The Cellular Concept-
System Design Fundamentals
(Continued)

Trunking

- The Telephone Company uses trunking theory to determine the number of channels needed to be allocated for hundreds of users
- Each user is allocated a channel on a per call basis and upon termination of the call, the occupied channel immediately returns to the available pool of channels
- When a user requests to call, but all the channels are busy, then the user will be blocked or delayed.

Erlang

- The fundamentals of trunking theory was developed by a Danish mathematician Erlang.
- Today the measure of traffic intensity bears his name
- One Erlang represents the amount of traffic intensity carried by a fully occupied channel during a fixed time.
- For example, if one channel is busy during 30 minutes within a hour, then it is said that the traffic intensity is .5 Erlang

Grade of Service (GOS)

- Grade of Service (GOS) is a measure of congestion which is specified as the probability of a call being blocked (Erland B) or a call being delayed for a certain amount of time (Erlang C)

- GOS of 2% blocking means that the channel allocation is designed in such a way that 2 out of 100 calls will be blocked due to channel occupancy during the busiest hour.

Terminologies

- Set up time
  - The time required to allocate a trunked radio channel to a user
- Blocked call
  - A call that cannot be completed due to congestion
- Load
  - Traffic intensity over the entire trunked radio system

Terminologies

- Traffic intensity
  - Measure of channel time utilization. It is the average channel occupancy measured in Erlangs.
  - **Denoted by A (dimensionless)**
- Request rate
  - The average number of call requests per unit time, **denoted by λ (sec^{-1})**
- Holding time
  - Average duration of a call, **denoted by H (sec)**

Equations

- The traffic intensity offered by each user is given by

  $$A_u = \lambda H$$

  where H is the average duration of a call and λ is the average number of call requests per unit time for a user.

- A system containing U users, the total traffic intensity is given by $A = UA_u$

- In a C channel trunked system, the traffic intensity per channel is given by $A_c = UA_u / C$

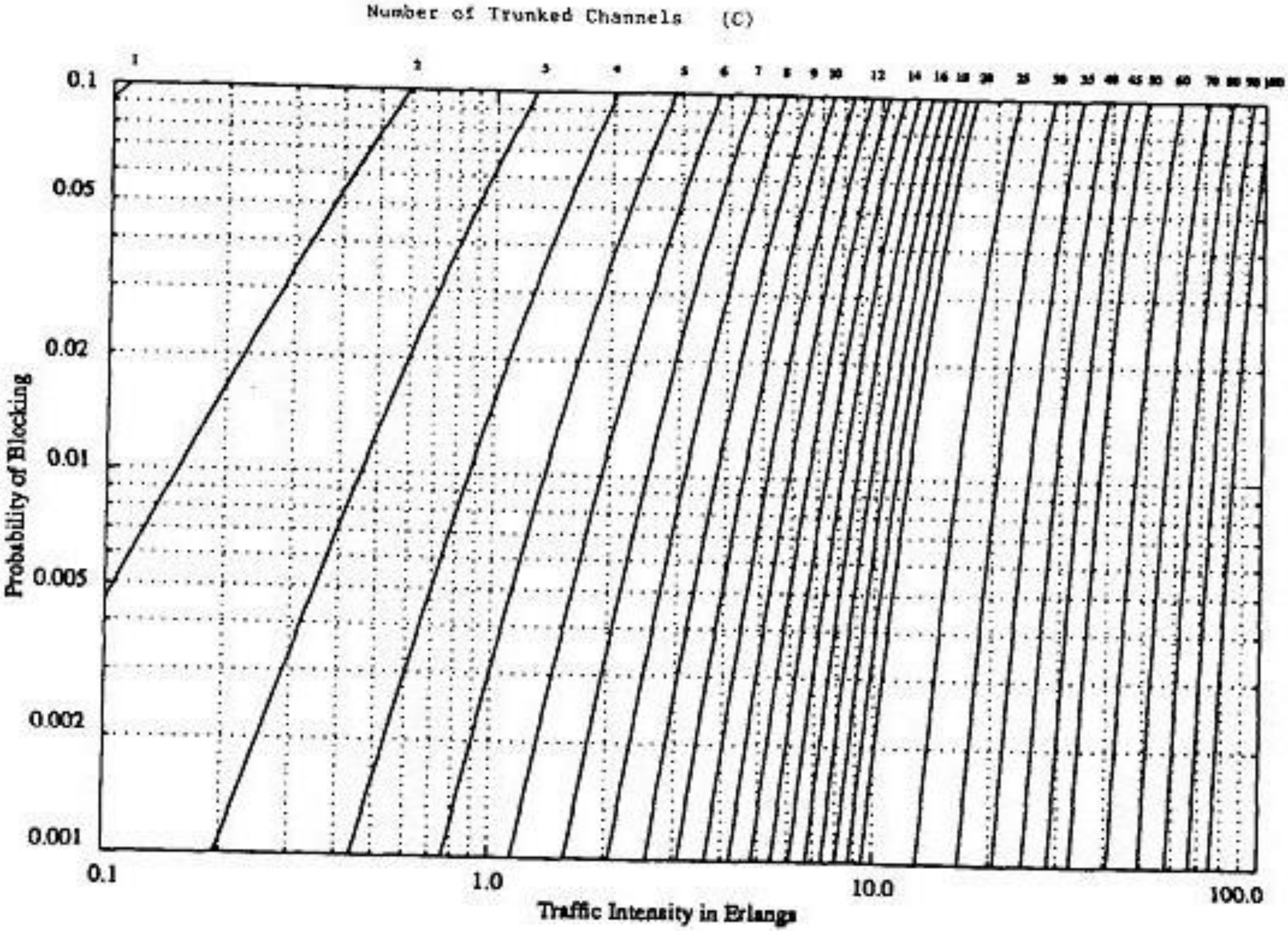
Erlang B formula

- The Erlang B formula determines blocking probability of a call

$$Pr[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS$$

Table 2.4 Capacity of an Erlang B System

Number of Channels C	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2


Number of Trunked Channels (C)
1
2
3
4
5
6
7
8
9
10
12
14
16
18
20
25
30
35
40
45
50
60
70
80
90
100
0.1
0.05
0.02
0.01
0.005
0.002
0.001
Probability of Blocking
0.1
1.0
10.0
100.0
Traffic Intensity in Erlangs

Trunking Efficiency

- Trunking efficiency is a measure of the number of users which can be offered a particular GOS with a particular configuration of fixed channels.

- The way in which channels area grouped can substantially alter the number of users handled by a trunked system.

- For example, 10 channels at 1% blocking can support 4.46 Erl of traffic whereas, 2 groups of 5 channels can support 2 x 1.36 Erl = 2.72 Erl.

- Hence, allocation of channel groups has a major impact on overall system capacity.

Example #1

- An operator has a total of 48 carrier frequencies in use and SIR requirement for the system is 14 dB. Suppose the propagation exponent for the area is n = 3. How many frequencies can be used per cell (frequency reuse factor) ?
- We know SIR equals $\frac{S}{I} = \frac{(\sqrt{3N})^n}{6}$

Given, SIR = 14 dB = $10^{14/10}$ = 25.11

$$So, N = \frac{(25.11 \times 6)^{\frac{2}{3}}}{3} = 9.43$$

The nearest possible value for N is 12. Therefore the required cluster size N has to be 12.

This means that 48/12 = 4 carrier frequencies can be used in each cell.

Example #2

- The maximum calls per hour in a mobile cell equals 400 and the average call holding time is 160 seconds. If the GoS is 2%, find the offered load A. How many service channels are required to handle the load?

- Traffic intensity, $A_u = \dfrac{400 \times 160}{3600} = 17.78$

  Using the Erlang B chart 25 channels give 18 Erlangs of traffic intensity at 2% blocking. So we need 25 service channels

Example #3

- How many mobile subscribers can be supported with 50 service channels at 2% GoS? Assume the average call holding time equals 120 seconds and the average busy hour call per subscriber is 1.2 calls per hour.

- From the Erlang B chart, for 50 channels at 2% blocking, the offered load is 40.26 Erlangs.
  Average Traffic per channel, A_u = $\frac{1.2 \times 120}{3600} = .04 Erl$

  Number of users, U = $\frac{A}{A_u} = \frac{40.26}{.04} = 100.6 \approx 1007 users$

Coverage VS Capacity

Maximizing coverage

- Use low frequency band
- Increase antenna height
- Maximize transmission power
- Reduce quality requirements

Maximizing capacity

- Maximize frequency band
- Reduce antenna height
- Reduce C/I requirements
- Re-use frequencies

Improvement Techniques

- All the cells are different
  - No. of subscribers, path loss, geography, usage statistics etc
- Cannot have one-and-for-all design
  - Require special techniques/schemes for different cells
- Also, the number of subscribers can grow
  - Don’t want to redesign the entire system
- Improvement techniques
  - Cell Splitting
  - Sectoring
  - Repeaters

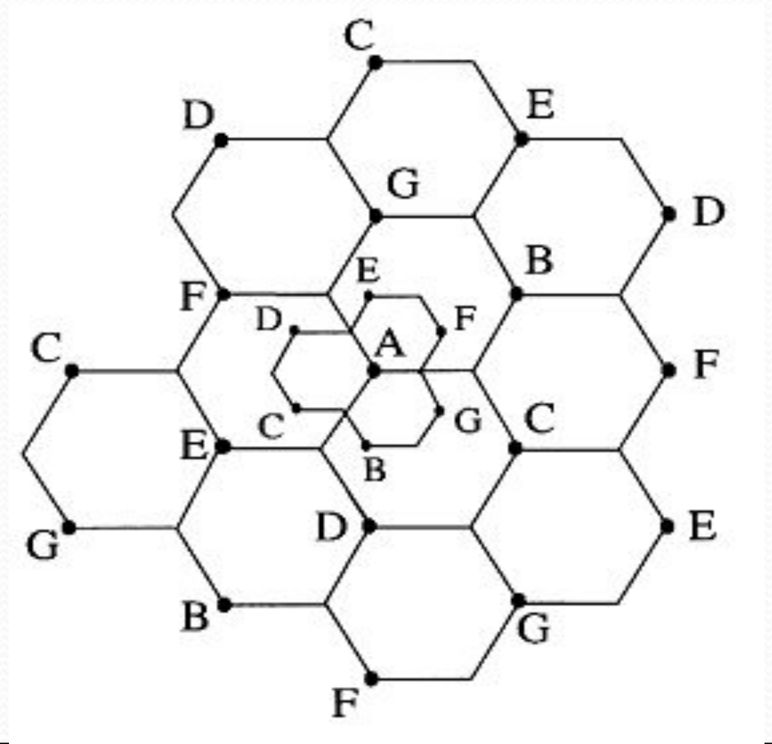
Cell Splitting

- In highly congested cell, there are many subscribers in a cell
  - Not enough channels to support the desired GOS

- Subdivide a congested cell into smaller cells (microcells)
  - Increases the system capacity by reusing the frequency channels more

  - Reduce the number of subscribers per cell such that the traffic generated is under the maximum provided

  - Need to reduce the transmit power accordingly to maintain the SIR



Cell Splitting (cont'd)

- Advantages
  - Increase system capacity
  - Reduce transmission power
- Disadvantages
  - More base station
  - More handoff traffic

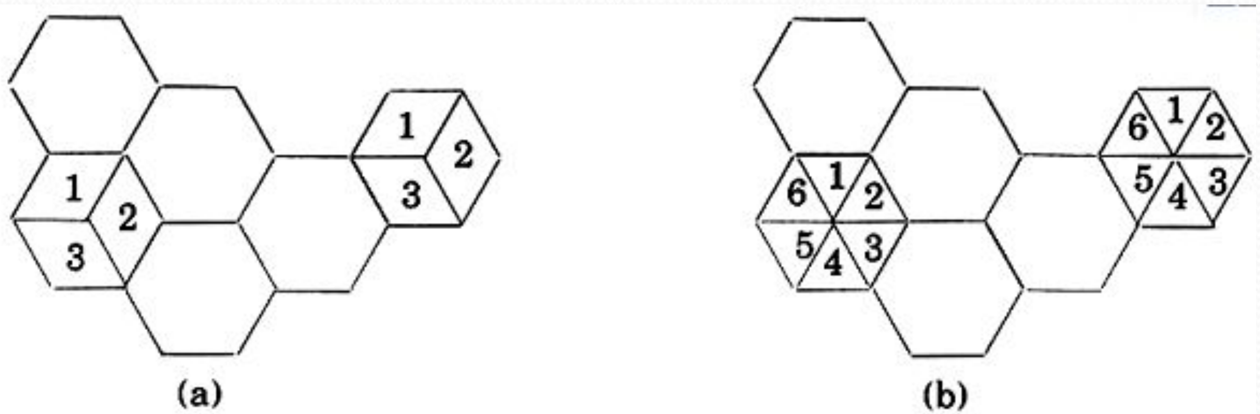
Macro Cell

Pico Cell

Micro Cell

Sectoring

- Use of directional antenna to divide cells to sectors
  - Normally partitioned into 3 120° sectors or 6 60° sectors
  - Co-channel cells drop from 6 to 2 for 120° sectors or 1 for 60° sectors
  - Divide the channels in 1 cell evenly among the sectors



(a) 120° sectoring; (b) 60° sectoring.

Sectoring (cont'd)

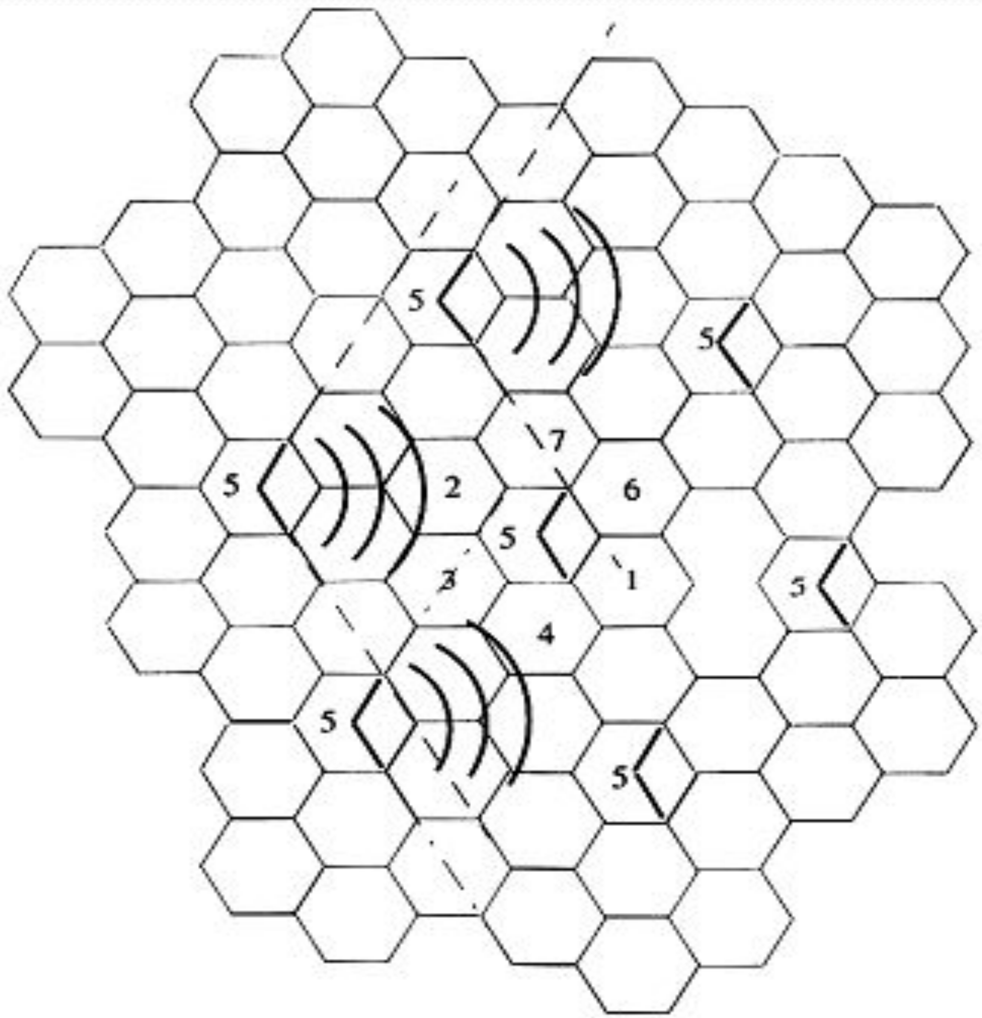


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

Sectoring (cont'd)

- Advantages
  - Increase system capacity
    - As SIR increased ⇒ so we can reduce cluster size (N ↓) ⇒ more frequencies can be reused (M ↑) ⇒ increase system capacity (C_{sys}↑)
- Disadvantages
  - Loss of trunking efficiency
    - Channels are divided into sectors.
    - Less trunked channels ⇒ less max system traffic
  - More handoffs
    - BS can handle handoff between sectors, without MSC computation
    - Better with DCA (Dynamic Channel Allocation) because no handoff required between sectors

Repeater

- For use in hard-to-reach areas, such as buildings, tunnels
- Often used with distributed antenna system
  - A number of antennas are distributed in different spots to transmit the same signal and for reception
- Downlink / Forward Link
  - Receive signal from “outside”, amplify and retransmit “inside”
- Uplink / Reverse Link
  - Receive signal from “inside”, amplify and retransmit “outside”
- No increase in capacity!!!!

Repeater (cont'd)

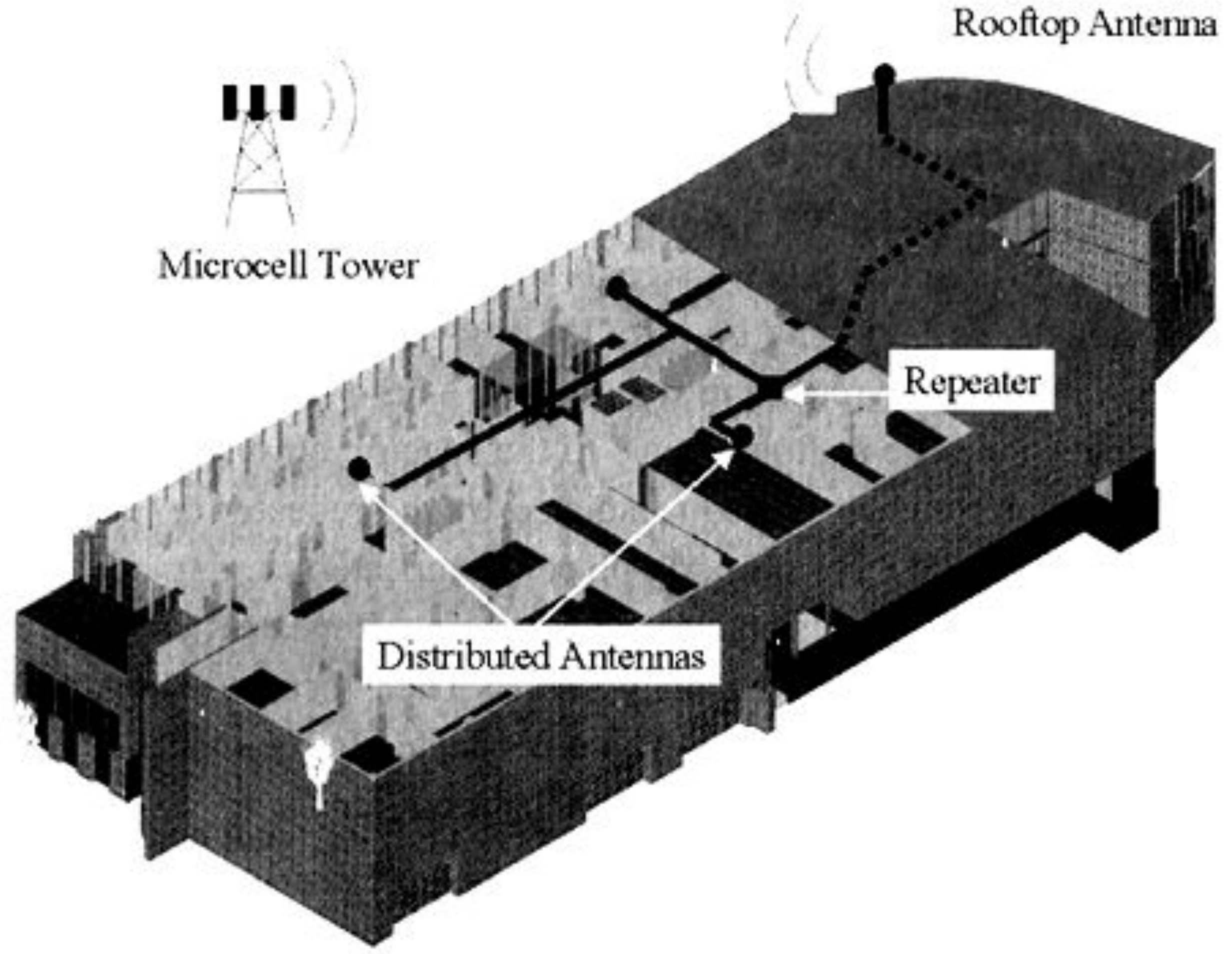


Figure 3.12 Illustration of how a distributed antenna system (DAS) may be used inside a building. Figure produced in SitePlanner®. (Courtesy of Wireless Valley Communications Inc.)

Summary

- Cellular concept is the core of mobile communication
  - Frequency reuse
  - Channel assignment schemes
  - Handoff
- Good system design is very important
  - High system capacity
  - Good GOS with trunking
  - Low transmission power
- System improvement techniques
  - Cell splitting
  - Sectoring
  - Repeaters

Reference

- Wireless Communications: Principles and Practice – Theodore S. Rappaport
  - E-Book, 1st Edition – Section 2.6 - 2.7.2, Page 44 - 60
  - Paper book, 2nd Edition – Section 3.6 - 3.7.3 Page 77 - 93