WiFi and WCDMA Network Design

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Outline

• WiFi
  • Access point selection
  • Traffic balancing

• Multi-Cell WCDMA with Multiple Classes
  • User modeling using 2D Gaussian distribution
  • Intra-cell and inter-cell interference and capacity
WiFi Outline

• IEEE 802.11 overview
• IEEE 802.11 network design issues
• Optimal access point selection and traffic allocation
• Overlapping-channel Interference Factor
• Optimal channel assignment
• Numerical results
IEEE 802.11 Overview

- Transmission medium
- Formed in 1990 for wireless LANs
- Unlicensed industrial, scientific, and medical bands – 915 MHz, 2.4 GHz, 5 GHz
- 802.11 (1997) – 2.4 GHz, 1 Mbps
- 802.11a (1999) – 5 GHz, 54 Mbps
- 802.11b (1999) – 2.4 GHz, 11 Mbps
- 802.11g (2003) – 2.4 GHz, 54 Mbps
IEEE 802.11 Design Issues

- Designing 802.11 includes two major components:
  - Placement of access points
  - Coverage
  - Ample bandwidth
  - Channel assignment
    - Minimize adjacent channel interference
    - Minimize overlapping-channel interference
Designing 802.11 wireless LANs

• Creation of service area map
• Placement of candidate APs
• Creation of signal level map
• Selection of the APs from candidate APs
• Assignment of radio frequencies to APs
A service area map for a three story building with 60 demand clusters
A signal level map for a three story building with 14 APs
Candidate AP assignment graph for 14 APs and 20 demand clusters

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AP Selection and traffic allocation Optimization Problem

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\begin{align*}
\min_{x_{ij}} & \quad \max \{C_1, C_2, \ldots, C_M\}, \quad (1) \\
\text{subject to} & \quad \sum_{i=1}^{L} x_{ij} \leq 1, \quad (2) \\
& \quad C_j = \frac{1}{B_j} \sum_{i=1}^{L} T_i x_{ij}, \quad (3) \\
& \quad \text{for } i = 1, \ldots, L, \\
& \quad \text{for } j = 1, \ldots, M
\end{align*}
\]

• \(x_{ij}\) = a binary variable; 1 when demand cluster \(i\) is assigned to AP \(j\) and 0 otherwise
• \(C_i\) = the congestion factor
• \(B_i\) = the maximum bandwidth of AP \(i\)
• \(T_i\) = the average traffic load of a demand cluster \(i\)
• \(L\) = total number of demand cluster
• \(M\) = total number of candidate APs
Numerical Analysis

Parameters

• 20 demand clusters and 14 APs in a three story building

• Number of users per demand cluster = between 1 and 10 (randomly chosen)

• Average traffic demand per user = 200 Kbps

• Maximum bandwidth of AP = 11 Mbps

• Average traffic load of a demand cluster $i$ ($T_i$) = Average traffic demand per user $x$ number of users at demand cluster $i$
A signal level map for a three story building with 14 APs and 20 demand clusters.
### Candidate AP assignment graph

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Optimal Access Point Selection and Traffic Allocation
Congestion factor of 14 APs with 15, 20, 25, and 30 demand clusters.
Average congestion across the networks as the number of demand clusters is increased.
Channel Assignment Problem

- **Frequency and channel assignments**

<table>
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<tr>
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<th>Frequency</th>
<th>Channels</th>
<th>Frequency</th>
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<td>2.442 GHz</td>
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802.11b Channel Overlap

Rooms in Party (11 rooms)

- Blue – noise from room 1
- Red – noise from room 6
- Yellow – noise from room 11
- Only 3 quite rooms available; 1, 6, and 11
**802.11b Channel Overlap**

Only 3 non-overlapping channels: 1, 6, and 11.
Overlapping-channel Interference Factor

- Relative percentage gain in interference between two APs as a result of using overlapping channels.

\[ w_{ij} = \begin{cases} 
1 - |F_i - F_j| \times c & \text{if } w_{ij} \geq 0 \\
0 & \text{otherwise} 
\end{cases} \]

- \(F_i\) = the channel assigned to AP \(i\)
- \(c\) = the overlapping channel factor, which is 1/5 for 802.11b

- For example if we used channels 1 and 2 we would have 80% interference
- Channels 1 and 5 would have 20% interference
- Channels 1 and 6 would have 0% interference
Types of Channel Interference

- Adjacent channel interference: inversely proportional to the distance raised to path loss exponent

- Co-channel interference: directly proportional to the overlapping-channel interference factor
Channel Assignment Optimization Problem

\[
\begin{align*}
\min_{(F_1, F_2, \ldots, F_N)} & \quad \max \left\{ V_1, V_2, \ldots, V_N \right\}, \\
\text{subject to} & \quad V_i = \sum_{j=1}^{N} I_{ij}, \\
& \quad I_{ij} = \frac{w_{ij}}{d_{ij}^m} \\
& \quad w_{ij} = \begin{cases} 
1 - |F_i - F_j| \ast c & \text{if } w_{ij} \geq 0, \\
0 & \text{otherwise}
\end{cases} \\
\text{for} & \quad i, j = 1, \ldots, N, \\
\text{for} & \quad F_i \in \{1, \ldots, K\}
\end{align*}
\]

- \( V = \) the total interference at AP \( i \)
- \( I_{ij} = \) the relative interference that AP \( j \) causes on AP \( i \)
- \( w_{ij} = \) overlapping-channel interference factor between AP \( i \) and AP \( j \)
- \( d_{ij} = \) the distance between AP \( i \) and AP \( j \)
- \( m = \) a pathloss exponent
- \( c = \) the overlapping channel factor
Channel Assignment using channels 1, 6, and 11 only

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<th>AP</th>
<th>Channel</th>
<th>Interference</th>
<th>AP</th>
<th>Channel</th>
<th>Interference</th>
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Channel Assignment Map using channels 1, 6, and 11 only
## Optimal Channel Assignment

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Optimal Channel Assignment Map
The relative interference of APs when using only channels 1, 6, and 11 and optimal assignment.
Average interference across the networks as the number of APs is increased
WiFi Results

- Our Access Point Selection optimization balances the load on the entire network.

- By minimizing the bottleneck APs, we can get better bandwidth utilization for the whole network, which results in higher throughput.

- We define an overlapping-channel interference factor that captures the interference in overlapping channels.

- Our Channel Assignment optimization minimizes the interference at each AP.

- By optimally using more than just the 3 non-overlapping channels, the average interference across the network can be reduced.
WCDMA Outline

- Introduction to CDMA networks
- Calculation of Intra-cell interference in CDMA
- Calculation of Intra-cell interference in WCDMA with multiple classes of users.
- User modeling using 2D Gaussian Distribution
- Capacity analysis
- Numerical results
Code Division Multiple Access (CDMA) Overview

- Multiple access schemes
**Factors Affecting Capacity**

- **Power Control**

Pt1: Power transmitted from c1
Pt2: Power transmitted from c2
Pr1: Power received at base station from c1
Pr2: Power received at base station from c2

Pr1 = Pr2
\[ I_{ji} = \text{Relative average interference at cell } i \text{ caused by } n_j \text{ users in cell } j \]

\[
I_{ji} = \mathbb{E} \left[ \iint_{C_j} \frac{r_j^m(x,y) \xi_j}{r_i^m(x,y)} \frac{N_j}{A_j} dA(x,y) \right] \]

\[
I_{ji} = e^{(\gamma \sigma_s)^2} \frac{n_j}{A_j} \iint_{C_j} \frac{r_j^m(x,y)}{r_i^m(x,y)} dA(x,y)\]

where \[ \gamma = \frac{\ln(10)}{10} \]

\[ \sigma_s \] is the standard deviation of the attenuation for the shadow fading

\[ m \] is the path loss exponent
WCDMA with Multiple Classes of Users

- Inter-cell Interference at cell $i$ caused by $n_j$ users in cell $j$ of class $t$

$$ I_{ji,t} = S_t v_t n_{j,t} \frac{e^{(\gamma \sigma_s)^2}}{A_j} \iiint_{c_j} \frac{r_j^m(x, y)}{r_i^m(x, y)} w(x, y) dA(x, y) $$

$$ \kappa_{ji,t} = \frac{e^{(\gamma \sigma_s)^2}}{A_j} \iiint_{c_j} \frac{r_j^m(x, y)}{r_i^m(x, y)} w(x, y) dA(x, y). $$

$w(x,y)$ is the user distribution density at $(x,y)$

$\kappa_{ji,t}$ is per-user (with service $t$) relative inter-cell interference factor from cell $j$ to BS $i$, 

$A_j$ is the area of cell $j$.
Model User Density with 2D Gaussian Distribution

\[ w(x, y) = \frac{\eta}{2\pi \sigma_1 \sigma_2} e^{-\frac{1}{2} \left( \frac{x-\mu_1}{\sigma_1} \right)^2} e^{-\frac{1}{2} \left( \frac{x-\mu_2}{\sigma_2} \right)^2} \]

- \( \eta \) is a user density normalizing parameter
- \( \mu_1, \mu_2 \) means
- \( \sigma_1, \sigma_2 \) variances of the distribution for every cell

\[ I_i^{\text{own}} = \frac{1}{W} \sum_{t=1}^{T} S_t v_t n_{i,t} \]

is the total intra-cell interference density caused by all users in cell \( i \)
Total Inter-cell Interference Density in WCDMA

\[ I_{i,\text{inter}}^\text{MT} = \frac{1}{W} \sum_{j=1, j\neq i}^{M} \sum_{t=1}^{T} S_t v_{t,n_{j,t}} K_{ji,t} \]

- \( M \) is the total number of cells in the network
- \( T \) is the total number of services
- \( W \) is the bandwidth of the system
Signal-to-Noise Density in WCDMA

\[ \left( \frac{E_b}{I_0} \right)_{i,t} = \frac{S_t}{R_t} N_0 + I_i^{\text{own}} + I_i^{\text{inter}} - \frac{S_t v_t}{W} \]

\[ \tau_t \leq \frac{S_t^*}{R_t} N_0 + \frac{S_t^*}{W} \left[ \sum_{t=1}^{T} n_{i,t} v_t + \sum_{j=1, j \neq i}^{M} \sum_{t=1}^{T} n_{j,t} v_t K_{ji,t} - v_t \right] \]

where

- \( N_0 \) is the thermal noise density,
- \( R_t \) is the bit rate for service \( t \)
- \( \tau_t \) is the minimum signal-to-noise ratio required
Simultaneous Users in WCDMA Must Satisfy the Following Inequality Constraints

\[
\sum_{t=1}^{T} n_{i,t} v_t + \sum_{j=1, j \neq i}^{M} \sum_{t=1}^{T} n_{j,t} v_t k_{ji,t} - v_t \leq c_{eff}^{(t)}
\]

where

\[
c_{eff}^{(t)} = \frac{W}{R_t} \left[ \frac{1}{\tau_t} - \frac{R_t}{S_t^*/N_0} \right]
\]

\(\tau_t\) is the minimum signal-to-noise ratio

\(S_t^*\) is the maximum signal power

\(n_{i,t}\) the number of users in BS i for given service t

The capacity in a WCDMA network is defined as the maximum number of simultaneous users \((n_{1,t}, n_{2,t}, \ldots, n_{M,t})\) for all services \(t = 1, \ldots, T\)
Simulations

- **Network configuration**
  - COST-231 propagation model
  - Carrier frequency = 1800 MHz
  - Average base station height = 30 meters
  - Average mobile height = 1.5 meters
  - Path loss coefficient, $m = 4$
  - Shadow fading standard deviation, $\sigma_s = 6$ dB
  - Processing gain, $W/R = 21.1$ dB
  - Bit energy to interference ratio threshold, $\tau = 9.2$ dB
  - Interference to background noise ratio, $I_0/N_0 = 10$ dB
  - Activity factor, $\alpha = 0.375$
Multi-Cell WCDMA Simulation
Uniform User Distribution

• Simulated network capacity where users are uniformly distributed in the cells. The maximum number of users is 554.

• 2-D Gaussian approximation of users uniformly distributed in cells. $\sigma_1 = \sigma_2 = 12000$, $\mu_1 = \mu_2 = 0$. The maximum number of users is 548.
Simulated network capacity where users are densely clustered around the BSs causing the least amount of inter-cell interference. The maximum number of users is 1026 in the network.

2-D Gaussian approximation of users densely clustered around the BSs. $\sigma_1 = \sigma_2 = 100$, $\mu_1 = \mu_2 = 0$. The maximum number of users is 1026.
Extreme Cases Using Actual Interference
Non-Uniform Distribution

- Simulated network capacity where users are densely clustered at the boundaries of the cells causing the most amount of inter-cell interference. The maximum number of users is only 108 in the network.

- 2-D Gaussian approximation of users densely clustered at the boundaries of the cells. The values of $\sigma_1=\sigma_2=300$, $\mu_1$, and $\mu_2$ are different in the different cells. The maximum number of users is 133.
WCDMA Results

- Model inter-cell and intra-cell interference for different classes of users in multi-cell WCDMA.

- We approximate the user distribution by using 2-dimensional Gaussian distributions by determining the means and the standard deviations of the distributions for every cell.

- Compared our model with simulation results using actual interference and showed that it is fast and accurate enough to be used efficiently in the planning process of WCDMA networks.
Thank You!!

Questions?