Joint EPC and RAN Caching of Tiled VR Videos for Mobile Networks

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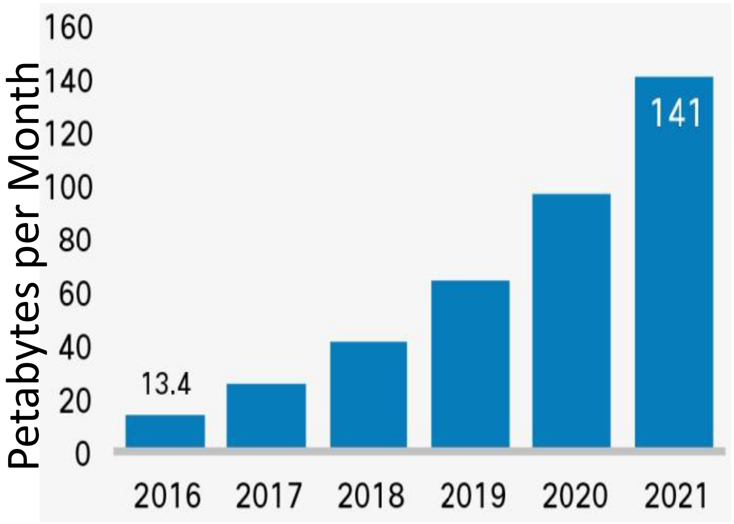
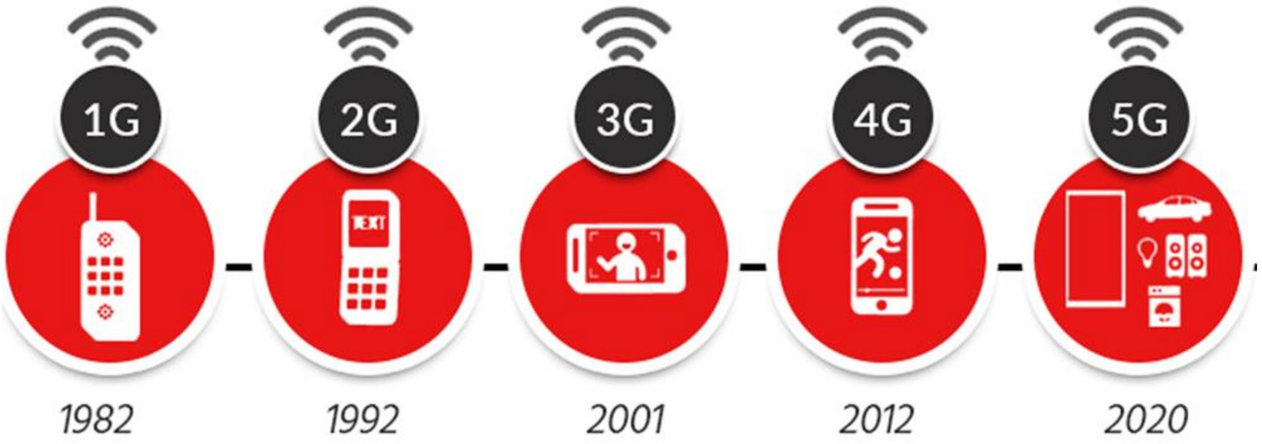
Outline

- Introduction
- Related works
- Proposed scheme
- Experimental results
- Conclusion

- The boom of 360-degree video applications.





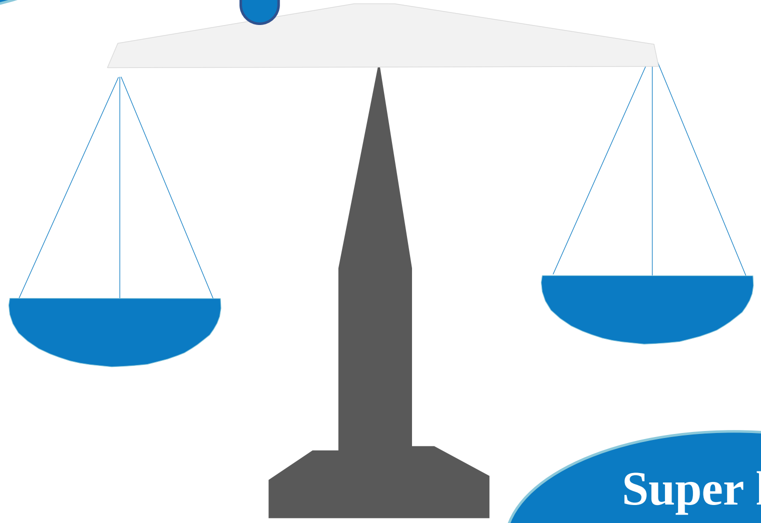
Introduction

It is extremely challenging to deliver VR videos over mobile networks!

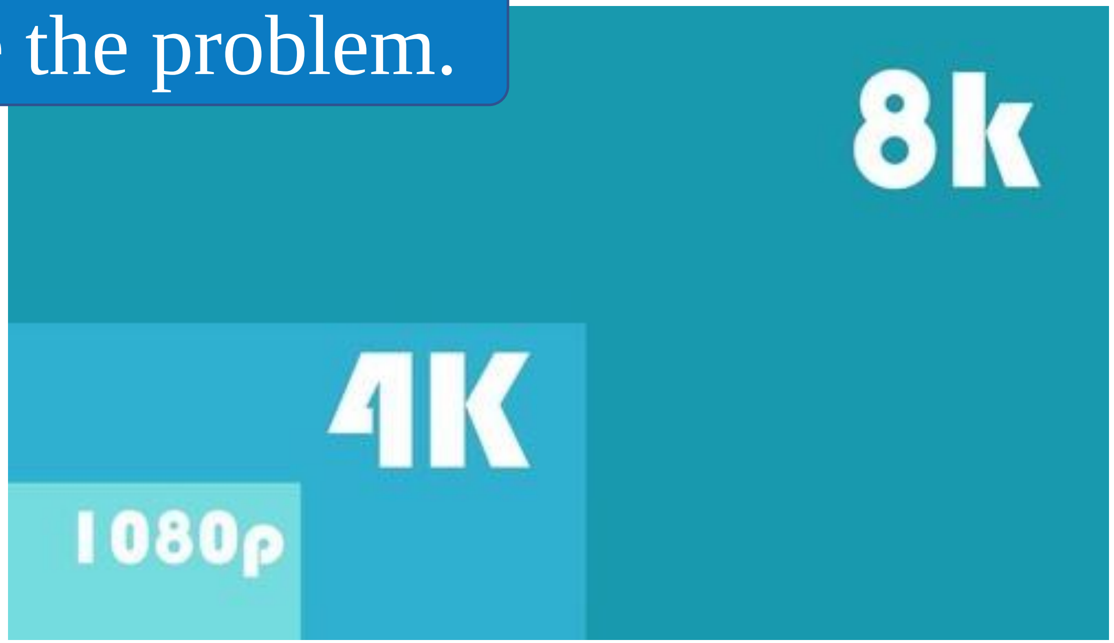
- Problem

We can use the way of CACHING to solve the problem.

Strict latency requirements & Huge bandwidth cost



Super high bit-rate of VR videos



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VR video coding and transmission approaches

- In [1], a region-adaptive video smoothing approach was proposed to improve the encoding efficiency by considering the particular characteristics of sphere-to-plane projection.
- In [2], Gaddam *et al*. applied a tiling scheme to deliver different quality levels for different parts of the panoramic VR videos.
- Corbillon *et al*. in [3] proposed a viewport-adaptive 360-degree video streaming system to transmit VR videos.

Current VR video applications still consume higher bandwidth that incurs large transmission delay.

- [1] Budagavi, M., *et al*., 360 degrees video coding using region adaptive smoothing., 2015
- [2] Gaddam, *et al*., Tiling in interactive panoramic video: approaches and evaluation., 2016
- [3] Corbillon, X., *et al*., Viewport-adaptive navigable 360-degree video delivery., 2017

Related works

Video caching

- In [4], Xie *et al*. studied the effects of different access types on Internet video services and their implications on Content Delivery Network (CDN) caching.
- Franky *et al*. in [5] studied a video cache system which can reduce the video traffic and the loading time.
- In [6], Zhou *et al*. proposed a QoE-driven video cache allocation scheme for mobile cloud server.

They cannot achieve the same results in mobile networks.

- [4] Xie, G., *et al.*, Access types effect on internet video services and its implications on CDN caching., 2018
- [5] Franky, O.E.A., *et al.*, System design, implementation and analysis video cache on internet service provider., 2016
- [6] Zhou, X., *et al.*, A new QoE-driven video cache allocation scheme for mobile cloud server., 2015

We propose the scheme of joint EPC and RAN caching of tiled VR videos to save latencies.

Related works

Mobile caching

- In [7], Shen *et al*. designed an information-aware QoE-centric mobile video cache scheme.
- In [8], Ahlehagh *et al*. introduced a video-aware caching scheme in the RAN.
- Ye *et al*. in [9] studied the quality-aware DASH video caching scheme at mobile network edge.

They neglected the collaboration between the EPC and RAN and cannot efficiently work for the VR videos.

- [7] Shen, S., *et al*., An information-aware QoE-centric mobile video cache. 2013
- [8] Ahlehagh, H., *et al*., Video-aware scheduling and caching in the radio access network. 2014
- [9] Ye, Z., *et al*., Quality-aware dash video caching schemes at mobile edge. 2017

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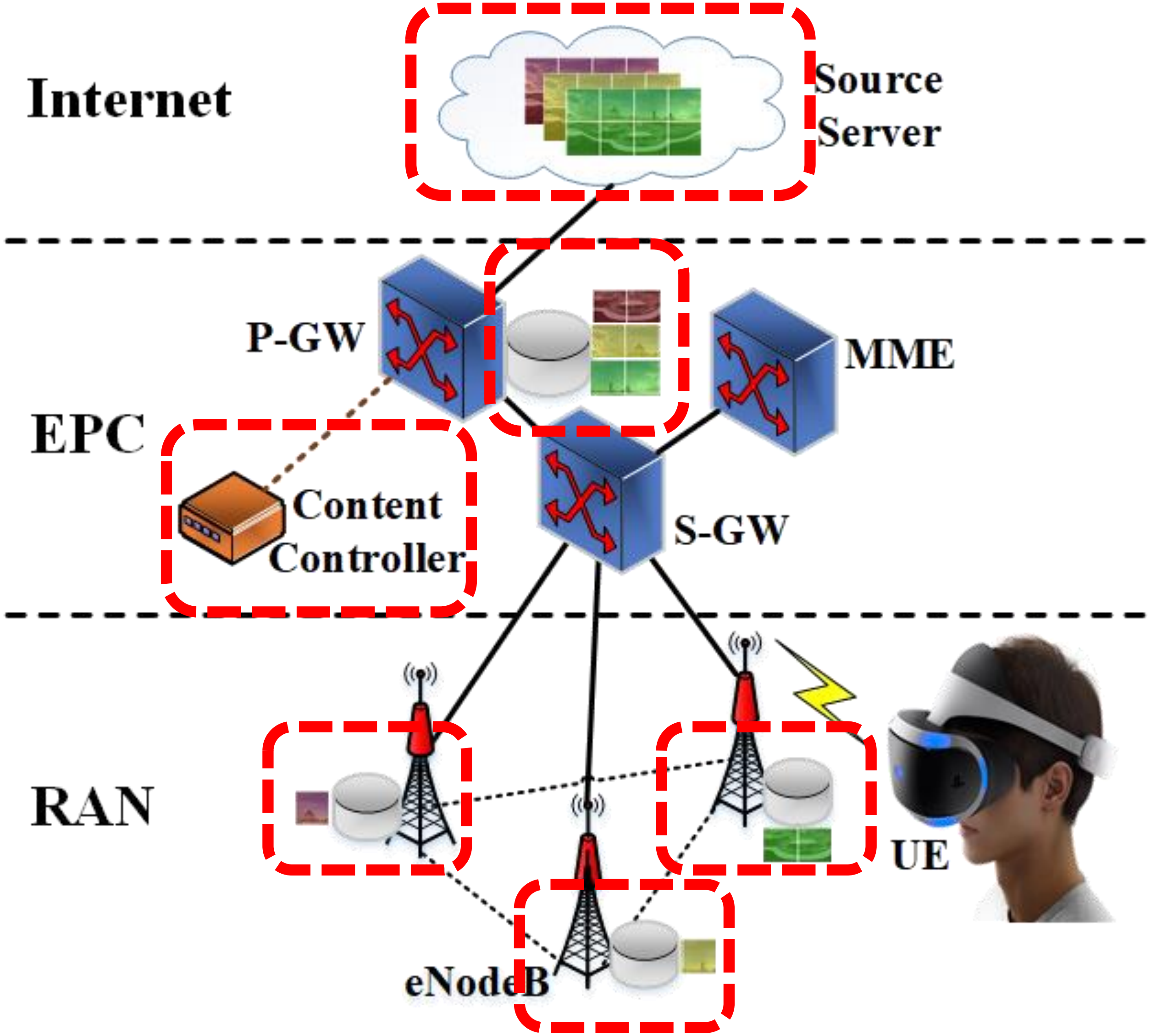
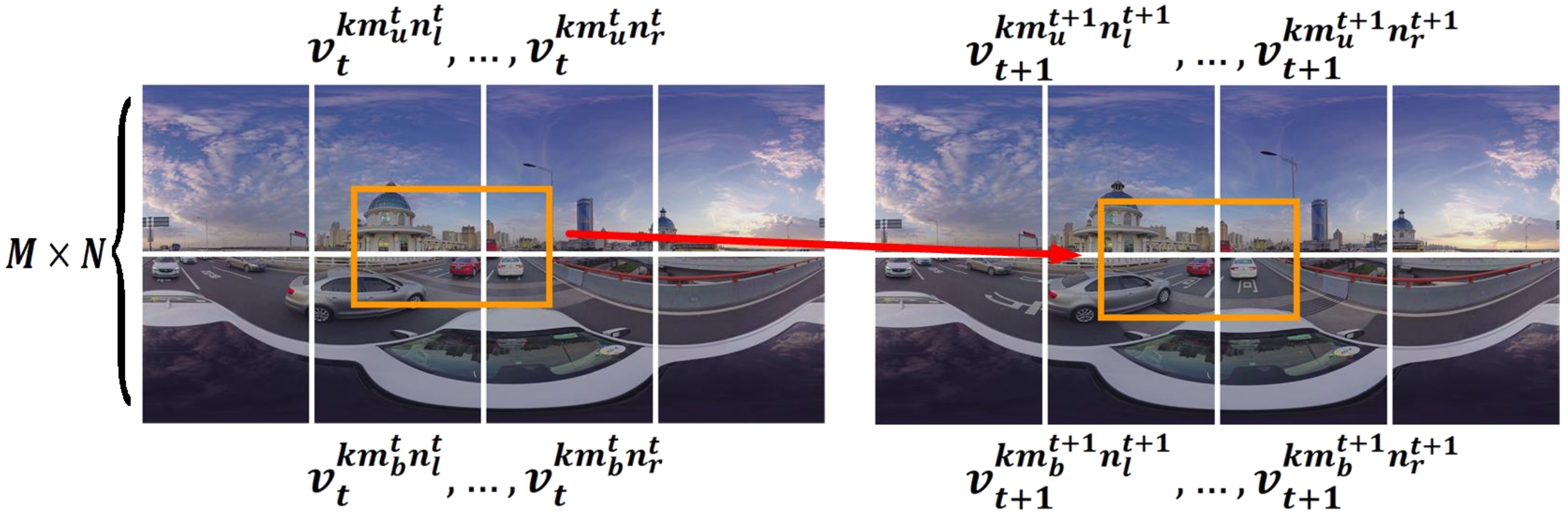
Proposed scheme



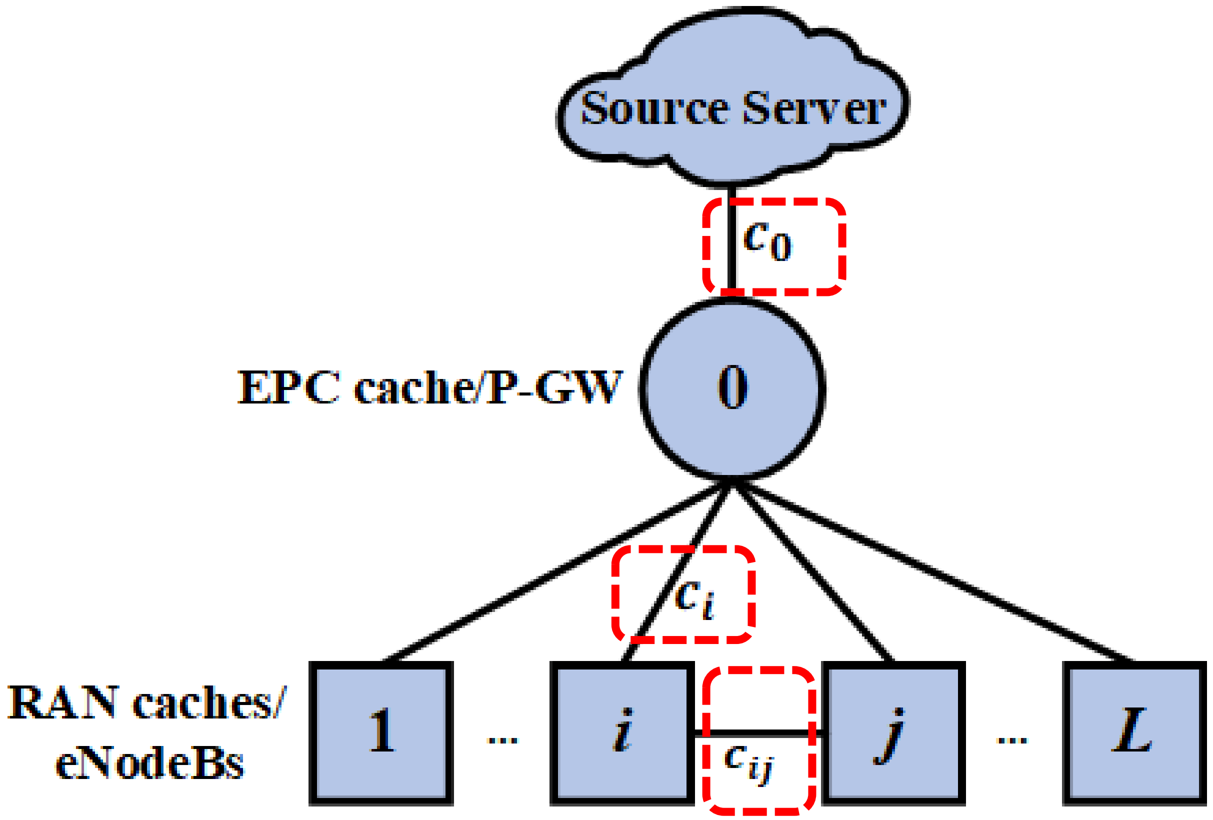
Contributions

- A VR video tile-caching scheme is proposed to selectively cache VR video tiles.
- Cache nodes are deployed in both the EPC and RAN to jointly perform the optimization.

Tile partition and viewport moving



The joint EPC and RAN tile-caching network architecture



- Denote the 0-1 variable $x_{t,i}^{kmn}$ as the indication of whether the VR video tile v_t^{kmn} is cached in the cache node *i*. 1: cached, 0: not cached.
  - If the cache node *i* can fulfill the request from the UE locally for the VR video tile v_t^{kmn} , the unit cost saving is $c_0 + c_i$ compared to fulfilled from the source server.
  - If the request cannot be fulfilled locally by *i* but can be fulfilled by the other eNodeBs, e.g., the node *j* , the unit cost saving can be written as $c_0 + c_i - c_{ij}$.
  - If the request can be fulfilled by the EPC cache at the P-GW, the unit cost saving is c_0 .
  - If the request can only be fulfilled from the source server on the Internet, the unit cost saving is 0.

Tile-Caching Problem Formulation

- Saved bandwidth cost

$$P_{t,i}^{kmn} = c_0 \times x_{t,0}^{kmn}.$$

$$Q_{t,ij}^{kmn} = \max_{j \in \mathcal{L} \setminus \{i\}} \{(c_0 + c_i - c_{ij}) y_{t,ij}^{kmn}\}$$

- Total saved cost

$$\begin{aligned}\tau &= \sum_{t \in \mathcal{T}} \sum_{k \in \mathcal{K}} \tau_k(\boldsymbol{X}_t) \\ &= \sum_{t \in \mathcal{T}} \sum_{k \in \mathcal{K}} \sum_{i \in \mathcal{L}} \sum_{m_u^t \le m \le m_b^t} \sum_{n_l^t \le n \le n_r^t} \lambda_{t,i}^{kmn} \cdot s_t^{kmn} \cdot [x_{t,i}^{kmn} \cdot \\ &\quad (c_0 + c_i) + (1 - x_{t,i}^{kmn}) \cdot \max\{P_{t,i}^{kmn}, Q_{t,ij}^{kmn}\}],\end{aligned}$$

$$\boldsymbol{X}_t = (x_{t,0}^{k11}, x_{t,0}^{k12}, \ldots, x_{t,0}^{kmn}, \ldots, x_{t,i}^{kmn}, \ldots, x_{t,L}^{kMN})$$

Tile-Caching Problem Formulation

- Request probability

$$\lambda_{t,i}^{kmn} = \xi_i^k \cdot \theta_t^{kmn}$$

- Problem formulation

$$\max_{\boldsymbol{X}_t} \tau$$

$$s.t. \sum_{t\in\mathcal{T}} \sum_{k\in\mathcal{K}} \sum_{m\in\{1,2,\ldots,M\}} \sum_{n\in\{1,2,\ldots,N\}} s_t^{kmn} x_{t,i}^{kmn} \leq B_i$$

$$x_{t,i}^{kmn} \in \{0,1\}, \forall i \in \mathcal{L}, t \in \mathcal{T}, k \in \mathcal{K},$$
$$m \in \{1,2,\ldots,M\}, n \in \{1,2,\ldots,N\}$$

$$\begin{cases} \max_i \left\{ \frac{x_{t,i}^{kmn} \cdot s_t^{kmn}}{w_i} \right\} \leq T, & \text{when} \sum_i x_{t,i}^{kmn} \neq 0, \\ \frac{s_t^{kmn}}{w_s} \leq T, & \text{otherwise}, \\ \quad \forall t \in \mathcal{T}, k \in \mathcal{K}, m_u^t \leq m \leq m_b^t, n_l^t \leq n \leq n_r^t, \end{cases}$$

Solution

Algorithm 1. GA for the joint EPC and RAN tile-caching optimization

Input: The population size s_{pop}, the chromosome length l, the probability of performing crossover p_c, probability of mutation p_m and the termination number of generations n_{ge}.

Output: The optimal caching result $\boldsymbol{X}$.

1: Initialization: generate the population of $\boldsymbol{X}$. The number of generation $g \leftarrow 0$.
2: **repeat**
3: **Selection:** calculate the fitness function according to Eq. (3), specially $\tau \leftarrow 0$ if the $\boldsymbol{X}$ cannot satisfy the constraints.
4: **Sort** the individuals according to τ in a decending order and select a portion of population using roulette wheel selection to breed a new generation.
5: **Crossover:** update p_c, calculate the number of crossover $s_{pop} \times p_c$, and do the crossover operation to generate a new generation.
6: **Mutation:** calculate the number of mutation $s_{pop} \times p_m$, and mutate to generate a second generation.
7: $g \leftarrow g + 1$.
8: **until** $g = n_{ge}$.
9: **return** $\boldsymbol{X}$ of the highest τ.

Selection: calculate the fitness value.

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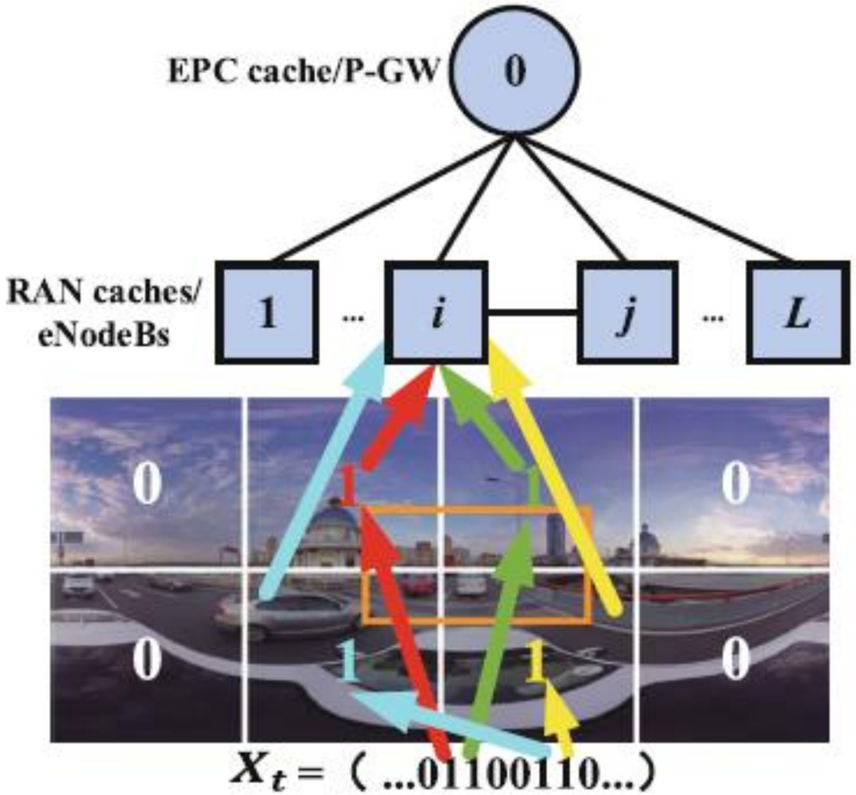
Experimental results

- An example of tile placement



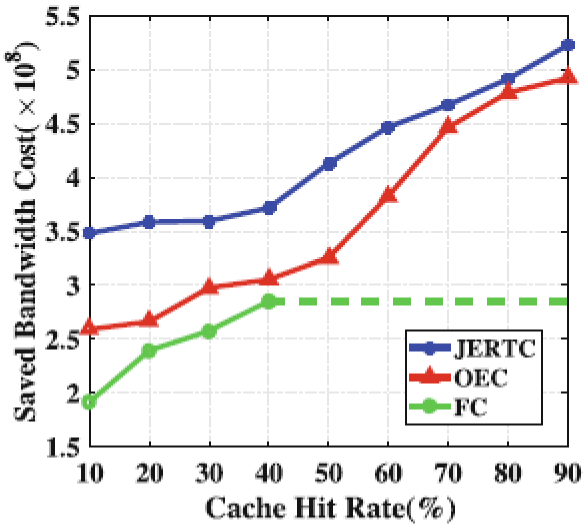
- Experimental parameters

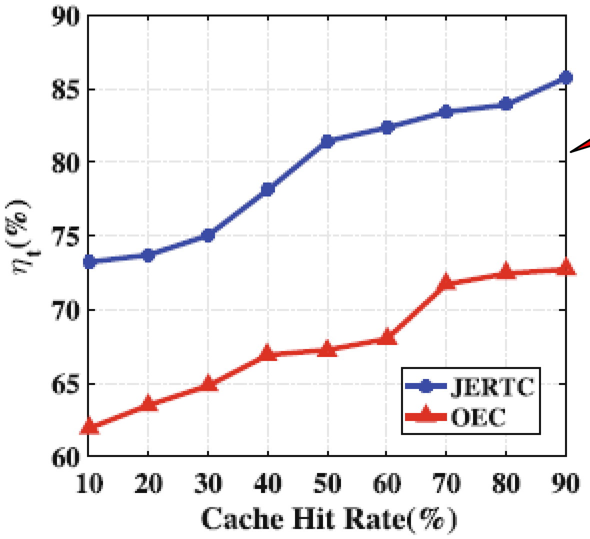
Table 1. Experimental parameters

Tile size	Viewport size	Chunk length	RAN cache number (L)	Cache size in eNodeB	UE number per eNodeB	T	c_0	c_i
960×960	1920×1080	1 s	40	$10G$	100	15 ms	100	5
c_{ij}	w_i	w_s	s_{pop}	l	p_c	p_m	n_{ge}	
2–10	600 Mbps	150 Mbps	50	2000	0.7–0.9	0.02	500	

Experimental results

Experimental results



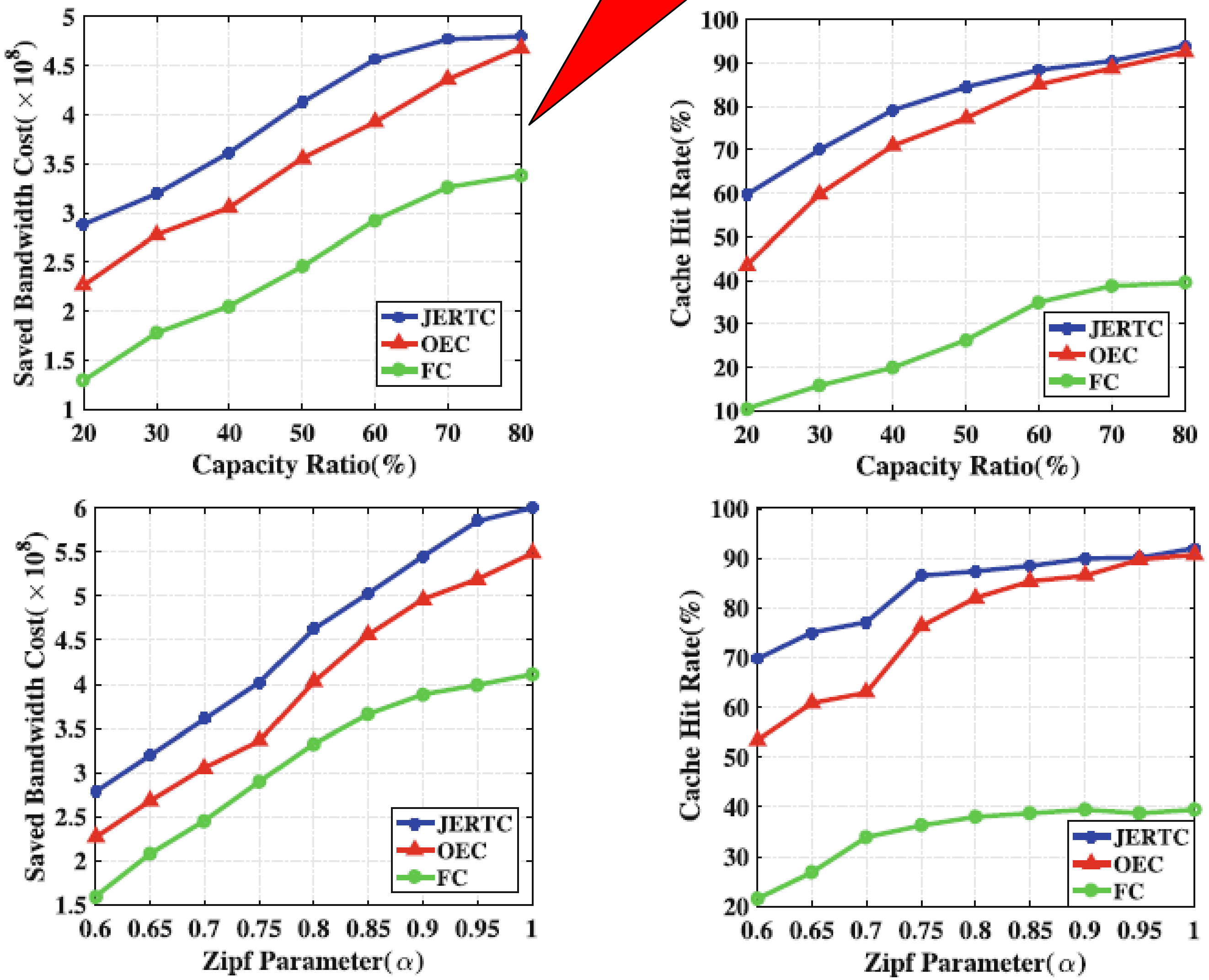


Save about 10% latencies.

Experimental results

Save about 20% bandwidth cost.

Experimental results



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Conclusion

- In this paper, a joint EPC and RAN tile-caching scheme (JERTC) of 360-degree VR videos is proposed for mobile networks.

- By fully considering the tiling characteristics of VR videos and the restriction nature of the cache space in mobile networks, 360-degree VR video tiles are jointly cached in both EPC and RAN using the 0-1 knapsack optimization.

- Experimental results show that the proposed JERTC scheme can significantly reduce the duplicate video tile transmissions which relieves the pressure on mobile networks and at the same time reduces the latency to ensure the requirements of VR applications.

Thank you for your time !

Any questions?

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