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

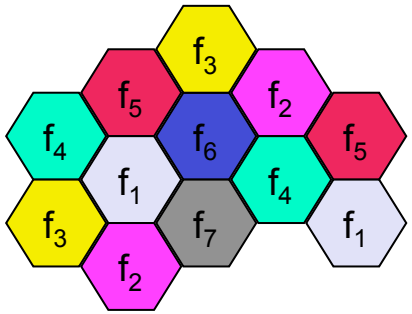
- Introduction
- Cell layout
- Interference
- Capacity Improvement

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

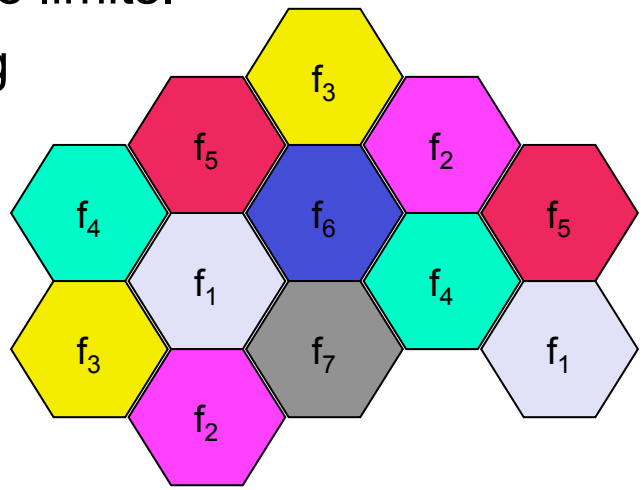
- Solves the problem of spectral congestion and increases user capacity.
- Offer very high capacity in a limited spectrum
- Reuse of radio channel in different cells.
- Enable a fixed number of channels to serve an arbitrarily large number of users by reusing the channel throughout the coverage region.



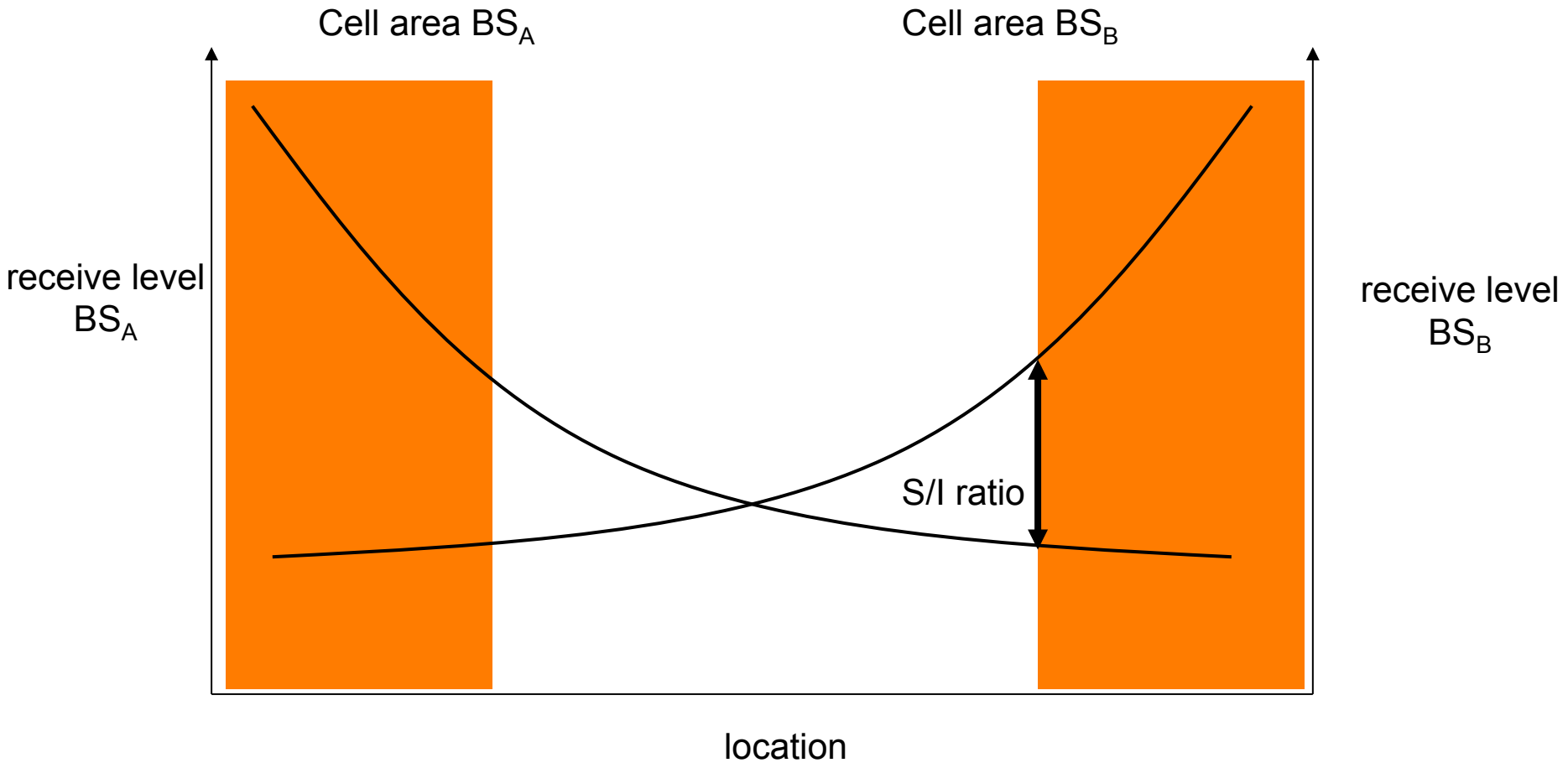
Basic principles of cellular systems

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

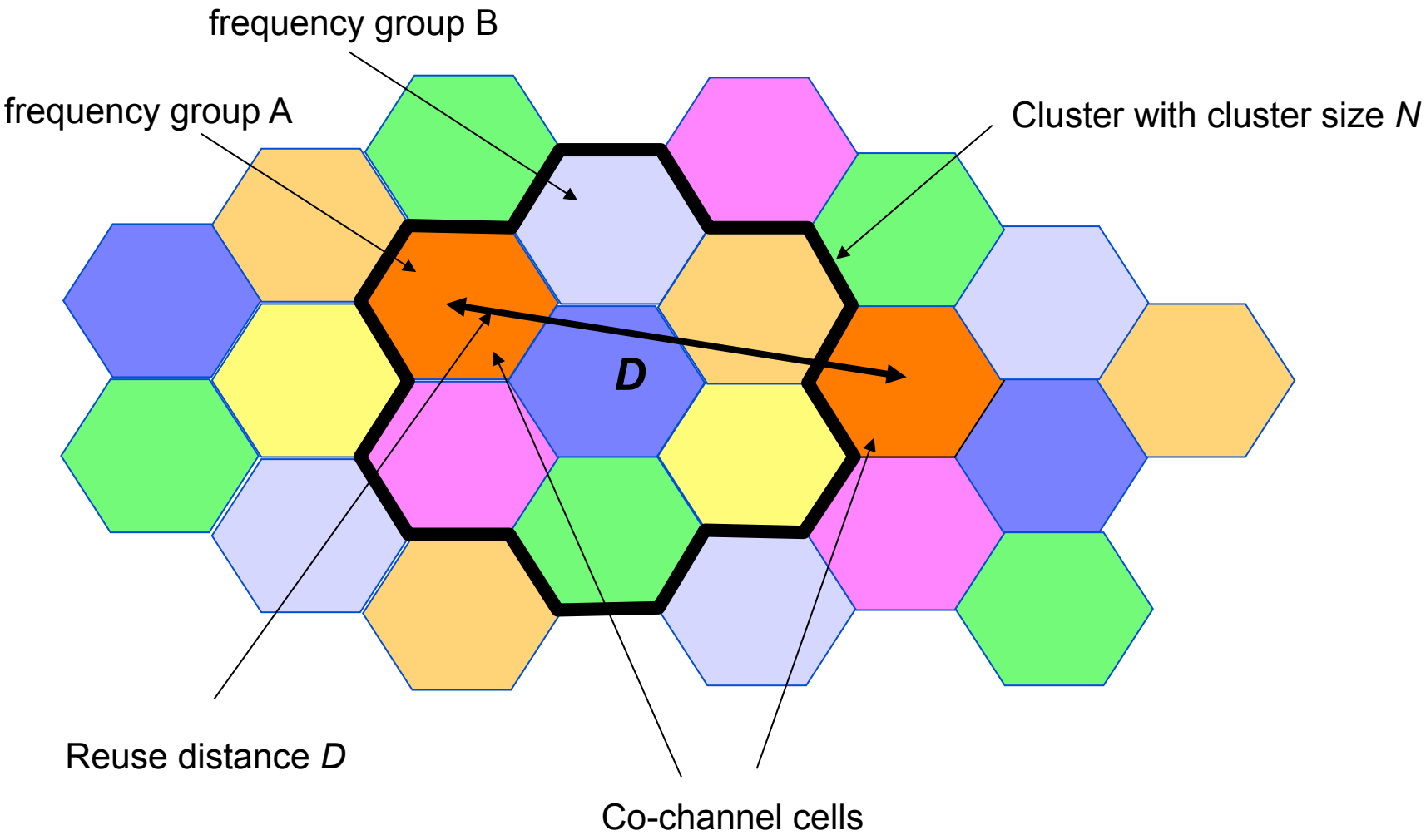
- Each cellular base station is allocated a group of radio channels within a small geographic area called a cell.
- Neighboring cells are assigned different channel groups.
- By limiting the coverage area to within the boundary of the cell, the channel groups may be reused to cover different cells.
- Keep interference levels within tolerable limits.
- Frequency reuse or frequency planning



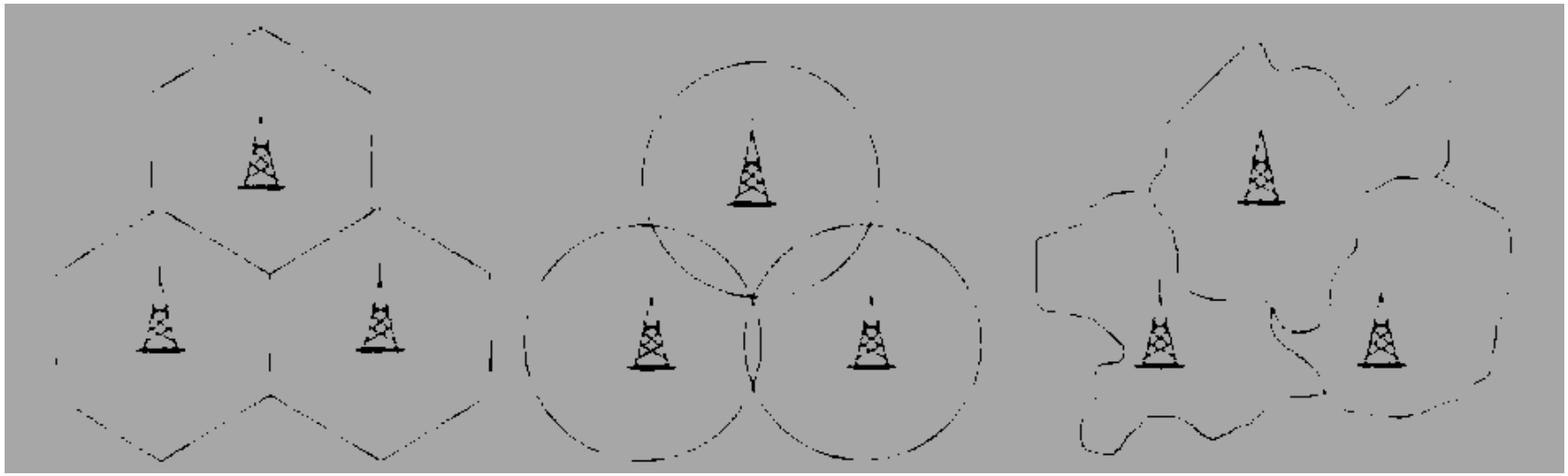
Cell area vs. Signal to Interference Ratio



Cluster size and reuse distance



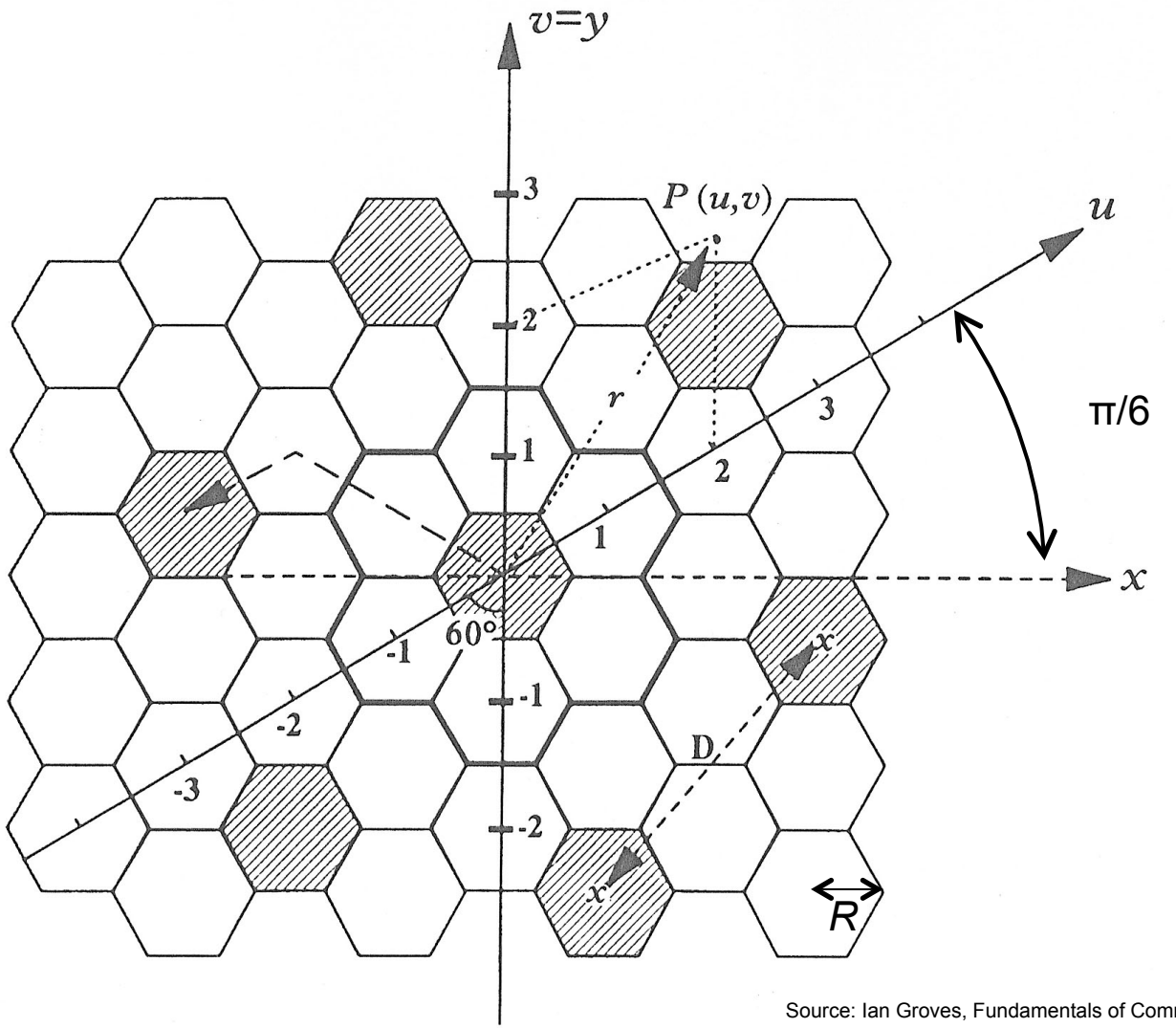
Differences between theoretical and real coverage



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:

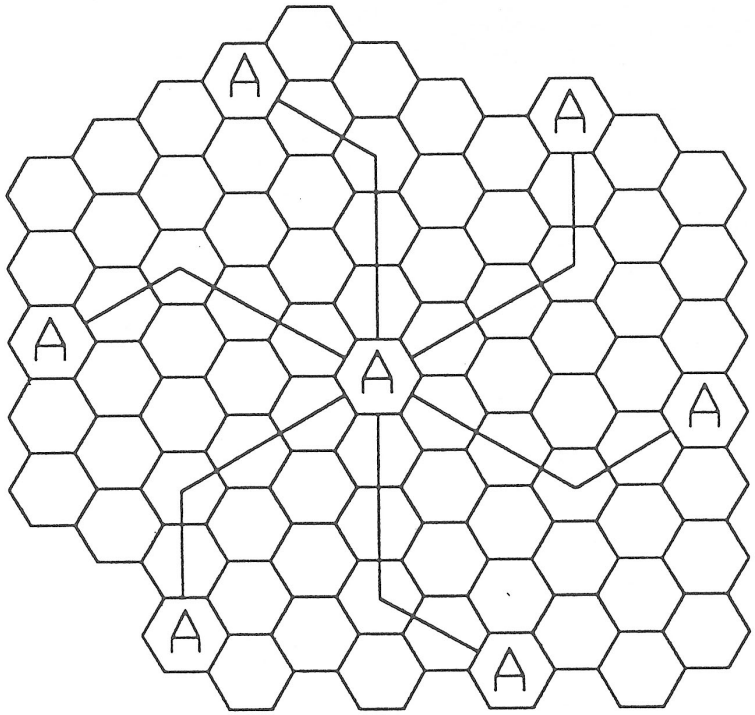
$$N = \left(\frac{D}{\sqrt{3}R}\right)^2 = i^2 + j^2 + ij$$

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

Source: Ian Groves, Fundamentals of Communications (course slides)

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
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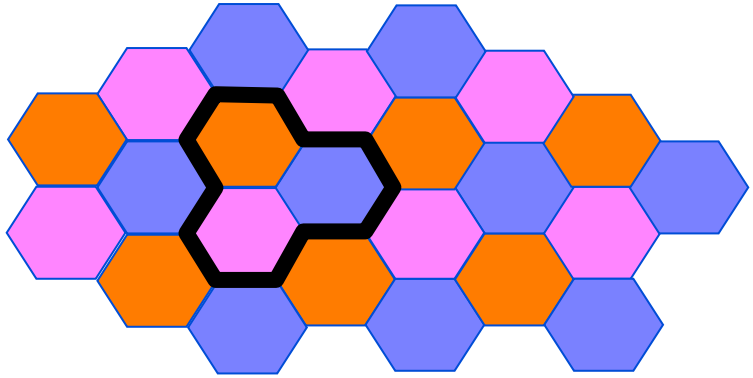
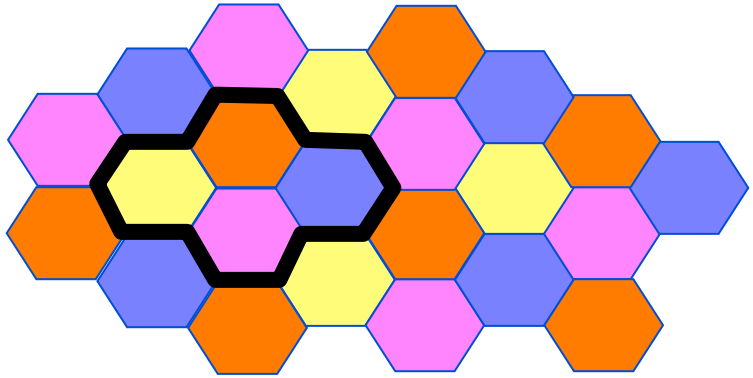


N = 3



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
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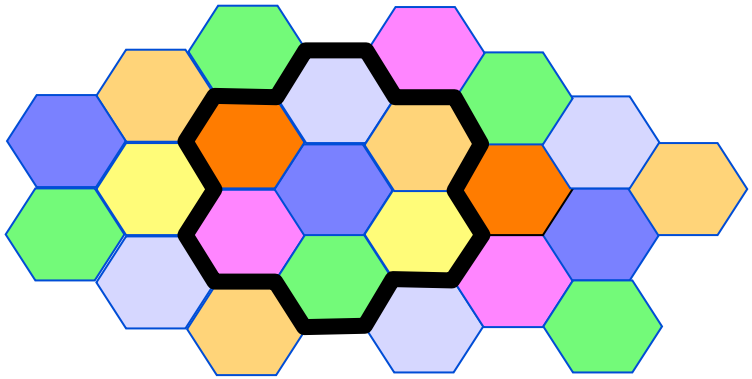
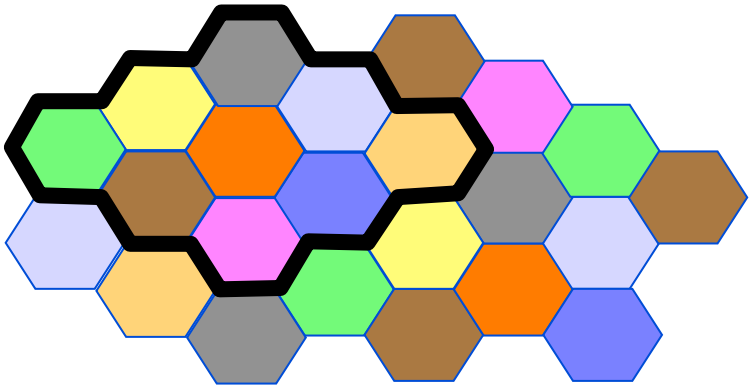
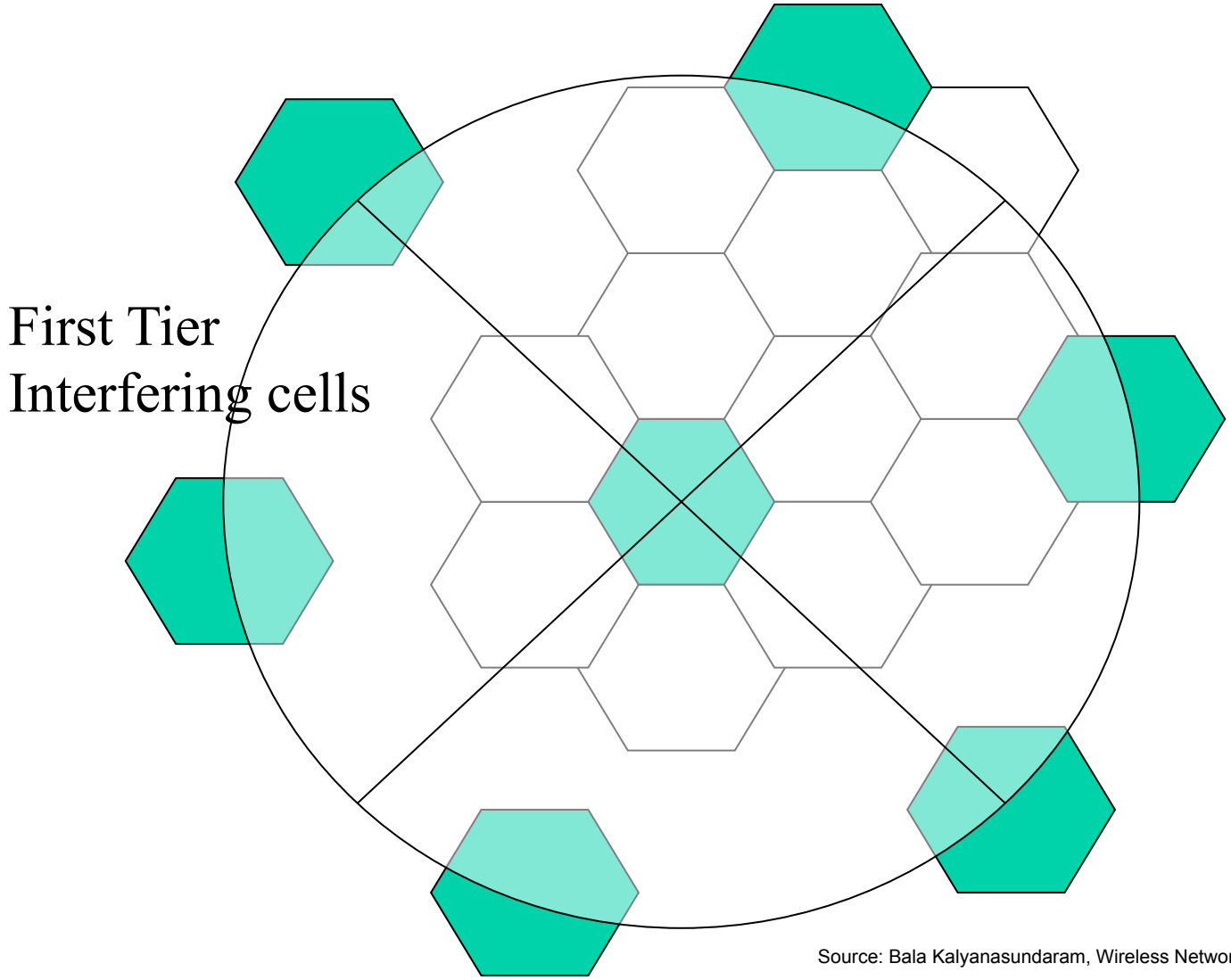


N = 7



N = 9

Co-channel Interference (1)



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

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

- where ν (nu) is the path loss exponent

In dB:

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

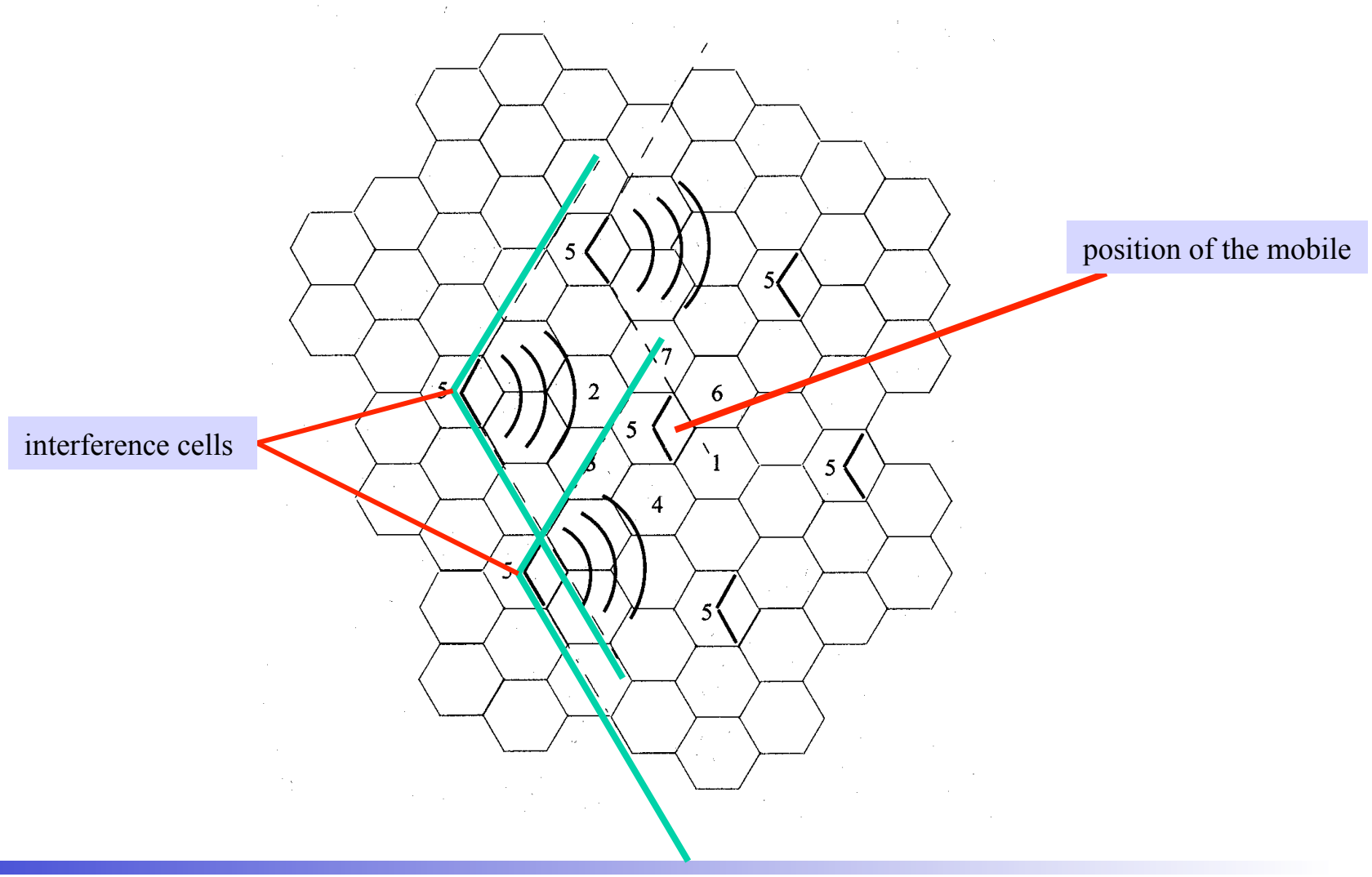
- *S*/*I* is independent of cell size!

S/I for different cluster sizes

For ν=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



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

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

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
- 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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  - Handover types and phases
  - Handover triggering algorithms
  - Hard / seamless / soft handover
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  - 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
  - GSM cell is between 100 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 = *T*1: pos. A

  Threshold = *T*2: pos. B

  Threshold = *T*3: 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

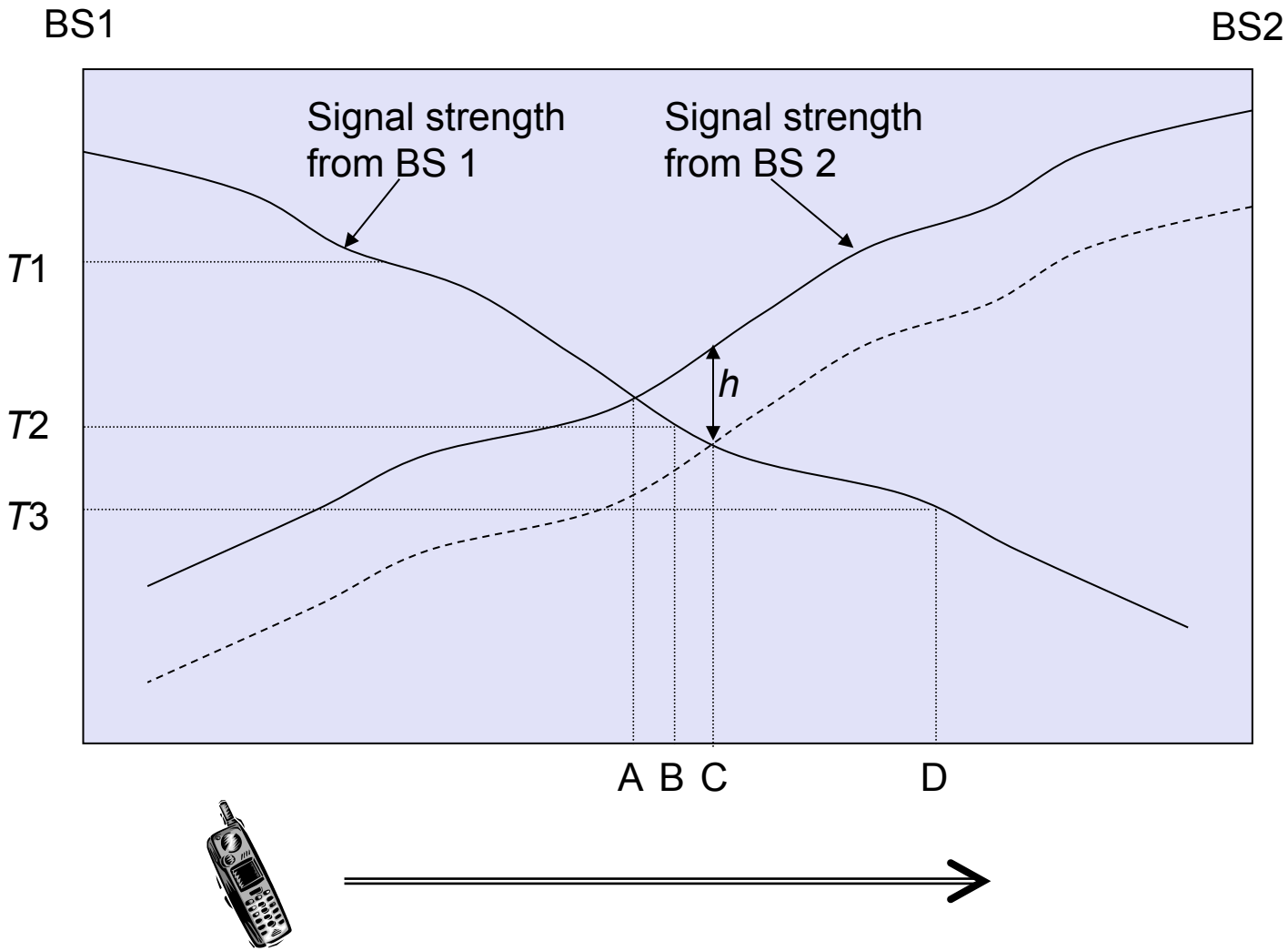
  Threshold = *T*1 or *T*2: pos. C

  Threshold = *T*3: pos D

Prediction techniques

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

Handover triggering algorithms (3)



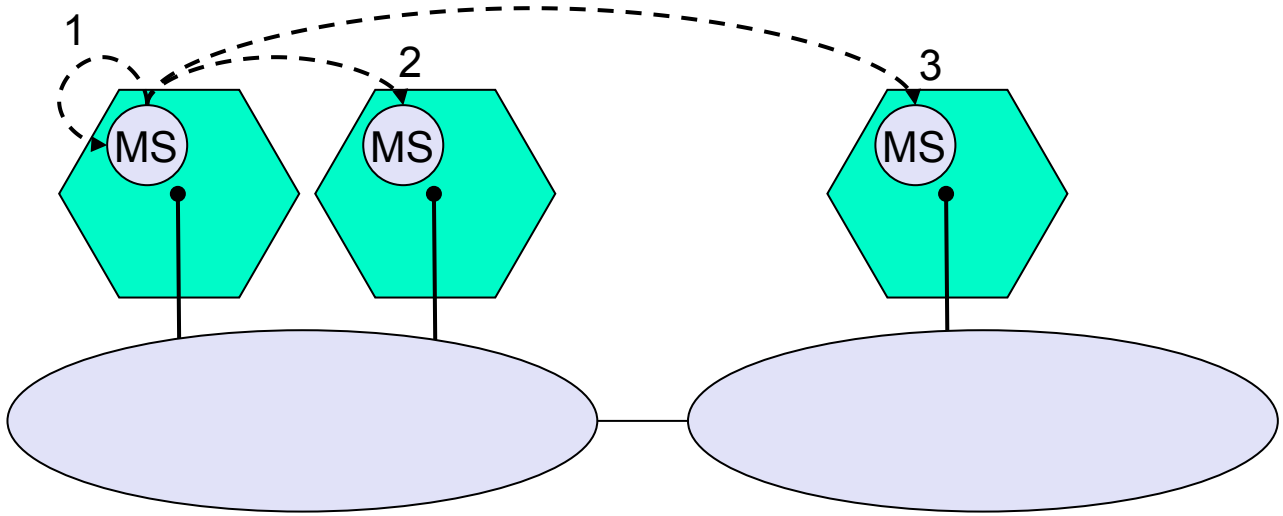
Different handover execution procedures:

- 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 GSM and UMTS

More types later



Layered cell structures

Small cells:

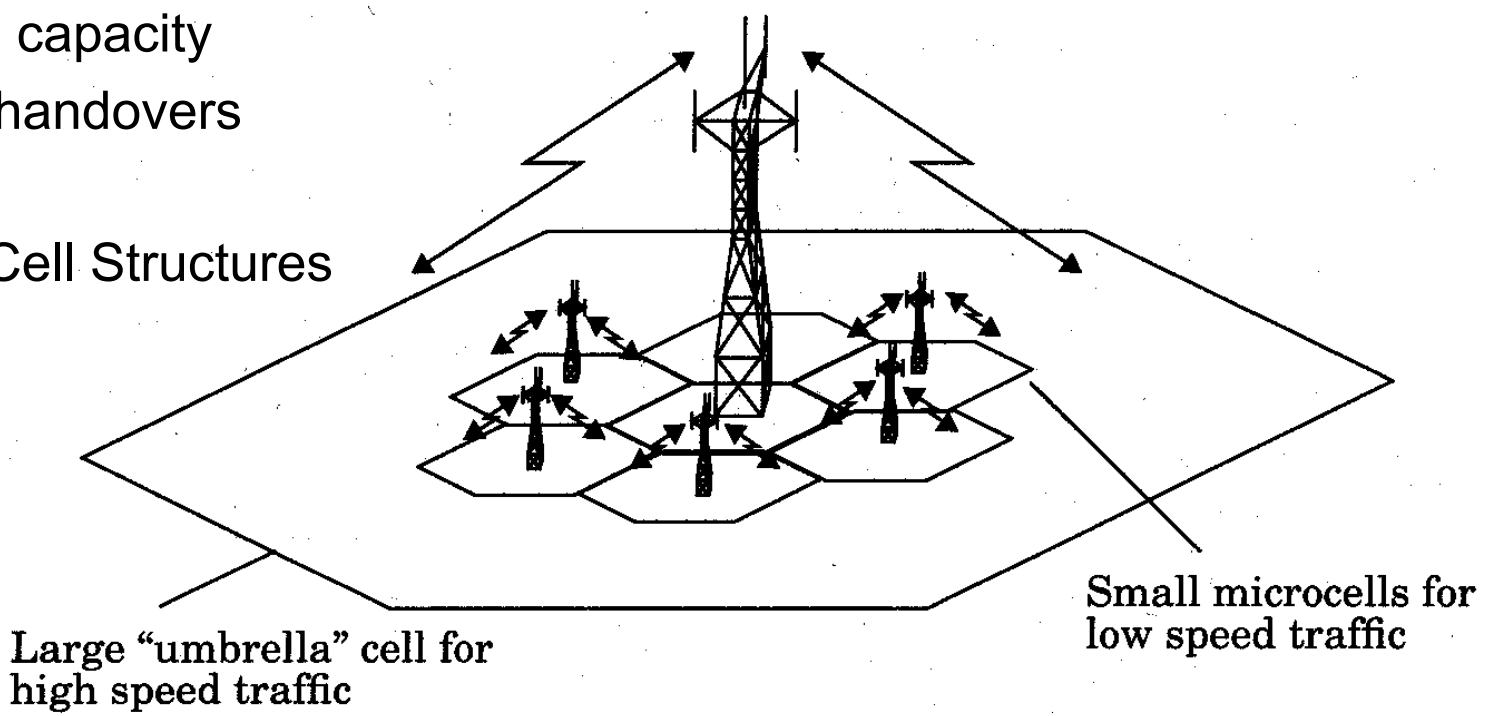
- high capacity
- many handovers for fast-moving mobiles

Large cells:

- limited capacity
- fewer handovers

Solution:

Layered Cell Structures



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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

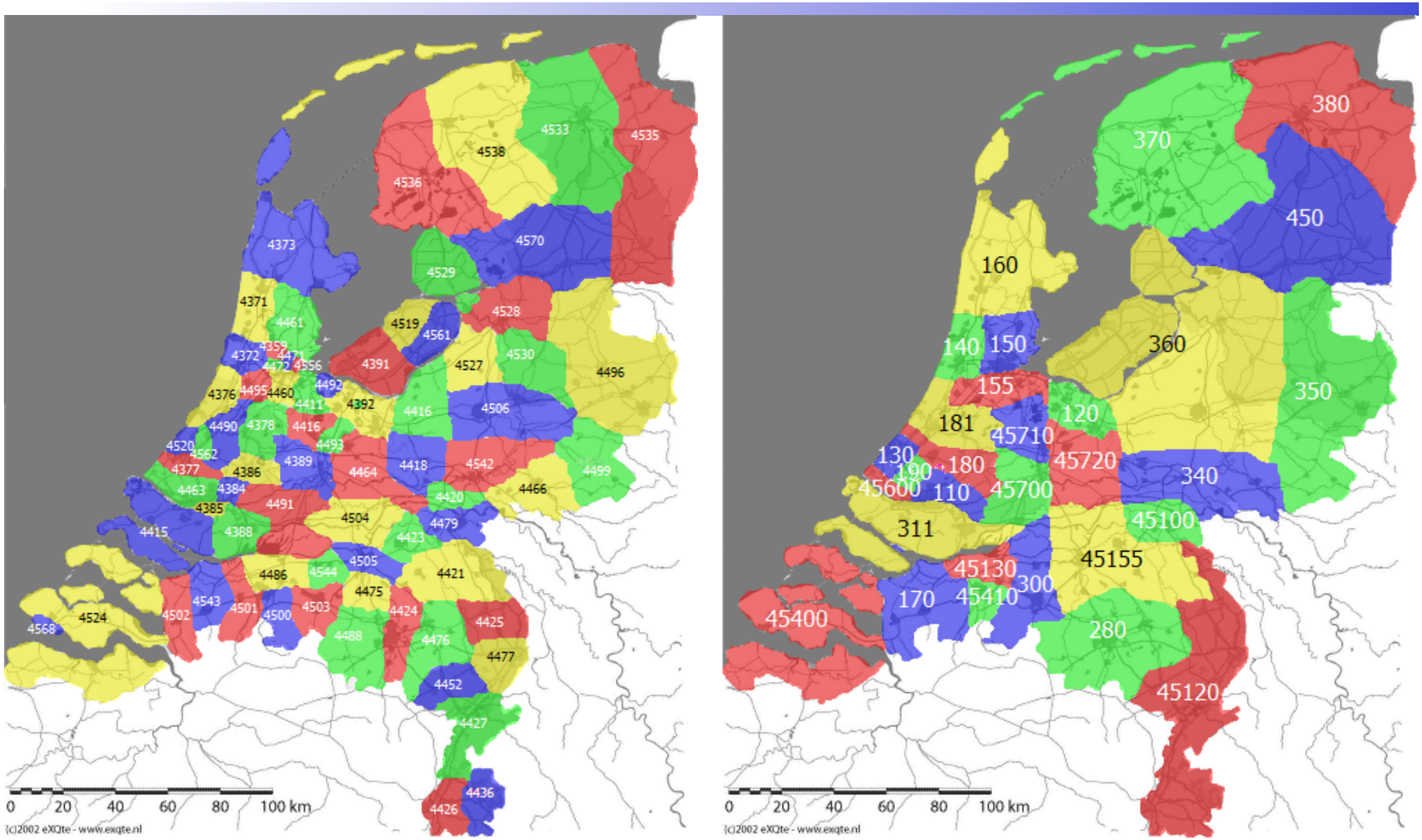
Location updating on LA crossing

- 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)

- 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

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

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)