Minimizing Power Consumption of Source Encoding and Radio Transmission in CDMA Systems

Xiaoan Lu

Department of Electrical and Computer Engineering
Polytechnic University, Brooklyn, NY

Background

- Power control is essential to CDMA wireless networks
  - Relax the near far problem.
  - Improve the quality of service.
  - Increase the channel capacity.
  - Increase the battery life of the mobile terminal.
- Power control as an optimization problem
  - Minimize the total transmission power
  - Maintain a required SINR threshold

SINR: the signal to interference and noise ratio, depends on transmission power of all users.
Motivation (2/1)

- Previous power control focused on voice signal
- Video signal is integrated into the new generation wireless communication system
  - Constraint: PSNR or distortion (MSE), not SINR
  - Lossy compression $D_s$
  - Erroneous transmission $D_t$ ($D_s + D_t = D_0$)
  - PSNR: peak signal-to-noise ratio, MSE: mean squared error

![Diagram](https://via.placeholder.com/150)

Motivation (2/1)

- Previous power control focused on voice signal
- Video signal is integrated into the new generation wireless communication system
  - Constraint: PSNR or distortion (MSE), not SINR
  - Minimize: transmission power + signal processing power
  - Parameters: {bit rate, compression complexity}, {transmission power}

![Diagram](https://via.placeholder.com/150)
Motivation (2/2)

- Proposed solution: **Dynamically Reconfigurable Energy Aware Multimedia Information Terminal (DREAM-IT)**
  - Adapting operating parameters of all components simultaneously and dynamically to minimize total power consumption
- This subproject focuses on power allocation between video source coding, and radio transmission
- Parameter: bit rate $R_{v,i}$,
  - compression complexity $\beta_i$,
  - transmission power $P_{t,i}$

System description

Adapt $c_i = \{ R_{v,i}, \beta_i, P_{t,i} \}$ to minimize $P_{tot} = \sum_{i=1}^{N} (P_{r,i} + P_{t,i})$, subject to $D_{tot,i}(R_{v,i}, \beta_i, \gamma) = D_{tot,0}$

- the uplink of a CDMA cell
- video transmission

$R_{v,i}$: bit rate, $\beta_i$: compression complexity, $P_{t,i}$: transmission power
One terminal

<table>
<thead>
<tr>
<th>Component</th>
<th>Parameters</th>
<th>Distortion</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video compressor</td>
<td>Bit rate $R_s$</td>
<td>$D_s(R_s, \beta)$: lossy compression</td>
<td>$P_s$</td>
</tr>
<tr>
<td></td>
<td>Complexity $\beta$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel encoder</td>
<td></td>
<td>$p_L(\gamma)$: packet error rate</td>
<td></td>
</tr>
<tr>
<td>Transmitter</td>
<td>Transmission power $P_t$</td>
<td>$D_t(\beta, p_L)$: (1) transmission error (2) Error propagation</td>
<td>$P_t$</td>
</tr>
</tbody>
</table>

$\gamma$: signal to interference and noise ratio, SINR, depends on transmission power of all users.

Minimize $\sum_{i=1}^{N} (P_{t,i} + P_{s,i})$ subject to $D_{s,i} = D_{s} + D_{t,i} \leq D_{0}$

Conceptual illustration

- Special case example: $D_s, D_t$ fixed individually, one user
  - Signal compression Bit rate $\uparrow$, power $\downarrow$
  - Transmission Bit rate $\uparrow$, power $\uparrow$
  - Total Bit rate $\uparrow$, power $?$
Why optimize jointly?

- Separate optimization
  - Operating parameters for terminal $i$, $C_i$ is decided by base station + user $i$
    - bit rate $R_{s,i}$
    - compression complexity $\beta_i$
    - transmission power $P_{t,i}$

- One user’s signal is other users’ interference
  - All users interact with others
  - Local minima may not be global optimum

- Optimize jointly: Base station + all terminals
  - Full search: good for a small number of users
  - Iterative algorithm: converge?
  - Our approach:
    - Simplified models + Lagrangian method
    - Two-step fast algorithm

Simplified models

- Power consumption
  - Distortion = $f$ (compression, transmission)

- From compression
  - $D_{s,i} = D_{s,R}(R_{s,i})D_s(\beta_i)$

- Total distortion
  - $D_{tot,i}(R_{s,i}, \beta_i, \gamma) = (1 - p_{l,i})D_{s,i}(\beta_i, R_{s,i}) + p_{l,i}\sigma_{x_i}^2$

- Source compression power $P_{s,i}$

- Increase linearly with complexity $\beta_i$
  - Transform coding: transform block size
  - H.263 encoder (periodic INTRA update, full ME search): INTER rate

- Independent of bit rate $R_{s,i}$

Adapt $C_i = \{R_{s,i}, \beta_i, P_{t,i}\}$

to minimize $P_{tot} = \sum_{i=1}^{N} (P_{s,i} + P_{t,i})$ subject to $D_{tot,i} = D_0$
Method

- Lagrangian Multiplier method
  \[ J = \sum_{i=1}^{N} \left\{ c_s P_{tot,i} (R_s, i, \beta_i, P_i) + \lambda_i (D_{tot,i} (R_s, i, \beta_i, P_i) - D_{i,0}) \right\} \]

- Equations:
  \[ \frac{\partial J}{\partial R_{s,i}} = 0, \quad \frac{\partial J}{\partial \beta_i} = 0, \quad \frac{\partial J}{\partial P_{i,t}} = 0, \quad D_{tot,i} (R_s, i, \beta_i, \gamma) = D_{i,0} \]

- Unknowns: \( R_s, i, \beta_i, P_{i,t}, \lambda_i \)

- \( \Gamma^* = (\gamma_1^*, ..., \gamma_N^*) \) is used to re-parameterize the equations

\[
\begin{align*}
\frac{\partial J}{\partial R_{s,i}} &= 0 \rightarrow R_{s,i} \sim \gamma_i^* \\
\frac{\partial J}{\partial \beta_i} &= 0 \rightarrow \beta_i \sim \gamma_i^* \\
\frac{\partial J}{\partial \lambda_i} &= 0 \rightarrow \lambda_i \sim \gamma_i^* \\
\frac{\partial J}{\partial P_{i,t}} &= 0 \\
\end{align*}
\]

Simulation

- Transform coding
- Gauss-Markov source
- Two users
  - 1st user moves around
  - 2nd user stands still

- As distance increases, more compression is needed (lower source rate)
- The “better” users (with a small distance) needs to compress less
Comparison

- our adaptive algorithm vs. fixed schemes (both users have same parameters)
  - Fixed simple compression (good for small distance)
  - Fixed complex compression (good for large distance)
- significant power saving

![Graph showing comparison of power consumption for different compression methods.]

Two-step approach

- Computation
  - Dimensions
    - Bit rate: $M_R$
    - Complexity: $M_\beta$
    - SINR: $M_\gamma$
  - Full search
    - $\{R_{sf}, B, \Gamma\}$
    - $(M_\beta \times M_R \times M_\gamma)^N$
  - Two-step (can be further reduced)
    - $\{B\}$
    - $N \times M_R \times M_\gamma + (M_\beta)^N$

Choose the optimum complexity set $\{\beta_1^*, \beta_2^*, ..., \beta_N^*\}$ to minimize the total power consumption, corresponding $R_\gamma(\beta^*)$ and $\gamma(\beta^*)$ are together taken as the optimum operating parameters.

For each terminal, get the maximum quality factor $q_{i, max}(\beta)$ for all possible complexity, $R_\gamma(\beta)$ and $\gamma(\beta)$ achieving this optimum are recorded.
Conclusions

- Minimize total power consumption while maintaining the video quality at the receiver
  - Mobile users sending video to a base station in one CDMA cell
  - Video compression power + radio transmission power are considered
  - An analytical solution based on simplified models
  - A two-step fast algorithm

Results

- Operating parameters depend on the distance
- “Better” users compress less.
- Adaptive solution leads to significant power savings