Mobile Networking

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1393

Main elements, Cells, Frequency Reuse, Capacity, …

CELLULAR ARCHITECTURES AND CONCEPTS

Contents

- Main Architecture
  - Cellular Network Architecture
  - History of Cellular Networks (1st, 2nd, 3rd and 4th Generation)
  - Operation of Cellular Systems
- Cellular Network Organization
  - Hexagonal Patterns
  - Frequency Reuse and Capacity
- Mobility Management
  - Handoff Strategies
- Traffic Engineering

Cellular Networks Generations

- **1G:** analog systems → not in use anymore
- **2G:** GSM (introduced in 1992): FDMA/TDMA (900 and 1800MHz)
  - 2.5G: with GPRS: packet switching, extended to E-GPRS (nicknamed EDGE)
- **3G:** UMTS (introduced in 2002): CDMA (2100 MHz)
  - 3.5G: with HSPDA (up to 14.4Mb/s); with HSPA+ (up to 84Mb/s)
- **4G:** LTE (being introduced in 2013): OFDMA (800 and 2600MHz, then technology neutrality); up to 100Mb/s

- **GPRS:** General Packet Radio Service
- **HSPDA:** High Speed Downlink Packet Access
- **LTE:** Long Term Evolution

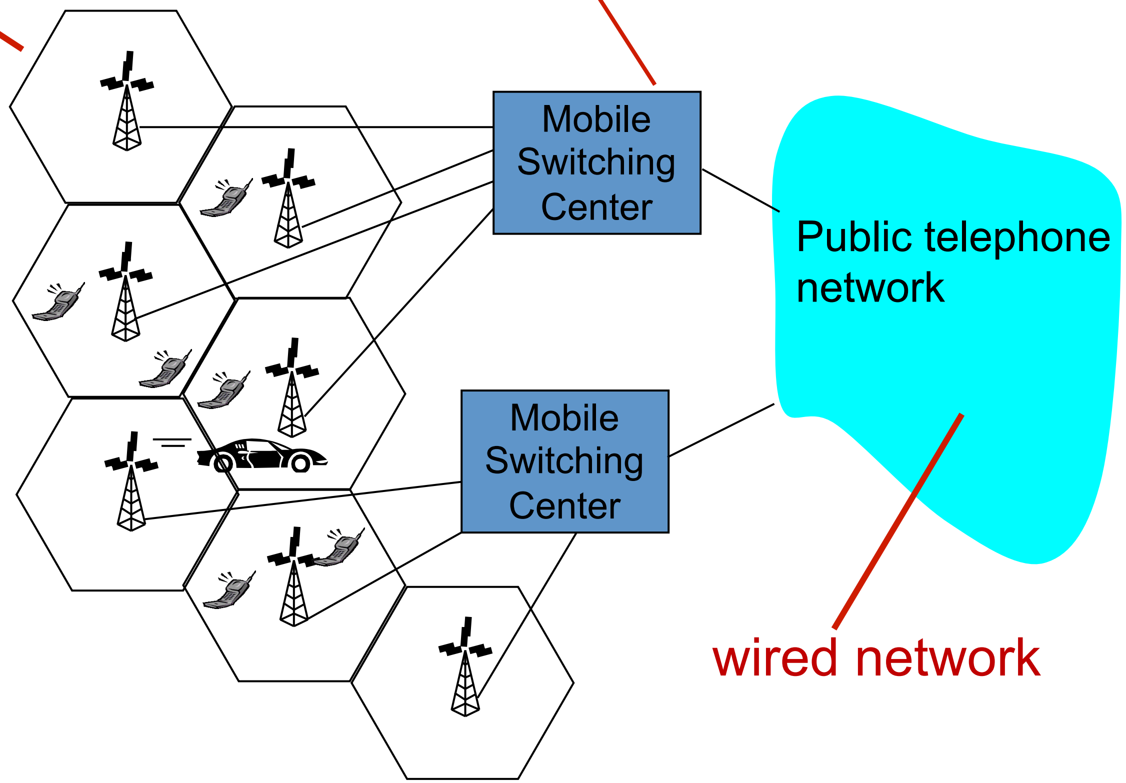
Components of Cellular Network Architecture

MSC

- connects cells to wired tel. net.
- manages call setup (more later!)
- handles mobility (more later!)

cell

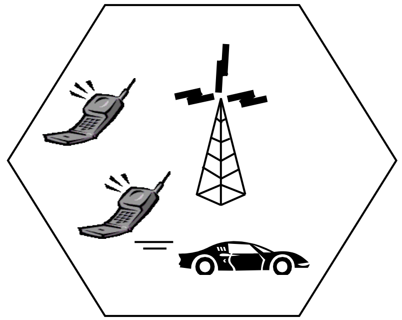
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

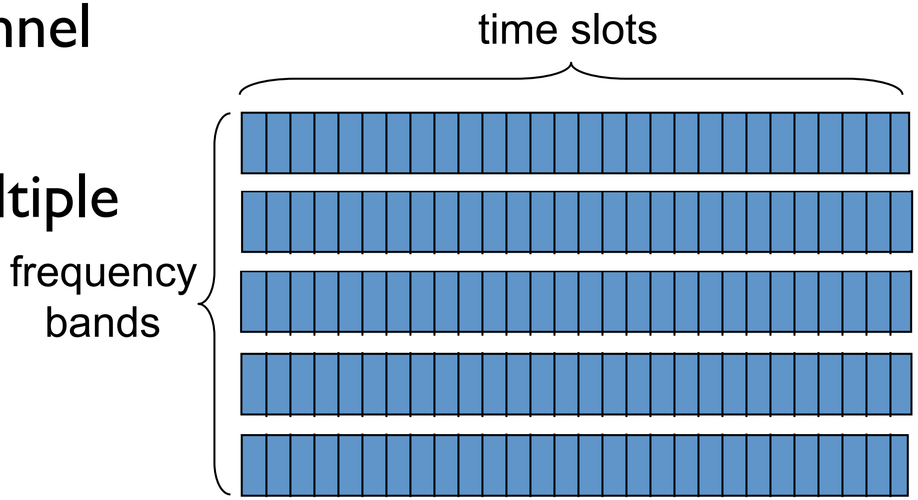


Cellular Networks: the First Hop

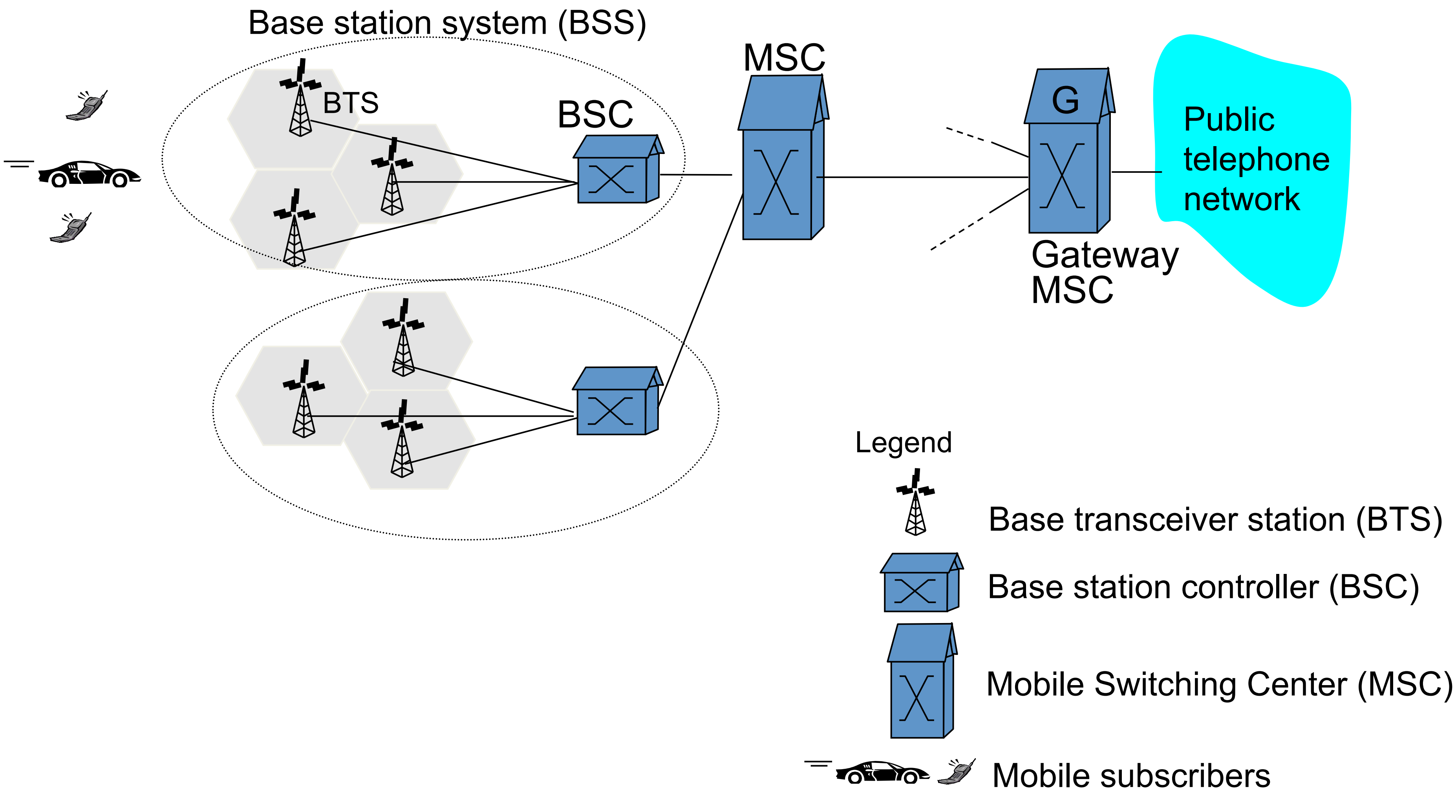
Two techniques for sharing mobile-to-BS radio spectrum

- Combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access

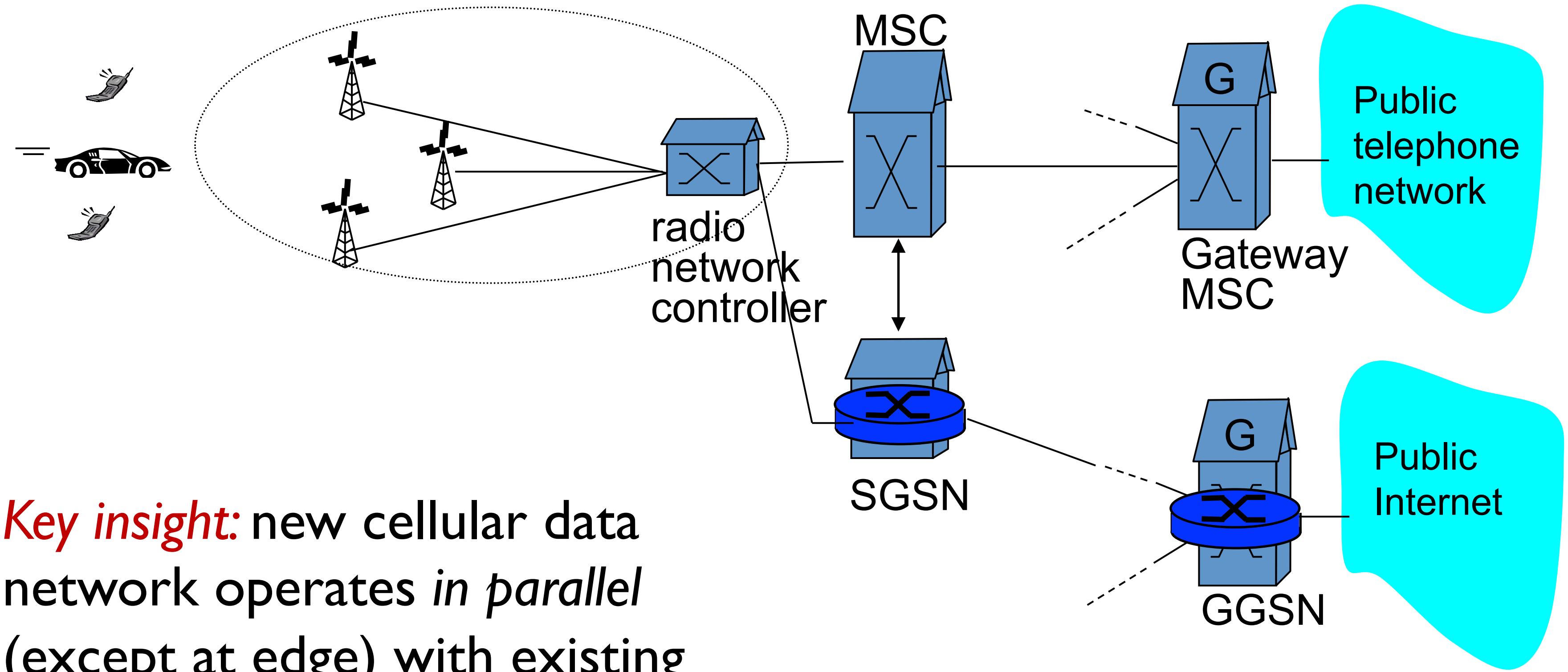




2G (voice) Network Architecture

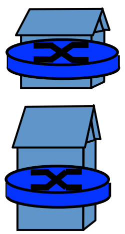


3G (voice+data) Network Architecture

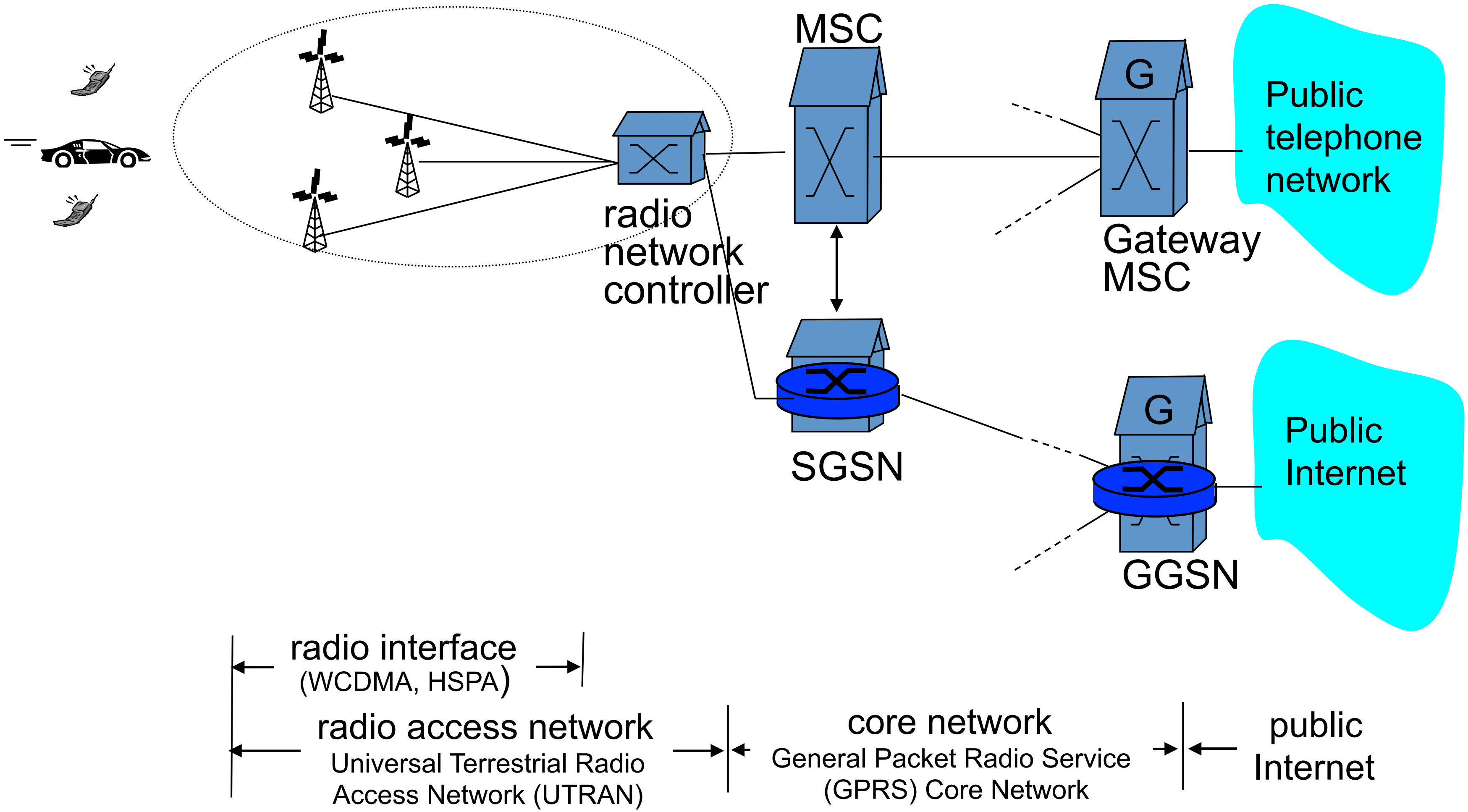


Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

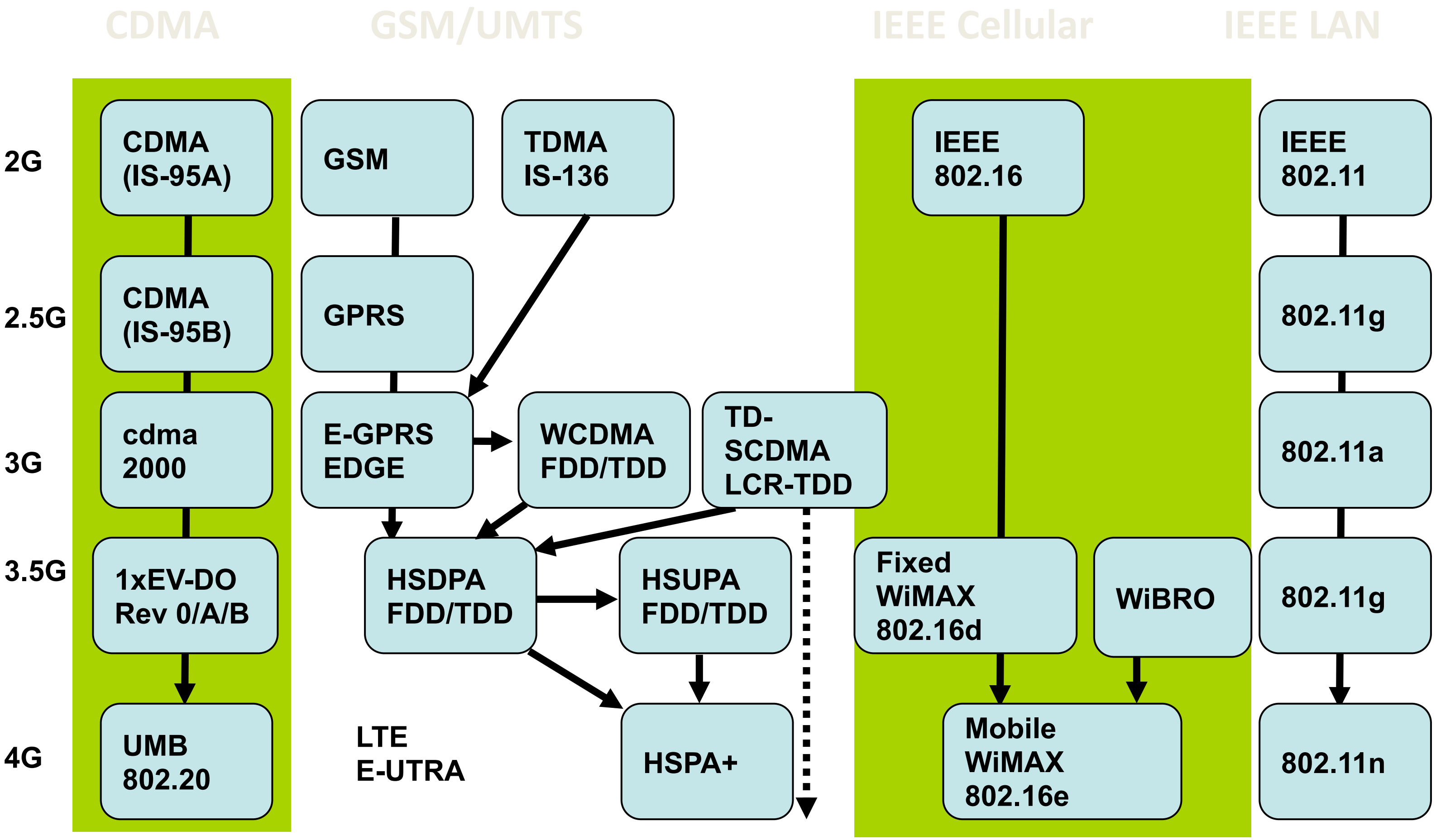
- voice network unchanged in core
- data network operates in parallel



3G (voice+data) Network Architecture

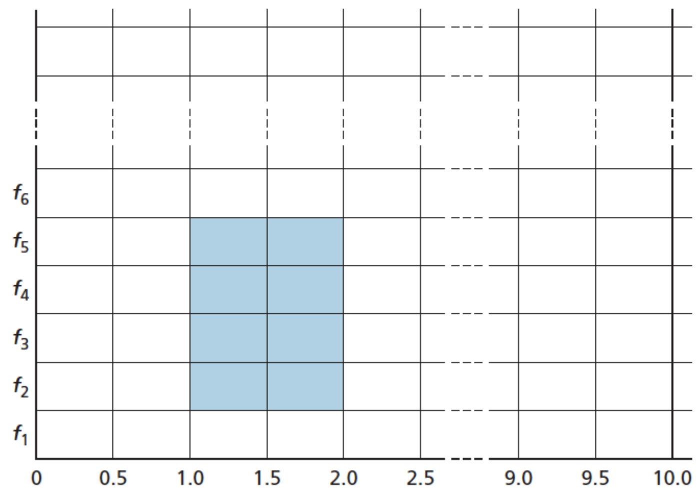


Wireless Technology Evolution to 4G

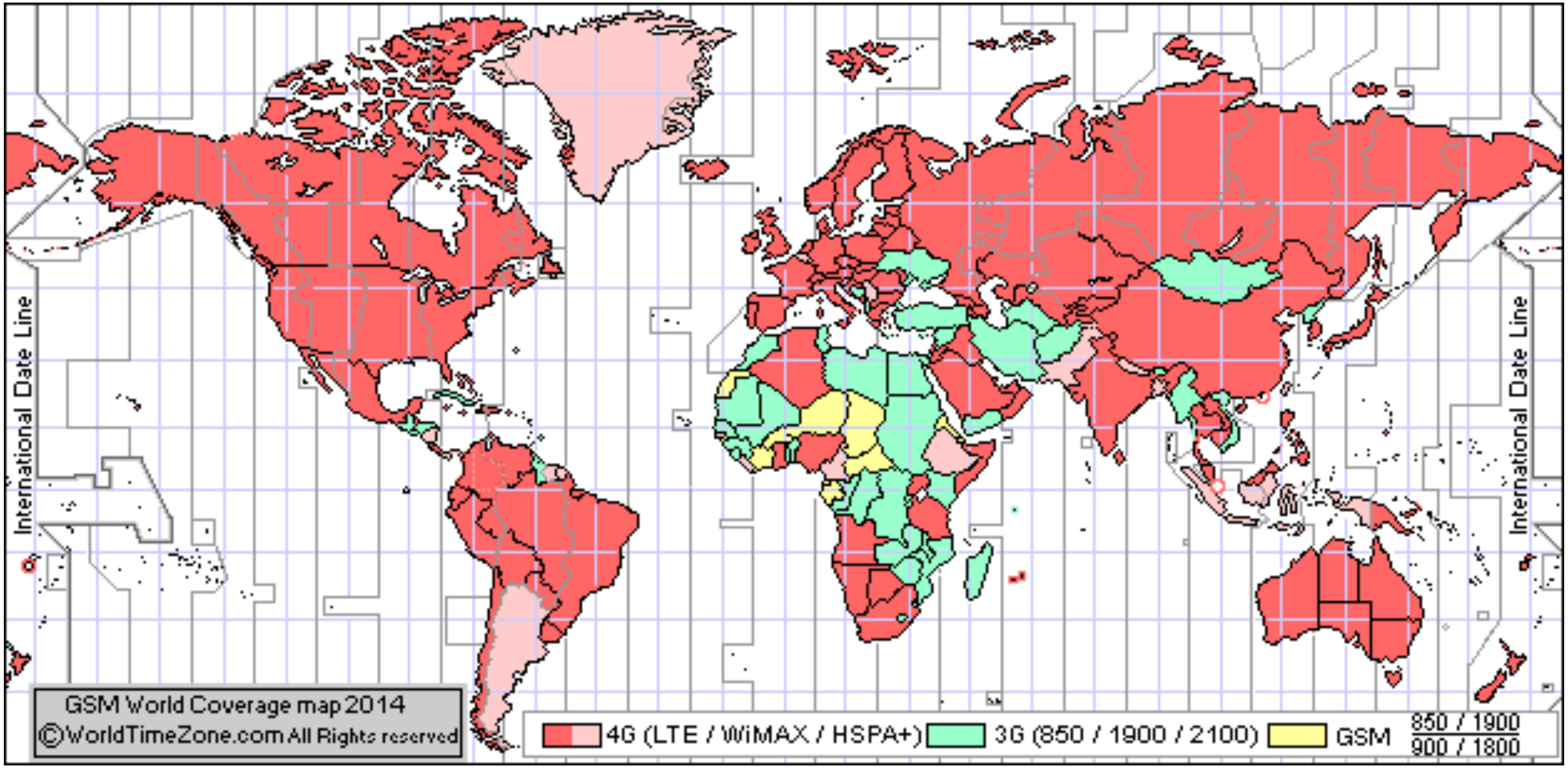


4G: LTE

- **All-IP core network**
- Need to provide QoS for VoIP:
  - **Evolved Packet Core:**
    - Manage network resources to provide high quality of service
    - Separation between the network control (Mobility) and user data planes
    - Allows multiple types of radio access networks (2G and 3G) to attach
  - **LTE Radio Access Network:**
    - OFDM
    - MIMO



LTE (Long Term Evolution) Coverage



LTE Penetration and Speed

Data speeds of LTE Advanced

	LTE Advanced
Peak download	1 Gbit/s
Peak upload	500 Mbit/s

Data speeds of LTE

	LTE
Peak download	100 Mbit/s
Peak upload	50 Mbit/s

Data speeds of WiMAX

	WiMAX
Peak download	128 Mbit/s
Peak upload	56 Mbit/s

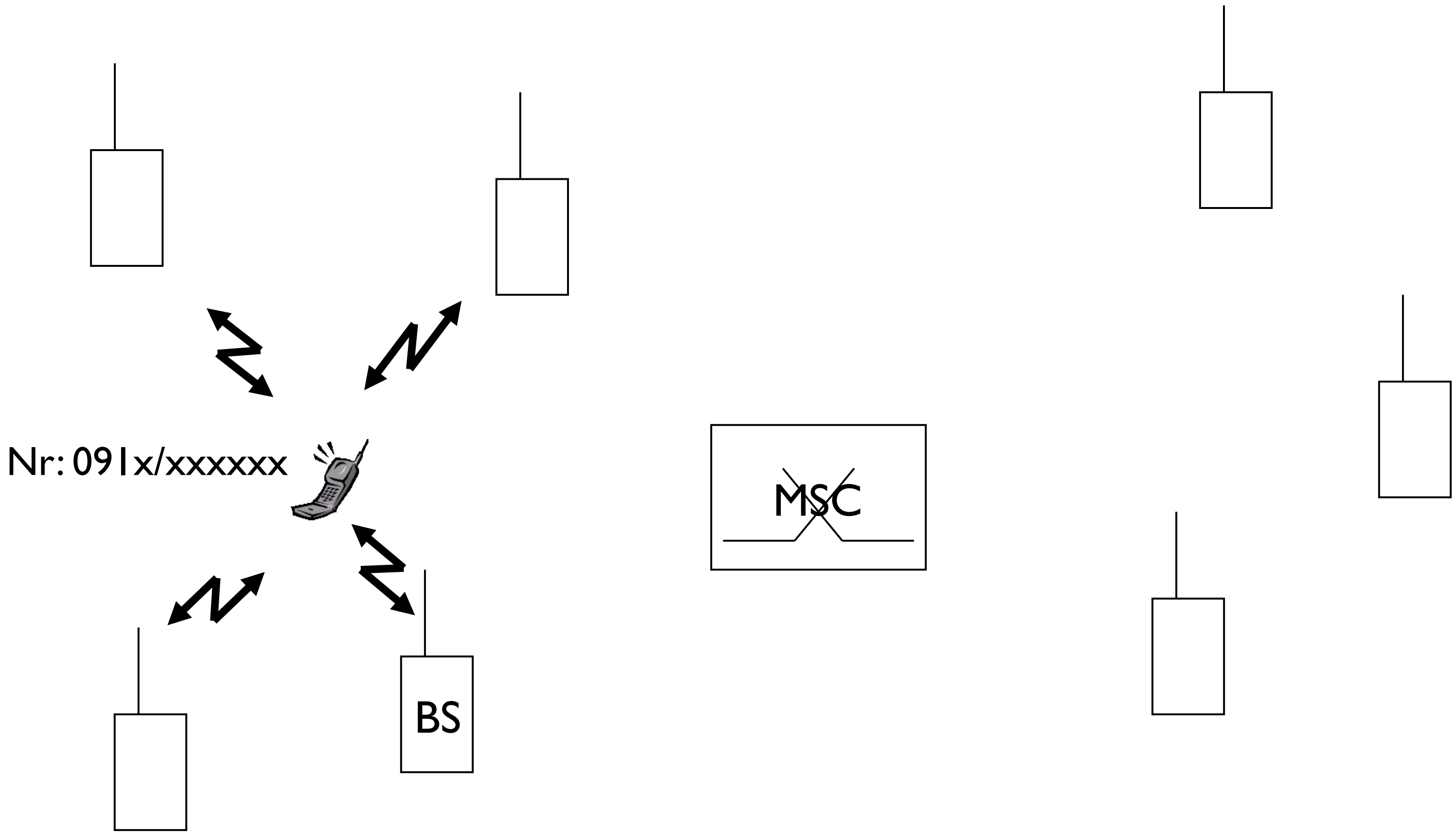
Rank	Country/Territory	Penetration
1	South Korea	62.0%
2	Japan	21.3%
3	Australia	21.1%
4	United States	19.0%
5	Sweden	14.0%
6	Canada	8.0%
7	United Kingdom	5.0%
8	Germany	3.0%
9	Russia	2.0%
10	Philippines	1.0%

In February 2007, the Japanese company NTT DoCoMo tested a 4G communication system prototype with 4×4 MIMO called VSF-OFCDM at 100 Mbit/s while moving, and 1 Gbit/s while stationary.

NTT DoCoMo completed a trial in which they reached a maximum packet transmission rate of approximately 5 Gbit/s in the downlink with 12×12.

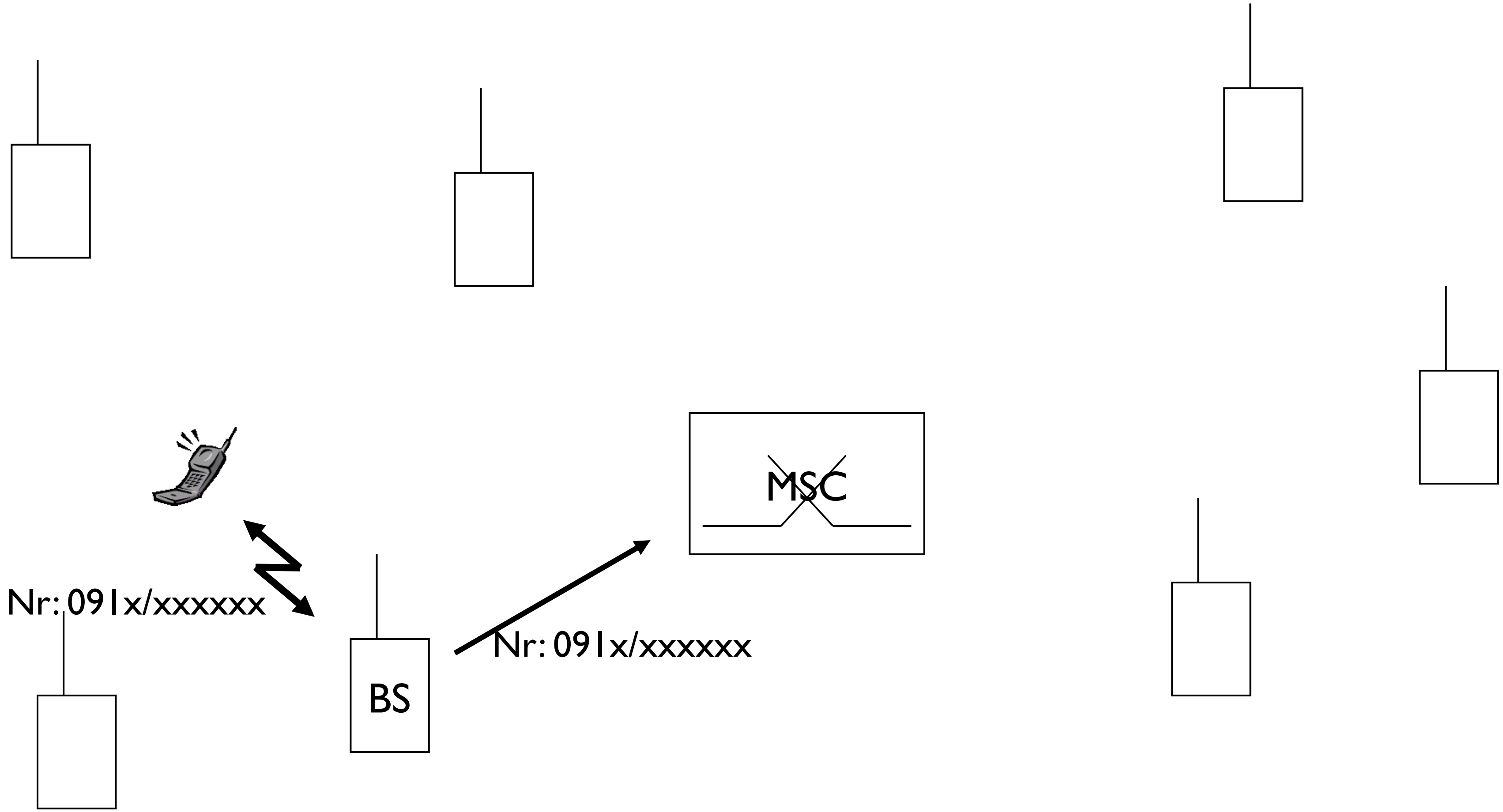
OPERATION OF CELLULAR NETWORKS

Registration

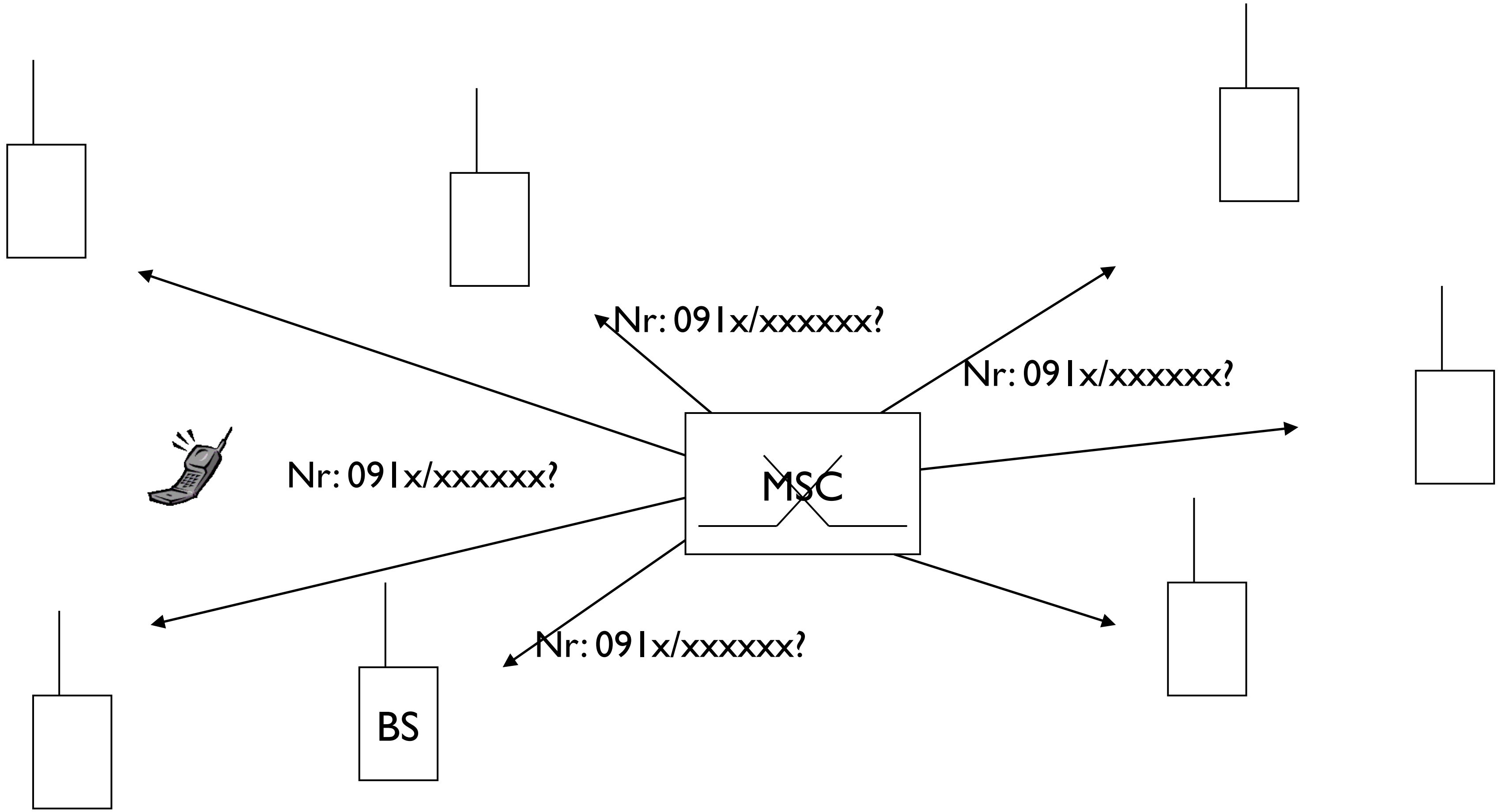


Tune on the strongest signal

Service Request

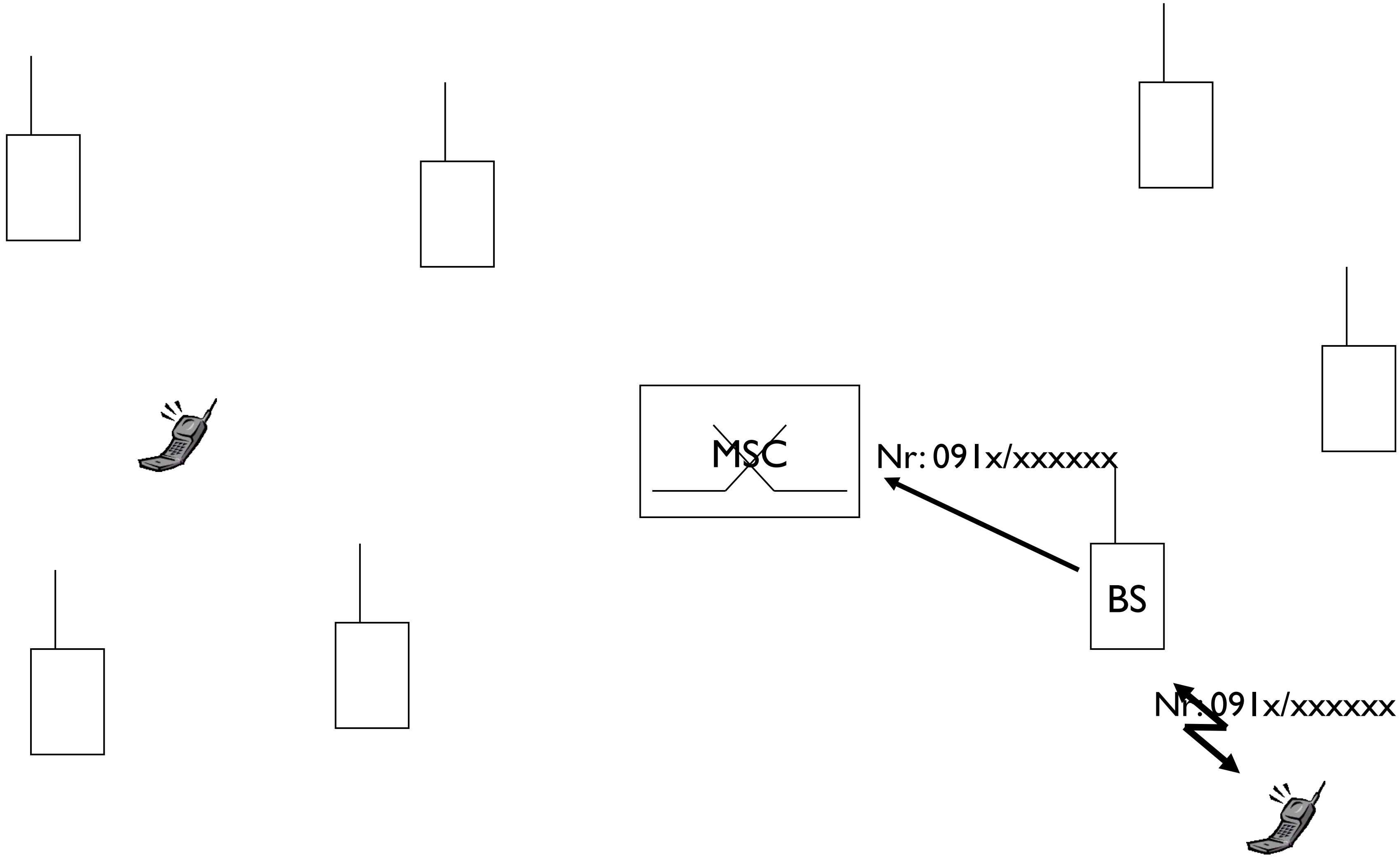


Paging

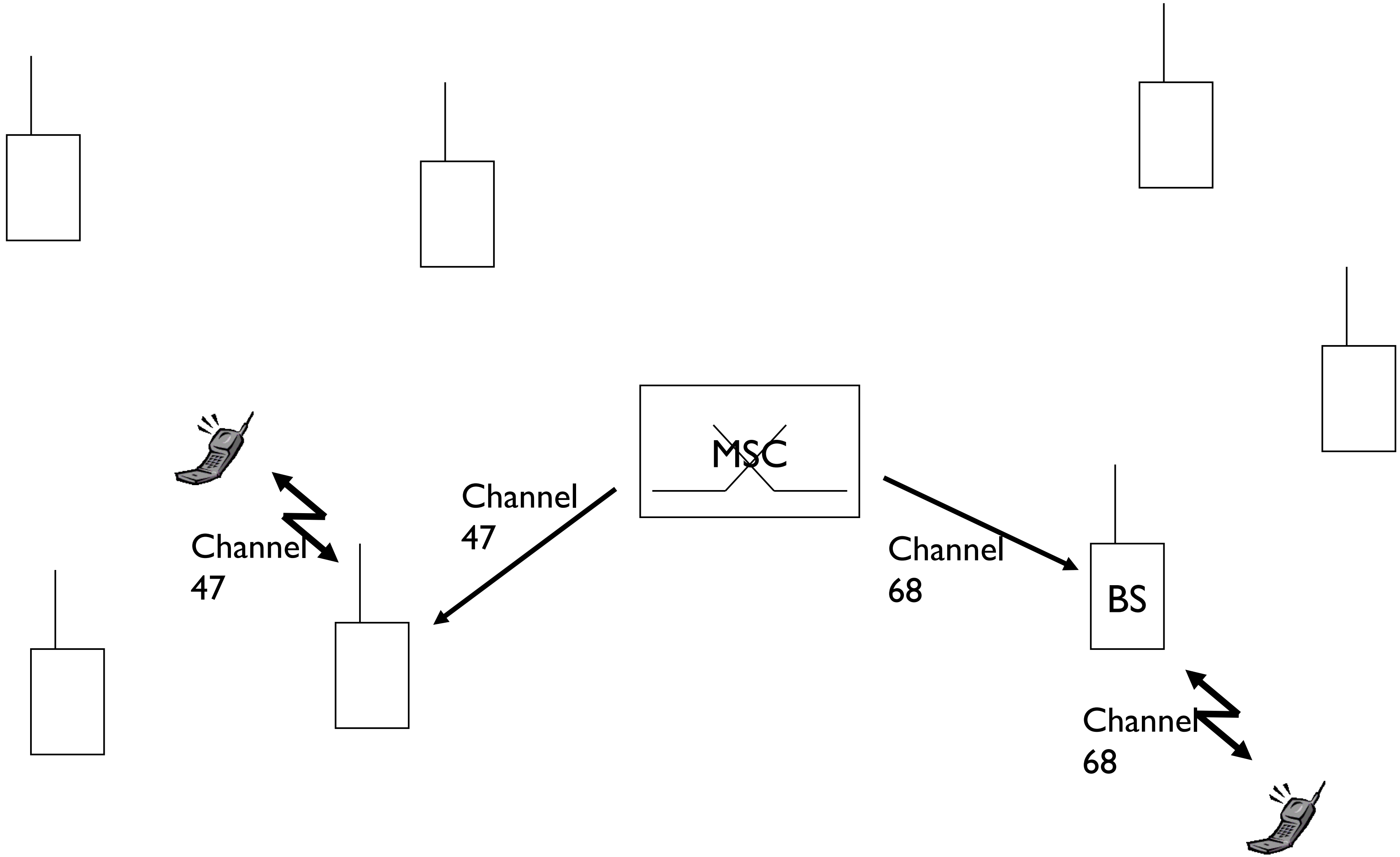


Note: paging makes sense only over a *small* area

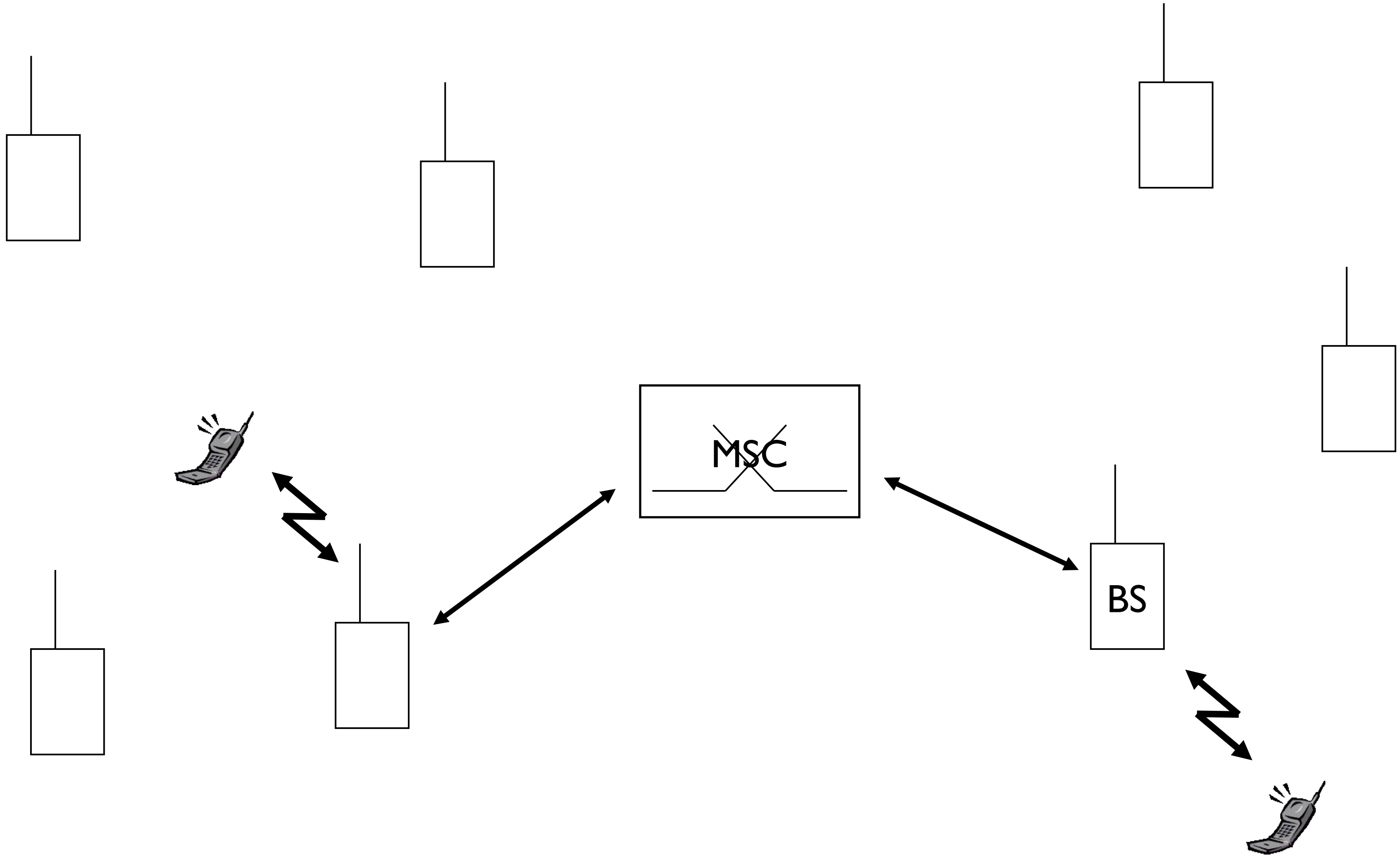
Response



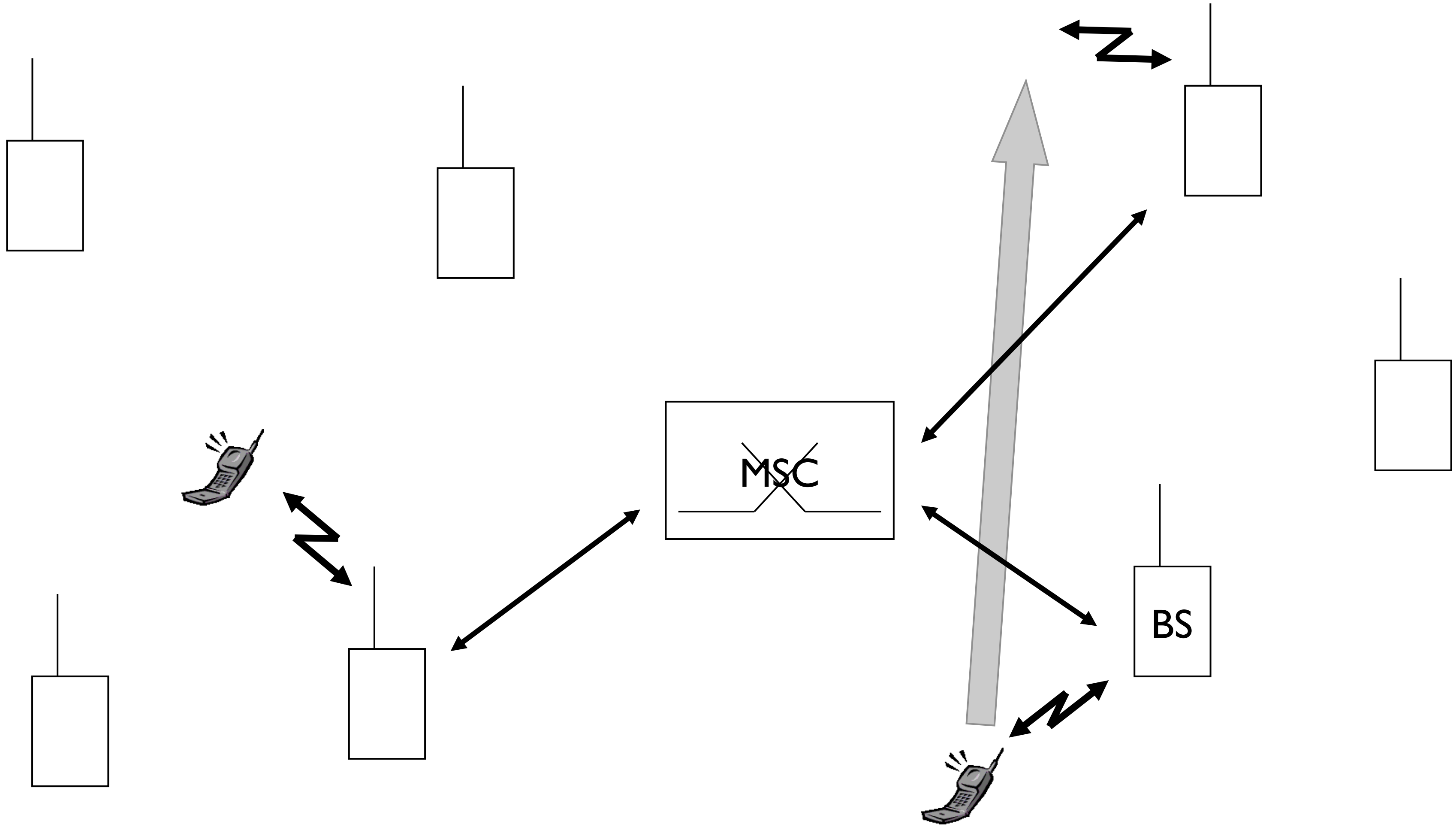
Channel Assignment



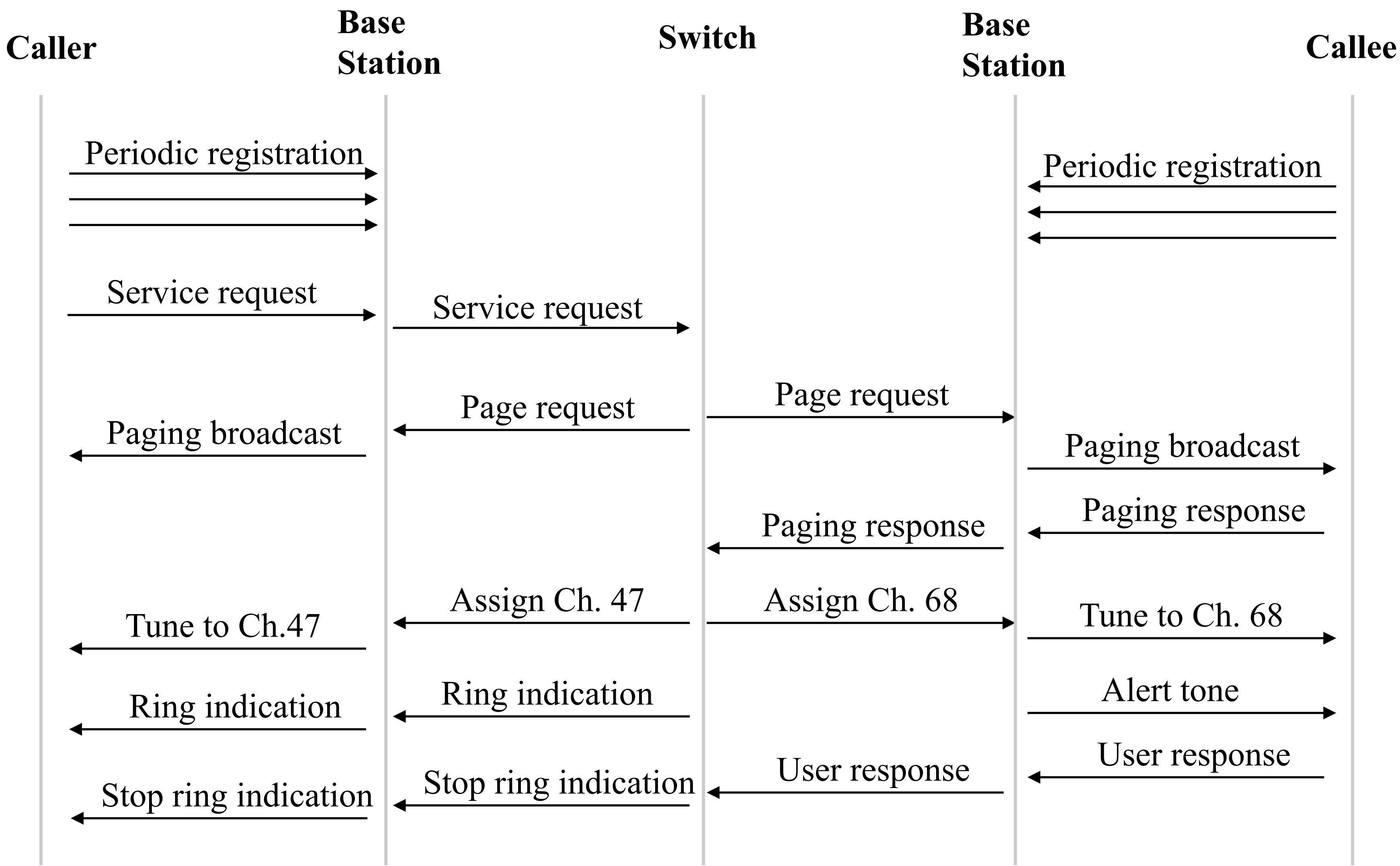
Conversation



Handover (or Handoff)



Message Sequence Chart



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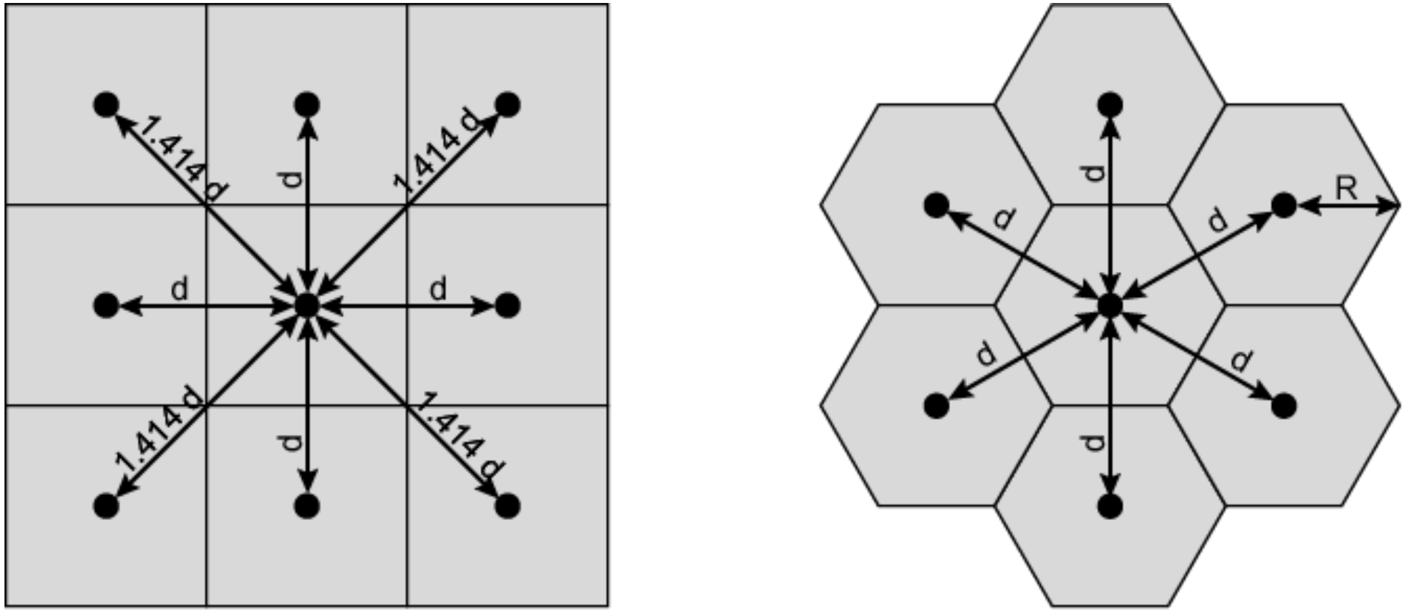
Cellular Networks: Why Hexagonals?



(a) Square pattern

(b) Hexagonal pattern

Area of the hexagon: $1.5R^2\sqrt{3}$

Distance between adjacent cells: $d = \sqrt{3}R$

Note: In practice, a precise hexagonal pattern is not used. Variations from the ideal are due to topographical limitations, local signal propagation conditions, and practical limitation on siting antennas

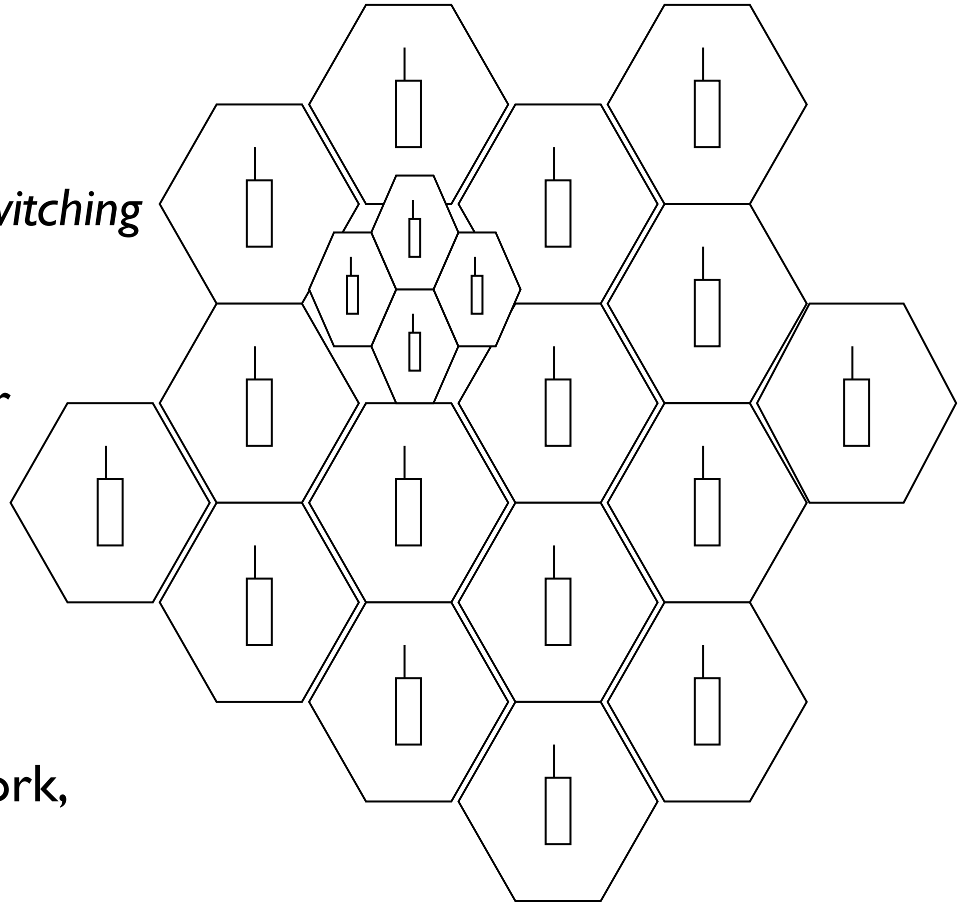
Cellular Networks

- Covered area *tesselated* in cells
  - One antenna per cell
  - Cells are controlled by *Mobile Switching Centers*

- A mobile communicates with one (or sometimes two) antennas

- Cells are modeled as hexagons
- Cells interfere with each other

- To increase the capacity of the network, increase the number of cells



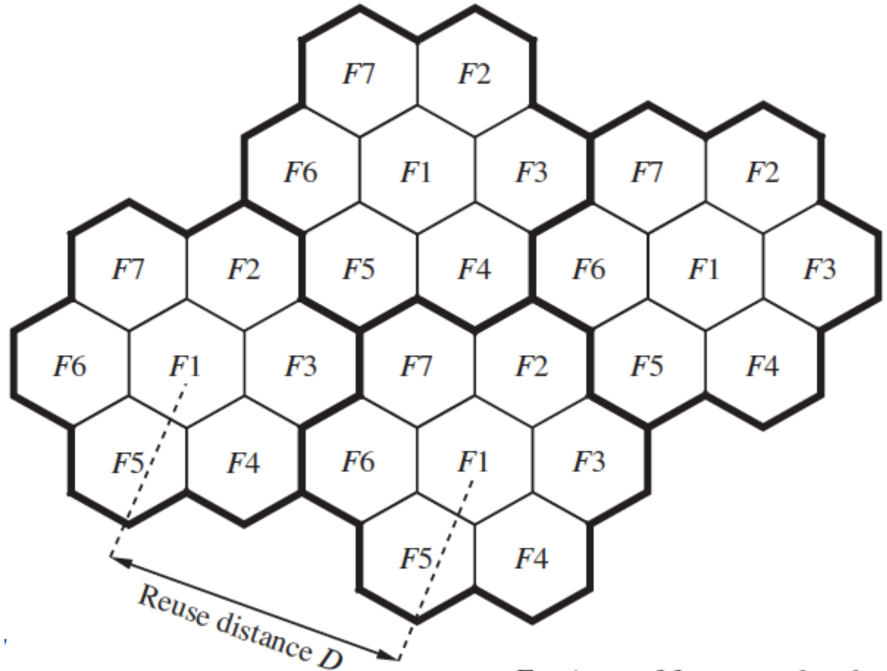
Frequency Reuse

- Cells with the same name use the same set of frequencies
- Cells are organized into clusters, e.g., the cluster size N = 7
- In order to tesselate, the geometry of hexagons is such that N can only have values which satisfy

$$\mathbf{N = i^2 + ij + j^2}$$

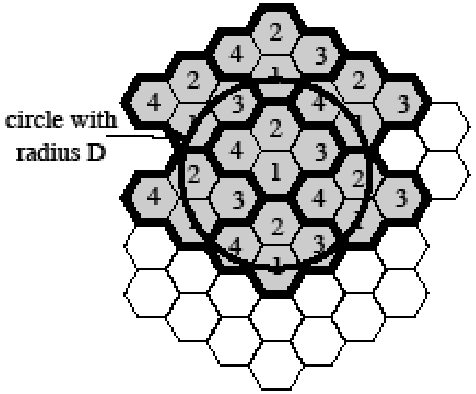
with i = 0,1,2,… and j = 0,1,2,…

Hence: N= 1, 3, 4, 7, 9, 12, 13, 16, …



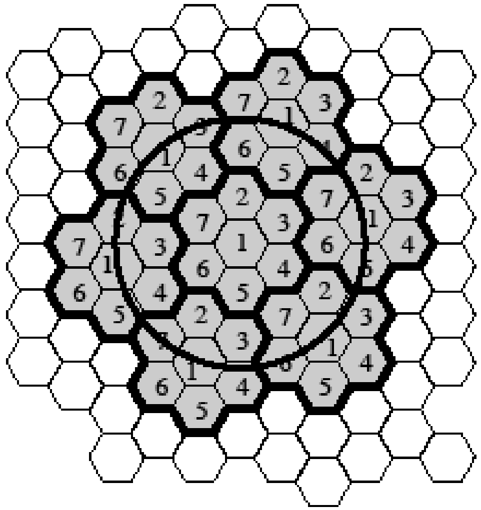
Fx: A set of frequency bands

- Channel assignment strategies
  - **Fixed:** each cell is allocated a predetermined set of channels
  - **Dynamic:** each time a call request is made, the serving base station requests a channel from the MSC



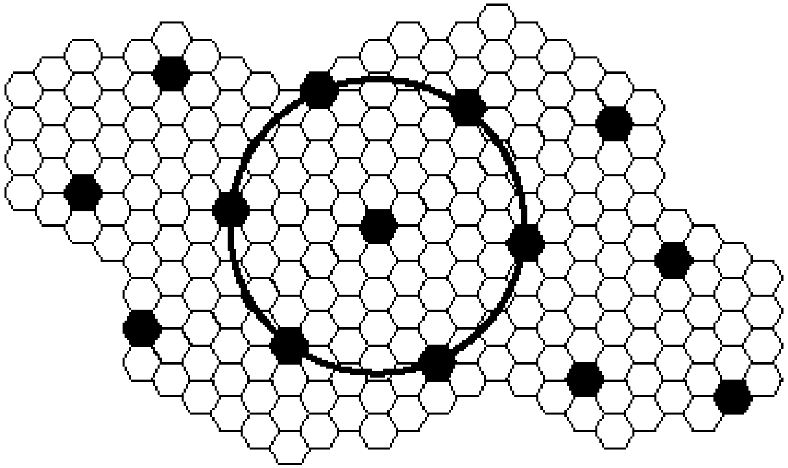
(a) Frequency reuse pattern for $N = 4$

i=2, j=0



(b) Frequency reuse pattern for $N = 7$

i=2, j=1

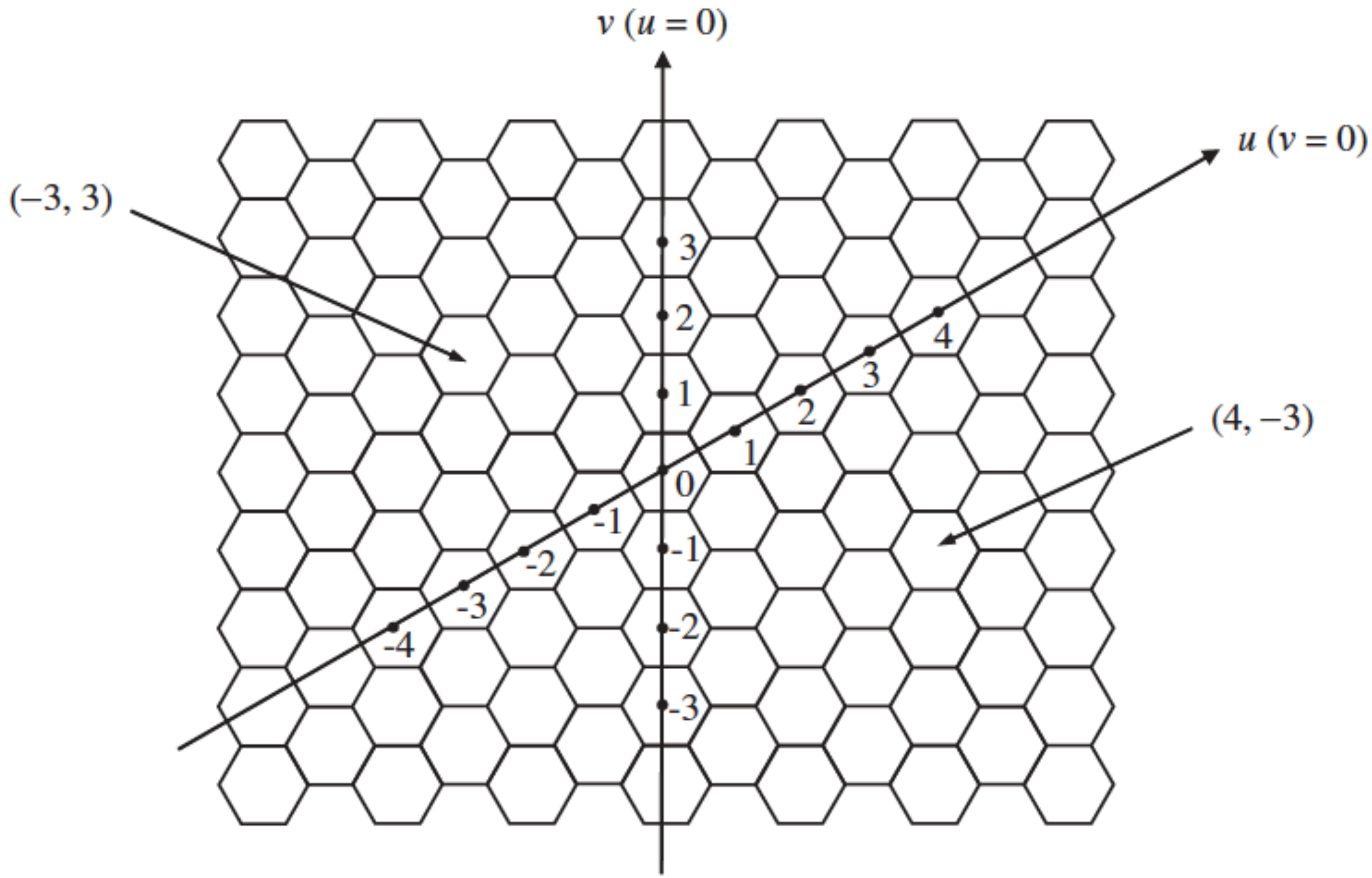


(c) Black cells indicate a frequency reuse for $N = 19$

i=3, j=2

N: cluster size

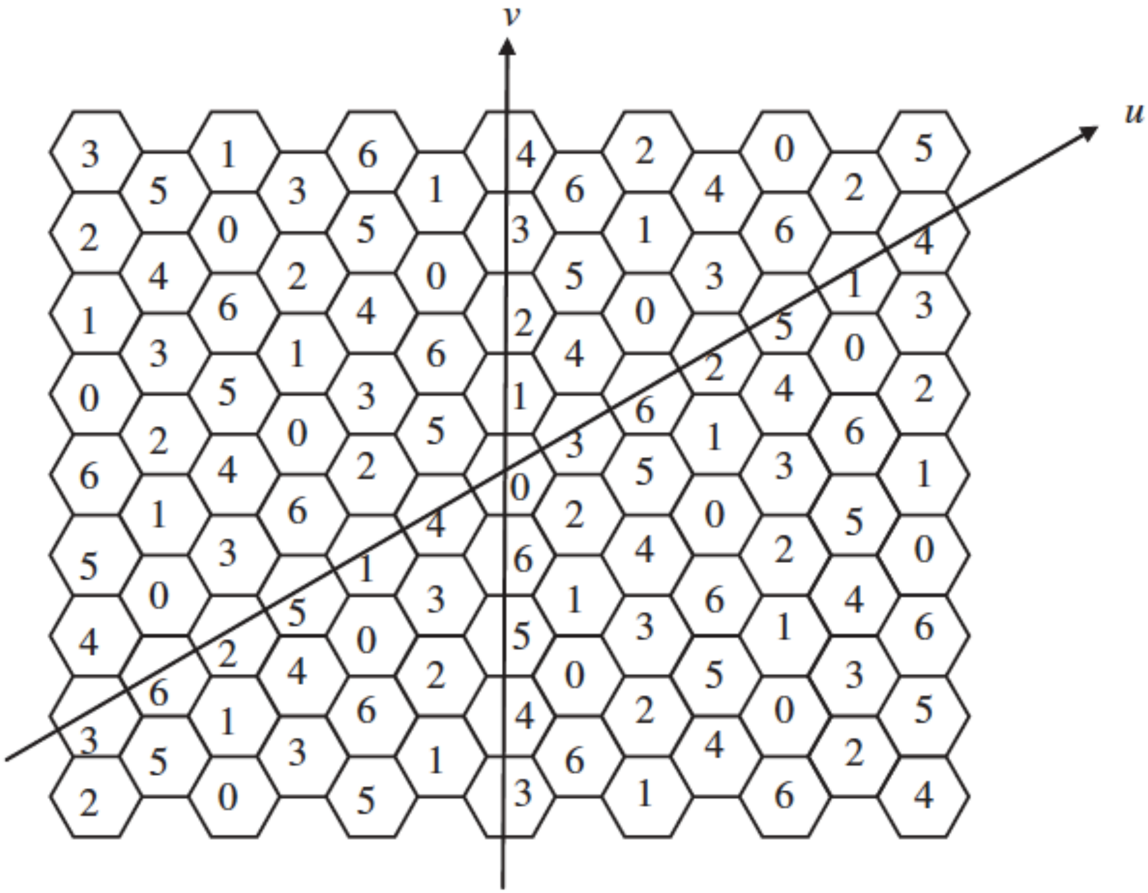
How to assign frequencies?



Define u and v axis as above

How to assign frequencies?

$i = 2$



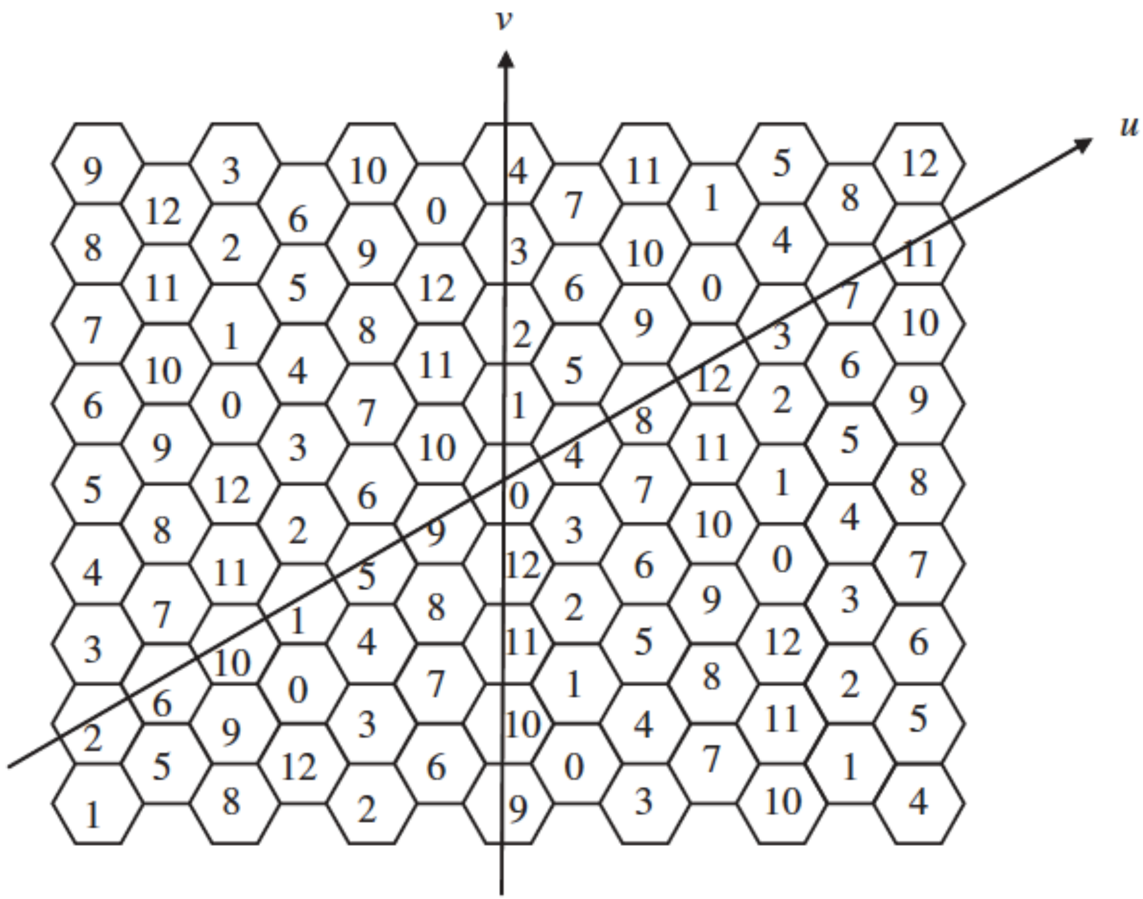
$$N = i^2 + ij + j^2$$

$$= i^2 + i + 1.$$

The cell label: $L = [(i+1)\,u + v] \bmod N$

How to assign frequencies?

$i = 3$

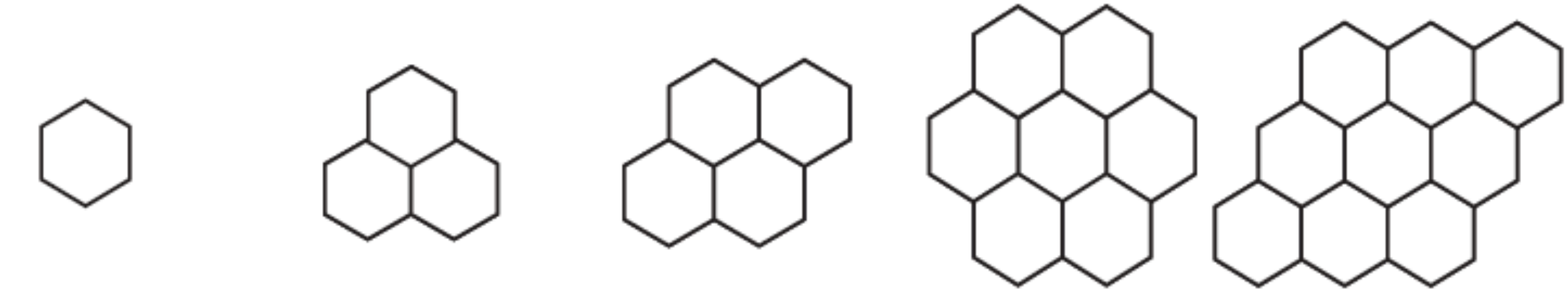


$$N = i^2 + ij + j^2$$

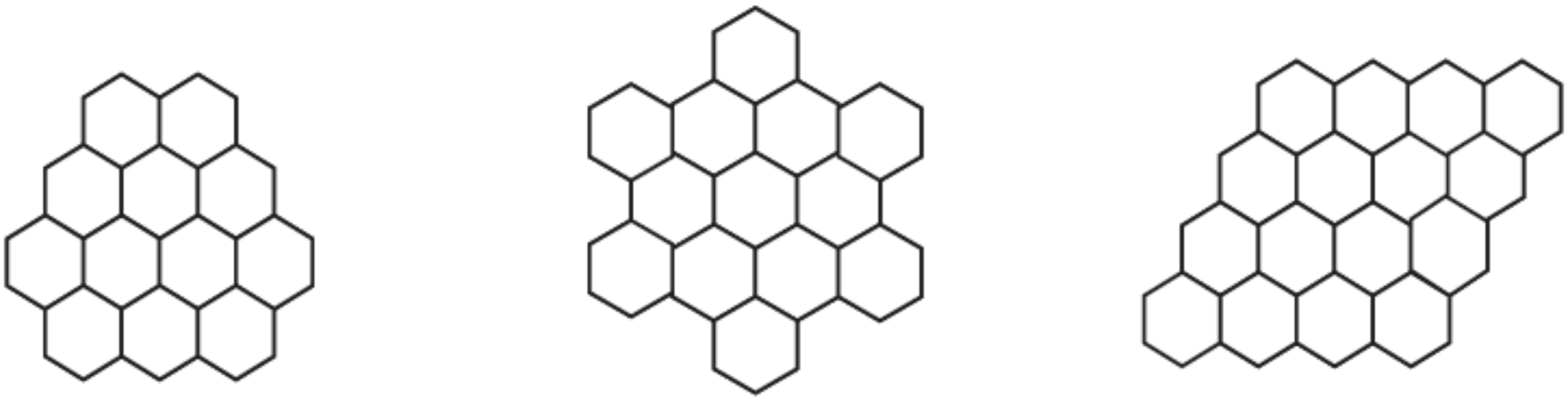
$$= i^2 + i + 1.$$

The cell label: $L = [(i+1)\,u + v] \bmod N$

Reuse Patterns of hex Cell Clusters



(a) 1 cell (b) 3 cells (c) 4 cells (d) 7 cells (e) 9 cells



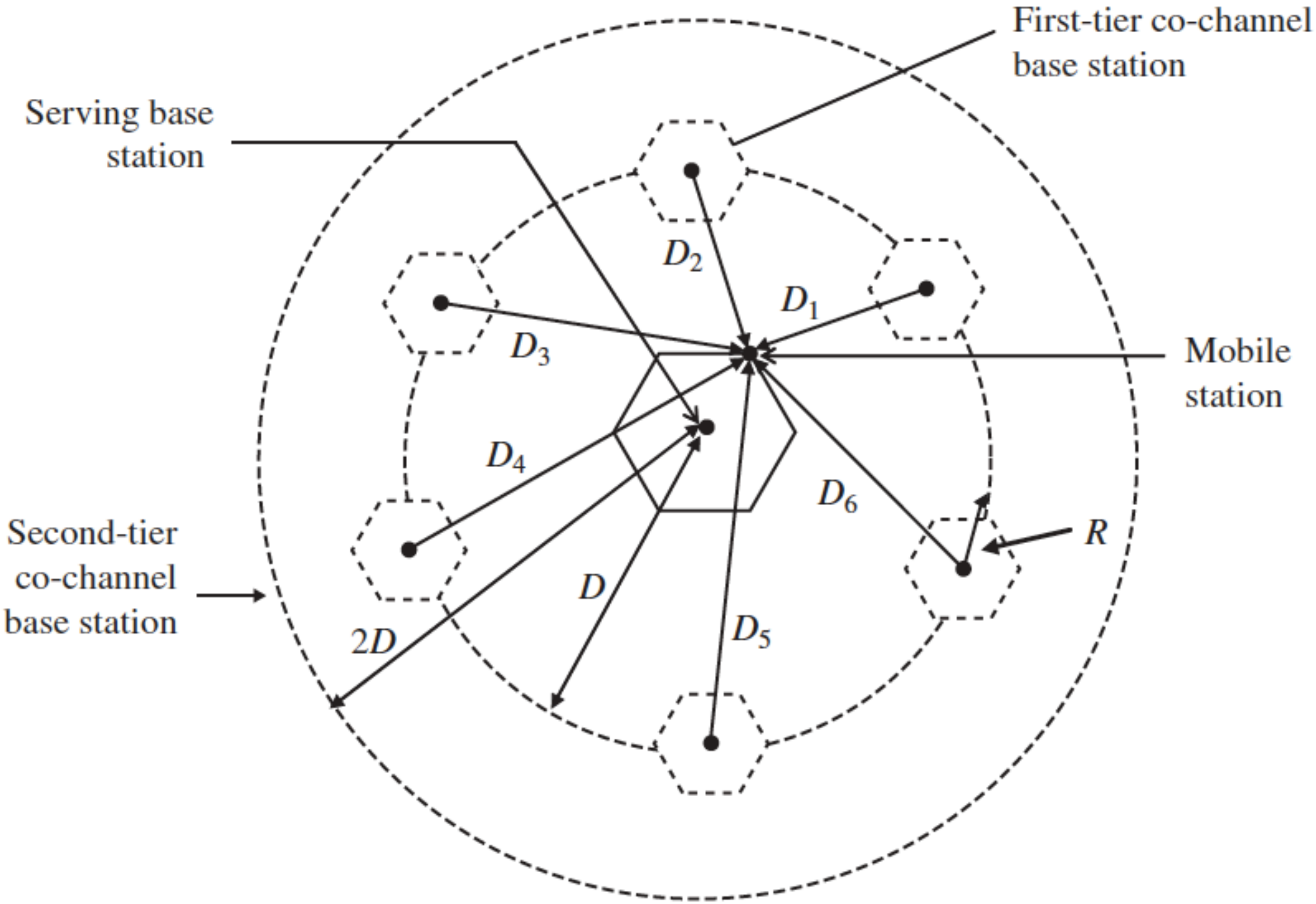
(f) 12 cells (g) 13 cells (h) 16 cells

Interference & System Capacity

- **Sources of interference**
  - **Co-channel** interference (same frequency)
    - A call in a neighboring cell
    - Other base stations operating in the same frequency band
    - Non-cellular system leaking energy into the frequency band
  - **Adjacent channel** interference (adjacent frequency)
    - Another mobile in the same cell

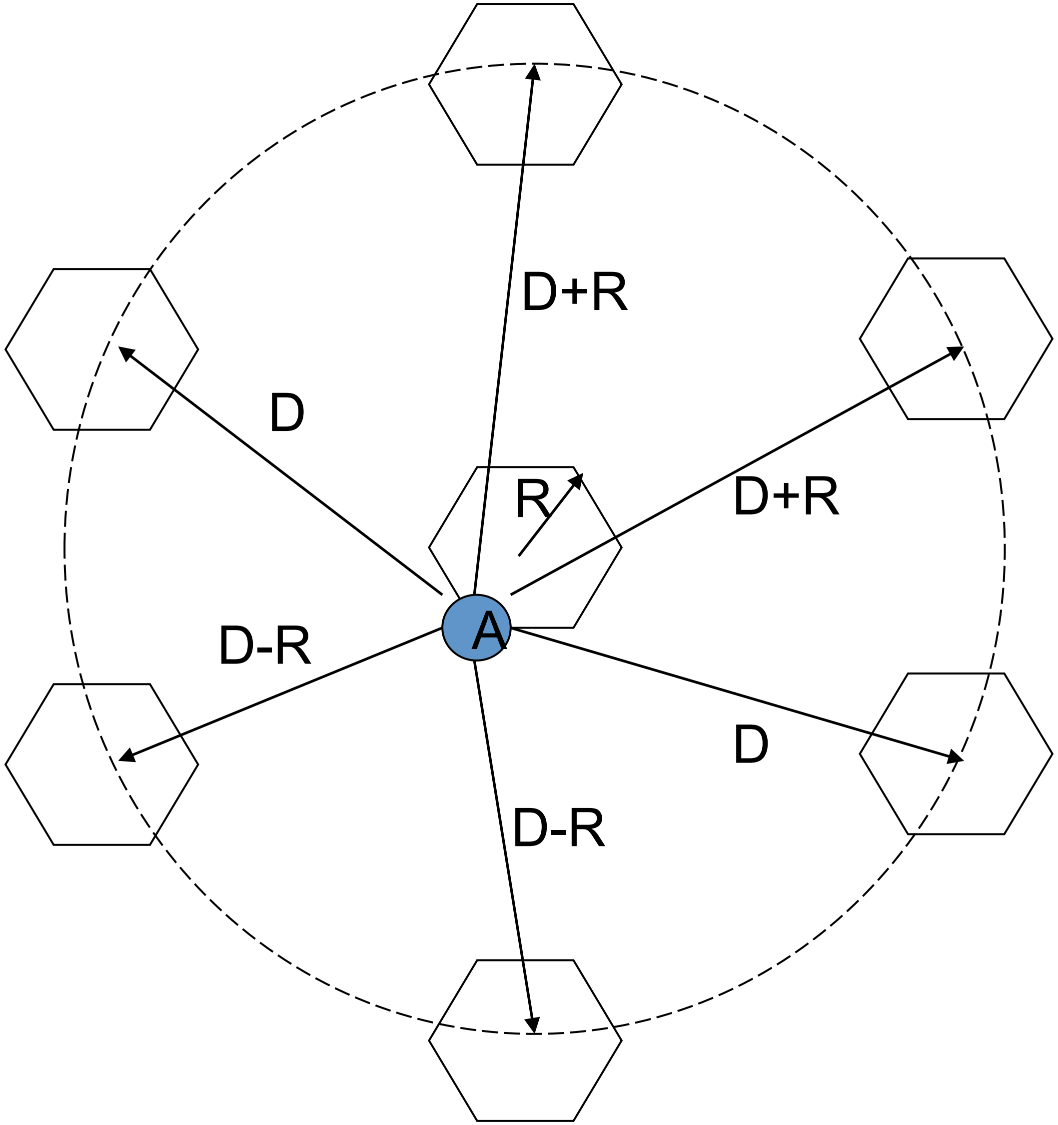
- **Consequences of interference**
  - **On data channel:**
    - Crosstalk (voice)
    - Erroneous data (data transmission)
  - **On control channel:**
    - Missed/dropped calls

Co-Channel Interference: An Example



$$\frac{C}{I} = \frac{\text{Carrier}}{\text{Interference}} = \frac{C}{\sum_{k=1}^{M} I_k},$$

Co-channel Interference: An Example



First tier of co-channel cells for a cluster size of N=7
Note: the marked distances are approximations

Co-channel Interference

Approximation of the SIR at point A

$$\frac{C}{I} = \frac{R^{-\gamma}}{2(D-R)^{-\gamma} + 2D^{-\gamma} + 2(D+R)^{-\gamma}}$$

Using the co-channel ratio

$$\frac{C}{I} = \frac{1}{\sum_{k=1}^{M} \left(\frac{D_k}{R}\right)^{-\gamma}} = \frac{1}{2\,(q-1)^{-\gamma} + 2q^{-\gamma} + 2\,(q+1)^{-\gamma}}$$

$q = D/R$ Freq. reuse factor

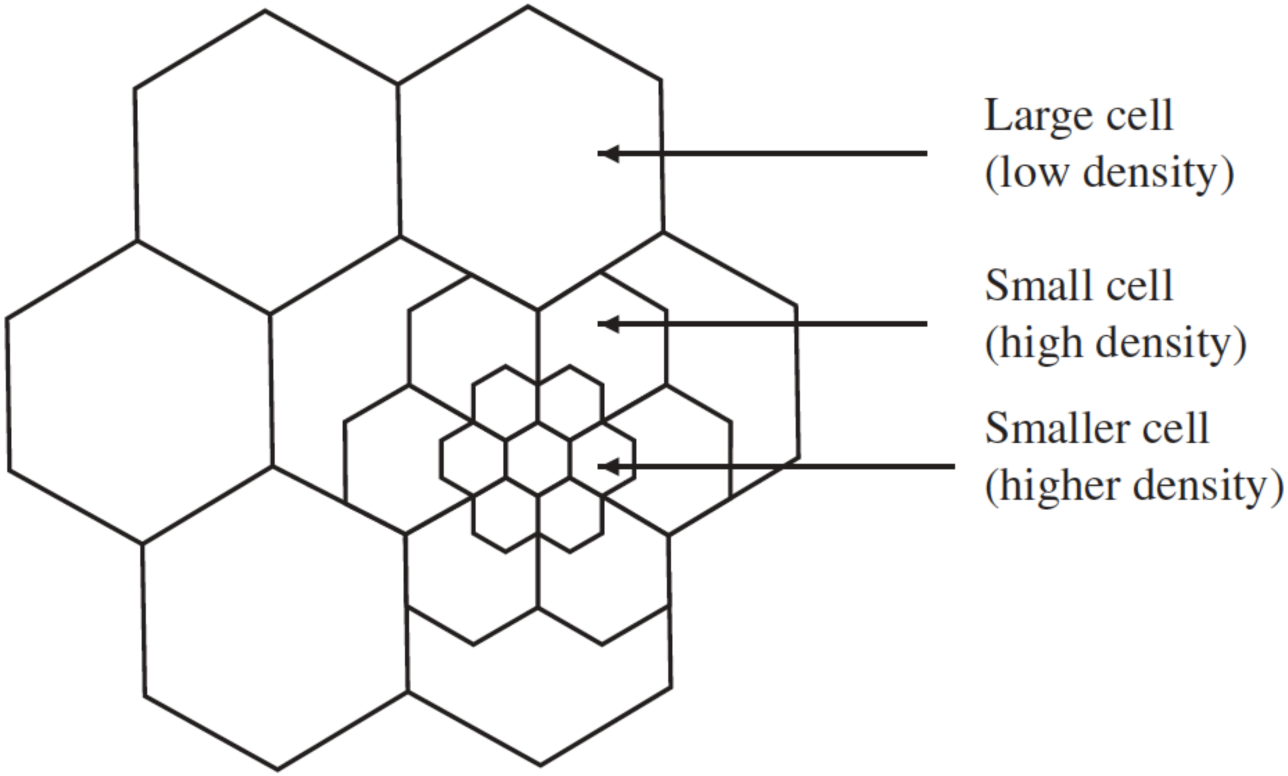
Numerical example: If N=7, gamma= 4, then q~4.6 and

$$\frac{C}{I} \approx 49.56 \approx 17.8\ dB$$

How to increase the capacity?

1. **Adding new channels**
2. **Frequency borrowing**
   – frequencies are taken from adjacent cells by congested cells
3. **Cell Splitting**
   – Cells in areas of high usage can be split into smaller cells
4. **Cell Sectoring**
   – a cell is divided into a number of wedgeshaped sectors, each with its own set of channels, typically 3 or 6 sectors per cell.
5. **Microcells**
   – As cells become smaller, antennas move from the tops of tall buildings or hills, to the tops of small buildings or the sides of large buildings, and finally to lamp posts, where they form microcells

Cell Splitting



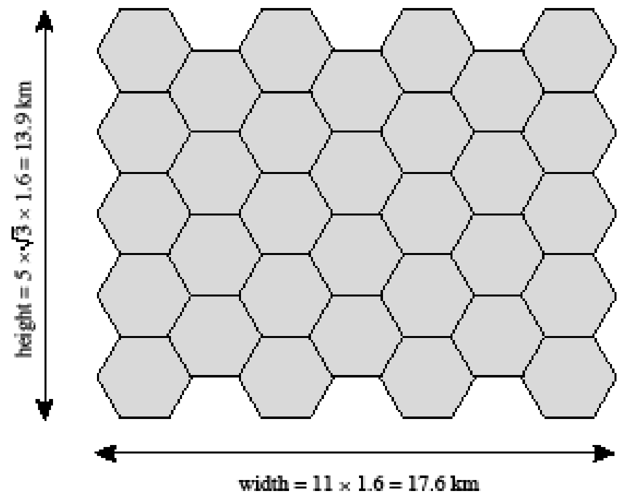
Frequency Reuse with Smaller Cells

Example: system of 32 cells with cell radius of 1.6km
Total frequency bandwidth supporting 336 traffic channels
Reuse factor (or cluster size) = 7
What geographic area is covered?
Total number of supported channels?

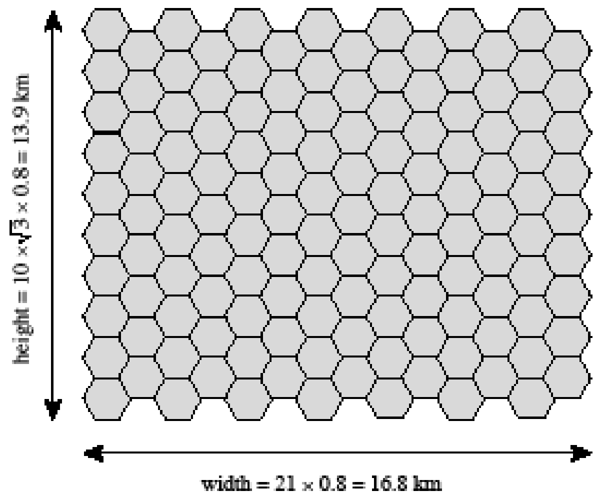
Solution:
Cell area = 6.65km2
Covered area: 32*6.65=213km2
Channels/cell = 336/7=48
Total channel capacity: 32*48=1536 channels

Same question for a system of 128 cells with cell radius of 0.8km. As before:
- total frequency bandwidth supporting 336 traffic channels
- reuse factor (or cluster size) = 7

Solution:
Cell area: 1.66km2
Covered area: 128*1.66=213km2
Total channel capacity: 128*48=6144

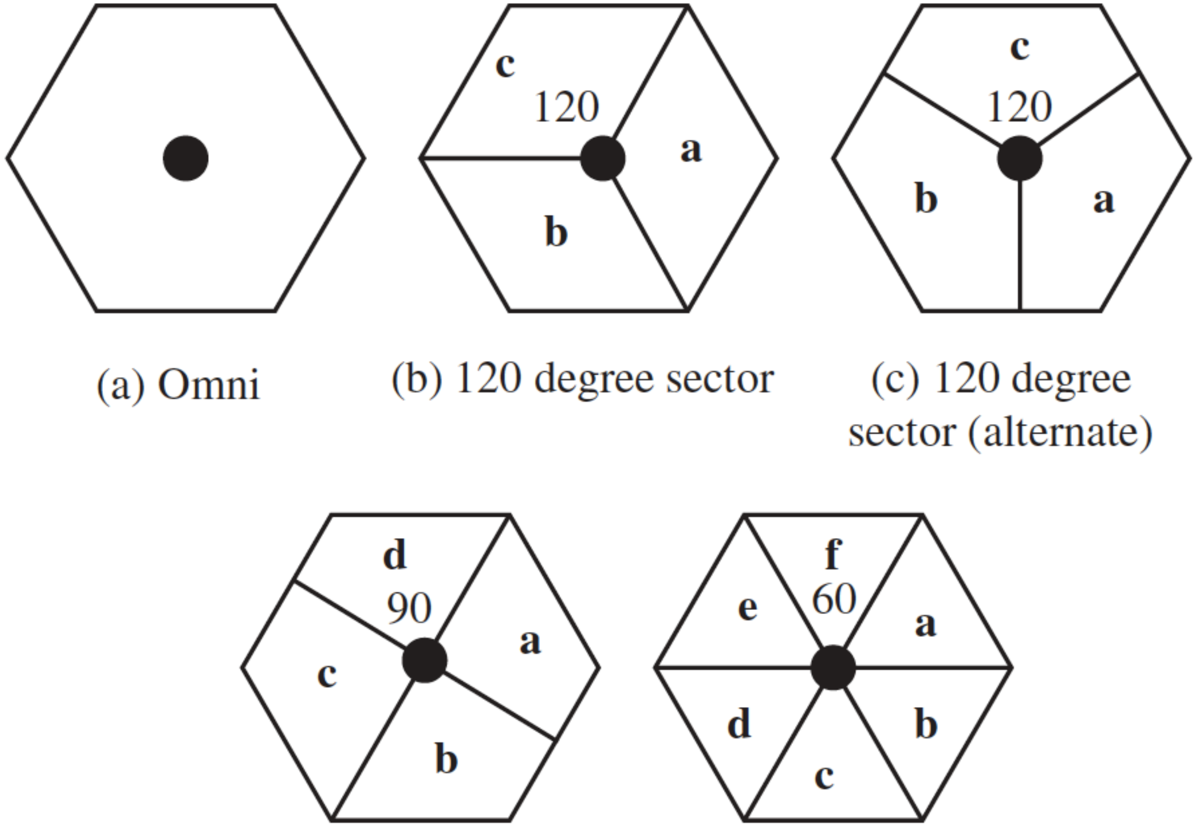


(a) Cell radius = 1.6 km



(b) Cell radius = 0.8 km

Cell Sectoring



(a) Omni (b) 120 degree sector (c) 120 degree sector (alternate)

(d) 90 degree sectors (e) 60 degree sectors

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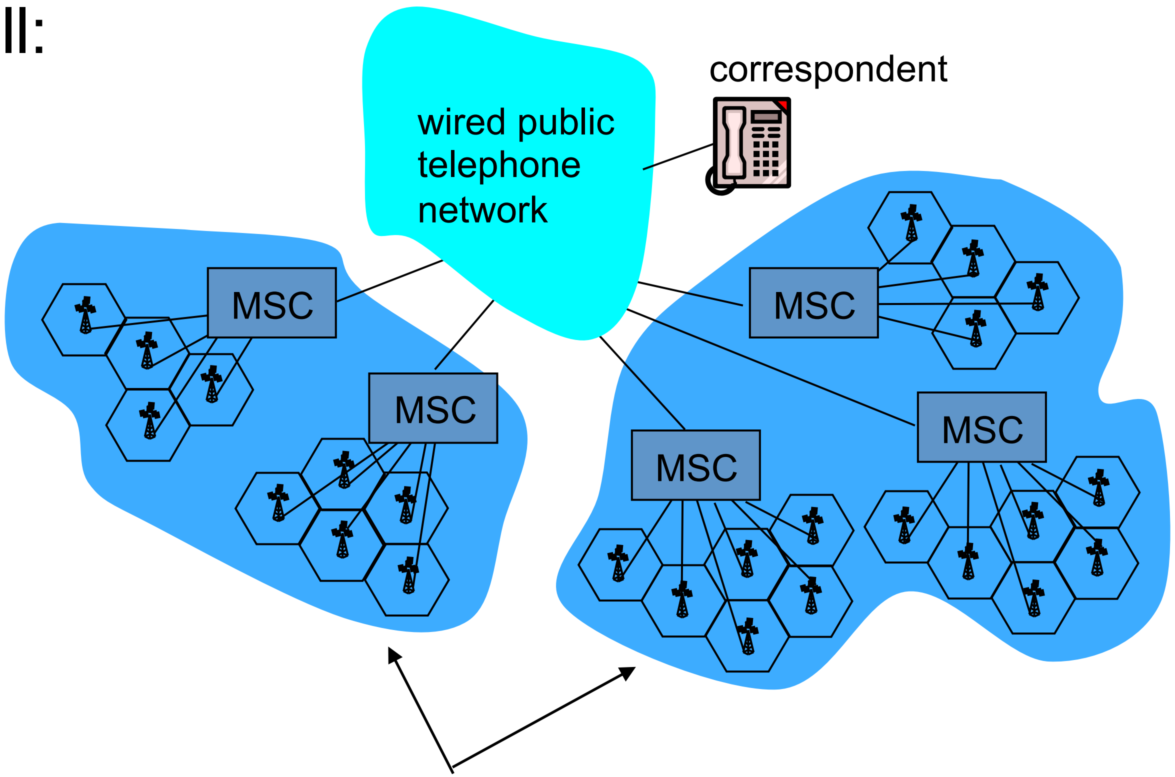
Components of Cellular Network Architecture

recall:

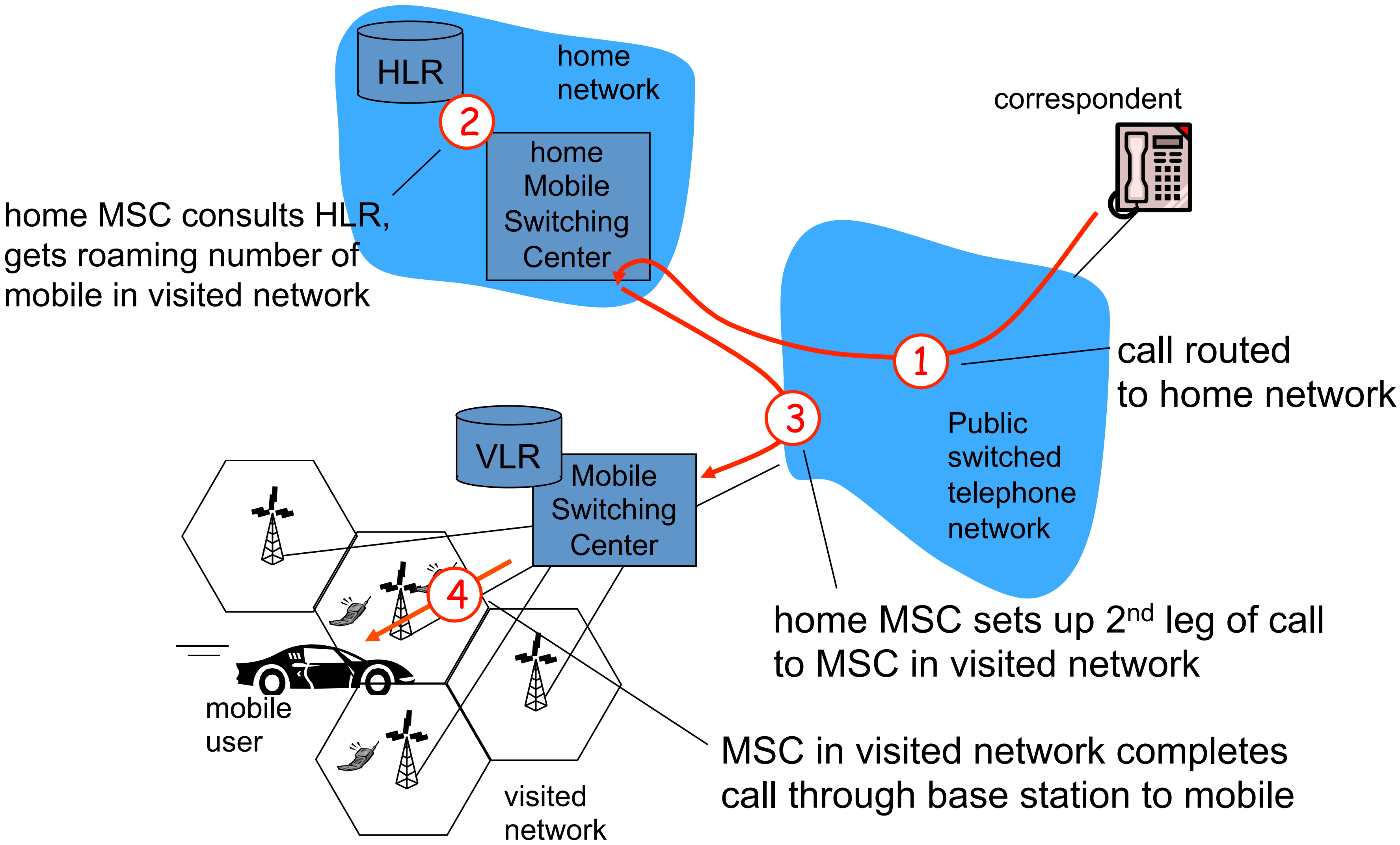


different cellular networks,
operated by different providers

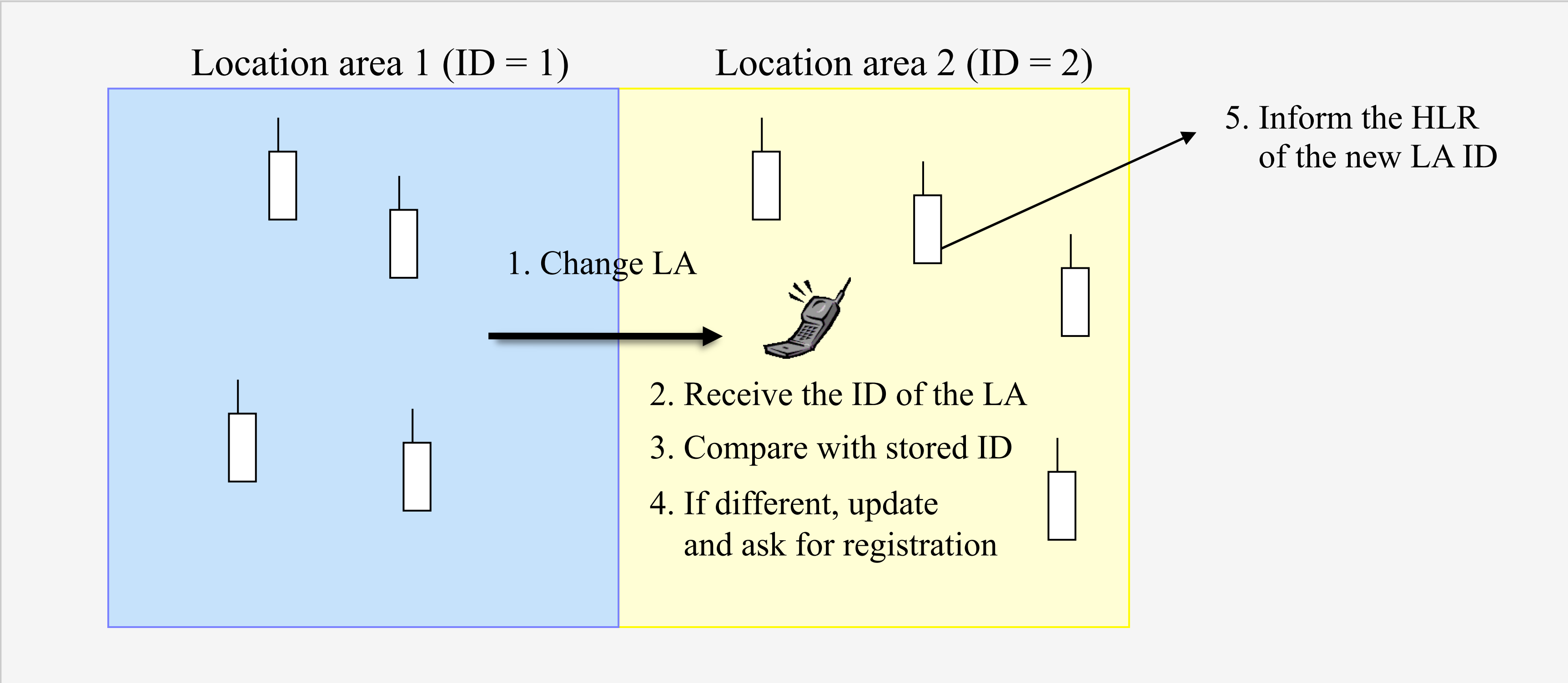
Handling mobility in cellular networks

- *home network:* network of cellular provider you subscribe to (e.g., Sprint PCS, Verizon)
  - *home location register (HLR):* database in home network containing permanent cell phone #, profile information (services, preferences, billing), information about **current location** (could be in another network)
- *visited network:* network in which mobile currently resides
  - *visitor location register (VLR):* database with entry for each user currently in network
  - could be home network

GSM: indirect routing to mobile



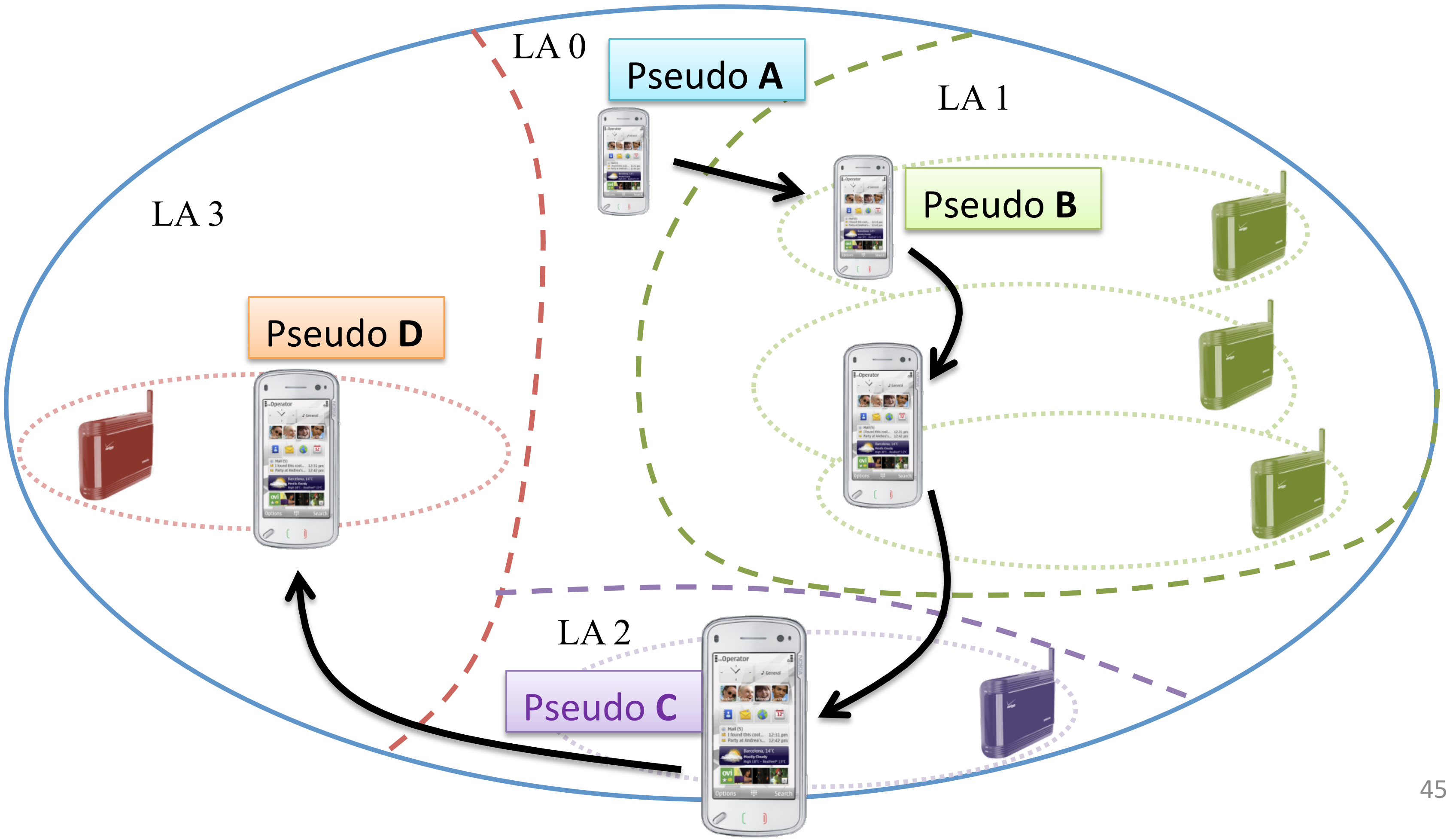
User Tracking: Geographic-based Strategy



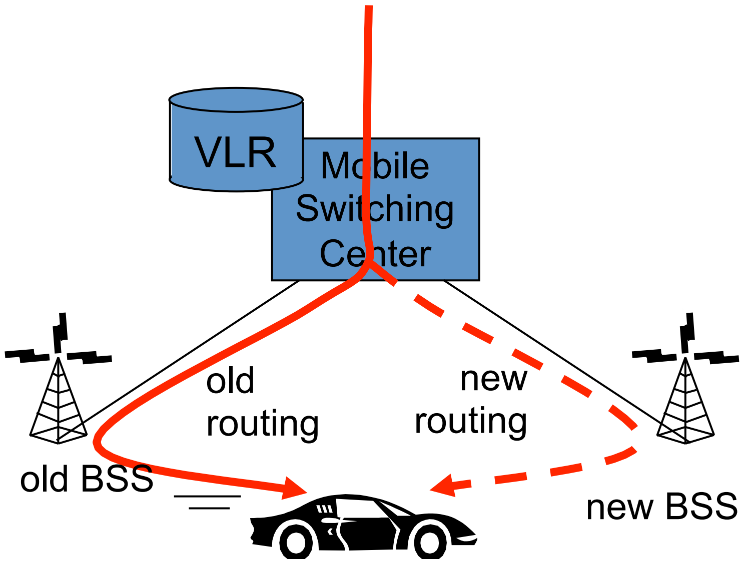
- Base stations periodically broadcast the ID of the LA
- Users compare their last LA ID with the current ID, and transmits a registration message whenever the ID is different
- When there is an incoming call directed to a user, all cells within its current LA are paged

Location and Identity Privacy

- Temporary Mobile Subscriber identifiers – TMSI – changed after crossing Location Area (LA) border or time-out trigger

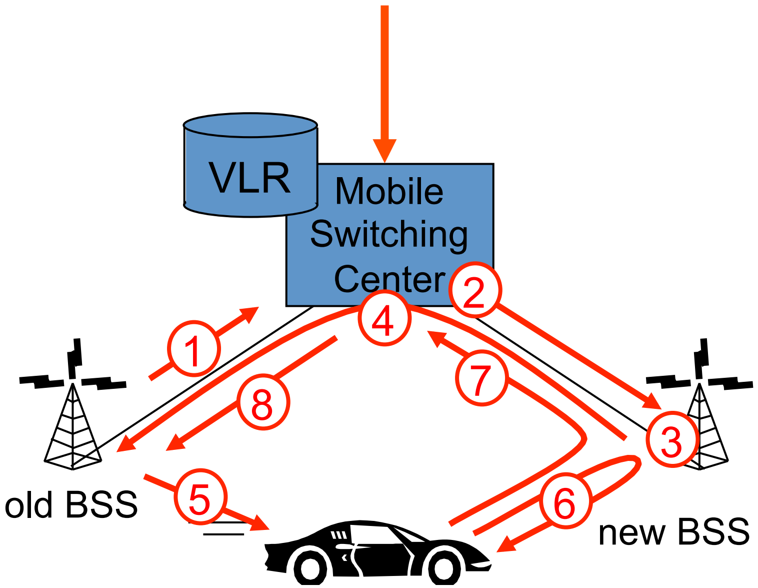


GSM: Handoff with Common MSC



- *handoff goal:* route call via new base station (without interruption)
- reasons for handoff:
  - stronger signal to/from new BSS (continuing connectivity, less battery drain)
  - load balance: free up channel in current BSS
  - GSM doesn't mandate why to perform handoff (policy), only how (mechanism)
- handoff initiated by old BSS

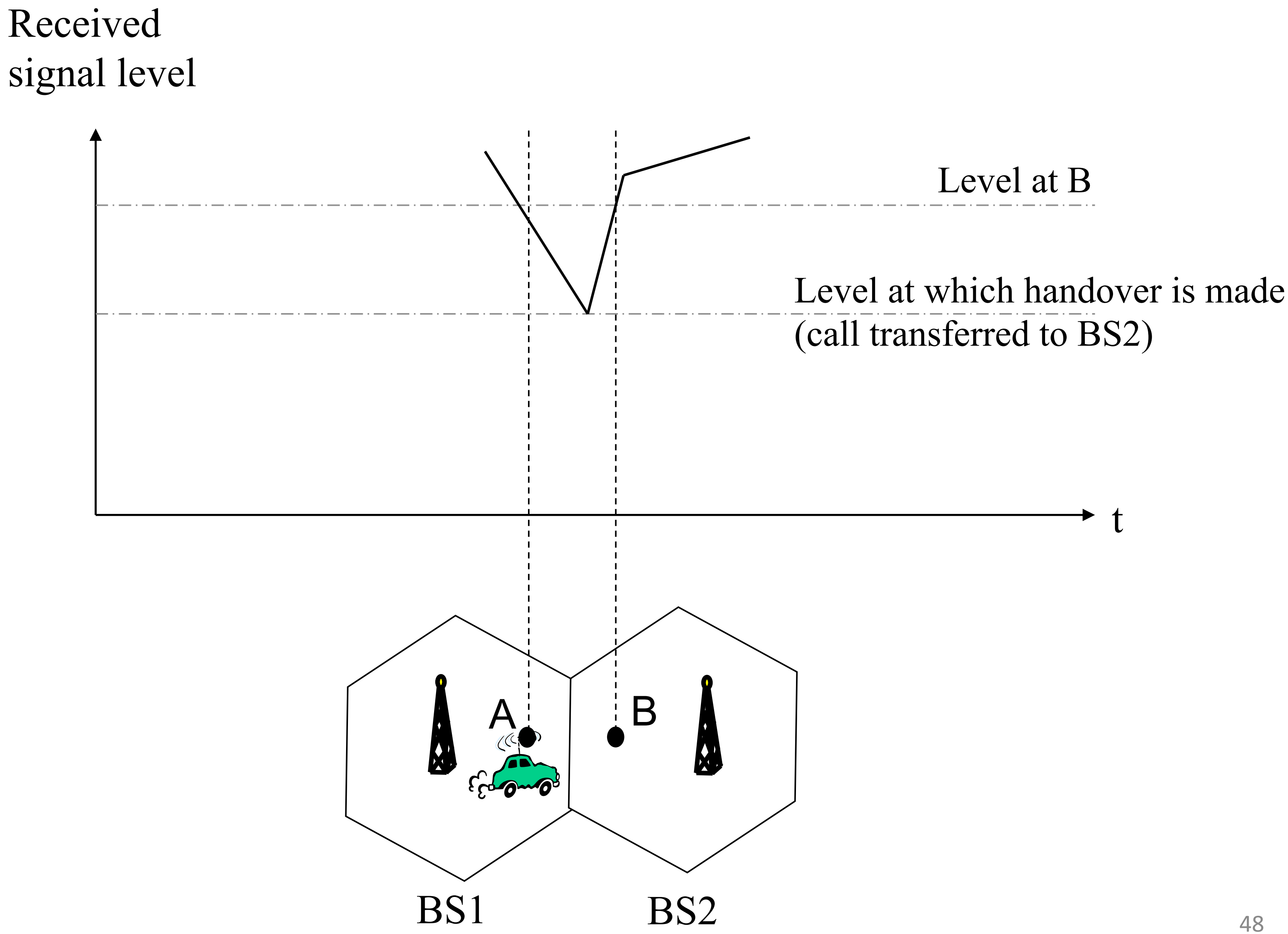
GSM: Handoff with Common MSC



1. old BSS informs MSC of impending handoff, provides list of 1+ new BSSs
2. MSC sets up path (allocates resources) to new BSS
3. new BSS allocates radio channel for use by mobile
4. new BSS signals MSC, old BSS: ready
5. old BSS tells mobile: perform handoff to new BSS
6. mobile, new BSS signal to activate new channel
7. mobile signals via new BSS to MSC: handoff complete. MSC reroutes call

8 MSC-old-BSS resources released

Hand off



Received
signal level
Level at B
Level at which handover is made
(call transferred to BS2)
t
A
B
BS1
BS2

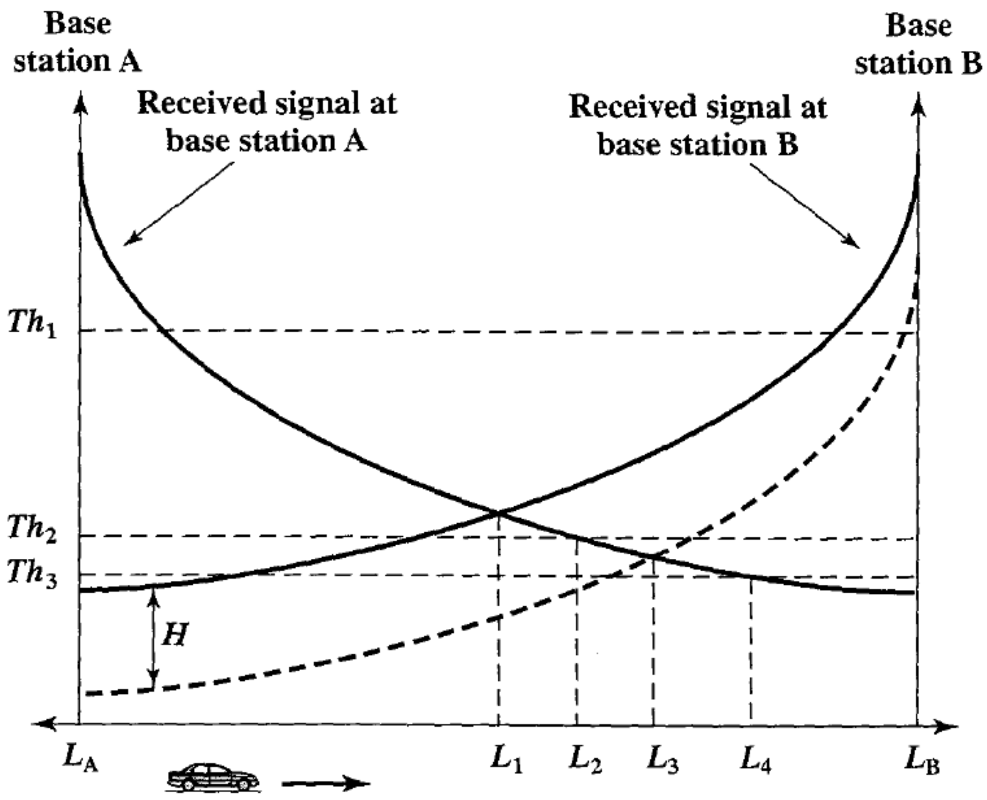
Hard/Soft Handover

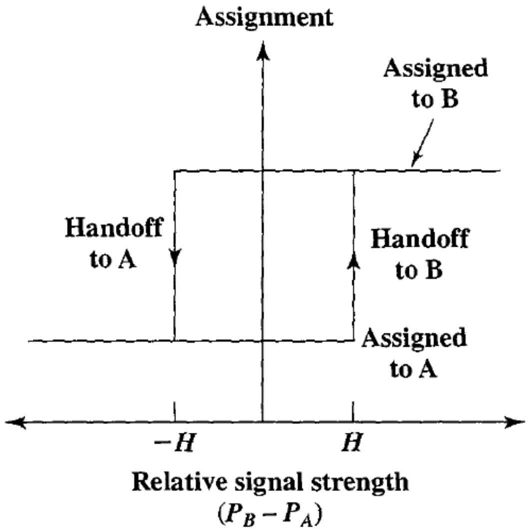
Hard: Communicate with one cell at a time
Soft: Communicate with two cells simultaneously

- **TDMA & FDMA: Hard**
  - Could technically use soft handover, but would be costly as it would require multiple parallel radio modules
- **CDMA: Soft**
  - Needed to avoid near-far problem (i.e., Detect weaker signal amongst strong signals)

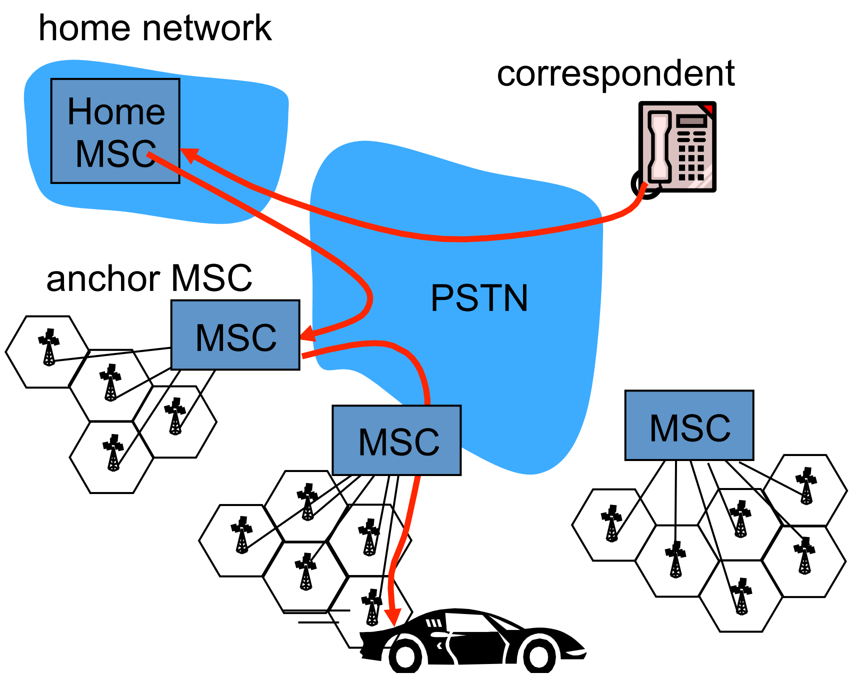
Hand off Strategies

1. Relative Signal Strength
2. Relative Signal Strength with Threshold
3. Relative Signal Strength with Hysteresis
4. Relative Signal Strength with Threshold and Hysteresis
5. Prediction Techniques





GSM: Handoff between MSCs



(a) before handoff

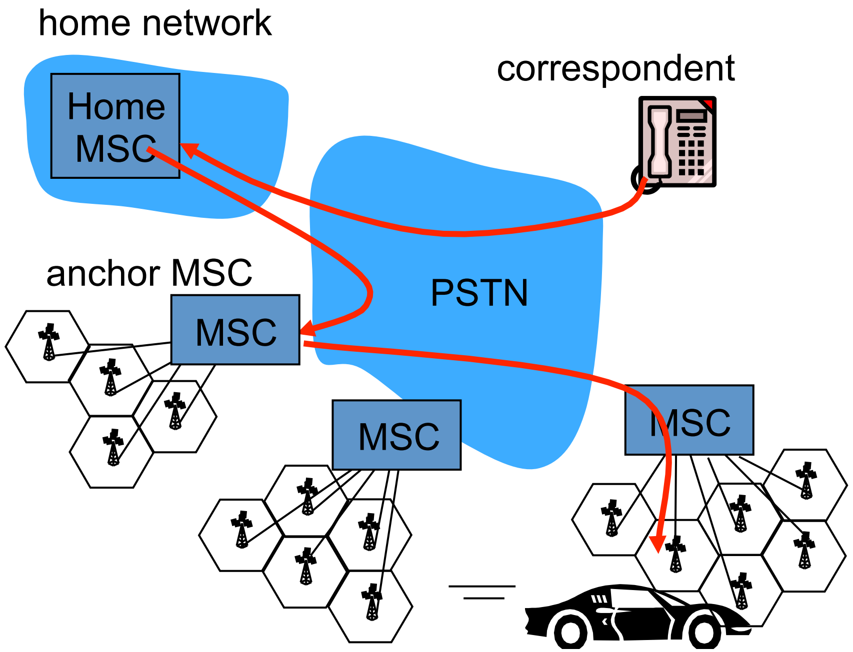
- *Anchor MSC:* first MSC visited during call

  - call remains routed through anchor MSC

- New MSCs add on to end of MSC chain as mobile moves to new MSC

  - optional path minimization step to shorten multi-MSC chain

GSM: Handoff between MSCs



(b) after handoff

- *Anchor MSC:* first MSC visited during call
  - call remains routed through anchor MSC
- New MSCs add on to end of MSC chain as mobile moves to new MSC
  - optional path minimization step to shorten multi-MSC chain

Contents

- Main Architecture
  - Cellular Network Architecture
  - History of Cellular Networks (1st, 2nd, 3rd and 4th Generation)
  - Operation of Cellular Systems
- Cellular Network Organization
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  - Frequency Reuse and Capacity
- Mobility Management
  - Handoff Strategies
- Traffic Engineering

Traffic Engineering

- Consider a cell
  - has *L* potential subscribers *(L* mobile units)
  - Able to handle *N* simultaneous users (capacity of *N* channels)
- If $L <= N$ ➔ *The system is nonblocking system*
- *If L > N* ➔ The system is *blocking*

Traffic Engineering: Main Questions

1. What is the probability that a call request will be blocked?
   - What capacity *(N)* is needed to achieve a certain upper bound on the probability of blocking?
2. If blocked calls are queued for service, what is the average delay?
   - What capacity is needed to achieve a certain average delay?

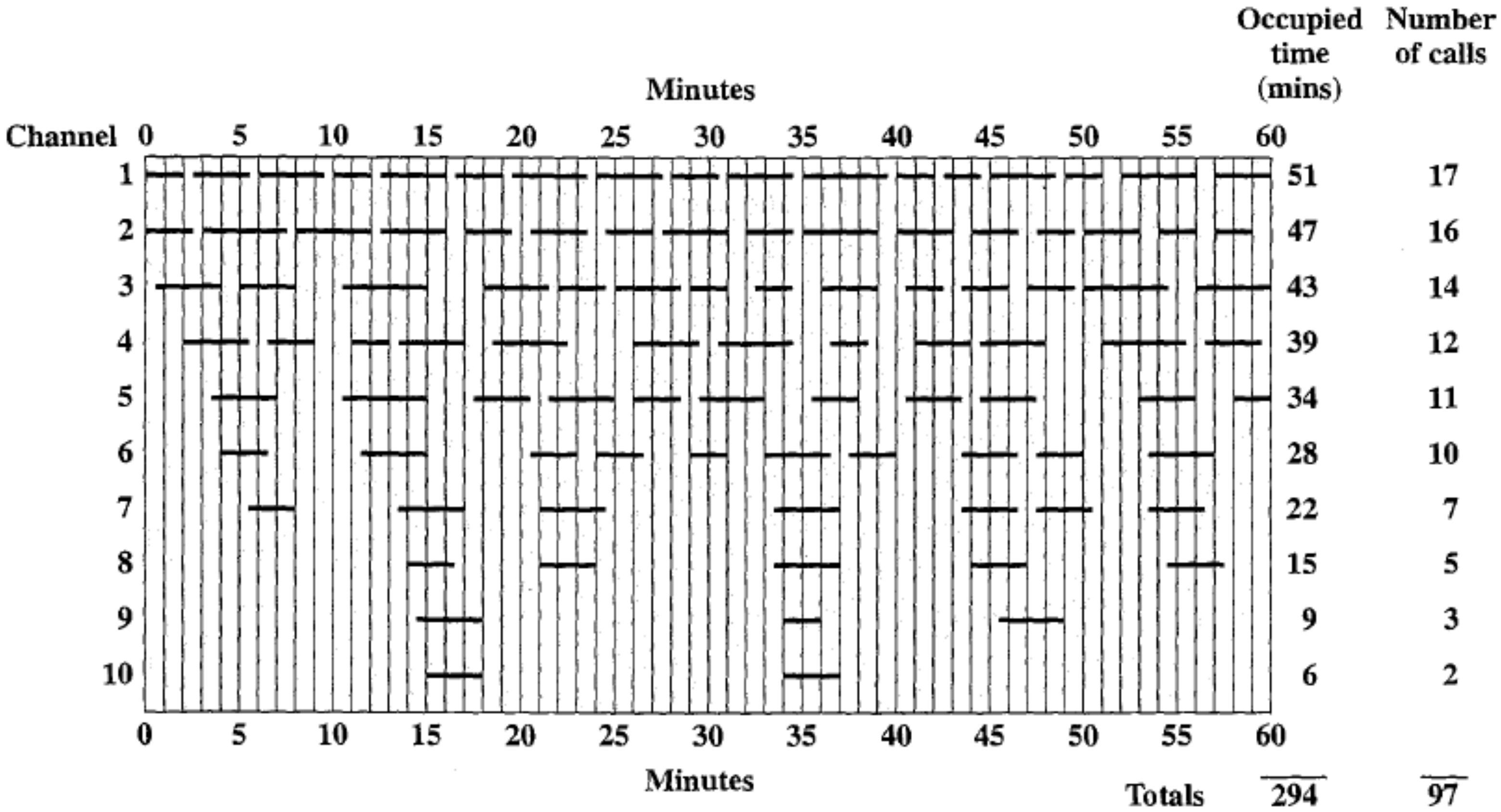
Traffic Intensity

$$A = \lambda \cdot h \text{ [Erlangs]}$$

where h = The mean holding time per successful call
λ = The mean rate of calls (connection requests) attempted per unit time
N = Number of Servers

$$\Pr_{Blocking} = \Pr(\text{"call dropped because line busy"}) = \text{Erlang-B}(A, N) = \frac{A^N}{N! \sum_{i=0}^{N} \left(\frac{A^i}{i!} \right)}$$

Example Distribution of Traffic in a Cell with Capacity 10



h = The mean holding time per successful call = 294/97

λ = The mean rate of calls (connection requests) attempted per min = 97/60

A= (97/60) (294/97) = 4.9 erlangs

Eralng B Table

(Offered Load) A in Erlangs

n	0.01%	0.02%	0.03%	0.05%	0.1%	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%
	P_B (Blocking Probability)												
1	0.0001	0.0002	0.0003	0.0005	0.0010	0.0020	0.0030	0.0040	0.0050	0.0060	0.0070	0.0081	0.0091
2	0.0142	0.0202	0.0248	0.0321	0.0458	0.0653	0.0806	0.0937	0.105	0.116	0.126	0.135	0.1443
3	0.0868	0.110	0.127	0.152	0.194	0.249	0.289	0.321	0.349	0.374	0.397	0.418	0.4374
4	0.235	0.282	0.315	0.362	0.439	0.535	0.602	0.656	0.701	0.741	0.777	0.810	0.8415
5	0.452	0.527	0.577	0.649	0.762	0.900	0.994	1.07	1.13	1.19	1.24	1.28	1.326
6	0.728	0.832	0.900	0.996	1.15	1.33	1.45	1.54	1.62	1.69	1.75	1.81	1.867
7	1.05	1.19	1.27	1.39	1.58	1.80	1.95	2.06	2.16	2.24	2.31	2.38	2.448
8	1.42	1.58	1.69	1.83	2.05	2.31	2.48	2.62	2.73	2.83	2.91	2.99	3.069
9	1.83	2.01	2.13	2.30	2.56	2.85	3.05	3.21	3.33	3.44	3.54	3.63	3.7110
10	2.26	2.47	2.61	2.80	3.09	3.43	3.65	3.82	3.96	4.08	4.19	4.29	4.3811
11	2.72	2.96	3.12	3.33	3.65	4.02	4.27	4.45	4.61	4.74	4.86	4.97	5.07
12	3.21	3.47	3.65	3.88	4.23	4.64	4.90	5.11	5.28	5.43	5.55	5.67	5.78
13	3.71	4.01	4.19	4.45	4.83	5.27	5.56	5.78	5.96	6.12	6.26	6.39	6.50
14	4.24	4.56	4.76	5.03	5.45	5.92	6.23	6.47	6.66	6.83	6.98	7.12	7.24
15	4.78	5.12	5.34	5.63	6.08	6.58	6.91	7.17	7.38	7.56	7.71	7.86	7.99
16	5.34	5.70	5.94	6.25	6.72	7.26	7.61	7.88	8.10	8.29	8.46	8.61	8.75
17	5.91	6.30	6.55	6.88	7.38	7.95	8.32	8.60	8.83	9.03	9.21	9.37	9.52
18	6.50	6.91	7.17	7.52	8.05	8.64	9.03	9.33	9.58	9.79	9.98	10.1	10.3
19	7.09	7.53	7.80	8.17	8.72	9.35	9.76	10.1	10.3	10.6	10.7	10.9	11.1
20	7.70	8.16	8.44	8.83	9.41	10.1	10.5	10.8	11.1	11.3	11.5	11.7	11.9