192620010
Mobile & Wireless Networking

Lecture 4:
Cellular Concepts & Dealing with Mobility

[Reader, Part 3 & 4]

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# Outline of Lecture 4

Cellular Concepts

- ❑ Introduction
- ❑ Cell layout
- ❑ Interference
- ❑ Capacity Improvement

Dealing with Mobility:

· Handover

- ❑ Handover types and phases
- ❑ Handover triggering algorithms
- ❑ Hard / seamless / soft handover
- ❑ Intra-cell / inter-cell / inter-system handover
- ❑ Layered cell structures

· Mobility Management

- ❑ Cell selection
- ❑ Location management
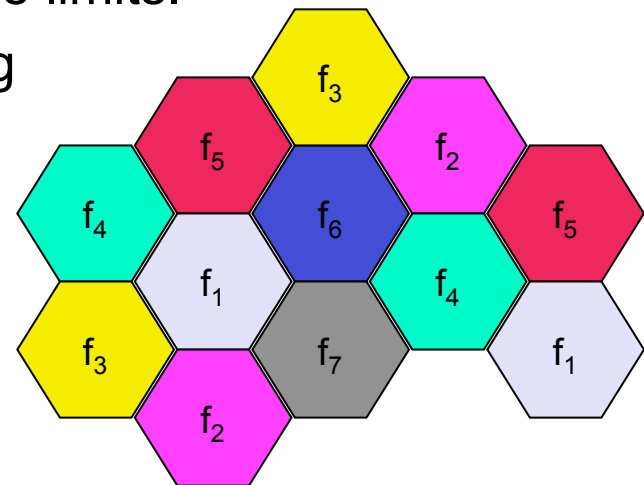
Rationale behind cellular systems

- Solves the problem of spectral congestion and increases user capacity.
- Offer very high capacity in a limited spectrum
- Reuse of radio channel in different cells.
- Enable a fixed number of channels to serve an arbitrarily large number of users by reusing the channel throughout the coverage region.
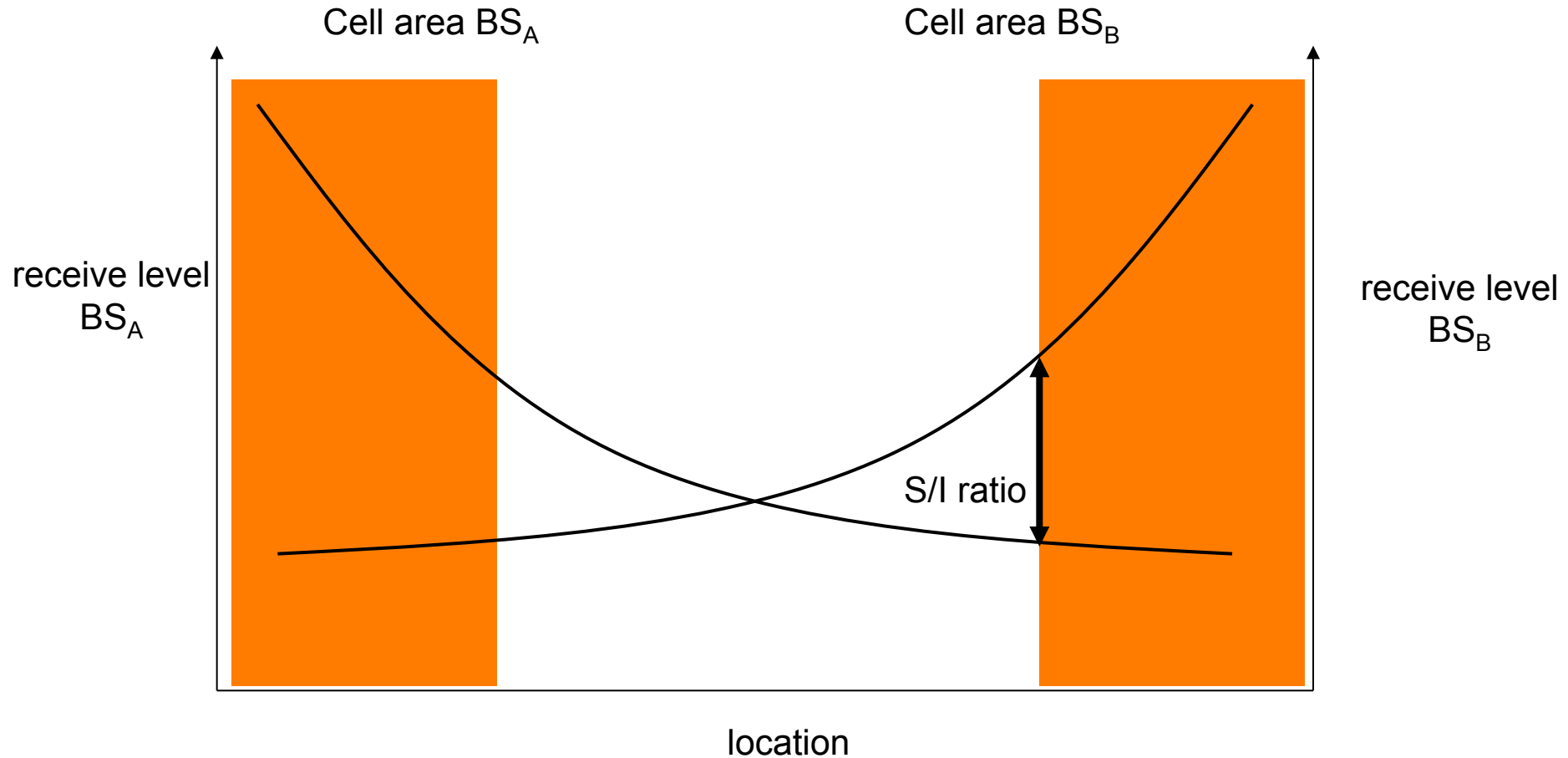

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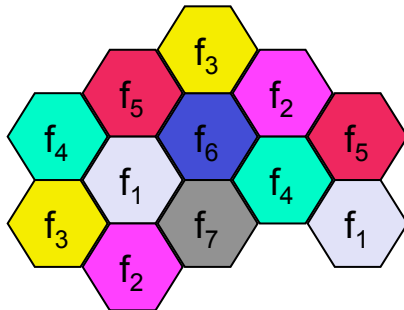
Basic principles of cellular systems

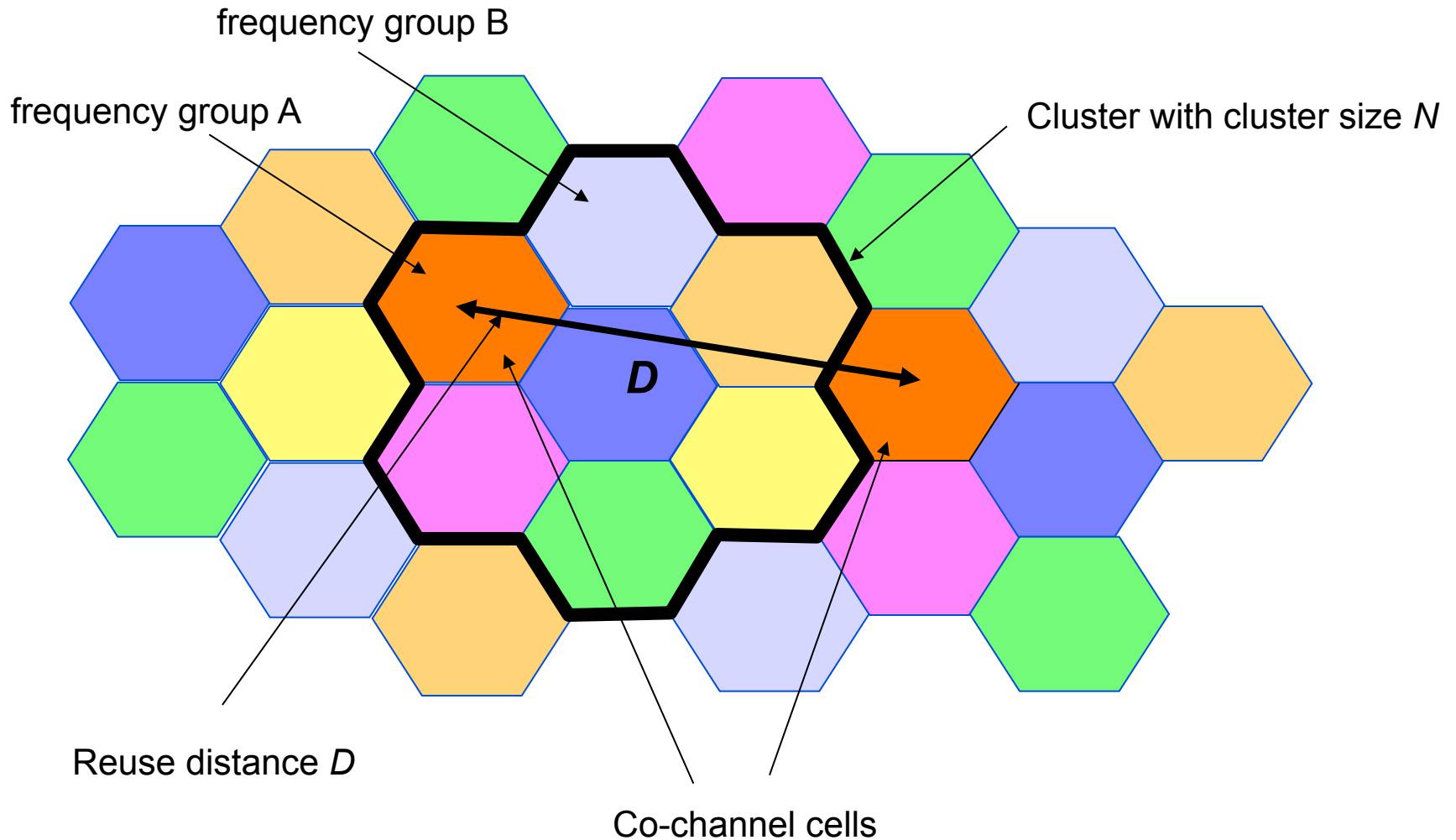Communication is always between mobile and base station (not directly between mobiles)

- Each cellular base station is allocated a group of radio channels within a small geographic area called a cell.

- Neighboring cells are assigned different channel groups.

- By limiting the coverage area to within the boundary of the cell, the channel groups may be reused to cover different cells.

- Keep interference levels within tolerable limits.

- Frequency reuse or frequency planning

Cell area vs. Signal to Interference Ratio

Cell area BS$_A$

Cell area BS$_B$

receive level BS$_A$

receive level BS$_B$

S/I ratio

location

Cluster size and reuse distance

frequency group B

frequency group A

Cluster with cluster size *N*

D

Reuse distance *D*

Co-channel cells

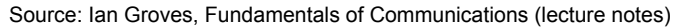# Differences between theoretical and real coverage
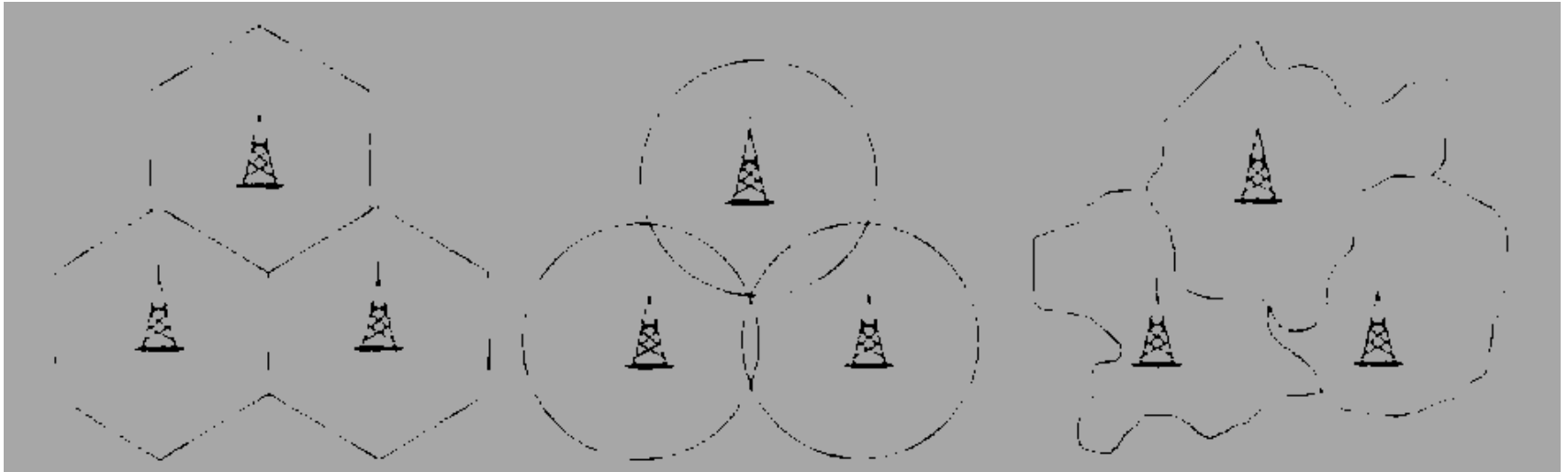
Theoretical Coverage   Ideal Coverage   Real Coverage

Source: Tabbane, Handbook of Mobile Radio Networks

Geometry of a hexagonal cell (1)

Source: Ian Groves, Fundamentals of Communications (lecture notes)

Geometry of a hexagonal cell (2)

Unit scale is distance between neighboring cell centers.

For cell radius R:

$$2R\cos(\pi/6) = 1$$

$$R = 1/\sqrt{3}$$

To find the distance to the origin, r, of point (u,v), do (u,v) to (x,y) transformation:

$$x = u\cos(\pi/6)$$

$$y = v + u\sin(\pi/6)$$

$$r^2 = x^2 + y^2 = u^2\cos^2(\pi/6) + v^2 + u^2\sin^2(\pi/6) + 2uv\sin(\pi/6)$$

$$r = \sqrt{u^2 + v^2 + uv}$$

Geometry of a hexagonal cell (3)

Using this equation to locate co-channel cells, we start from a reference cell and move *i* hexagons along the *u*-axis then *j* hexagons along the *v*-axis. Hence the distance between co–channel cells in adjacent clusters is given by:

$$D = \sqrt{i^2 + j^2 + ij} \cdot \sqrt{3}R$$

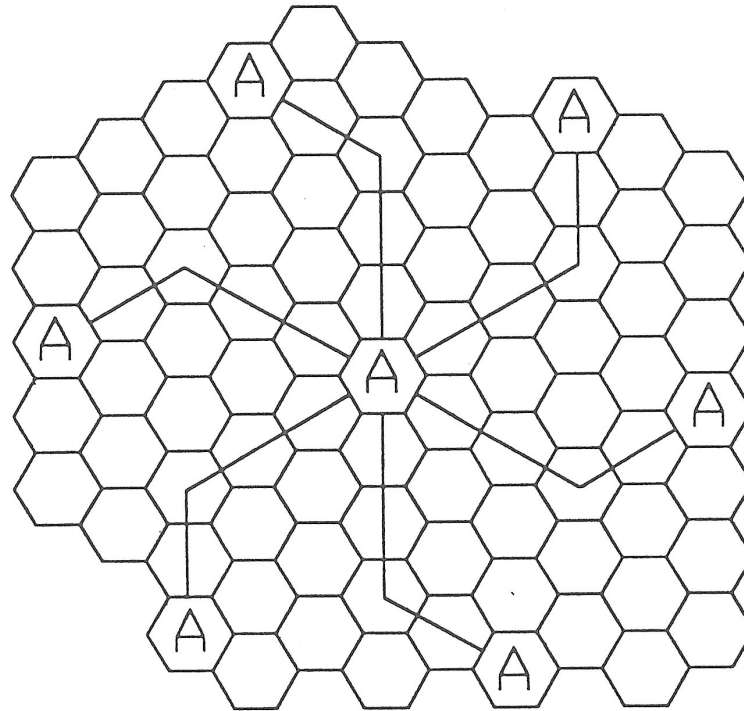The number of cells in a cluster, *N,* is given by:

$$N = \left(\frac{D}{\sqrt{3}R}\right)^2 = i^2 + j^2 + ij$$

since *i* and *j* can only take integer values we find values for *N*.

The frequency reuse factor, *Q*, is given by:

$$Q = \frac{D}{R} = \sqrt{3N}$$

Co–channel cell location

❑ Method of locating co–channel cells

❑ Example for *N*=19, *i*=3, *j*=2

Possible Cluster Sizes (N) and Frequency reuse factor (Q)

i	j	N	Q
1	0	1	1.732
1	1	3	3
2	0	4	3.464
2	1	7	4.583
3	0	9	5.196
2	2	12	6
3	1	13	6.245
4	0	16	6.928
3	2	19	7.55
4	1	21	7.937
5	0	25	8.66
3	3	27	9
4	2	28	9.165

Examples (1)

i	j	N	Q
1	0	1	1.732
1	1	3	3
2	0	4	3.464
2	1	7	4.583
3	0	9	5.196
2	2	12	6
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4	2	28	9.165
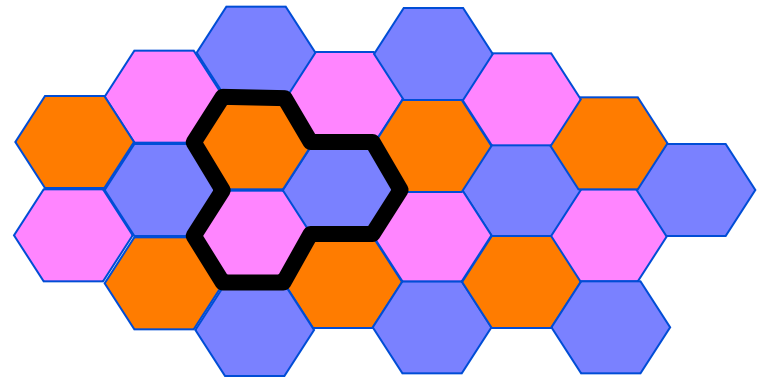
$N = 3$
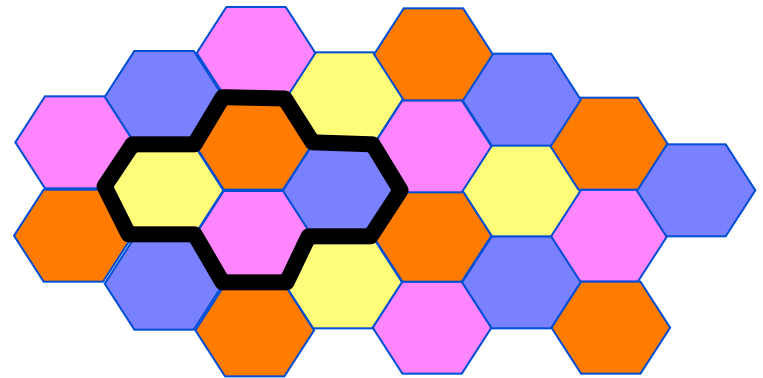
$N = 4$

Examples (2)

i	j	N	Q
1	0	1	1.732
1	1	3	3
2	0	4	3.464
2	1	7	4.583
3	0	9	5.196
2	2	12	6
3	1	13	6.245
4	0	16	6.928
3	2	19	7.55
4	1	21	7.937
5	0	25	8.66
3	3	27	9
4	2	28	9.165

N = 7

N = 9

Co-channel Interference (1)
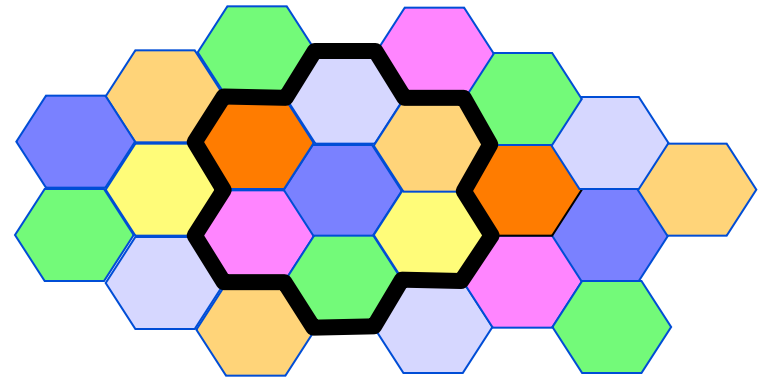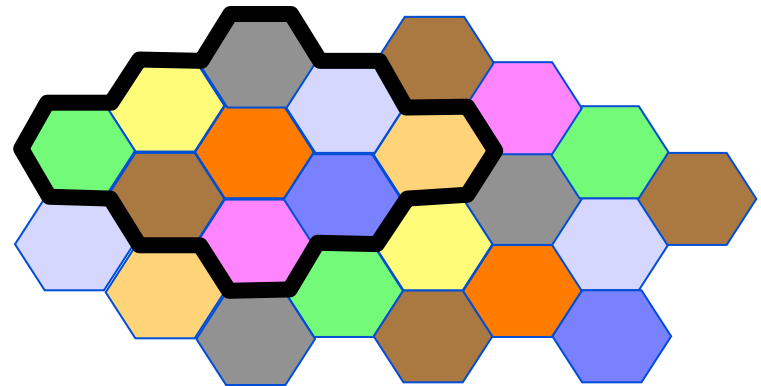
First Tier
Interfering cells

Source: Bala Kalyanasundaram, Wireless Networks (lecture notes)

Co-channel Interference (2)

Now consider a mobile at the edge of cell, distance *R* from transmitter (downlink only).
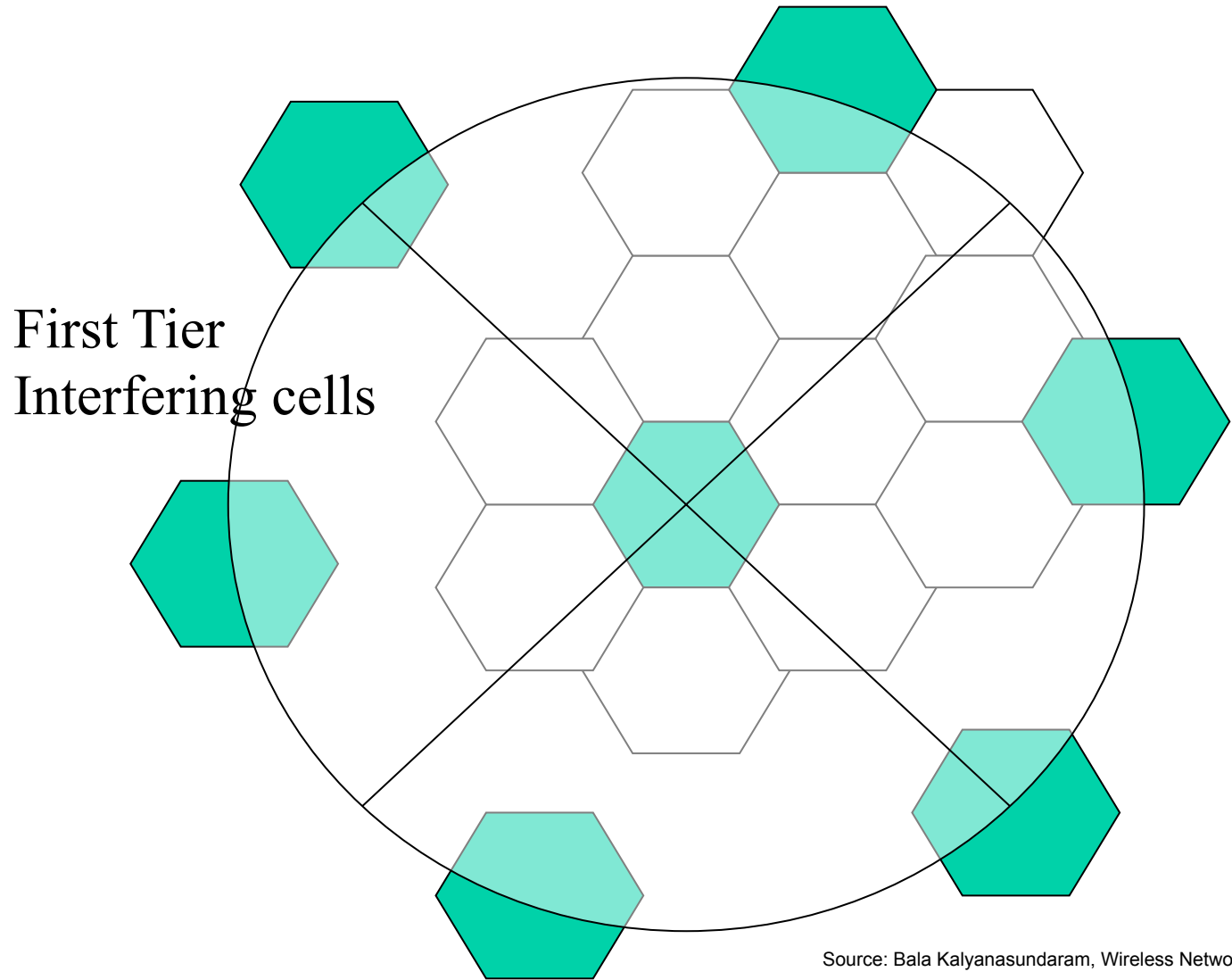
- ❑ Number of first-tier co-channel cells is 6 (always)
- ❑ Average 'first tier' co-channel cell is distance *D* away

$$\frac{S}{I} \approx \frac{R^{-v}}{6D^{-v}} = \frac{1}{6}(Q)^{v} = \frac{1}{6}(Q)^{v}$$

- ❑ where *v* (nu) is the path loss exponent

In dB:

$$\frac{S}{I} = 10\log(\frac{1}{6}Q^{v}) = 10\log\frac{1}{6} + 10\log(Q^{v}) = v10\log(Q) - 7.8$$

- ❑ *S/I* is independent of cell size!

S/I for different cluster sizes

For v=4

i	*j*	*N*	*Q*	*S/I*
1	0	1	1.732	1.742
1	1	3	3	11.28
2	0	4	3.464	13.78
2	1	7	4.583	18.64
3	0	9	5.196	20.83
2	2	12	6	23.33
3	1	13	6.245	24.02
4	0	16	6.928	25.82
3	2	19	7.55	27.32
4	1	21	7.937	28.19
5	0	25	8.66	29.7
3	3	27	9	30.37
4	2	28	9.165	30.69

Use of directional antennas

position of the mobile

interference cells
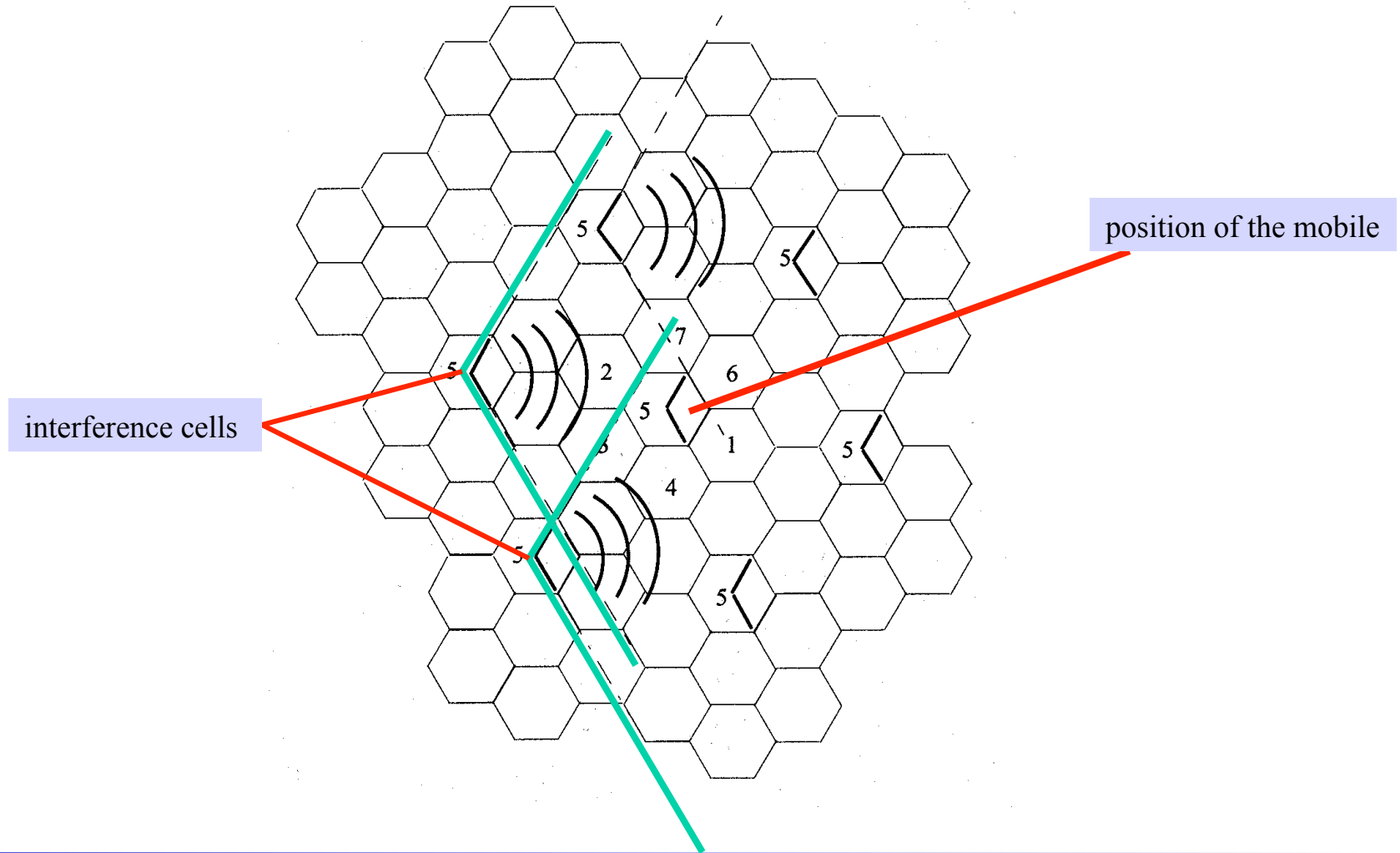
Effect of using directional antenna

For a 3 sector antenna:

Each sector uses 1/3 of the allocated channels

Mobile is interfered by 2 base stations instead of 6

$$\left[S/I \right]_{120°} = \left[S/I \right]_{omni} + 10\log 3 = \left[S/I \right]_{omni} + 4.8\text{dB}$$

Result:

18.6 dB *S*/*I* requirement

❑ omnidirectional→ *N*=7

❑ 3-sector→ *N*=4

Also extended coverage

Capacity improvement

Initially, cellular systems are often noise limited:

- ❑ The main deployment concern is coverage

As traffic increases, systems become interference limited:

- ❑ The main deployment concern is capacity

How to increase capacity?

- ❑ Use sectorized antenna
- ❑ Cell splitting
- ❑ Discontinuous Transmission (DTX)
  - Use speech detection / silence suppression
- ❑ Power control
  - Adapt transmission power to what is just needed (given the position of the mobile)
- ❑ Frequency hopping
  - spread interference over whole spectrum, pseudo random
- ❑ Multiple Input Multiple Output (MIMO)
- ❑ Fractional Frequency Reuse
- ❑ Dynamic Channel Allocation

Dynamic Channel Allocation

Traffic demand is typically non-homogeneous and time-varying.

→ Allocate channels dynamically

❑ Centralized
- ❑ Channel borrowing
  - ● Reuse distance constraint

❑ Decentralized
- ❑ Fully distributed algorithm, based on measurements in BS and Mobile (used in DECT)

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- ❑ Capacity Improvement

Dealing with Mobility:

· Handover
- ❑ Handover types and phases
- ❑ Handover triggering algorithms
- ❑ Hard / seamless / soft handover
- ❑ Intra-cell / inter-cell / inter-system handover
- ❑ Layered cell structures

· Mobility Management
- ❑ Cell selection
- ❑ Location management

Handover: basic principle

Change radio channel during communication

Reasons for handover (USA: Handoff):

❑ User (mobile) is moving between cells while communicating
   ❑ cell in a mobile cellular system is between 10 m and 35 km
❑ Current channel has bad radio conditions
❑ Balance traffic load between cells
❑ Minimize mobile power consumption and global interference level
❑

Types of handover

- ❑ **Mobile-initiated**
  - ❑ Mobile makes decision
- ❑ **Network-initiated**
  - ❑ Network makes decision
- ❑ **Mobile-assisted**
  - ❑ Mobile provides information
    - ● E.g. about signal strength of base stations
  - ❑ Network makes decision

Handover Phases

1. Monitoring and link measurement
2. Target cell determination and handover triggering
3. Handover execution

Monitoring and link measurement

- ❑ Performed continuously
- ❑ In GSM: done by mobile, data sent to network ~2x per second
- ❑ Many parameters (for 6 most powerful neighboring base stations):
  - ● Received signal strength indication (RSSI) (averaged)
  - ● Bit error ratio (BER)
  - ● Distance to base station (from timing advance)
  - ● BS identity
  - ●

Target cell determination and handover triggering

Target cell determination:

Mobile / System maintains lists of base stations / channels:

- ❑ Active set
    - ● currently used
- ❑ Candidate set
    - ● good enough for handover
- ❑ Neighbor set
    - ● almost good enough
- ❑ Remaining set
    - ● other channels

Handover triggering algorithms (1)

Relative signal strength

❑ Select BS with strongest (averaged) signal

pos. A (see figure)

Relative signal strength with threshold

❑ If current signal < threshold, select BS with strongest signal

Threshold = $T1$: pos. A

Threshold = $T2$: pos. B

Threshold = $T3$: pos. D (or dropped call?)

Relative signal strength with hysteresis

❑ If new signal > current signal + hysteresis margin h, select new BS

pos. C

Handover triggering algorithms (2)

Relative signal strength with hysteresis and threshold

- ❑ If current signal < threshold and new signal > current signal + h, select new BS
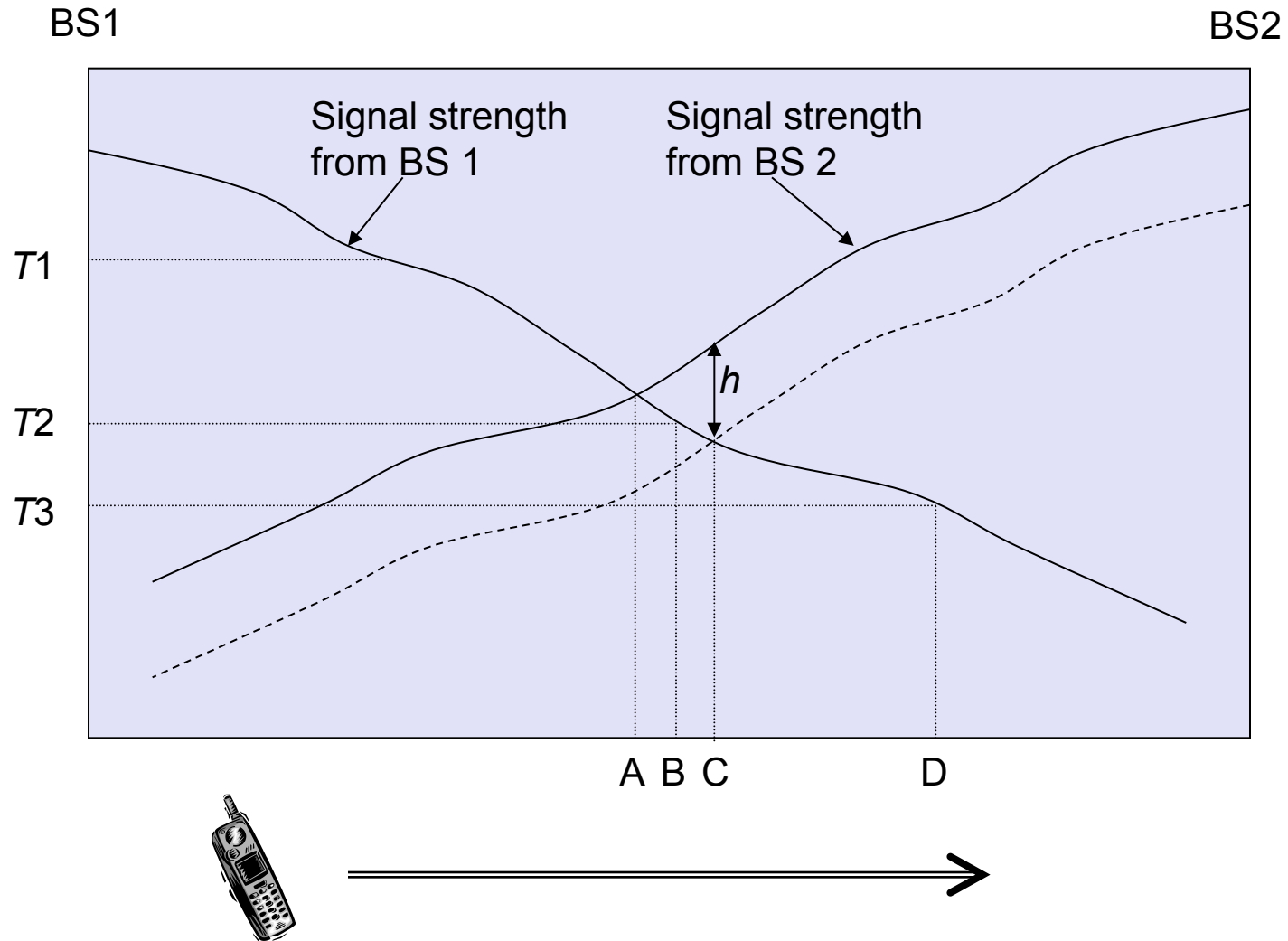
   Threshold = $T1$ or $T2$: pos. C

   Threshold = $T3$: pos D

Prediction techniques

- ❑ Use expected value of signal strength, e.g., based on mobile speed and direction

Handover triggering algorithms (3)

BS1

BS2

Signal strength from BS 1

Signal strength from BS 2

$T1$

$T2$

$T3$

h

A B C   D

Different handover execution procedures:

- ❑ Hard handover
  - ● Radio link to existing base station is released **before** radio link to new base station is established
  - ● Network link is established in advance (from switch/router to base station)
  - ● Interruption of data flow
  - ● Mobile only needs to support 1 radio channel
- ❑ Seamless handover
  - ● Radio link to existing base station is released **after** radio link to new base station is established
  - ● For a short period, 2 radio links are available, during which network link is switched.
  - ● No interruption of data flow
 - ● Mobile needs to transmit on 2 channels simultaneously
- ❑ Soft handover (used in CDMA)
  - ● 2 (or more!) radio links are available and active for a relatively long period of time
  - ● Data is flowing over 2 (or more) radio links simultaneously
  - ● Improved Quality of Service

Handover types (network view)

1. **Intra-cell handover**
   - ❑ Same base station, different channel (e.g. to avoid interference)
2. **Inter-cell handover**
   - ❑ Other base station
3. **Inter-system handover**
   - ❑ E.g. between 3G and LTE

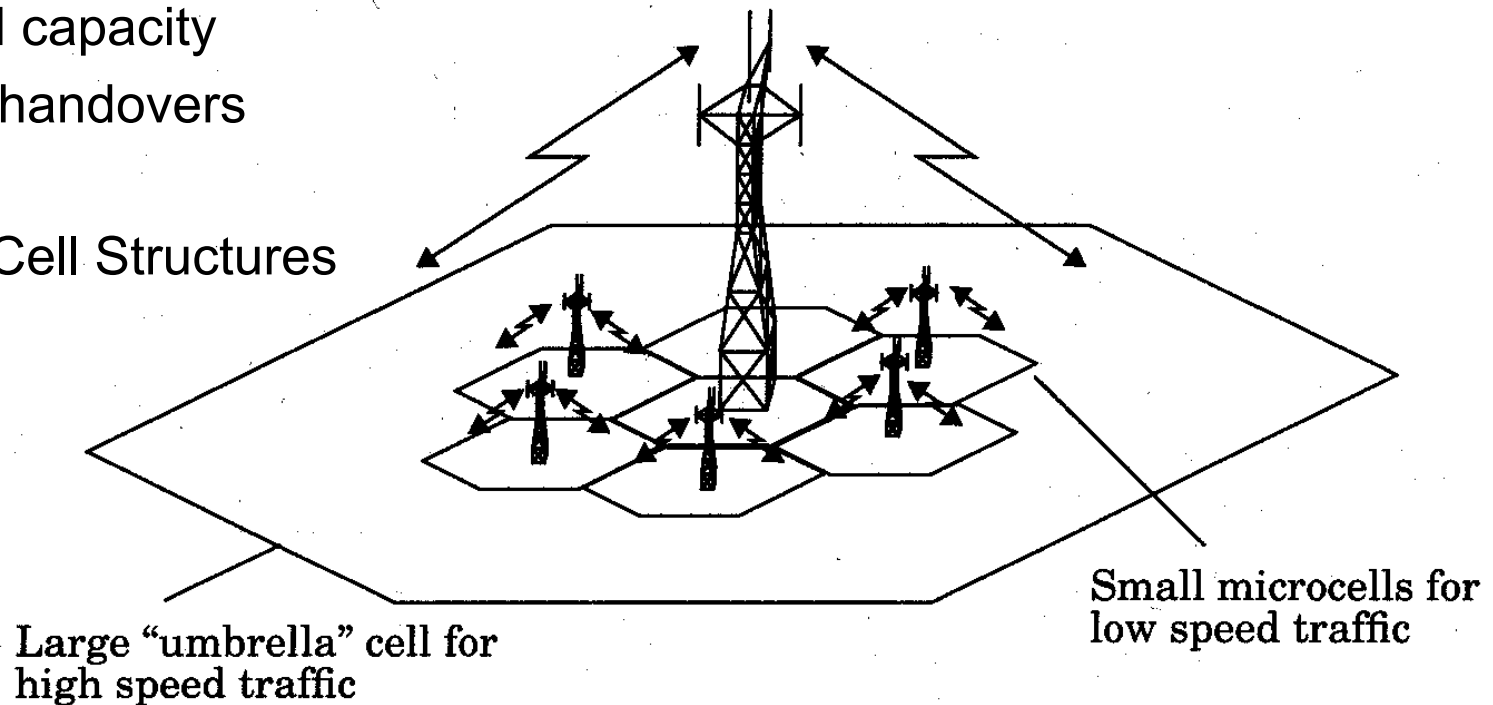More types later
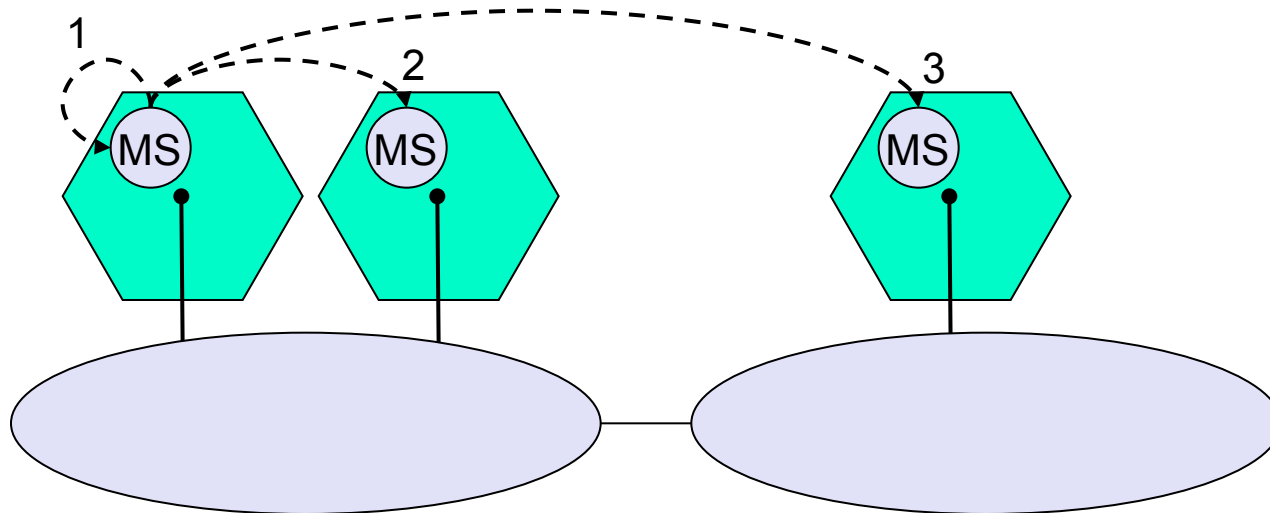
Layered cell structures

Small cells:

❑ high capacity

❑ many handovers for fast-moving mobiles

Large cells:

❑ limited capacity

❑ fewer handovers

Solution:

Layered Cell Structures

Large "umbrella" cell for high speed traffic

Small microcells for low speed traffic

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· **Mobility Management**
- ❏ **Cell selection**
- ❏ **Location management**

Mobility management

Mobile has no fixed point of attachment to the network

❑ During call handover needs to be performed

❑ In between calls, mobility management is needed, to allow for timely call setup

Cell selection

  ❑ Makes mobile ready for network access

Location management

  ❑ Allows mobile to roam

    roaming: move between points of attachment / networks while still receiving service

  ❑ Enable network to find mobile for incoming call

Authentication and privacy are very important aspects!

Cell selection / reselection

Record data transmitted by BSs to Mobiles

Be ready to access network

Inform network about movement

- ❑ Search for system carriers
    - Use list, or
    - Scan all channels
- ❑ Select most powerful carriers
- ❑ Collect system data (listen to broadcast channel)
    - Access allowed
    - Access parameters
    - Synchronization
- ❑ Register with the network
    - Provide identity, location (see later)
- ❑ If BS no longer received, select better BS
- ❑ If paging message received, report to network
- ❑ Report (new) location to network
- ❑ If network no longer received, reselect network

Location management

Location management procedures enable the network to locate a mobile or its user (GSM) in case of incoming communication

❑ Location registration

  ❑ Register the approximate location (location area) of the mobile/user

❑ Paging

  ❑ Broadcast a message in a certain area to inform the user about incoming communication

Location registration

Periodic location updating

- ❑ Mobile transmits identity / location to network periodically

Location updating on LA crossing

- ❑ Each base station broadcasts its location area (LA)
- ❑ If broadcasted LA is different from current LA, mobile invokes location update procedure
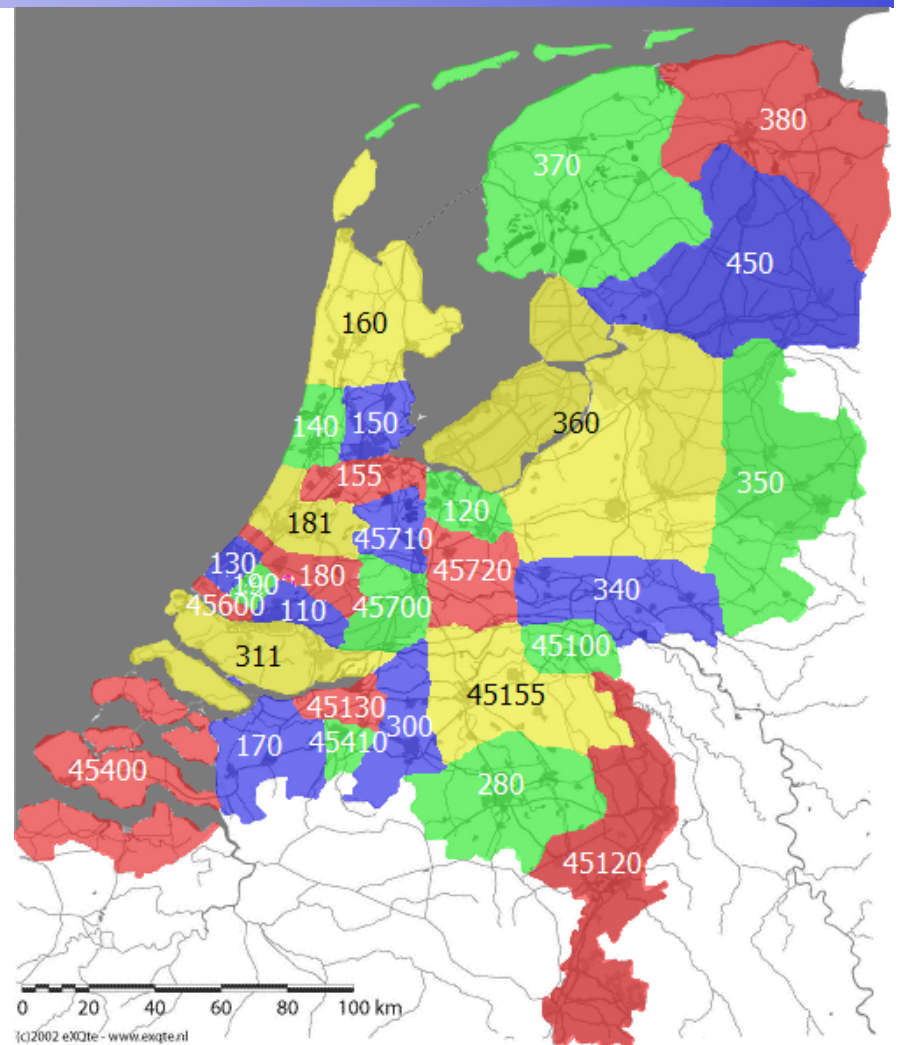
Hybrid method (e.g. GSM, 3G, LTE)

- ❑ Mobile sends location update on LA crossing, or after certain period without LA change.
- ❑ Allows system to recover from database failure, and to clean database

Location Areas in NL (2002)

KPN

T-Mobile

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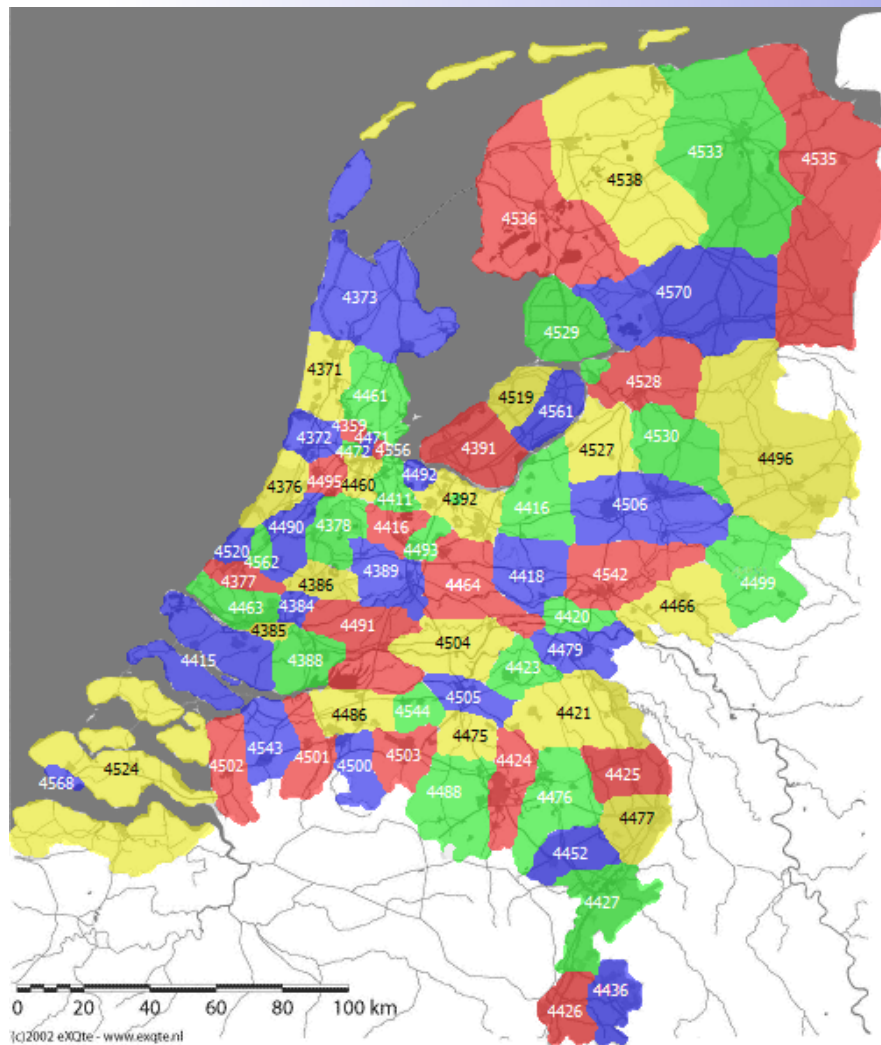
Paging

Broadcasting by base stations in the location area of id of mobile, so that mobile will contact the network (page reply).

- Blank polling (GSM)
    - Broadcast paging messages on all BSs in LA simultaneously
    - Short delay
    - High paging load
- Sequential polling
    - Try different (sets of) BSs sequentially
        - BS(s) with highest likelihood first
        (e.g., BS from which last LU was issued first)
    - Less paging load
    - Higher delay

Location area size optimization

Incoming call →

- ❑ Lookup location area in database
- ❑ Perform paging in location area

Optimal location area size depends on

- ❑ Cost of location update procedure vs. paging procedure
- ❑ Incoming call rate
- ❑ User/mobile velocity

Terminology:
- ❑ Location Area = Routing Area (data) = Tracking Area (LTE)

Database architecture for location management

Home Database
- ❑ Stores info about all subscribed mobiles/users:
  - Id
  - Location (e.g., visitor database id)
  - access rights
  - authentication info (possibly in separate authentication center)
- ❑ Starting point for finding the mobile/user
- ❑ Can be distributed, but user id leads to unique Home Database

  GSM: Home Location Register (HLR)

  Mobile IP: Home Agent (HA)

Visitor Database
- ❑ Stores info about mobiles/users in its location areas
  - Partial copy of home database info for mobile/user
  - Location area of mobile/user
- ❑ Usually many (sometimes hierarchical)

  GSM: Visitor Location Register (VLR)

  Mobile IP: Foreign Agent (FA) (not IPv6)