Auction Based Resource Allocation and Pricing for Heterogeneous User Demands in eMBMS

Sadaf ul Zuhra, Prasanna Chaporkar & Abhay Karandikar
IIT Bombay

Department of Electrical Engineering
Indian Institute of Technology Bombay, Mumbai, India - 400076

April 17, 2019
Outline

1. Introduction
2. Problem Formulation
3. VCG Based Auction Mechanism for eMBMS
4. Practical Implementation
5. Simulations
6. Conclusions
Outline

1. **Introduction**
2. **Problem Formulation**
3. **VCG Based Auction Mechanism for eMBMS**
4. **Practical Implementation**
5. **Simulations**
6. **Conclusions**
Motivation

- Plethora of devices and services - extremely heterogeneous
- Varying allocation objectives
Existing Standards and Literature

Standards:
- eMBMS: mostly focused on MBSFN
- Multicast within a cell a more useful and interesting use case
Existing Standards and Literature

Standards:
- eMBMS: mostly focused on MBSFN
- Multicast within a cell a more useful and interesting use case

Literature:
- Same channel in all PRBs - PRB identity immaterial
- Algorithms designed around specific objectives
Contributions:

- Address the lack of a ‘generalized’ allocation algorithm - a strategy-proof VCG mechanism
Contributions:

- Address the lack of a ‘generalized’ allocation algorithm - a strategy-proof VCG mechanism
- A computationally efficient MWBM implementation of the proposed mechanism
Contributions:

- Address the lack of a ‘generalized’ allocation algorithm - a strategy-proof VCG mechanism
- A computationally efficient MWBM implementation of the proposed mechanism
- Simulations to show effectiveness of the proposed mechanism
Outline

1 Introduction
2 Problem Formulation
3 VCG Based Auction Mechanism for eMBMS
4 Practical Implementation
5 Simulations
6 Conclusions
System Model 1

- A cell with $M$ users
- Unicast and multicast UEs
- $L$ entities (unicast UEs + multicast groups)
- $N$ PRBs available in a sub-frame
- Rate $R_i$ for group $G_i$
- One PRB every sub-frame, transmit at rate $R_i$ to $G_i$
Problem Formulation

System Model II

- $r_{kj}[t]$ - maximum rate achievable by UE $k$ in PRB $j$ in sub-frame $t$
- Loss:
  \[
  \ell_{kj}[t] = \begin{cases} 
  0, & \text{if } R_i \leq r_{kj}[t], \\
  1, & \text{otherwise}.
  \end{cases}
  \]
- $v_k[t]$ - valuation of UE $k$ for being scheduled for service
  - Private information
  - A function of any number of factors (data plan, video quality, amount of packet loss)
  - No restrictions whatsoever
- $b_k[t]$ - bid submitted by UE $k$ in sub-frame $t$
Definitions

Feasible resource allocation:
Assigns at most one PRB to each multicast group

- Allocation vector $\mathbf{A}^\Gamma[t]$: if $A^\Gamma_i[t] \neq 0$, then $A^\Gamma_i[t] \neq A^\Gamma_{i'}[t] \forall i' \neq i$.

Auction based resource allocation policy $\Gamma$:

- INPUT: bids $b_k[t] \ \forall \ k$
- OUTPUT: $\mathbf{A}^\Gamma[t]$ and prices $p^\Gamma_k[t] \ \forall \ k$

Utility of a UE:

- $u^\Gamma_k[t] = v_k[t] - p^\Gamma_k[t]$
- 0 if not scheduled for reception
Problem Definition

Social utility:

\[ V^\Gamma[t] = \sum_k v_k[t] \sum_j x^\Gamma_{i(k)j}[t](1 - \ell_{kj}[t]) \text{ where,} \]

\[ i(k) = \text{group to which UE } k \text{ belongs} \]

\[ x^\Gamma_{ij}[t] = \begin{cases} 
1, & \text{if } A^\Gamma_i[t] = j, \\
0, & \text{otherwise.} 
\end{cases} \]
Problem Definition

Social utility:

\[ V^\Gamma[t] = \sum_k v_k[t] \sum_j x_{i(k)j}^\Gamma[t] (1 - \ell_{kj}[t]) \]

where,

\[ i(k) = \text{group to which UE } k \text{ belongs} \]

\[ x_{ij}^\Gamma[t] = \begin{cases} 
1, & \text{if } A_i[t] = j, \\
0, & \text{otherwise.} 
\end{cases} \]

**THE PROBLEM:**

What is the optimal social utility maximizing auction based resource allocation policy \( \Gamma^* \)?
Challenges

- UE valuations unknown - have to rely on reported valuations
- Existence of multicast groups
  - Decisions based on individual valuations but PRBs allocated to the group
  - UE may not be served even after it's group is scheduled
- Bound to allocate same PRB to entire group
Outline

1. Introduction
2. Problem Formulation
3. VCG Based Auction Mechanism for eMBMS
4. Practical Implementation
5. Simulations
6. Conclusions
The Solution - $\Gamma^*$

Algorithm:

- Bids $b_k$ reported to the eNB
- Determines $A^\Gamma$ and $x^\Gamma_{ij}$ that maximize:

$$\sum \sum b_k x^\Gamma_{i(k),j} (1 - \ell_{kj})$$

- Calculate price $p^\Gamma_k$ for every $k$ - periodically transmitted to the PCRF

$$p^\Gamma_k = \sum \sum b_q x^\Gamma_{i(q),j} (1 - \ell_{qj}) - \sum \sum b_q x^\Gamma_{i(q),j} (1 - \ell_{qj})$$
Strategy-proofness

Theorem 1
Γ* is strategy-proof

Proof sketch:
Does not follow directly from strategy-proofness of VCG

- For bid $b_k = v_k$, price $p_k$ and utility $u_k$
- For bid $b'_k \neq v_k : u'_k \leq u_k$

No incentive to deviate from bidding $v_k$
Strategy-proofness

Theorem 1

$\Gamma^*$ is strategy-proof

Proof sketch:

*Does not follow directly from strategy-proofness of VCG*

- For bid $b_k = v_k$, price $p_k$ and utility $u_k$
- For bid $b'_k \neq v_k$: $u'_k \leq u_k$

No incentive to deviate from bidding $v_k$

Drawback:

Complexity: $\mathcal{O}\left(\binom{N}{L} L^L\right)$
Outline

1. Introduction
2. Problem Formulation
3. VCG Based Auction Mechanism for eMBMS
4. Practical Implementation
5. Simulations
6. Conclusions
Polynomial-time Implementation of $\Gamma^*$

$$w_i^j = \sum_{k \in G_i} b_k \times (1 - \ell_{kj})$$

Complexity: $O(L^2N)$
Polynomial-time Implementation of $\Gamma^*$

$$w^i_j = \sum_{k \in G_i} b_k \times (1 - \ell_{kj})$$

Complexity: $O(L^2N)$

Lemma 2

$\text{MWBM for graph } \mathcal{G} \text{ results in the same allocation as that given by } \Gamma^*.$
Outline

1. Introduction
2. Problem Formulation
3. VCG Based Auction Mechanism for eMBMS
4. Practical Implementation
5. Simulations
6. Conclusions
Simulation Setup

- LTE cell, 100 UEs, 5 eMBMS streams
- UEs can tolerate some loss - function of factors like the streaming quality, eMBMS service
- Valuation - some function of the loss tolerance and the loss encountered
- Comparison with a throughput maximizing greedy policy
Results I

(a) Proposed algorithm

(b) Greedy algorithm
Results II

Figure 2: Average loss pattern over time
Outline

1. Introduction
2. Problem Formulation
3. VCG Based Auction Mechanism for eMBMS
4. Practical Implementation
5. Simulations
6. Conclusions
Conclusions

Addressed the problem of resource allocation for heterogeneous UE demands encompassing unicast and multicast services

A strategy-proof auction mechanism $\Gamma^*$ - meets the QoS requirements of the UEs in all the eMBMS groups

Proposed a polynomial time implementation of $\Gamma^*$ - efficient and inexpensive
Thank You!!!