College of Engineering

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

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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, 1Mbps
- 802.11a (1999) – 5 GHz, 54 Mbps
- 802.11b (1999) – 2.4 GHz, 11 Mbps
- 802.11g (2003) – 2.4 GHz, 54 Mbps

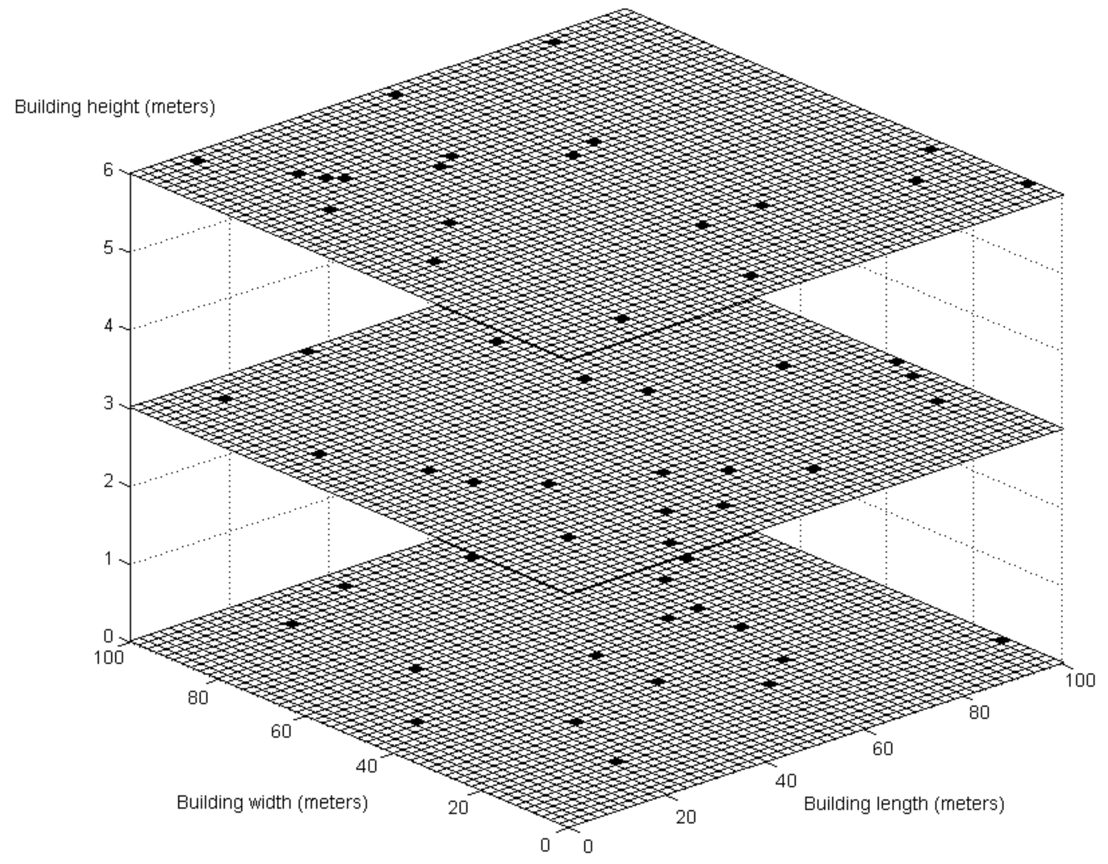
IEEE 802.11 Design Issues

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

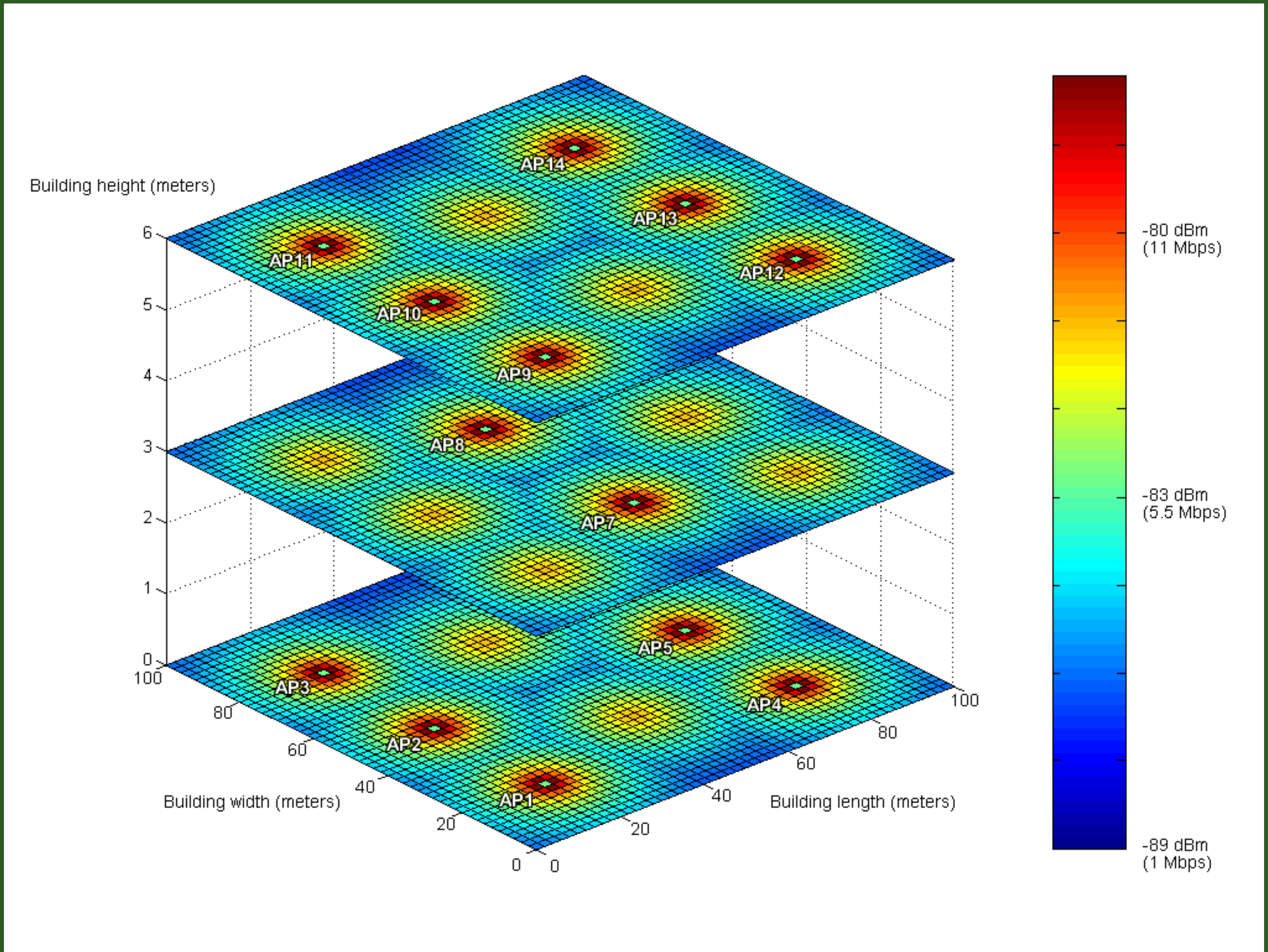
Designing 802.11 wireless LANs

- 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

E	AP_1	AP_2	AP_3	AP_4	AP_5	AP_6	AP_7	AP_8	AP_9	AP_{10}	AP_{11}	AP_{12}	AP_{13}	AP_{14}
D_1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
D_2	0	1	1	0	0	0	0	0	0	0	0	0	0	0
D_3	0	1	1	0	0	0	0	0	0	0	0	0	0	0
D_4	0	0	0	1	0	0	1	0	0	0	0	0	0	0
D_5	0	0	0	0	0	0	0	1	0	0	0	0	0	0
D_6	0	0	0	0	0	1	0	0	0	0	0	0	0	0
D_7	0	1	1	0	0	0	0	1	0	0	0	0	0	0
D_8	0	0	1	0	0	0	0	0	0	0	1	0	0	0
D_9	1	1	0	0	0	0	0	0	1	1	0	0	0	0
D_{10}	0	0	0	0	1	1	0	0	0	0	0	0	1	1
D_{11}	0	0	0	1	0	0	1	0	0	0	0	1	0	0
D_{12}	0	0	0	0	0	1	0	1	0	0	0	0	0	1
D_{13}	0	0	0	1	1	0	0	0	0	0	0	1	1	0
D_{14}	0	0	0	0	0	0	1	1	0	1	0	0	0	0
D_{15}	0	0	0	0	0	0	0	0	0	1	1	0	0	0
D_{16}	0	0	0	0	0	0	0	0	0	0	0	0	1	1
D_{17}	0	0	0	0	0	0	0	0	1	1	0	0	0	0
D_{18}	0	0	0	0	0	0	0	1	0	0	1	0	0	0
D_{19}	0	0	0	0	0	0	1	0	0	0	0	1	1	0
D_{20}	0	0	0	0	0	0	1	0	0	0	0	1	0	0

AP Selection and traffic allocation Optimization Problem

$$\min_{x_{ij}} \quad \max\{C_1, C_2, \ldots, C_M\}, \quad (1)$$

$$\text{subject to} \quad \sum_{i=1}^{L} x_{ij} \le 1, \quad (2)$$

$$C_j = \frac{1}{B_j} \sum_{i=1}^{L} T_i x_{ij}, \quad (3)$$

$$\text{for} \quad i = 1, \ldots, L,$$

$$\text{for} \quad j = 1, \ldots, M$$

- 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

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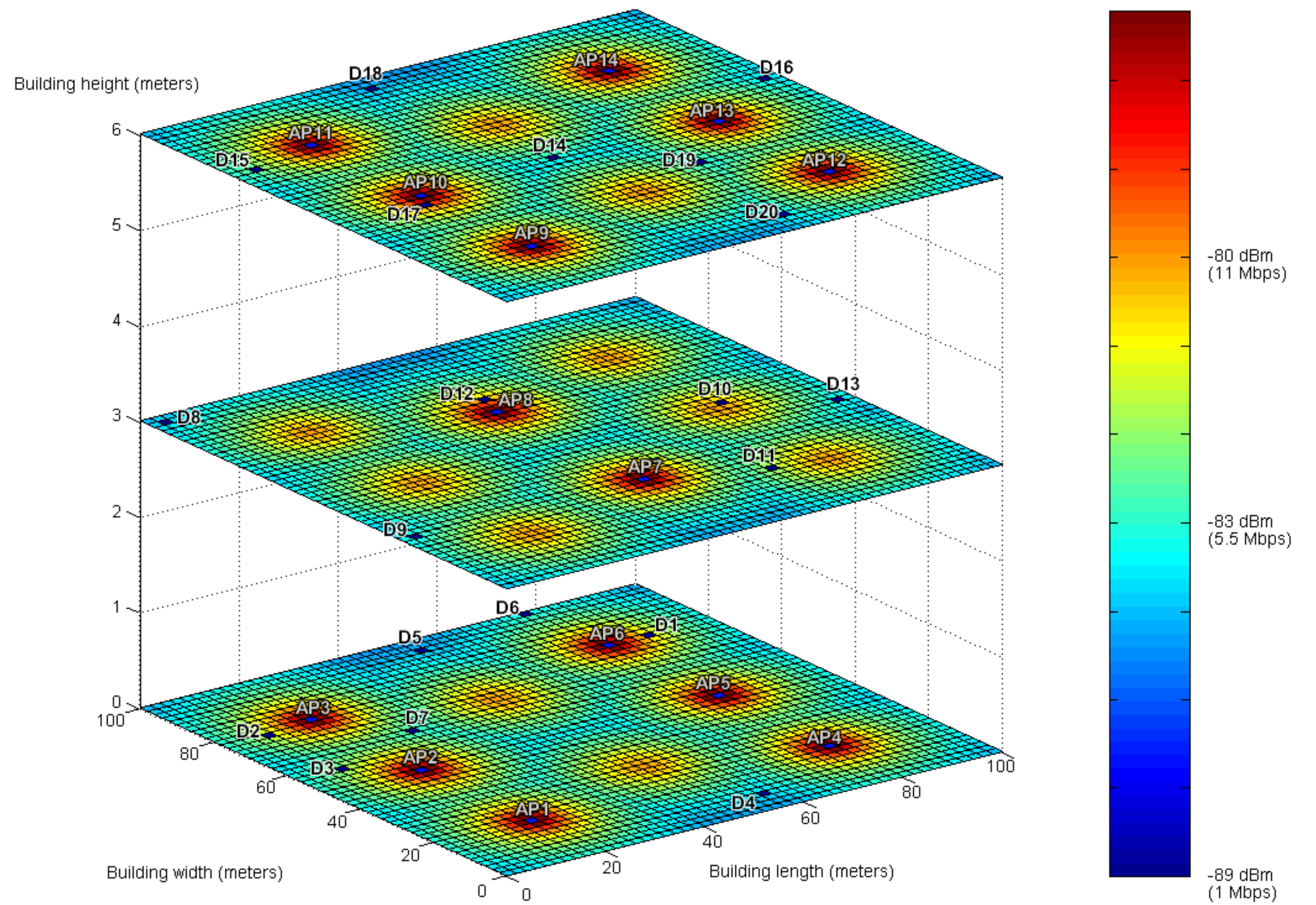
Numerical Analysis

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

E	AP_1	AP_2	AP_3	AP_4	AP_5	AP_6	AP_7	AP_8	AP_9	AP_{10}	AP_{11}	AP_{12}	AP_{13}	AP_{14}
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D_2	0	1	1	0	0	0	0	0	0	0	0	0	0	0
D_3	0	1	1	0	0	0	0	0	0	0	0	0	0	0
D_4	0	0	0	1	0	0	1	0	0	0	0	0	0	0
D_5	0	0	0	0	0	0	0	1	0	0	0	0	0	0
D_6	0	0	0	0	0	1	0	0	0	0	0	0	0	0
D_7	0	1	1	0	0	0	0	1	0	0	0	0	0	0
D_8	0	0	1	0	0	0	0	0	0	0	1	0	0	0
D_9	1	1	0	0	0	0	0	0	1	1	0	0	0	0
D_{10}	0	0	0	0	1	1	0	0	0	0	0	0	1	1
D_{11}	0	0	0	1	0	0	1	0	0	0	0	1	0	0
D_{12}	0	0	0	0	0	1	0	1	0	0	0	0	0	1
D_{13}	0	0	0	1	1	0	0	0	0	0	0	1	1	0
D_{14}	0	0	0	0	0	0	1	1	0	1	0	0	0	0
D_{15}	0	0	0	0	0	0	0	0	0	1	1	0	0	0
D_{16}	0	0	0	0	0	0	0	0	0	0	0	0	1	1
D_{17}	0	0	0	0	0	0	0	0	1	1	0	0	0	0
D_{18}	0	0	0	0	0	0	0	1	0	0	1	0	0	0
D_{19}	0	0	0	0	0	0	1	0	0	0	0	1	1	0
D_{20}	0	0	0	0	0	0	1	0	0	0	0	1	0	0

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Average Traffic Load

T_1	1,600 Kbps	T_{11}	1,400 Kbps
T_2	2,000 Kbps	T_{12}	2,000 Kbps
T_3	800 Kbps	T_{13}	1,800 Kbps
T_4	1,800 Kbps	T_{14}	400 Kbps
T_5	1,200 Kbps	T_{15}	400 Kbps
T_6	400 Kbps	T_{16}	2,000 Kbps
T_7	800 Kbps	T_{17}	200 Kbps
T_8	400 Kbps	T_{18}	800 Kbps
T_9	1,800 Kbps	T_{19}	800 Kbps
T_{10}	1,600 Kbps	T_{20}	400 Kbps

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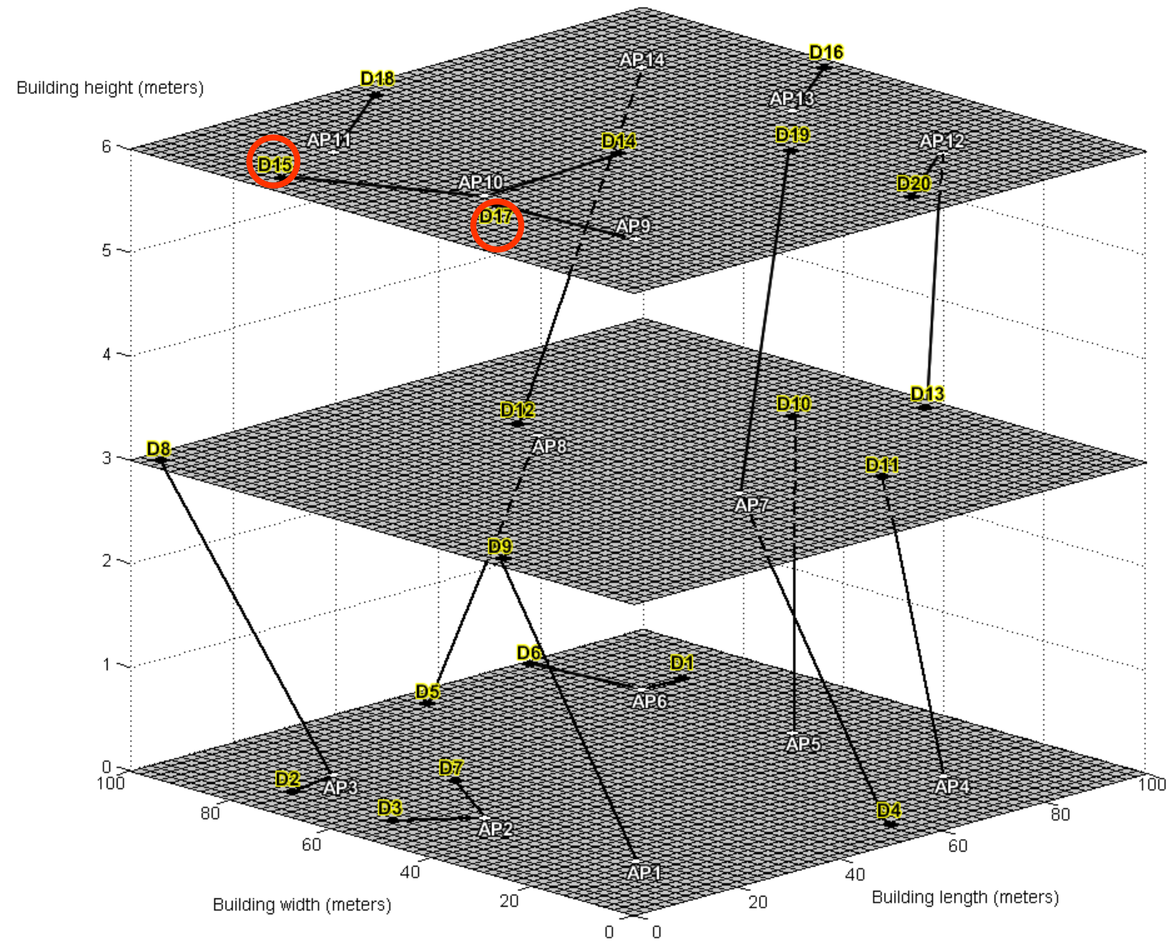
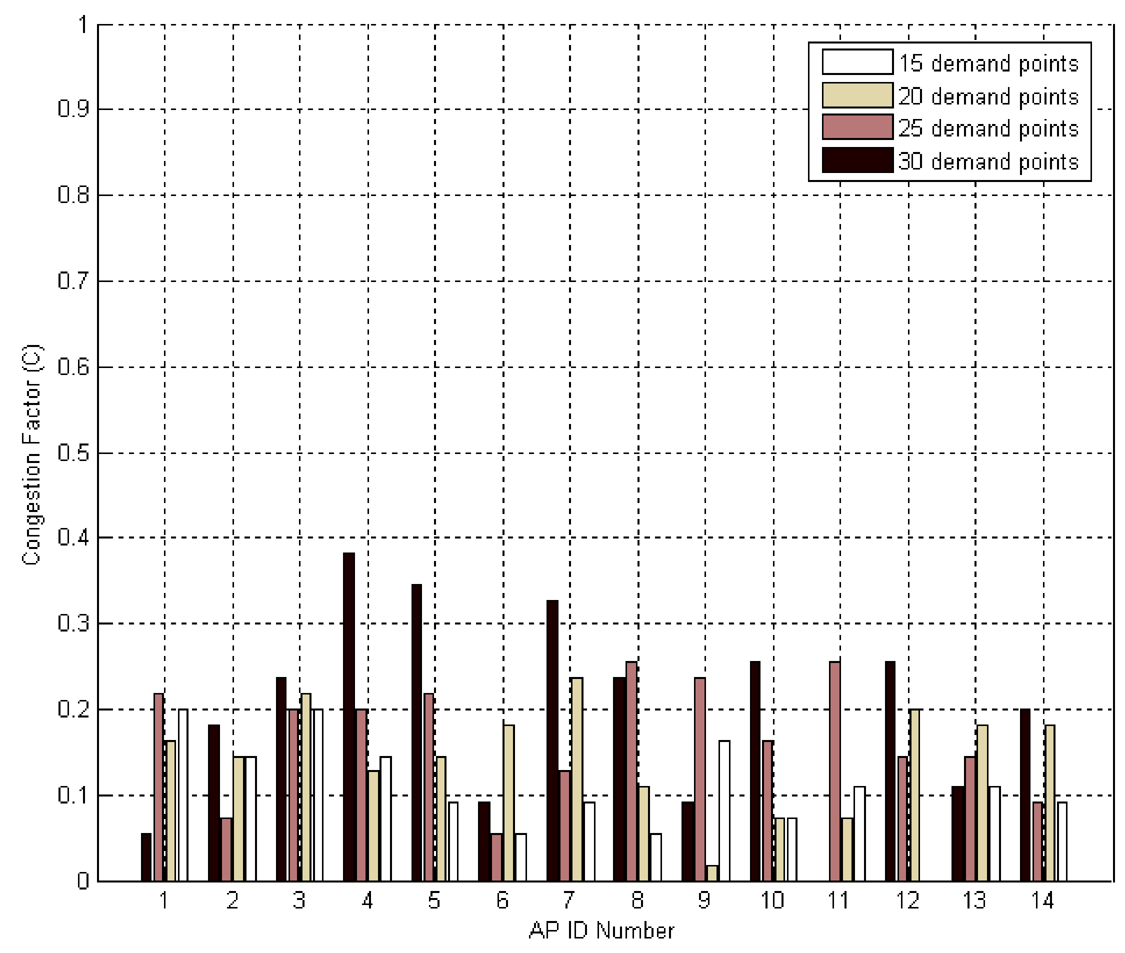
Results of the optimization AP selection graph

x_{ij}	AP_1	AP_2	AP_3	AP_4	AP_5	AP_6	AP_7	AP_8	AP_9	AP_{10}	AP_{11}	AP_{12}	AP_{13}	AP_{14}
D_1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
D_2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D_3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
D_4	0	0	0	0	0	0	1	0	0	0	0	0	0	0
D_5	0	0	0	0	0	0	0	1	0	0	0	0	0	0
D_6	0	0	0	0	0	1	0	0	0	0	0	0	0	0
D_7	0	1	0	0	0	0	0	0	0	0	0	0	0	0
D_8	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D_9	1	0	0	0	0	0	0	0	0	0	0	0	0	0
D_{10}	0	0	0	0	1	0	0	0	0	0	0	0	0	0
D_{11}	0	0	0	1	0	0	0	0	0	0	0	0	0	0
D_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	1
D_{13}	0	0	0	0	0	0	0	0	0	0	0	1	0	0
D_{14}	0	0	0	0	0	0	0	0	0	1	0	0	0	0
D_{15}	0	0	0	0	0	0	0	0	0	1	0	0	0	0
D_{16}	0	0	0	0	0	0	0	0	0	0	0	0	1	0
D_{17}	0	0	0	0	0	0	0	0	1	0	0	0	0	0
D_{18}	0	0	0	0	0	0	0	0	0	0	1	0	0	0
D_{19}	0	0	0	0	0	0	1	0	0	0	0	0	0	0
D_{20}	0	0	0	0	0	0	0	0	0	0	0	1	0	0

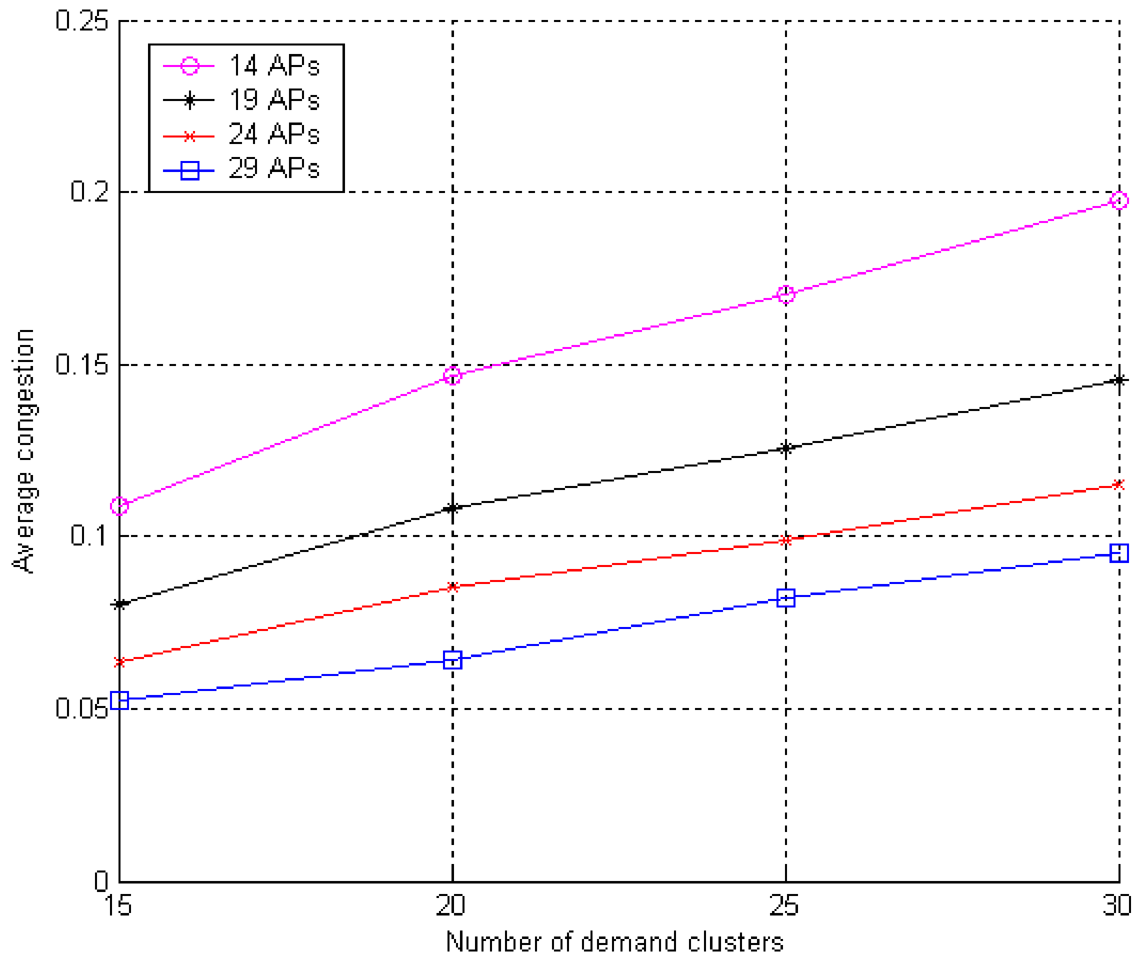
Optimal Access Point Selection and Traffic Allocation



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



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Channel Assignment Problem

- **Frequency and channel assignments**

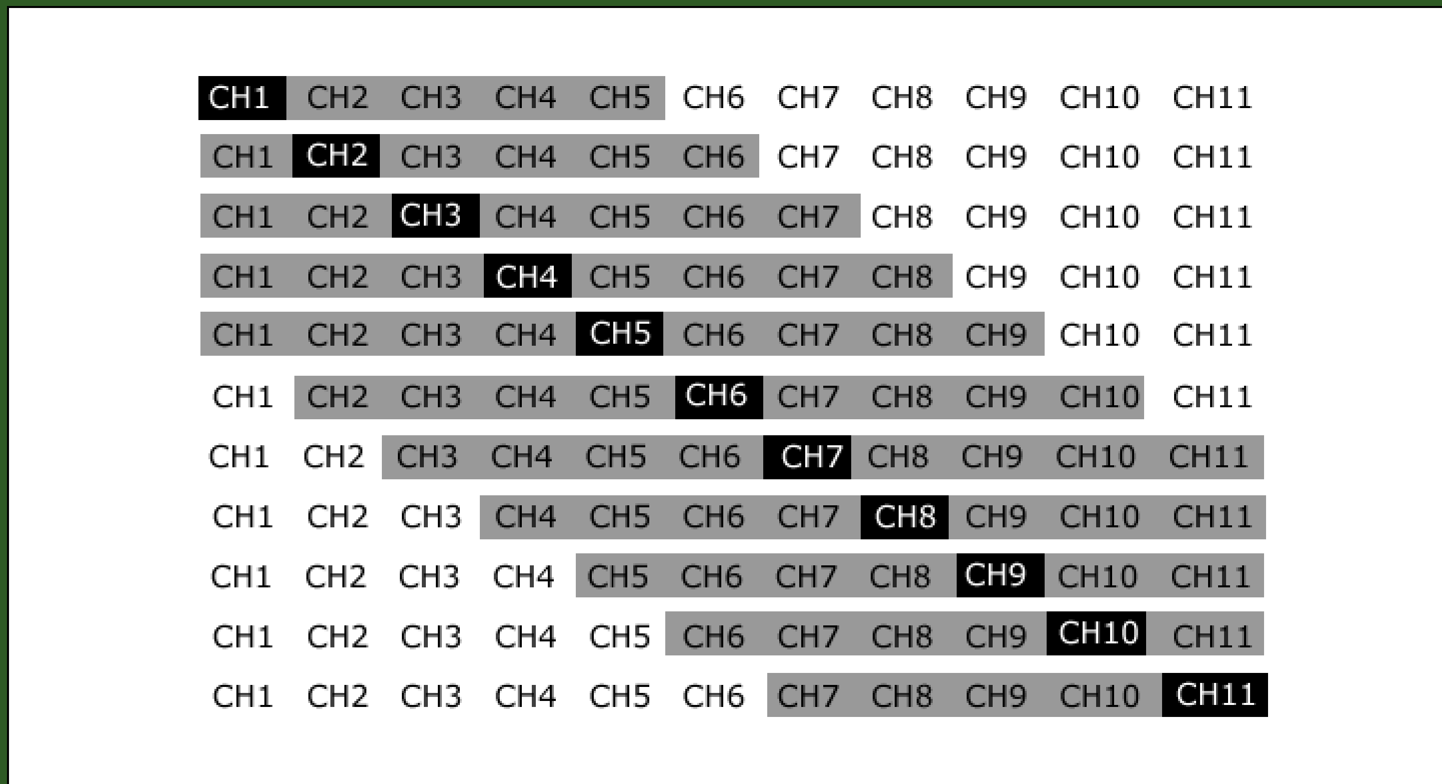
Channels	Frequency	Channels	Frequency
1	2.412 GHz	**8**	2.447 GHz
2	2.417 GHz	**9**	2.452 GHz
3	2.422 GHz	**10**	2.457 GHz
4	2.427 GHz	**11**	2.462 GHz
5	2.432 GHz	**12**	2.467 GHz
6	2.437 GHz	**13**	2.472 GHz
7	2.442 GHz	**14**	2.484 GHz

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.**

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

- 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

$$\min_{(F_1, F_2, \ldots, F_N)} \quad \max\{V_1, V_2, \ldots, V_N\}, \qquad (1)$$

subject to

$$V_i = \sum_{j=1}^{N} I_{ij}, \qquad (2)$$

$$I_{ij} = \frac{w_{ij}}{d_{ij}^{m}} \qquad (3)$$

$$w_{ij} = \begin{cases} 1 - |F_i - F_j| * c & \text{if } w_{ij} \geq 0, \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

$$\text{for} \quad i, j = 1, \ldots, N,$$

$$\text{for} \quad F_i \in \{1, \ldots K\}$$

- 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

AP	Channel	Interference	AP	Channel	Interference
1	1	0.00643	8	1	0.01101
2	6	0.00858	9	11	0.00303
3	11	0.00249	10	1	0.00878
4	11	0.00546	11	6	0.00662
5	1	0.00878	12	6	0.00635
6	6	0.00418	13	11	0.00558
7	6	0.00918	14	1	0.00913

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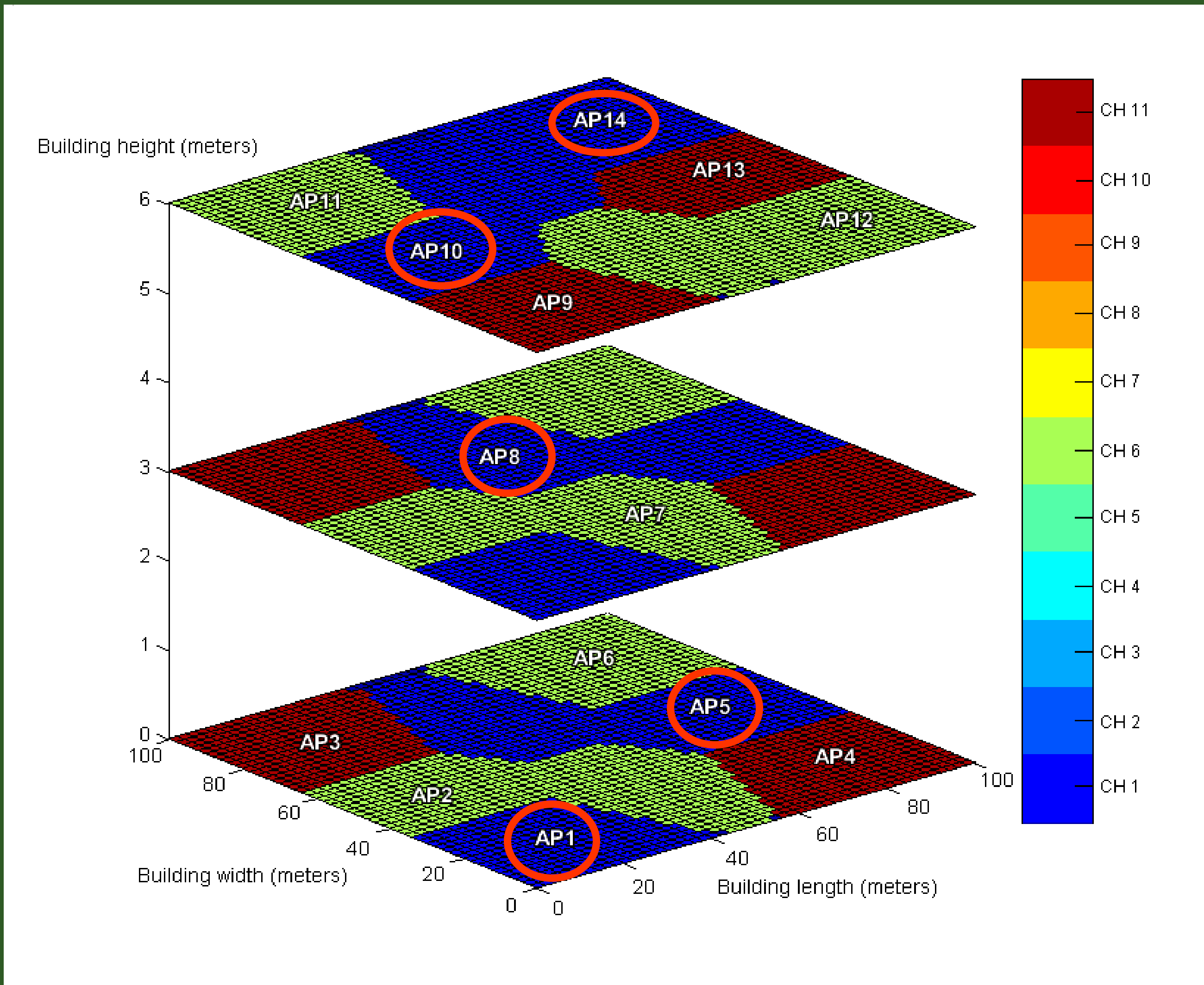
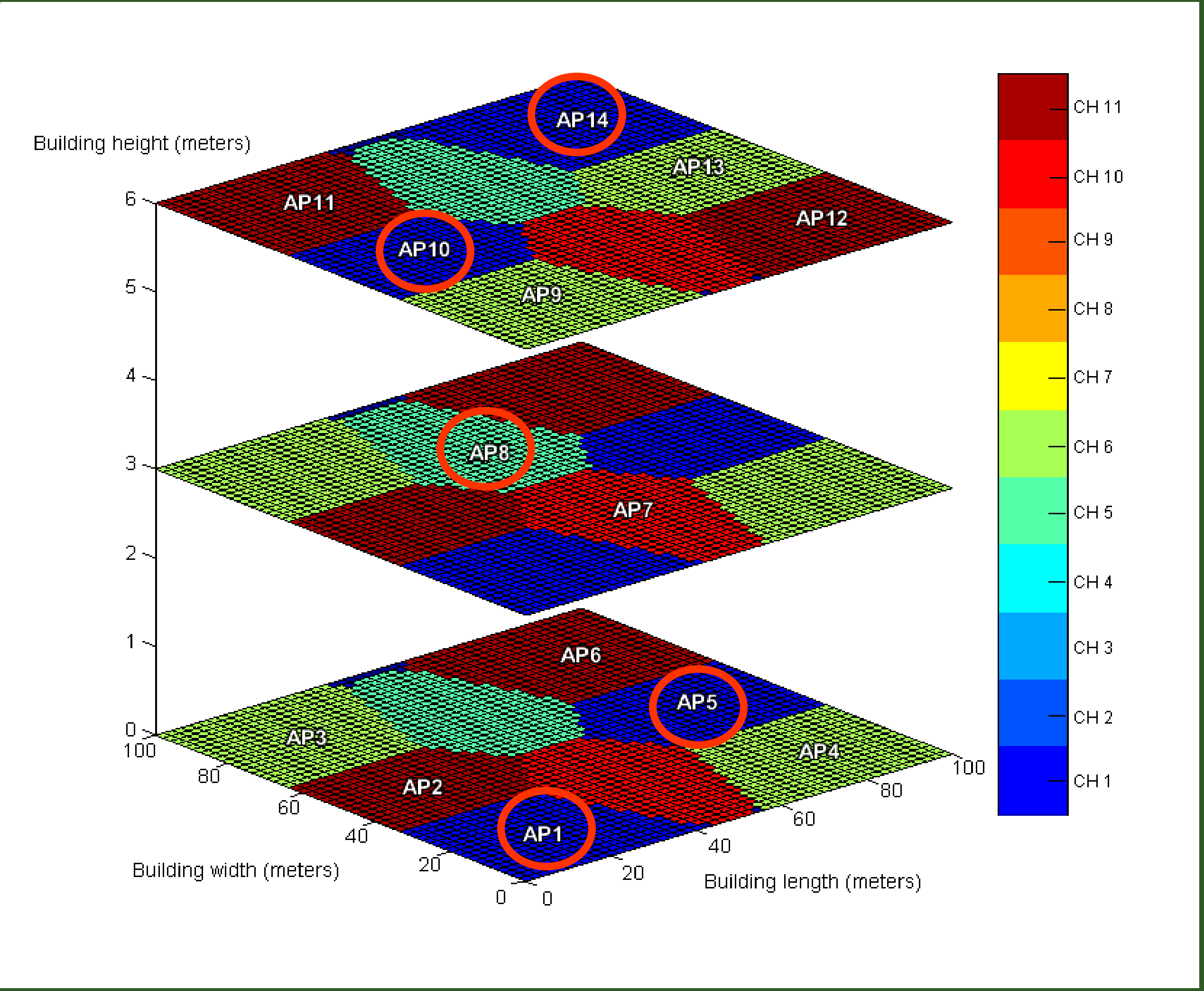
Channel Assignment Map using channels 1, 6, and 11 only



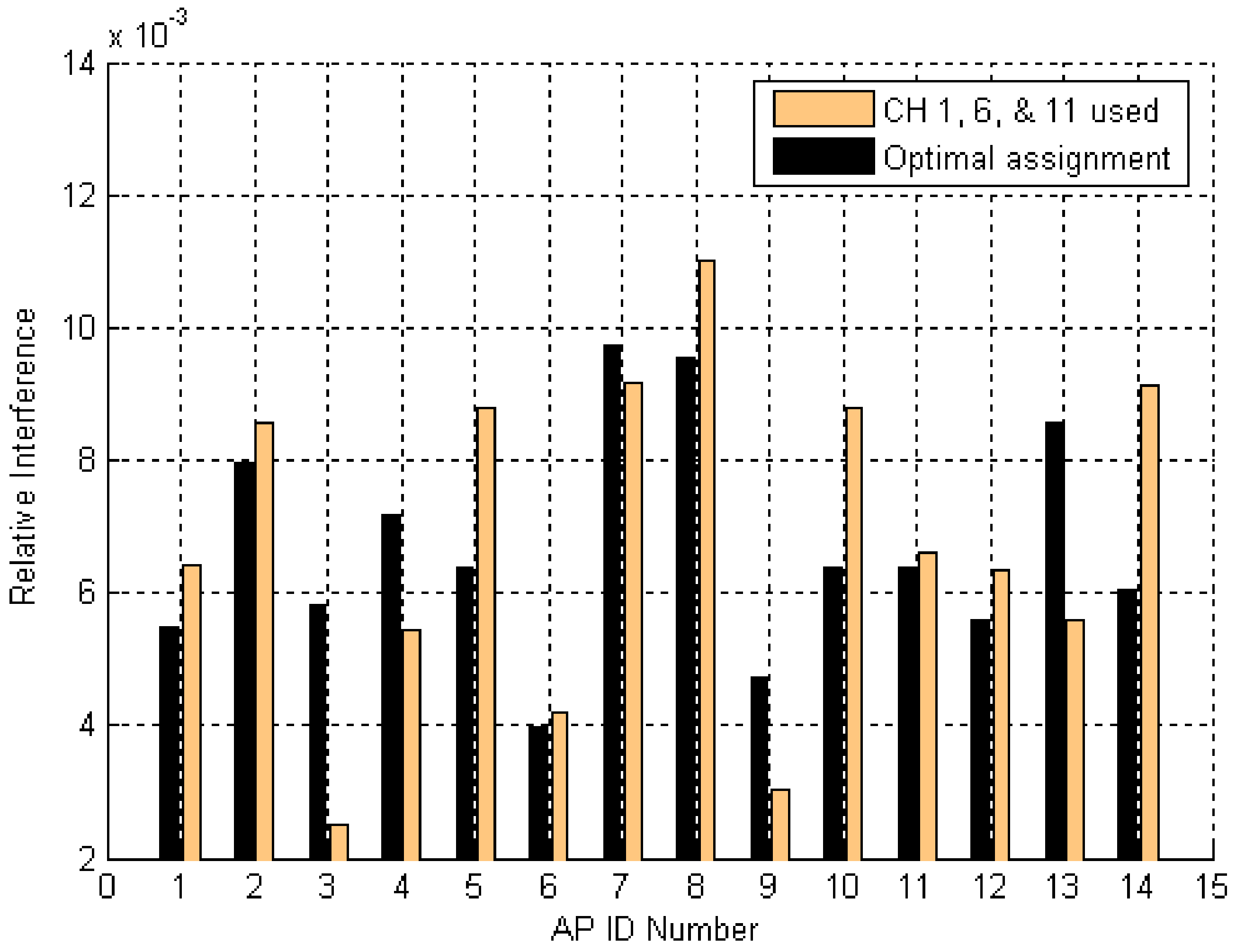
Optimal Channel Assignment

AP	Channel	Interference	AP	Channel	Interference
1	1	0.00549	8	5	0.00954
2	11	0.00797	9	6	0.00472
3	6	0.00580	10	1	0.00638
4	6	0.00715	11	11	0.00638
5	1	0.00638	12	11	0.00557
6	11	0.00395	13	6	0.00857
7	10	0.00972	14	1	0.00603

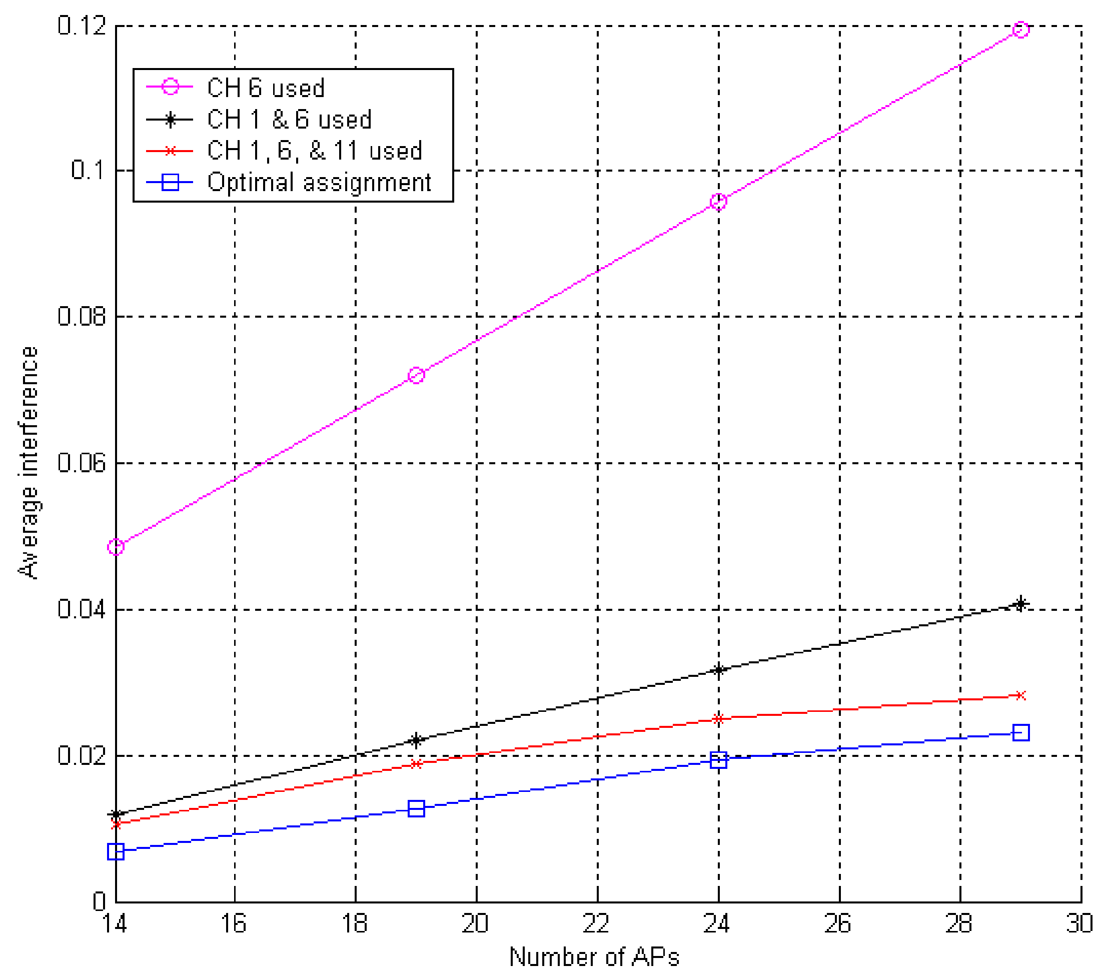
Optimal Channel Assignment Map



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 result 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

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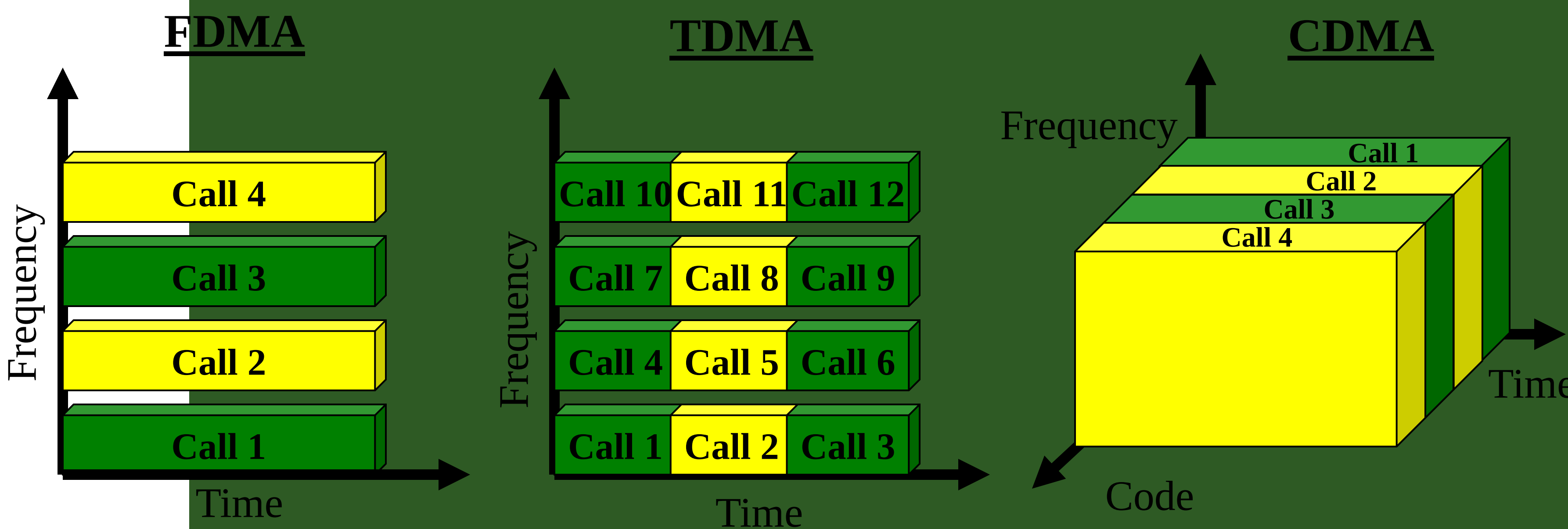
WCDMA Outline

- 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

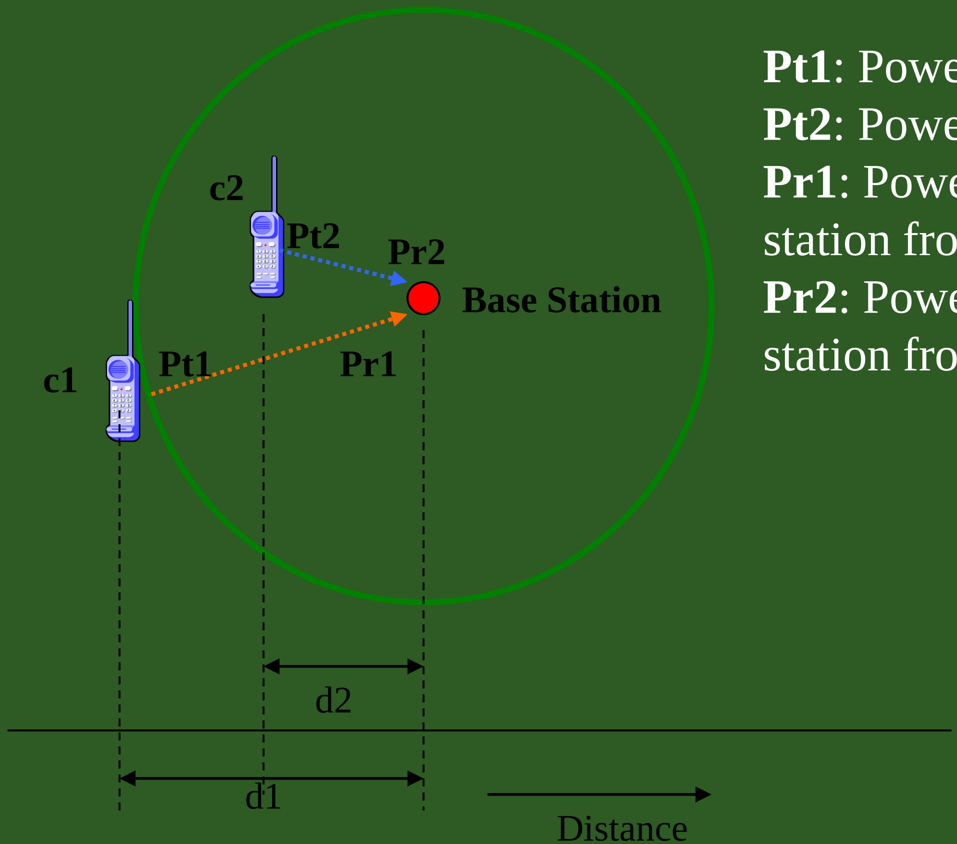
Code Division Multiple Access (CDMA) Overview

- **Multiple access schemes**



Factors Affecting Capacity

- **Power Control**

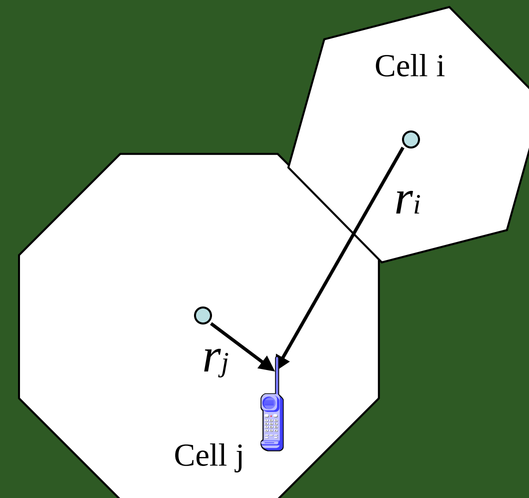


Pt1: Power transmitted from c1
Pt2: Power transmitted from c2
Pr1: Power received at base station from c1
Pr2: Power received at base station from c2

Pr1 = Pr2

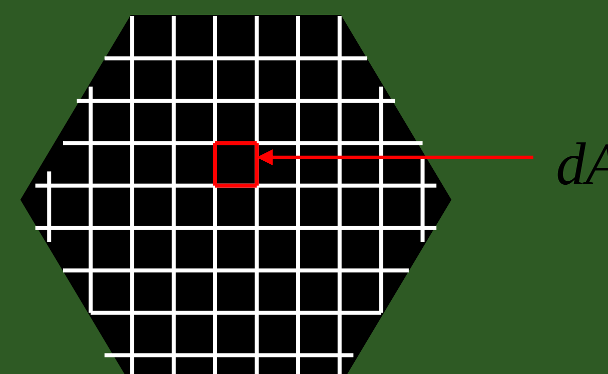
CDMA with One Class of Users

I_{ji} = Relative average interference at cell i caused by n_j users in cell j



$$I_{ji} = \mathrm{E}\left[\iint_{Cj} \frac{r_j^m(x,y)10^{\zeta_j/10}}{r_i^m(x,y)/\chi_i^2} \frac{n_j}{A_j}\, dA(x,y) \right]$$

$$I_{ji} = e^{(\gamma\sigma_s)^2} \frac{nj}{Aj} \iint_{C_j} \frac{r_j^m(x,y)}{r_i^m(x,y)}\, dA(x,\, y)$$



where $\gamma = \frac{\ln(10)}{10}$

σ_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***

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

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

$w(x,y)$ 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,

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Model User Density with 2D Gaussian Distribution

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

η	is a user density normalizing parameter
$\mu_1,\ \mu_2$	means
σ_1, σ_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

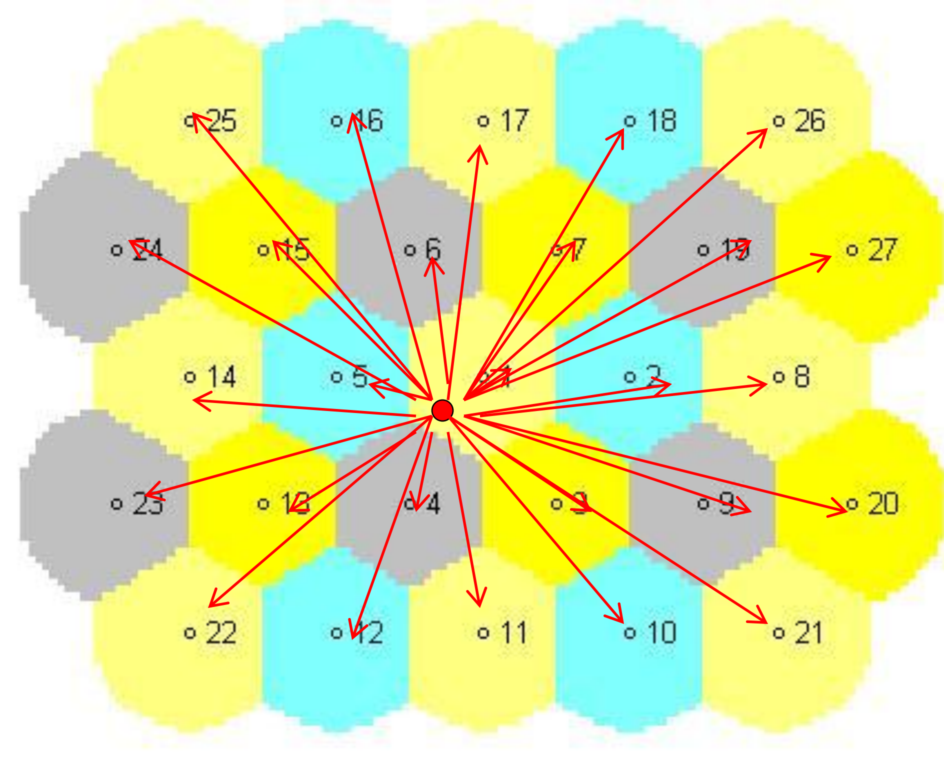
Total Inter-cell Interference Density in WCDMA

$$I_i^{\text{inter}} = \frac{1}{W} \sum_{j=1, j \neq i}^{M} \sum_{t=1}^{T} S_t \nu_t n_{j,t} \kappa_{ji,t}$$

M is the total number of cells in the network

T total number of services

W is the bandwidth of the system



Signal-to-Noise Density in WCDMA

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

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

where N_0 is the thermal noise density,

R_t is the bit rate for service t

τ_t is the minimum signal-to-noise ratio required

Simultaneous Users in WCDMA Must Satisfy the Following Inequality Constraints

$$\sum_{t=1}^{T} n_{i,t}\nu_t + \sum_{j=1, j\neq i}^{M} \sum_{t=1}^{T} n_{j,t}\nu_t\kappa_{ji,t} - \nu_t \leq c_{eff}^{(t)}$$

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

τ_t is the minimum signal-to-noise ratio

S_t^* is the maximum signal power

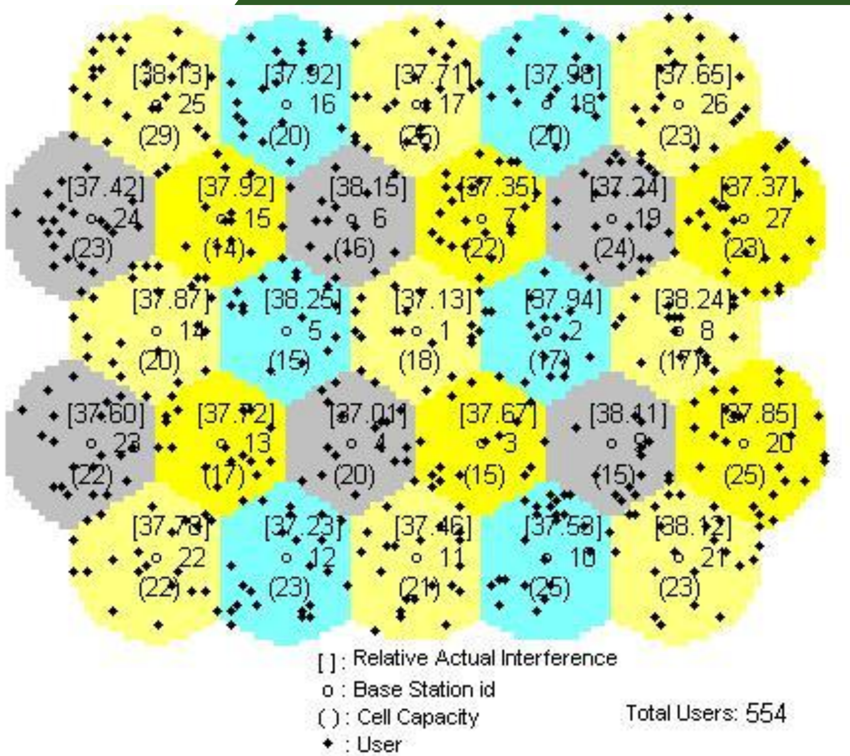
$n_{i,t}$ the number of users in BS i for given service t

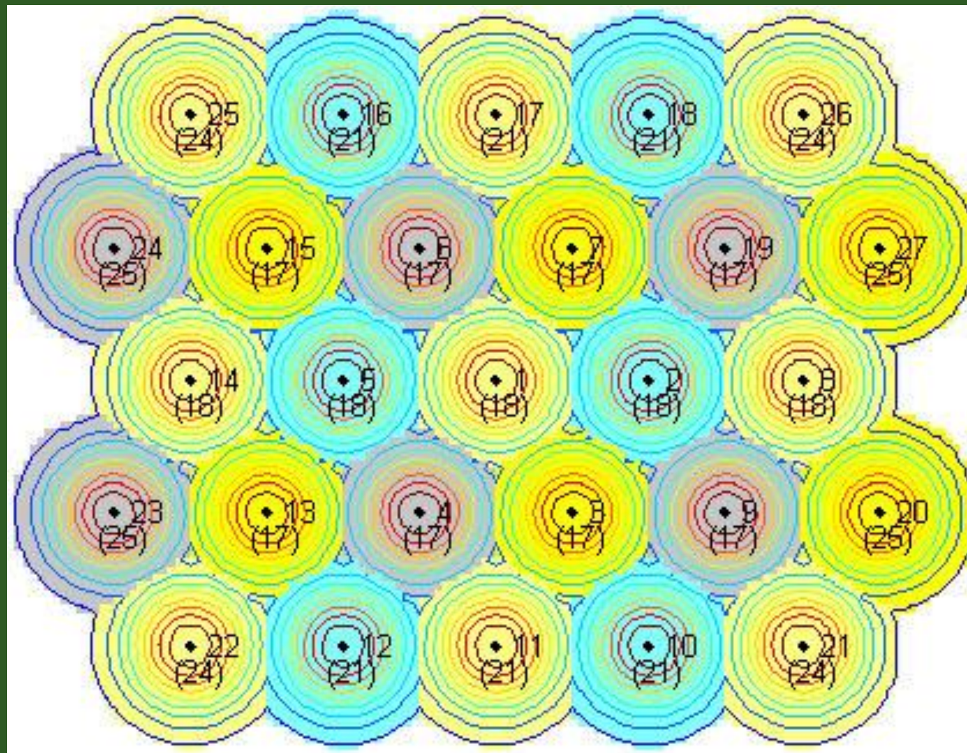
The capacity in a WCDMA network is defined as the maximum number of simultaneous users $(n_{1,t}, n_{2,t}, \ldots, n_{M,t})$ for all services $t = 1, \ldots, T$

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, σ_s = 6 dB
  - Processing gain, W/R = 21.1 dB
  - Bit energy to interference ratio threshold, τ = 9.2 dB
  - Interference to background noise ratio, I_0/N_0 = 10 dB
  - Activity factor, α = 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. σ1= σ2=12000, μ1=μ2=0. The maximum number of users is 548.

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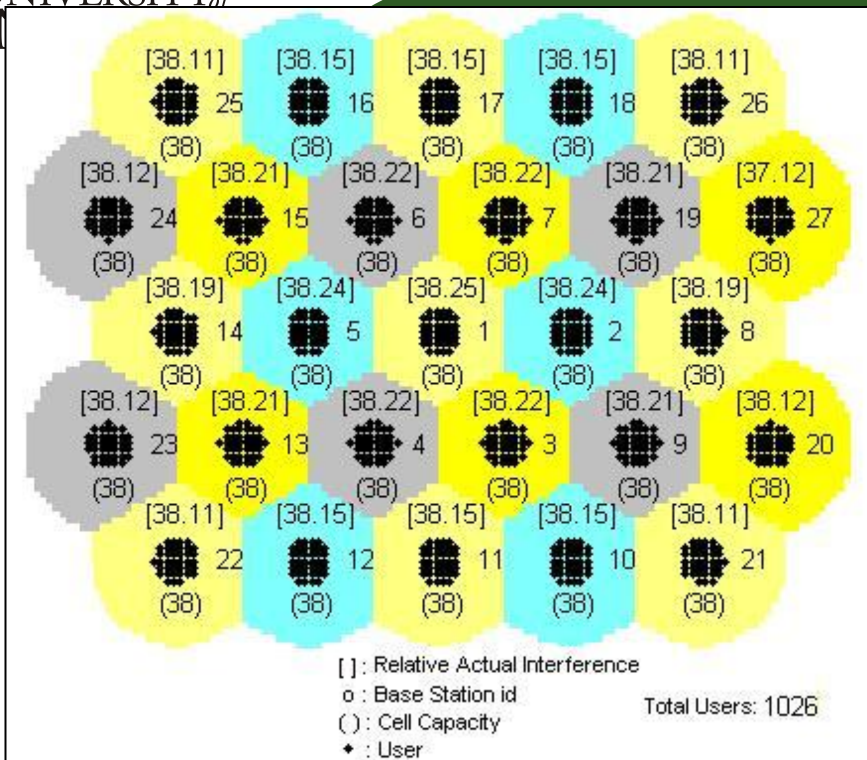
Extreme Cases Using Actual Interference Non-Uniform Distribution



- 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.

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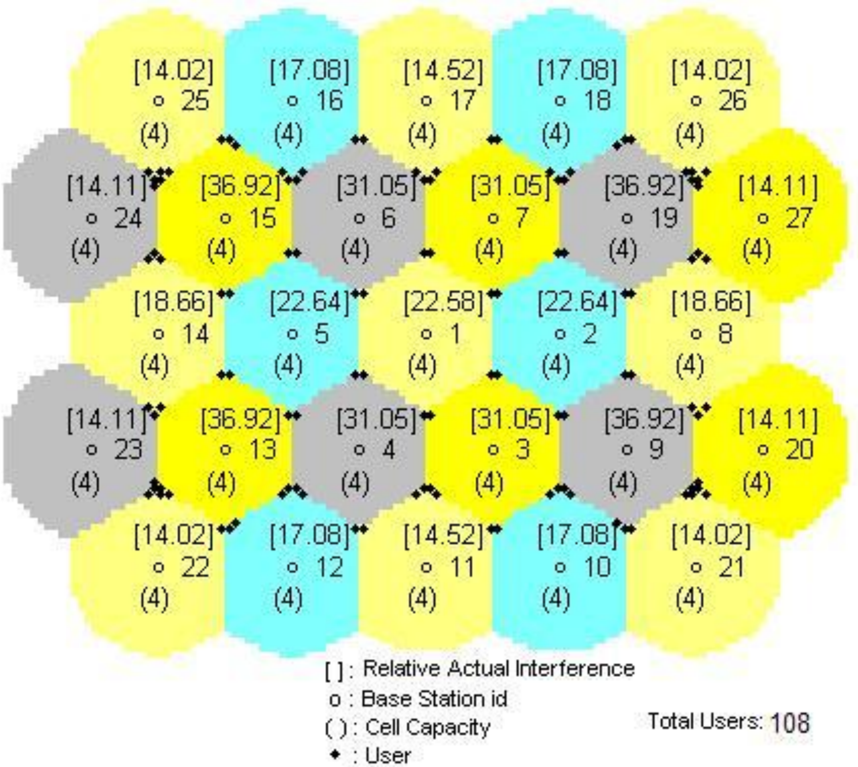

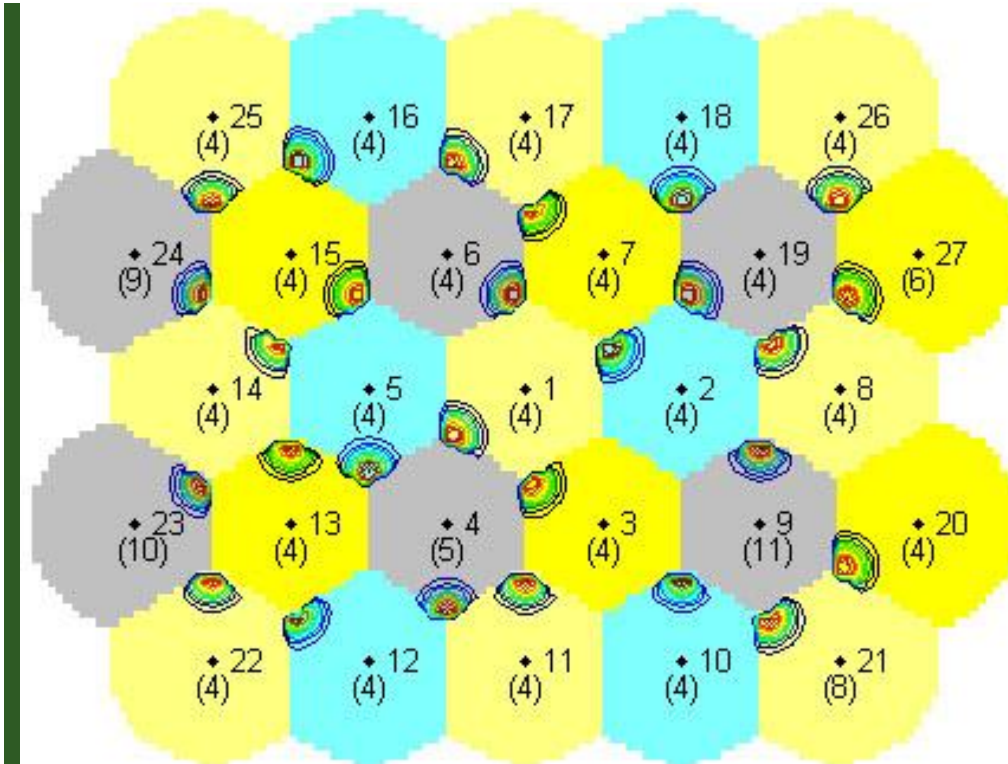

- Simulated network capacity where users are densely clustered at the boundaries of the cells causing the most amount of inter-cell interference. The maximum number of users is only 108 in the network.

- 2-D Gaussian approximation of users densely clustered at the boundaries of the cells. The values of $\sigma_1=\sigma_2=300$, μ_1, and μ_2 are different in the different cells. The maximum number of users is 133

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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.

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Thank You!!

Questions?