Enhancing Mobile Video Streaming by Lookahead Rate Allocation in Wireless Networks

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Overview

- Motivation and limitations of traditional wireless resource allocation
- How can rate predictions improve user QoS?
- Resource allocation (RA) model
- Lookahead RA: improving video quality and fairness
- Results: presentation of the potential gains
- Conclusion
Radio Resource Allocation: *Short-term Goals*

Traditional Resource Allocation

- Channel and Queue Aware Scheduling.
- Satisfy immediate user QoS demands.

**Limitations: Achieves only short-term goals**

- No long-term QoS provisions.
- No incorporations of long-term predictions of user locations or of application demands.
Motivation

Video growth:

- Recent forecasts project a 16-fold growth of mobile traffic from 2012 to 2017, with video accounting for 66 percent of the total traffic.

Emergence of in-car infotainment:

- Consumption in vehicular environments is predicted to increase; both personal and in public transit.

Challenge of mobile video delivery:

- Mobile users experience rapid wireless link fluctuations, resulting in streaming disruptions.

Novel video delivery mechanisms are needed!
Rate Predictions: Coupling Mobility Patterns and Radio Maps

- If we are aware of
  1. The user’s mobility trajectory [1]
  2. The geographical location-data rate correlation

Then it is possible to predict the future data rates a user is will experience.

The Potential of Rate Predictions

Users headed to coverage holes are prioritized

Users predicted to arrive from coverage holes are reserved resources in advance

Road Radio Map

coverage hole
low data rate
Resource Sharing Model: *Airtime Optimization*

- **Prediction Window** $T$: duration over which user rates are predictable
- **Resource allocation interval**: duration over which predicted rate is constant ($\sim 1$ second)
- $x_{i,t}$: optimization variable that determines the fraction of time a BS will transmit to user $i$ during slot $t$

**Lookahead Resource Allocation (LRA):** more airtime is planned for time instances when the channel is predicted to be high

- *Predicted rate is assumed to be error-free to investigate the bounds of the gains*
- *Allocated airtime will depend on the QoS requirements and the network load*
Long-term resource allocation plans are made

Resource Sharing Model: *Airtime Optimization*

Lookahead Resource Allocation (LRA)

BS₁

BS₂

<table>
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<th>Time slot (t)</th>
<th>UE₁</th>
<th>UE₂</th>
<th>UE₃</th>
<th>UE₄</th>
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</tbody>
</table>

Enhancing Mobile Video Streaming by Lookahead Rate Allocation in Wireless Networks
Lookahead RA: *Video Stream Pre-buffering*

Non realtime videos can be opportunistically prebuffered using rate predictions.
Lookahead RA: **Minimizing Video Degradation**

Accumulative resources allocated is what we are concerned about.

**OBJECTIVE:** Minimize this degradation by exploiting rate predictions.

- **User predicted to enter coverage hole:** video stream is pre-buffered.
- **User not allocated but stream is buffered:** **no video degradation**.
- **Slight video degradation:** received content less than target.
Lookahead RA: \textbf{Minimizing Video Degradation}

\[ \text{VideoDeg}_{i, t} = \max \left( 0, D_{i, t} - \sum_{t' = 1}^{t} x_{i, t'} r_{i, t'} \right) \]

\begin{center}
\begin{tikzpicture}
\begin{axis}[
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height=0.5\textwidth,
axis lines=left,
grid=major,
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xticklabels={0, 50, 100, 150, 200, 250, 300},
ytick={0,2,4,6,8,10,12},
yticklabels={0, 2, 4, 6, 8, 10, 12},
xlabel=\text{Time [sec]},
ylabel=\text{Total data [bits]},
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/pgfplots/xbar legend style={at={(0.5,\baselineskip*2)},anchor=north},
]
\addplot+[ybar,fill=blue] coordinates {
(0,1)\times10^8
(50,2)\times10^8
(100,4)\times10^8
(150,6)\times10^8
(200,8)\times10^8
(250,10)\times10^8
(300,12)\times10^8
};
\end{axis}
\end{tikzpicture}
\end{center}

\textbf{Target accumulative video content}
\textbf{Received accumulative video content}

\textbf{Optimization variable:}
Air-time Sharing Factor [0,1]
**Lookahead Rate Allocation: Problem Formulation**

- Jointly minimizes the *total network VD and the individual user video degradations during the N slots.*
- Formulated as a multi-objective optimization problem

\[
\begin{align*}
\text{minimize} \quad & \alpha \sum_{i=1}^{M} \sum_{n=1}^{N} \frac{VD_{i,n}}{\tau n V} + \beta \max_{i} \sum_{n=1}^{N} \frac{VD_{i,n}}{\tau N V} \\
\text{subject to:} \quad & C1: \sum_{i \in U_{k,n}} x_{i,n} \leq 1, \quad \forall k, n \\
& C2: \sum_{n=1}^{N} \hat{r}_{i,n} x_{i,n} \leq \tau NV, \quad \forall i \\
& C3: 0 \leq x_{i,n} \leq 1 \quad \forall i, n.
\end{align*}
\]

- **Total network video degradation**
- **Individual user video degradation over N slots**
- **Resource constraints**
Lookahead Rate Allocation: *Problem Formulation*

- **Equivalent Linear Program:**

\[
\begin{align*}
\text{minimize} & \quad \alpha \sum_{i=1}^{M} \sum_{n=1}^{N} \frac{D_{i,n}}{\tau n V} + \beta \ Y \\
\text{subject to:} & \quad \text{C1, C2, C3} \\
\forall i, n & \quad \text{C4: } \tau n V - \sum_{n'=1}^{n} x_{i,n'} \hat{r}_{i,n'} - D_{i,n} \leq 0, \\
\forall i & \quad \text{C5: } -\sum_{n=1}^{N} \frac{D_{i,n}}{\tau NV} + Y \leq 0, \\
\forall i, n & \quad \text{C6: } D_{i,n} \geq 0.
\end{align*}
\]
Lookahead Rate Allocation: *Heuristic Algorithm*

**Key ideas:**

- **Step 1:** keep track of the *cumulative rates allocated to users* up to slot \( n \).
- **Step 2:** estimate the *future video degradation users are predicted to experience* in the future.
- **Step 3:** Each base station \( k \) allocates the *full air-time at slot \( n \)* to the user \( i^* \) that satisfies

\[
i^* = \arg \max_i r_{i,n} \tilde{V}D_{i,n}^\gamma \quad \forall i \in \mathcal{U}_{k,n}
\]

The intuition of this *new allocation metric* is to prioritize users with *both a high current channel quality and a high future*.

- \( \gamma \) controls the influence of the future user \( \tilde{V}D \) in the metric. A higher value will prioritize users with \( \tilde{V}D \) and provide more video quality fairness.
Performance Evaluation
Performance Evaluation: Simulation Set-up

- Road network with vehicle movement using SUMO
- 19 cell two tier network with RWP mobility
- Channel Path-loss: $128.1 + 37.6 \log(d)$
- Prediction window=200s, slot duration=1s
- Metrics: Network-wide video degradation, Jain’s fairness in video degradations
Gains from Lookahead Rate Allocation (LRA)

Baseline Allocators

- Equal Share, Rate Proportional

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**Performance with increasing load: Video Quality**

- Streaming rate: 3 Mbit/s
- RWP with 10 m/s mobility

**Road Network**

**RWP**
Performance with increasing load: *Video Fairness*

- Streaming rate: 3 Mbit/s
- RWP with 10 m/s mobility
Summary

- Presented a lookahead resource allocation (LRA) to enhance video streaming in wireless networks.
- LRA exploits user mobility trajectories and radio maps to generate a long-term rate vector for each user.
- LRA achieves both video quality improvements and user fairness.

Future work

- Studying the effect of prediction errors.
Some additional/ongoing work on LRA


Thank You

- Questions?

- Please feel free to contact us at h.abouzeid@queensu.ca