ECS455 Chapter 2

Cellular Systems

2.1 Frequency Reuse

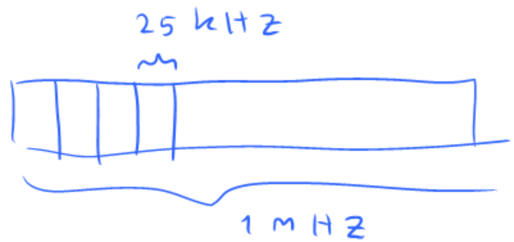
Office Hours:
BKD 3601-7
Tuesday 10:00-11:30
Thursday 9:30-11:30

Pre-Cellular System

Area over which **reliable** radio comunication can occur btw a BS and MSs.

- Achieve a **large coverage area** by using a single, **high powered** transmitter.
  - Put BS on top of mountains or tall towers
- Next BS was so **far away** that interference was not an issue.
- Severely limit the number of users that could communicate simultaneously.
- Noise-limited system with few users.
- Bell mobile system in New York City in the 1970s could only support a maximum of twelve simultaneous calls over a thousand square miles.

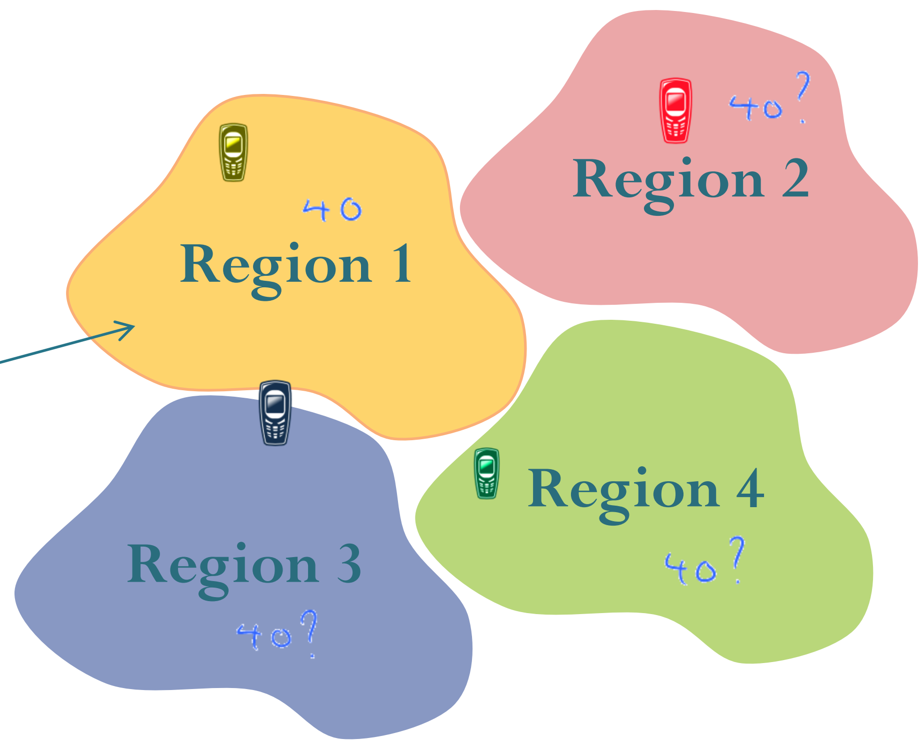
Examples



- Using a typical analog system, each channel needs to have a bandwidth of around **25 kHz** to enable sufficient audio quality to be carried, as well as allowing for a guard band between adjacent signals to ensure there are no undue levels of interference.
- Can accommodate only **40 users** in a frequency "chunk" of 1-MHz wide.
- Even if **100 MHz** were allocated to the system, this would enable only **4000 users** to have access to the system.
- Today cellular systems have millions of subscribers, and therefore a far more efficient method of using the available spectrum is needed.

Pre-Cellular System (2)

- All regions use the **same group of frequencies**.
- Non-overlapping coverage of the regions is NOT enough



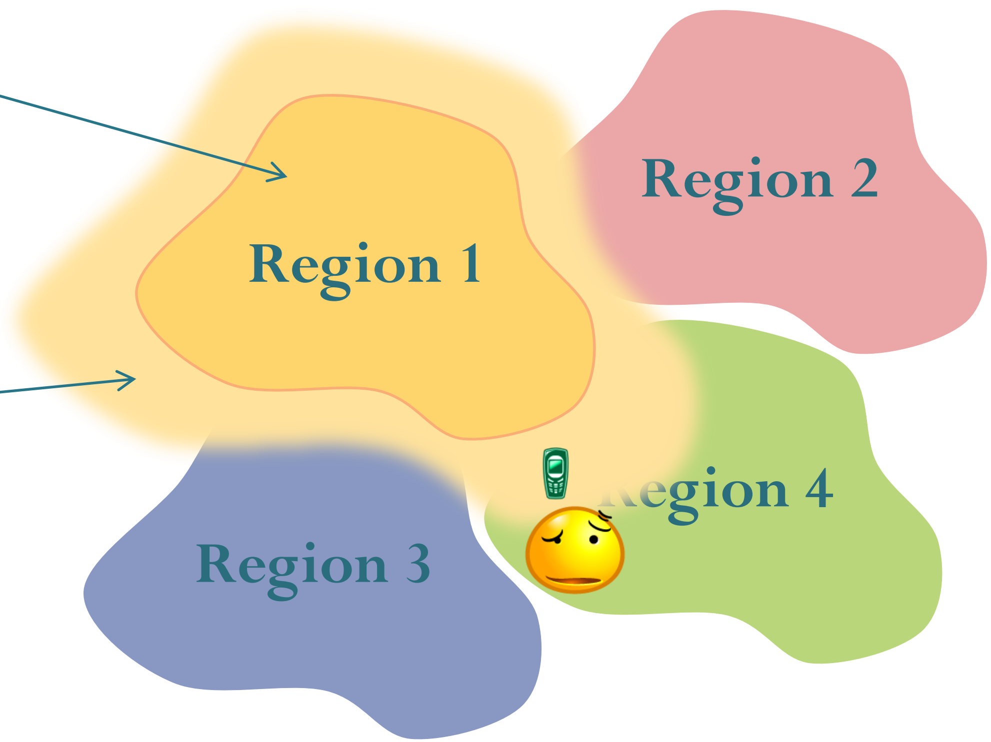
Colored area indicates the coverage area of the central transmitter in the corresponding region

Pre-Cellular System (2)

- All regions use the same group of frequencies.
- Non-overlapping coverage of the regions is NOT enough

Downlink signal in this region is strong enough for communication

The signal in this region is ***not*** strong enough for communication but still impose significant ***interference*** on users in other regions



Pre-Cellular System (2)

- All regions use the same group of frequencies.
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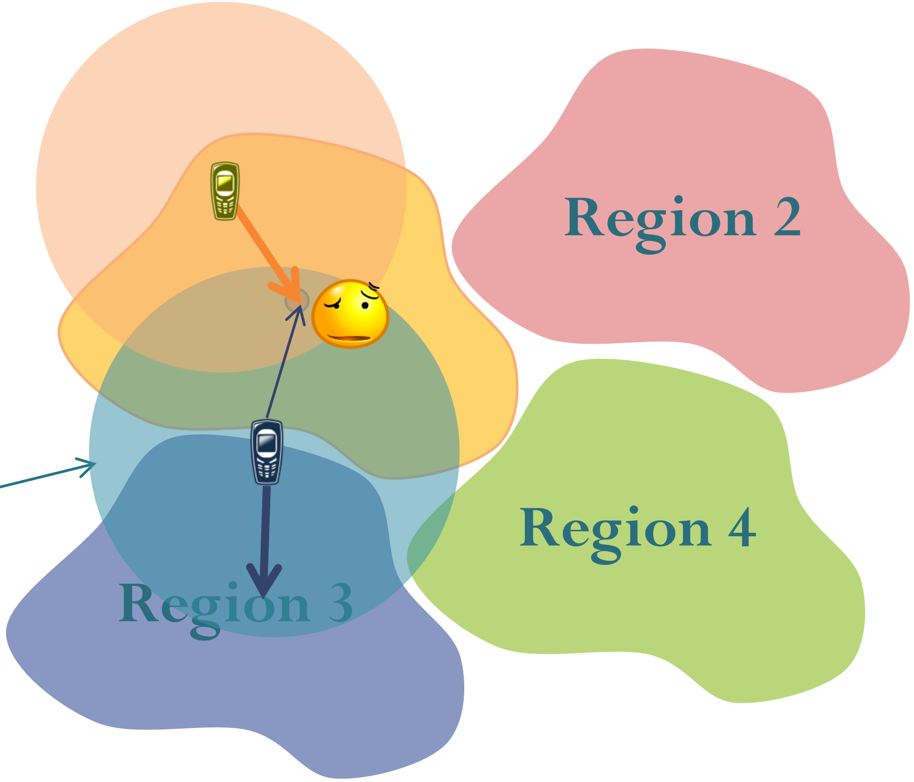
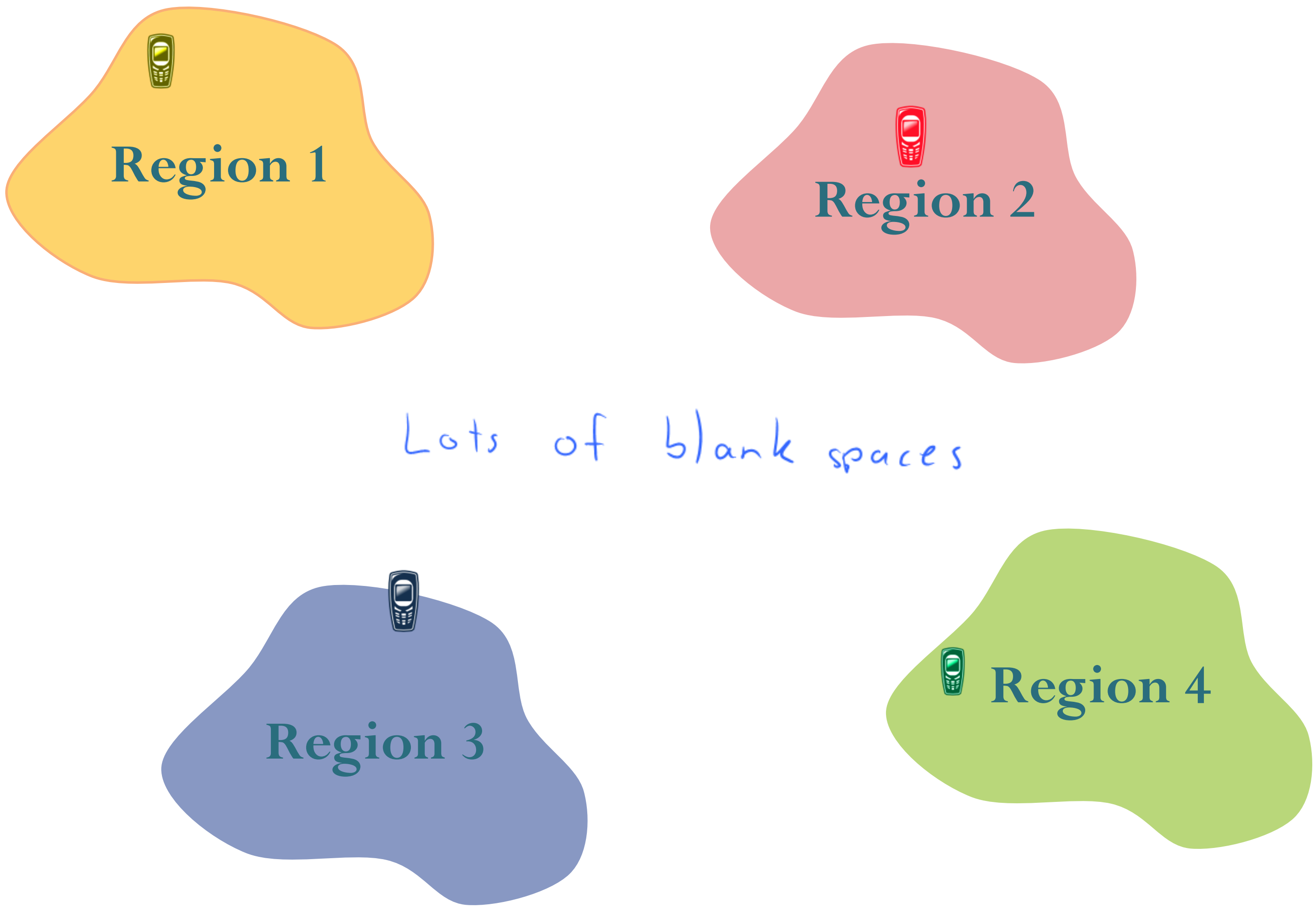


Uplink signals from user of a cell can reach the BS of a different region.

Pre-Cellular System (3)

- Regions need to be well-separated!



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Cellular systems

- The coverage area is divided into many small areas (**cells**).
- Replace
  - a single, high power transmitter

  with
  - **many low-power** transmitters each providing **coverage** to only one cell area (a small portion of the service area).
    - Power is lowered from hundreds of watts to a few watts, or even less than one watt per channel. [Klemens, 2010]

Area over which **reliable** radio comunication can occur btw a BS and MSs.

- **Frequency Reuse**: The same radio channels (**frequency** bands) may be **reused** by another base station located some distance away.

“Reliable”?

Subjective tests found that people regard an FM signal using a 30 kHz channel bandwidth to be clear if the signal power is at least **sixty times** higher than the noise power.

$$10\log_{10} 60 = 17.78 \approx 18 \text{ dB}$$

We will soon revisit and use these numbers for some more specific calculation

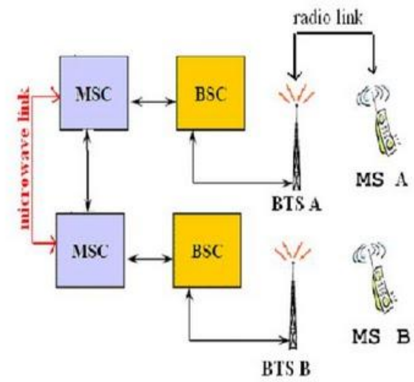
Cellular systems: Handoff

- Sophisticated **switching** technique
- Enable a call to proceed **uninterrupted** when the user moves from **one cell to another**.
- The system can switch moving users between towers to find the **strongest signal**.

Cellular systems: History

- The concept of cells was first proposed (in an unpublished work) as early as **1947** by Douglas H. Ring at **Bell Lab**oratories in the US
- Detailed proposal for a "High-Capacity Mobile Telephone System" incorporating the cellular concept submitted by Bell Laboratories to the FCC in 1971.
- The first **AMPS** system was deployed in Chicago in **1983**.

Basic cellular system



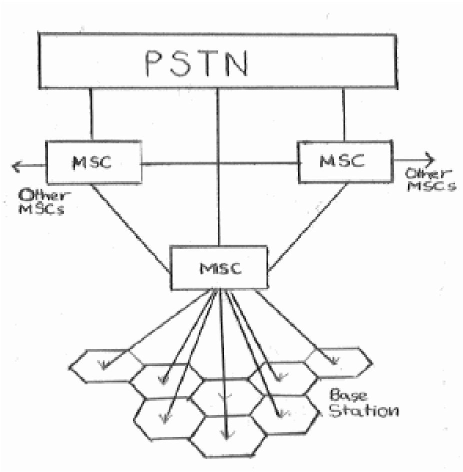
1. **Mobile stations (MS)**
2. **Base stations (BS)**
    - Serve as a bridge between all mobile users in the cell and connects the simultaneous mobile calls via telephone lines or microwave links to the MSC.
    - Generally have towers which support several transmitting and receiving antennas.
        - Simultaneously handle full duplex communications.

- Each mobile communicates via radio with one of the base stations and may be handed-off to any number of base stations throughout the duration of a call.

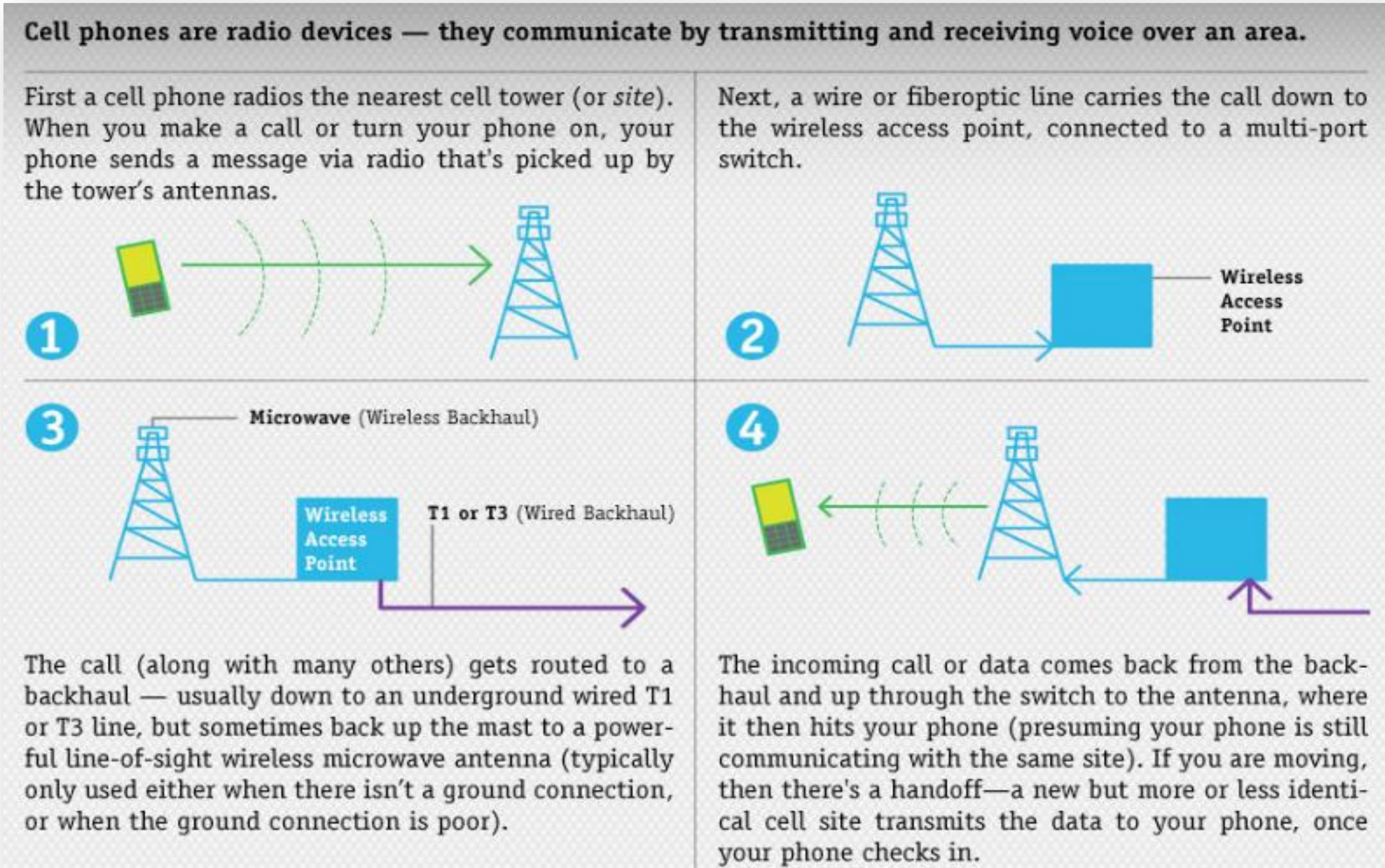
Basic cellular system (2)

3. **Mobile switching center** (**MSC**)

- Sometimes called a **mobile telephone switching office (MTSO)**
- Coordinates the activities of all of the base stations
  - Coordinating which BS will handle a call to or from a user and when to handoff a user from one base-station to another.
- Connect the entire cellular system to the PSTN (public switched telephone network).

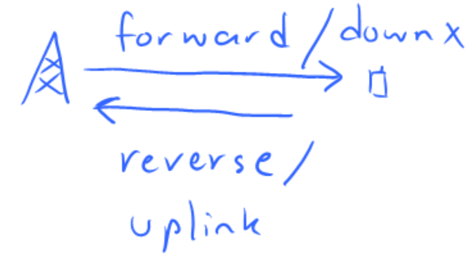


How a Cell Phone Call Works



[http://cellphones.org/blog/how-cell-phone-calls-work/]

Common Air Interface (CAI)



- Standard for communication between BS and MSs

1. **Voice channels**
   - **Forward voice channels (FVC)** : voice transmission from BS to MSs
   - **Reverse voice channels (RVC)**: voice transmission from MSs to BS
2. **Control channels**
   - Often called **setup channels**
   - **Forward control channels (FCC)** and **reverse control channels (RCC)**
   - Involve in setting up a call and moving it to an unused voice channel.
   - Transmit and receive data messages that carry call initiation and service requests
   - Monitored by mobiles when they do not have a call in progress.

- Typically, 5% control channels and 95% voice channels.

Frequency Reuse: Definition

"The use of radio channels on the **same carrier frequency** to cover **different areas** which are separated from one another by sufficient distances so that **co-channel interference** is not objectionable."

[Mac Donald, 1979, p 16]

- Employed not only in mobile-telephone service but also in entertainment broadcasting and many other radio services.

Frequency Reuse

- Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region
- Each cellular BS is allocated a **group** of radio channels to be used within the corresponding cell.
- BSs in **adjacent** cells are assigned channel groups which contain completely **different** channels than neighboring cells.
- By limiting the coverage area within the boundaries of a cell, the same group of channel may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits.
- The distance between two cells that use the same frequency channels is called the **reuse distance**.

Cell Shape

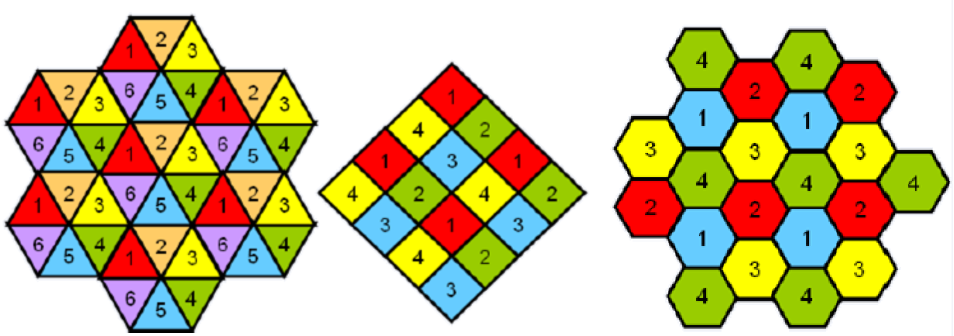
- The actual radio coverage of a cell is known as the **footprint**.
  - Determined from field measurements or propagation prediction models.
- In reality, it is **not possible to define exactly the edge of a cell**.
  - Signal strength gradually reduces, and towards the edge of the cell performance falls.
  - MSs have different levels of sensitivity, this adds a further greying of the edge of the cell.
  - Impossible to have a sharp cut-off between cells.
- In some areas they may overlap, whereas in others there will be a hole in coverage.
- Although the real footprint is amorphous in nature, a regular cell shape is needed for systematic system design and adaptation for future growth.

Hexagonal cell shape

- Simplistic model of the radio coverage for each BS.
- Universally adopted
- Permit easy and manageable analysis

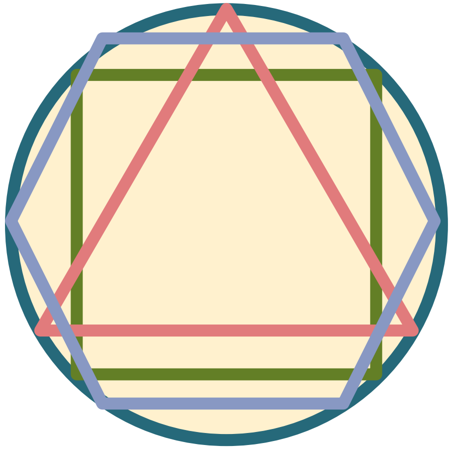
Why hexagon?

- Omnidirectional BS antenna and free space propagation → Circular radiation pattern.
  - Adjacent **circles** cannot be overlaid upon a map without leaving gaps or creating overlapping regions.
- **Tessellating Cell Shapes**: When considering geometric shapes which cover an entire region without overlap and with equal area, there are three sensible choices: a square, an equilateral triangle, and a hexagon.



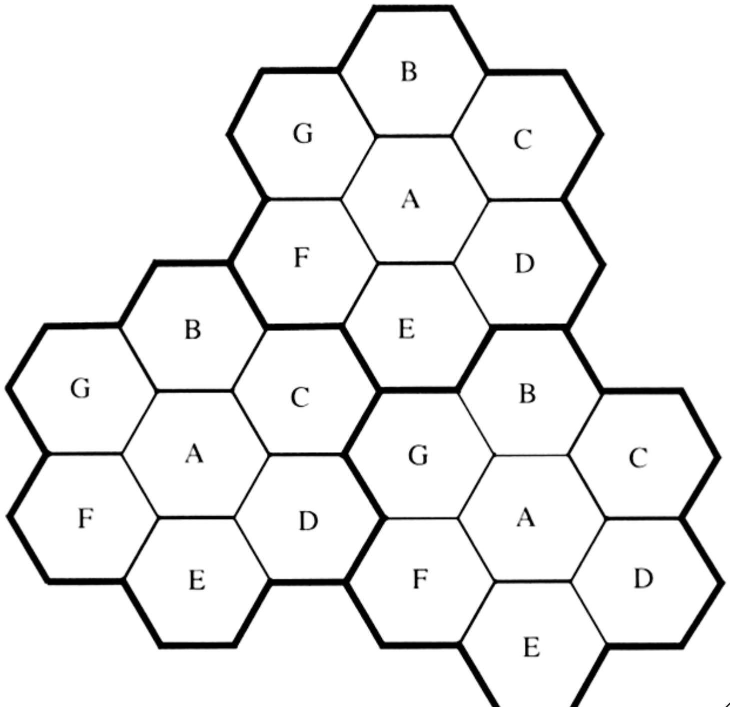
Why hexagon? (2)

- A cell must be designed to serve the weakest mobiles within the footprint, and these are typically located at the edge of the cell.
  - For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area of the three.
  - By using the hexagon geometry, the fewest number of cells can cover a geographic region



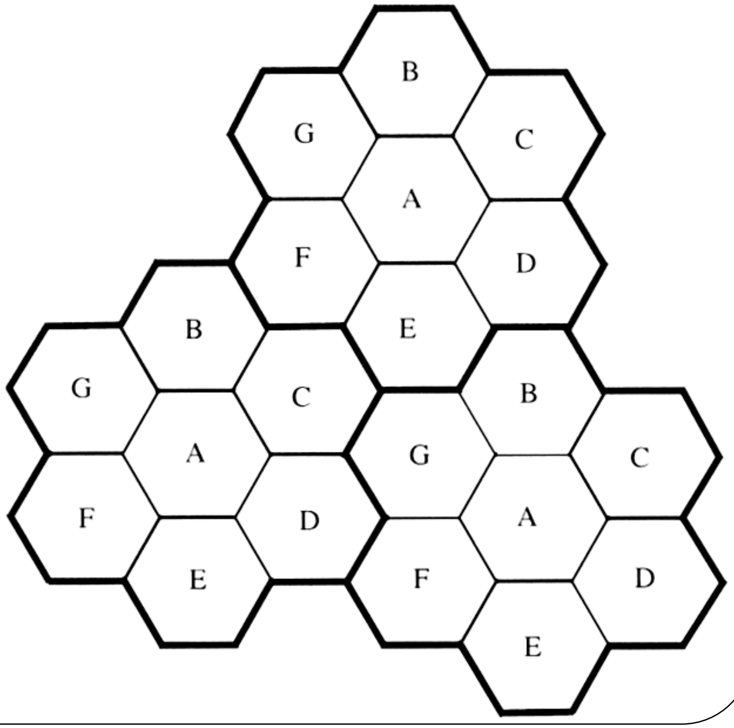
Frequency Reuse Plan

- The **frequency reuse plan** is overlaid upon a map to indicate where different frequency channels are used.
- Cells labeled with the same letter use the same group of channels.
  - Create **co-channel interference**



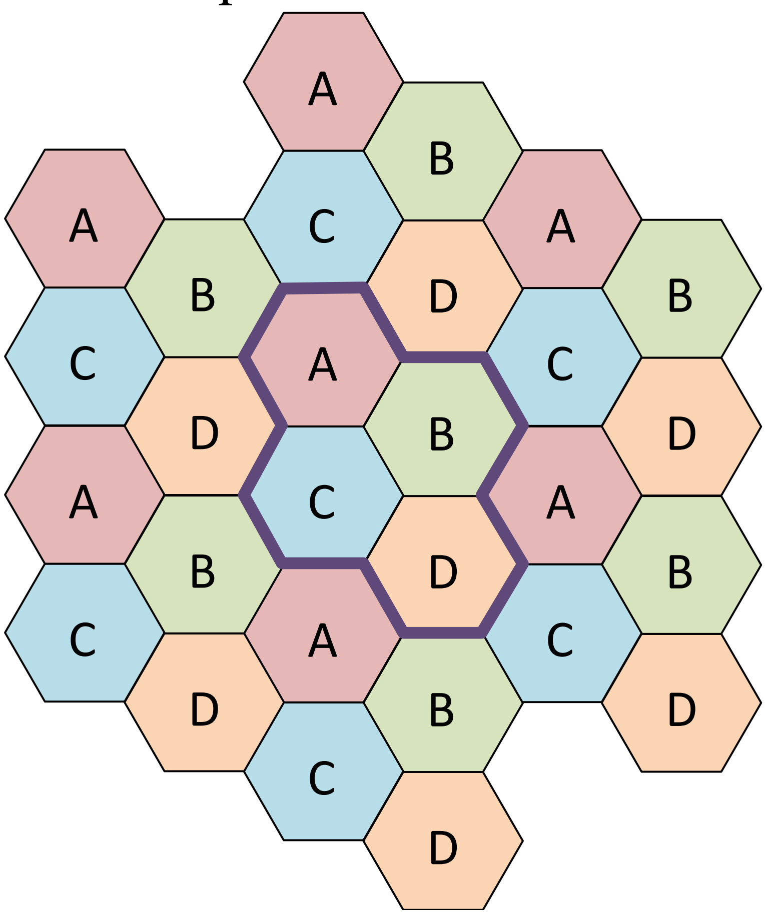
Clusters

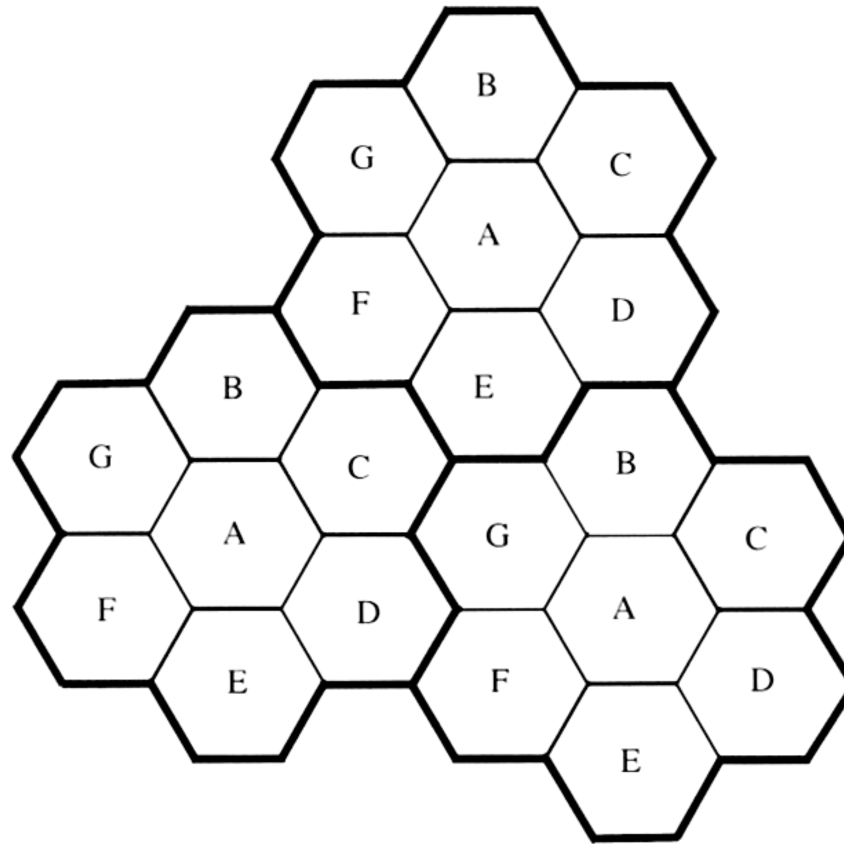
- The total coverage area is divided into **clusters.**
- A group of ***N*** cells. The number of cells in a cluster is called the **cluster size**.
- Cells in a cluster collectively use the complete set of available frequencies.
- *No* co-channel interference *within* a cluster.
- Replicated over the coverage area.
- Example: The picture shows clusters of size $N = 7$, outlined in bold.



Frequency Reuse (N = 4, N = 7)

- **Cluster**: a group of N cells use the complete set of available frequencies





"Capacity"

$$S = mN$$

- S: total # available duplex radio channels for the system
- N: cluster size
- m: #channels allocated to each cell

"Capacity" $$C = \frac{A_{\text{total}}}{A_{\text{cell}}} \times m = \frac{A_{\text{total}}}{A_{\text{cell}}} \times \frac{S}{N}$$

- $\frac{A_{\text{total}}}{A_{\text{cell}}}$: total # cells in the system

This formula suggests that if the cluster size N is reduced, more capacity is achieved.*

*Tradeoff: Small value of N may lead to large interference.

Cluster: Summary

A cluster is a grouping of cells in which each cell uses different frequencies. A cell's frequencies may be reused by other cells in the system, but those cells will be in other clusters and therefore sufficiently far away not to cause interference.

[Klemens, 2010, p 59]

Cluster size (*N*)

- There are only certain cluster sizes and cell layouts which are possible.
- *N* can only have values which satisfy

$$N = i^2 + i \times j + j^2$$

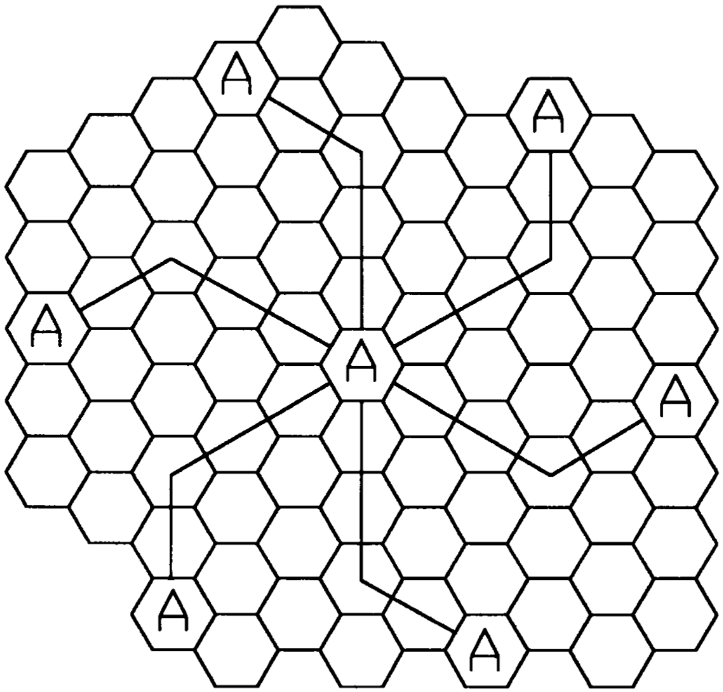
where *i* and *j* are *non-negative* integers.

	Cluster Size (*N*)
$i = 1,\ j = 1$	3
$i = 1,\ j = 2$	7

- **Exercise**: For $N = 4$, what are the values of *i* and *j*?

Locating co-channels

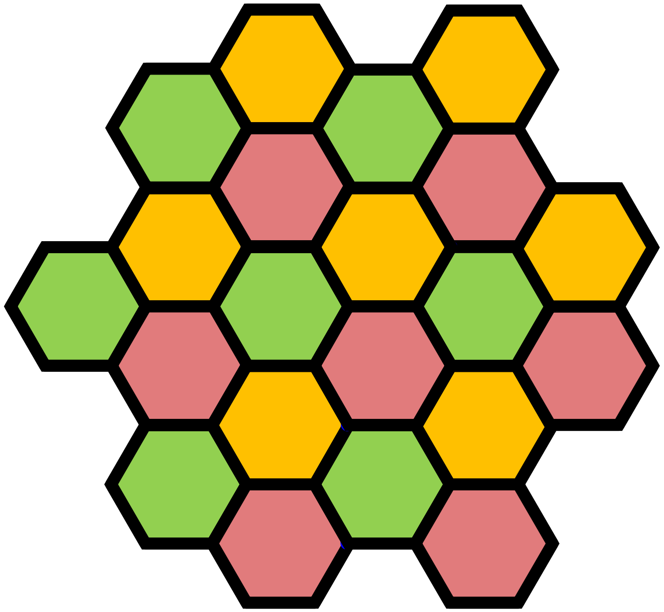
- To locate the nearest co-channel neighbors of a particular cell,
  - move *i* cells along any chain of hexagons and then
  - turn 60 degrees counter-clockwise and move *j* cells.
- Try $N = 19$
  - i = 3
  - j = 2



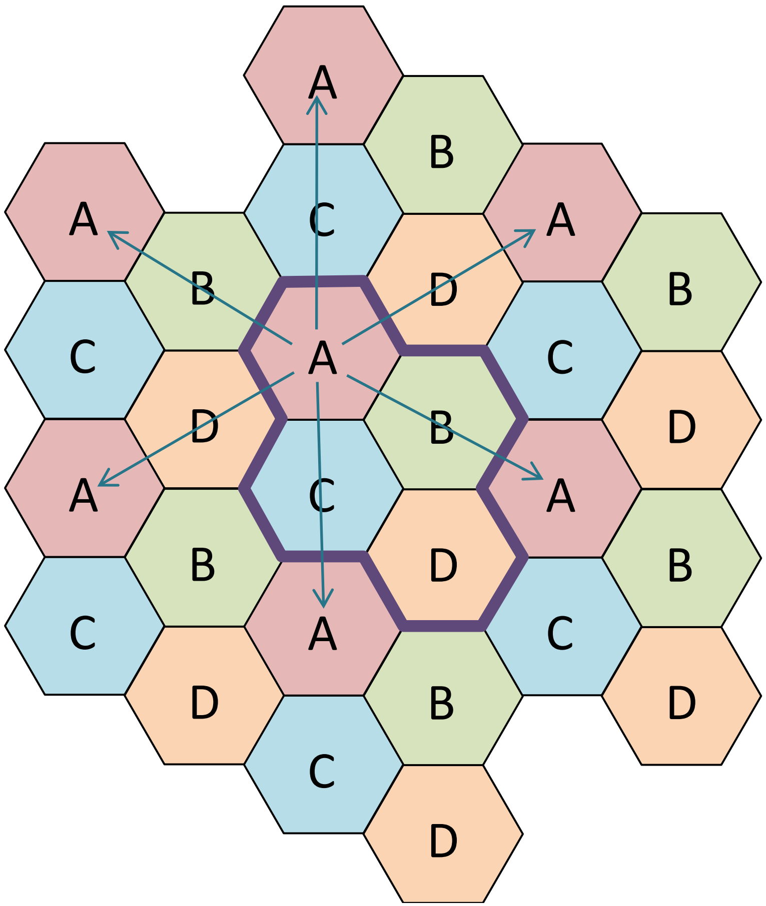
$$3^2 + 2 \cdot 3 + 2^2 = 9 + 6 + 4 = 19$$

Locating co-channels (N = 3)

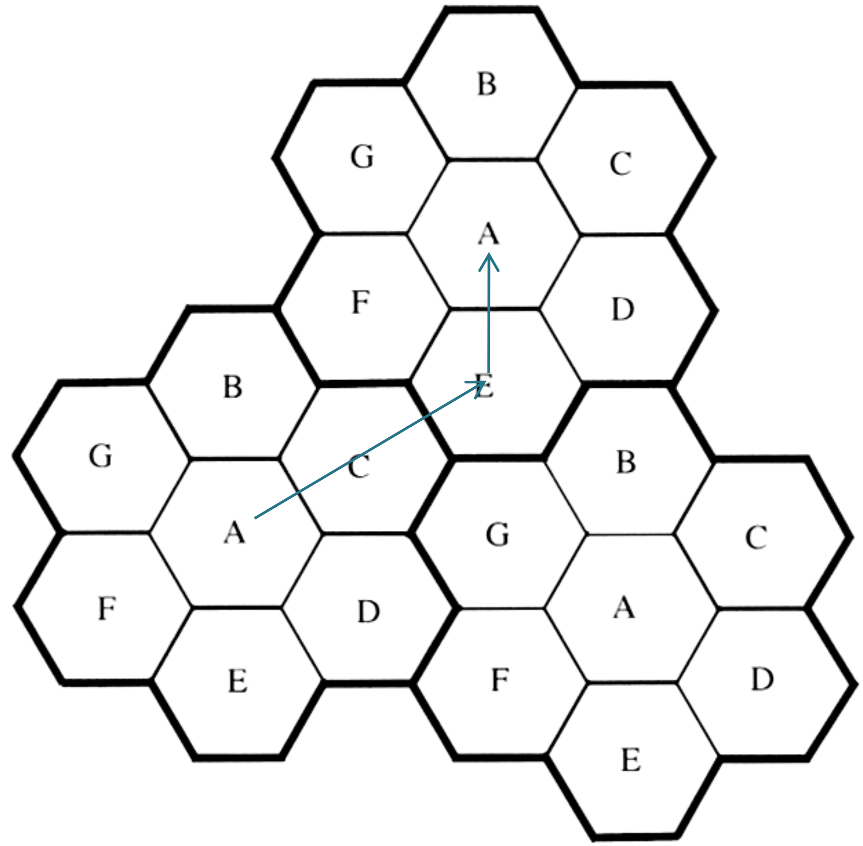
- To locate the nearest co-channel neighbors of a particular cell,
  - move *i* cells along any chain of hexagons and then
  - turn 60 degrees counter-clockwise and move *j* cells.



Locating co-channels (N = 4, N = 7)

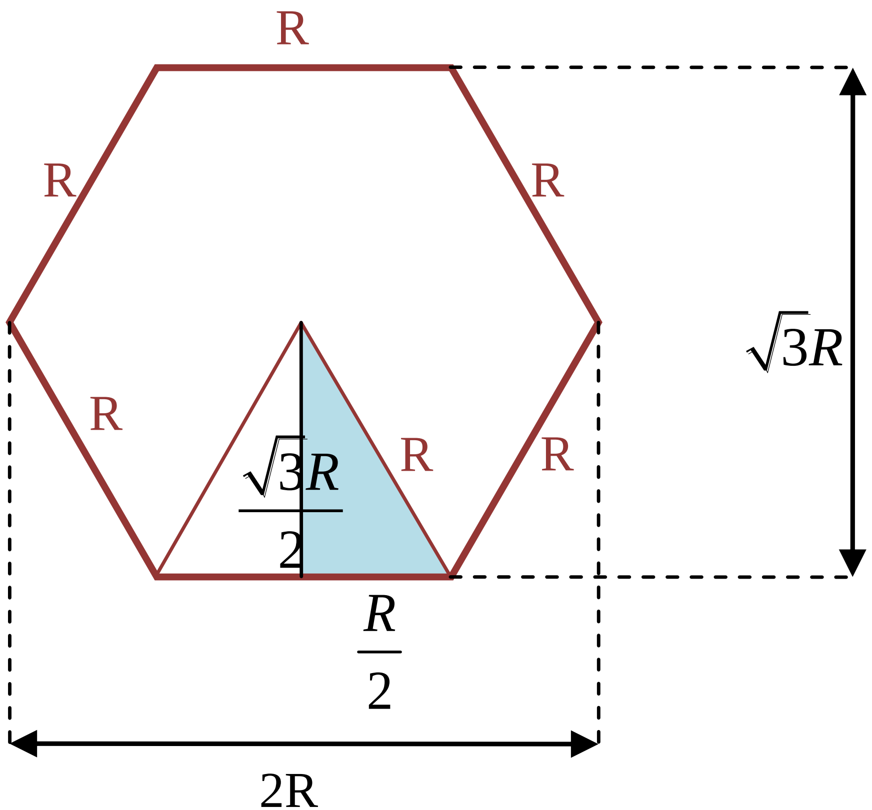


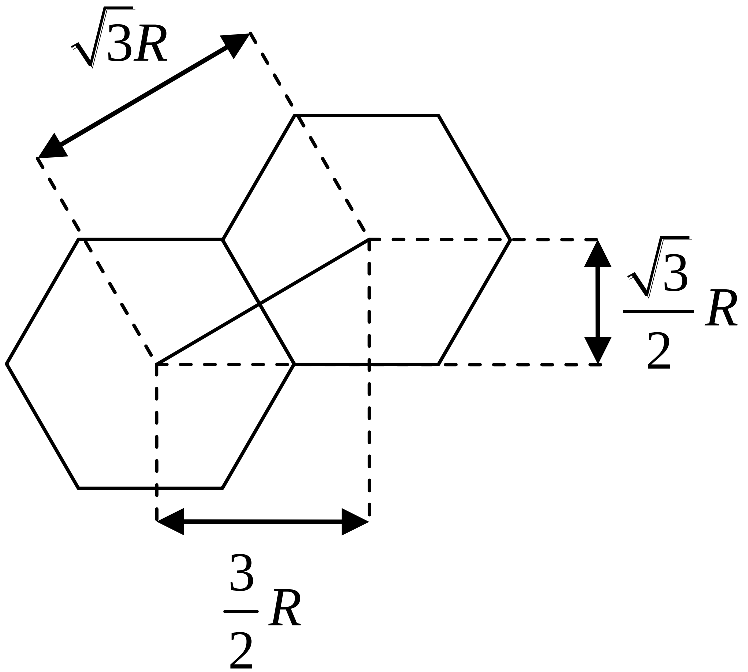
(i = 2, j =0)



(i = 2, j =1)

Hexagon





$$\text{Area} = 6 \times 2 \times \left(\frac{1}{2} \times \frac{\sqrt{3}}{2} R \times \frac{1}{2} R \right) = \frac{3\sqrt{3}}{2} R^2 \approx 2.598 R^2$$