MISL

RTOP: Optimal User Grouping and SFN Clustering for Multiple eMBMS Video Sessions

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INFOCOM 2019

This publication has emanated from research conducted with the financial support of Science Foundation Ireland (SFI) under Grant Number: 13/IA/1892.

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Science Foundation Ireland sfi For what's next

Why Live Video?

- Live video is the **fastest growing traffic** over the Internet
  - 20% of all video traffic by 2022. 15-fold increase from 2017

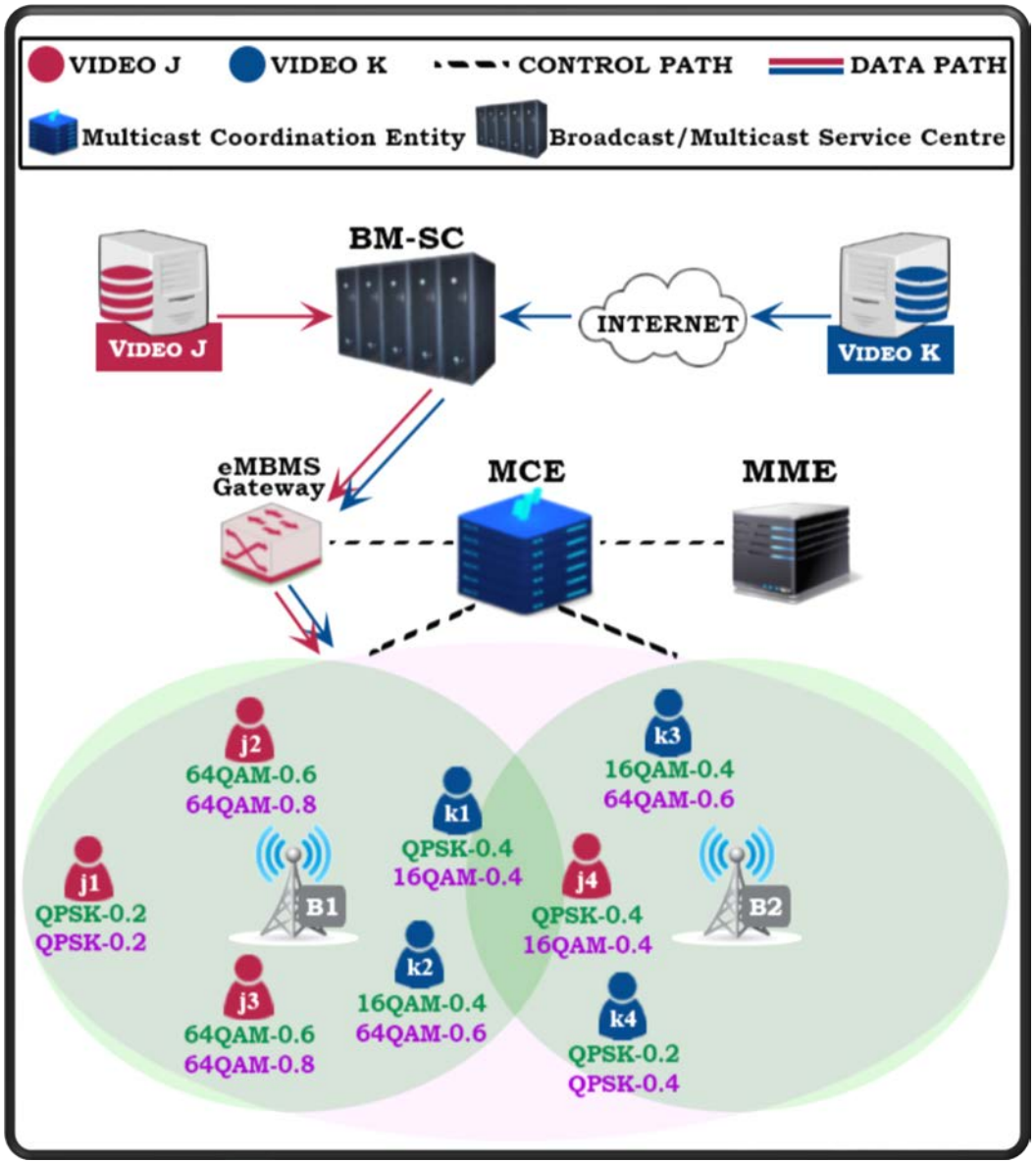
https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html

- Flash-crowds and mega-events are challenging to handle
  - Especially for cellular operators, due to the **limited wireless spectrum**

What Is eMBMS?

- Evolved Multimedia **Broadcast Multicast** Service
- A 3GPP standard for: 3G, 4G and **most likely 5G**
- Improves the **utilization** of scarce cellular resources
- Two key features:
  - **User groups**: Based on channel conditions
  - **Single Frequency Network** (SFN)

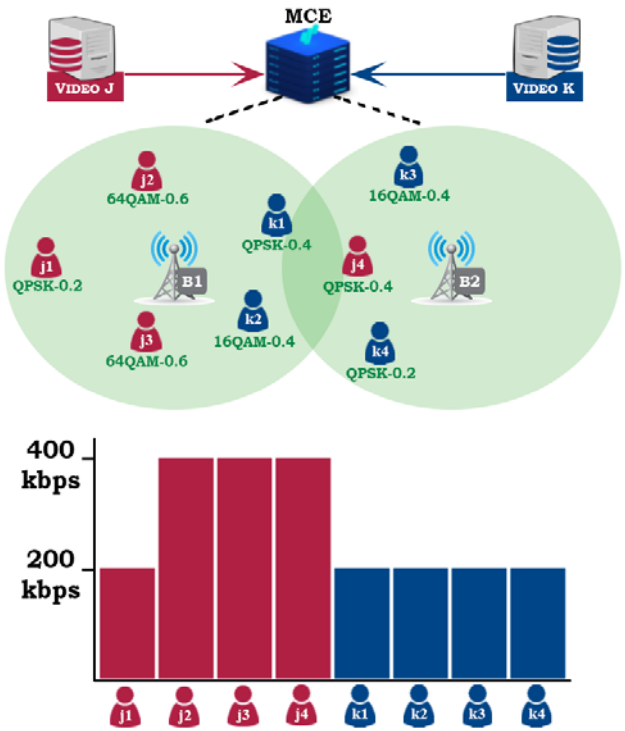
We propose an **optimization model** and real-time heuristics for eMBMS that makes the best use of the available resources and **maximizes user experience**



EXAMPLE: UNICAST & STANDARD EMBMS

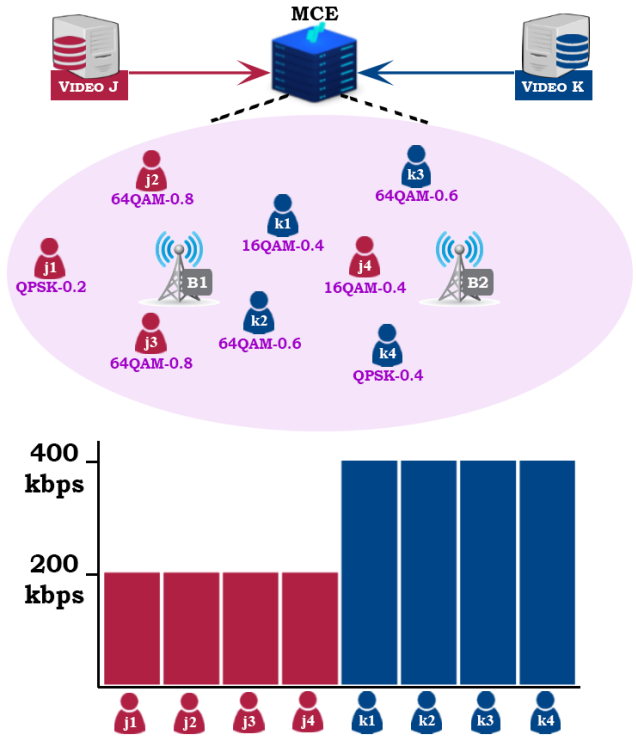
- Two videos each served at two different bitrates: **200 kbps and 400 kbps**
- **10 resource blocks** available for eMBMS at each base station

CASE A: NO EMBMS



Utility = 44.46 & Avg. Rate = 275

CASE B: STANDARD EMBMS



Utility = 45.12 & Avg. Rate = 300

EXAMPLE: SFN CLUSTERS & USER GROUPS

- Two videos each served at two different bitrates: **200 kbps and 400 kbps**
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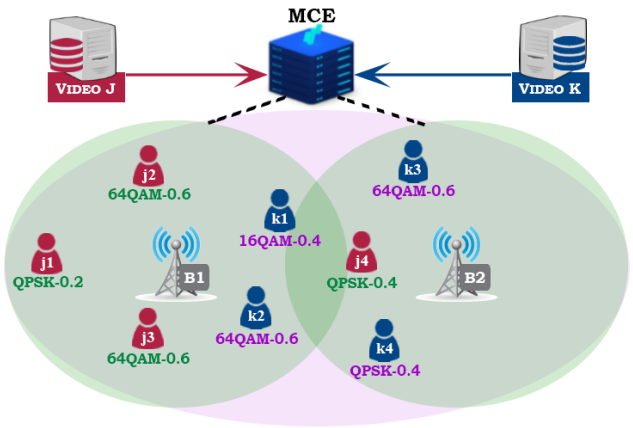
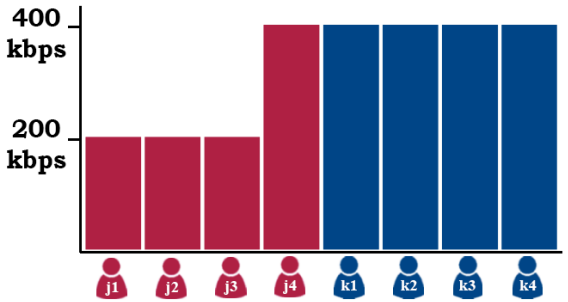
CASE C: SFN CLUSTERS (1)





Utility = 45.84 & Avg. Rate = 325

(1): R. Sivaraj et al., "BoLTE: Efficient network-wide LTE broadcasting", ICNP 2017

Example: SFN Clusters & User Groups

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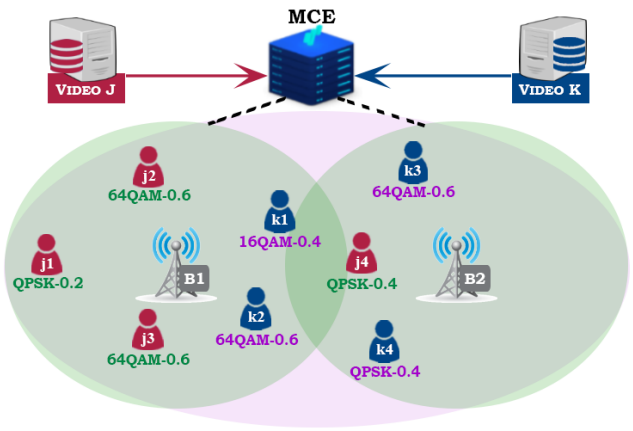

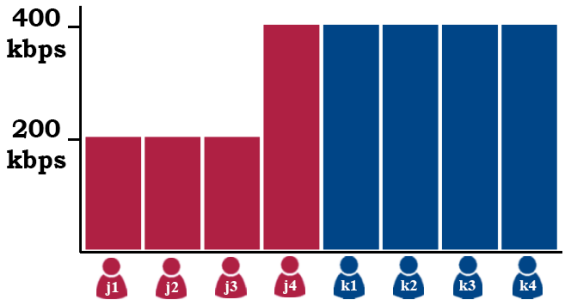

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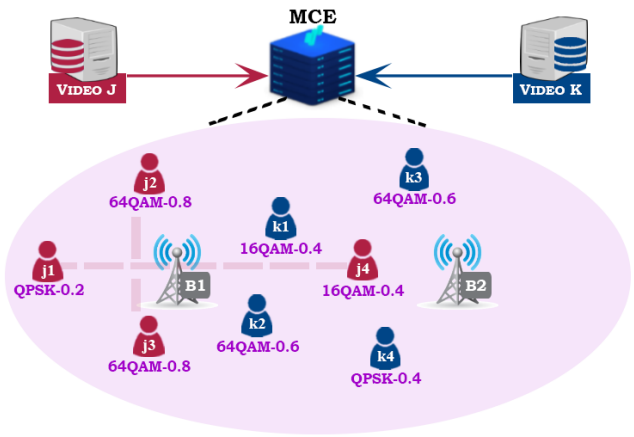
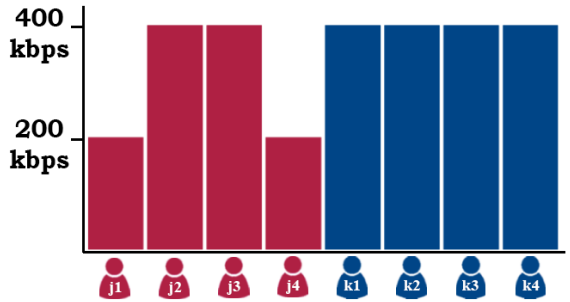
Case D: User Groups (2)





Utility = 46.54 & Avg. Rate = 350

(1): R. Sivaraj et al., "BoLTE: Efficient network-wide LTE broadcasting", ICNP 2017
(2): J. Chen et al., "Fair and optimal resource allocation for LTE multicast (eMBMS): Group partitioning and dynamics", INFOCOM 2015

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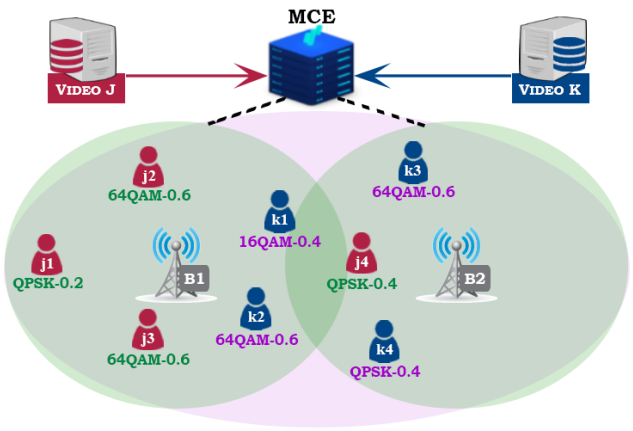
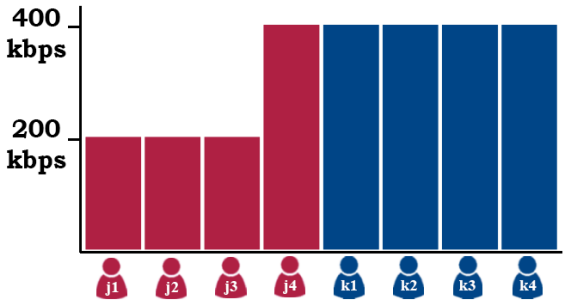
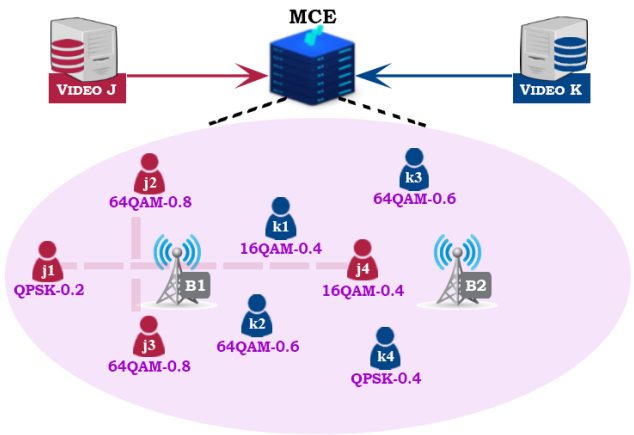
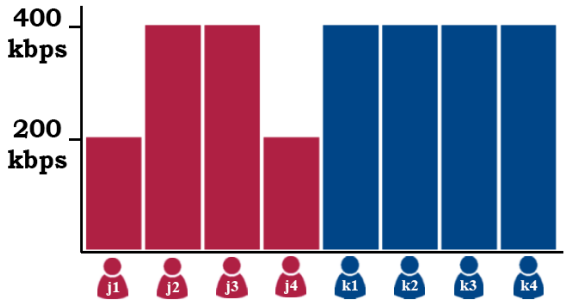




Utility = 45.84 & Avg. Rate = 325

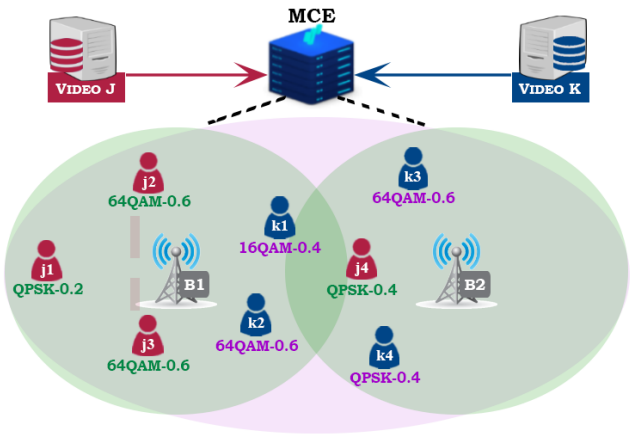
CASE D: USER GROUPS (2)

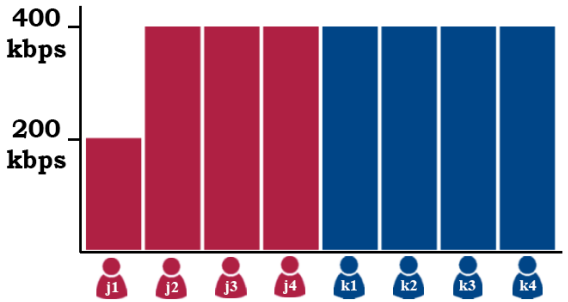




Utility = 46.54 & Avg. Rate = 350

CASE E: JOINT SOLUTION





Utility = 47.24 & Avg. Rate = 375

(1): R. Sivaraj et al., "BoLTE: Efficient network-wide LTE broadcasting", ICNP 2017
(2): J. Chen et al., "Fair and optimal resource allocation for LTE multicast (eMBMS): Group partitioning and dynamics", INFOCOM 2015

Optimization Model

Outputs: **eNB configurations – Bitrates for user groups – RBs for user groups**

Maximize **Rate-based utility function for user groups of all videos**

Subject to: **Available resources at each eNB**

Clusters not overlapping

Each user assigned a bitrate

Users able to decode bitrates

Optimization Model

Outputs: **eNB configurations – Bitrates for user groups – RBs for user groups**

$$P_{vp} \qquad M_{vpcer} \qquad X_{vpcr}$$

Maximize **Rate-based utility function for user groups of all videos**

$$\sum_{v \in V} \sum_{p \in P} P_{vp} \cdot \sum_{c \in p} \sum_{r \in R_v} \left(f(r) \cdot \sum_{e=1}^{E} M_{vpcer} \cdot M_{vpce} \right)$$

Subject to: **Available resources at each eNB**

$$\sum_{v \in V} \sum_{p \in P} \sum_{c \in p} \sum_{r \in R_v} b_{pc} \cdot X_{vpcr} \leq \min\left(\alpha T, T - Y_b\right)$$

Clusters not overlapping

$$\sum_{p \in P} P_{vp} = 1, \ \forall v \in V$$

Each user assigned a bitrate

$$\sum_{p \in P} \sum_{c \in p} \sum_{r \in R_v} \sum_{e=1}^{E} M_{vpcer} \cdot M_{vpce} = M_v, \ \forall v \in V$$

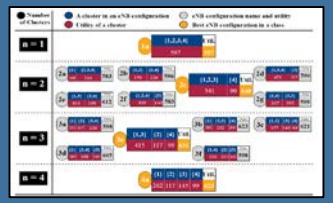
Users able to decode bitrates

$$X_{vpcr} \geq \max_{e} \left(\frac{M_{vpcer} \cdot r}{S_e} \right), \forall r \in R_v, c \in C$$

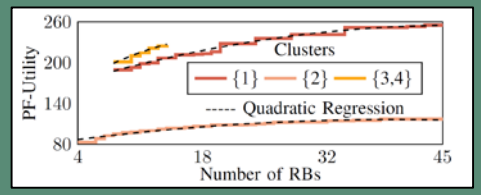
Heuristics: Overview

- Finds the **optimal** solution or a near-optimal solution with **less than 1% gap**
- Solves the problem in less than 500ms **regardless of the number of users**

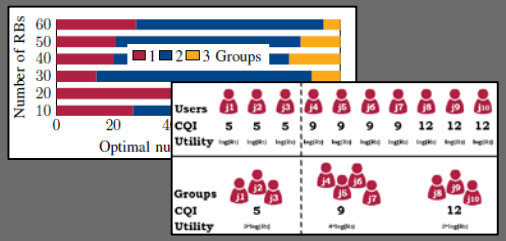
Choose Candidate eNB Configs. For Each Video



Find Utility vs RB Graphs For Candidate Configs.



Find The utility of partitioning users



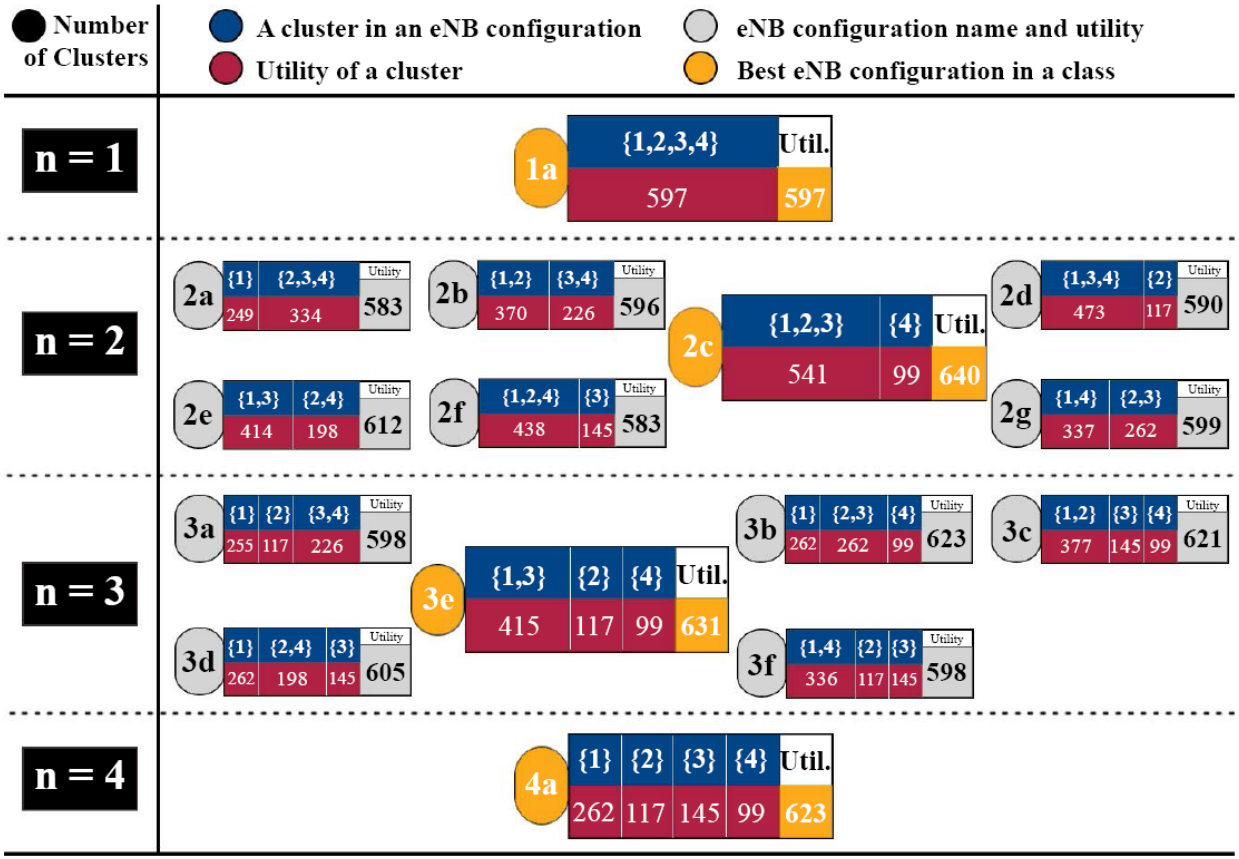
Solve For Different Combinations Of Candidate Configs.

$$max \sum_{v \in V} \sum_{c \in P_v} i_{vc} \cdot X_{vc}^2 + j_{vc} \cdot X_{vc} + k_{vc}$$

$$X_{vc} \geq L_{vc}, \forall\, v \in V, c \in C$$

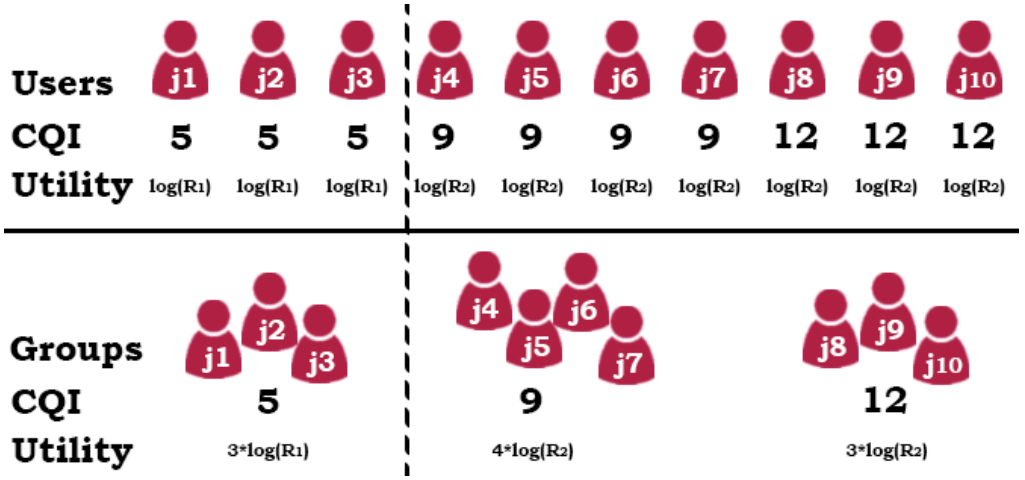
HEURISTICS: eNB CONFIGURATION

- Classify configurations based on the **number of clusters** in them
- **For multiple video** scenarios, choose one configuration from each class

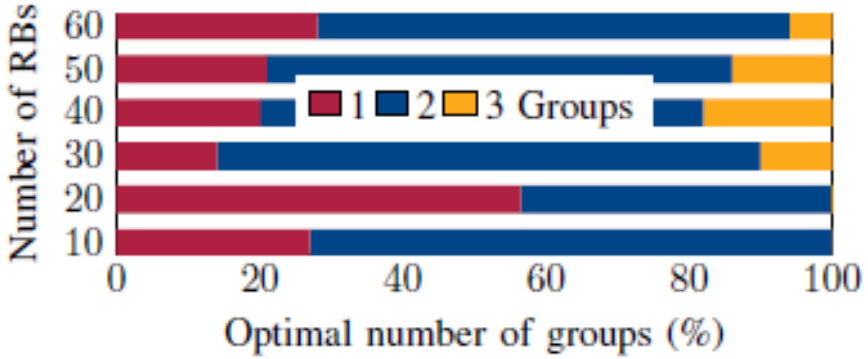


HEURISTICS: USER GROUPS

- **Pre-group users** based on their CQI values

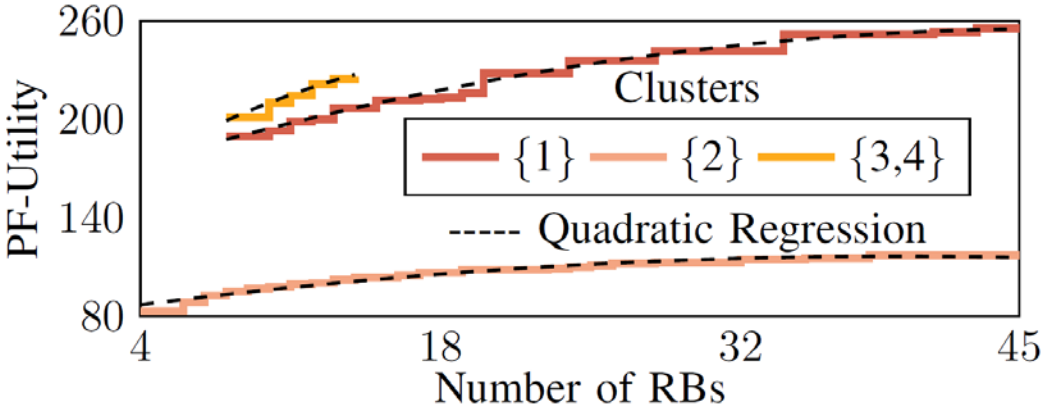


- Limit the maximum **number of groups allowed** for users



HEURISTICS: RESOURCE ALLOCATION

- Use **quadratic regression** to approximate Utility vs RB graphs for each SFN cluster



- Solve the resource allocation problem with **regressed graphs** for videos and clusters

Maximize: **Utility for all videos in their clusters**

$$max \sum_{v \in V} \sum_{c \in P_v} i_{vc} \cdot X_{vc}^2 + j_{vc} \cdot X_{vc} + k_{vc}$$

Subject to: **Available resources at each eNB**

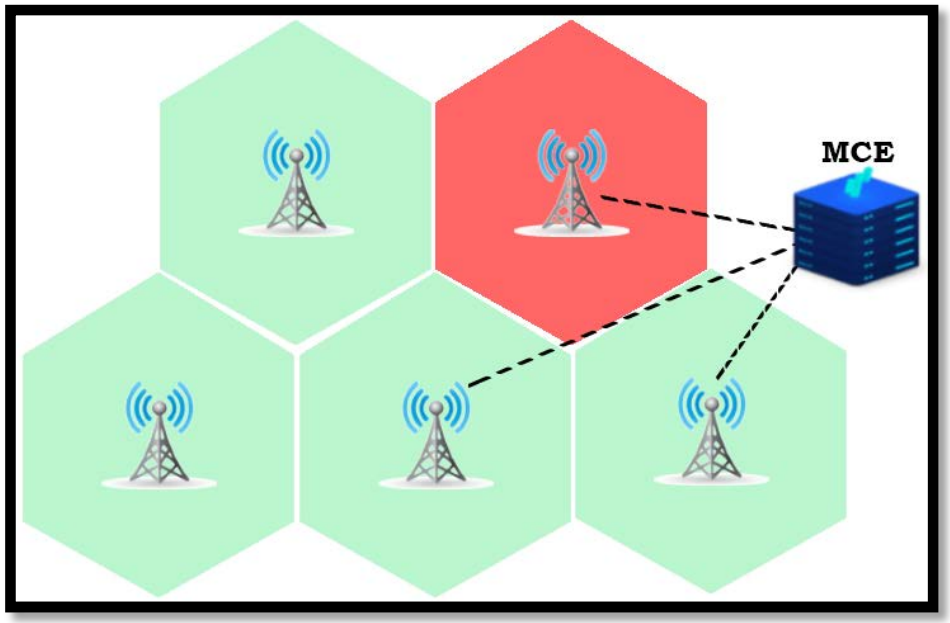
$$\sum_{v \in V} \sum_{c \in P_v} b_{pc} \cdot X_{vc} \leq \min\left(\alpha T, T - Y_b\right), \forall\, b \in B$$

Allocate sufficient RBs to each video

$$X_{vc} \geq L_{vc}, \forall\, v \in V, c \in C$$

EVALUATION

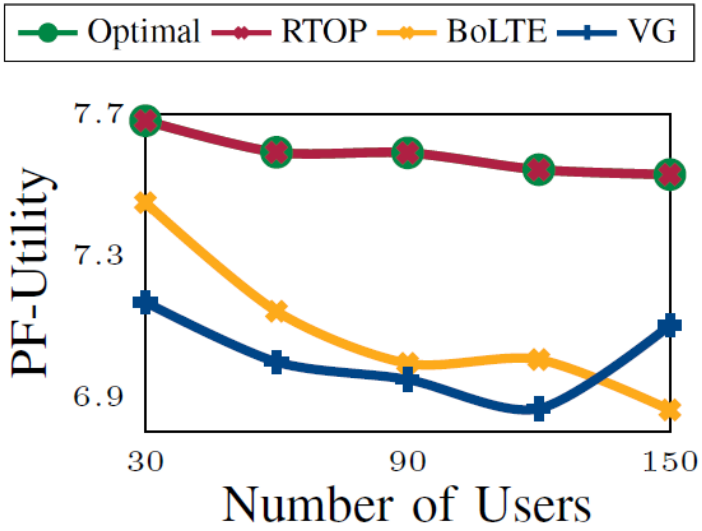
- Discrete event-based simulation testbed with **LTE/4G** physical-layer parameters
- Comparison with state-of-the-art approaches
  - **BoLTE (1):** Creates **SFN clusters** but no user groups
  - **VG (2)/LSFN:** Only creates **user groups**
- Two different simulation scenarios:
  - Generic: **Multiple videos**
  - **Mega-Event**: Large number of users
- Realistic user distributions
  - Uniform: e.g. Shopping malls
  - Normal: e.g. Stadiums
- Performance metrics:
  - **Proportional fairness** utility
  - **Probability Mass Function** of user-bitrates
  - Degraded users: Throughput lower than all bitrates
  - Computation time: Time taken to find the solution



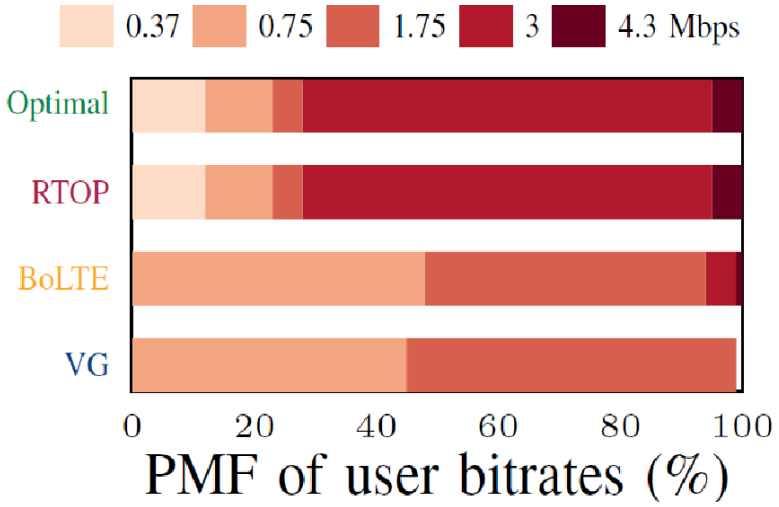
(1): R. Sivaraj et al., "BoLTE: Efficient network-wide LTE broadcasting", ICNP 2017
(2): J. Chen et al., "Fair and optimal resource allocation for LTE multicast (eMBMS): Group partitioning and dynamics", INFOCOM 2015

RESULTS: UTILITY & PMF

- Our approach:
  - **Increases the percentage of users receiving high bitrates** (5% *to* 75%)
  - Reduces the percentage of users receiving low bitrates (50% *to* 20%)



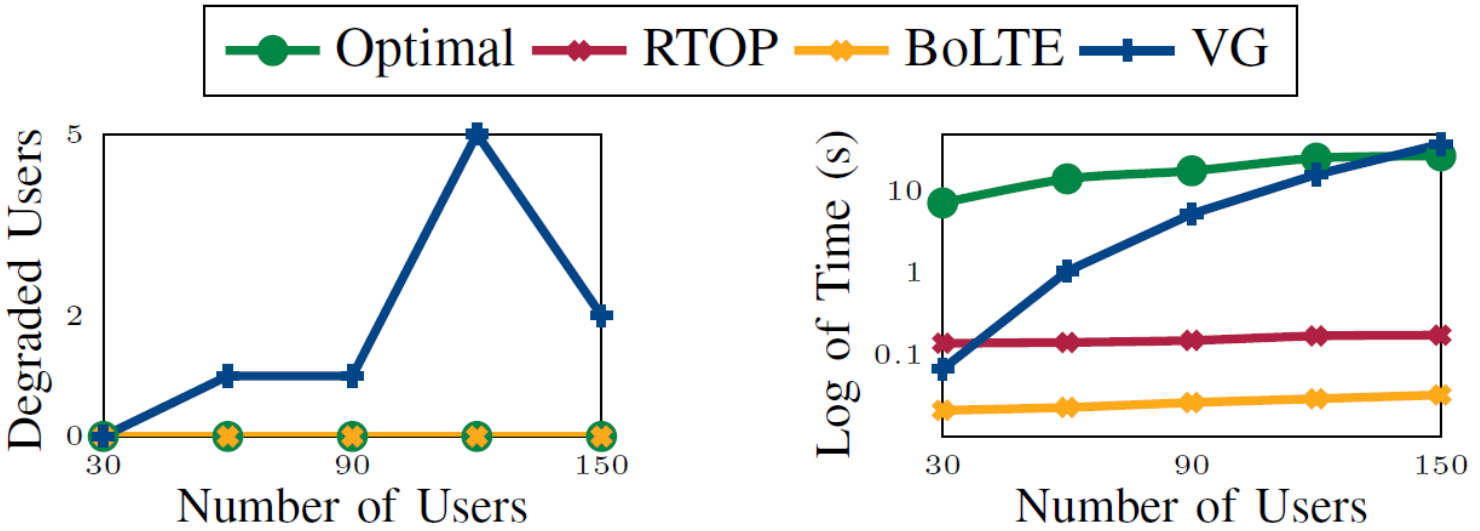
AVERAGE SYSTEM UTILITY ACHIEVED PER USER



PROBABILITY MASS FUNCTION OF BITRATES ASSIGNED TO USERS

Results: Degraded Users & Time

- Our approach:
  - **Ensures that each user is assigned a bitrate**
  - Solves the problem **in real-time** and does not increase with number of users



Total Number Of Degraded Users

Time Taken to Find The Final Solution

SUMMARY

Rapid increase in popularity of live video streaming created challenges for cellular operators

User grouping and SFN clustering problems should be jointly optimized for eMBMS users

We maximize user experience rather than lower-layer network throughputs

Real-time heuristics for practical deployment in dynamic cellular networks

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