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

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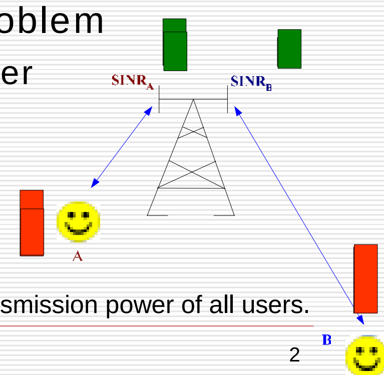
Background

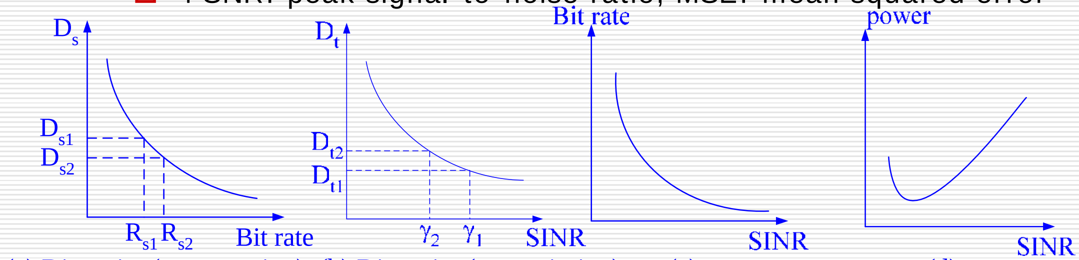
- Power control is essential to CDMA wireless networks
  - Relax the near far problem.
  - Improve the quality of service.
  - Increase the channel capacity.
  - Increase the battery life of the mobile terminal.
- Power control as an optimization problem
  - Minimize the total transmission power
  -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

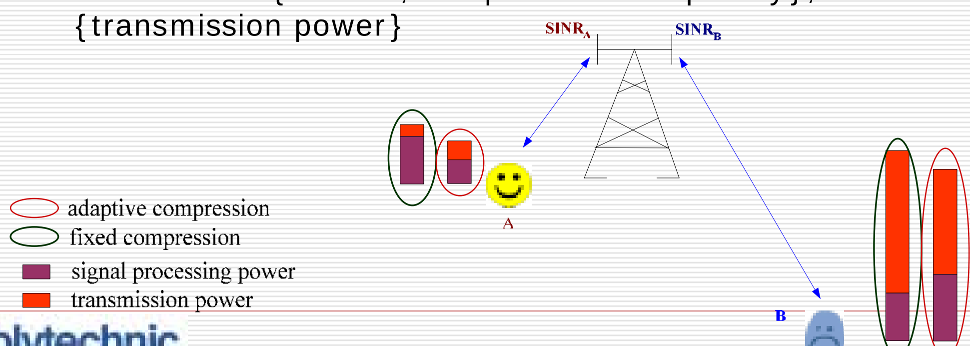


(a) Distortion(compression) (b) Distortion(transmission) (c) (d)

Power ∝ bit rate x SINR

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}

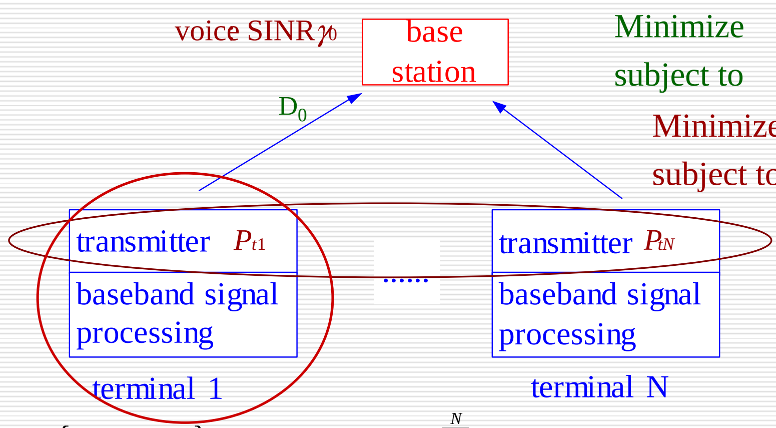


Power ∝ bit rate x SINR

Motivation (2/2)

- Proposed solution: **D**ynamically **R**econfigurable **E**nergy **A**ware **M**ultimedia **I**nformation **T**erminal (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 $R_{s,i}$,
    compression complexity β_i,
    transmission power $P_{t,i}$

System description



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

Minimize $\sum_{i=1}^{N} P_{t,i}$
subject to $\gamma_i \ge \gamma_0$

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 $D_{tot,i}(R_{s,i}, \beta_i, \gamma_i) = D_{i,0}$

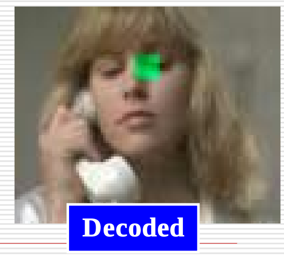
- the uplink of a CDMA cell
- video transmission

$R_{s,i}$: bit rate, β_i : compression complexity, $P_{t,i}$: transmission power

One terminal

Component	Parameters	Distortion	Power
Video compressor	Bit rate R_s Complexity β	$D_s(R_s, \beta)$: lossy compression	P_s
Channel encoder		$p_L(\gamma)$: packet error rate	
Transmitter	Transmission power P_t	$D_t(\beta, p_L)$: (1) transmission error (2) Error propagation	P_t

γ: 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 $D_{tot,i}=D_{s,i}+D_{t,i}\le D_{0}$

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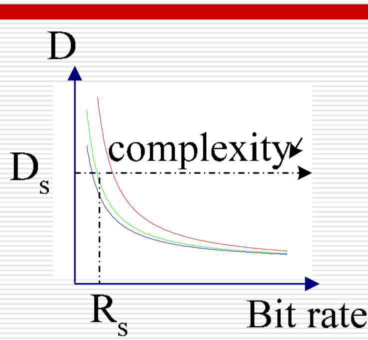
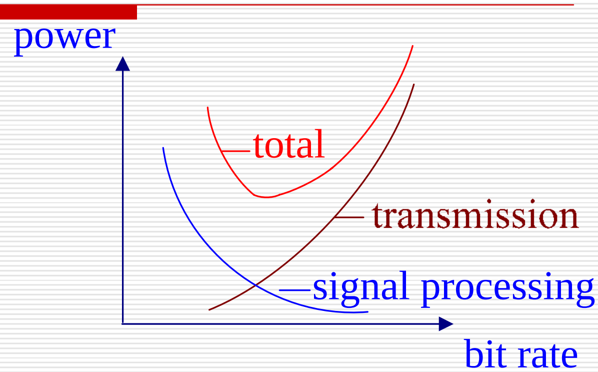
Conceptual illustration





- Special case example: D_s, D_t fixed individually, one user
  - Signal compression Bit rate ↑, power ↓
  - Transmission Bit rate ↑, power ↑
  - Total Bit rate ↑, power ?

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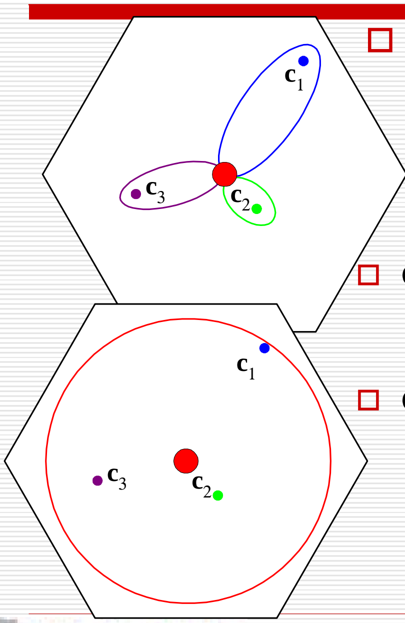
Why optimize jointly?



- Separate optimization
  - Operating parameters for terminal i, c_i is decided by base station + user i

$$c_i = \begin{Bmatrix} \text{bit rate } R_{s,i} \\ \text{compression complexity } \beta_i \\ \text{transmission power } P_{t,i} \end{Bmatrix}$$

- 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 + Lagarangian method
    - Two-step fast algorithm

Simplified models

- Power consumption
  - Distortion=f(compression, transmission)
    - From compression $D_{s,i} = D_{s,R}(R_{s,i}) D_{s,\beta}(\beta_i)$
    - Total distortion $D_{tot,i}(R_{s,i}, \beta_i, \gamma_i) = [1 - p_{L,i}] D_{s,i}(\beta_i, R_{s,i}) + p_{L,i} \sigma_{s,i}^2$
  - Source compression power $P_{s,i}$
    - Increase linearly with complexity β_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

- Lagarangian Multiplier method

$$J = \sum_{i=1}^{N} \left\{ c_{s,i} P_{tot,i}(R_{s,i}, \beta_i, \mathbf{P}_t) + \lambda_i \left(D_{tot,i}(R_{s,i}, \beta_i, \mathbf{P}_t) - D_{i,0} \right) \right\}$$

- Equations: $\frac{\partial J}{\partial R_{s,i}} = 0, \frac{\partial J}{\partial \beta_i} = 0, \frac{\partial J}{\partial P_{t,i}} = 0, D_{tot,i}(R_{s,i}, \beta_i, \gamma_i) = D_{i,0}$
- Unknowns: $R_{s,i}, \beta_i, P_{t,i}, \lambda_i$
- $\Gamma^* = (\gamma_1^*, ..., \gamma_N^*)$ is used to re-parameterize the equations

$$\left.\begin{matrix} \frac{\partial J}{\partial R_{s,i}} = 0 \\ D_{tot,i} = D_0 \end{matrix}\right\} \rightarrow R_{s,i} \sim \gamma_i$$

$$\left.\begin{matrix} R_{s,i} \sim \gamma_i \\ \frac{\partial J}{\partial \beta_i} = 0 \end{matrix}\right\} \rightarrow \beta_i \sim \gamma_i$$

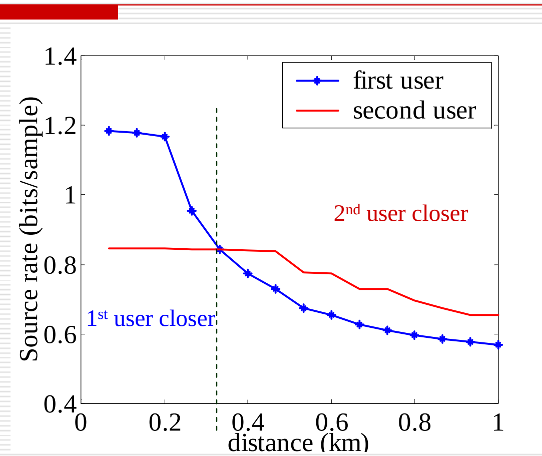
$$\left.\begin{matrix} R_{s,i} \sim \gamma_i \\ \beta_i \sim \gamma_i \\ \frac{\partial J}{\partial \lambda_i} = 0 \end{matrix}\right\} \rightarrow \lambda_i \sim \gamma_i$$

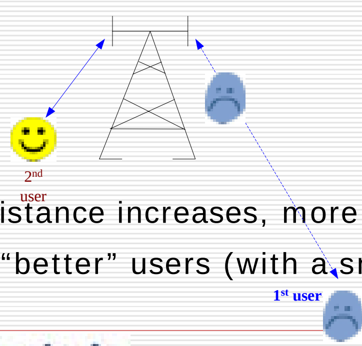
$$\left.\begin{matrix} R_{s,i} \sim \gamma_i \\ \beta_i \sim \gamma_i \\ \lambda_i \sim \gamma_i \\ \frac{\partial J}{\partial P_{t,i}} = 0 \\ P_{t,i}(\gamma_1, ..., \gamma_N) \end{matrix}\right\}$$

N equations, with solutions $(\gamma_1^*, ..., \gamma_N^*)$

Simulation

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

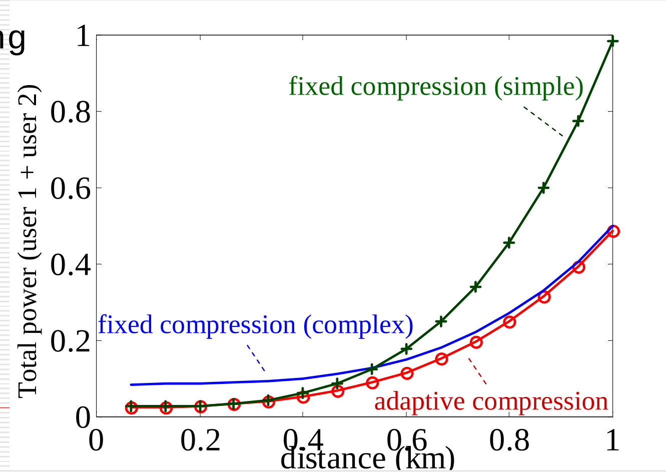




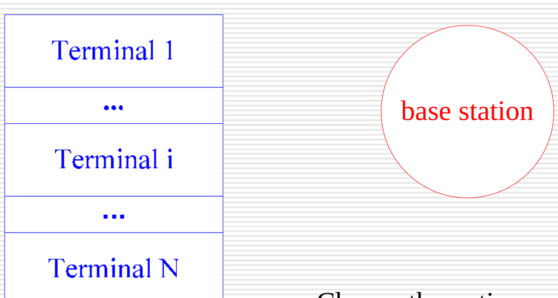
- As distance increases, more compression is needed (lower source rate)
- The "better" users (with a small distance) needs to compress less

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



Two-step approach



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

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

- Computation
  - Dimensions
    - Bit rate: M_R
    - complexity: M_β
    - SINR: M_γ
  - Full search
    - $\{\mathbf{R_s}, \mathbf{B}, \mathbf{\Gamma}\}$

      $(M_\beta \times M_R \times M_\gamma)^N$
  - Two-step (can be further reduced)
    - $\{\mathbf{B}\}$

      $N \times M_R \times M_\gamma + (M_\beta)^N$

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