Game Theory for Wireless Networks

Lecture 9

Course outline

- Adaptive modulation for wireless networks
  - Paper on joint power control and link adaptation
  - Paper on dynamic energy minimization for wireless transceivers

- Your presentations
  - Power control
  - Power control and pricing

Adaptive modulation

- Recall – we transmit symbols over the air by modulating a carrier
  - Sinusoidal carriers: $A\sin(2\pi f t + \theta)$

    Amplitude modulation (A), Frequency modulation (f), Phase modulation (θ)

  - Quadrature modulation: we use as carriers both sin and cos
  - M-ary modulation: $A_1, A_2 = \pm 1, \pm 3, \ldots, \pm\sqrt{M} - 1$
    - Example M - QAM
      - $\log_2 M$ bits encoded into one symbol
  - Large M – higher rates!!!
    - Higher BER too → need higher SNR/SIR → better quality channel

Adaptive modulation

- BER target → application specific: imposed
- Channel quality fluctuates → change modulation to meet target BER
  - Fading
  - Interference changes (burstiness, mobility, access control, etc.)
- Channel quality fluctuates → change transmission power to achieve target BER
- Adaptive modulation and power control: related → joint optimization??

Joint link adaptation and power control

- Reference: “Game theoretic Analysis of Joint Link Adaptation and Distributed Power Control in GPRS”, S. Ginde, J. Neel, R. M. Buehrer, VTC, fall 2003.

- Application for GPRS
  - General Packet Radio Service → standard for wireless data communications → extension from GSM (Global System for Mobile Communications): digital cellular system, based on TDMA technology

System model – cellular with TDMA technology

Similar as in our SIR analysis:
- First tier of interferers
- cellular reuse factor: 3

-Compute SIR in dB for user i:

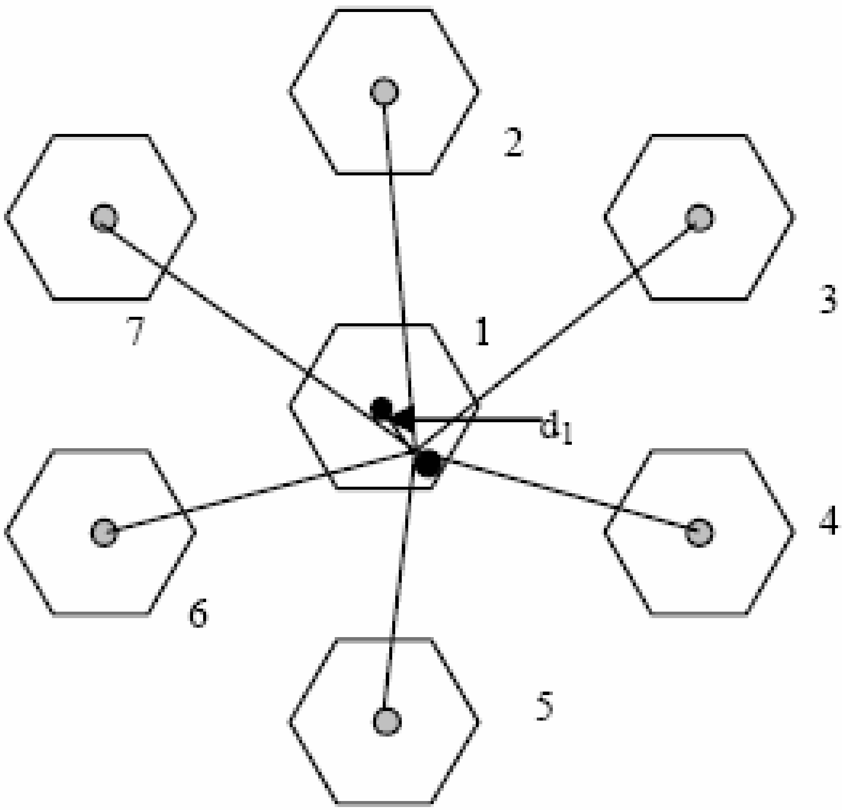
SIR

$$\gamma_i = 10\log_{10}\left(\frac{G_{ii}P_i}{\sum_{j\neq i}^{N} G_{ij}P_j + \eta_i}\right)$$

Transmitted Power for user j

link gain (path loss)

noise at receiver i



Performance measure

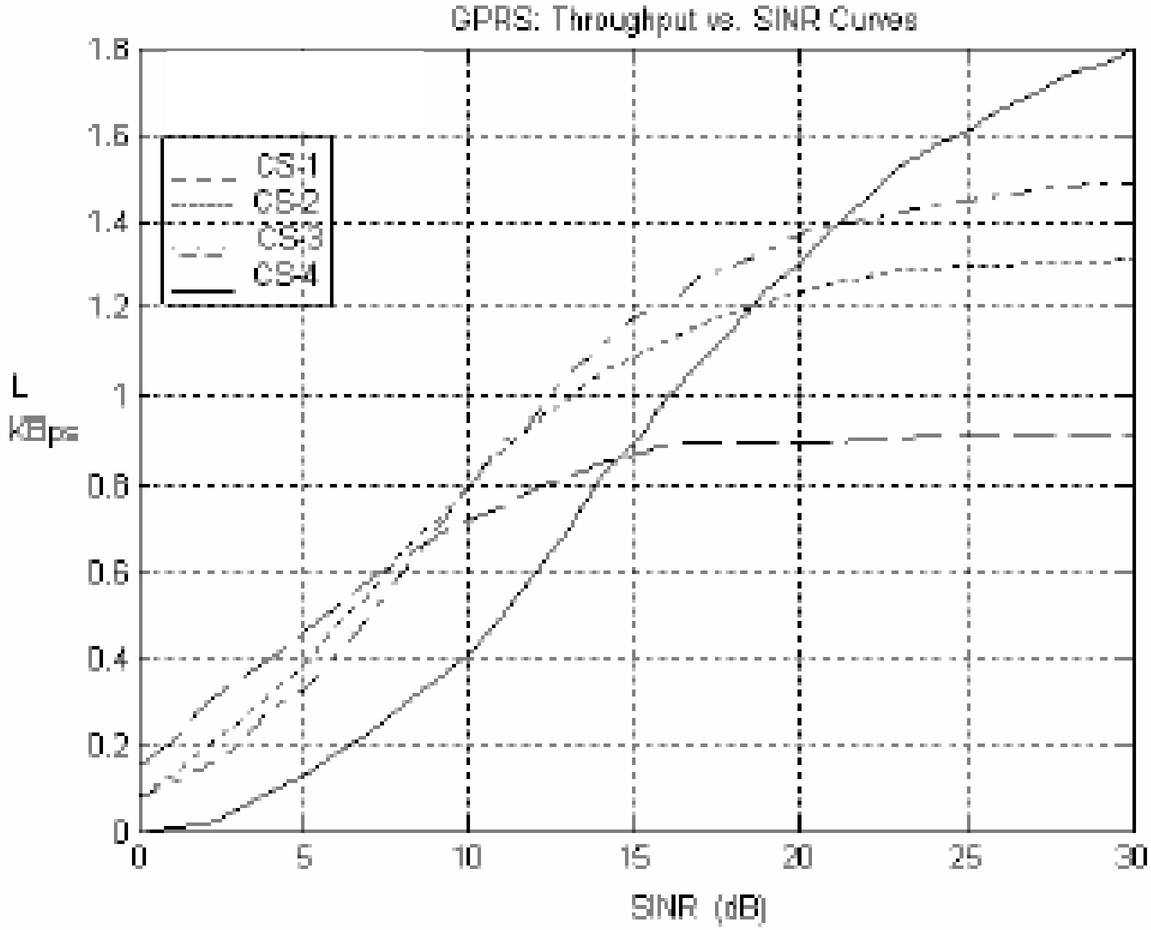
- Performance measure: analytical model for throughput
  - Depends on the SNR(SIR)
  - Can be modeled by a sigmoid function of the SIR, with some parameters: A, λ, and δ → fitted for given modulation and coding

$$L(\gamma) = \frac{A}{1 + \exp[-\lambda(\gamma - \delta)]}$$

TABLE I. GPRS CODING SCHEMES [3]

Coding Scheme	Modulation	Code Rate	Data rate/ Time slot
CS-I	GMSK	0.49	9.05 kbps
CS-II	GMSK	0.64	13.4 kbps
CS-III	GMSK	0.73	15.6 kbps
CS-IV	GMSK	1	21.4kbps

Performance measure: Throughput



CS	A kbps	λ	δ dB
CS-1	7.36	0.272	4.75
CS-2	10.52	0.256	8.250
CS-3	11.88	0.256	9.5
CS-4	14.36	0.231	15

Game theoretic formulation

- Players: set of co-channel links
- Actions: select powers and rates:

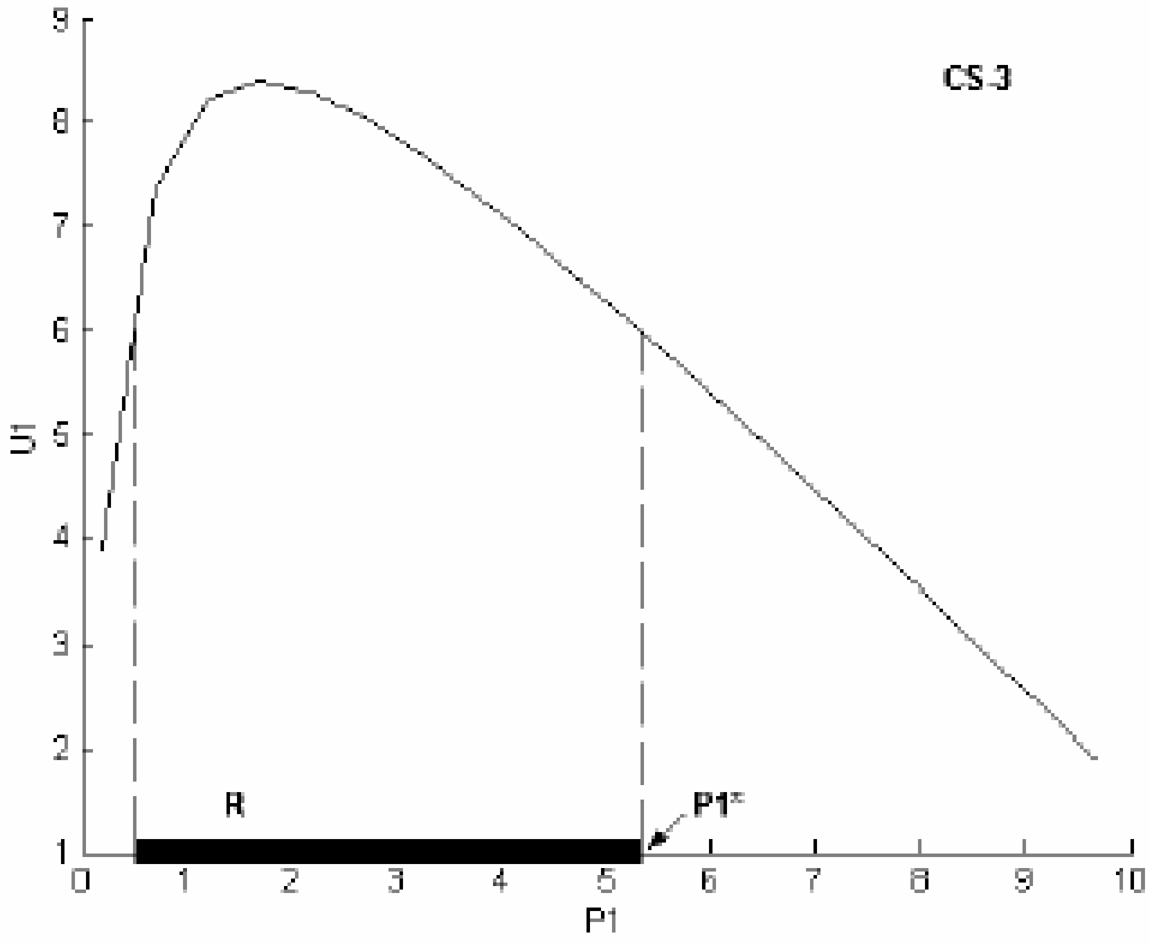
$$A_i = \{(P_i, r_i) \mid P_i \in \lfloor P_{i,\min}, P_{i,\max} \rfloor, r_i \in \{r_1, r_2, r_3, r_4\}\}$$

- Utility function: throughput measure with pricing function

$$U_i(\mathbf{P}, r_i) = \frac{A(r_i)}{1 + \exp\{-\lambda(r_i)[\gamma_i - \delta(r_i)]\}} - KP_i^q$$

Existence of Nash equilibrium

- If keep rates constant (select only powers) → Debreu's theorem holds → guaranteed to have at least 1 Nash equilibrium



Joint power control and rate assignment solution

- Two step optimization:
  - start with some initial values for powers and rates
  - Step1: select power to maximize utility function

$$P_{i,eqm} = \max_{P_i} U_i(P_i, P_{-i}, r_i)$$

  - Step 2: for the given selected powers, determine rates

$$r_{i,eqm} = \arg\max_{r_i} U_i(r_i, \mathbf{P}_{eqm})$$

  - Continue until no improvement in rates can be achieved

Figures of merit definition

- FOM1: ratio between system throughput and sum of the fractions of peak power consumed by links

$$FOM1 = \frac{\sum_i L_i}{\sum_i \frac{P_i}{P_{\max}}}$$

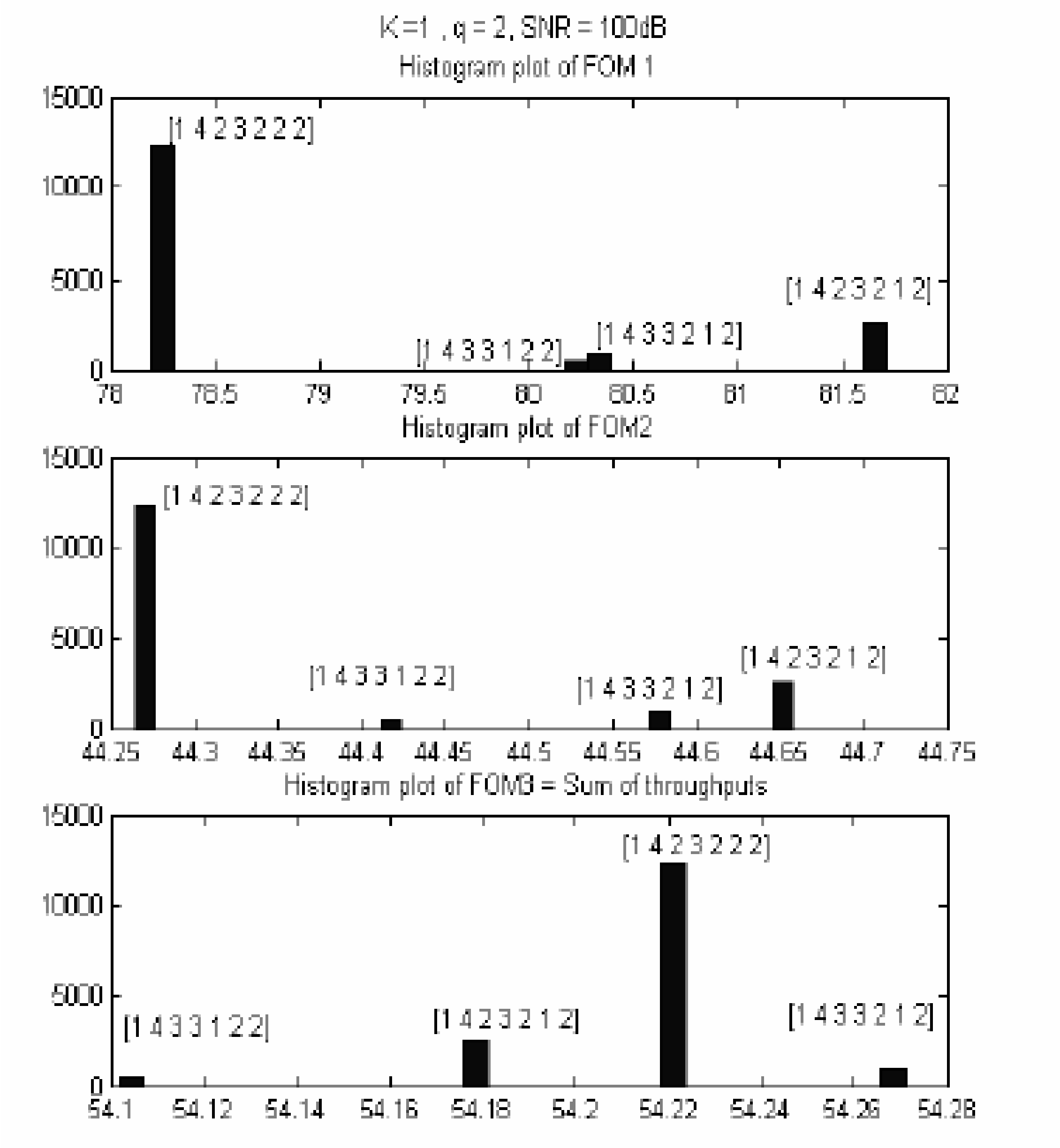
- FOM2: difference between system throughput and sum of the fractions of peak power consumed by links, scaled by the peak throughput

$$FOM2 = \sum_i L_i - A_{\max} \sum_i \frac{P_i}{P_{\max}}$$

- FOM3: system throughput

$$FOM3 = \sum_i L_i$$

Nash equilibrium: not unique



Some performance results

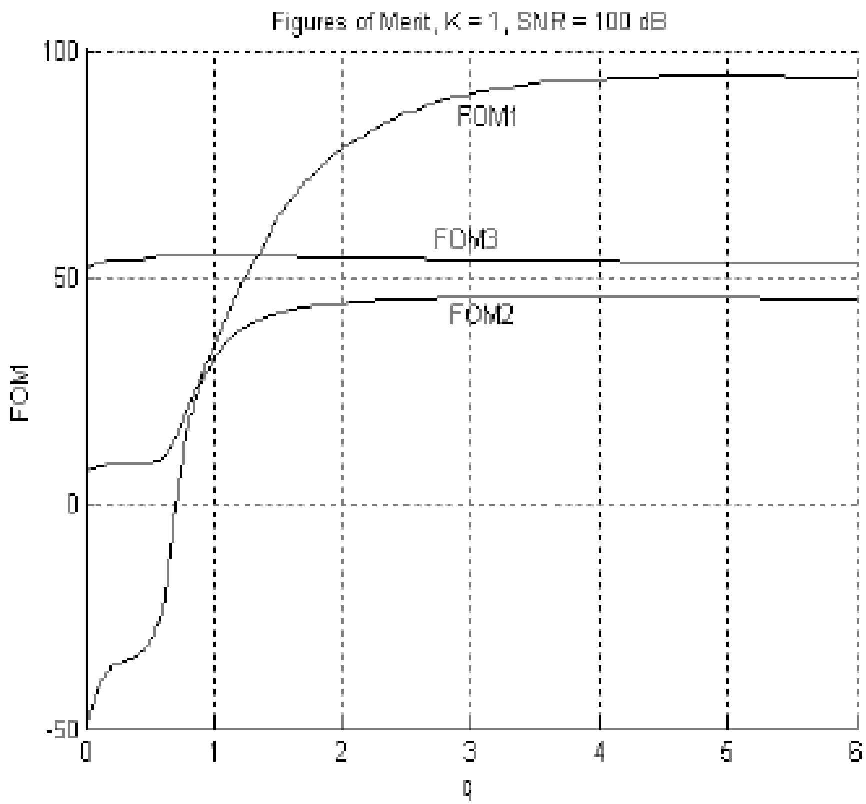


Figure 5. Effect of q on FOM's, SNR = 100 dB

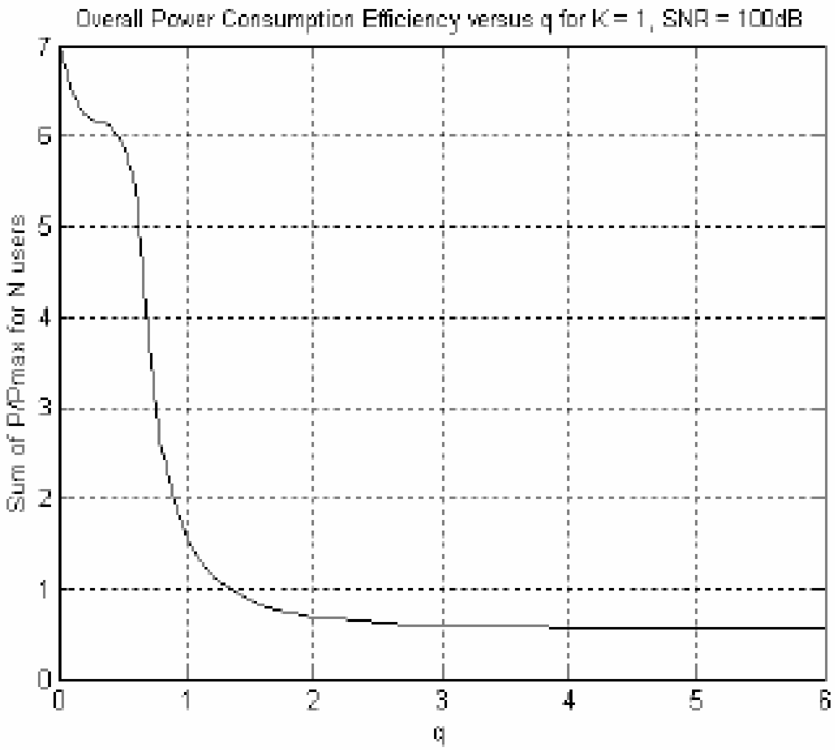


Figure 6. Effect on q on power consumption

More performance results

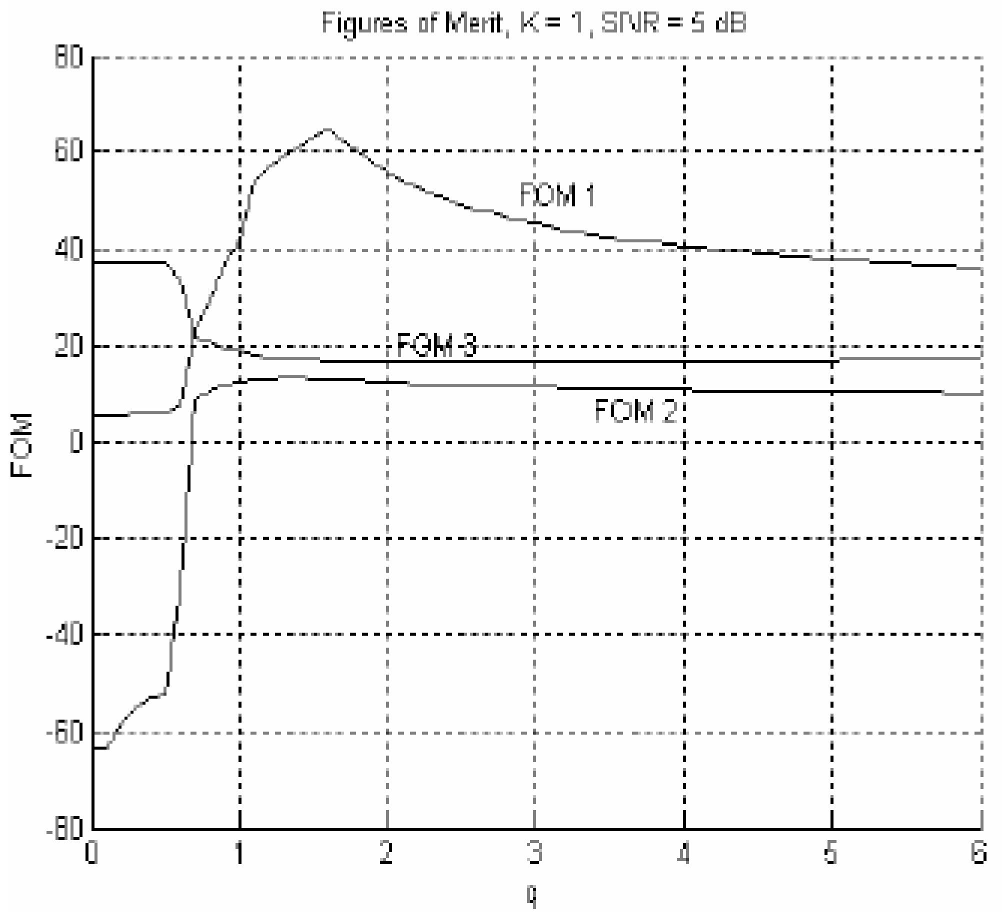


Figure 7. Effect of q on FOM's, SNR = 5 dB

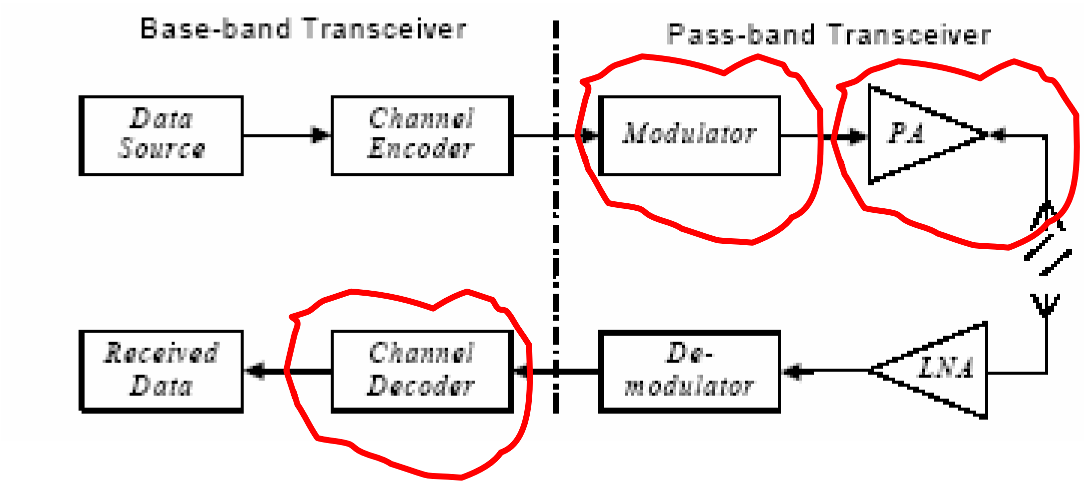
Dynamic energy minimization in wireless transceivers

- Reference: “A Game Theoretic Approach to Dynamic Energy Minimization in Wireless Transceivers”, A. Iranli, H. Fatemi, M. Pedram, Int’l Conference on Computer Aided Design, November 2003, pp. 504-509.

- System model: ad hoc network, OFDM (Orthogonal Frequency Division Multiplexing) transmission (802.11a)
  - OFDM = multicarrier transmission technique, which allows a more tight packing of multiple carrier frequencies, by keeping the carriers orthogonal
  - A signal is split into sub-signals that are transmitted in parallel on the multiple carriers

Optimization problem

- Minimize total energy consumption for a link
  - (A) Minimize energy at transmitter
  - (B) Minimize energy at receiver



Optimization problem

- No interference is considered
- Transmitter: can select powers and modulation levels → influences the total energy expenditure
- Receiver: can choose decoder's parameters:
  - For convolutional codes → Adaptive Viterbi decoder → accuracy of decoder increases as the number of decoding stages increases; however, the power consumption of the decoder increases also
  - Parameters chosen: Truncation length (number of paths consider to find the optimum path) of the decoder
- Receiver and transmitter alone cannot optimize energy independently, depend one of another
- Optimization modeled as a Stackelberg game → multi-level optimization problem formulated

Optimization problem

- Strategy for the receiver: $x \in X$

$$X = \{(TL_1, TL_2, ...TL_n \mid \forall i : TL_i \in TLS\}$$

- Strategy for transmitter: $y \in Y$

$$Y = \{P_{Tx}, b_1, b_2, ..., b_n \mid i : b_i \in MLS, P_{Tx} \in PLS\}$$

- Optimization:

$$\{(\hat{X}, \hat{Y}) \mid A\hat{X} + B\hat{Y} < R\hat{E}Q_{Tx}, D\hat{Y} \geq R\hat{E}Q_{Tx}, \hat{X}, \hat{Y} \geq 0\}$$

Coef. Matrices – account for channel characteristics

Vector → upper bound on overall Energy consumption

Coef. Matrix for linear est. of throughput and BER, in terms of SNR and mod. level

Some performance results

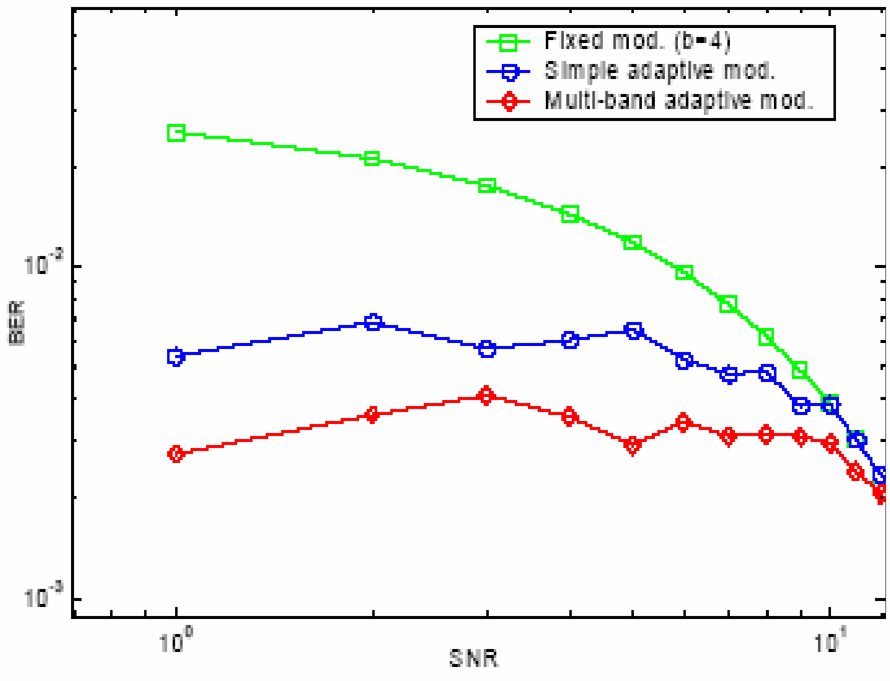
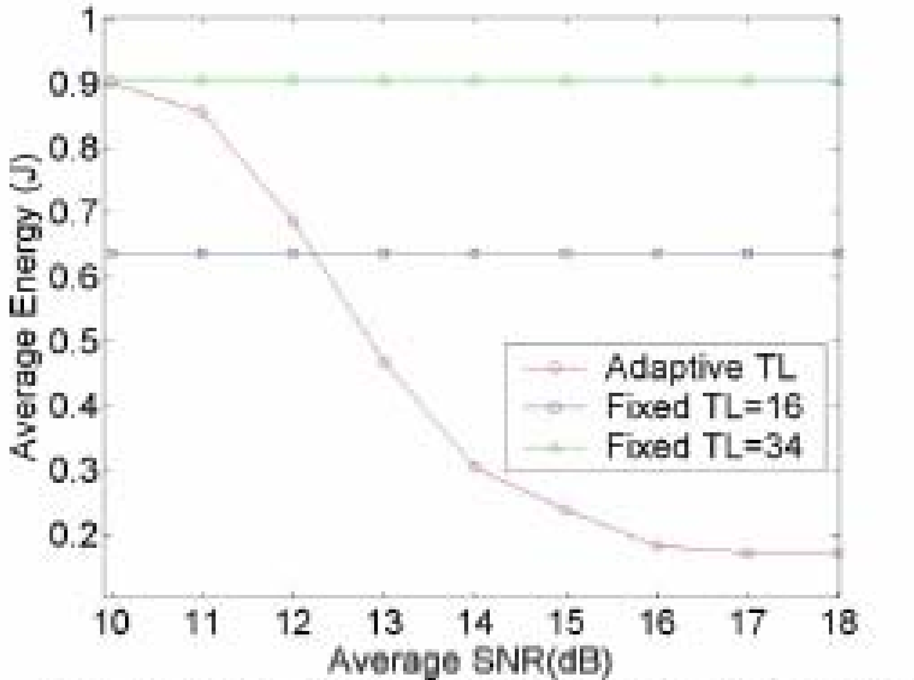


Figure 5. Average BER as a function of SNR for adaptive and fixed modulations



(a) Average Energy vs. SNR (BER=10^{-4} & b=4)

More performance results

$$E_{avg} = \alpha \cdot E_{Transmit} + (1-\alpha) \cdot E_{Receive}$$

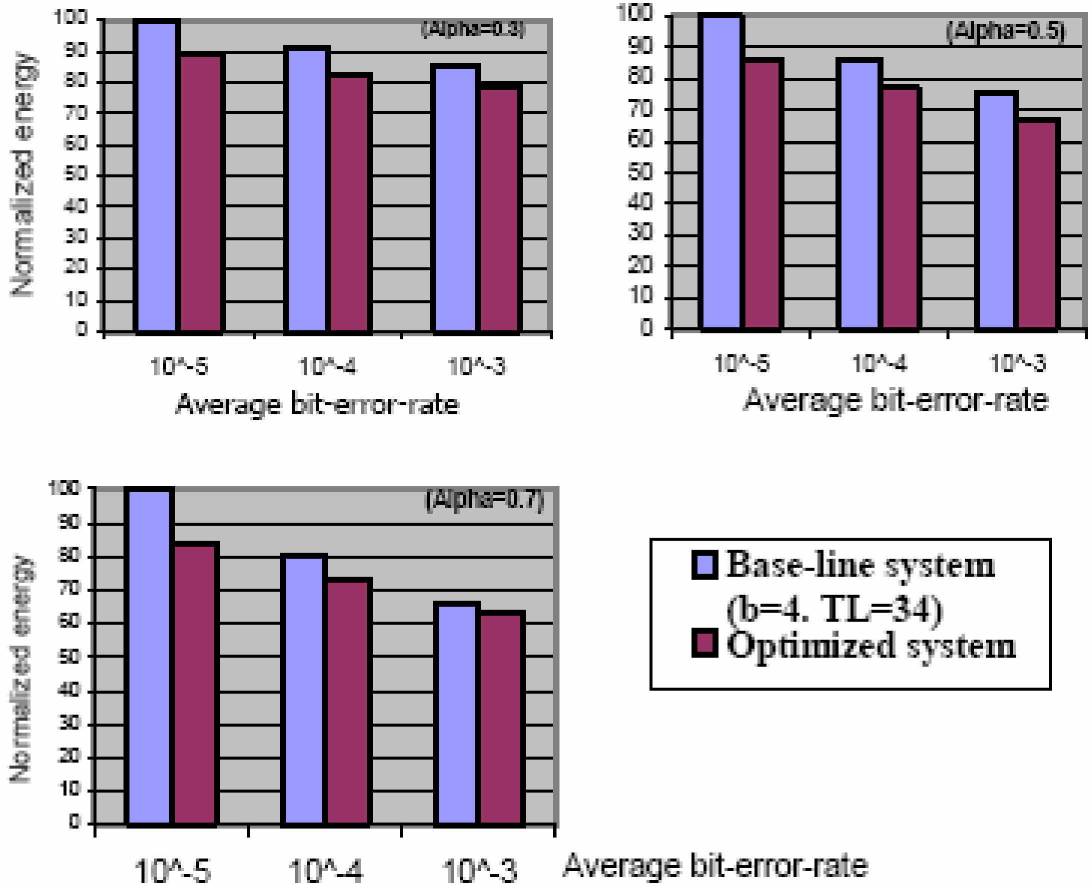


Figure 7. Normalized energy consumptions