S-72.333 Postgraduate Course in Radio Communications

CDMA System Coverage and Capacity Improvement Using Smart Antennas

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Outline

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2. Smart Antenna Techniques for CDMA
3. Coverage Extension
4. Capacity Improvement
5. Summary
6. Homework

Smart Antennas

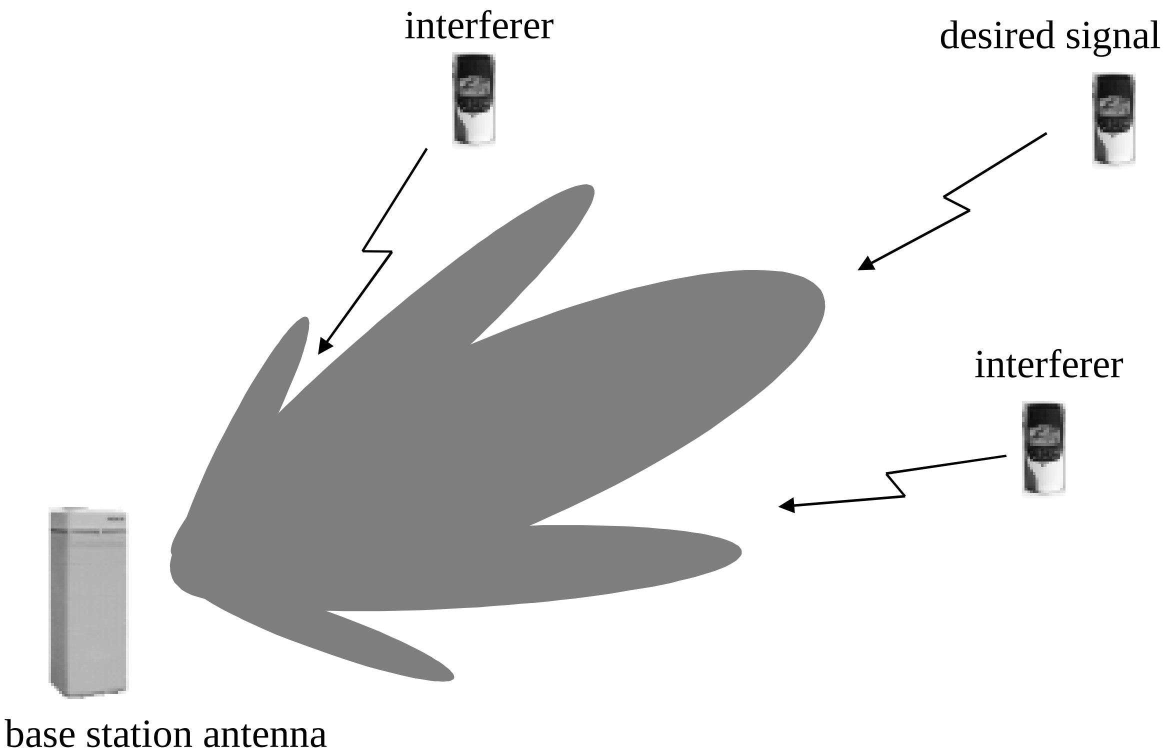
Smart antennas are one way to improve the performance of wireless radio systems. The following benefits can be achieved using smart antennas:

- ► Coverage extension
- ► Capacity improvement
- ► Quality improvement
- ► Initial deployment cost reduction
- ► Spectrum efficiency increase
- ► Transmit power reduction
- ► High power jammer prevention

Two different smart antenna systems:

- ► Adaptive antenna system
- ► Switched beam system

Adaptive Antenna System



PROS AND CONS

Better performance when the number of users is small.

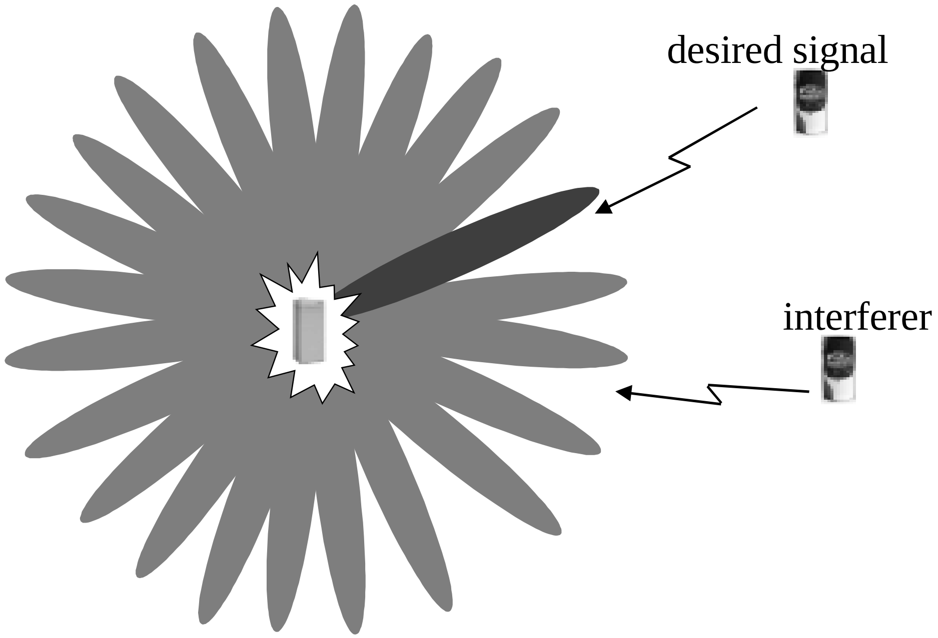
Capable of cancelling co-channel interference.

Better coverage.

Expensive.

Complicate to implement.

Switched Beam System



PROS AND CONS

Much more easier to implement in the existing cellular infrastructure.

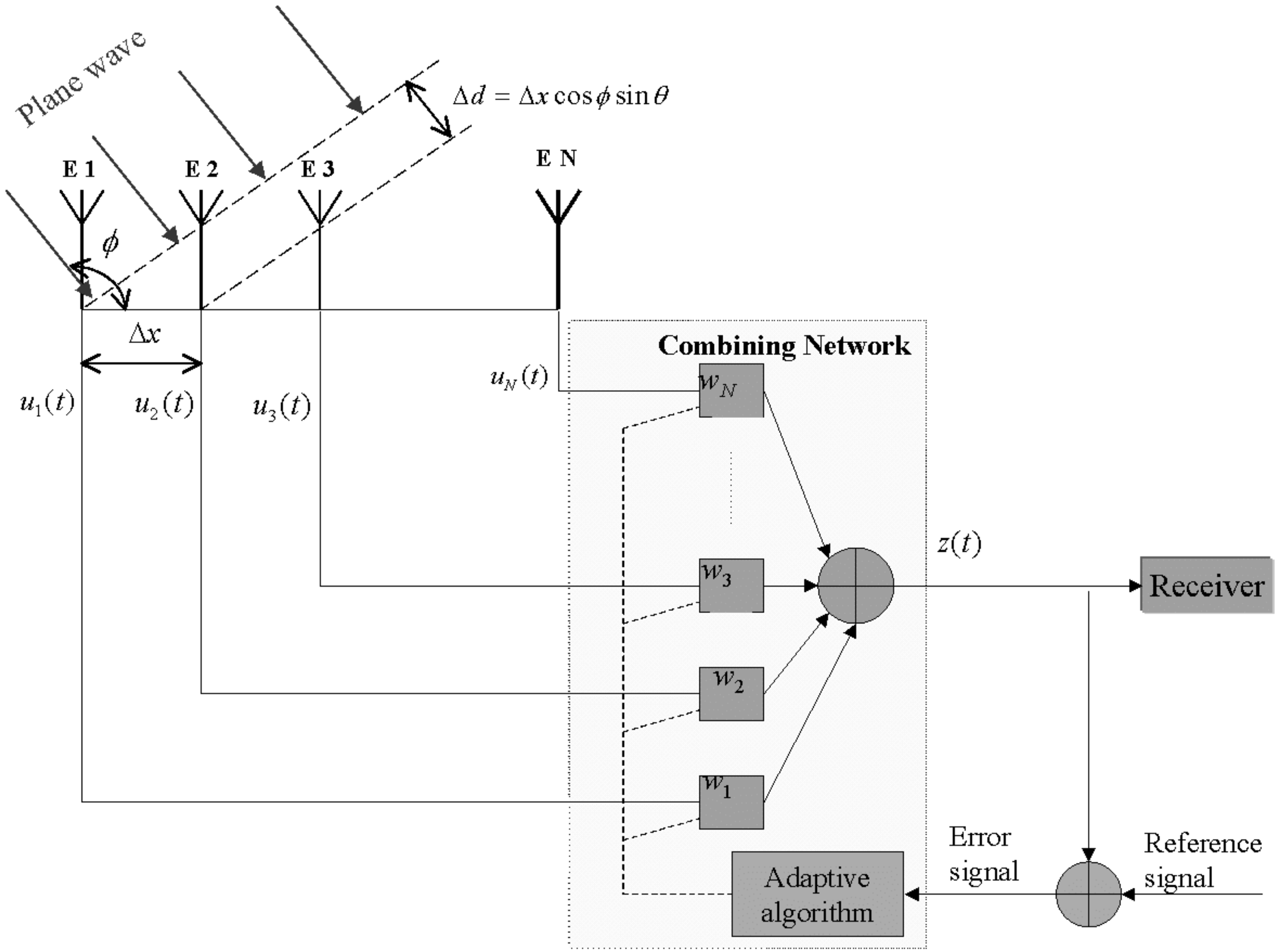
Not so expensive.

Can do the tracking much more faster.

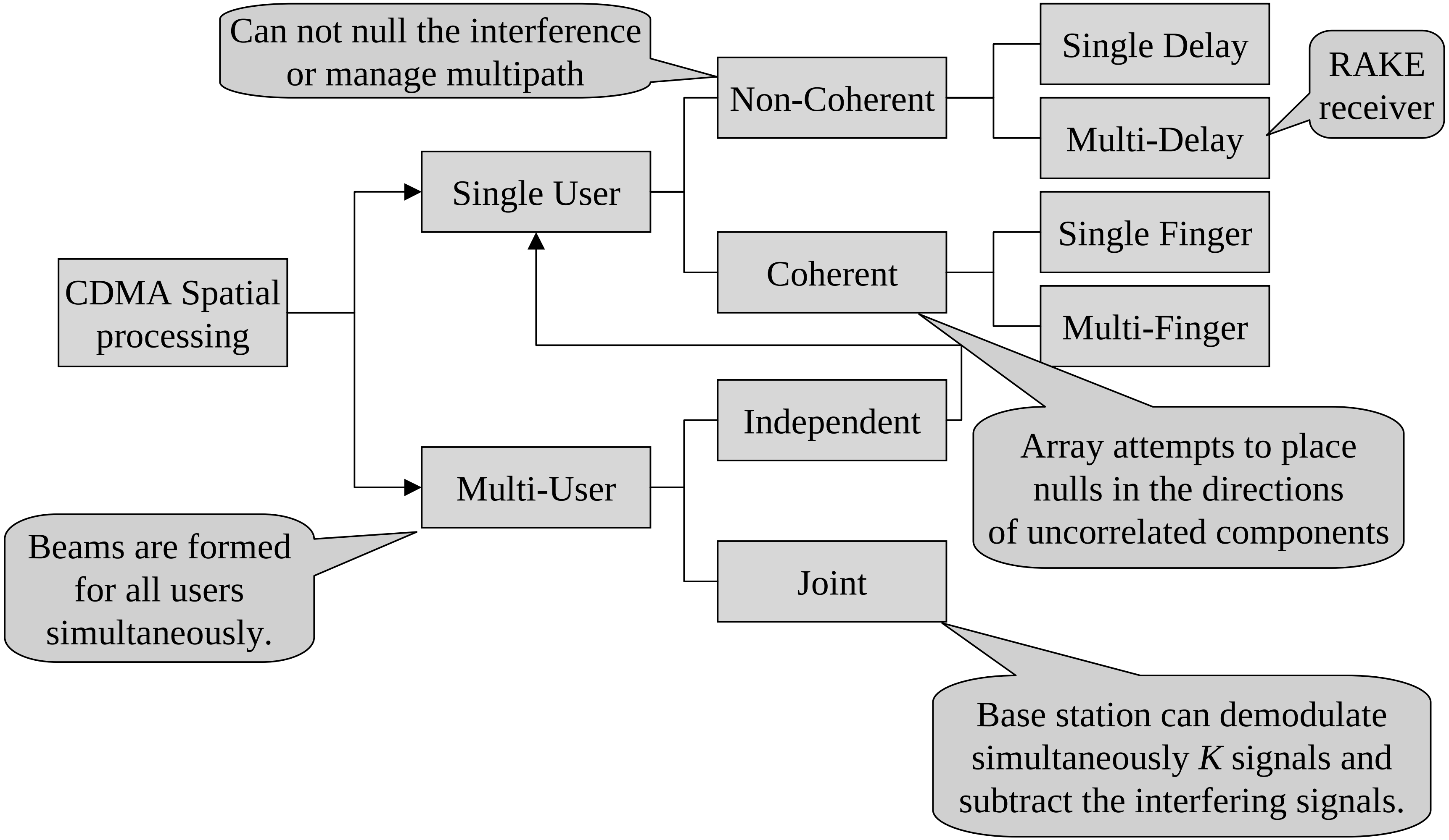
Can not cancel the co-channel interference as well as the adaptive antenna system.

Lesser coverage extension.

Beamforming



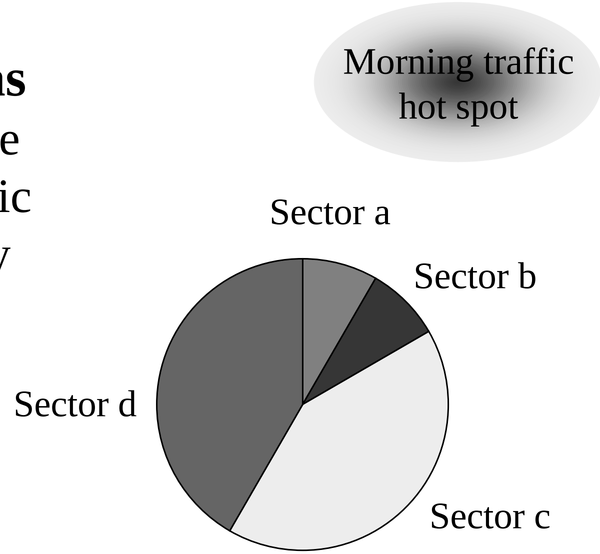
Smart Antenna Techniques for CDMA



Smart Antenna Techniques for CDMA

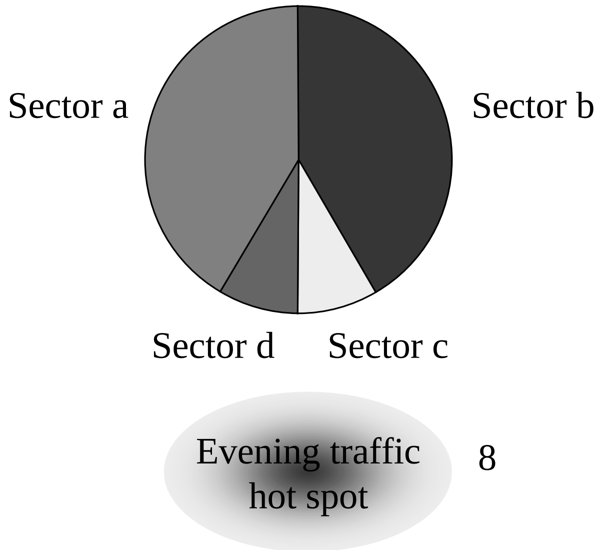
- **Dynamic re-sectoring using smart antennas**

  In CDMA systems, the ability to accommodate dynamic traffic densities is important. Dynamic sectoring is used to reduce the area covered by a sector. Dynamic re-sectoring can be used to adjust to time-varying traffic needs such as morning and evening hot spots.



- **Downlink beamforming for CDMA**

  Few downlink channels must be supplied continuously to all areas covered by a sector. Downlink beam can not be focused only where it is needed. Thus base station transmitter uses a broad beam to provide universal channels through a sector and beamforming is used to provide individual traffic channels.



Coverage Extension

- Coverage extension is one of the benefits that can be achieved with smart antennas.
- It allows the mobile to operate farther from base station with same transmitting power. Because base station coverage is larger, the number of base stations can be reduced.
- The range and coverage extension can be given by

$$\frac{R_S}{R_C} = M^{1/n},$$

$$\frac{A_S}{A_C} = M^{2/n}$$

R_S Range of a cell using smart antennas
R_C Range of a cell using conventional antennas
A_S Area of a cell covered with smart antennas
A_C Area of a cell covered with conventional antennas
M Number of antenna elements
n Path loss exponent

Path Loss Exponent	**3**	**3.5**	**4**	**4.5**	**5**
Range Extension	59 %	49 %	41 %	36 %	32 %
Coverage Extension	152 %	121 %	100 %	85 %	74 %

M = 4

Capacity Improvement

- Capacity improvement is much more difficult to analyze than the coverage extension. The interference from other users has to be considered, and many assumptions and simplifications have to be made.
- Subscribers are independent and uniformly distributed and every subscriber contributes a single component. The maximum number of users that can be supported by an omni-directional cell is

$$K \le \frac{fG_pG_a}{v(E_b / N_0)}$$

K	Number of users
f	Reuse factor < 1
G_p	Processing gain
G_a	Antenna gain
v	Voice activity factor
E_b	Energy per bit
N_0	Power spectral density of thermal noise + power spectral density of total multiple access interference

Capacity Improvement

- If optimal MMSE (Minimum Mean Square Error) adaptive antenna algorithm is used instead of the switched beam system, the maximum number of users that can be supported by each sector with M-element antenna array is

$$K_{\max} \le \frac{G_p M f}{G_i(M) v(E_b / N_0)} + 1$$

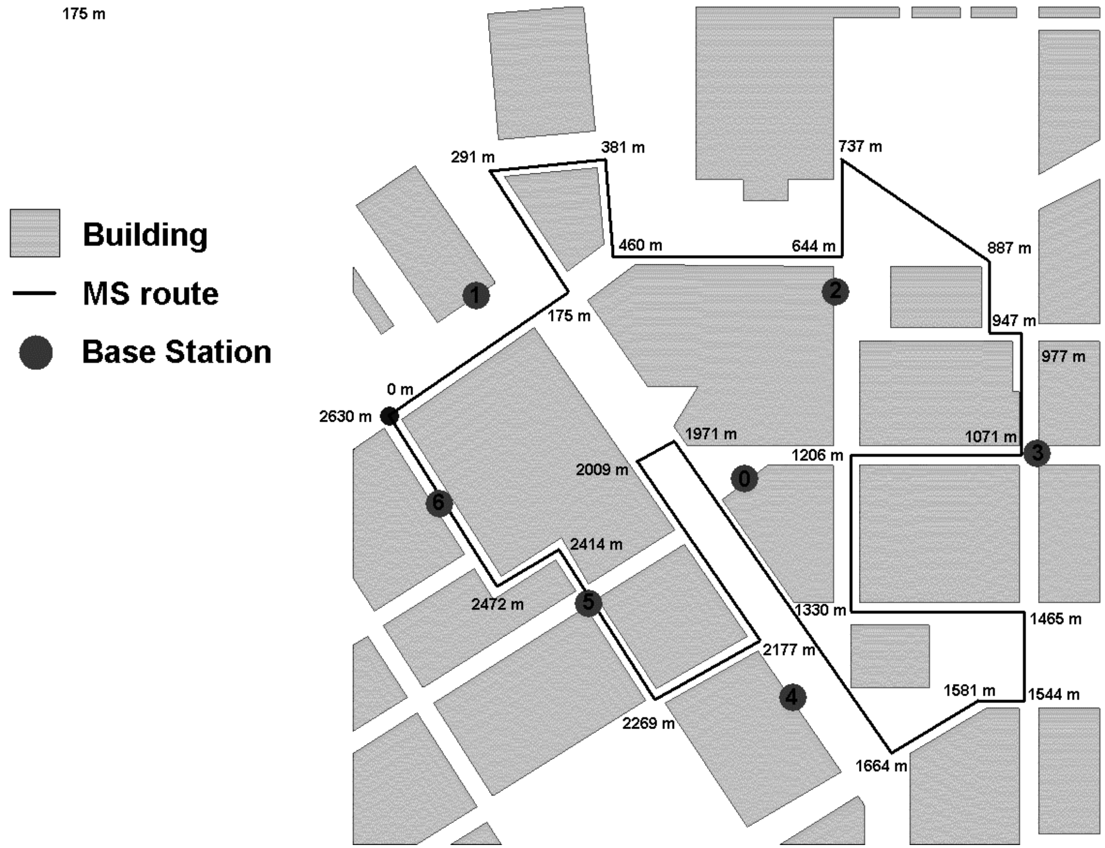
G_i Interference gain, is the degradation from the ideal gain of M that can be achieved relative to noise due to the specific array geometry and the distribution of interferers.

M	**1**	**2**	**3**	**4**	**6**	**8**	**10**
G_i	1.0	1.6	1.8	2.0	2.2	2.4	2.5

- The main reasons for larger capacity in CDMA systems using smart antennas are:
  - ► Larger antenna gains
  - ► Interference reduction
  - ► Lower transmit powers

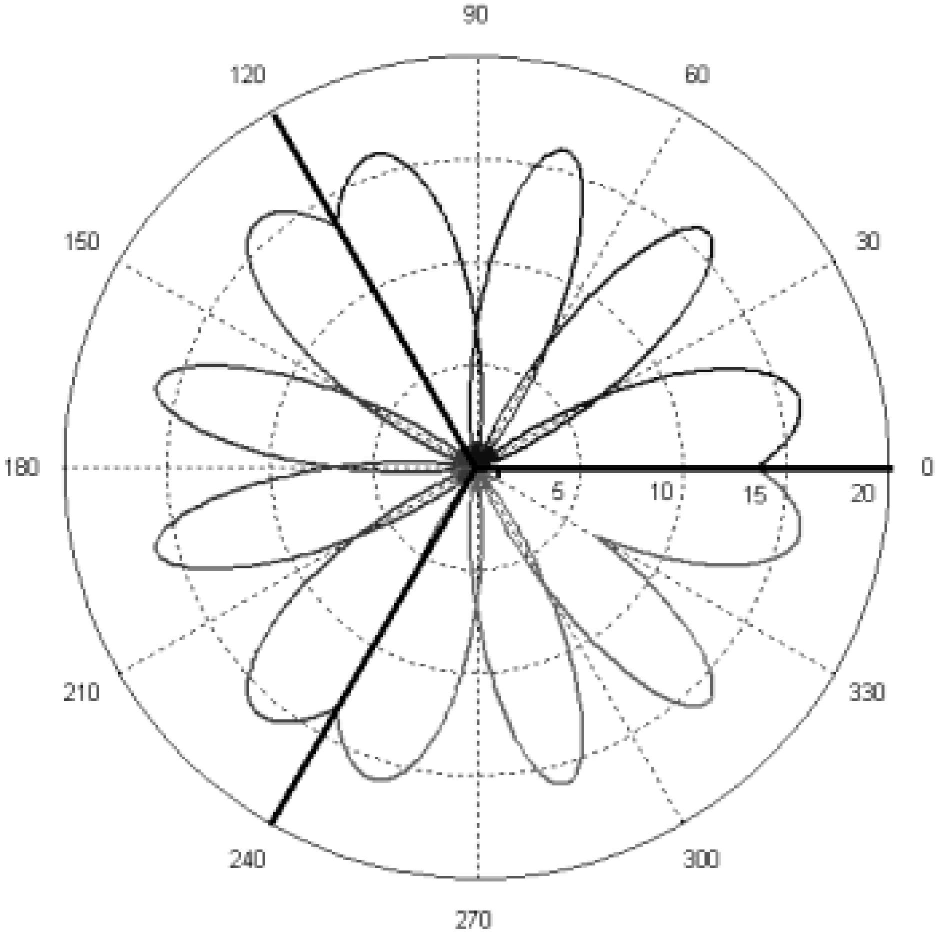
Simulation Environment

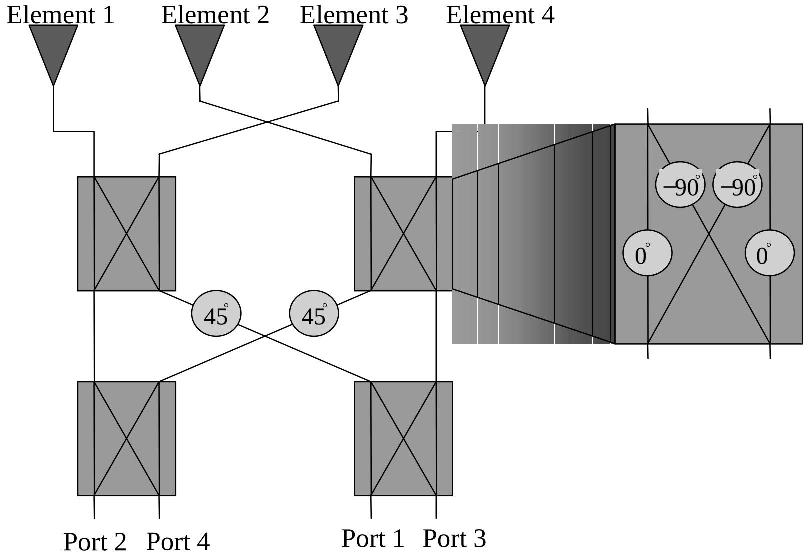
- Simulation were made with NetSim, which is a DS-CDMA network simulator developed in HUT.



Switched Beam Smart Antenna System

- Every base station had three sectors each containing 4-element linear antenna array and a Butler beamforming network. The beam with best SIR is selected.

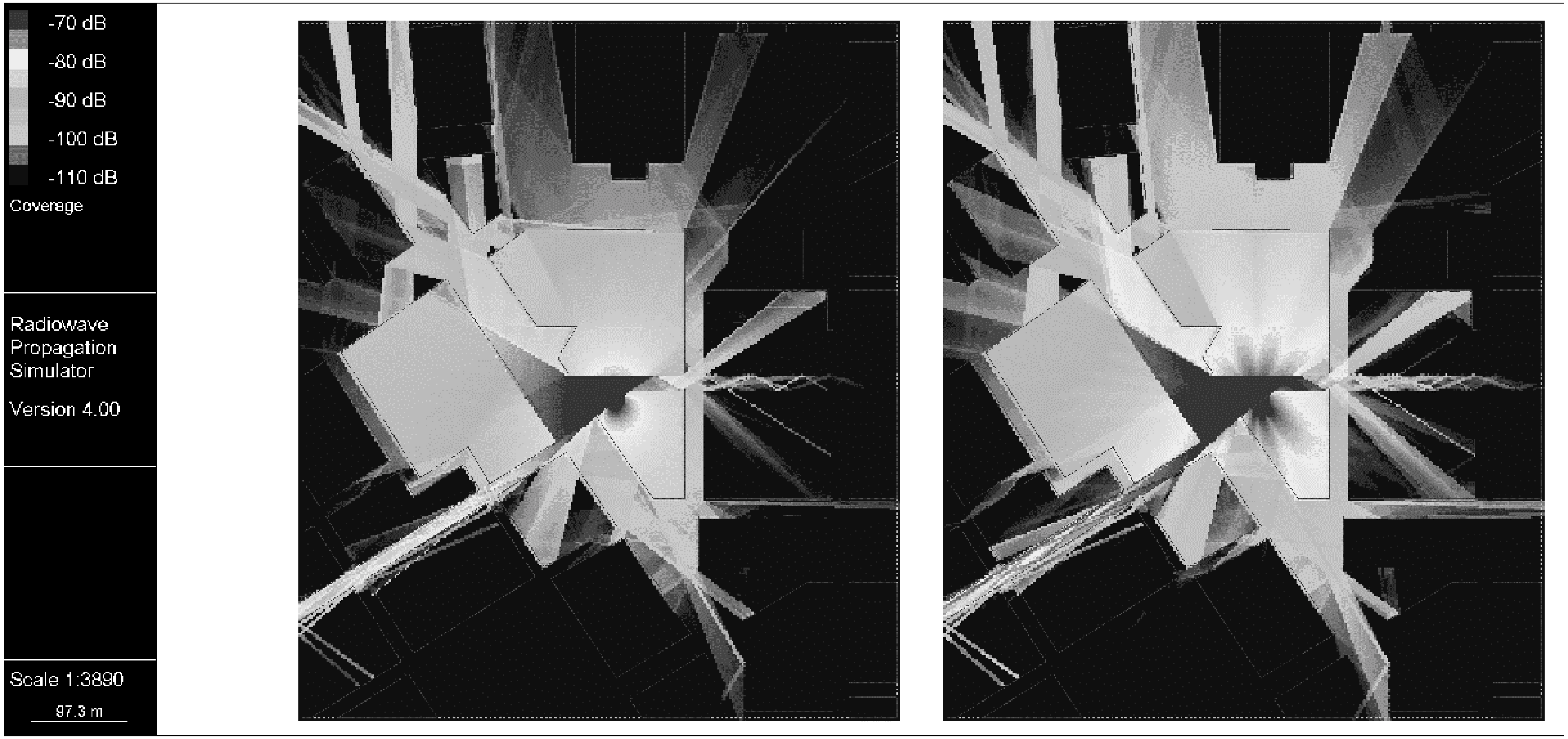




$$P_r = \frac{1}{2} \cdot \left| \sum_{m=1}^{M} w_m e^{-j\pi(m-1)\cos\phi \sin\theta} \right|^2$$

Coverage Analyzis

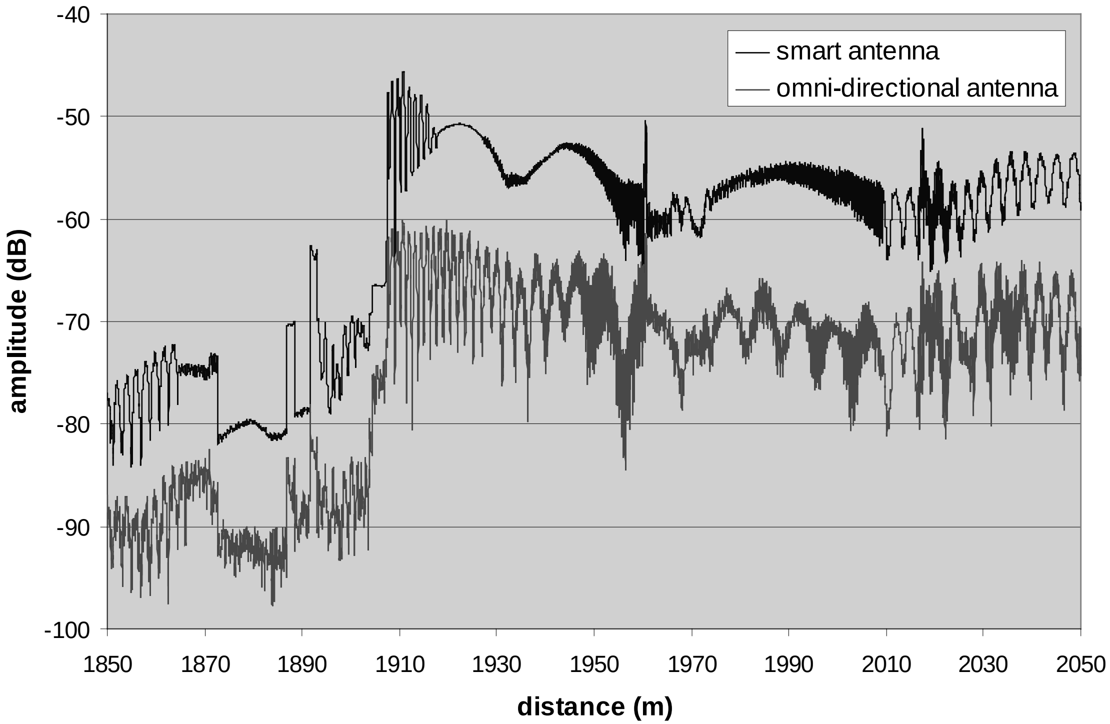
- Numerical results from coverage extension is difficult to obtain, and it is highly dependent on the environment.



Omni-directional antenna   Smart antenna

Coverage Analyzis

- Received power level at the mobile station is one way to examine coverage extension. Smart antenna system can provide larger antenna gain, which is dependent on the angle between base station and mobile station.



The received power at the mobile is 10 dB larger when smart antennas are used.

Power level fluctuates more when omni-directional antennas are used.

Capacity Analyzis

- Network capacity was simulated using omni-directional antennas and smart antennas. Simulation time was 860 seconds and number of users in the network was measured in every second.

	BS 0	BS 1	BS 2	BS 3	BS 4	BS 5	BS 6	BS TOTAL
Omni-directional antenna	16	21	23	22	39	14	13	105
Smart antenna	55 243 %	78 271 %	92 300 %	77 250 %	124 217 %	47 235 %	25 92 %	340 223 %

Capacity improvement is more than 220 %.

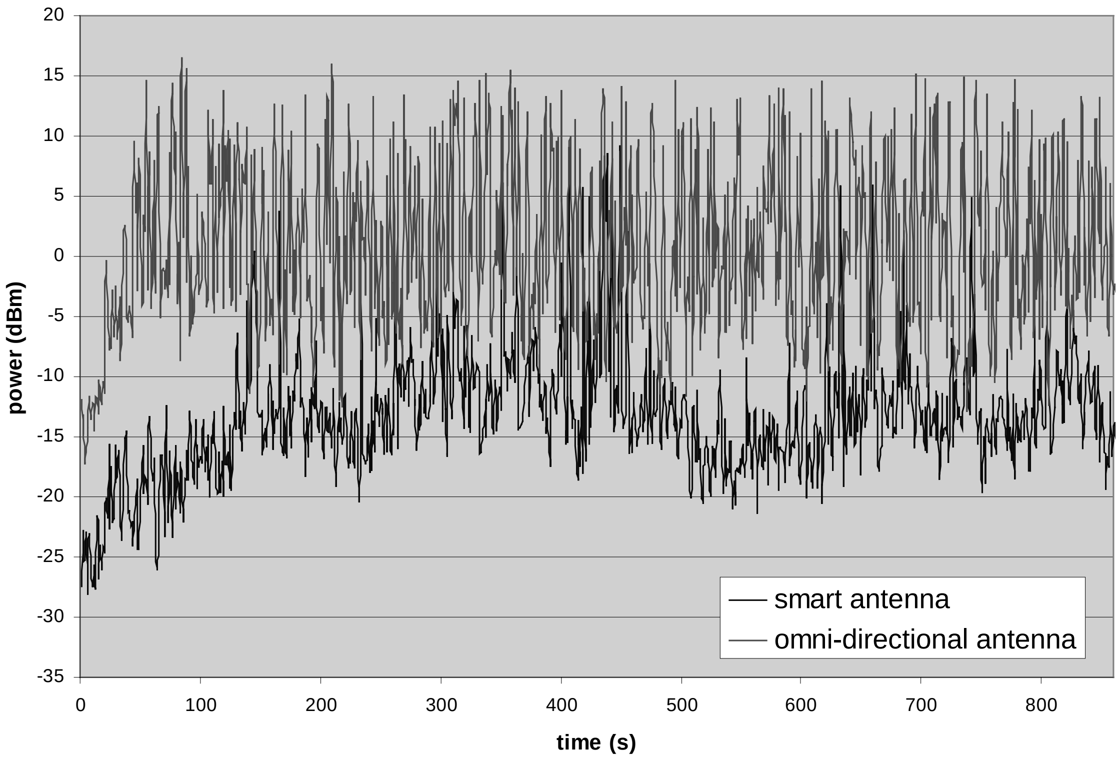
Capacity improvement is not the same in different base stations.

Capacity is highly dependent on base station location, environment and user distribution.

Simulation parameters are also an important factor in network capacity.

Transmit power reduction

- Transmit power reduction is one of the reasons for larger capacity. The transmission powers of every active mobile station were averaged and calculated for every second.



Transmit power reduction is more than 10 dB when smart antennas are used.

Mobiles can use lower transmit powers to obtain the same SIR target, because of the larger antenna gain and lower interference caused by other mobiles.

Interference decreases and mobile's battery life increases.

Summary

- Adaptive antenna system and switched beam system are the two smart antenna technologies.
- Switched beam system is not so complicated and it is much more cheaper to add to the existing cellular systems. However, adaptive antenna system will give a better performance and is probably the main technology in the future.
- Smart antenna systems will extend the coverage area because of the larger antenna gains. Coverage extension is depend on the environment.
- Capacity improvement is the most important benefit that can be achieved using smart antennas. User distribution, environment and network parameters are the key factors that have an influence to the amount of capacity improvement.
- When using smart antennas at the base stations, lower transmit powers can be used, which improves capacity.

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Homework

What is the effect of the environment to the capacity improvement?
Consider a smart antenna system that is using 8-element antenna array at the base station. Processing gain is 128, required CINR 7 dB and voice activity factor 0,6. Ratio of in-cell interference to total interference, f can be calculated with equation 1/(1+8b), where b is given on table 1. Calculate the capacity improvement of a sector compared to the omni-directional system (which does not have antenna gain) using different path loss exponents 2, 3 and 4. The in-cell interference to total interference in omni-directional system is given on table 2.

Table 1

Path loss exponent n	***b***
2	0.1496
3	0.0824
4	0.0551

Table 2

Path loss exponent n	***F(omni)***
2	0.454
3	0.601
4	0.693