Chapter 2 - Wireless Network Models

http://mobnet.epfl.ch

Note: some of the slides of this and other modules and derived from Miao’s book
What are the technical issues?

- Wireless system
  - Infrastructure
    - Base stations (APs)
    - Fixed network
  - Terminals
    - Coverage requirements
    - Service requirements
Radio Resources

Resources to be managed/conserved
- Radio frequency spectrum
- Power consumption
- Infrastructure cost
- Terminal cost

Why consuming radio resources?
- Mobile services
Cellular operator costs

- Administration: 15%
- Billing: 12%
- Marketing: 28%
- Network Maintenance: 14%
- Annualized Equipment: 6%
- Annualized Capital Costs: 16%
- Interconnect: 9%
Wireless Network Models

Classic communication theory
- Point-to-point links
- Disturbed by thermal (Gaussian) noise
- Adverse propagation conditions
- Channel variations

Wireless networks
- No radio link or system is alone in its allocated frequency band.
- Other radio transmitters, near and far, constantly cause interference.
- Interference is in many cases the limiting factor to the performance of the system.
Wireless Network Analysis

Multiple transmitters – Multiple receivers
Complex propagation pattern

Two step Analysis:
- What is the current interference situation?
- What is the received quality for a given interference situation?
Abstraction is necessary to simplify network analysis

1. Compute Carrier to Inference (C/I) in individual links
2. Map C/I with Quality
Wireless Access Network Models

A provider perspective and a consumer perspective

- Operator: profitable business
- User: pay for the services he appreciates

Network design problems

- Deployment
  - Base station density, location, cell capacity, spectrum in each cell, etc.
  - Long-term design

- Resource management
  - How should the wireless resources be allocated to maximize capacity while best meeting the instantaneous demand of the users/mobile terminals moving around in the network?
SERVICES AND SERVICE QUALITY
Services and Quality of Service

Perception

Technical measures

- Capacity
  - Number of subscribers served
  - Bitrate/Bandwidth provided

- Quality
  - Bit error rate
  - Delay
  - User data rate ("goodput")

Service probability

- Coverage
- Outage probability
- Blocking/Service denial
Common Service Types

Best Effort (Non-real time) traffic
- Guarantee minimum throughput (average data rate)
- Utilize all available throughput at any time (best effort)

Guaranteed service (RT/Voice/Video) traffic
- Guaranteed constant data rate & delay
Perceived Quality of service (QoS)
### 3G Service Classes

<table>
<thead>
<tr>
<th>Service Class</th>
<th>Typical applications</th>
<th>Service functional characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversational</td>
<td>Voice</td>
<td>• Preserve time relations between entities</td>
</tr>
<tr>
<td>Real Time (RT)</td>
<td></td>
<td>• Stringent preservation of conversational patterns (low delay)</td>
</tr>
<tr>
<td>Streaming RT</td>
<td>Video/Audio streams</td>
<td>Preserve time relations between entities</td>
</tr>
<tr>
<td>Interactive</td>
<td>Web-browsing</td>
<td>• Request-response pattern</td>
</tr>
<tr>
<td>Best effort (BE)</td>
<td></td>
<td>• Preserve payload (low error rate)</td>
</tr>
<tr>
<td>Background BE</td>
<td>File transfer, E-mail</td>
<td>• Not time critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Preserve payload (low error rate)</td>
</tr>
</tbody>
</table>

Note: in more recent networks, these classes have been dramatically simplified, because of the dominance of IP and the (relative) abundance of transmission resources.
RADIO RESOURCE MANAGEMENT
Radio Resource Management (RRM)

Network/Infrastructure Deployment
- How many & Where to place the base stations
- What fixed infrastructure to deploy
- How much spectrum to allocate?

Radio Resource Allocation
- How to manage the given assets Base stations
- Spectrum
- Power/Energy
Assign to each active terminal:

- Base station
- Waveform ("Channel")
- Transmitter power

→ such that Link Quality & power constraints are satisfied for as many terminals as possible

Note: the terms base station, access point and access port are used interchangeably in this chapter
Arbitrary collection of wireless links

→ Propagation conditions on link (i,j) characterized by $g_{ij}$, the instantaneous link gain.

$P_{rx, j} = P_{tx, i} \times g_{ij}$

Where $G = \text{Link gain matrix}$

$B$: number of base stations

$M$: number of mobiles

The matrix is not square!
Uplink and Downlink

Uplink communication or channel

Downlink communication or channel

\( i_0 \) to \( j \)
Interference and Quality Model

SINR of uplink (u) and downlink (d)

\[ \Gamma_{ioj}^u = \frac{P_j g_{ij}}{\sum_{m \neq j} P_m k_{c(i),c(m)} g_{iom} + N_{i0}} \]

\[ \Gamma_{ioj}^d = \frac{P_{i0} g_{ij}}{\sum_{b \neq i_0} P_b k_{c(i),c(b)} g_{bj} + N_j} \]

If channels are orthogonal:

\[ \Gamma_{ioj}^u = \frac{P_j g_{ij}}{\sum_{m \neq j, m \in M^{(c)}} P_m g_{iom} + N_{i0}} \]

\[ \Gamma_{ioj}^d = \frac{P_{i0} g_{ij}}{\sum_{b \neq i_0, b \in B^{(c)}} P_b g_{bj} + N_j} \]

In this case, the interference is due only to the transmitters using the same channel (c)
Service Quality for the Two Common Types

Constraint on service quality:

Uplink: \[ \Gamma_{i_0 j}^u = \frac{P_j g_{i_0 j}}{\sum_{m \neq j} P_m k_{0, m} g_{i_0 m} + N_{i_0}} \geq \gamma_j^u \]

Downlink: \[ \Gamma_{i_0 j}^d = \frac{P_{i_0} g_{i_0 j}}{\sum_{b \neq i_0} P_b k_{0, b} g_{b j} + N_j} \geq \gamma_j^d \]
Traffic Modeling

$M$ terminals uniformly distributed
$\omega$ terminals per area unit

Uniformity distribution assumption: Let $A$ be the deployment area; the probability density of the location $R=(X,Y)$ of some given active terminal is constant:

$$p(x, y)dx\,dy = \Pr\left[X \in [x, x+dx], Y \in [y, y+dy]\right] = \frac{1}{A} dx\,dy$$
Capacity definition: Guaranteed Quality Services - blocking

M terminals active, Y terminals served
Z=M-Y assignment failures
("blocking")

→ Assignment failure rate

\[ \nu = \frac{E[Z]}{E[M]} = \frac{E[Z]}{\omega A} \]

→ Capacity: the maximum allowed traffic load in order to keep the assignment failure rate below some threshold level \( \nu_0 \)

\[ \max \omega : \nu \leq \nu_0 \]
**Best effort – non-blocking**

Performance metric: data rate of each user

**Capacity** defined as the total rate that can be delivered by the system in the service area

\[
R_i = f(\Gamma_i)
\]

\[
\bar{R}^* = E\left[\sum_{i=1}^{M} R_i\right] = E\left[\sum_{i=1}^{M} f(\Gamma_i)\right]
\]

Data rate at terminal \(i\):

\[
R_i = \min\left(R_{\text{max}}, cW \log_2 \left(1 + \Gamma_i\right)\right)
\]

- Max rate that the hardware is able to achieve (on both the transmitting and receiving sides)
- Shannon limit; constant \(c\) is a function of implementation imperfections
Input data

- User QoS requirements (Traffic conditions)
- Environmental conditions (Propagation, location, ..)

$G'$: updated version of $G$ (link gain matrix) based on the measurements

$\gamma_i$s: QoS requirement of users for a service
Resource Management Strategies

1. Static assignment
   - Based on *a priori* statistical information
   - During the planning phase of the network

2. Perfect dynamic channel assignment
   - Ideally based on instantaneous (true) values
   - Traffic adaptive assignment
   - Signal strength adaptation
   - Interference adaptive assignment

3. In practice: Random assignment (see next lectures)
   - DS-CDMA
   - ALOHA
   - Etc.
Quizzes with Clickers

Quizzes can give you a **bonus** for your final grade

- Up to 0.5 points
  - if you obtain at least 7/10 (or similar threshold) correct responses in at least N of the quizzes, where N < 10 will be precisely defined at a later stage.

- Partial bonus
  - proportional to # quizzes in which you achieve this goal

- It is your duty to check that your clicker works properly!


Caution: the quiz usually begins at 13:15 and lasts for just a few minutes!!!
For Next Week

- Read the Web site Mobnet.epfl.ch, including last year exams

- Get the Miao et al. book (hardcopy or e-book)

- Review the lecture; get prepared for the quiz!! - Starts at 13:15

- Get your clicker
  - From the Library at the Rolex Learning Center, room RLC D1 210, Monday to Friday 8:00 – 18:00
  - As mentioned, please register your clicker before next lecture!
  - The app on smartphone or tablet is not allowed
  - For all clicker-related issues, please contact Alexandra: alexandramihaela.olteanu@epfl.ch
  - Beware of the bag-hopping inability of clickers

- Try to solve the homework posted on the Moodle;
  We will help you as of 15:00 next time