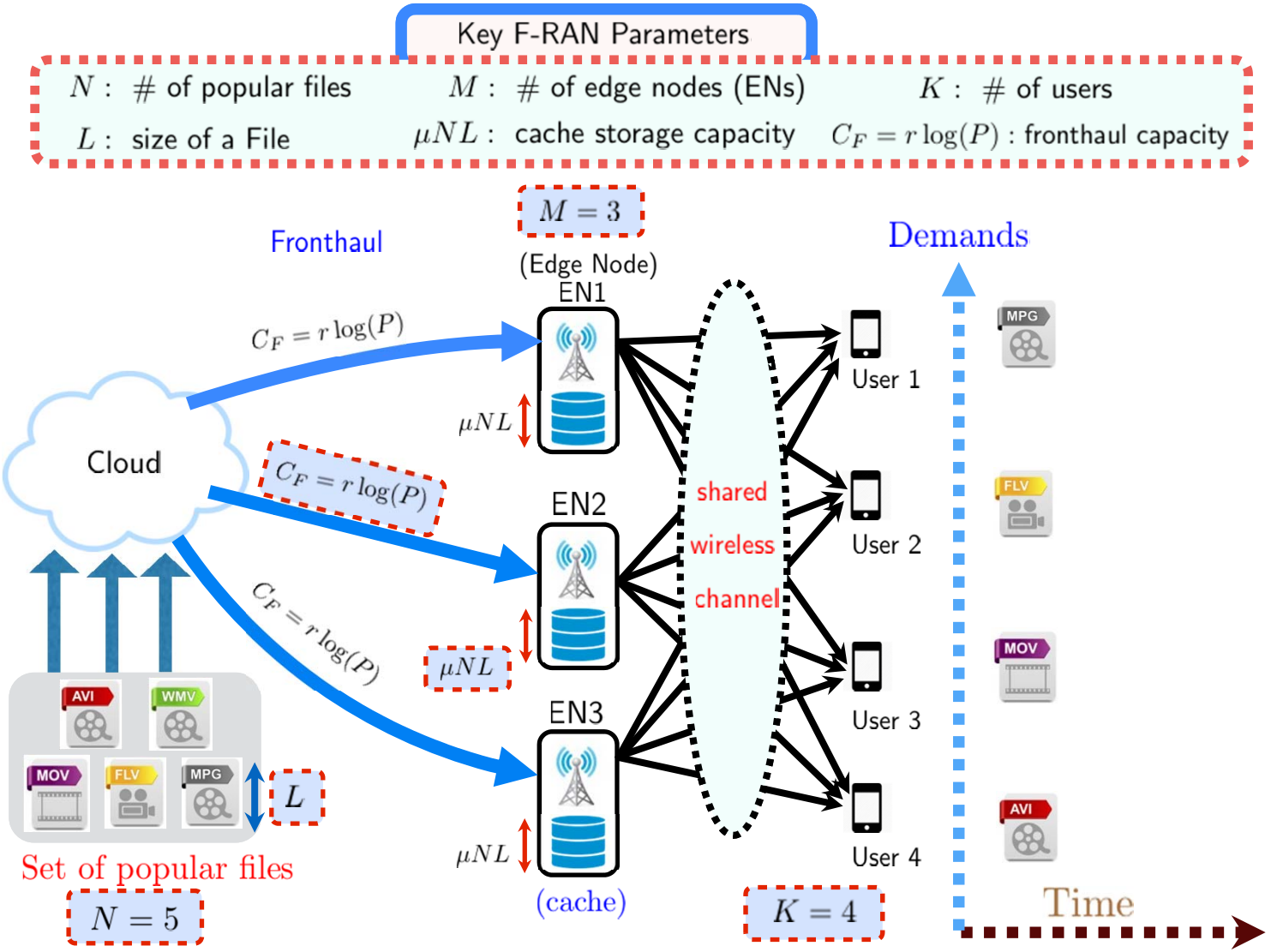
System Model

Key F-RAN Parameters

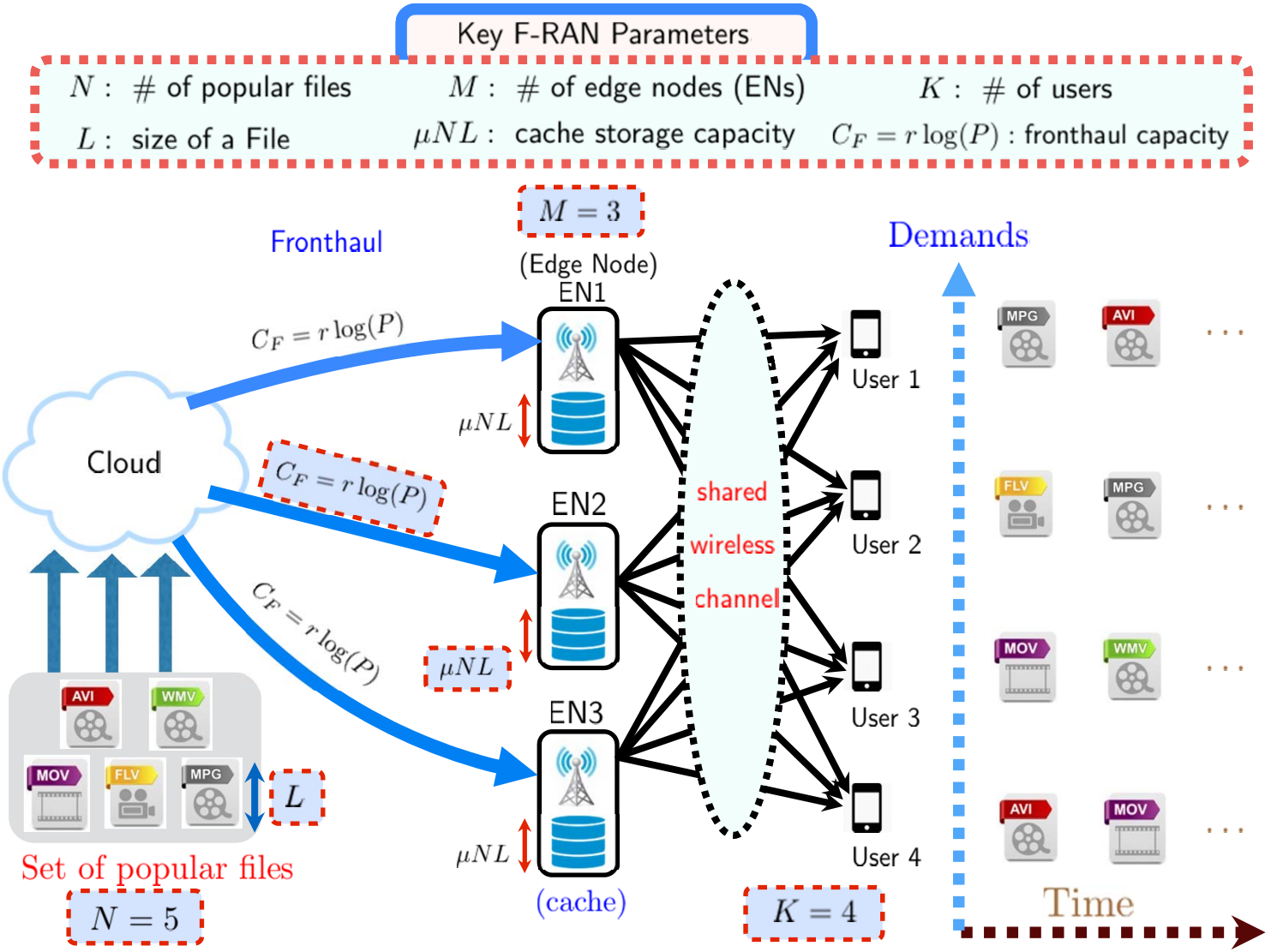
N : # of popular files	M : # of edge nodes (ENs)	K : # of users
L : size of a File	μNL : cache storage capacity	$C_F = r\log(P)$: fronthaul capacity



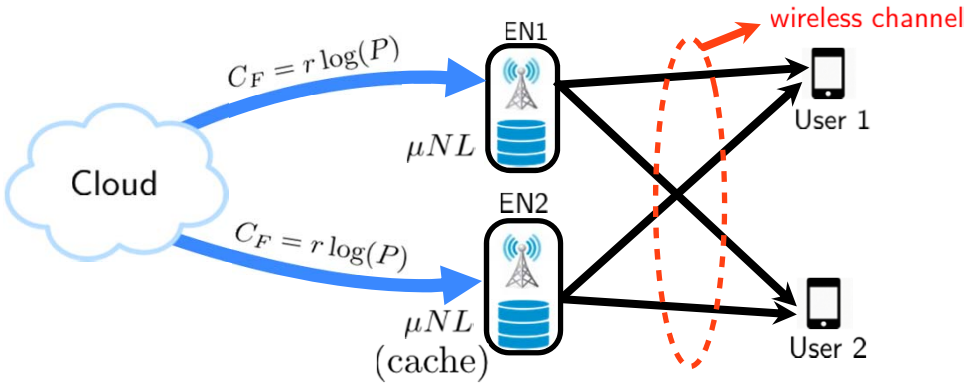
System Model

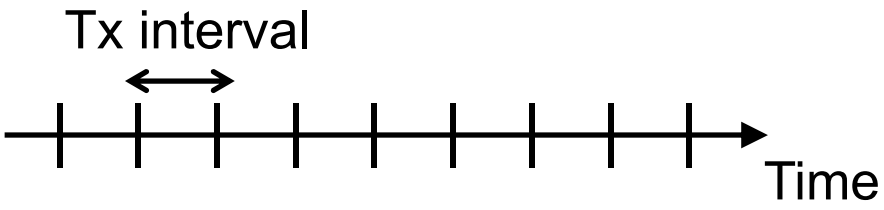


System Model

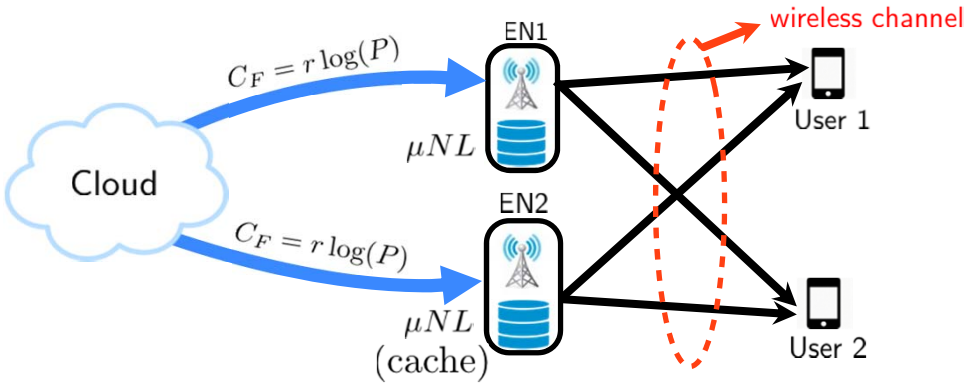


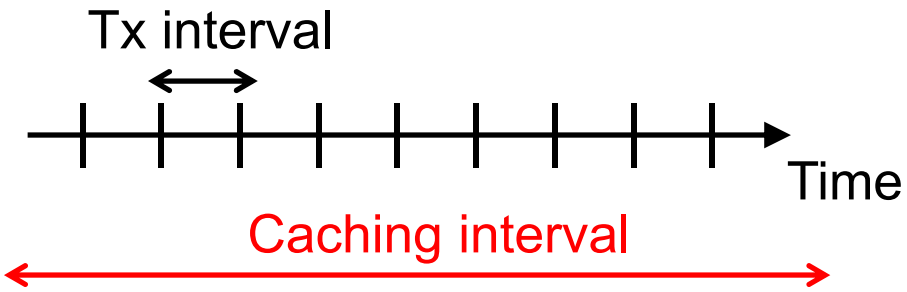
Design Space





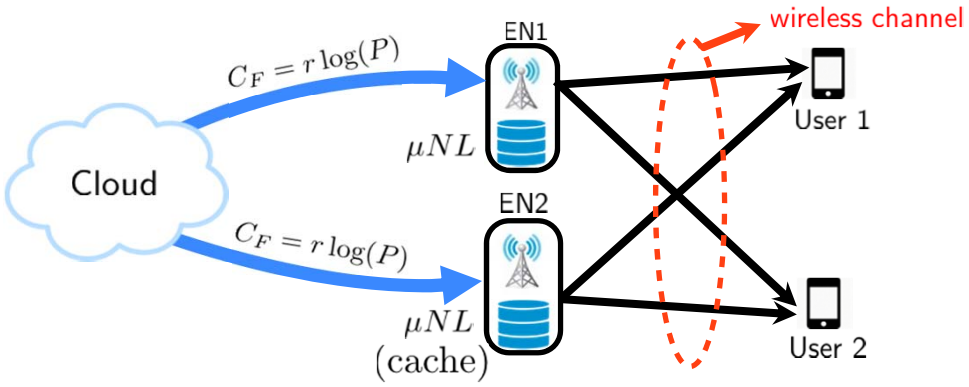
Design Space

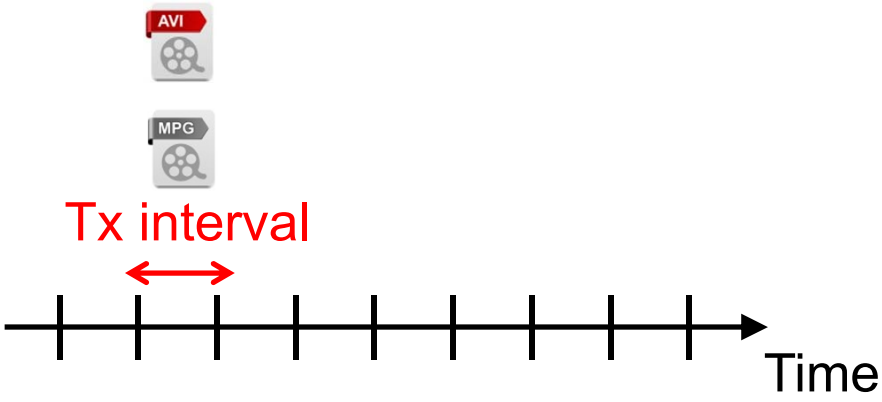




- Cache storage policy: What to cache

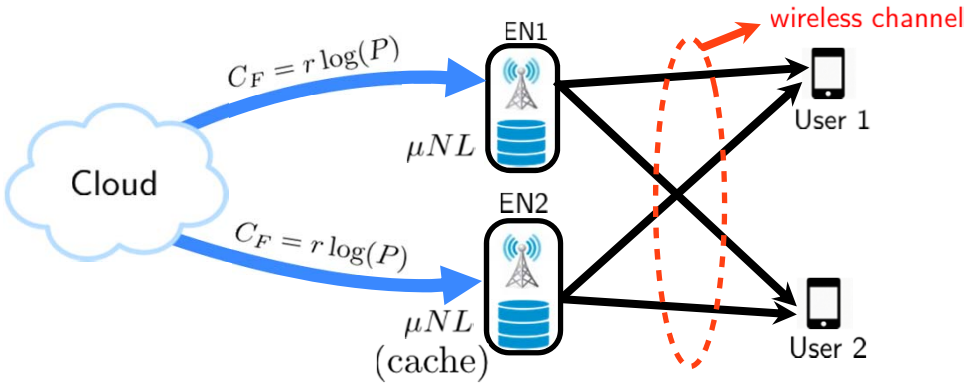
Design Space

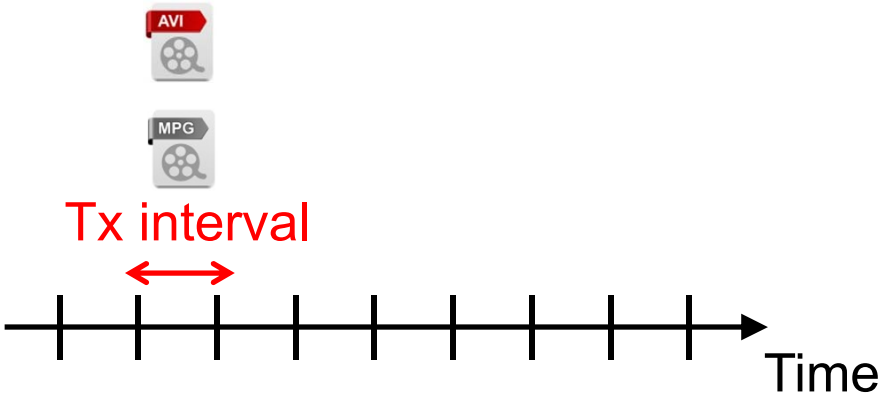




- Cache storage policy: What to cache
- Fronthaul policy: What to transmit on the fronthaul links
    - Hard/ soft-transfer mode

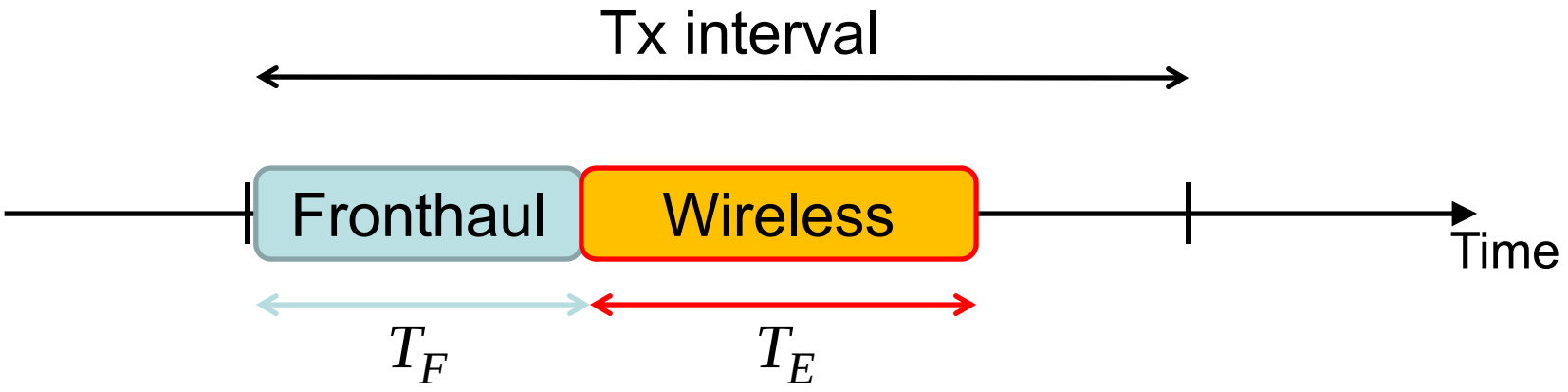
Design Space





- Cache storage policy: What to cache
- Fronthaul policy: What to transmit on the fronthaul links
    - Hard/ soft-transfer mode
- Edge transmission policy: What to transmit on the wireless channel

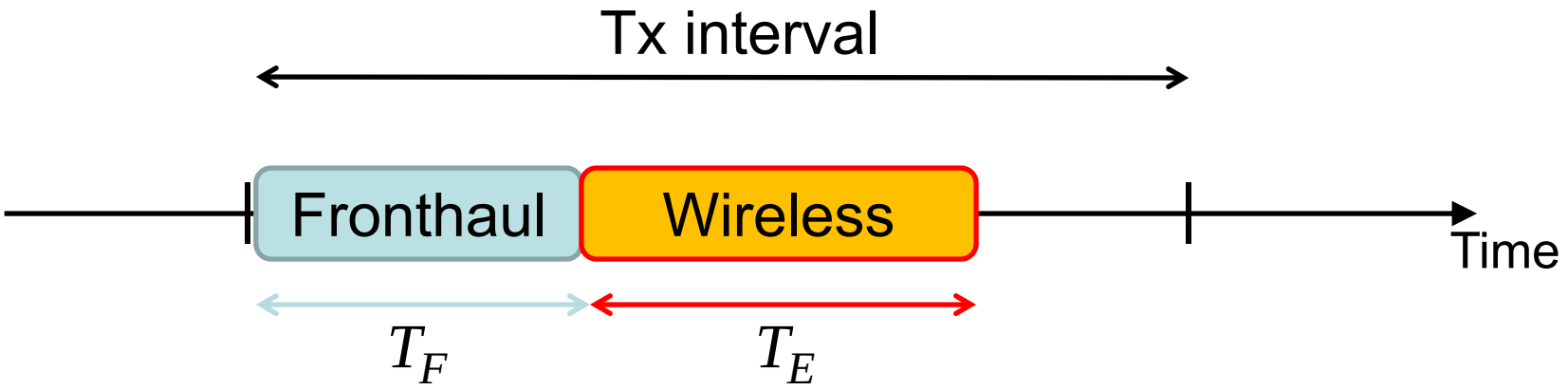
Performance Metric



- Delivery time per bit

$$\Delta(\mu, C_F, P) = \min_{\text{user's requests}} \frac{T_F + T_E}{L}$$

Performance Metric



- Delivery time per bit

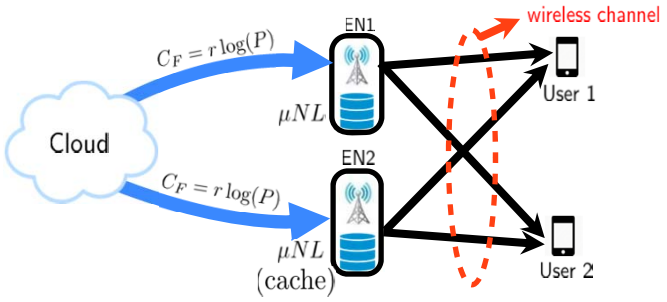
$$\Delta(\mu, C_F, P) = \min_{\text{user's requests}} \frac{T_F + T_E}{L}$$

- Normalized Delivery Time (NDT):

$$\delta^*(\mu, r) = \lim_{P\to\infty} \frac{\Delta(\mu, r\log P, P)}{1/\log P}$$

Ideal system: interference-free and unlimited caching

Normalized Delivery Time



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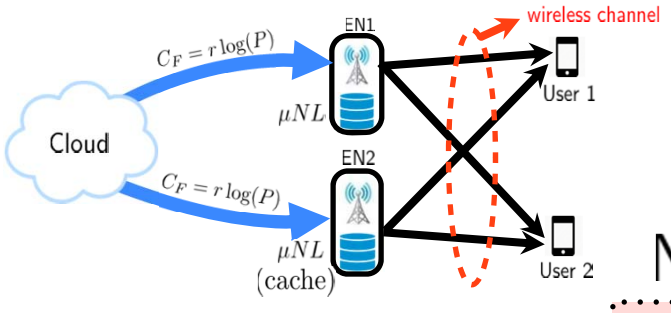
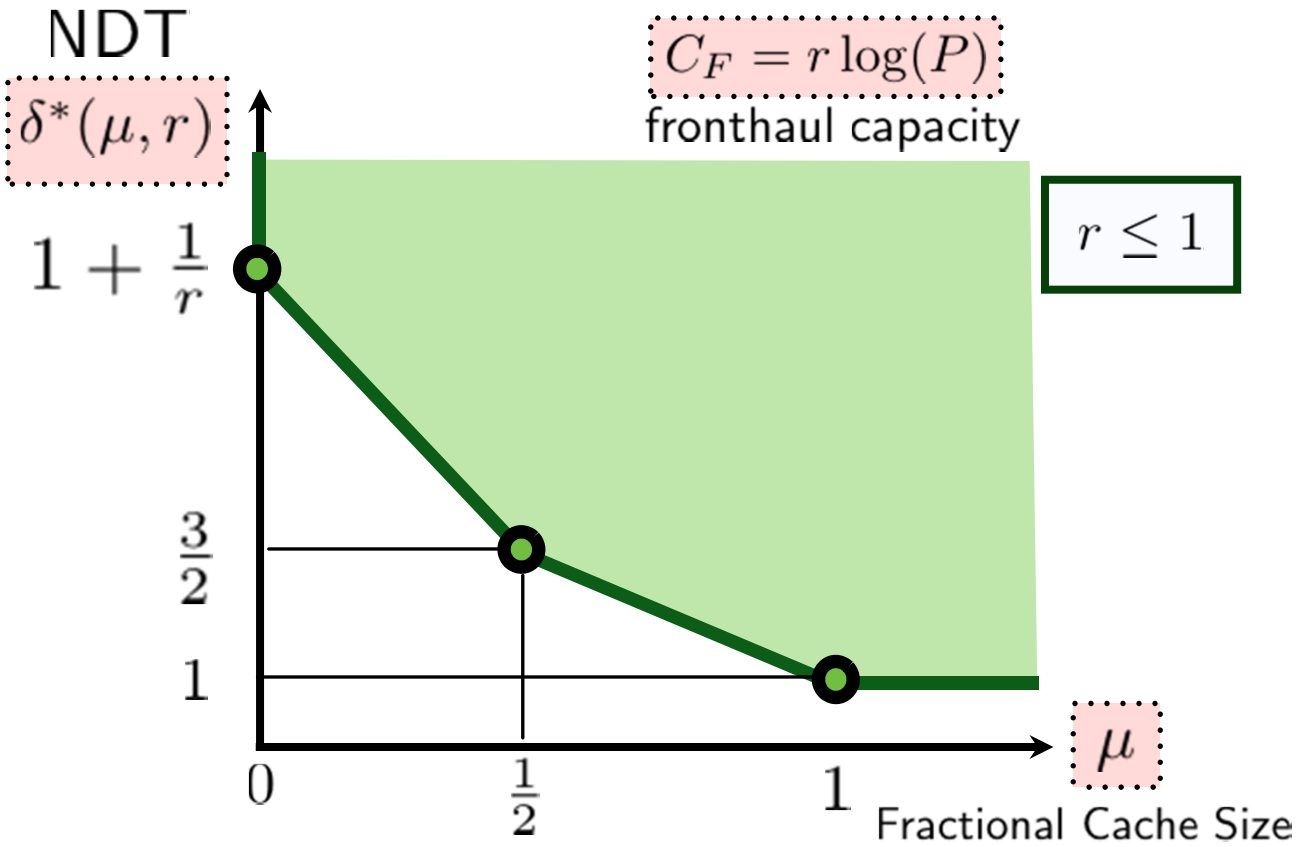
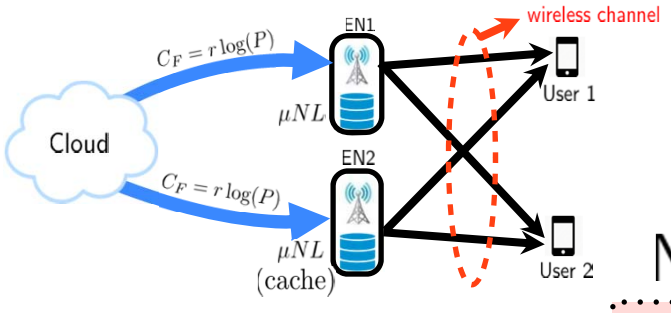


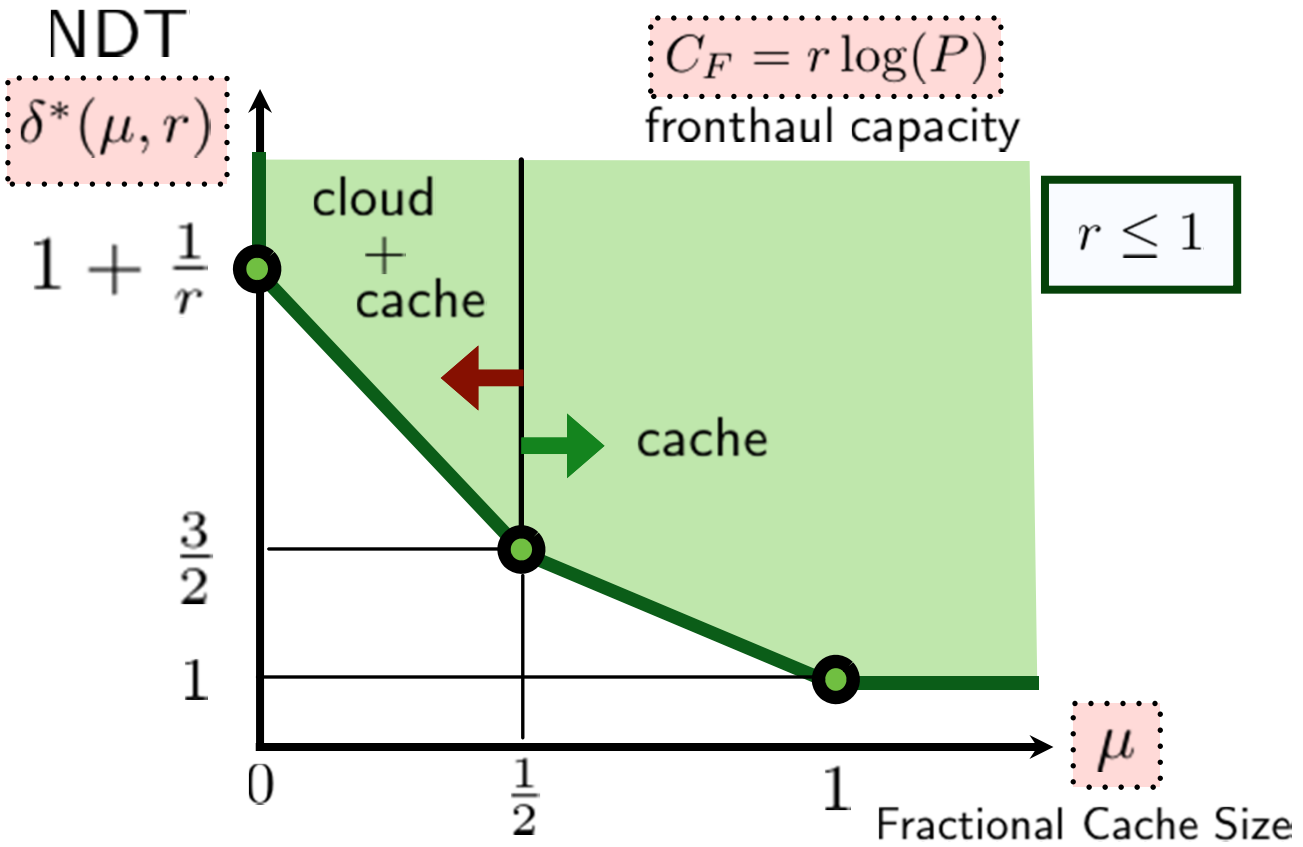
Low Fronthaul Capacity Regime



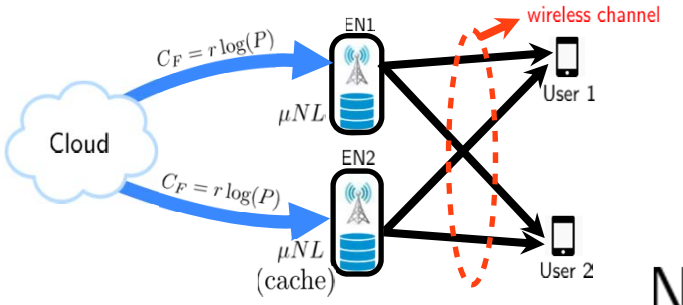
Normalized Delivery Time



Low Fronthaul Capacity Regime



Normalized Delivery Time



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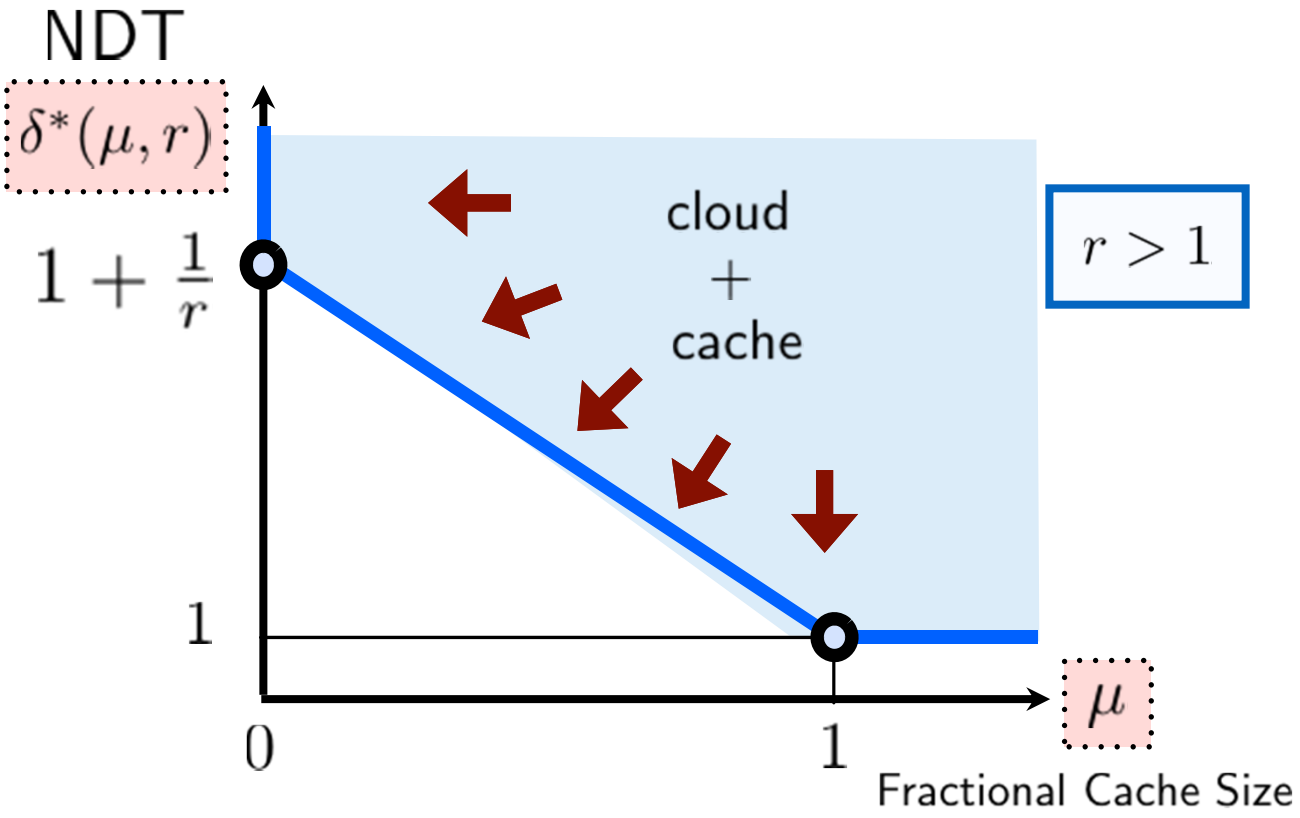

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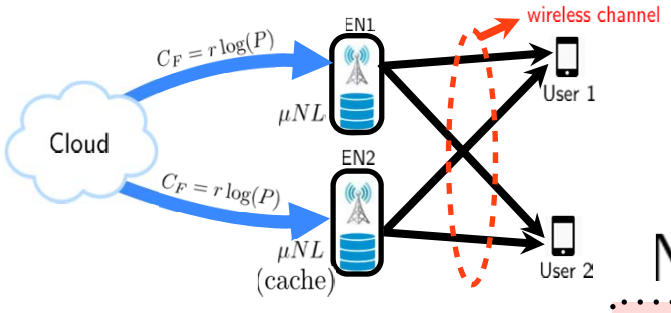


Low Fronthaul Capacity Regime

NDT

$\delta^*(\mu, r)$

$C_F = r\log(P)$

fronthaul capacity

$r \leq 1$

$1 + \frac{1}{r}$

cloud + cache

cache

$\frac{3}{2}$

1

0

$\frac{1}{2}$

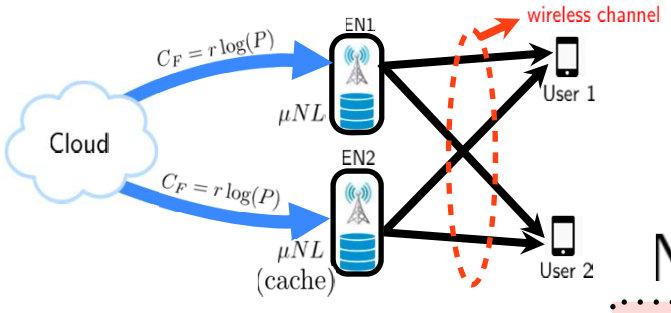
1

μ

Fractional Cache Size

Full caching: Cooperative zero-forcing beamforming at the ENs

Normalized Delivery Time



Low Fronthaul Capacity Regime

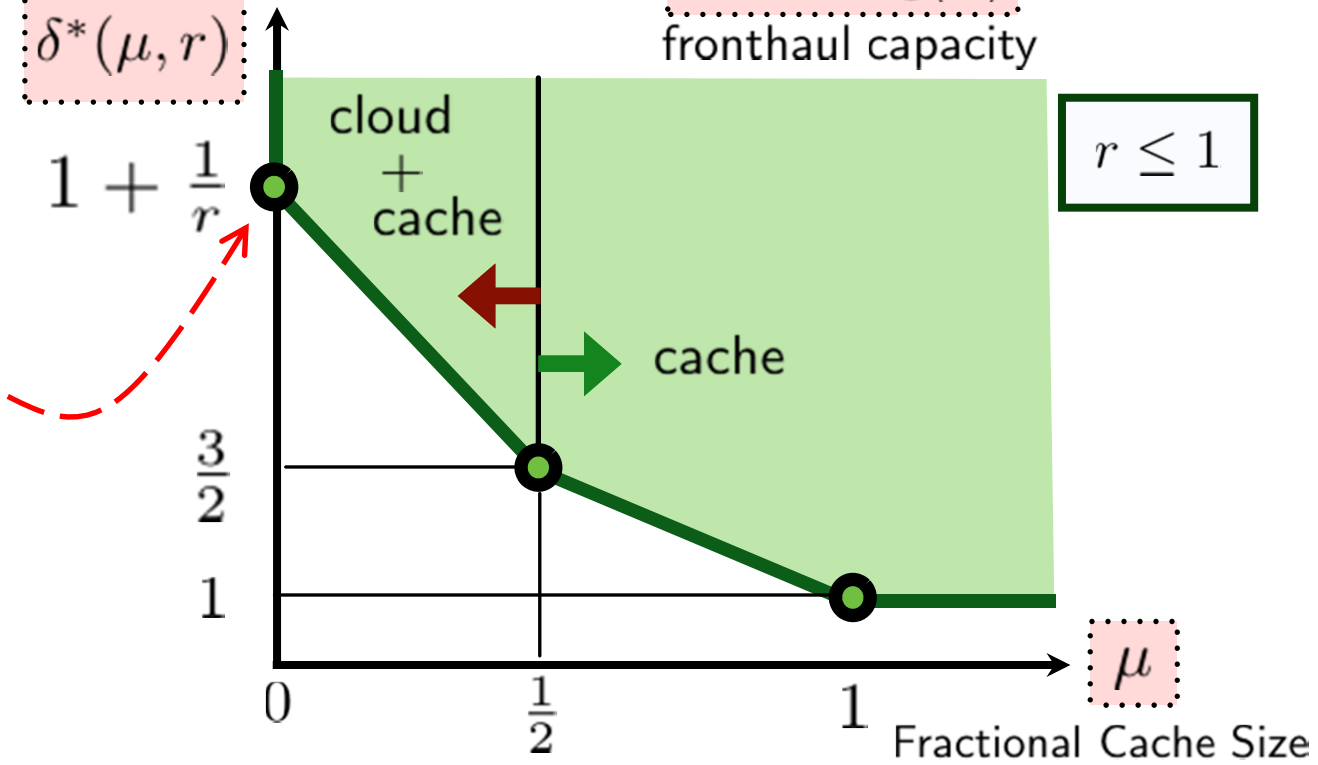
NDT

$\delta^*(\mu, r)$

$C_F = r\log(P)$

fronthaul capacity

No caching: Zero-forcing beamforming at the cloud + soft-transfer fronthauling



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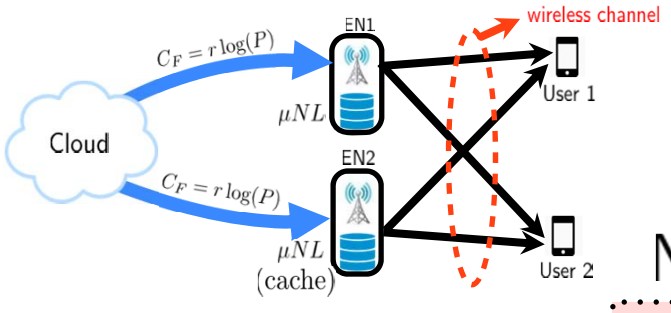

Low Fronthaul Capacity Regime

NDT

$\delta^*(\mu, r)$

$C_F = r\log(P)$

fronthaul capacity

$r \leq 1$

$1 + \frac{1}{r}$

cloud + cache

cache

$\frac{3}{2}$

1

0

$\frac{1}{2}$

1

μ

Fractional Cache Size

Caching of half file: Interference alignment on an "X-channel"

Conclusions

- F-RAN leverages the synergy and complementarity of cloud processing and edge caching

- Information-theoretic framework to obtain fundamental insights into the optimal trade-offs between latency and system resources (fronthaul and caching)

The Science and Technology University of New Jersey