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Power and Data Rate Assignment for Max. Weighted Throughput in 3G CDMA: A Global Solution with Two Classes of Users

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Problem description

- One “important” terminal shares a VSG-CDMA cell with several “ordinary” terminals.
- All terminals are delay-tolerant, and can operate at many data rates. They have “plenty of power”.
- Administrator wants to assign the data rate and transmit power of each terminal to maximize the cell weighted throughput.
- The throughput of the important terminal is weighted by $\beta > 1$.
- Weights admit various interpretations (price, utility, “priorities”, etc.)
- We knew that (i) *some* terminals should operate at maximal data rate, and (ii) *the others* should operate at a certain specific SIR value determined by the physical layer.
- We now determine how many terminals should be in each operating condition. This leads us to a global maximizer.

Fundamental quantities of interest

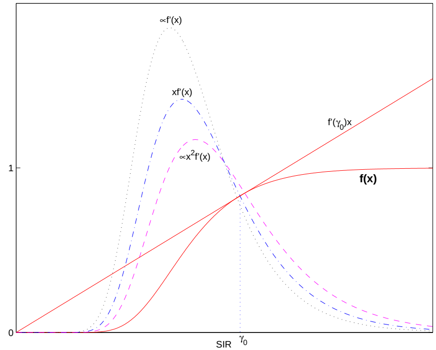
- Terminals send data to a base station
- R_c: chip rate ; R_i : data rate ; $G_i = R_c/R_i$: Spread Gain
- $G_i \geq G_0 \geq 1$ is required ($R_i \leq R_{MAX} \leq R_C$)
- $f_s(\gamma_i)$: probability of correct reception of a data packet, in terms of received SIR. The properties of the physical layer (modulation, channel characteristics, FEC, diversity, etc.) are embodied into the FSF
- $\gamma_i := G_i \alpha_i$ is the SIR with α_i the CIR given by

$$\alpha_i = \frac{h_i P_i}{\sum_{\substack{j=1 \\ j \neq i}}^{N} h_j P_j + \sigma^2} := \frac{Q_i}{\sum_{\substack{j=1 \\ j \neq i}}^{N} Q_j + \sigma^2}$$

- h_i: gain ("path loss"); $h_i P_i := Q_i$: received power
- Throughput of terminal i, $T_i(G_i, \alpha_i) \propto R_i f(G_i \alpha_i) \propto f(G_i \alpha_i)/G_i$

An abstraction of the physical layer

- To accommodate most physical layers of interest, all that is assumed on the FSF is that it is a smooth "S-curve":
  - "starts out" convex.
  - smoothly transitions to concave, as it approaches a horiz. asymptote.



- Ex: for non-coherent FSK with packet size M=80, no FEC, and perfect error detection, the FSF is $f_s(x) = \left[1 - \frac{1}{2}\exp\left(-\frac{x}{2}\right)\right]^{80}$

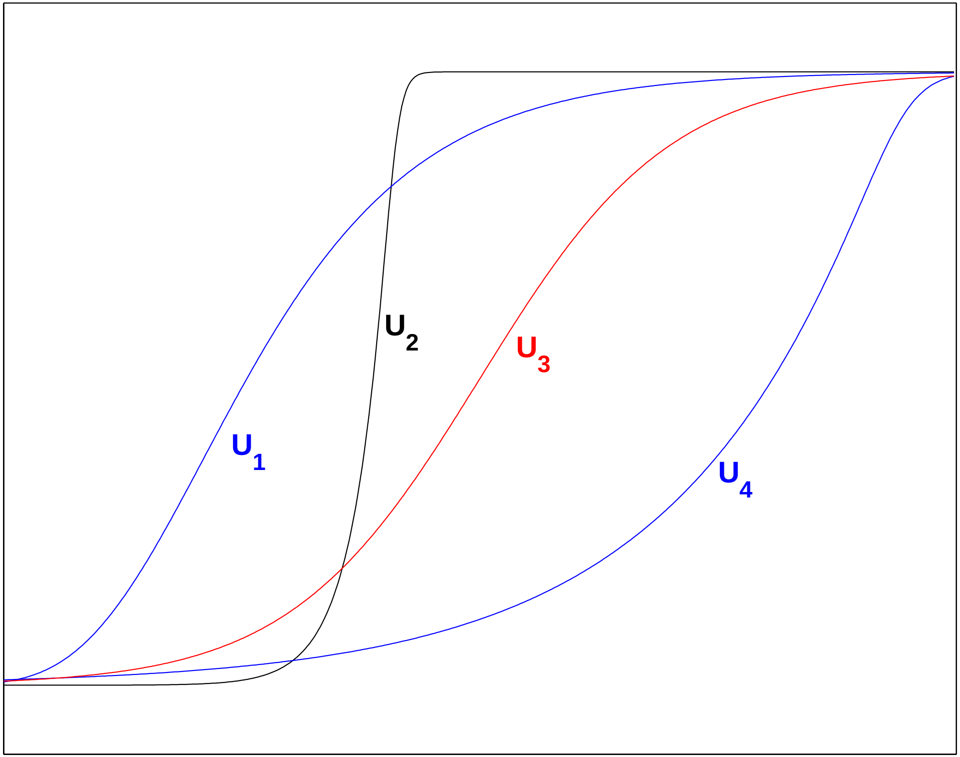


Figure 1: (1-FER) vs. SIR. S-curves can approximate “steps”, ramps, as well as concave and convex curves

Optimization Model

- data rates can be determined through spreading gains, G_i
- Power levels can be determined through power ratios. BUT CIR's need to be constrained so that they lead to feasible power levels

$$\max_{G_i,\alpha_i} \sum_{i=1}^{N-1} T_i(G_i,\alpha_i) + \beta T_N(G_N,\alpha_N)$$

$$\begin{aligned} &\text{subject to :} \\ &\sum_{i=1}^{N} \frac{\alpha_i}{1+\alpha_i} \; = \; 1 \\ &\qquad G_i \; \geq \; G_0 \; , \; i \in \{1,2\} \end{aligned}$$

- It is straightforward to write the Lagrangian for this problem and set up the associated first-order necessary optimizing conditions (FONOC)

How many favored terminals?: Basic idea

- We know that (i) *some* terminals ("favored") should operate at maximal data rate, and (ii) *the rest* should operate at the SIR γ_0, which maximizes $f(x)/x$.
- The SIR of the favored terminals, and the data rates of the non-favored must be chosen to satisfy FONOC.
- But how many in each group?
  - First, find, if available, a solution to FONOC with only the "important" terminal operating at maximal data rate ("single favorite" solution). Then seek a solution to FONOC in which both the important terminal and an ordinary one operate at maximal data rate. And so on.
  - After each solution is obtained, calculate the resulting throughput.
  - Choose the solution that gives the largest overall throughput

Solving FONOC with one "favorite"

- To find the FONOC-solving SIR of the important terminal, find solutions to:

$$\phi\left(\frac{x}{G_0}\right) = \frac{1}{\beta}$$

- $\phi()$ is a "bell curve", obtained from f. Therefore, this equation will have either 2 positive solutions, say x_1^* and x_2^*, or no solution at all (see fig).
- For any of these values that is greater than γ_0, obtain a corresponding α, the FONOC-solving CIR for the non-favored terminals.
- The matching spreading gain is γ_0/α. If $\gamma_0/\alpha > G_0$, a complete *feasible* solution to FONOC has been found, and the corresponding weighted throughput can be calculated.

Solutions with many "favored" terminals

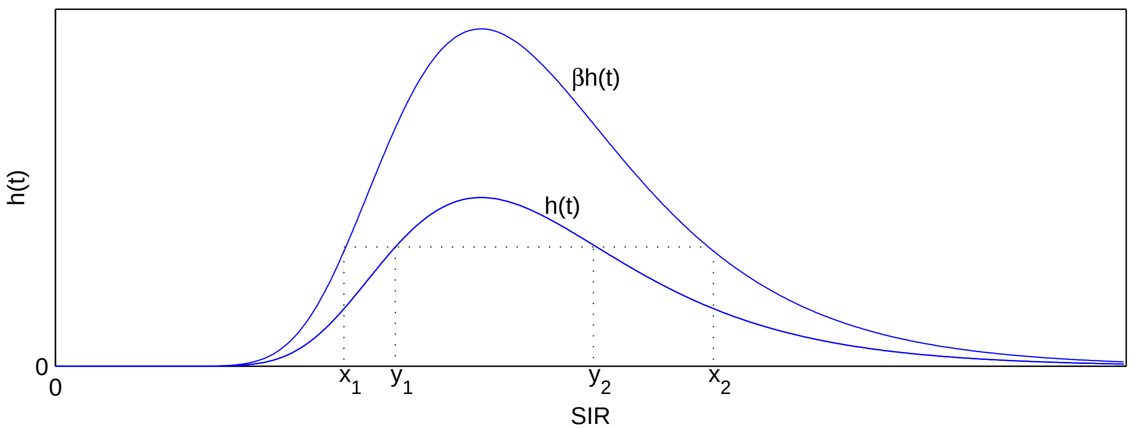
Let x and y be the SIR of, respect., the important and ordinary terminals operating at maximal data rate.

- To obtain x and y we must solve a system of 2 non-linear equations of the form:

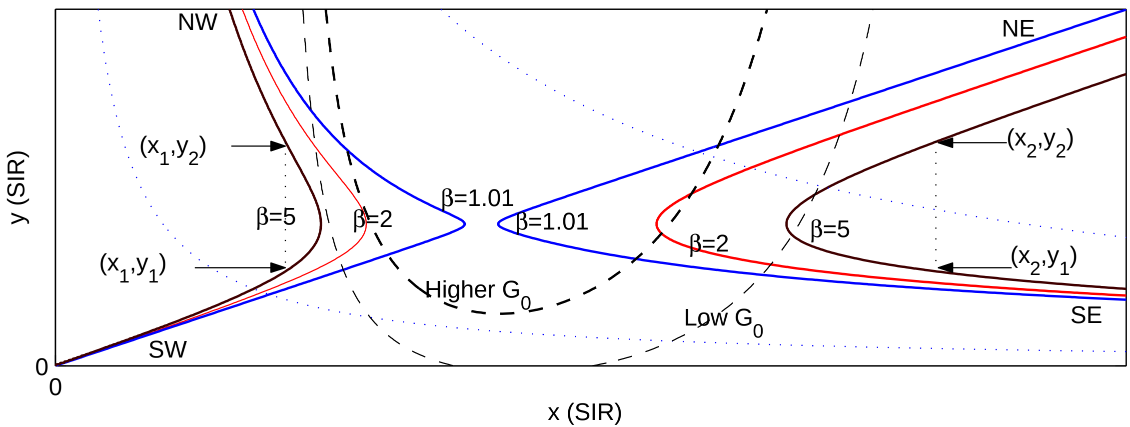
$$\beta h(x) = h(y) \text{ and } \pi(x,y) = 0$$

- $h()$ is a "bell curve" obtained from f. The pairs (x,y) that satisfy $\beta h(x) = h(y)$ give rise to an "X-shaped" graph.
- $\pi(x,y) = 0$ follows directly from the constraint on the CIR's $(\sum() = 1)$. and give rise to a U-curve, which turns into an L-curve (hyperbola) when all terminals operate at maximal data rate.
- The 4 intersections between the X and U (or 2 between the X and the L) are candidates for (local) maximizers. Some of them can be eliminated by applying some additional conditions.

(x_1,y_1), (x_2,y_2), (x_1,y_2) and (x_2,y_1) are possible solutions to βh(x)=h(y)



"X−shaped" graphs showing points (x,y) satisfying βh(x)=h(y)



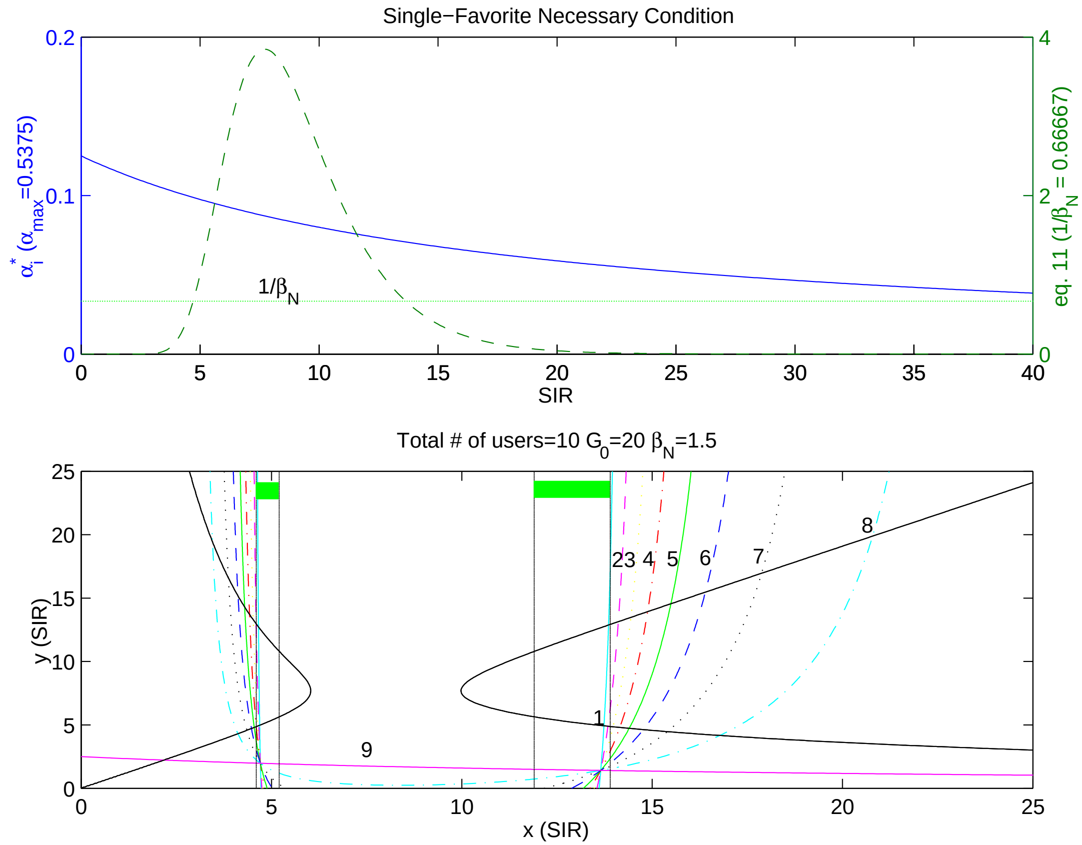


Figure 2: Single-favorite solution, at $x \approx 13$ (top), yields a *weighted* throughput of $0.12R_c$. DFBS at (13.8, 12.8) maximizes the weighted throughput at $0.7R_c$. The “all favored” solution ($n_1 = 9$) leads to a minimum.

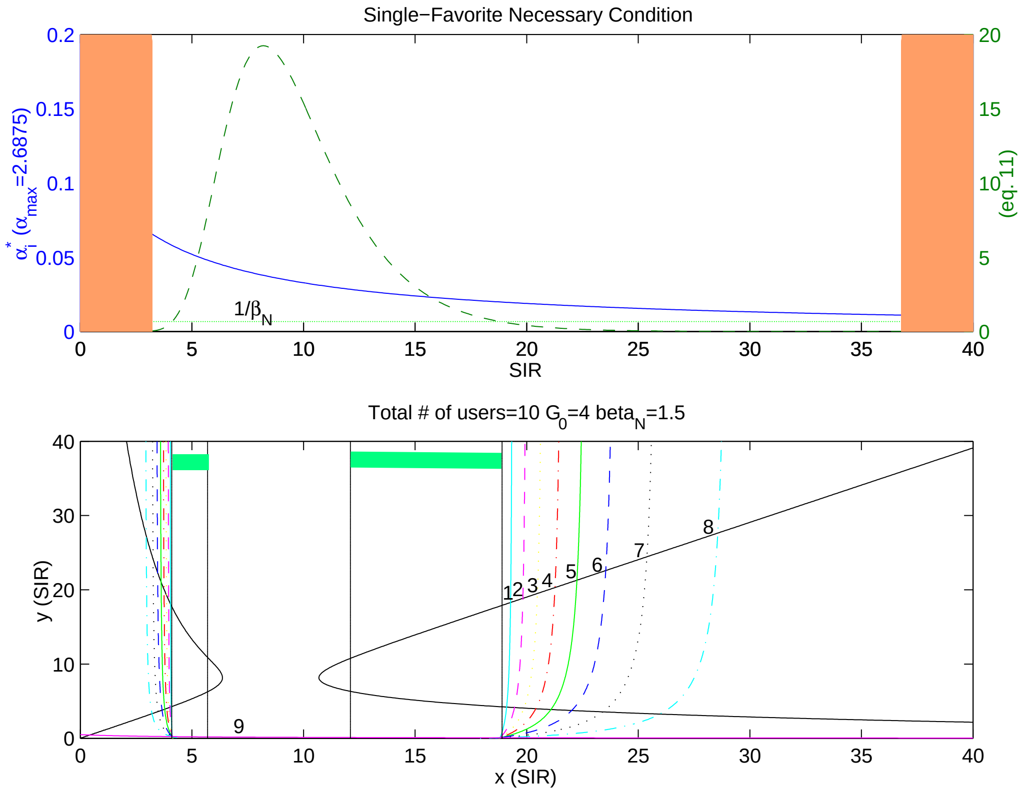


Figure 3: With a small $G_0 = 4$ and a moderate $\beta = 1.5$ the SFBS exists (top), and leads to the maximum. But all the multi-favorite solutions fail . The "all favored" solution leads to a minimum.

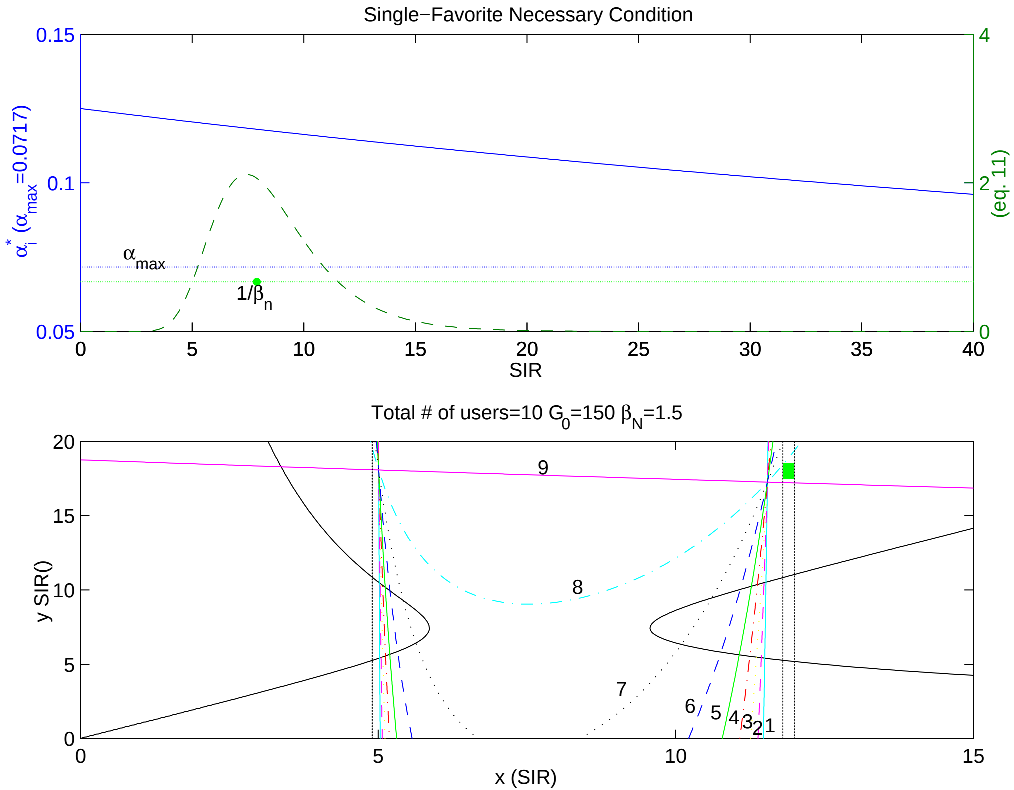


Figure 4: With a high $G_0 = 150$ and $\beta = 1.5$ *no* SFBS is available because for any x, α will be too high (its matching spreading gain will fall below G_0). Multi-favorite solutions with $1 \leq n_1 \leq 8$ also fall outside the acceptable range. The "all-favored" solutions leads to the global maximizer.

Discussion

- We have allocated data rate and power for maximal weighted throughput in a 3G CDMA (VSG) cell. Weights may reflect "importance", utility, or price paid per bit delivered.
- To accommodate most physical layers, we assume that all that is known about the frame-success function (FSF) is that it is an "S-curve".
- Each physical layer has a "preferred" SIR, at the "knee" of the FSF.
- (i) *Some* terminals ("favored"), including the important one, should operate at maximal data rate, and (ii) *the others* should operate at the SIR "preferred" by the physical layer.
- With several terminals operating at the highest data rate, the intersection of an X-shaped graph and a U or L-shaped graph (from SIR-feasibility constraint) determines the SIR of the "favored" terminals.
- We have presented a procedure to determine how many terminals should operate at maximal data rate; this has led us to the global maximizer.

Extensions and future directions

- We have already started to extend this analysis to include noise (out of cell interference), and the presence of power-limited media terminals (CISS-04).
- This analysis can be further extended to consider
  - QoS requirements
  - power limits
  - many cells

Technological Motivation : VSG-CDMA

- Modern (3G) wireless nets are expected to accommodate terminals operating at very different data transmission rates.
- Variable Spreading Gain CDMA can accommodate multi-rate traffic, and is supported by current 3G standards.
- In a VSG CDMA system, chip rate is common, but each terminal's spreading (processing) gain is the ratio of the common chip rate to the terminal's bit rate.

Outline of research program

- Analytical Core
- Single-user applications: choose power, data rate and/or coding rate for data, image, video transmission
- Decentralized multi-user applications:
  - Game formulation
  - Mechanism design
- Centralized data throughput maximization
  - Without noise
  - With noise and media terminals present

Overview of our analytical framework

- Many radio-resource optimizations share a common analytical core, which enables robust and tractable analysis and provides clear answers in fairly general scenarios
- It involves
  - A tractable abstraction of the physical layer
  - A tractable abstraction of the human visual system
  - A fundamental result: maximize $f(x)/x$ with f an "S-curve".
- Problems to which this framework applies:
  - Power and coding rate choice for media files (images, video)
  - Choosing the "right amount" of media distortion
  - Decentralized power control for 3G CDMA
  - Data rate and power allocation for maximal cell throughput when data and media terminals share a CDMA cell

THANK YOU!!!

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