SDMA → Space Division Multiple Access

→ FDMA review

→ Radio channel review
  - Transmitter
  - Receiver

→ Voice Switching review

Radio Channel Review

Voice → BW → 4kHz

Sample at 8k Sps / 8kHz sample

Base band bit-rate = \( \frac{8 \text{ bits} \times 8000 \text{ samples}}{\text{sec}} \) = 64 kbps

Consider PSK

Radio BW = 80kHz

Channel Rate = 64 kbps
Consider receiver

\[ \text{LNA} \quad \text{\[x\] } \quad \text{\(S(t)\) } \quad 64\text{kbps} \]

Power considerations in Rx
sensitivity = ? or MDS = ?

Defn: the power at the input such that the (SNR)output satisfies a given level.

\[
(\text{SNR})_{\text{output}} = \frac{\text{Average Information Power (I)}}{\text{Average Noise Power (N)}}
\]

Example:

- Class noise

\[
(\text{SNR})_0 = \frac{I}{N} = \frac{10}{1} = 10 = 10\log_{10}10 = 10\text{dB}
\]

\[
= \frac{200}{2} = 100 = 10\log_{10}100 = 20\text{dB}
\]

E.g. MDS = -100dBm \(\Rightarrow\) GS\(\approx\) 900

-105dBm \(\Rightarrow\) GS\(\approx\) 1800
Questions

\[ P_T = 1 \text{ W} \]
\[ P_T = 30 \text{ dBm} \]

\[ L_p = 50 + 35 \log d \text{ (m)} \ [\text{dB}] \]

Calculate \( D_{\text{max}} \)

\[ P_T = 1 \text{ W}, \quad 10 \log 1 \text{ W} = 0 \text{ dBW} \]
\[ = 30 \text{ dBmW} \]

\[ P_R = P_T - L_p \]
\[ -95 \text{ dBmW} = 30 \text{ dBmW} - [50 + 35 \log d] \text{ dB} \]
\[ \frac{-125 + 50}{-35} = \log d = \frac{-75}{-35} \]
\[ d = 139 \text{ m} \]

An Important Concept in Networks

Understanding dBs
Understanding dBs

\[ \text{Pin} \quad \rightarrow \quad \text{Gain} = 10,000 \quad \rightarrow \quad \text{Pout} \]

\[ \text{Pout} = \text{Pin} \times \text{Gain} = 20\,\text{mW} \times 10,000 = 200,000\,\text{mW} = 200\,\text{W} \]

or \[ \text{Pout} = 0.02\,\text{W} \times 10,000 = 200\,\text{W} \]

Consider dBs

\[ 20\,\text{mW} \rightarrow \text{dB scale} \rightarrow 10\log(20\,\text{mW}) = 13\,\text{dBm} \]

\[ \text{dBm} \quad \rightarrow \quad \text{Pout} = \text{Pin} + \text{Gain} = 13\,\text{dBm} + 10\log(10,000) = 53\,\text{dBm} \rightarrow 200\,\text{W} \]

\[ \text{dBW} \quad \rightarrow \quad \text{Pin} = 10\log(0.02\,\text{W}) = -17\,\text{dBW} \]

\[ \text{Pout} = \text{Pin} + \text{Gain} = -17\,\text{dBW} + 40\,\text{dB} = +23\,\text{dBW} \rightarrow 200\,\text{W} \]
What is the implication of the above?
Consider a service area

**Frequency Re-Use**

**SDMA**

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Hire a frequency \( \rightarrow \text{FCA} \rightarrow \text{Lm2000 pa} \)

one frequency at \( 951 \text{ MHz} \)

consider a cross-section in the elevation

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co-channel interference
Do not use the same frequencies in adjacent cells.
FDMA
Frequency Division Multiple Access

ESTI decides to allocate
900 MHz $\rightarrow$ 901 MHz for radio telephony

Assume that one single Radio Channel = 80 kHz
Total no of RCs = \( \frac{1000 \text{ kHz}}{80 \text{ kHz}} = 12 \text{ channels} \)

We are considering telephony $\rightarrow$ Full duplex
$\rightarrow$ two virtual channels (FWD, REV) (DL, UL)

Divide 12 Channels $\frac{12}{2} = 6$ Duplex channels

Uplink  Downlink

\[
\begin{array}{cccccccc}
\text{U1} & \text{U2} & \text{U3} & \text{U4} & 5 & 6 & \text{D1} & \text{D2} & 3 & 4 & 5 & 6
\end{array}
\]

FDD
Full Duplex Channel
Frequency Division Duplex
Voice Switching Review

The 6 FD channels are dynamically assigned to parties wishing to communicate.

Example:

109 $\Rightarrow$ 102  Intra-cell call

Probability of Blocking
Given a finite no. of channels and a calling statistics.
The cellular approach

20 FD VCs available
area to be covered with radio telephony
15km

Assume that 1 VC is required to service one telephone call.

Self-Mobile ↔ PSTN (1 VC)
Self-Mobile ↔ other-Mobile (1 VC)
Mobile ↔ Mobile (need 2 VCs)

Statistics
A = \lambda \times S
S = 65 sec
A = 13.18

N=20 \quad \lambda = 730 \text{ cells/hr} \quad P(B) = 2\% 

One year later subscribers increased

N=20 \quad \lambda = 2000 \text{ cells/hr} \quad P(B) > 40\% 

Solutions
1. Increase tariffs
2. Increase cells (more BSs)
3. More...
**Increase no of cells**

<table>
<thead>
<tr>
<th>N₁ = 10</th>
<th>N₂ = 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>B₁</td>
<td>B₂</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>λ₁ = 1000</td>
<td>λ₂ = 1000</td>
</tr>
<tr>
<td>Pₖ₁ &gt; 40%</td>
<td>Pₖ₂ &gt; 40%</td>
</tr>
</tbody>
</table>

**Advantage**

- lower Tx Power
- Battery lasts longer
- less absorption of EM Energy in human body tissue.

Above system is even worse in terms of P(k)

**Improved situation**

<table>
<thead>
<tr>
<th>(A)</th>
<th>(B)</th>
<th>(A)</th>
<th>(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₁ = 10</td>
<td>N₂ = 10</td>
<td>N₃ = 10</td>
<td>N₄ = 10</td>
</tr>
<tr>
<td>B₁ X</td>
<td>B₂ X</td>
<td>B₃ X</td>
<td>B₄ X</td>
</tr>
<tr>
<td>λ₁ = 500</td>
<td>λ₂ = 500</td>
<td>λ₃ = 500</td>
<td>λ₄ = 500</td>
</tr>
<tr>
<td>Pₖ₁ = 15%</td>
<td>Pₖ₂ = 15%</td>
<td>Pₖ₃ = 15%</td>
<td>Pₖ₄ = 15%</td>
</tr>
</tbody>
</table>

Split 20 VC's into two sets

Set A = \{1, 2, \ldots, 10\}

Set B = \{11, 12, \ldots, 20\}
Another try?

4 sets of channels
A = \{1, 2, \ldots, 5\} \quad B = \{6, 7, \ldots, 10\}
C = \{11, 12, \ldots, 15\} \quad D = \{16, 17, \ldots, 20\}

Total no of cells = 32
Total traffic = 36.11
traffic/cell = \frac{36.11}{32} = 1.128 \text{ Erl/cell}

N = 5 / cell \quad A = 1.128 \text{ Erl/cell}
P(B) = 0.5\%

Good but expensive!

What is the optimal no of cells?

From table traffic/cell = 1.66 Erl
Total no of cells = \frac{36.11}{1.66} = 22
Problems & Complexities in SDMA

1. Limit on the size of a cell
   * Co-channel Interference
   * Backhaul cost
   * Handover overhead

2. The physical boundaries of a cell is not also circular
   * Calculation of co-channel interference is not simple
   * Frequency assignment is more & more difficult

3. We therefore need robust computer algorithms & optimisation
   * Neural network
   * Adaptive systems
   * Search
   * Self-learning
   * Game Theory

   → applied R&D topics

   → AI techniques
The need of a control channel

Channel 1 from Set A is dedicated to a common control channel.
MS builds up a table of CCs

<table>
<thead>
<tr>
<th>CC</th>
<th>dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-70</td>
</tr>
<tr>
<td>6</td>
<td>-120</td>
</tr>
<tr>
<td>11</td>
<td>-95</td>
</tr>
<tr>
<td>16</td>
<td>-105</td>
</tr>
</tbody>
</table>

MS will contact BS on CC-1
BS sends the cell identity to MS

We need an ALOHA-style MAC on the UL
For the DL we do not this.
Re-sketch service area

Frequency re-use factor = 4
4 sets of Frequency channel
A = \{1, 2, ... 5\}  B = \{6, 7, ... 10\}
C = \{11, 12, ... 15\}  D = \{16, 17, ... 20\}

Channel Data Rate = 64 kbps

Functions for CC
1) Mobile Phone registration
2) Initiating a call
3) Receiving a call
4) Sending/Receiving SMS
5) Handovers partially

The CC carries a substantial amount of traffic. There is a limit on the amount of traffic.
Calculation of Traffic on CC

1. Mobile phone registration
   registration packet = 500 bits → Hey I am here!
   transmitted over the uplink CC
   pure-Aloha → ≈ 18–22%
   slotted-Aloha ≈ 36%
   ISMA ≈ 60–80%
   This implies that the effective data rate for the uplink CC
   ≈ 64 kbps × 0.65 = 42 kbps

   How many mobile phone registrations can be supported.
   \[ \frac{42000}{500} = 84/sec \]

2. Call initiation
   packet = 800 bits
   \( n \) if CC is used exclusively for calls
   \[ n = \frac{42000}{800} = 52/sec \]
(3) Sending/Receiving SMS

GSM → 160 characters

\[ 160 \times 8 = 1280 \text{ bits} \]

→ say 2000 bits
down to 500 bits

average → 1000 bits / SMS

If CC is used exclusively for SMS

then \[ \frac{42000}{1000} = 42/\text{sec} \]

can be serviced

(4) A combination of all

if

\( 1 \) registrations 5/sec
\( 2 \) Calls 21/sec
\( 3 \) SMS 15/sec

Can the CC support the above traffic?

Yes/No

\( 1 \) → 5 \times 500 → 2500 bits
\( 2 \) → 21 \times 800 → 16800 bits
\( 3 \) → 15 \times 1000 → 15000 bits

\[ \frac{34300}{\text{bits/sec}} \]
The need of a Backhaul Infrastructure

Consider again the service area

MSC → mobile Switching Centre

How is the call switched?

We need a backhaul connection

We could use

- optical fibre → WDM
- microwave links → 2 Mbps
- DSL connections
- leased copper connections

The call is then routed over the backhaul/backbone
Call switching

Consider two cells & the MSC

MSC network operations

1. Home subscriber database
2. Mobile phone registration data → locating the mobile
3. Billing functions
4. Routing of traffic
5. Visitor’s database
6. Gateway connections
7. Frequency allocation
8. Handover of calls