EEL 6591
Wireless Networks

Radio Resource Management

(RRM)

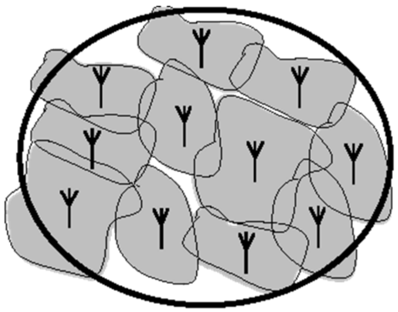
Outline

- Overview of Radio Resource Management (RRM)
- Family of RRM functions
  - power control
  - channel allocation (channel assignment)
  - admission control
  - handover control (mobility management)

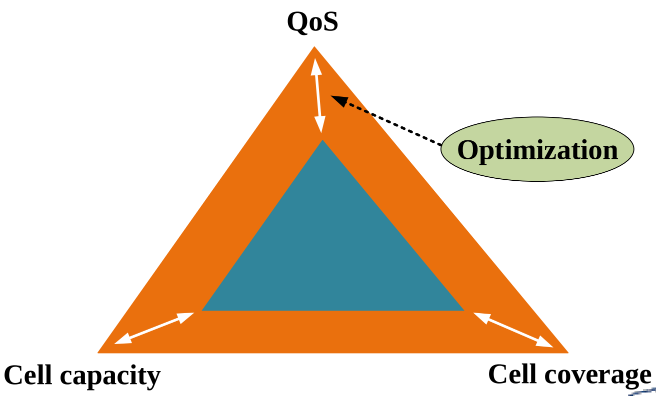
Discuss Later

RRM Overview

- RRM is an elementary part in 3G (and beyond) wireless cellular networks.
- The importance of RRM is due to the feature of cellular system in that
  - bandwidth-limited
  - range-limited
  - interference-limited



- RRM is responsible for efficient utilization of network resources to
  - ❖ guarantee QoS
  - ❖ maintain the coverage area
  - ❖ optimize the cell capacity

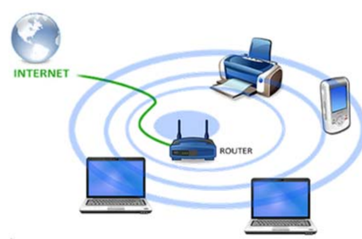


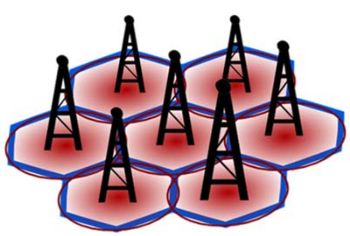
Introduction

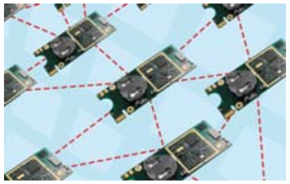
- Definition of power control

  "Power control, broadly speaking, is the intelligent selection of transmitter power output in a communication system to achieve good performance within the system. [Wikipedia]"

  - ❑ Intelligent Selection: an optimization algorithm
  - ❑ Communication System: cellular networks, WLANs, wireless sensor networks and etc.
  - ❑ Good Performance: link data rate, network capacity, outage probability, lifetime of networks, geographic coverage and etc.

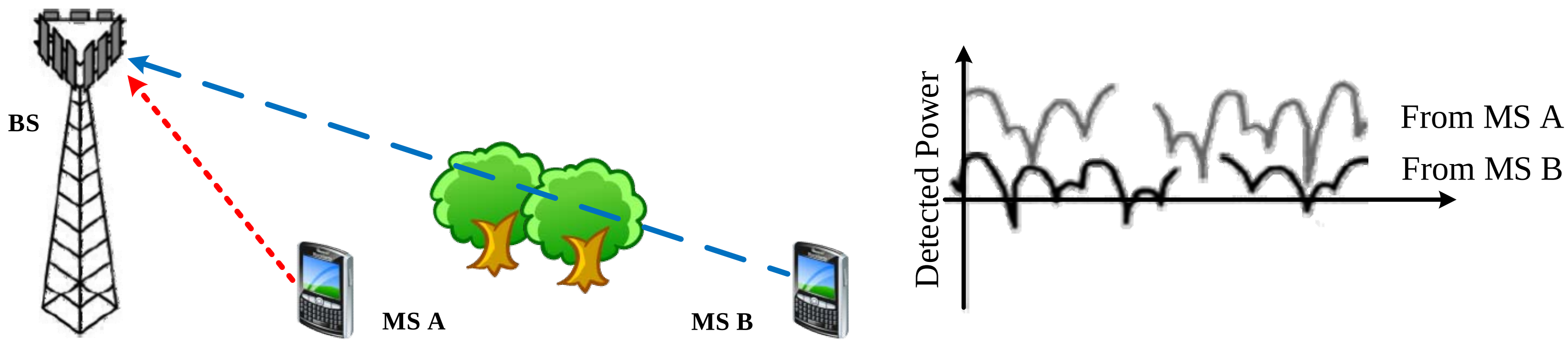






Introduction

- Objective of power control in cellular networks
  - ❑ Maintain link quality of uplink and downlink by controlling transmission powers
  - ❑ Prevent near-far effect (e.g. W-CDMA system)
  - ❑ Minimize effect of channel fading
  - ❑ Minimize interference in networks



Near-far problem in uplink of W-CDMA system

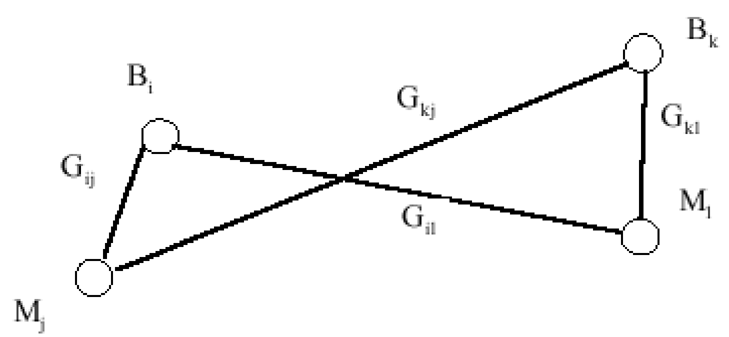
Introduction

- Let's give a demonstrative example to show the uplink power control optimization in a UMTS/WCDMA system.

$$\begin{array}{ll} \text{minimize} & \sum_i p_i \\ \text{subject to} & \mathsf{SIR}_i(\mathbf{p}) \geq \gamma_i, \ \forall i \\ \text{variables} & \mathbf{p} \end{array}$$

For instance, minimizing total transmitting powers while satisfying each user's SIR.

- Problem formulation
  - Mobiles: (M1,M2, ..., MM)
  - BSs: (1,2,..., B)
  - Codes: (1,2,...,C)



Introduction

- Problem formulation (cont)
  - Link gain: G_{ij} between BS i and mobile j, $G=(G_{ij})$
  - P_j: transmitting power used by mobile terminal j
  - θ_{jm}: normalized cross-correlation factor between signals (codes) from mobiles j and m
  - N: receiver noise power
  - Γ_j: SIR at the BS receiver j
  - γ: the desired SIR to maintain the QoS

Introduction

- Problem formulation (cont): choose the BS i, the codes (channels), the powers so that for all mobile j we have

$$\Gamma_j = \frac{P_j G_{ij}}{\Sigma_m P_m G_{im} \theta_{jm} + N} \geq \gamma$$

Problem Formulation

- Power control: Given BS i and the channel, find power set P_j such that

$$\Gamma_j = \frac{P_j G_{ij}}{\Sigma_m P_m G_{im} \theta_{jm} + N} \geq \gamma$$

- Variation: Given the BS i and the channel, find power set Pj so that $P_j G_{ij} = P_m G_{im}$ for j,m in the cell I
- Minimization: minimize the total power with power constraints

Power Control

- Standard interference function

$$P_j \geq \frac{\gamma \sum_m P_m G_{im} \theta_{jm} + N}{G_{ij}} = I_j(P)$$

$$P = (P_1, P_2, \ldots, P_M), I(P) = (I_1(P), I_2(P), \ldots, I_M(P))$$

A interference function $I(P)$ is *standard* if for all $P \geq 0$, we have

- **Positivity:** $I(P) > 0$
- **Monotonicity: If** $P \geq P'$, **then** $I(P) \geq I(P')$
- **Scalability: For all** $\alpha > 1$, $I(\alpha P) < \alpha I(P)$

Power Control

- New problem formulation: Find the power set P such that

$$P >= I(P)$$

  - a vector P is said to be feasible if P satisfies the above inequality
  - I(P) is feasible if there exists a feasible P
- Theorem: If I(P) is a feasible standard interference function, then power control algorithm $P_{n+1}=I(P_n)$ will converge to the unique fixed point P’: P’=I(P’)

Power Control

- Observations
  - the fixed point P' has the following property: P_jG_{ij} are all equal--received powers are all equal
  - powers are synchronously updated for all mobiles
- Optimization problem
  - minimize the total received power: enough is good
  - minimize the total transmitted power: stingy is good
  - Power control with adaptive sectorization: JSAC paper by Yener (2001)

Power Control

- Asynchronous power control algorithm: update whenever requested

$$P_j(n+1) = \begin{cases} I_j(P(\tau^j(n)), & n \in T^j \\ p_j(t), & \textbf{otherwise} \end{cases}$$

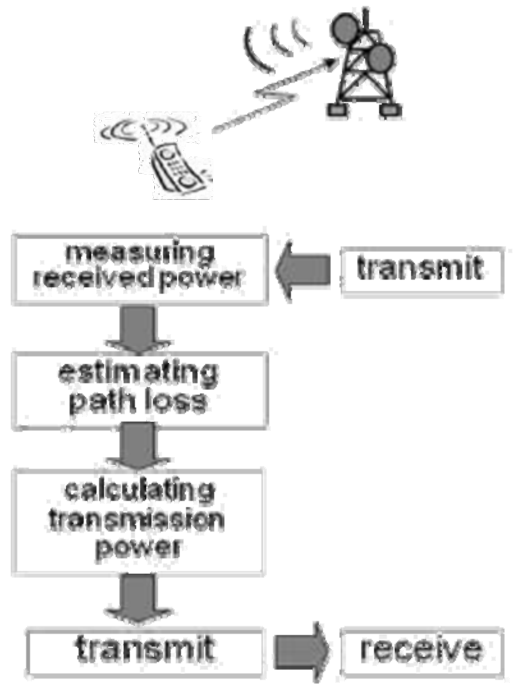
where T^j denotes the set of times at which j mobile updates power, $\tau^j(n)$ denotes the most time instant the mobile j knows power level

- Theorem: If I(P) is feasible, the asynchronous power control will converge to the unique equilibrium point P': P'=I(P')

Power Control

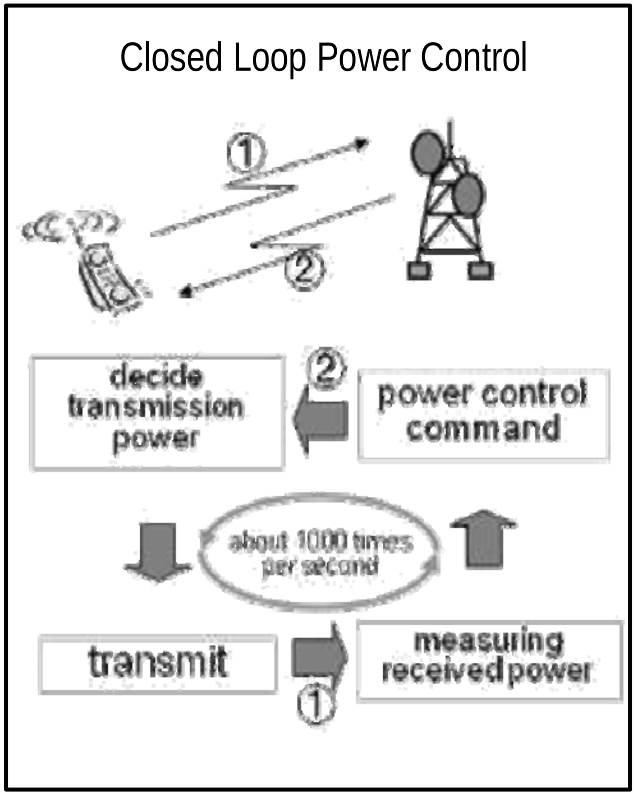
- CDMA Standard (IS-95) power control
  - Open-Loop Power Control: MS observes the forward link pilot signal strength and determines the power to transmit--pilot signal strength indicates the distance between MS and BS

Open Loop Power Control



Power Control

- CDMA Standard (IS-95) power control
  - Centralized Closed-Loop Power Control: BS observes link quality such as energy-to-interference ratio EIR
    - if measured EIR is greater than the current target EIR, BS informs the MS to decrease its power by 1 dB;
    - Otherwise, BS informs the MS to increase its power by 1 dB.
  - Convergence is slow (sluggish)

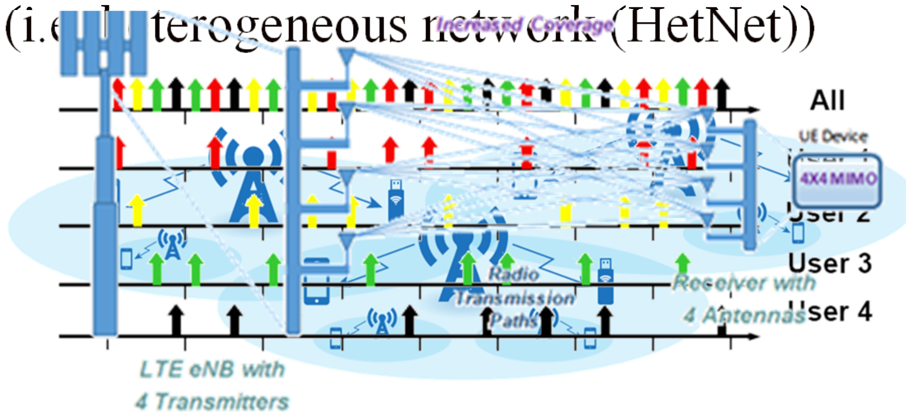


RRM for Current Systems

- Next, let's take a look at current 4G/LTE system and its radio resource management (RRM) functions.

Overview of 4G/LTE

- LTE is the successor technology for UMTS/WCDMA.
- LTE provides high data rate and low latency services.
  - 300Mbps peak downlink
  - 75Mbps peak uplink
  - 10ms minimum latency
- LTE incorporates several new techniques.
  - Orthogonal Frequency-Division Multiple Access (OFDMA)
  - Multiple-input and multiple-output (MIMO)
  - Small cell (i.e. heterogeneous network (HetNet))



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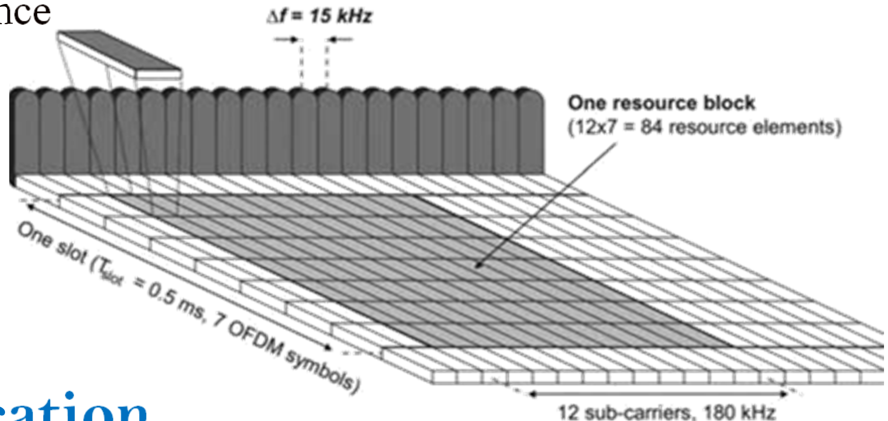
RRM in 4G/LTE

- LTE uses multi-carrier OFDM for downlink
  - Total carrier bandwidths range from 1.4MHz to 20MHz.
  - BS (a.k.a. eNB) allocates resource blocks (RBs) to mobiles (a.k.a. UE) to transmit data.
  - Resource block is in the form of **time-frequency grid**.
  - Advantages
    - Robust to fading and interference
  - Drawbacks
    - High peak-to-average ratio
    - Sensitive to frequency offset



- RRM in downlink LTE

mainly focuses on **RBs allocation.**

RRM in 4G/LTE

- For instance, finding the **optimal subcarrier** and **power allocation** to achieve **max. throughput**. (a.k.a. rate adaptive (RA) optimization)

$$\max_{c_{k,n}, p_{k,n}} \quad R_T = \frac{B}{N} \sum_{k=1}^{K} \sum_{n=1}^{N} c_{k,n} \log_2 \left(1 + \frac{p_{k,n} h_{k,n}^2}{N_0 \frac{B}{N}} \right)$$

subject to :

$$\left.\begin{aligned} &C1 : c_{k,n} \in \{0,1\}, \quad \forall k,n \\ &C2 : \sum_{k=1}^{K} c_{k,n} = 1, \quad \forall n \end{aligned}\right\}$$

Each subcarrier is only assigned to one user.

$$C3 : p_{k,n} \geq 0, \quad \forall k,n$$

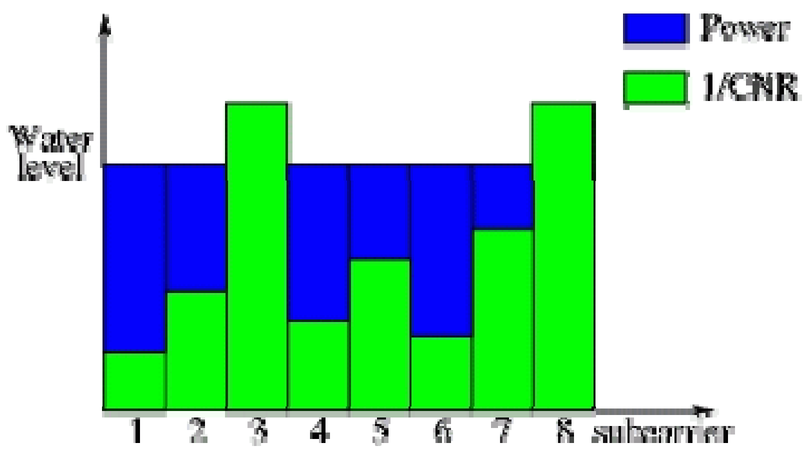
Power should be positive.

$$C4 : \sum_{k=1}^{K} \sum_{n=1}^{N} c_{k,n} p_{k,n} \leq P_{total},$$

Total power has a budget.

RRM in 4G/LTE

- In specific, the optimal solution is obtained if each subcarrier is assigned to the user with the **best channel gain** on it and the power is distributed using **water-filling** policy.
  - Good subcarriers get more power than poor subcarriers. (The rich becomes richer.)



RRM for Future Systems

- Future wireless systems (e.g. 5G) have the following demands
  - high bandwidth: multimedia applications or Internet applications tend to require high data rate
  - bursty data traffic: Internet traffic tends to be bursty
  - mixed traffic: voice, data, video/audio, images, ...
  - QoS: different traffic may need different QoS requirements
- The diversity and heterogeneity of device & data traffic (e.g. from smart cities and IoT) along with multi-dimensional radio resource intertwining makes RRM for future system challenging!
- New problems and new solutions!