QoE-Oriented Resource Allocation for 360-degree Video Transmission over Heterogeneous Networks

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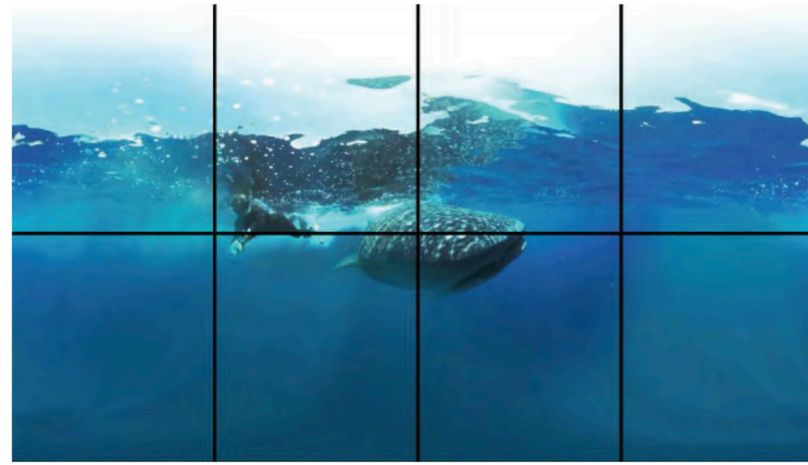
Introduction

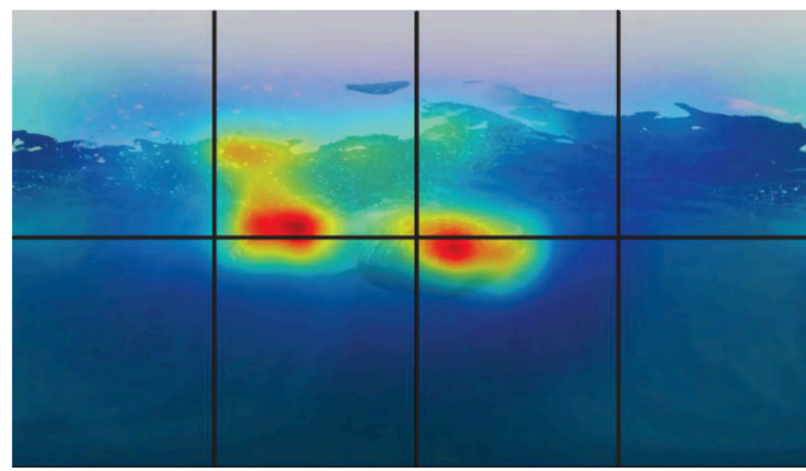
- immersive media has gained increasing popularity
- A lot of researchers have tried to better exploit the bandwidth by utilizing the heterogeneous LTE and WLAN multi-radio networks
- application-layer (APP-layer) resource allocation scheme for 360-degree/VR video transmissions over multi-RAT systems with multiple users

Tile-Based 360-degree VR Video

n	User index
N	Total number of users
U_n	The Utility of user n
A, B	Normalization coefficients of U_n
j	Tile index
J	Total number of tiles in one video
A, B	Normalization coefficients of U_n
m	Tile representation level index
M	Total Number of tile representation
D_m	Video rate of tile representation m
θ_0	The prediction filed of view on sphere
φ	Azimuth angle in spherical coordinate
θ	Polar angle in spherical coordinate
ρ	Guarantee probability of FoV prediction
y	Probable FoV index
Y_n	Total number of probable FoV for user n
$P_y^{(n)}$	The probability of probable FoV n for user n
$D_{n,j}$	Video rate of tile j on user n
m	Tile representation index
M	Total number of tile representation in server
d_n	Total transmission rate of user n through LTE and WLAN
d_n^{LTE}	Transmission rate of user n through LTE channel
$d_{n,i}^{wifi}$	Transmission rate of user n on AP i
r_n^{LTE}	Achievable rate of user n through LTE channel
$r_{n,i}^{wifi}$	Achievable rate of user n when connected to AP i
$W_{n,j}$	Saliecny weight of tile j on user n
$C_{n,j}^m$	Cost of tile j on user n when m-th representation is selected
$\tilde{U}_{n,j}^m$	Improvement utility of tile j on user n when m-th representation is selected
$\nu_{n,j}^m$	Utility over cost of tile j on user n when m-th representation is selected
B_1	Buffer threshold length
B_2	Buffer maximum length
B_c	Current buffer length
μ	Coefficient of QoE metric
l	Coefficient of buffer strategy
σ	Coefficient of penalty function



(a)



0.1	0.3	0.21	0.07
0.04	0.13	0.13	0.02

System Models

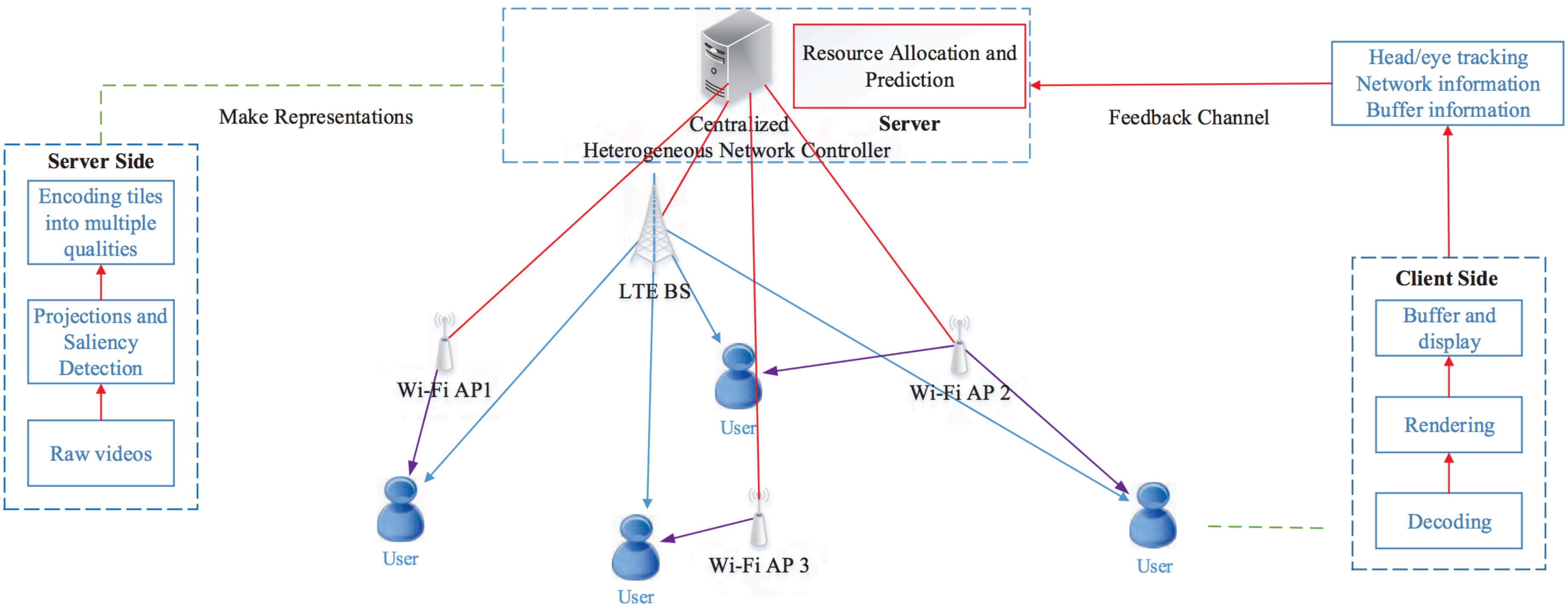
- Utility Model

$$U(D) = A \log B \frac{D}{D_M},$$

- Video Quality

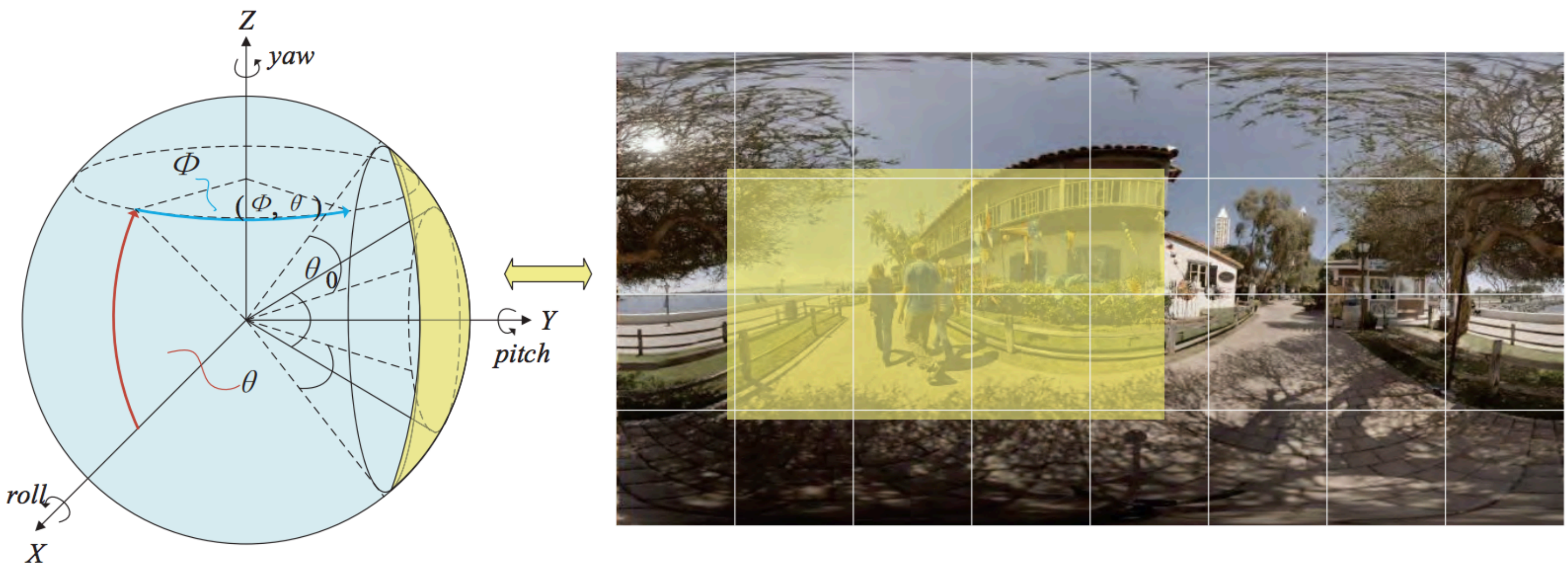
$$\sum_{j \in \mathrm{FoV}} U_{n,j} * W_{n,j} + \mu \mathbf{min}_{j \in \mathrm{FoV}}(U(D_{n,j}))$$

The system of Tile-based 360-degree Video Transmission in Multi-RAT Network



Resource Allocation in Multi-RAT Networks

- FoV Probability



- Expected QoE

$$\sum_{y}^{Y_n}\left(\sum_{j\in \mathrm{FoV}_y} U(D_{n,j}) * W_{n,j} + \mu \min_{j\in \mathrm{FoV}_y} \left(U(D_{n,j})\right)\right) P_y$$

Problem Formulation

n	User index
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OPT-1 :

$$\max \sum_{n}^{N} \left(\sum_{y}^{Y_n} \left(\sum_{j \in \mathrm{FoV}_y} U(D_{n,j}) W_{n,j} + \mu \min_{j \in \mathrm{FoV}_y} U(D_{n,j}) \right) P_y \right),$$

$$\text{s.t.} \sum_j D_{n,j} \le d_n, \ \forall n, \tag{4}$$

$$d_n = d_n^{\mathrm{LTE}} + \sum_i d_{n,i}^{\mathrm{wifi}}, \tag{5}$$

$$\sum_n \frac{d_n^{\mathrm{LTE}}}{r_n^{\mathrm{LTE}}} \le 1, \tag{6}$$

$$\sum_n \frac{d_{n,i}^{\mathrm{wifi}}}{r_{n,i}^{\mathrm{wifi}}} \le 1, \ \forall i, \tag{7}$$

$$\mathrm{card}\left(\left[d_{n,1}^{\mathrm{wifi}}, \cdots, d_{n,I}^{\mathrm{wifi}} \right] \right) = 1, \tag{8}$$

$$D_{n,j} \in \{D_1, \cdots, D_M\}. \tag{9}$$

Algorithm 1: Greedy

Algorithm 1 Greedy Algorithm

Variable definition:

$\mathcal{Q}_B$: the set of fixed users and corresponding association;
$\mathcal{Q}_C$:the set of users have not been placed;
(n, i): the user n is connected to Wi-Fi AP i;

Initial: $\mathcal{Q}_B = \Phi, \mathcal{Q}_C = \{1, 2, \cdots, N\}$;

while $\mathcal{Q}_C! = \Phi$ **do**
  $sum = 0; j = 0; t = 0;$
  for $n = 1, n \leq N, n++$ **do**
    if $n \in \mathcal{Q}_C$ **then**
      for $i = 1, i \leq I, i++$ **do**
        solve the OPT-1 when user n is fixed to Wi-Fi AP i;
        $temp = \max U_{\mathcal{Q}_B + \{(n,i)\}}$,
        $D^* \leftarrow \arg\max U_{\mathcal{Q}_B + \{(n,i)\}}$;
        if $temp > sum$ **then**
          $sum = temp; j = n, t = i;$
        end if
      end for
    end if
  end for
  update $\mathcal{Q}_B \leftarrow \mathcal{Q}_B + \{(j, t)\}; \mathcal{Q}_C \leftarrow \mathcal{Q}_B - \{j\}$ and D^*;
end while
Round D^* to appropriate representation.

Algorithm 2: Heuristic Algorithm with Penalty Function

- introducing a penalty function into the problem and relaxing the OPT-1 into a convex problem

OPT-2 :

$$\max \sum_{n}^{N} \left(\sum_{y}^{Y_n} (\mu \min_{j \in \mathrm{FoV}_y} U(D_{n,j}) + \sum_{j \in \mathrm{FoV}_y} U(D_{n,j}) W_{n,j}) P_y \right) - \sigma \sqrt{\sum_n \left(\sum_i d_{n,i}^{\mathrm{wifi}} \right)^2}$$

$$\text{s.t.} \sum_j D_{n,j} \le d_n, \ \forall n,$$

$$\sum_n \frac{d_n^{\mathrm{LTE}}}{r_n^{\mathrm{LTE}}} \le 1,$$

$$\sum_n \frac{d_{n,i}^{\mathrm{wifi}}}{r_{n,i}^{\mathrm{wifi}}} \le 1, \ \forall i,$$

$$d \ge 0,$$

$$D_1 \le D_{n,j} \le D_m.$$

Algorithm 2 Heuristic Algorithm with Penalty Function

1: Convert OPT-1 to OPT-2 with penalty function;
2: Solve OPT-2 and get $d_{n,i}^{\mathrm{wifi}}$;
3: Find the K users (indexed by k) connected to more than a single AP;
4: **for** $k = 1, n \le K, k++$ **do**
5: Use greedy approach only on these users while fixed others and update D^*;
6: **end for**
7: Round D^* to appropriate representation.

Algorithm 3: Decomposition Algorithm

OPT-3 :

$$\max \sum_{n}^{N} \left(U_n(d_n) \sum_{y}^{Y_n} \Big(\sum_{j \in \mathrm{FoV}_y} W_{n,j} \Big) P_y \right)$$

$$\text{s.t. } d_n = d_n^{\mathrm{LTE}} + \sum_i d_{n,i}^{\mathrm{wifi}},$$

$$\sum_n \frac{d_n^{\mathrm{LTE}}}{r_n^{\mathrm{LTE}}} \le 1,$$

$$\sum_n \frac{d_{n,i}^{\mathrm{wifi}}}{r_{n,i}^{\mathrm{wifi}}} \le 1, \ \forall i,$$

$$\mathrm{card}([d_{n,1}^{\mathrm{wifi}}, \cdots, d_{n,I}^{\mathrm{wifi}}]) = 1.$$

Algorithm 3 Decomposition Algorithm

```
Solve OPT-3, get d_n and Wi-Fi AP allocation;
for n = 1, n ≤ N, n++ do
    sort the utility over the cost of each tile ν^m_{n,j} and set
    d_current = 0;
    while d_current ≤ d_n do
        update the representation level to each tile according
        to the utility over the cost continuously ;
        update d_current = d_current + d_consumed;
    end while
end for
```

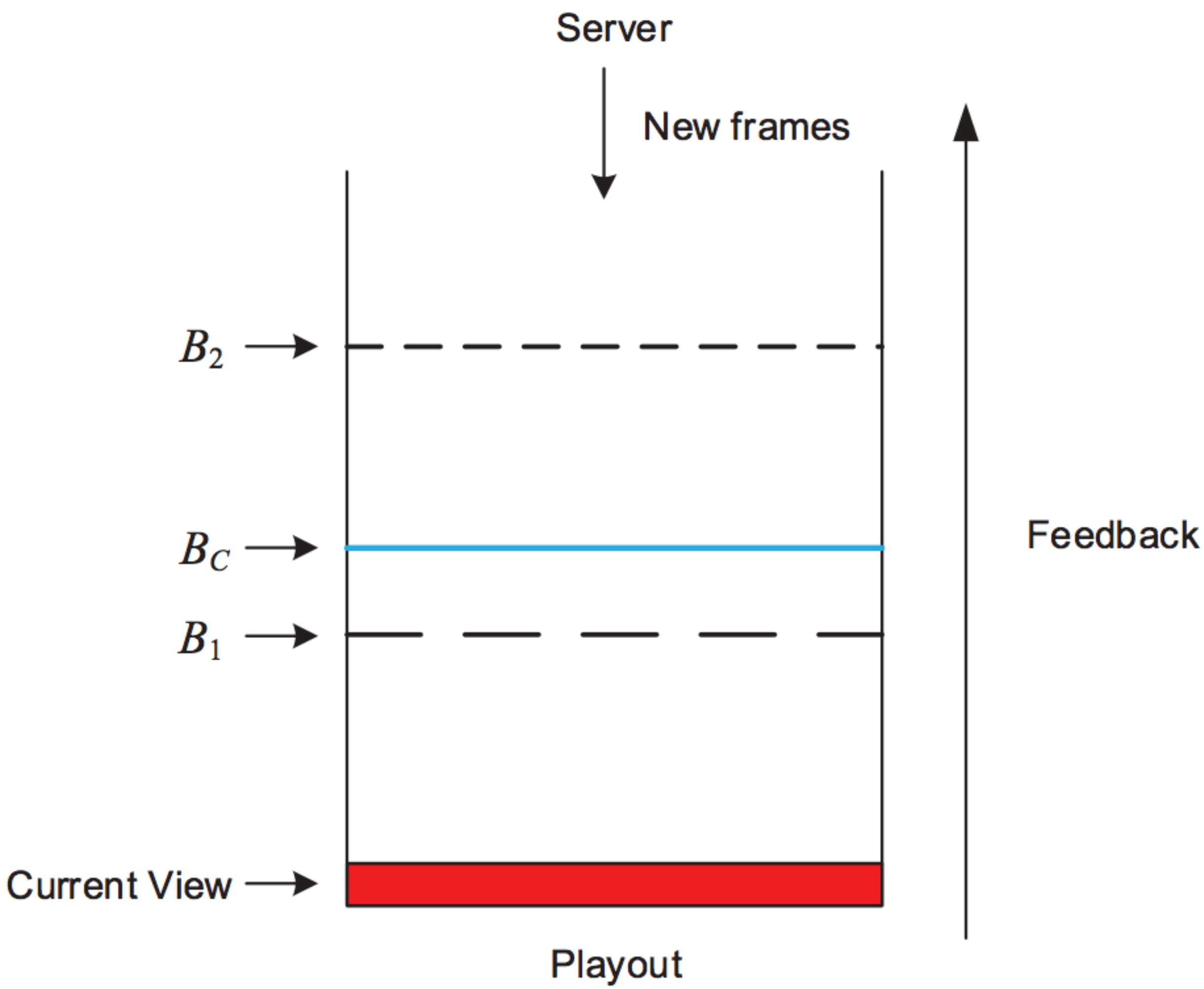
OPT-4 :

$$\max \left(\sum_{y}^{Y_n} \mu \min_{j \in \mathrm{FoV}_y} U(D_{n,j}) + \sum_{j \in \mathrm{FoV}_y} U(D_{n,j}) W_{n,j} \right)$$

$$\text{s.t. } \sum_j D_{n,j} \le d_n, \tag{19}$$

$$D_{n,j} \in \{D_1, \cdots, D_M\}. \tag{20}$$

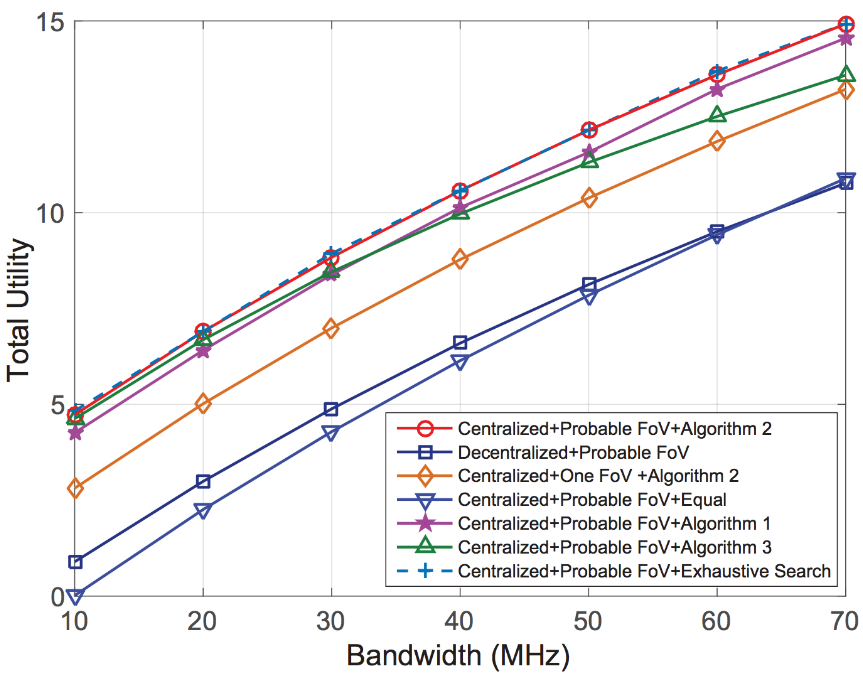
Buffer Measurement Strategy

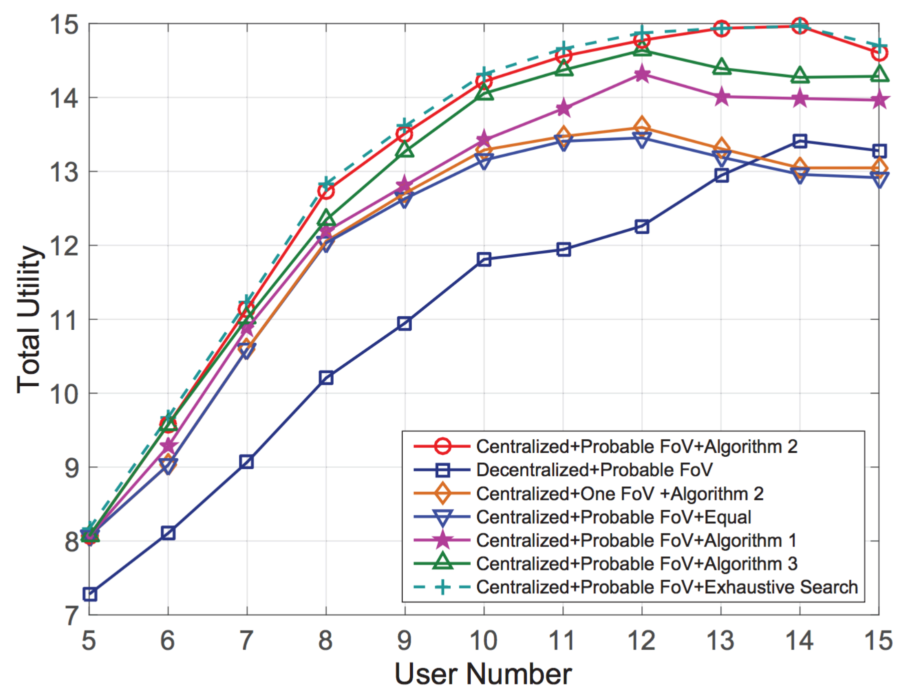


Simulation Setup

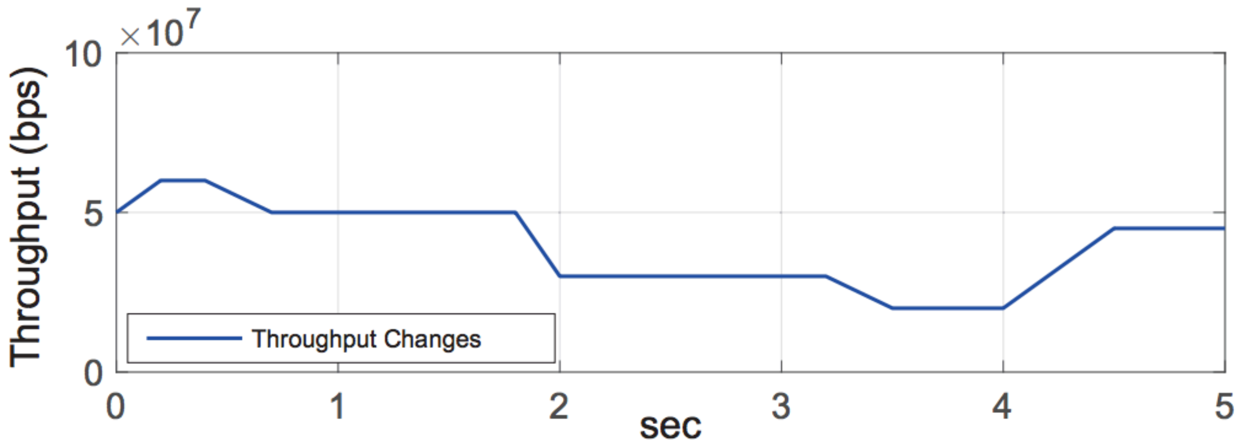
- 18 distinct 360-degree videos from MPEGJVET (Joint Video Exploring Team) 360-degree VR video datasets and YouTube
- 32 tiles, 10 different-bitrate representations
- NS-3
  - The users are uniformly distributed around 5 Wi-Fi APs within the coverage of LTE BS within 200m
  - When more users are involved into the system, they will be set close to AP 1 to simulate the congestion scenario

Simulation Results





Simulation Results



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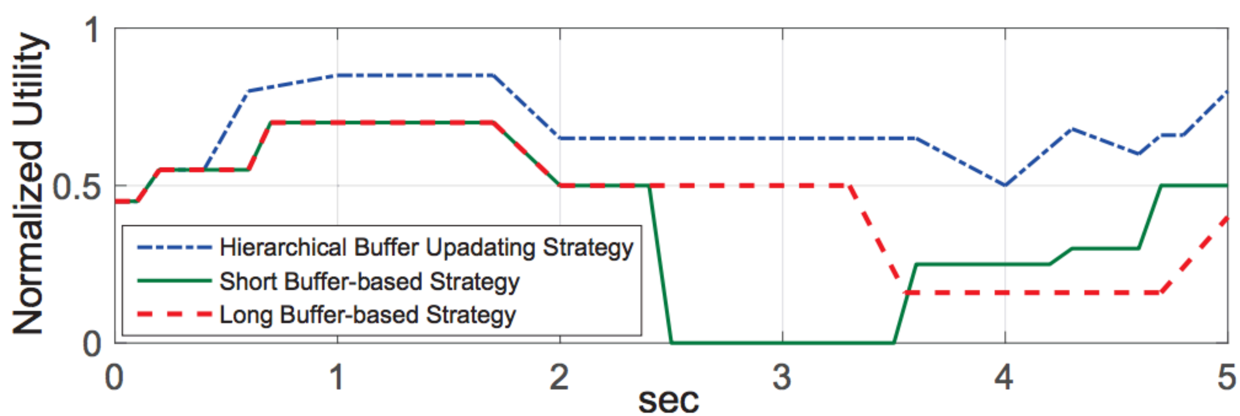

(b)

Conclusion

- tile-based 360-degree VR video transmission scheme and a corresponding buffer strategy on heterogeneous networks with multi-user access
- jointly consider saliency in videos, filed of view and the channel quality states of users